The Loggia Cornaro (1524) as a bridge between the ancient and the modern theatre.

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ABSTRACT

In ancient open-air Roman theatres, the *scaenae frons* increases the directivity of the sound source to better convey the actors' speech to the audience. Since such an acoustic effect is closely related to the presence of architectural elements such as awnings and columns, specific insights are needed for each case. The present work concerns the acoustics of the Loggia Cornaro in Padua (Italy), an outstanding example of Renaissance columned portico (1524) with a well-preserved Roman-style *scaenae frons* intended to host open-air theatre performances. Acoustic measurements were performed in the Loggia and the adjacent forecourt according to ISO 3382 -1. In addition, a numerical model of this hybrid indoor-outdoor site was developed and tuned till the match with the measurements' outcomes. Bayesian multi-decay analyses determined the actual influence of the scenery on sound propagation throughout the audience area. The main results prove that the Loggia not only increases the sound source level but also leads to different multi-slope sound energy decays depending on the sound sources' location, which are typical traits of modern indoor theatres.

Keywords: open-air theatres, acoustic simulations, multi-decay analysis, cultural heritage.

1. INTRODUCTION

Ancient open-air Roman theatres often include a portico with a colonnade as an integral part of the whole complex. The *scaenae frons* contributes to enhance the sound propagation throughout the audience area. During the Renaissance era the general attention to the past gave the concept of Roman theatres a new life. The Loggia Cornaro in Padua is the first tangible reconstruction of ancient theatres' architectural concept dating back to the XVI Century [1]. This performance space belongs to one of the most interesting Venetian architectures of that historical period [2, 3]. Such an open-air space was conceived as an ancient theatre since the beginning, when it was designed by the architect Falconetto for the patron of arts Alvise Cornaro [4, 5]. According to historical writers, the Loggia is the perfect interpretation of Vitruvius theatre: from the *columnato* ("colonnade") to the *cavea* (the seating area in ancient theatres). This is confirmed by Falconetto's renowned expertise in terms of ancient theatres' architectural features. Even though the stone employed in the construction is particularly sensitive to the deterioration caused by time, atmospheric agents, and pollution, the space is so well preserved that it is still nowadays used for theatre performances (see Figure 1). The presence of the audience located in the forecourt is witnessed by several manuscripts [3, 6]. The same historical references confirm the exploitation of the Loggia for Ruzzante's plays and comedies.

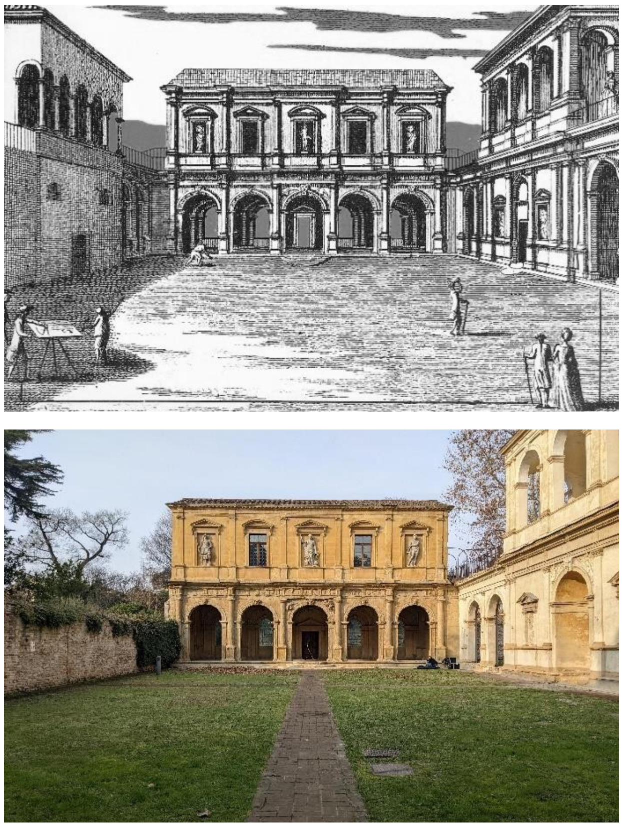

Figure 1 – Historical picture and current view of the Loggia Cornaro (Padua).

