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The Teatro Colón in Buenos Aires as a double- function hall

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ABSTRACT

The Teatro Colón in Buenos Aires is well known for its acoustic quality. It is considered not only one of the best opera houses in the world, but also an exceptional space for symphonic music, as highlighted by Leo Beranek and colleagues in two articles published in 2000 and 2003. The architectural and acoustical analysis of the hall shows some of the possible causes of this dual behavior, derived from a specific combination of architectural features such as the shape of the horseshoe, the height and depth of the boxes at the upper levels and the design of the proscenium and pit. These components contribute to create a very enveloping sound field when used for symphonic music, similar to those of a shoebox auditorium, and allow the maintenance of the acoustical balance between the singers and the orchestra when used as an opera theatre. As can be seen from audience opinion polls on the sound perceived, acoustic measurements and the outcomes of a digital model, this behavior is more noticeable on the main floor. In this work, the acoustic quality of the Teatro Colón as a double-function hall is analyzed.

Keywords: Opera house, acoustical quality, lateral reflections

1. INTRODUCTION

The Teatro Colón of Buenos Aires, which opened in 1908, is well known for its excellent acoustical quality. General opinion considers that it is not only one of the finest opera theatres in the world, but also one of the best halls for symphonic music. Along with the usual sources of information, based on the opinions of the audience, musicians and critics who have attended functions during its history, the assumption that the Teatro Colón has a superior acoustical quality was supported by two extensive research works developed at the beginning of the 21st century. The first of them, published in 2000, was carried out by Takashuki Hidaka and Leo Beranek (1). In that paper, they surveyed 22 musicians, who had vast experience performing in halls around the world. The musicians were asked to rate the acoustic quality of 23 well known opera houses and the theatres were then ranked on a scale from "poor" to "very good". The Teatro Colón was not only among the best, but actually placed highest of all the theatres. In another article, published in 2003, Beranek repeats the previous methodology and classifies the auditoriums for symphonic music according to their acoustical quality (2). In this paper the Teatro Colón was placed joint top, with the same rating as two shoebox-shaped concert halls built specifically for that purpose: the Vienna Musikverein and the Boston Symphony Hall.

Why is the acoustic of the Teatro Colón so good? Perhaps one possible answer to this question could be that the Teatro Colón behaves like a double hall, with some features typical of opera theatre and others of an auditorium for symphonic music.

In order to understand the physical origins of the acoustic quality of the hall, it was decided to analyze the acoustic field of the best seats beyond the limits imposed by ISO-3382 standard. Some theories, based on the structure of the lateral reflections, as the cause of the strong sound presence and the great enveloping sensation experienced in the room, were then considered as possible explanations of its acoustical behaviour. The main objective of this work is to present part of the outcome of this analysis, in which some of the architectural causes of the acoustic fingerprint of the Teatro Colón were exposed. Part of the material shown has already been presented in previous congresses and scientific meetings, but in this case a more comprehensive perspective is followed.

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2. METHODOLOGY

In order to determine the possible architectural causes of the acoustic behaviour of the Teatro Colón, several activities were carried out:

1. Analysis of historical records and opinions of well-known artists. A new series of opinion polls was also performed to complete the picture from the point of view of the audience.
2. Acoustic measurements of the hall based on the ISO-3382 standard (3).
3. Simulations in a digital model, developed using the software CATT-Acoustic, which was fine-tuned using the data collected from the measurements described in point 2 and with the data obtained taken of measurements of the acoustic materials–seats, chairs, curtains and carpets–in a certified laboratory (4).
4. Analysis of the relationships among the physical data collected and the outcomes of the subjective evaluations of the hall.
5. Analysis of the probable architectural causes of the acoustical quality of the hall, based on the conclusions obtained in point 4.

Following the methodological process listed above, the condensed results of this stage of the analysis are described in the next subsections. The results are presented in two parts: firstly in reference to the theatre as an auditorium for symphonic music and secondly regarding its use as a theatre for opera.

