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THE NEW TEATRO "AMINTORE GALLI" IN RIMINI: ACOUSTIC DESIGN AND MEASUREMENTS ON DIFFUSING PANELS

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1 INTRODUCTION

The town of Rimini, North East of Italy, will complete within 2018 the realization of the new Teatro "Amintore Galli", which was partially damaged in 1944 during the Second World War and demolished. The new theatre recalls the original architectural idea of the existing theatre (designed by Luigi Poletti), but improves the technological equipment, including noise insulation and acoustic quality. However, some constraints have conditioned the original acoustic design, especially the new archaeological area that was inserted underneath the ground floor, which required to change the original wooden structure into a concrete-based one.
The acoustic design of sound quality included the study of the orchestra pit, the acoustic absorptions of tissues in the main hall, the measurements sound absorption of seats. Since the shape and the characteristics of the material (*marmorino*, *stucco*), might cause focalization, a special care was reserved design diffusing panels located in the main hall.
The paper focuses on the acoustic design in the theatre, especially considering the diffusing acoustic panels inserted in the main hall. Starting from the drawings, the paper will examine the results of the scattering and diffusion measurements on the panels, as well as the overall sound quality of the theatre after the opening (scheduled for October 28th, 2018).

2 THE NEW THEATRE "AMINTORE GALLI"

2.1 History of the theatre and the new design

The history of the Teatro "Amintore Galli" in Rimini is similar to the histories of other buildings in Italy. The theatre was designed by Luigi Poletti from Modena, an architect who designed several buildings within the Pontifical States, and opened August 16th, 1857. The theatre had a semi-circular shape, similar to the horse-shoe shape that characterises many other Italian theatres, and it could host about 800 people.

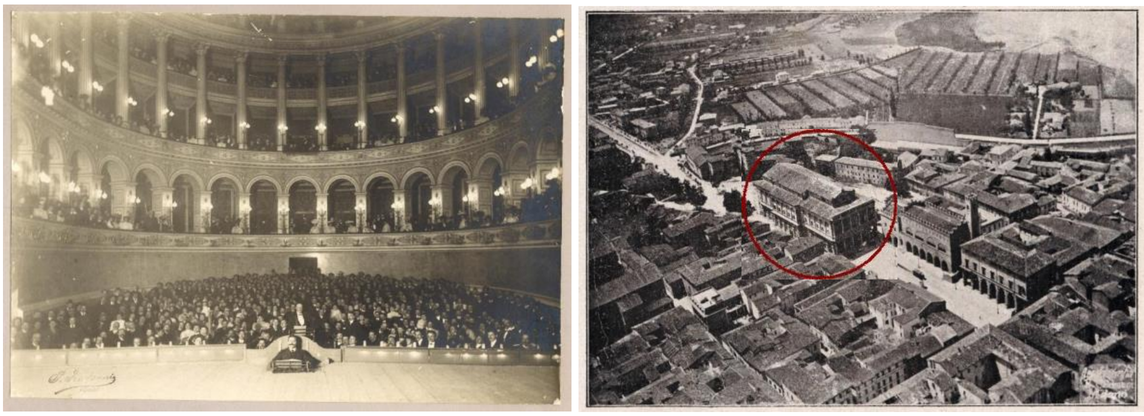

Figure 1 – the original theatre in 1910 (left) and 1925 (right)

Perhaps one of the most interesting characteristics of the theatre was the number of columns between the second and third order of the boxes, which was a typical aspect of Poletti's design.
The photograph taken in 1910 shows a very crowded hall, both in the stalls and in the boxes, and maybe the theatre in some cases could also host much more than 800 people. Perhaps, the high number of people could compensate the reverberation that it might be in the empty room, and the focalisations caused by the reflecting walls around the stalls at the first level.
The few opinions of the people that were in the theatre before its destruction in 1944 are in contrast: some of them reported about the good acoustics during the performances (therefore with occupied seats), other opinions reported about some problems experimented by the musicians in the stage area and in the stalls (i.e. with unoccupied seats). After the air attack in 1944 which damaged the main hall of theatre, whereas the foyer was only slightly injured, the area of the theatre was temporary transformed into a gym, and any further decision about the theatre was postponed.
Since the 1950s, when Rimini became the most important and populated coastal centre in Italy, the local Municipality started a debate which involved the most outstanding cultural personalities of the town, about the reconstruction of the theatre. For many years a long debate involved not only the inhabitants of Rimini but all the cultural community of Northern Italy, in order to decide which could have been the suitable solution for the theatre.
In 1995 an International competition for the new theatres was launched. The final project that was chosen (arch. Natalini et al) proposed a completely new theatre, totally different from the Poletti theatre of 1857, but immediately a large number of cultural personalities expressed their concerns of the project.
At the beginning of the new millennium, accordingly with the Regional and National authorities on cultural heritage (the Regional Superintendence and Ministry of Cultural Affairs), a new project was developed, following the rule "*as it was, where it was*", in the same way as the theatres Petruzzelli in Bari and Fenice in Venice were rebuilt after the burning. This induced to develop a totally new project for the theatre.
Accordingly, the new project had to take into account all the technical requirements that a new theatre requires about acoustics and safety.
The Municipality started then to develop a design that included all these improvements.
The original semi-circular shape of the main hall was changed in a horse-shoes shape, with the purpose to avoid the focalisation in the centre of the stalls.
The new design also included a concrete structure instead of the original (wooden) one, with the purpose of increase the resistance of the theatre and guarantee the safety requirements.