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The present study explores the acoustic properties of the Loggia Cornaro with a specific focus on the different effects provided by the portico on the signal depending on the location of the sound source. A 3D model was built basing on in situ geometric surveys. Then, it has been tuned on the experimental results (ISO 3382-1 room criteria) through ray-tracing techniques. The main outcomes prove the place to be acoustically similar to an indoor theatre, confirming the role of the Loggia as a unique bridge between the ancient and the modern theatre [7]. Unsurprisingly, a few decades later and not far from Padua – in Vicenza - the renowned architect Andrea Palladio designed the Teatro Olimpico ("Olympic Theatre"), which is one of the first examples of indoor theatres [1-5].

2. ACOUSTIC MEASUREMENTS

In February 2022, a geometrical and an acoustic survey of the Loggia Cornaro were carried out. The aim was to create a reliable 3D virtual model of the space and to investigate the acoustics of such a particular place. The main geometrical features of the Loggia are provided in Table 1.

Table 1 – Main geometrical features of the Loggia.

Feature	Quantity
Length [m]	20
Depth [m]	6.2
$h_{portico}$ [m]	5.8
h_{total} [m]	10.7
Arches [n°]	5
Forecourt [m^2]	620

The most significant room criteria have been collected according to guidelines outlined for Renaissance-Baroque theatres and in compliance with ISO 3382-1. Also, the layout of the acoustic measurements was set according to the guidelines outlined for Italian opera houses [8, 9]. Therefore, the Loggia was considered as a stage, and the forecourt as the stalls area of a theatre. Three points were selected for the location of the dodecahedron (omnidirectional sound source): the first on the proscenium (S1); the second at the centre of the portico (S2); the third one in the forecourt among the receivers (S3), as it is shown in Figure 2. Nine monaural microphones were used as receivers and placed according to a regular grid (3x3) throughout the outdoor court. Regarding the reverberation time, the main experimental results are reported in Table 2. The mean value of measured reverberation time is 1.58 seconds (125 – 4kHz), considering all the source-receiver pairs. As expected, when the sound source is at the centre of the columned portico (S2) the measured values of reverberation time are longer than the rest of the values (T_{30} = 1.67 s). By contrast, when the source is in the audience area (S3), the values obtained are shorter than in the other cases (T_{30} = 1.51 s).

Figure 2 – Two of the three sound source locations employed: on the proscenium below the main arch (S1) and at the centre of the portico (S2).

Instead, the sound strength values are very similar for the three source positions (st. dev. < 1dB), proving that the *scaenae frons* together with all the surrounding buildings behave as a single volume. Moreover, the high value of measured G (mean values equal to 8 dB) proves that the hybrid indoor-outdoor theatre contributes to significantly increasing the sound source level at the receivers, as it happens in indoor theatres [10,11]. With this purpose, the trend of G values as functions of source-receiver distance has been analysed. Figure 3 shows the spatial distribution of measured G values at mid frequencies (500 – 1 kHz) compared to the predic- tive trend according to Barron and Lee's *revised theory* (input data T_{S1} = 1.57 s; T_{S2} = 1.67 s; T_{S3} = 1.51 s; V = 7000 m^3). It is interesting to notice that the spatial distribution of the sound strength is in line with the slope of the predictive curves, which have been developed for concert auditoriums [12]. Moreover, as expected, the most significant gain is given when the sound sources are in the Loggia (S1 and S2). Such data justify the intended use of the hybrid indoor-outdoor space as a place for theatre performances, where proper voice support and adequate speech intelligibility are required even at 20 meters from the speaker.

