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Acoustical design of the new canopy for the Ginastera Hall of the Teatro Argentino of La Plata

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Abstract

After its inauguration in 1999, the opinions of musicians, critics and general audience about the acoustical quality of the Ginastera Hall were diverse. The sound was round and well balanced at the upper levels, but some problems appeared in the main floor: lack of bass frequencies, low sensation of envelopment, plain and distant sound, poor instrumental balance and the inaudibility of certain sections of the orchestra. In opera representations, the singers' voices were overpassed by the sound in the pit. In order to discover the reasons of such behaviour, we carried out a lot of acoustical measurements, some based on ISO 3382, and developed a digital model of the Hall. From the results of the analysis of the collected data, we detected at the main floor level a lack of acoustical energy in the first 100 ms after the direct sound, insufficient lateral energy and a strong seat dip effect caused by the small angle of arrival to the audience and the particular design of the seats. By means of that diagnosis, we decided to work mainly in the temporal and spatial structure of the early reflections focused towards the audience. A new canopy to be placed over the pit was designed. Its main objective was to fix the problems detected in the main floor without changing the acoustical quality at the upper levels. In this paper the design process of the acoustical reflector, made with a distributed array of rectangular panels with cylindrical curvature and based on the works of Rindel and Skålevik, is described. The final measurements carried out to analyze the results of the work and the opinions of some specialists about the musical outcomes of the intervention are showed.

Keywords: opera hall, acoustical quality, canopy design

Acoustical design of the new canopy for the Ginastera Hall of the Teatro Argentino of La Plata

1 Introduction

After the total destruction of the former *Teatro Argentino* of La Plata, caused by a fire in 1977, the government decided to build a completely new complex named *Centro de las Artes del Espectáculo Teatro Argentino de La Plata*. Instead of the traditional horse shoe type theatre, the architects in charge (Enrique Bares, Tomas García, Roberto Germani, Inés Rubio, Alberto Sbarra and Carlos Ucar) and the acoustical consultants (Rafael Sánchez Quintana and Federico Malvarez) chose a modern shape for the Sala Alberto Ginastera, the opera hall of the building. The hall was a combination of some theatre typologies, like a fan-shape and a shoe-box with three rows of big frontal balconies.

For the acoustical design of the hall, the more advanced tools of that time were used: two dimension's geometrical models, statistical analysis and a physical model which was examined with laser lighting [1].

The hall was inaugurated in 1999 and, although the general opinion about its acoustic was at first favourable, the idea soon grew up, shared among musicians, critics and specialists, that it lacked the desired acoustical quality. Those opinions were caused, partially, by the inevitable comparison with the well-known and celebrated acoustics of the *Teatro Colón* of Buenos Aires. The main complaint was referred to as deficiency of bass frequency sound and the lack of envelopment in the main floor. On the contrary, the acoustic behaviour at the upper levels was judged as satisfactory.

Based on those opinions, the authorities of the TA decided to call the acoustical team of the University of La Plata to carry out a thorough study of the acoustics of the Sala Ginastera. This study, which involved a diagnosis of the acoustical behaviour of the hall, the design of a set of possible actions to fix the problems and the construction of the system chosen for solving them, is the main subject of this paper.

Before the intervention of the University, the general idea, shared by the acousticians who were asked, was that the lack of reverberation in bass frequencies and the poor sensation of envelopment in the main floor could be corrected by removing part of the absorption of the walls, specially the materials with high absorption coefficients in the lower bands of the spectrum. This action, very expensive and difficult to explain due to the short time passed after its inauguration, did not answer with confidence the main question: if the extra absorbing material was removed, would the detected acoustical issues of the hall be corrected?

2 Diagnosis

The acousticians of the University of La Plata decided to perform a complete study of the main hall using the new tools provided by the acoustical science that were not accessible in the times of its original design. The diagnosis of the quality of the site would be based on measurements of the acoustic field, opinion polls about the perceived sound by musicians, audiences and critics and the results of simulations in a digital model to be developed.

2.1 Acoustical measurements

A complete set of acoustical measurements based on the ISO-3382 Standard [2] were accomplished in March 2012. A dodecahedral source was used and more than 12 points of measurement were distributed in the main floor and the balconies.