3 THE ACOUSTIC DESIGN

The acoustic design, developed by Tronchin and Partners, has involved different aspects in the theatre, including sound insulation and acoustic quality: the most relevant on sound quality are the realization of the orchestra pit with variable acoustics, the modelling of the vibrating ceiling in the main hall, and the introduction of acoustic panels in the cavea, i.e. in the boxes and on the incoming doors in the stalls.

3.1 Building acoustics in the theatre

As far as building acoustics is related, the design of the new building was developed with the purpose of reaching high acoustic standards, but maintaining a low global cost, using technologies and materials highly performant and at the same time easily available on the local market.

	Target values for sound insulation in the Theatre (dB)				
	R_W	$D_{2m,nT,w}$	$L_{n,w}$	L_{Aeq}	L_{ASmax}
Values prescribed for Galli	53	45	52	30	30
Values prescribed by Italian regulation	50	42	55	35	35

Table 1 – Target values for sound insulation in the Theatre (dB)

The target values for the new theatre are reported in table 1, together with the values prescribed by the Italian regulation. Some specific partition required to be specifically designed. Among them, the floor of the stage (figure 2, right) and those of the main hall and of the rehearsal room, which correspond to the ceiling of the main hall (figure 2, centre and right, respectively).

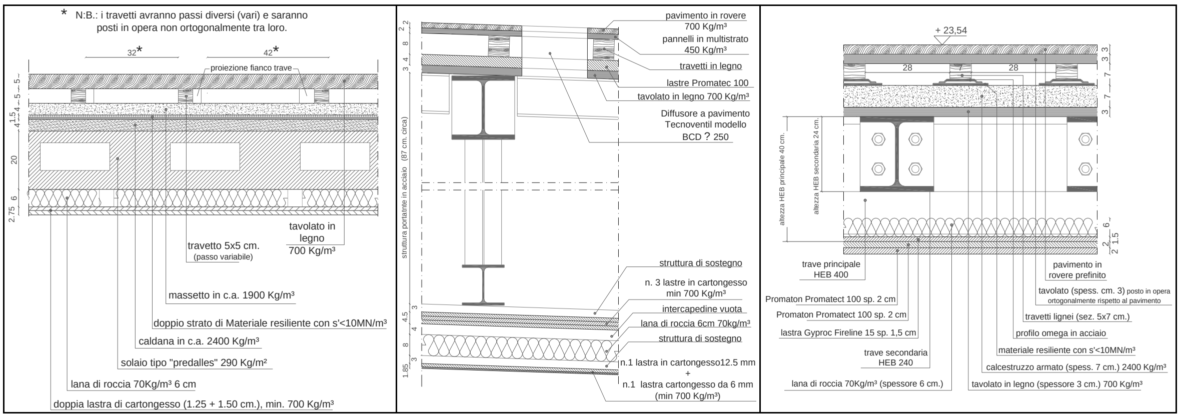

Figure 2 – Sketches of the floors: stage (left), main hall (centre), rehearsal room (right)

Regarding the floor of the rehearsal room, the upper structure is suspended over metallic elements ("omega" structures), in order to let the floor itself to vibrate elastically at very low frequencies (below 50 Hz).

3.2 Acoustic quality in the theatre

The reconstruction of the theatre followed the role: "as it was, where it was". To properly design the acoustic quality in the theatre, an important preliminary task was to assess how the acoustic quality was before the destruction, similarly to the reconstruction of the theatre La Fenice in Venice, where the starting point of the acoustic design was the acoustic campaign made by Tronchin in 1995 [2]. However, in this case obviously no acoustic data were available. In order to foresee the acoustic intentions of Poletti, it is interesting to consider the opinions of Francesco Milizia (1725-1798), who wrote in 1794 a book "del Teatro" in which he described the characteristics of the ideal theatre [3]. Milizia had a great influence on the Italian architects, and for this reason presumably Poletti knew Milizia's work.