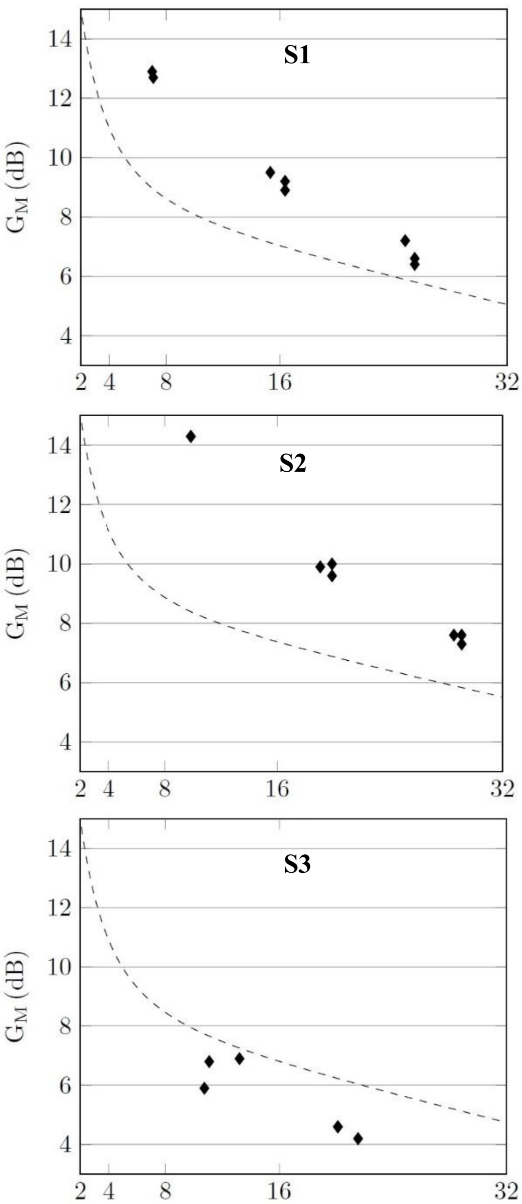

Figure 3 – Measured G_M values as functions of source-to-receiver distance. “M” subscript indicates the values averaged over the central octave-bands 500 -1 kHz. Dashed curves are the *revised theory* curves by Barron and Lee [12].

3. NUMERICAL MODEL

A ray-tracing time-dependent approach was adopted to better analyse the acoustics of the Loggia and the adjacent buildings (ODEON Room Acoustics). The 3D virtual model of the whole space was created according to the geometrical acoustics (GA) state-of-the-art (see Figure 3) [13]. The calibration of the model was achieved by considering two main materials - the stone and the grass - with the equivalent area of all the surfaces involved. The α coefficients in octave bands are provided in Table 2, along with the comparison between measured and simulated T_{30} at the end of the calibration process. The scattering value was set equal to 0.5 for the surfaces corresponding to the capitals' decorations, and equal to 0.1 for the remaining surfaces (floors, columns, ceilings). A transition order equal to 2, an impulse response length of 2 s, and 60 k rays were used during the simulations.

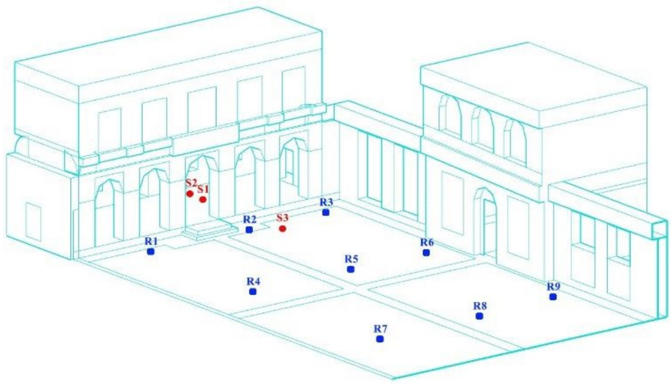

Figure 4 – Layout of sound sources (red) and receivers (blue) in the 3D model (Sketchup 2021).

Table 2 – Measured and simulated T_{30} values along with the absorption coefficient of the materials employed in the numerical model.