3. THE TEATRO COLÓN AS AN AUDITORIUM FOR SYMPHONIC MUSIC

The results of the opinion polls about the acoustic quality of the hall as a auditorium for symphonic music were, in general, expected. They describe the sound differences at different levels and revealed some well-known small sectors of the main floor with a sound quality below the average. However, the item "comments", in which the listeners could express themselves freely, was very revealing. The majority highlighted the presence of the sound–one of them said it was "tangible", the feeling of being immersed in sound, and that the acoustic fingerprint of the room was maintained at the highest level of quality throughout the entire dynamic range, from the *pp* to the *ff*. Some musicians with vast international experience compared the quality of the main floor with the stalls in some of the best shoe-box auditoriums–Boston Symphony Hall and Vienna Musikverein were mentioned. This was quite unexpected, since in the Italian horseshoe halls, the highest acoustic quality is usually found at the upper levels, not in the stalls. The following section will focus principally on the main floor.

The signal in Figure 1 shows the impulse response at a seat near the centre of the main floor.

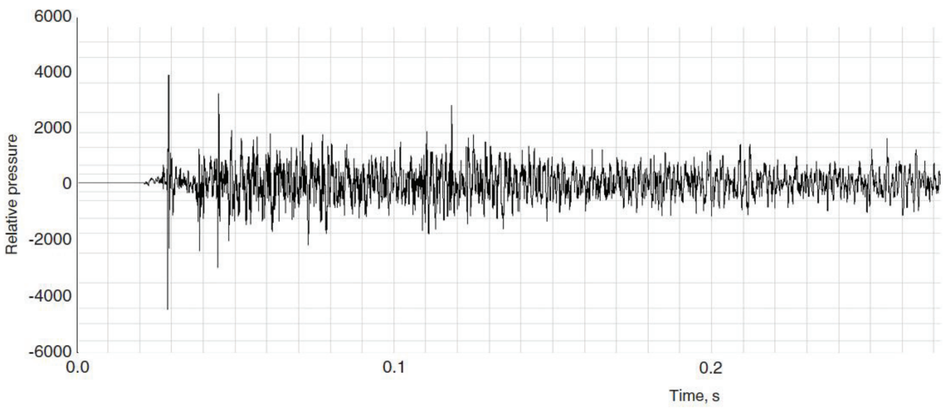


Figure 1 – The first 250 ms of the binaural impulse response measured at a seat near the centre of the main floor

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 of 15º to 80º in the horizontal plane and of 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 (4).

3.1 Architectural origins of the lateral reflections on the main floor

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. Figure 2 shows that its 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 of about 9º, which is quite small. This shape produces a lot of lateral early reflections that cover a big area of the main floor, in a way similar to that of a shoebox type auditorium.

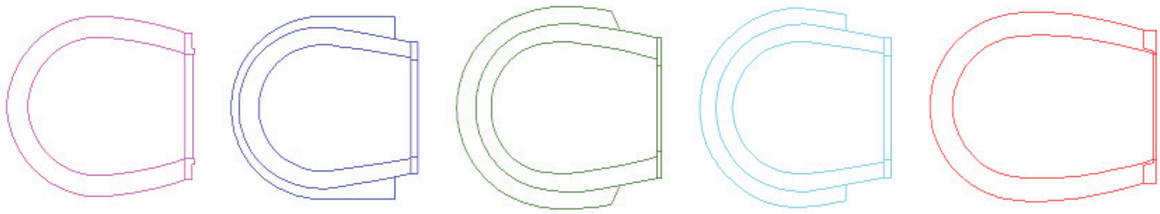
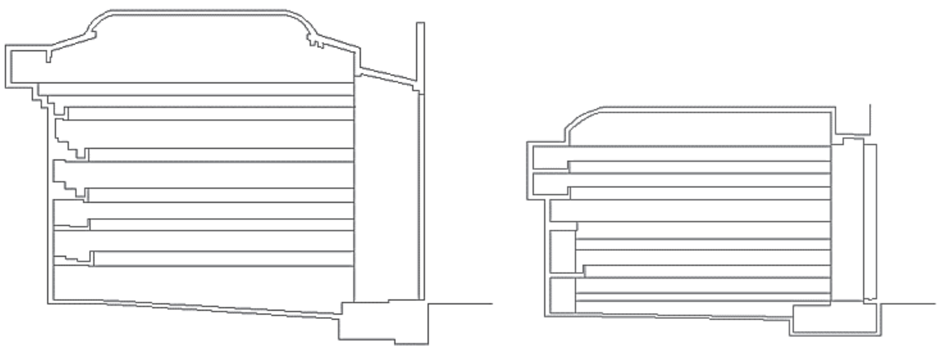