Figure 3 – The "Teatro della Fortuna" in Fano – measurements (2009)

One other key factor for assessing the acoustic characteristics of the Teatro Galli before its destruction was the analysis of other similar theatres. Poletti designed other two theatres during his

life: one in Terni ("Teatro Verdi") and the other in Fano ("Teatro della Fortuna"). The Teatro Verdi was damaged during Second World War and reconstructed completely different from the original Poletti theatre. In Fano, the "Teatro della Fortuna", after being itself damaged during the Second World War, was renovated in 1998 but following the original schemes drawn by Poletti.
For these reasons, in 2009 a campaign of experimental measurements in the "Teatro della Fortuna" was undertaken, as shown in figure 3, following both ISO 3382 standards and the new methods described by some of the Authors [4,5]. The information gathered during the measurements were used to finalise the acoustic design and underlined the importance of solving the focalization in the stalls.
After the acoustic design made by means of the numerical model (Ramsete), the following table 2 was obtained; it reports the final target values (average) for the theatre, for all the different configurations (symphonic music, opera, speech).

Frequency, Hz	63	125	250	500	1000	2000	4000
T20	2.7	2.0	1.6	1.5	1.6	1.5	1.1
EDT	2.2	1.6	1.3	1.2	1.2	1.1	1.0
C50	-2.2	-0.7	0.5	1.0	1.0	1.2	2.6
C80	-0.1	1.4	2.6	3.1	3	3.1	4.7
D50	37.6	45.8	52.9	55.9	55.8	56.7	64.8
Ts	142.2	103.9	82.5	75.1	75.8	73.4	54.9
G	5.1	3.8	2.3	2	2.1	2	1.3
RaSTI		0.65	0.69	0.7	0.7	0.7	0.75

Table 2 – Acoustic parameters after numerical simulations (average)

These values have been considered a good compromise for music and speech, also taking into account the peculiar characteristics of Italian-style Opera Houses.

4 ACOUSTIC DIFFUSION IN THE NEW THEATRE

The most important aspect of the acoustic design of the new "Teatro A. Galli" consists on the evaluation and design of specific acoustic diffusors in the main hall of the theatre. Two different typologies of acoustic diffusors have been specifically designed: the first on the boxes, and the second on the five doors accessing to the stalls, in the main hall. These devices will allow to obtain a condition of diffused sound field, that is particularly desired in concert halls and theatres, and will avoid focalization installs and boxes, that are very often found in Italian-style Opera Houses.
Both the solutions are very important and rare. The diffusing panels hanged on the doors have been designed as reported in figure 5 but not yet experimentally verified, because their production in actually still in course.

4.1 Design of the diffusing panels

The shape of the Italian-style Opera Houses, together with the acoustic characteristics of the *marmorino*, cause focalization in the stalls and in the boxes. For limiting these effects, two models of diffusing panels have been designed for the boxes and for the stalls, starting from the well-known Schröder theory. Figure 4 and 5 report the sketches of the two panels. For the new Teatro "A. Galli", the panels in the boxes were designed with the sequences of quadratic residue obtained from numbers 13 and 17.