	125 Hz	250 Hz	500 Hz	1k Hz	2k Hz	4k Hz
S1 Meas.	1.86	1.69	1.61	1.61	1.49	1.17
S1 Sim.	*1.93*	*1.76*	*1.71*	*1.57*	*1.48*	*1.17*
S2 Meas.	2.03	1.85	1.68	1.67	1.54	1.22
S2 Sim.	*1.96*	*1.78*	*1.73*	*1.59*	*1.51*	*1.20*
S3 Meas.	1.72	1.60	1.61	1.57	1.45	1.14
S3 Sim.	*1.76*	*1.57*	*1.53*	*1.40*	*1.32*	*1.04*
$\alpha_{sandstone}$	0.02	0.03	0.03	0.04	0.04	0.05
α_{grass}	0.05	0.06	0.06	0.06	0.08	0.20

4. MULTI-DECAY ANALYSIS

A Bayesian multi-slope analysis was carried out on the decay curves obtained from the measured room impulse responses (RIRs) [14]. Figure 4 shows the results for the three locations of the sound source, considering the receiver at the centre of the forecourt (R5). According to the following expression:

$$H_s(\mathbf{H},\mathbf{T},t_k)=\sum_{S=1}^{2} H_s e^{-13.8 t_k/T_s}$$

H_s is the Schroeder curve, **T**= T_1, T_2, and **H** = H_1, H_2 are the decay parameters shown in Figure 4 [14]. It is possible to notice that the non-linearity of the decay curves is slightly detectable for S1-R5 pair, totally absent for S2-R5 pair, and clearly visible for S3-R5 pair. This is also confirmed by measured EDT/T_{30} ratios at 1 kHz:

- 0.89 for the sound source located in S1,
- 1.02 for the sound source located in S2,
- 0.76 for the sound source located in S3.

The significant appearance of double slopes in S3 is probably due to early reflections' behaviour throughout the forecourt and to the proximity to the sound source [15]. Finally, the calibrated model was employed to confirm the multi-slope decay curves corresponding to the different locations of the sound source (simulated EDT/T_{30} ratios: 0.92 for S1, 1.03 for S2, 0.66 for S3).

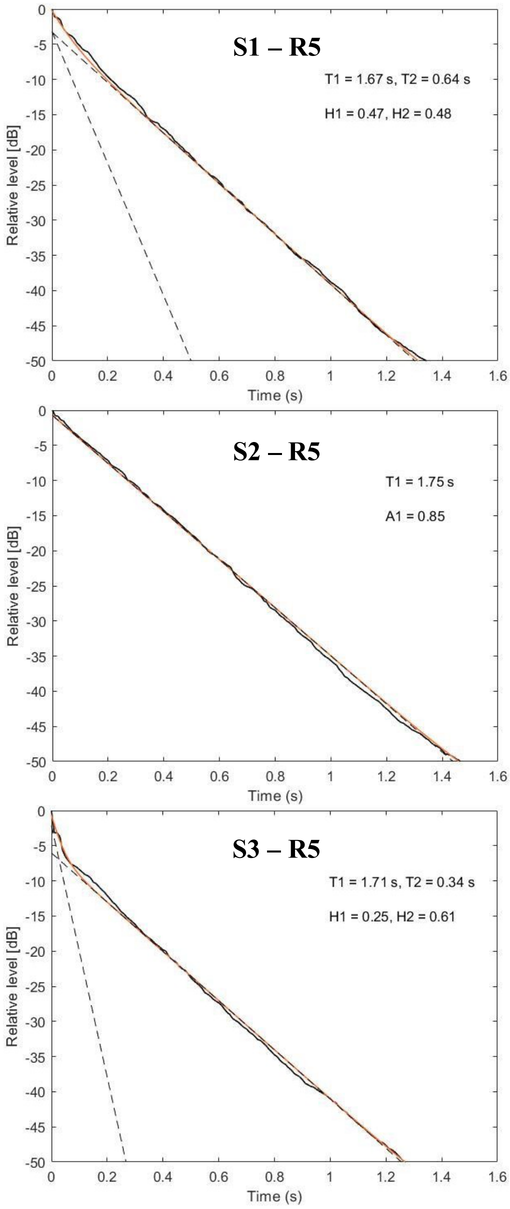

Figure 5–. Multi-decay analysis of measured IR at 1000 Hz with the sound source in S1, S2, and S3 positions and the receiver located in R5 (see Figure 3) [16].