Figure 2 – Horseshoes plan views of some opera theatres: Teatro alla Scala/Milan (magenta), Royal Opera House/London (blue), Staatsoper/Vienna (green), Opera Garnier/Paris (light blue) and Teatro Colón (red). After (5)

The rear part of the horseshoe of the Teatro Colón is comparable to a traditional horseshoe and allows even distribution of 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, seem to generate the even distribution of the acoustic energy on the main floor that was evidenced in the measurements.

The shape of the plan view does not produce by itself the reflections towards the audience on the main floor. It is necessary that the energy reaches a surface capable of reflecting it back to this area. 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 boxes that surround the stalls. The height of the balconies in the Teatro Colón is particularly effective 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, Figure 3 shows a comparison of the longitudinal section of the Teatro Colón and the Teatro alla Scala in Milan, Italy. The two theatres have the same number of levels, but the Teatro Colón has a greater height (approximately 30% higher). The energy returns clearly 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 (4).



(a) (b)

Figure 3 – Longitudinal section of the Teatro Colón (a) and the Teatro alla Scala of Milan (b). After (4)

Even with boxes of a considerable height, the energy could be confined inside them if they were too deep. In the case of the Teatro Colón, this does not happen as the boxes near the stage have rear walls that are very close to the front, allowing space for only two rows of seats (Figure 4). This pattern is repeated on almost all the levels of balconies.

Figure 4 – Boxes of the first level near the stage. The free path for the reflections from the wall/ceiling encounter can be easily seen

As an example of the efficiency of the three mentioned factors when they are combined, Figure 5 shows the origin of some strong lateral reflections in one seat on the main floor when a sound source is located on the stage.

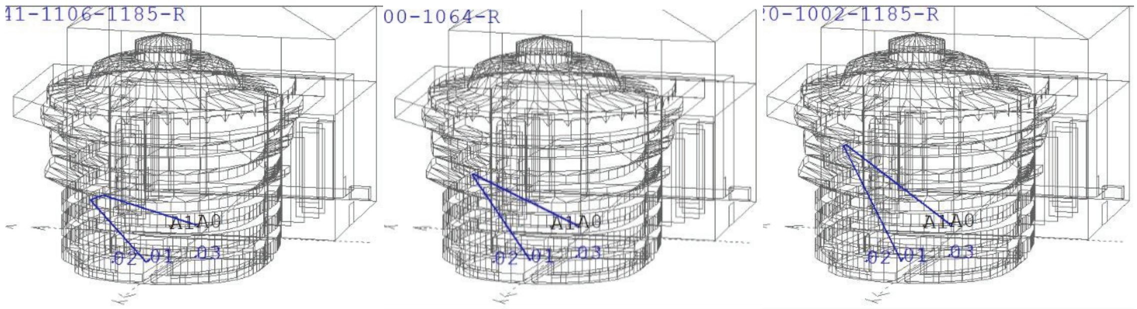


Figure 5 – Main lateral reflections at the same seat on the main floor coming unobstructed from the dihedral angles wall/ceiling at three balconies levels. After (4)

Those reflections have a broadband spectrum and the sound arrives at the main floor from almost ideal angles, well above the critical angle needed to avoid the seat-dip effect. Their delay and intensity are well within the Haas effect limit. 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. These characteristics are like those that can be found in the best shoebox-type auditoriums.

3.2 Acoustic field at the upper levels

At the upper levels the situation is completely different. The acoustic field is formed by the global acoustics of the hall, defined by the values of Reverberation Time TR, Bass Ratio BR or Strength G at each position, and from the early reflections generated by the stage floor, by the surfaces that surround the proscenium arch, and by the surfaces near the box that is being considered–such as its own ceiling and rear wall. This behaviour will be described in the section dedicated to the hall as an opera theatre.