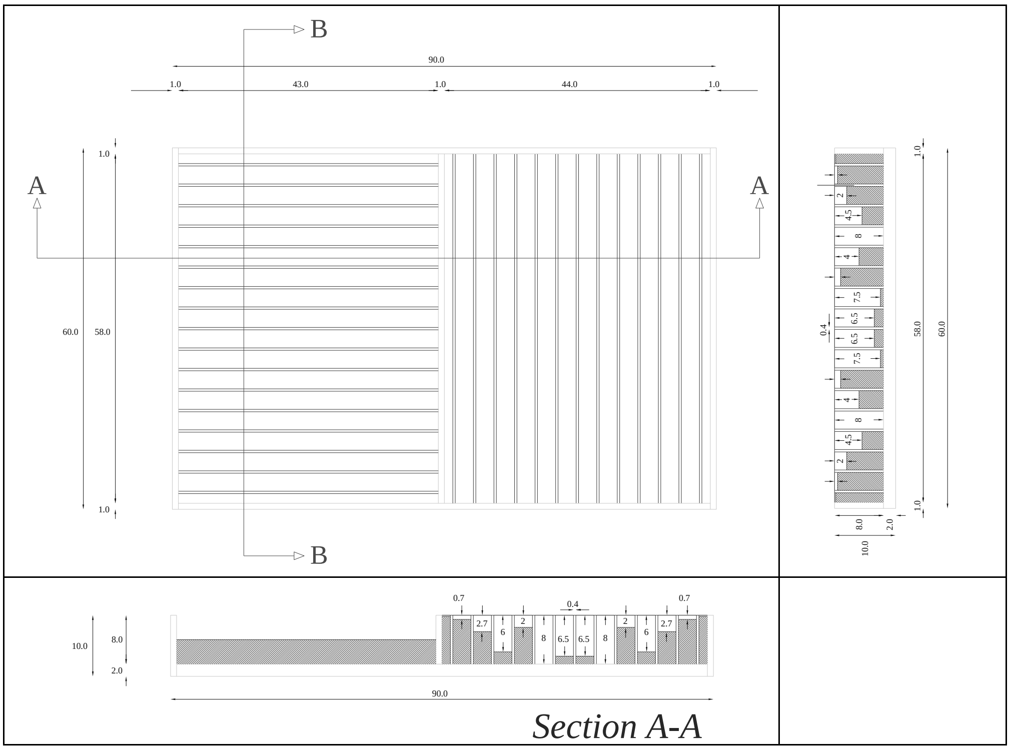

Figure 4 – Drawing of the diffusing panel in the boxes

These panels, made by MDF, are located above the entrance of each box, for the three levels. The original position (on the lateral walls of each box), even if accepted during the design phases in 2010, was rejected by the new Superintendent on arts and cultural heritage in 2015.

4.2 The diffusing panels on the doors

The other diffusing panels designed for the new “Teatro A. Galli” are those which are located on the five entrance doors in the main hall. Figure 5 reports their sketches. These panels will be realized in oak (QRD components) and cherry (remaining part). The dimensions of the panels are reported in figure 5.

5 MEASUREMENT METHOD ON THE PANELS

The methodology for measuring sound scattering and diffusion is described in the ISO 17497 standard (part 1 and 2). This method was utilized for calculating the acoustic performance of the diffusing panels. However, in this the purpose of the measurements was to obtain the diffusion coefficient of the panels, and therefore the measurements followed the ISO 17497 part 2.

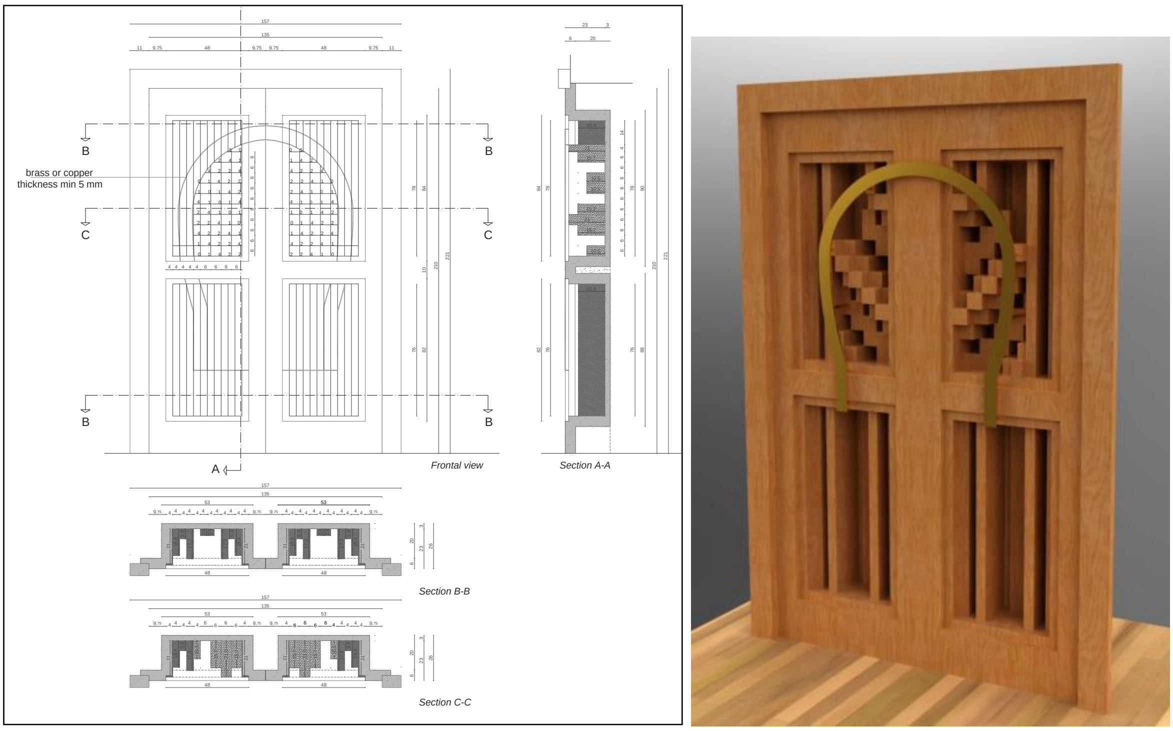

Figure 5 – Drawing of the diffusing panels on the doors (left) and rendering (right)

5.1 ISO 17497 – Part 2

In the second part of ISO 17487, a measurement method for the directional diffusion coefficient is introduced.
The diffusion coefficient is different from the random incidence scattering coefficient (introduced and described in the first one part), even though they are strictly related each other. The scattering coefficient measures the quantity of scattered sound from an energy point of view, whilst the diffusion coefficient describes the directional uniformity of the scattering, i.e. the quality of the diffusing surface. In other words, the diffusion coefficient might be used to describe the quality of a surface in terms of capacity of diffusing the incident sound.

