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Acoustical evaluation of the Teatro Colón of Buenos Aires

Gustavo Basso
Facultad de Bellas Artes, Universidad Nacional de La Plata, Province of Buenos Aires, Argentina; gusjbasso@gmail.com

The acoustical quality of the Teatro Colón of Buenos Aires as a symphonic auditorium, considered among the best of the world, is evaluated from different perspectives. From the results of opinion polls about the perceived sound by the audience and from physical measurements, some of its acoustical characteristics were identified. However, some discrepancies have been found between the values suggested by the methods to predict the acoustical quality of halls for music, such as Beranek's Acoustical Quality Index, and the data collected. A digital model of the hall was developed in order to identify the origin of that inconsistency. From the outcomes of this tool, the results of the measurements and the aural prospection in the real hall, some of the causes of its particular acoustical behaviour have been found out. A specific combination of architectural features like the shape of the horseshoe, the height and depth of the boxes at the upper levels and the design of the proscenium seems to play an important role in this sense. In this work, only the acoustical quality of the main floor of the Teatro Colón is analysed.

1. INTRODUCTION

The Teatro Colón of Buenos Aires is well known for its outstanding acoustical quality. The opinion of musicians, audiences and critics have coincided that it is one of the finest opera theatres in the world.

The acoustical quality is established from opinion polls about the perceived sound by the audience, not from physical measurements. One of the largest and deepest works in this direction was carried out by Takashuki Hidaka and Leo Beranek, and published in the year 2000 [1]. In that paper, they showed the answers of 22 musicians, mainly orchestra conductors that had performed in the most important halls in the world, about the acoustical quality of 23 well-known opera theatres and ordered them in a scale that went from “poor” to “very good”. The Teatro Colón was not only suited among the best, but it also was placed in the highest position well above the second. In another article, published in November 2003, Leo Beranek [2] repeats the previous methodology and classifies the auditoriums for symphonic music according to their acoustical quality. Here the Teatro Colón occupied the third place, after two rooms built specifically for that purpose: the Grosser Musikvereinssaal of Vienna and the Symphony Hall of Boston.

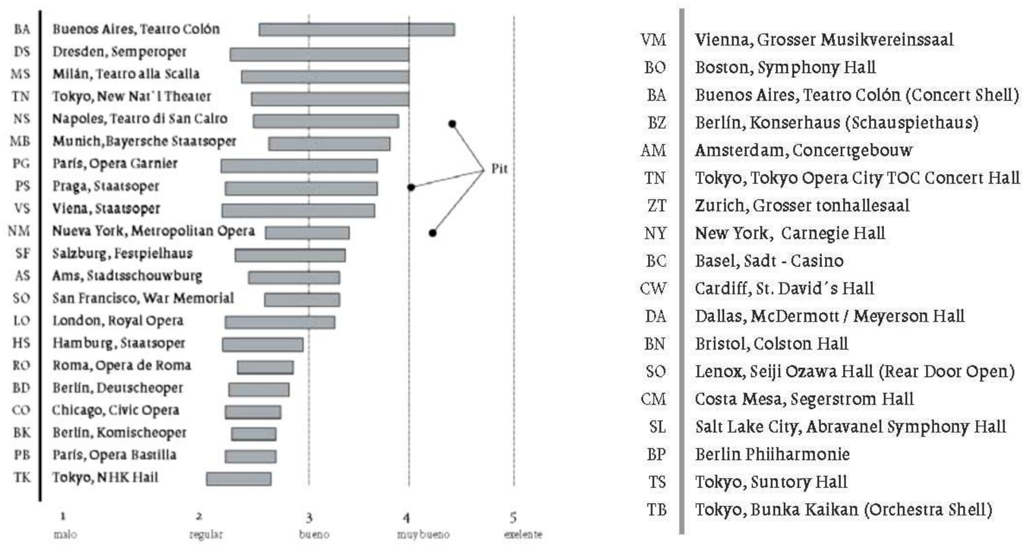

Figure 1. Results of opinion polls on acoustical quality of opera houses (after Hidaka [1]) and of auditoriums for symphonic music. After Beranek [2].