Despite the big amount of data acquired, the outcomes did not answer the question about the difference in acoustical quality between the main floor and the upper levels.

At that time, we decided to perform a new series of measurements designed ad-hoc to investigate the behaviour of the early field in the main floor. One of the impulse responses acquired, recorded in the zone of the worst acoustical quality, can be seen in Figure 1.

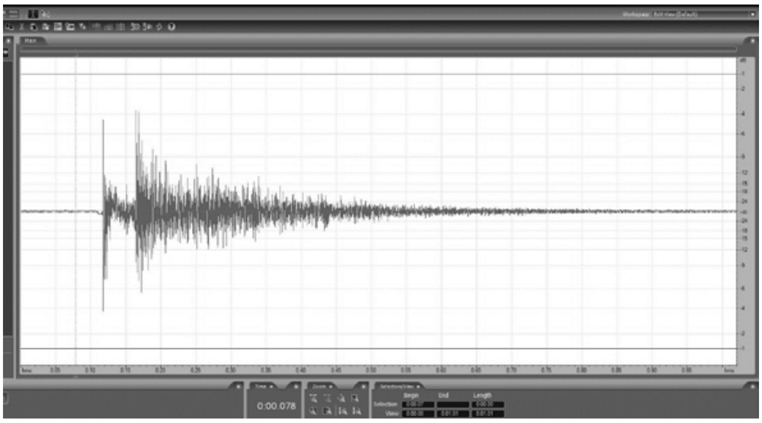


Figure 1: Impulse response measured in the seat 11 in the main floor

It is clear the absence of early reflections from 5 ms to 70 ms after the arrival of the direct sound, which could explain the lack of envelopment and the weak bass sound in the lower placements of audience. In the centre of the main floor the Lateral Fraction of Energy (LF) was only of 14%, well below the minimum of 30% recommended by the specialized literature.

2.2 Development of a digital model

Based on the huge amount of data collected in the measurements in the hall and in laboratory, a digital model of the hall using the software package *Catt-Acoustic-V8* was built. After tuning the model we could verify its reliability by comparing the values measured against the values simulated. For all the parameters, the absolute error was less than the recommended value in the ISO 3382 Standard. The simulations were made for more than 120 pairs of source/receptor.

One interesting outcome from the digital model can be seen in Figure 2, which displays the source of the first reflection delayed 72 ms from the direct sound that is showed in Figure 1.

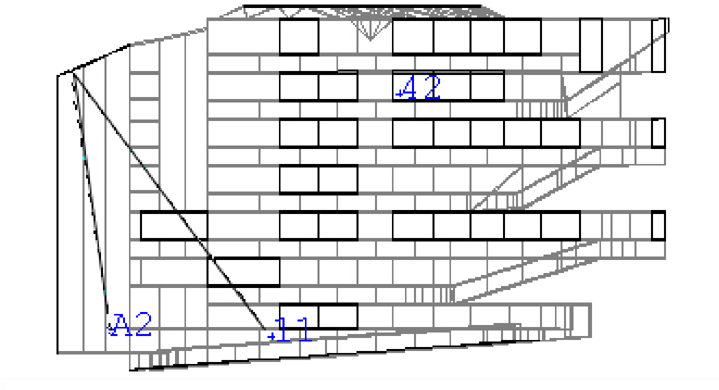


Figure 2: Origin of the reflection delayed 72 ms in the seat 11 in the main floor

To fix the acoustical problems detected in the main floor of the hall we have to fill with early reflections the detected gap in the first 80 ms. Therefore, it was decided to develop a canopy over the pit. This canopy would have to accomplish the following conditions:

3 Design of the canopy

The canopy would have to accomplish the following conditions:

1. Covering acoustically the main floor with reflections within the first 80 ms in a homogenous way.

2. Not deteriorating the upper levels of the hall.

3. Increasing the amount of lateral energy in the main floor.

4. Rising the angle of arrival of the early energy from the stage to reduce the seat-dip in the main floor.

5. Boosting the Early Delay Time (EDT) and the Strength (G) at low frequencies in the main floor.

6. Improving the Early Ensemble Level (EEL) for the musicians on the stage.

Clearly a traditional canopy, composed by big pieces of flat wood or another material, could not fulfil all of these requirements at the same time. With that kind of canopy the main problem was the impracticality to reflect bass frequencies to the main floor and, simultaneously, to allow the waves to reach the upper levels not to reduce the existing acoustical quality in the balconies.