6 MEASUREMENTS

6.1 Test signal

The amplitude of the polar responses has been obtained post processing the impulse responses which were measured by means of ESS sequences, as described in the following.

6.2 Experiments

For the experiments, the measurement hardware was made by:

- 25 prepolarized Brüel&Kjær 4188 microphones with 2671 preamplifiers (phantom-powered);
- 4 8-channels Behringer AD-DA 8000 Converters;
- 1 audio interface firewire M-Audio “Profire Lightbridge”
- 1 Genelec “8351 SAM” sound source

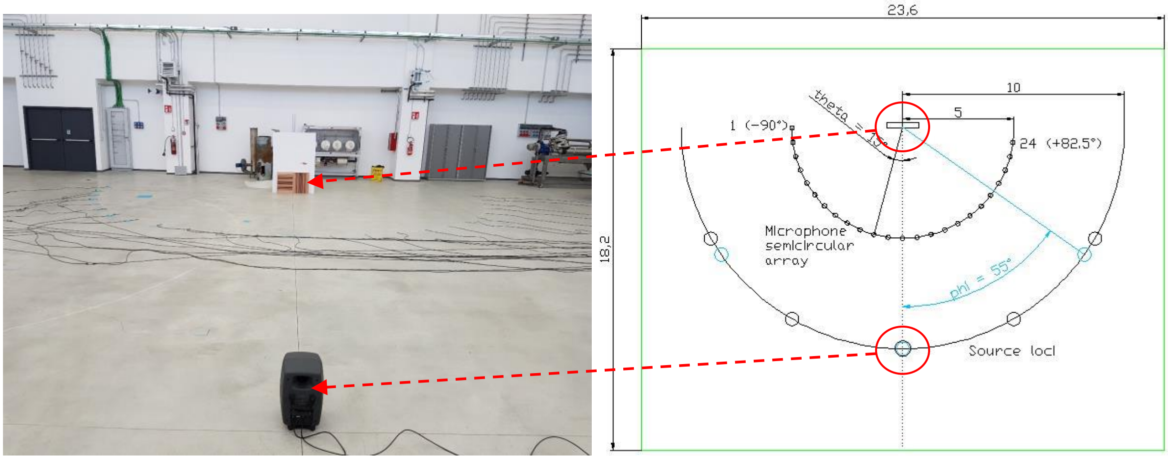

Figure 6 – The measurement on the diffusing panel

6.3 Procedure and post processing

The measurements were conducted in a large room of the University of Parma to ensure the condition of a free field (figure 6). The anechoic conditions for studying the panels' first reflection were obtained by setting the microphone array, the source and the panel itself on the floor of a very large industrial shed. The measurement ground should be larger than the minimum required volume of 18.2 x 23.6 x 9 meters of height, specifically re-calculated for a 10 ms long anechoic time window.

This setup is ideal to study single plane (anisotropic) diffusers and to actually characterise the first reflection geometry in the cylindrical emi-space in front of them.

The receiver array had a semicircular disposition as requested by the concept of uniform diffusivity, it had the suggested, standard radius of 5 meters, centred at the panels' frontal face vertical axis base. The source was located 10 meters in front of the panel, as depicted in figure 6. During this research, the position of the sound source was limited only to the point at 0 °C (i.e. in front of the panel). The impulse responses were taken using a logarithmic sine sweep, generated using the Aurora plug-ins. The signal ranged between 50 and 20000 Hz, lasted 10 seconds and had a 5 seconds silence interval at the end.

As required by the standard, the single reflection response is obtained by subtracting the two impulse responses h_1-h_2, this rejects most of the direct wave and spurious reflections.

The actual reflection (h_4) is then found by deconvolving the system response by division in the frequency domain:

$$h_4 = IFT\left[\frac{FT[h_1 - h_2]}{FT[h_3]}\right]$$

The first two impulse responses must be time windowed at the first reflection arrival: the time window start was initially decided by visual inspection as suggested.

After division in the frequency domain, a frequency window was applied to the data, to cut off all of the high frequency discrepancies due to time windowing; this operation was considered necessary after inspection of the single tracks. The diffusion coefficient was then calculated from the reflected sound pressure levels using the equations reported in the ISO 17494 Part 2:

$$d_\theta = \frac{\left(\sum_{i=1}^{n} 10^{L_i/10}\right)^2 - \sum_{i=1}^{n}\left(10^{L_i/10}\right)^2}{(n-1)\sum_{i=1}^{n}\left(10^{L_i/10}\right)^2}$$

Where L_i = sound pressure level of the *i*-th receiver, n = number of the receivers.
The experiments were conducted to test the diffusing panel for the Teatro "A. Galli" located in the boxes. The measurements were conducted with different position of the panel, to test its quality in each position.