Between 2006 and 2010, a very deep restoration of the theatre was carried out; one of its main objectives was to preserve its acoustical quality [3]. To achieve this goal, a large team of architects, engineers and historians, including two specialists on acoustics –Eng. Rafael Sánchez Quintana and the author–, was formed. Although the Italian horseshoe theatre typology was extensively studied in the last decades [4], we thought that the case deserves an individualized analysis.

The theatre was acutely analysed through a complete set of acoustical measurements based on the ISO-3382 Standard [5], opinion polls about the perceived sound by musicians, audiences and critics, and the results of simulations in a digital model.

During the restoration works, based on the results of the measurements completed between 2006 and 2008, we tried to test the most extended physical or objectives theories and methods to predict the acoustical quality of halls for music. By that time, we used Beranek’s *Acoustical*

Quality Index (AQI) [6] and Yoichi Ando's *Theory of Subjective Preference* [7]. An article published in 2008 [8] showed that the application of the Acoustical Quality Index AQI to some of the best seats on the main floor of the Teatro Colón did not match the perceptual judgements of these seats. The value of the AQI was equal to -1.99, while one expects a value near zero for those outstanding locations. The discrepancies found out may lead to the need of refining the tools used to predict the acoustical quality, especially in those cases do not fit the usual typologies. After the failure of this first attempt to understand the reasons behind the acoustical quality of the hall, we decided to analyse the acoustical field of the best seats on the main floor beyond the limits imposed by the Standard ISO 3382.

Showing the first part of the outcomes of this evaluation is the main objective of this paper.

2. ACOUSTICAL QUALITY OF THE THEATRE: THE MAIN FLOOR

A. DISTRIBUTION OF THE ENERGY ON THE MAIN FLOOR

Although it is widely known that the parameters of the Standard ISO 3382 cannot describe properly by themselves the acoustical field of a hall for music, it is interesting to see how some of them are distributed on the main floor of the Teatro Colón. Fig. 2 shows the distribution of the *Strength* G and the *Lateral Fraction of Energy* LF at 500 Hz on the main floor with an omnidirectional source placed on stage.

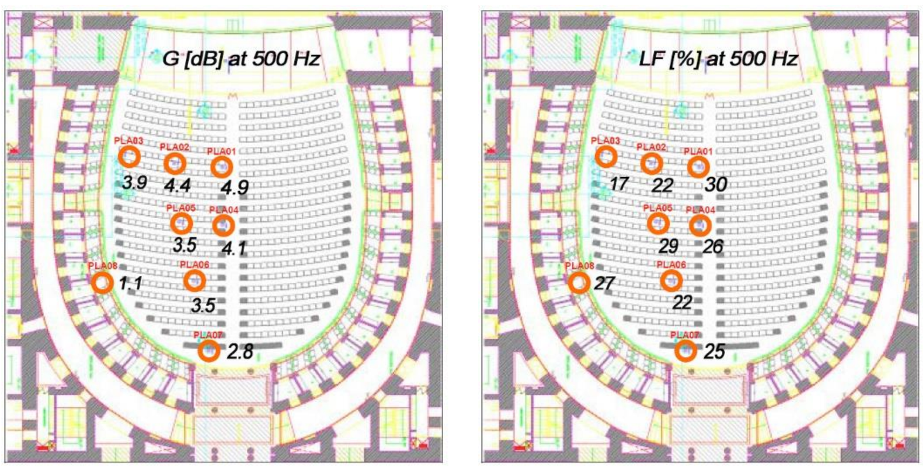

Figure 2. Distribution of G and LF at 500 Hz on the main floor.

The patterns at 500 Hz are similar to those at 250 and 1000 Hz. The behaviour of G and LF is different if the lower and upper regions of frequency are considered.

Between 10 m and 30 m, the Strength G is reduced 2 dB in the stalls of the Teatro Colón. If we complement the former data with the perceptual compensation for distance [9], which implies that the subjective experience of loudness is influenced by the source-receiver distance (in the sense that the same sound level is judged louder at positions further from the stage), it is easy to understand the opinion shared among the audience of the Teatro Colón: the loudness is almost the same on the entire main floor.