4. THE TEATRO COLÓN AS AN OPERA THEATRE

The Teatro Colón of Buenos Aires is mainly an opera theatre. Unlike auditoriums for symphonic music, in which the orchestra and the audience occupy the same architectural space, opera theatres have three different conjoined spaces, each with different acoustic functions: the stage tower, the area for the audience and the orchestra pit. The importance of the voice in this genre is obvious, so the sound balance between the singers on the stage and the orchestra in the pit is considered one of the key factors that determine the acoustical quality of an opera theatre. Simplifying the subject, the singers need clarity, intelligibility and timbre preservation, whereas the orchestra requires reverberation and spatial impression (6). The singers are at a disadvantage with respect to the orchestra, both in terms of their number and the power of the sound they produce, but these disadvantages can be mitigated by two concurrent factors: the nature of the sung voice, trained in the western operatic tradition, and the acoustics of the theatre. The singer can be heard over the orchestra in the frequency region of the so-called "singing formant", a fifth formant that usually lies in the frequency range of 2000-3000 Hz. In this spectral region, the singers' voice can overcome the sound of an orchestra and can be heard clearly (7, 8). There is another feature that contributes to the audibility of the singers: their position on the stage from where the sound projection reaches the listeners without obstacles. The orchestra, on the other hand, is located in the pit, a space acoustically separated from the area occupied by the audience (9). There are two additional factors: one is the complex dispersion of the audience in a traditional opera theatre, with listeners located in the stalls and in boxes at different heights. The other is the changing nature of the opera sets, with different scenery and constant changes in the location of the opera singers. This complexity of variables makes the task of finding average or global balance values unrealistic: the low acoustic homogeneity of such theatres forces us to study the balance of each source-receiver pair and try to obtain valid averages by audience zones alone.

4.1 Singer-orchestra balance

One of the problems in trying to characterize the balance is that it is not standardized. It does not appear, for example, among the parameters defined by the ISO-3382 standard. Nor are the measurement conditions stipulated. As we will see, the scenography and the location of the singer on stage could substantially modify the values of balance obtained. From all the existing definitions, we found it most appropriate to apply those of John O'Keefe and Nicola Prodi in the case of the Teatro Colón. O'Keefe suggested putting a directional sound source on stage and an omni-directional sound source in the pit (9, 10). In the Prodi proposal the Balance coincides with the difference in G values from stage and pit when both sources are omnidirectional and has the advantage of not needing the power equalization between the sources. In the case of the Teatro Colón, a complete set of G_{STAGE} and G_{PIT} measurements in the main floor and from several locations in the upper levels were available. The Strength was measured on the main floor with omnidirectional sources located in the pit and on the proscenium, with the textile curtain in position. Most of the data of B obtained falls within the average limits advised by the specialized literature. Some authors suggested the range from -2 dB to +4 dB (9, 11), while others go up as high as +7 dB (10). The spectral distribution of the balance is as important as the value of B. Figure 6 shows that the stage/pit balance in the main floor reaches its maximum in the region of the singers' formant, even in the seats in the stalls furthest away from the stage (6).