6.4 Reflectivity analysis through fitting of a theoretical model

the experimental data were used to fit a theoretical model of reflection, so to extract diffusion coefficients that can be used in an acoustical modelling software:

$$I_{diff} = \int_{y=-b}^{b} \int_{x=-a}^{a} \frac{W \cdot z_c}{4\pi \cdot r_1^3} \cdot \frac{(1-\alpha) \cdot \delta_{loc}}{2\pi \cdot r_2^2} dx \cdot dy$$

where:
W is the source's power;
z_c the distance between source and the centre of the panel;
r_1 the distance between the source and the a*b portion of the panel;
r_2 the distance between the panel and the receivers;
α the absorption coefficient.

Moreover, δ_{loc} is the computer program diffusion coefficient which increments to 1 as the surface particle in exam gets near the panel's border.

$$\delta_{loc} = 1 - (1-\delta)\frac{2 \cdot d_{min}}{\lambda}$$

Fitting the value of W on the filtered measurement data of pseudo intensity, the solver function was used to automatically optimise *α* and *δ* to maximally match the reflected pseudo intensity values.
The figure 7 reports the optimisation.

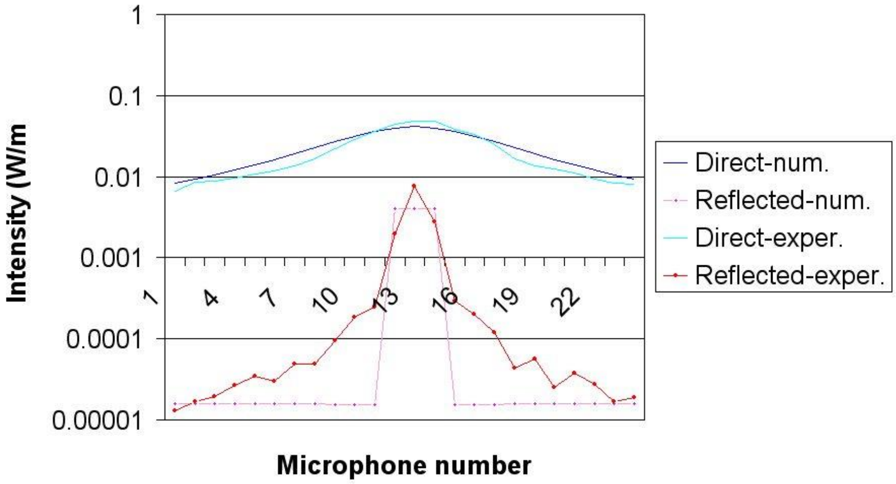

Figure 7 – The optimisation of *α* and *δ*

7 RESULTS

The measurements were repeated for different configurations, considering the panel in the original position (a), rotated (b), and with reflecting panels (c, d, e) as reported in figure 8.