The values of the Lateral Energy Fraction LF at 500 Hz shows a lot of non-frontal energy reaching the audience (Fig. 2), which could explain the remarkable sensation of envelopment on the main floor of the Teatro Colón. Nevertheless, it is necessary to point out that the regular parameters of the Standard ISO 3382 for evaluating the lateral information, such as the *Inter-Aural Cross-Correlation Coefficient* (IACC) or the *Lateral Energy Fraction* (LF), do not take into account the specific angles of arrival of the energy. In the case of the Teatro Colón, those angles are decisive to define its acoustical field.

B. USE OF A DIGITAL MODEL

In order to identify the origin of the described acoustical behaviour, we have developed a digital model with the software CATT-Acoustic, which was fine-tuned through the huge amount of data collected from the measurements in the hall and in the laboratory. After that, the digital model not only could replicate the values of the ISO 3382 parameters but, much more important, it allowed us to reproduce the impulse response of each individual location on the main floor and the balconies with a suitable accuracy in time and frequency.

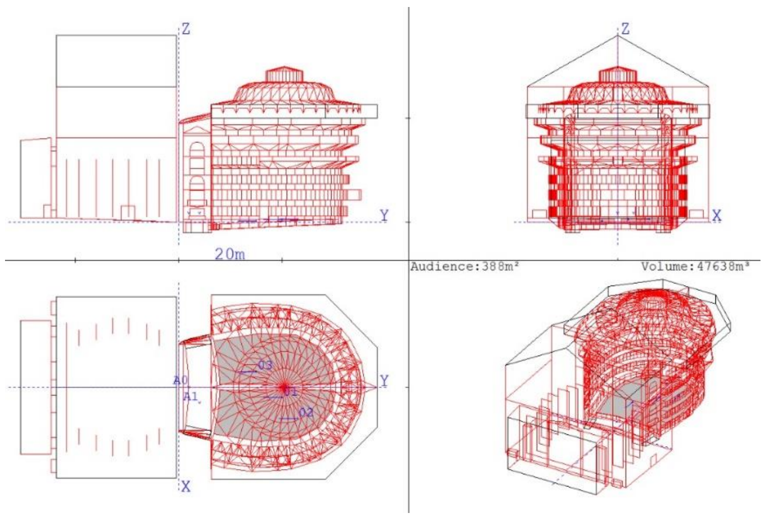

Figure 3. Views of the digital model of the Teatro Colón (Catt-Acoustic software)

With this tool, the results of the measurements and the aural prospection in the real hall, we have found some of the causes of its particular acoustical behaviour.

C. ANALYSIS OF SOME SEATS ON THE MAIN FLOOR

From the binaural signals recorded in 12 locations on the main floor, we can analyse the specific acoustic field that reaches the ears of the audience. One of the binaural impulse responses acquired can be seen in Fig. 4.

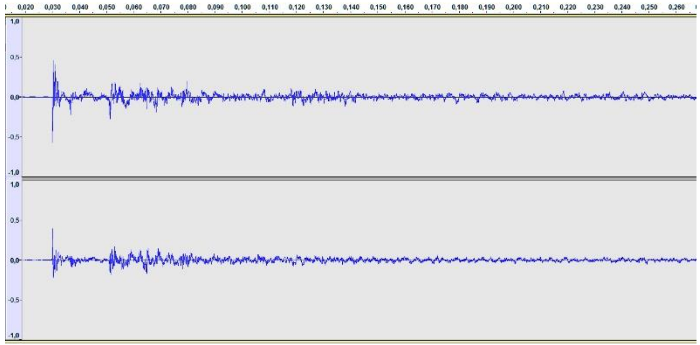

Figure 4. First 200 ms of the binaural impulse response measured at a seat near the centre of the main floor

The signal of Fig. 4 shows the impulse response at a seat near the centre of the main floor. It can be seen that there is a very rich texture after the first significant reflection, which arrives 21 ms after the direct sound. Further analysis shows that the signal has a lot of early lateral energy arriving from angles from 15º to 80º in the horizontal plane and from 10º to 50º in the vertical plane, given a polar system with its origin in the line of sight of an observer faced to the stage. This kind of acoustical field is shared quite well by almost the totality of the seats on the main floor.