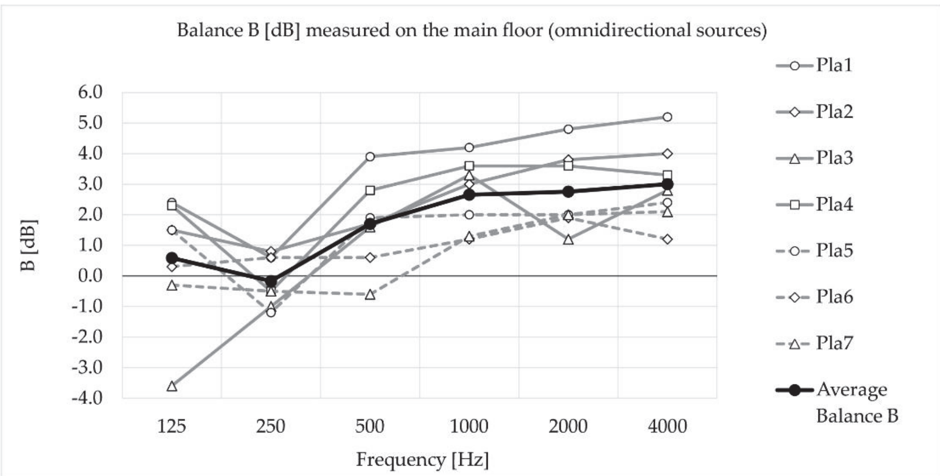
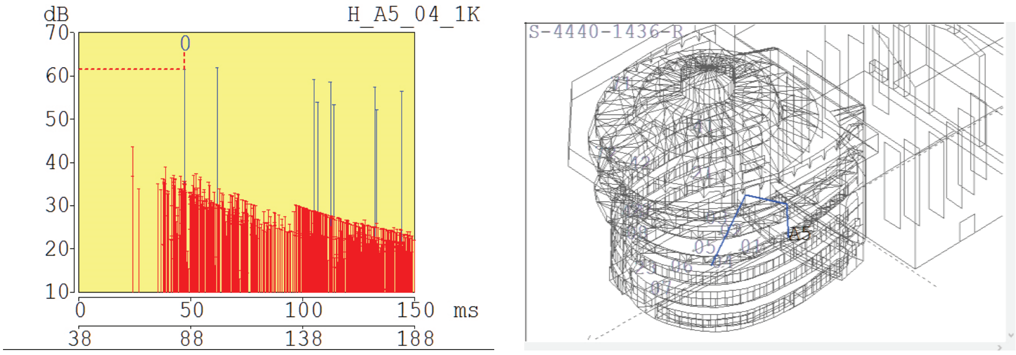


Figure 6 – Spectral characteristics of the balance on the main floor. Pla1 to Pla7 are seats on the main floor.

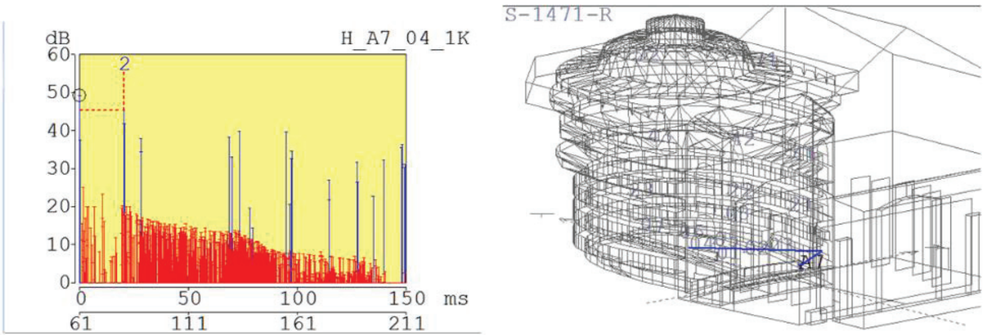
In order to identify the origin of the described acoustical behaviour, the digital model was used to replicate the values obtained in the measurements with two omnidirectional sources and the textile curtain. These balance values could be suitable reproduced from 500 Hz, while for values below 200 Hz the simulation proved ineffective because of its inability to solve the phenomena related to wave acoustics (i.e. diffraction and seat-dip effect). A characteristic stage set-up of an opera was simulated, with materials with an absorption between 10% and 30% in the mentioned frequency range. With an omnidirectional source in the pit there is no direct sound coming from the pit on the main floor, as can be seen in Figure 7. The first discrete reflections arrive 50 ms after the emission, later than the diffuse reflections.



(a) (b)

Figure 7 – Major early reflections on the main floor from an omnidirectional source in the pit. (a) Reflectogram; (b) origin of the reflections. After (6)

With a directional source on the stage the sound of the singers benefits from the specific architecture of the Teatro Colón, as in a symphonic concert with the orchestra on stage as shown in Section 4. Figure 8 a shows the simulated impulse response at a seat near the centre of the main floor. We can see that the first significant reflection arrives 21 ms after the direct sound (5).



(a) (b)

Figure 8 – Early reflections on the main floor from a directional source on the stage. (a) Reflectogram; (b) origin of the reflections. After (6)

The ability to hear the voice on the stalls is supported by the direct sound and its first reflections, which arrive much earlier than the reflections coming from the pit. This feature, added to the spectral reinforcement of the zone of the singers' formant, explains in part the good balance that the audience has on the main floor. However, if the source is placed well inside the stage (12 m from the proscenium) and the scenery is very absorbent, the balance is drastically reduced, falling below the recommended values (6).

