Acoustics of the Restored Petruzzelli Theater

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ABSTRACT
Petruzzelli theater in Bari has been recently restored after disastrous fire of 1991 that had seriously damaged the building. The restoration has focused on the aesthetics and functionality of the room, in particular has been given great attention to improving the acoustics of the theater. This paper review the acoustical design process that has been carried out using a computer model of the hall and measurements during the restoration process. Objective indexes from measurements of the renewed theater are compared with literature suggested values and with similar halls.

1. INTRODUCTION
The Petruzzelli theater in Bari is one of the largest opera houses in Italy after La Scala in Milan and the San Carlo theater in Naples.

It hosted many famous opera and ballet greats throughout the 20th century.

The theater has been recently restored and reopened after a big arson that completely destroyed the theater in 1991.

The authors were involved as acoustical consultants by the building contractor to manage the acoustical restoration work and design improvements to the already available acoustical design.

The restoration has posed a series of challenges, since at the time of the fire acoustical measurements of the room were not available.

This paper will report the experiences collected by the authors during the restoration works, from the review of the renovation design to the measurements of the fully restored theater.

2. HISTORICAL BACKGROUND
The history of the Petruzzelli theater in Bari began in the late 19th century, when the merchants and shipowners Onofrio ed Antonio Petruzzelli proposed to the Bari municipality the plans to build a theater designed by local architect Angelo Messeni.
Two years later, in October of 1898, the construction started and lasted until 1903. The Petruzzelli theater was opened on 14 February 1903 with the play of the masterpiece opera of Giacomo Meyerbeer “Les Huguenots”. During the last century the theater hosted opera, ballet, plays, musicals and concerts.

During the night between 26 and 27 October 1991, the theater was completely destroyed by an arson. The theater, completely restored using state funds in 2008, has been returned back to the Bari municipality on 7 September 2009, and it officially reopened after 18 years the 4 October 2009 with the Beethoven’s Ninth Symphony. Currently the theater is again fully working with a rich program of opera, symphony and ballet.

3. RESTORATION
At the early stage of the review of the existing acoustical restoration design we had to answer to a question that commonly arise in such kind of renovation works: the theater has to be rebuilt “as is” or its acoustics can be modified?

This is always a very difficult question to answer in a restoration of a building. The temptation to radically change the acoustics, as an example creating a variable acoustic environment, can be high. But, as in this case, we have to consider that this theater is an historical building, where a clear connection on how the hall sound and the arts that have been crafted on it for nearly hundred years is well established. The attempt to strongly modify the acoustics of this hall, to widen its range of possible uses, must be avoided. This theater is born as an opera house and must remain an opera house.

Nevertheless, it is impossible and silly to reconstruct the theater exactly with the same material and building practices of a century ago. Modern materials that obey with the recent fireproofing regulations and modern building standards must be used. It is also meaningless to recreate a “bad” acoustic, only because it was historically bad.

Our approach was very practical, thanks to several previous similar experiences[1]. We tried to keep the original acoustics as carefully studied by architect Angelo Messeni, trying at the same time, to reduce artifacts and well known defects.

Unfortunately, there were no measurements of the acoustics of the theater before the fire. We based our analysis on the available literature, which is controversial at times. The literature[2] give us reports of a “good acoustics” with some “redundancy” especially in the higher part of the theater.

We tried to keep the characteristic acoustics of the theater but trying to carefully get rid the excess of reverberation. Any attempt to reduce the reverberation with the insertion of vast amount of absorption using carpets and curtains, as it has been done in the past in other Italian theaters, is doomed to failure.

The Petruzzelli theater is a mixture of a classic Italian horseshoe theater shape (until the second order), that morph into a balcony on the higher orders (see figure 1 for a cut-view of a 3D reconstruction of the theater). This shape is similar to the Paris Opera.

The theater has a volume of about 18000 cubic meters (with an actual capacity of 1480 spectators) topped by an impressive dome which was originally entirely frescoed.

In order to get a better knowledge of the theater acoustics prior to the fire, we built a CAD model using an acoustic simulation software (EASE-AURA). The model itself has been already shown in a previous figure. The model has been created using drawings plans and sections, and photographic historical documentation.