3.1 Theoretical framework

Following J. H. Rindel [3], it is possible to deduce the intensity of the reflected wave of an array of rectangular reflectors from the Kirchhof-Fresnell approximation to diffraction.

For a single reflector, for all frequencies below a lower limiting frequency fc, the sound reflections are attenuated due to scattering effects caused by the size of the reflector.

The cut-off frequency fc can be calculated by [4]:

$$fc \ = \frac{1}{2} c \, a^{*} / (S \cos \theta) \tag{1}$$

Where c is the speed of sound, S is the area of the reflector, θ the angle of incidence and a^* is the characteristic distance. This can be calculated from the distances to the reflector from the source and the receiver a_1 and a_2:

$$a^{*} = \frac{2 \, a_1 \, a_2}{a_1 + \ a_2} \tag{2}$$

For a single reflector, the frequency fc represents a lower limit for the usable frequency range.

For an array of equal rectangular reflectors situated in the same plane (the x-y plane), the Kirchhof- Fresnell approximation to diffraction can be used if the distances a_1 and a_2 are larger than the wavelength and the size of the reflectors. The intensity of the reflected sound can be calculated as the product of a factor *K* -representing a specific reflection coefficient- and the intensity reflected by an ideal reflector of infinite surface [3].

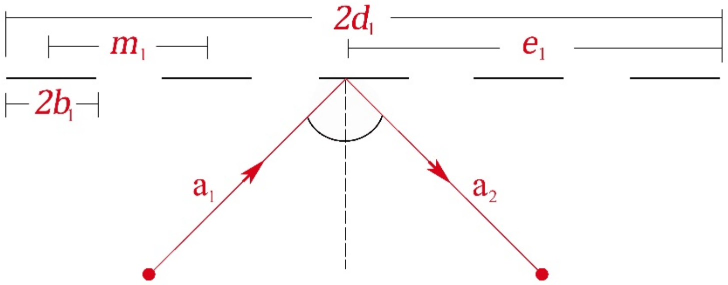


Figure 3: General scheme of a reflection in a periodic array (after Rindel [3])

The extra attenuation ΔL_{difr} due to the array can be expressed by:

$$\Delta \mathrm{L}_{\mathrm{difr}} = 10 \log K = 10 \log \ (K_1 \cdot \ K_2) \tag{3}$$

K_1 and K_2 are the reflection coefficients of the array in the *x* and *y* directions respectively. Following Rindel [3], K_1 can be expressed as:

$$K_1 = \frac{1}{2} \left[\left\{ \sum_{i=1}^{l} \left[C_{(v_{1,i})} - \ C_{(v_{2,i})} \right] \right\}^2 \right] + \left[\left\{ \sum_{i=1}^{l} \left[S_{(v_{1,i})} - S_{(v_{2,i})} \right] \right\}^2 \right] \tag{4}$$

Where:

$$v_{1,i} = \frac{2}{\sqrt{\lambda a^*}} \left(e_1 - (i-1)\, m_1\right) \cos\theta$$
$$v_{2,i} = \frac{2}{\sqrt{\lambda a^*}} \left(e_1 - 2b_1 - (i-1)\, m_1\right) \cos\theta \tag{5}$$

λ is the considered wavelength, i is the row number in the x direction and I is the total number of rows in the x direction. The functions *C* and *S* are the Fresnell integrals [3]:

$$C_{(v)} = \int_0^v \cos\left(\frac{\pi}{2}\, z^2\right) dz$$
$$S_{(v)} = \int_0^v \sin\left(\frac{\pi}{2}\, z^2\right) dz \tag{6}$$

The expression of the coefficient K_2 in the *y* direction is similar to the showed above.

If it is defined μ as the relative density of the array of reflectors, calculated by the ratio between the surface of the panels and the surface of the array, a rough approximation shows that $K_{1,2} \approx \mu^2$ for frequencies below fc (1).

Based on those results, it is possible to conclude that for low frequencies the efficiency of the array of reflectors is related to the relative density of the array. For high frequencies the intensity of the reflections is correlated with the dimensions and geometrical characteristics of each individual panel.