Contrary to in the stalls, at the upper levels there is a direct line of sight to instruments in the orchestra in the pit. In the stalls, the sound of the orchestra is attenuated by the barrier effect of the pit and the fence between the pit and the audience. Due to the diffraction and the excellent low frequency diffusion provided by the lateral boxes and the sides of the proscenium, this attenuation affects the low frequencies less. At the upper levels, this barrier disappears and the sounds of medium and high frequency grow at relative values. The digital simulation shows that, although the balance at higher levels loses part of the spectral advantage that the theatre has in terms of the stalls, this change is compensated for by the emergence of the powerful reflection of the singers' voices on the stage floor. This reflection is useful only for the voices and is almost non-existent for the audience on the main floor. This fact, plus the appearance of early reflections from the ceiling, allows the balance to be maintained within appropriate values at the upper levels. The contribution to the balance of the reflection on the stage floor is very important. If a carpet is used, the balance is reduced by an average of 2 dB. At the upper levels, the influence of the stage set-up is less pronounced than on the main floor when the singers are located well inside the stage box.

5. DISCUSSION

The aforementioned measurements and digital simulations of the main floor of the Teatro Colón show an acoustic field with a large amount of non-frontal energy, in which a dense structure of early lateral reflections appears behind the first significant reflection. These reflections fall well within the Haas limit, minimising echoes and colorations and, at the same time, increasing the perceived spatiality. From the answers obtained in the surveys on acoustic quality it is known that the sound in the Teatro Colón is very immersive and that it has a strong sound presence. It is interesting to point out that these characteristics are found in both uses of the hall, as an opera theatre and as an auditorium for symphonic music. In some sense, the theatre seems to behave acoustically as a double hall, as if it were a combination of an Italian horseshoe opera house and a shoebox-shaped auditorium.

The question that arises is: are the usual physical characteristics sufficient in describing the sound perceived by the audience? In a first attempt to answer this question, some descriptors defined by ISO-3382 standard were applied, such as the LF or the IACC, but these parameters do not take into account the specific time, level and direction of arrival of each individual reflection, and therefore they could not explain an acoustic field in which, seemingly, these features were critical. In a second attempt, some objective theories and methods were used in order to predict the acoustical quality of halls for music, among them Beranek’s AQI. This method did not explain the quality, however, with the best seats of one of the best halls for music obtaining only average ratings (12).

Nevertheless, a series of conjectures has been developed that could explain, at least qualitatively, the relationship between the existence of powerful early lateral reflections and the acoustic fields of halls such as the Teatro Colón. Among them, is an early work by Rüdiger Wettschurek who, in his PhD Thesis, pointed out the differential perception of lateral energy at different sound levels. In his own words, a musical crescendo was as a kind of “awakening” of the room through the increasing of the subjective room presence–(13), cited from (14).

More recently some authors, including Tapio Lokki, Jukka Pätynen and Eckhard Kahle, among others, have pointed out the importance of the strong lateral reflections in order to obtain a very immersive, enveloping acoustical field. They sustain that the presence of this kind of reflections increases the subjective dynamic spatial responsiveness [26, 27], the enveloping sensation and the presence of the sound (15, 16). Furthermore, these strong lateral reflections increase the emotional impact of the music and make the acoustics of auditoriums more engaging (16, 17).

Another notion put forward is the amount and nature of the diffusion needed inside a hall: too much diffusion would preclude the necessary reflections required in order to achieve an immersive acoustic field but, conversely, an insufficient or misplaced diffusion would prevent the homogeneous distribution of the acoustic energy. According to Kahle, some halls that lack quality do so as a result of having excessive diffusion (18). In this sense, the Teatro Colón seems to have a proper balance among reflective, diffusive and absorptive surfaces.