If we add a nice reverberation time of 1.8 s at 500 Hz –above average in opera theatres–, a powerful bass response –the theatre has a Bass Ratio of 1.2 without any seat-dip–, a very well balanced relation between early and late energy and a homogeneous distribution of energy –the Strength G on the main floor remains within an interval of +- 1.5 dB–, we begin to understand the reasons of its excellent musical reputation. The overall characteristic of the sound on the main floor is therefore a combination of the acoustical field of an excellent opera theatre and of a first rate shoebox auditorium.

D. ORIGINS OF THE LATERAL REFLECTIONS ON THE MAIN FLOOR

The main origin of the strong lateral reflections that have been measured is, clearly, the dihedral angle created at the encounter of the rear wall and the ceiling of the balconies near the stage. This situation is shared by almost all the Italian horseshoe type theatres so, why is the result so special in the case of the Teatro Colón? We have identified some geometrical characteristics that, although not exclusive to this theatre, may explain part of its behaviour.

i. Shape of the horseshoe

The first geometrical feature that stands out is the shape of the horseshoe plan view, which is slightly different from those of other Italian opera theatres. As can be seen in Fig. 5, the proportion is somewhat oblong in the longitudinal axis, and the first section of the horseshoe, near the stage, is near rectilinear with an angle of divergence quite small, of about 9º. This shape produces a lot of lateral early reflections that cover a big area of the main floor, in a similar way found in a shoebox type auditorium.

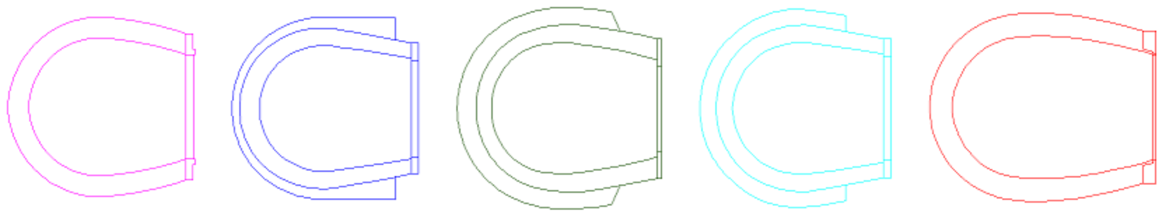

Figure 5. Horseshoes plan views of some opera theatres: Teatro alla Scala/Milan (magenta), Royal Opera House/London (blue), Staatsoper/Vienna (green), Opera Garnier/Paris (light blue) and Teatro Colón (red). [10].

The rear part of the horseshoe of the Teatro Colón is comparable to a traditional one, and allows distributing evenly the energy to the audience on the back area of the main floor. The combination of the two parts of the plan view, the first with its shoebox type behaviour and the second with its horseshoe contour, generates the even distribution of the acoustic energy on the main floor that was evidenced in the measurements.

ii. Height of the balconies

The shape of the plan view does not produce by itself the reflections towards the audience. It is necessary that the energy reaches a surface capable of reflecting it back to the main floor. The height of the balconies in the Teatro Colón is particularly efficient in that sense, because there is a lot of free space in the boxes above the heads of the audience that allows the energy to return unobstructed to the stalls.

As an example, Fig. 6 shows a comparison of the longitudinal section of the Teatro Colón and the Teatro Alla Scala of Milan, Italy. The same number of levels is solved in the Teatro Colón with a greater height (it is approximately 30% higher).

The energy returns clear to the main floor in the case of the Teatro Colón, whereas in other examples much of it is trapped and absorbed by the public, the curtains and the carpets present inside the boxes.