In a deeper analysis, following the work of Magne Skålevik [5], the behaviour of an array of rectangular panels is a combination of three different situations determined by two frequency limits fc and fg.

The first frequency limit is related to the reflection filter of an individual panel. For a single rectangular panel, Skålevik [6] suggested a simplified formula to calculate the cut off frequency fc:

$$f_c \approx 64 \cdot \varepsilon \tag{7}$$

Where ε is the relationship between the perimeter L and the area S of the panel ε = L/S.

The second frequency limit fg, deduced by Rindel [3], is defined by the Fresnel-Kirchhoff filter of the array of panels.

The system behaviour can be seen as a combination of two first order high pass filters, each one with frequency slopes of 6 dB per octave. Below the fg limit the slope is 12 dB per octave.

The useful frequency range is determined by frequencies fg and fc in the low range and by f_1, which depends on the geometrical design of each panel, in the upper range. Following the results of Skålevik [5], in the case of a canopy array of size M·M with N square panels of size n·n at H m above the stage, the effective frequency range can be calculated by:

$$f_g = \frac{c \cdot H}{(2 \cdot M^2)}$$
$$f_c \approx 64 \cdot \frac{4}{n} \qquad (8)$$
$$f_1 = \frac{c \cdot H}{(2 \cdot n^2)}$$

The value of the reflection in the pass band, from fc to f_1, is *20·log (μ)*, where the panel density μ = Spanel/Stotal is given by $\mu = N \cdot n^2/M^2$.

3.2 Design of the canopy for the Ginastera Hall

We decided to make a canopy of 17.5 m · 5 m to cover approximately the area over the pit, with a density of panels of 50%, built by square panels of 1.6 m · 1.6 m and situated from 7 m to 11 m over the stage floor.

The useful range was estimated from () () and (). The value M was calculated considering the equivalent area of the rectangle that covers the pit area:

$M^2 = M_1 \cdot M_2$ = 17.5 m · 5 m = 87.5 m^2

Then, from (8): fg = 340 m/s · 7 m / (2 · 87.5 m2) = 13.6 Hz
fc ~ 64·4/1.6 m = 160 Hz
f_1 = 340 m/s 7 m (2·1 m2) = 930 Hz

In Figure 4 it can be seen a scheme of the spectral behaviour of the canopy. Above f_1 the reflection level depends on the individual shape of each panel.

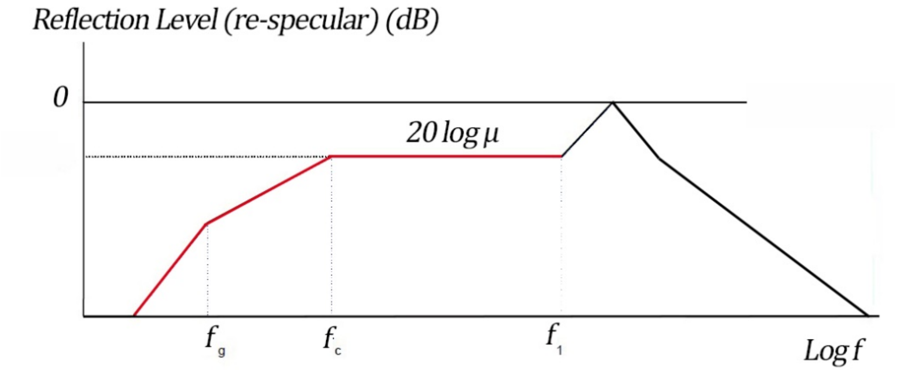


Figure 4: Spectral response of the canopy array designed for the Ginastera Hall (after [5])

To extend the useful range to higher frequencies, the individual panels were bent with a curvature radio of 5.5 m [7] (Cf. Figure 5).