6. CONCLUSIONS

The Teatro Colón seems to behave like a double hall, with some features typical of opera theatre and others of an auditorium for symphonic music. As an auditorium for symphonic music it seems to perform, on the main floor, like a combination of a shoebox-shaped hall and a horseshoe theatre. At upper levels it behaves like a traditional Italian horseshoe hall (4). As an opera house, the Teatro Colón combines two complementary situations: on the main floor, the voices of the singers are accompanied by a large number of early lateral reflections that, combined with the masking of the sound that comes from the pit, reinforce them in the singer's formant region. At the upper levels this spectral advantage disappears but is compensated for by the arrival of powerful reflections from the stage floor and the ceiling (6).

The theories that emphasize the importance of strong lateral reflexions not only coincide with the physical acoustic field observed in the Teatro Colón and with the subjective reactions it produces, but also help to understand some of its architectural characteristics. However, up to now the physical descriptors used in those new theories are mainly qualitative, so we need to develop some quantitative descriptors to analyze existing spaces and design new ones. The main goal is to find a new set of objective parameters that properly describe the acoustic fingerprint of a hall for music.

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REFERENCES

1. Hidaka, T.; Beranek L. Objective and subjective evaluations of twenty-three opera houses in Europe, Japan, and the Americas. J. Acoust. Soc. Am. 2000, 107 (1), 368-383.
2. Beranek, L. Subjective Rank-orderings and Acoustical Measurements for Fifty-Eight Concert Halls. Acta Acustica 2003, 89, 494-508.
3. ISO 3382-1. Acoustics—Measurement of Room Acoustic Parameters. Part1: Performance Rooms; International Organization for Standardization: Geneva, Switzerland, 2009.
4. Basso, G. Acoustical evaluation of the Teatro Colón of Buenos Aires. In Proc. Mtgs. Acoust. 2017, 30.
5. Farina, M. A. Determinación de la calidad acústica de salas para música a partir de las tipologías arquitectónicas. Unpublished Doctoral Thesis, Universidad Nacional de Quilmes, Argentina, 2015.
6. Basso, G. Acoustical balance between the stage and the pit in the Teatro Colón of Buenos Aires. In Proc. Mtgs. Acoust. 2018, 33.
7. Sundberg, J. The acoustics of the singing voice. Sci. Am. 1977, 236 (3), 82–91.
8. Sundberg, J. Level and center frequency of the singer’s formant. J. Voice 2001, 15, 176–186.
9. O’Keefe, J. Measurement of stage to pit balance in four proscenium arch theatres. In Proceedings of IOA Conference: Acoustics at the Millennium, Belfast, Northern Ireland, 1997.
10. Prodi, N.; Pompoli, R.; Martellotta, F.; Sato, S. Acoustics of Italian historical opera houses. J. Acoust. Soc. Am. 2015, 138, 769–781.
11. Barron, M. Auditorium Acoustics and Architectural Design. E&FN Spon, New York, 1993.
12. Canalis, I.; Basso, G. Evaluación de la calidad acústica del Teatro Colón de Buenos Aires. In Proceedings of the VI Congreso Iberoamericano de Acústica, Buenos Aires, Argentina, November 2008.
13. Wettschurek, R. Über die Abhängigkeit raumakustischer Wahrnehmung von der Lautstärke, PhD Thesis Technical University of Berlin, 1976. Cited from [26]
14. Green, E.; Kahle, E. Dynamic spatial responsiveness in concert halls. In Proceedings of the Institute of Acoustics: Auditorium Acoustics, Hamburg, Germany, October 2018.
15. Lokki, T.; Pätynen, J.; Kuusinen, A.; Tervo, S. Disentagling preference ratings of concert hall acoustics using subjective sensory profiles. J. Acoust. Soc. Am. 2012, 132, 3148-3161.
16. Lokki, T.; Pätynen, J.; Tervo, S.; Siltanen, S.; Savioja, L. Engaging concert hall acoustics is made up of temporal envelope preserving reflections. J. Acoust. Soc. Am., 2011, 129(6), 223-228.
17. Pätynen, J.; Lokki, T. Concert halls with strong and lateral sound increase the emotional impact of orchestra music. J. Acoust. Soc. Am. 2016, 139(3), 1214-1224.
18. Kahle, E. Halls without qualities - or the effect of acoustic diffusion. In Proceedings of the Institute of Acoustics: Auditorium Acoustics, Hamburg, Germany, October 2018.