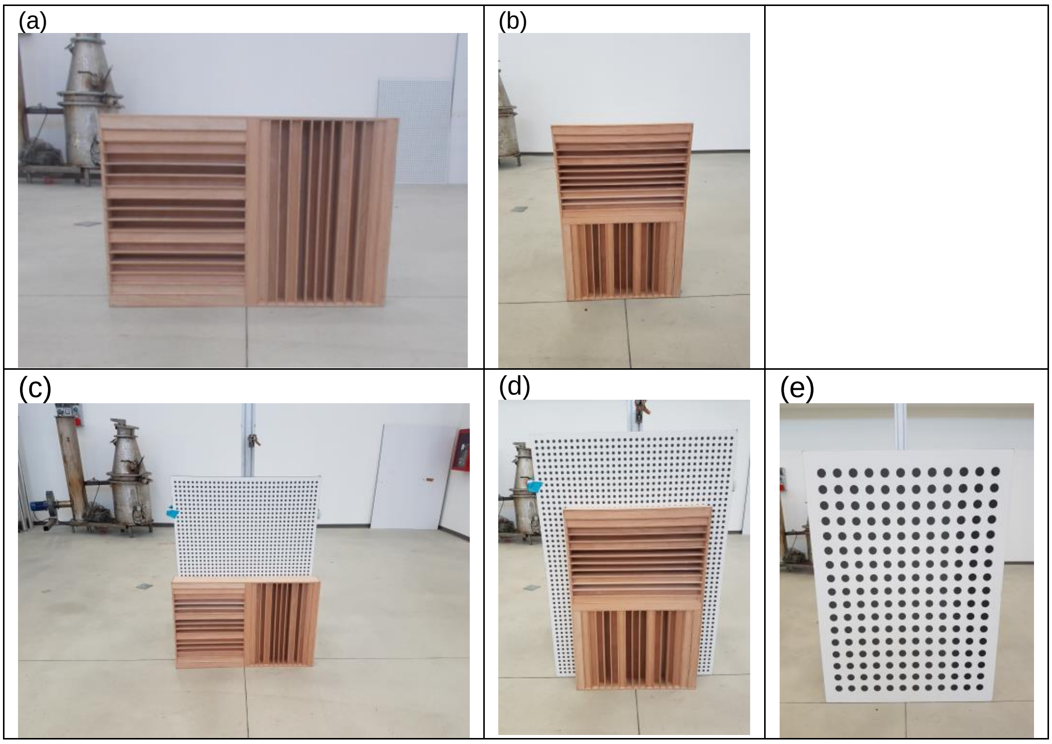

Figure 8 – The 5 configurations measured

The figure 9 reports the results for the single panel, i.e, configuration (a), whilst figure 10 reports the comparison for all the measurements.

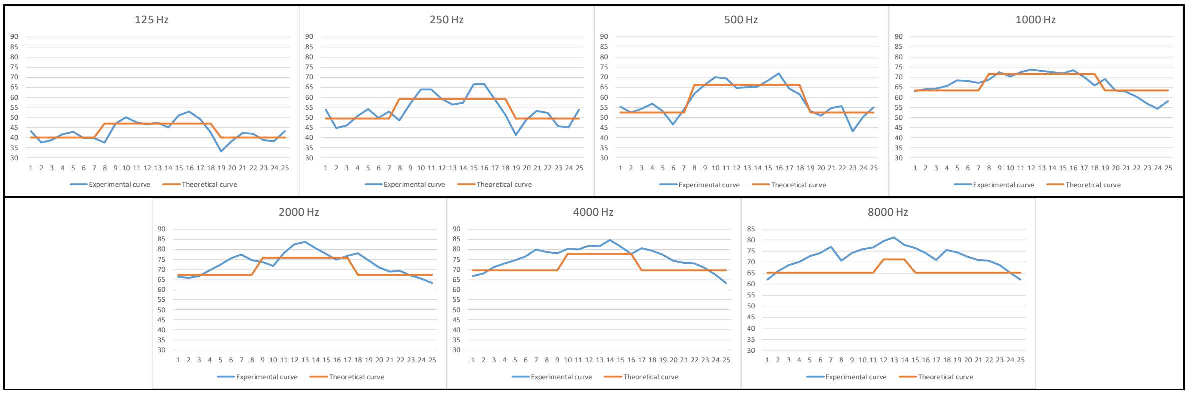

Figure 9 – Results for the single panel (a) *at a glance*

Considering the graphs reported in figure 9, we could find the effectiveness of the diffusing panels especially in the range starting from 45 degrees up to 135 degrees, i.e. for an angle of 90 degrees. For higher frequencies (4 kHz and higher), the measurements underlined that the presence of the wall behind the panel (see figure 8) have slightly influenced the measurements, and the results were less satisfactory.