The range of possible interventions is limited by the architecture of the hall that cannot be modified, the only option available to control the reverberation is the choice of materials. In order to correctly choose materials absorption characteristics and treated surfaces we briefly investigated the theater acoustics by means of the computer model. This indicated the dome as the main weak element. The preliminary acoustic design already provided an absorption treatment of the dome. We extended the treatment to the very top of the dome, where a rooflight is present.

We tried to avoid as much as possible the usage of tents and carpets. Unfortunately this is a bad habit that deadened a bunch of Italian historic theaters (this came with the cinema era, when most theaters were adapted with projection screens and audio systems).
In the case of the orchestra pit, we had the possibility to do some structural changes. We designed a bigger movable orchestra pit, which is more suitable for an opera house of such size, and gives more freedom of usage in case of ballet or other performing arts. The orchestra pit walls were designed using a very light wood in order to avoid absorption at low frequencies, quadratic residue diffusers (to be placed at the end wall of the pit) were also designed.

We modified the seat disposition of the audience, avoiding the empty central corridor which creates reflections right in the center of the focus of the curved walls and the dome. It must be noted that this seems to be the original disposition of the seats, as we found in an old map. The floor of the audience has been designed to use a wooden structure supported on masonry as in the Italian theater tradition.

We will not go here into the details of all steps taken to reduce the noise produced by air treatment, other noise equipments, and transmitted through walls. Great attention has been spent to assure the lowest attainable noise criteria.

3.1. Characterization of the dome acoustical plaster

As mentioned earlier the dome and the rooflight were designed to be completely covered with an absorptive material. After a research of suitable materials we decided to use a layered structure made of an acoustical plaster sprayed over a metal net, attached over wooden supports and with a backing air cavity.

Since there were no available literature data of the absorption coefficient of such structure, we field tested a sample of about 7 square meters. We tested the sample using an impulse response measurement with the microphone placed at 50 cm from the sample and on axis with a loudspeaker source (see figure 2), then we calculated the absorption coefficient by separation of the two impulses: direct sound and reflected sound by the sample[3].

Since this procedure give only a value that is valid over a certain frequency range and in case of normal incidence, we measured also the effect of the sample on the reverberation of an empty rectangular room (see figure 3). The estimated absorption coefficients are shown in see figure 4.
3.2 Tuning of the CAD model

We passed the estimated absorption coefficients of the dome material to the computer model to get a preview of the treatment effect on room acoustics.

It must be taken into account that this approach has some limitations. The simulation results are qualitative, and in fact this is what one has to expect from a computer model.

A computer room model needs to be “tuned” before it is possible to get results which are directly comparable (quantitatively) with the real world. The tuning consists in a verification of the simulation results with measurements of the real room, adjusting the room geometry (by enhancing or reducing the geometrical details) and the surfaces absorption coefficients (and scattering coefficients). In this case the tuning was particularly challenging because the room was not completely restored and there are no previous measurements of the room.

In order to tune the model during the restoration of the theater we proceeded creating a temporary model of the theater. We measured the theater acoustics during the restoration, with the room in a rough state. We created a computer model of the same state, and tuned this model using the measurements.

We measured the room acoustical parameters using a dodecahedron loudspeaker with subwoofer, a CLIO-fw measurement system and an Earthworks M30 measurement microphone. The measurements were carried out using the LogChirp technique implemented into the software, which basically is an Exponential Sine Sweep ESS method. This technique has the advantage in respect to the Maximum Length Sequence that the loudspeaker distortion can be separated from the room response[4].

The room was sampled in a series of points with the source positioned on the stage, right above the fireproof curtain that at time was closed.

Picture 5 shows a comparison of the reverberation time measured and calculated by the model, after the tuning, which basically consisted in the editing of the absorption coefficients of the fireproof curtain.

Fig. 2: Normal incidence time response of dome treatment material

Fig. 3: Rectangular room reverberation with and without sample

Fig. 4: Estimated absorption coefficient of sample
4. ACoustics of the Restored Theatre

In October 2009 the theater restoration was finally completed, and we were able to measure the theater acoustics.

We used the same equipment already used in the rough state measurements, but this time the theater was completed and instead of in front of the fireproof curtain we put the source in front of the real curtain lowered.