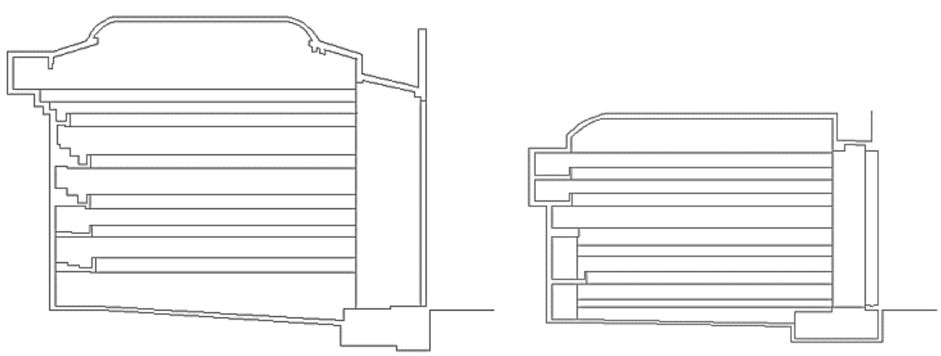

Figure 6. Longitudinal section of the Teatro Colón and the Teatro Alla Scala of Milan.

iii. Depth of the balconies

Even with boxes of a considerable height, the energy could be confined inside them if they were deeper. In the case of the Teatro Colón, this possibility does not happen since the boxes near the stage have their rear wall very close to the front, allowing only 2 rows of seats inside them (Fig. 7). This pattern is repeated in almost all the levels of balconies.

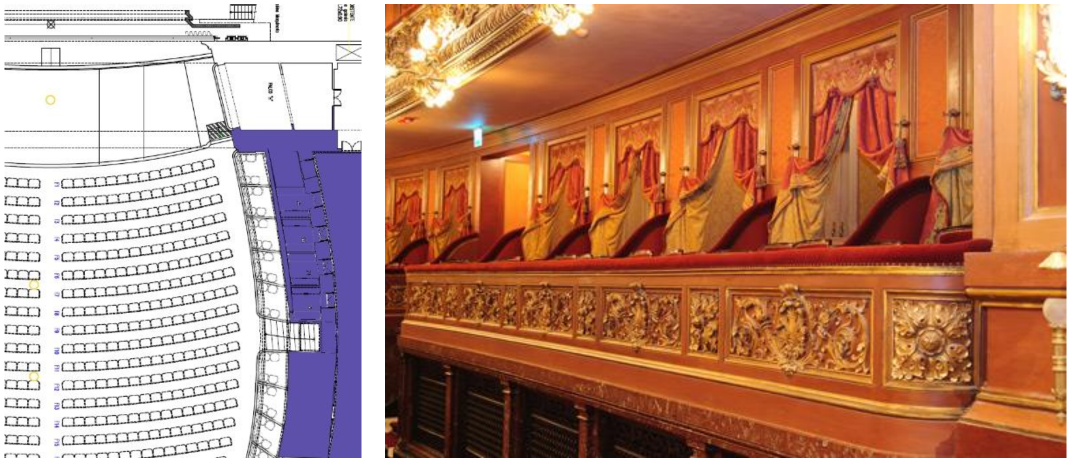

Figure 7. Plan view and photo of the boxes of the first level near the stage. It can be seen the free path for the reflections from the wall/ceiling encounter.

iv. Action of the three first factors combined

As an example of the efficiency of the three factors when they are combined, Fig. 8 shows the origin of some strong lateral reflections in one seat on the main floor.

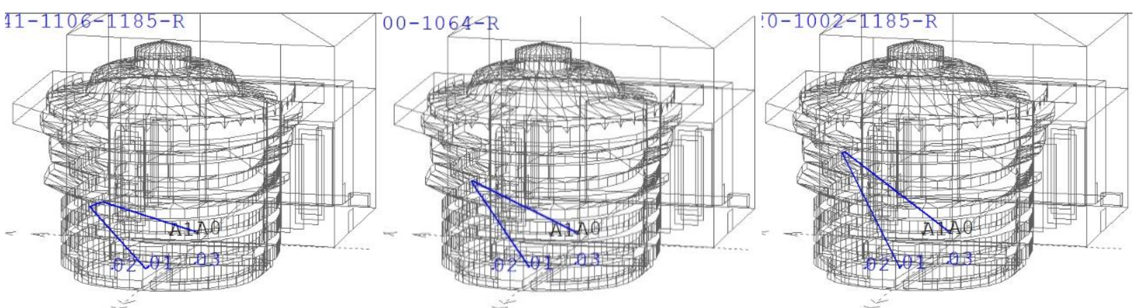

Figure 8. Main lateral reflections at the same seat on the main floor coming unobstructed from the dihedral angles wall/ceiling at three balconies levels.