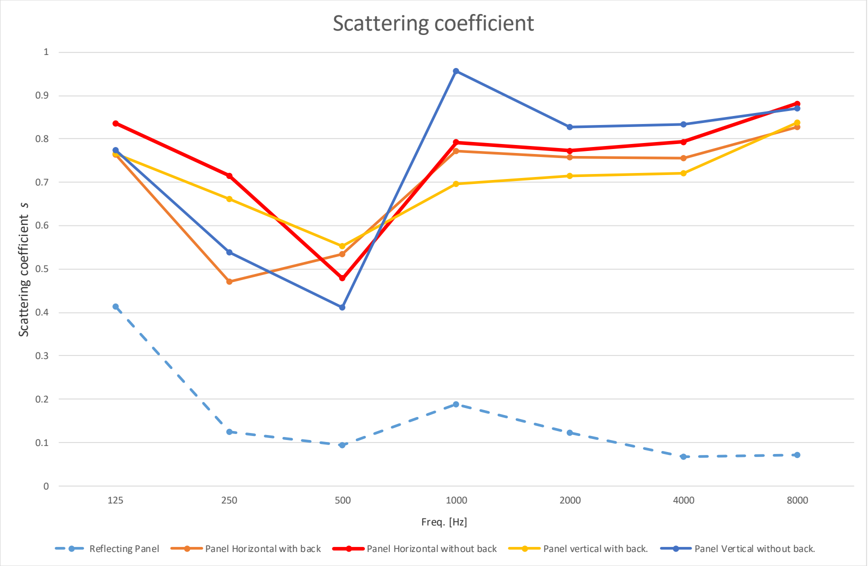

Figure 10 – Comparison among scattering coefficients

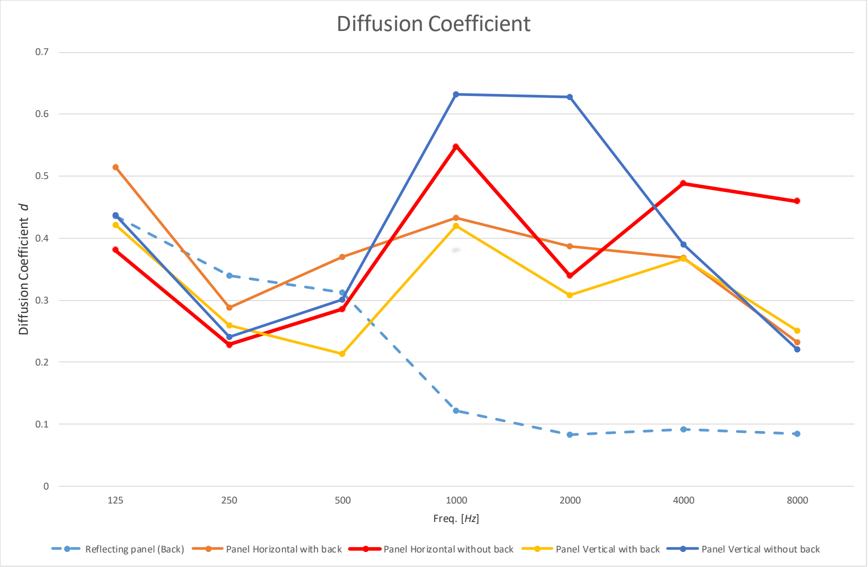

Figure 11 – Comparison among diffusion coefficients

The graphs in figures 10 and 11 report the comparison among the different 5 configurations of figure 8. The dotted line reports the values of the reflecting panel (alone), whilst the other lines report the values of the 4 configurations which include the diffusing panel. The red, bold, line reports the values related to the panel in the configuration effectively used in the theatre.
From the graphs, the scattering coefficients (figure 10) resulted higher than 0.8 for all the frequencies, except for 250 Hz (the scattering value is 0.72) and 500 Hz. At this frequency, all the configurations showed a lower value, and it might be caused by the effect of the wall already descripted earlier. It is evident the difference between the reflecting surface (dotted line) and the other 4 configurations which included the diffusing panel.

On the other hand, figure 11 reports the results of the diffusion coefficients. In this graph the effectiveness of the diffusing panels appears clearly starting from 1 kHz, where the reflecting surface shows no diffusion, whereas the diffusing panel is much more diffusing. For these reasons the use of the diffusing panels located in each box could be useful for increasing diffusiveness in the boxes. Further measurements are scheduled for September 2018, both on the diffusing panels and in the main hall of the theatre, before the opening.

8 CONCLUSIONS

The paper showed the results obtained after the measurements of diffusion and scattering coefficients for a specific diffusing panel designed for the Teatro “A. Galli” in Rimini which has been inserted in each box for the first three levels. Starting from the graphs, is was possible to assess the effectiveness of the panel with reference to the scattering and diffusion coefficients. The values obtained give a proper description of the diffusion and scattering coefficients, which are considered quite important to reach the highest value of spatiality and diffusiveness in a theatre.
In the next weeks, the experiments will include the measurements on the diffusing panels located in the entering doors, which consists of two different parts (QRD and RPG panels), reported in figure 5. These panels represent the first attempt to solve the focalization often found in the stalls of Italian-style opera houses, and for these reasons the opening of the theatre (scheduled for 28th October 2018) will be a great occasion to check the effectiveness of these panels in the overall sound quality, as well as the reaction of the musicians and of the listeners to these acoustic devices.

9 ACKNOWLEDGMENTS

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10 REFERENCES

1. L. Tronchin, The reconstruction of the Teatro Galli in Rimini: the acoustic design, Proc. ISRA 2010, Melbourne (2010).
2. L. Tronchin, A. Farina, ‘Acoustics of the former Teatro la Fenice in Venice’, J.Audio.Eng.Soc. 45(12) 1051-1062. (December 1997).
3. L. Tronchin ‘Francesco Milizia (1725-1798) and the acoustics of his Teatro Ideale (1773)’, Acta Acustica united with Acustica. 99(1) 91-97. (January 2013).
4. A. Farina, L. Tronchin ‘Measurements and reproduction of spatial sound characteristics of auditoria’, Acoustical Science and Technology 26(2) 193-199. (March 2005) doi: 10.1250/ast.26.193.
5. A. Farina, L. Tronchin ‘3D sound characterisation in theatres employing microphone arrays’, Acta Acustica united with Acustica. 99(1) 118-125. (January 2013).
6. L. Rizzi, A. Farina, P. Galaverna, P. Martignon, L. Conti, A. Rosati, Proc. Audio Engineering Society – 123rd Audio Engineering Society Convention pp. 24-37 (2007).