

Soundscapes analysis: Piazza Tre Martiri in Rimini and Piccadilly Circus in London

Alessandro Martinetti
Gruppo CSA Spa
Rimini, Italy
amartinetti@pageambiente.it

Giacomo Tentoni
Gruppo CSA Spa
Rimini, Italy
gtentoni@csaricerche.com

Antonella Bevilacqua
Department of Engineering and
Architecture, CIDEA
University of Parma
Parma, Italy
antonella.bevilacqua@unipr.it

Luca Guardigli
Department of Architecture
University of Bologna
Bologna, Italy
luca.guardigli@unibo.it

Beatrice Turillazzi
Department of Architecture
University of Bologna
Bologna, Italy
Beatrice.turillazzi@unibo.it

Luca Battisti
CIRI-EC
University of Bologna
Bologna, Italy
Luca.battisti5@unibo.it

Adriano Farina
CIRI-EC
University of Bologna
Bologna, Italy
Adriano.farina3@unibo.it

Lamberto Tronchin
Department of Architecture
University of Bologna
Bologna, Italy
lamberto.tronchin@unibo.it

Abstract—Research in outdoor acoustics is not widely studied in room acoustics from an immersive-experience point of view. However, the combination of 3D audio with a panoramic view makes the urban environment more engaging when played back. For this campaign of measurements, a 64-channel spherical array microphone has been used, corresponding to a resolution equal to high-order ambisonics (HOA). Still, for simplicity, it has been analyzed up to the 3rd order (O3A). This paper deals with the analysis of a soundscape taken in Piazza Tre Martiri in Rimini, a historical square located in Emilia-Romagna, Italy, and in Piccadilly Circus, London, UK. In contrast to the first place, resulting is not very busy in terms of road traffic noise; the second square is the main crossover of the city center. Both of them are characterized by events and gatherings for many citizens who like to find the opportunity to socially engage and interact with other people. In addition, their historical value related to architecture gives more importance to this study, as it has never been carried out from this perspective. The audio recording has been analysed by using environmental parameters such as loudness, sharpness, prominence, and roughness.

Keywords—soundscape, signal processing, Rimini, London, Agora.

I. INTRODUCTION

Soundscape capture is important for understanding specific outdoor environments that characterize public spaces. When the audio is even 3D that fully embraces the solid angle with a high order Ambisonics, the experience is furthermore engaging. Additionally, a 3D audio experience results with a more detailed sound spatialization in terms of sound perception, as the sound arrives to the listener from multiple directions featured with a narrower beaming directionality [1].

This paper analyses a pedestrian square located in Rimini, Emilia-Romagna, one of the Italian northern regions, comparing it with the busy Piccadilly Circus in London. The scope of this study is to understand, through the soundscape, the reasons for individuals' preferences for some places over others [2]. The microphone was installed at the center of the

squares, while the 360° camera recorded a video-clip used during the post-processing phase to coordinate audio and video rendering in a single file.

According to the literature, scholars have developed predictive models for the vibrancy descriptor based on objective parameters, which have been calibrated using questionnaires administered to individuals. This soundscape model gains robustness by combining environmental parameters, such as roughness and sharpness, with subjective ratings of pleasantness, eventfulness, and vibrancy [2].

The limitations of this study lie in the correlation between objective parameters and the personal feedback of individuals experiencing the space, as well as in the limited time allocated for recording. Long-term measurements correlated with participants' feedback would have provided a more robust basis for determining soundscapes [3, 4]. However, the present analysis focuses on detailing the directivity of sound, which shapes perception not only through the direct sound emitted by typical outdoor sources but also through the reflections from surrounding buildings [5].

II. HISTORICAL VALUE OF PIAZZA TRE MARTIRI IN RIMINI

Piazza Tre Martiri in Rimini sits atop the ancient Roman forum, once the administrative and civic center of Ariminum. Tradition says that Julius Caesar addressed his troops in this square after crossing the Rubicon in 49 BC. The square is characterized by the iconic clock tower dating back to 1547, with an astronomical dial added in 1750, showcasing zodiac signs, moon phases, and planetary symbols, while its pavement features a radiant sun pattern echoing the Tempio Malatestiano's imagery. Another icon of this square is a small octagonal St Antony's temple from the 16th century, which recalls the local legend of a mule kneeling in reverence to St Anthony as he distributed the Eucharist [6].

Originally known as Piazza Giulio Cesare, the square was renamed in 1946 to honor three young partisans, Mario Capelli, Luigi Nicolò, and Adelio Pagliarani, who were executed by Nazis during WWII. Their sacrifice is

memorialized by a war monument that now stands in this square.

Today, Piazza Tre Martiri is a vibrant blend of history and modern life, lined with caf  s, shops, and offices. Whether you linger at the clock tower, explore its Roman links, or pause at the war memorial, it offers a journey through Rimini's evolving identity [7]. A view of the square is shown in Figure 1.



Fig. 1. Aerial view of Piazza Tre Martiri in Rimini, Italy (from Google Earth).