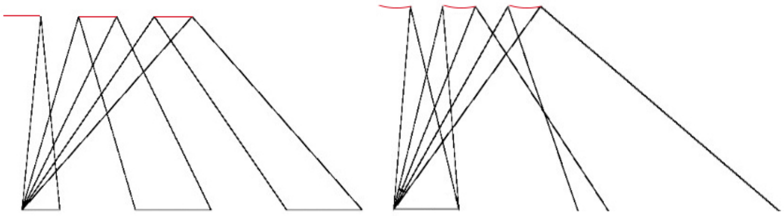
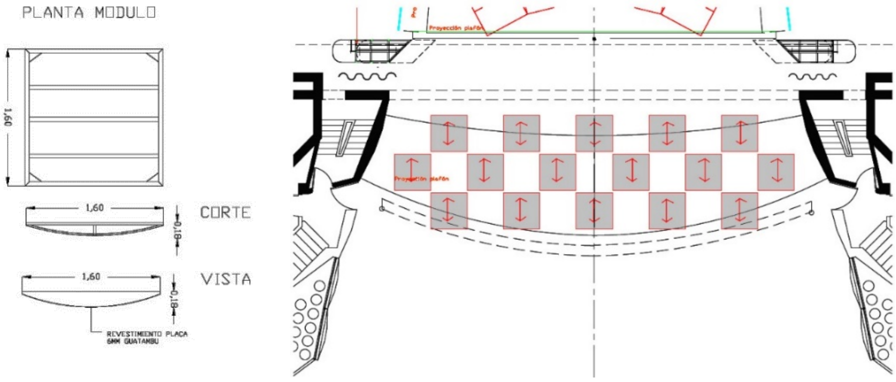


Figure 5: Longitudinal coverage with flat panels (left) and with cylindrical panels of r = 5.5 m (right)

From this design we could expect a fairly flat spectral behaviour from fc = 160 Hz and an effective performance between fg = 13.6 Hz and fc. For the high frequencies we rely on the particular geometrical design of each single panel. The final design can be seen in Figure 6.



Source: Arq. María José Besozzi; Juan Carlos Greco
(*Technical Office* of the Teatro Argentino)

Figure 6: Final design of the canopy array

4 Results

Once concluded the design of the array the construction of the physical canopy began in 2011. In Figure 8 it can be seen a rehearsal with the system in position.

A new set of complete measurements were carried out in March 2012. From the results of those measurements we concluded that:

1. The lack of early energy in the main floor was fixed. In Figure 7 is showed the equivalent impulse response of Figure 18 obtained after putting in place the canopy.

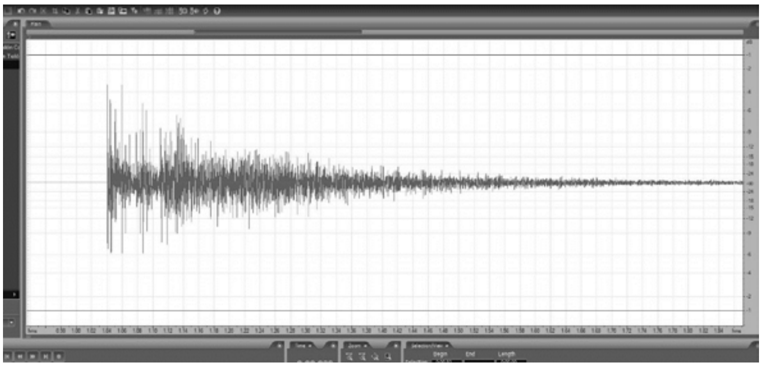


Figure 7: Impulse response measured in the seat 11 in the main floor with the canopy in position

2. The amount of lateral energy LE in the main floor was significantly increased. As an example, for the position 11 the value rose from 14% to 35%. The origin of this change was mainly the greater number of lateral reflections coming from the front of the balconies after being reflected by the canopy.

3. The bass frequency Strength G, below 300 Hz, was increased 3 dB on average.

4. The upper levels did not show appreciably changes.

Figure 8: Canopy in position during a rehearsal of the *Missa Solemnis* by Beethoven, October 2011

5 Conclusions

Four years after the installation of the canopy, a lot of information about the acoustical quality of the hall was collected from opinion polls answered by musicians, audiences and music critics.

Briefly, the sound field in the main floor is now more enveloping, the basses are richer and the sensation of “flat sound” has disappeared. At the same time, the upper levels maintain their quality and the ensemble level for the musicians on the stage has been improved.

In summary, the global quality of the hall has been improved after an intervention focused only on its early acoustical field.

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