Those reflections have a broadband spectrum and arrive on the main floor from almost ideal angles, well above the critical angle needed to avoid the seat-dip effect. Their delay and intensity are properly suited within the Hass effect limit. The outcome of this situation is a sound with a great Apparent Source Width (ASW) and the inexistence of any source shift. The perceptual field is, therefore, very enveloping and, at the same time, the localization of the sound sources on the stage is clear and the timbre of each instrument is well preserved.

v. Shape of the boxes around the proscenium

We have described so far the architectural origins of the strong early lateral energy reaching most of the seats on the main floor. However, this explanation cannot justify the acoustical behaviour of the first rows on the main floor, those that are near the pit/stage, because the reflections from the sidewalls of the horseshoe become effective only from the 5th row onwards. For this area, the Teatro Colón has very efficient diffusive boxes around the proscenium, which distributes the energy evenly and without any spectral distortion or source shifting.

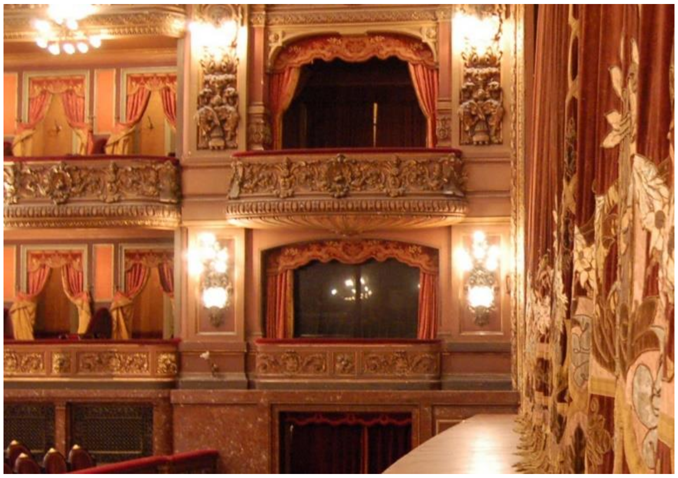

Figure 9. Boxes around the proscenium of the Teatro Colón.

E. BASS RESPONSE ON THE MAIN FLOOR

The bass sound on the main floor is very powerful and no seat-dip effect is detectable. The apparent reasons of this behaviour is a combination of three factors: the angles of arrival of the energy from the upper levels; a strong low frequency reflection from the wall of marble surrounding the main floor; and the air space under the floor, which communicates with the sound field of the hall through the holes of the air-conditioning system.

3. CONCLUSIONS

We have identified some geometrical characteristics of the Teatro Colón that create on its main floor an acoustical field of a very rich texture after the first significant reflection, in which a lot of lateral energy arrives from almost ideal angles in the horizontal and the vertical planes. This acoustical behaviour, shared by almost the totality of the seats on the main floor, is produced by a combination of architectural features like the shape of the horseshoe, the height and depth of the boxes in the upper levels, and the design of the proscenium.

Other features that could contribute to define the acoustical quality on the main floor, like the nonexistence of echoes or flutter echoes, the balance between the singers on stage and the orchestra in the pit, and the support for the singers on stage, are shared by the totality of the levels of the theatre and will be described in further publications.

The acoustical quality of the main floor of the Teatro Colón seems to be, therefore, a mix of different factors which coincide in a very positive way. Although more research is needed to discover other elements that could contribute to this regard, we believe that the highlights in this work allow not only to improve our understanding of such a wonderful theatre, but also to help in the design of new rooms for music.

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