Therefore, even though the Loggia Cornaro shows typical traits of ancient theatres, such as the *scaenae frons* and the small proscenium for an orchestra, the presence of surrounding buildings contributes to giving the performance space the acoustic features of indoor theatres [16].

5. CONCLUSIONS

The present work investigates the acoustics of a Renaissance *scaenae frons* (1524) intended to host open-air theatre performances. The experimental results confirmed the increase in the sound source level and clarified the distinct acoustic behaviour depending on the location of the sound source. High values of sound strength (up to 14 dB) have been obtained for all the sound sources involved. This is probably the consequence of a natural amplification caused by the Loggia and the surrounding architectures on the sound signal. The multi-decay analysis and the EDT/T_{30} ratios (measured and simulated) confirm the different acoustic behaviour depending on the location of the sound source. Since the Loggia combines elements of the past with typical acoustic traits of opera houses, it can be considered as an interesting bridge between the acoustics of the ancient and the modern theatres.

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6. REFERENCES

[1] D. Howard, Four centuries of literature on Palladio. Journal of the Society of Architectural Historians, 39(3), 224-241, 1980.

[2] A. Böhm, Notizie sulla storia del teatro a Padova nel sec. XV in“Atenero Veneto” 1899, II fasc I p. 102.

[3] E. Lippi, Cornariana: studi su Alvise Cornaro (Vol. 1). Antenore,1983.

[4] Schweikhart, G. (1968). Eine Fassadendekoration des Giovanni Maria Falconetto in Verona. Mitteilungen des KunsthistorischenInstitutes in Florenz, 325-342.

[5] G. B. Alvarez, G. B. Le fabbriche di Alvise Cornaro. Alvise Cor-naro e il suo tempo, 52, 1980.

[6] Fiocco, G., & Cornaro, L. (1965). Alvise Cornaro, il suo tempo e le sue opere: 6 tavole a colori e 64 in nero (Vol. 8). Neri Pozza.

[7] D. D’Orazio, S. Nannini, Towards Italian opera houses: a review of acoustic design in pre-Sabine scholars. In Acoustics (Vol. 1, No. 1, pp. 252-280). Multidisciplinary Digital Publishing Insti- tute, 2019.

[8] Pompoli, R., & Prodi, N. (2000). Guidelines for acoustical meas- urements inside historical opera houses: procedures and valida- tion. Journal of sound and vibration, 232(1), 281-301.

[9] Prodi, N., Pompoli, R., Martellotta, F., & Sato, S. I. (2015). Acoustics of Italian historical opera houses. The Journal of the Acoustical Society of America, 138(2), 769-781.

[10] D'Orazio, D., Fratoni, G., Rovigatti, A., & Hamilton, B. (2019). Numerical simulations of Italian opera houses using geometrical and wave-based acoustics methods (pp. 5994-5996). Universi- tätsbibliothek der RWTH Aachen.

[11] D’Orazio, D., Fratoni, G., & Garai, M. (2020). Enhancing the strength of symphonic orchestra in an opera house. Applied Acoustics, 170, 107532.

[12] Barron, M., & Lee, L. J. (1988). Energy relations in concert au- ditoriums. I. The Journal of the Acoustical Society of America, 84(2), 618-628.

[13] M. Vorländer, *Auralization*. Berlin/Heidelberg, Germany:Springer International Publishing, 2020.

[14] Xiang, N., Goggans, P., Jasa, T., & Robinson, P. (2011). Bayesian characterization of multiple-slope sound energy decays in cou- pled-volume systems. The Journal of the Acoustical Society of America, 129(2), 741-752.

[15] Alberdi, E., Martellotta, F., Galindo, M., & León, Á. L. (2019). Dome sound effect in the church of San Luis de los Franceses. Applied Acoustics, 156, 56-65.

[16] Paini, D., Rindel, J. H., Gade, A. C., & Turchini, G. (2004, Au- gust). The acoustics of public squares/places: a comparison be- tween results from a computer simulation program and measure- ments in situ. In INTER-NOISE and NOISE-CON Congress and Conference Proceedings (Vol. 2004, No. 7, pp. 825-832). Insti- tute of Noise Control Engineering.