The curtain lowered avoid the acoustic coupling between the room and the stage, in this way it is possible to evaluate the room acoustics only independently from the scenery that can significantly change the overall acoustics due to its materials and dimensions.

Figure 6 shows the measured acoustical parameters of the theater.

The acoustical parameters are analyzed in detail in respect to the optimal values available in literature[5][6][7].

The EDT and T30 curves shape are regular and both indicates a natural decay at high frequencies, the correlation between the two indexes is good and constrained into small values. The averaged values in the band 125 to 4 kHz are into the optimal range both for opera and for symphonic music, with RT30=1.93 s and EDT=1.85 s.

The **center time** has a fairly linear shape, taking into account the complex architecture of the hall. The average value ts=111.93 ms is perfectly aligned with the expected values for this theater.

The average **clarity** C50=-1.05 dB is slightly under the optimal values for speech, but is good for music while the average clarity C80=1.68 dB is optimal for opera and symphonic music.

The average value for the **definition** D50=42.68 %, again slightly less than optimal for speech but good for music.

The **Speech Transmission Index** average value STI=0.53, is a good rating for an opera house.

We reported in this article only the spatial averaged values, the previous indexes are varying with measurement positions. Anyway, the analysis of the collected data proved that the variation of the parameters as function of the position is limited, taking into account the room dimensions.

The Initial Time Delay Gap **ITDG**, defined as the interval between the arrive of the first sound and the first reflection, can describe the intimacy of an hall. Optimal ITDG values are in the 12 and 25 ms range, the values are referred to an average of the impulse measurements taken near the central axis of the theater. In our case the average ITDG=15.43 ms which is rated as optimum by the literature for symphonic music and opera.

The **tonal balance** TB is defined as:

\[
TB = \frac{EDT(2kHz) - EDT(250Hz)}{3}
\]

represents the average slope of the EDT curve, ideal values of the TB must be near 0 s/oct. In our case the TB=-0.12 s/oct.

The **Bass Ratio** BR is a parameter that describe the warmth of an hall. The BR evaluates the tonal balance of the hall. The BR is defined as follows:

\[
BR = \frac{RT30(125Hz) + RT30(250Hz)}{RT30(500Hz) + RT30(1kHz)}
\]

The ideal BR value for a theater with reverberation time equal or greater than 1.8 s (as in the case of the Petruzzelli theater) is on the range from 1.1 to 1.25. The Petruzzelli has a BR=1.02, slightly less but near the optimal values.
The **Strength** $G$ is calculated with the equation:

$$G_{\text{mid}} = 10 \log \left( \frac{RT_{\text{mid}}}{V} \right) + 44.4$$

The optimal values for the $G$ index for a theater with more than 1400 seats are ranging from 1.5 to 5.5 dB. For concert hall, excellence values are from 4 to 5.5 dB. The spatial average value for the strength parameter in the Petruzzelli theater $G=4.97$ dB with minimal spatial deviations.

### 4.1. Comparison measurements with computer model

During the design stage we used the computer model to help to check between different correction solutions.

The simulations were run using a particle tracing algorithm, the results are then post processed to get octave band indexes.

The comparison of some of the acoustical parameters is shown in figure 7.

The model was able to match the overall shape of the parameters and absolute values seems to be within a reasonable range. We have to point out that in a complicated hall the fine-tuning of the model can be very time-consuming. In our case we had given up with the fine tuning of the model preferring to invest our time to simulate different treatment scenarios.

Some significant discrepancies are in the low frequency range, this is probably due to the non-optimal modeling of the seats and of the curtain.

### 5. CONCLUSIONS

The restoration of the Petruzzelli theater has allowed to recreate the original appearance of the hall using modern building materials, as requested by actual fire-proof regulation. In fact, since the theater
was rebuilt in a way faithful to the original the only variables available for the acoustic correction concerned the choice of materials.

The acoustics of the theater has been studied carefully using a computer model of the room. This has allowed to simulate the correction interventions in depth. The in-situ measurements and the simulations at various stages of the renovation were powerful tools for the support in the treatment choices. As a result the original acoustics of the hall has been restored, with the perception of a large and “rich” hall, as is indeed the theater, but without excess and defects that had characterized past reviews of the room.

6. REFERENCES