III. HISTORICAL VALUE OF PICCADILLY CIRCUS IN LONDON

Piccadilly Circus is one of the most iconic public spaces in London, located in the City of Westminster at the intersection of several major roads. Established in 1819 to connect Regent Street with Piccadilly, it has since evolved into a vibrant hub of activity and a major tourist attraction, often considered the heart of London's West End [8].

The term "Circus" refers to its original circular shape, though the layout has changed over time due to traffic developments. Piccadilly Circus is famous for its giant illuminated advertising screens, which dominate the northeastern corner. The first electric advertisements appeared in 1908, and today's LED displays have become a defining visual element of the area, symbolizing the energy and dynamism of modern London [8].

Piccadilly Circus is also a gateway to many of London's cultural and entertainment venues. It lies adjacent to districts like Soho, Leicester Square, and Covent Garden, with restaurants, nightlife, and entertainment options. Figure 2 shows the aerial view of the square.



Fig. 2. Aerial view of Piccadilly Circus in London, UK (from Google Earth).

IV. AUDIO RECORDING

The equipment related to audio capture is a multichannel microphone, which is composed of 64 transducers, known as em64 Eigenmike  , utilized in both Rimini and London [9]. This microphone can enrich a high level of ambisonics resolution, up to 7th order, making the subdivision of the solid angle very accurate to detect the sound arrival [10]. In addition to the microphone, the recorded files were stored on a personal computer connected to the microphone.

The microphone was positioned at a height of 1.7 m above the ground and equipped with a windshield. The average wind speed during the entire 5-minute measurement period was below 1.3 m/s [11]. As already discussed in the introduction, a longer audio recording would have been preferable to capture the full range of fluctuations from early morning to late night, as the space is consistently vibrant and rich in events; however, this would have required permission from the local authority, which was not obtained in this case [12].

The audio reproduction can then be realized in two different ways: by using an audio system inside a specialized listening room, where the disposition of the speakers is distributed over the surface of a sphere with a seat at the center of it [13]. Alternatively, a head-mounted display (HMD) can be another optimal solution with limited costs and similar audio quality, in combination with a pair of headphones [14]. Both solutions can have an audio resolution equivalent to O3A.

V. VIDEO OVERLAY

The video was captured with a 360   camera (Insta360) that was installed above the microphone, and oriented on the x-axis along the channel No. 1. This setting allows the audio to be captured by the microphone with the video captured by the camera [15].

The video can be saved in MKV and/or MP4 formats to be readable with VLC software or similar commercial software, where the user is able to navigate the virtual space on the screen, or alternatively by using a visor like Oculus Quest2 for a more immersive experience. An additional option is represented by overlapping the colour map over the raw video [16].

VI. SOUNDSCAPE MEASUREMENTS

The audio recording has been carried out during weekdays, between 1200 and 1600, as the busiest time of day. The total recording duration was 5 minutes, intended to represent a typically busy day. However, this period should not be considered sufficient to characterize these squares based on the measured parameters, as events vary over time, not only from day to day, but also within the same 24-hour period [17].

Piazza Tre Martiri in Rimini was dominated by occasional conversations among individuals. Figure 3 shows the elaboration of the acoustic video mapping and the visualization of sound intensity highlighted with orange colors while an individual was talking [18]. The color scale indicates the sound energy arriving at the microphone probe, with orange-red illustrating a higher level of sound. This technique is similarly applied to many enclosed spaces, as

experimented by the authors within different opera theatres [10, 11].



Fig. 3. Acoustic survey in Piazza Tre Martiri in Rimini.

In Piccadilly Circus, the main source of noise was represented by vehicular road traffic, as shown in Figure 4, highlighted in green along the main road, and random pedestrians' conversations [19].

Since the microphone was installed at the centre of Piccadilly Circus, just behind the statue, the reflections from the building were not detected. This is due to the dissipation of sound with the outdoor thermo-hygrometric conditions other than to the gain level calibrated to capture the noise from traffic road.



Fig. 4. Acoustic measurement in Piccadilly Circus in London.

VII. ACOUSTIC ANALYSIS OF MEASURED RESULTS

The acoustic parameters analyzed for outdoor soundscapes are different from those related to building acoustics. These environmental parameters are Loudness [20], Sharpness [20], Roughness [21], and Prominence [22]. Table I summarizes the values of each parameter based on the measured audio recordings.

TABLE I. ENVIRONMENTAL ACOUSTIC PARAMETERS.

Location	Mean Loudness (sones)	Mean Sharpness (acum)	Mean Roughness (asper)	Mean Prominence (dB)
P.za Tre Martiri	1.6	1.1	18	0.4
Piccadilly Circus	2.4	0.5	11	0.5

Among the two case studies, the loudness in Piazza Tre Martiri in Rimini was found to be around 1.5 sones, on average, across the period, while some peaks also reach 5.3 sones. As it is known that 1 sone corresponds to the loudness of a 1 kHz tone at 40 dB SPL, Figure 5 shows that the main noise level in Piazza Tre Martiri corresponds to SPL around

50-55 dBA. In Piccadilly Circus, in contrast, the noise levels were higher, averaging around 2.4 sones for most of the time, and with peaks around 5 sones in some cases. This means that Piccadilly Circus presents a higher background level, equivalent to a SPL 53-55 dBA, while the peaks correspond to SPL 63-65 dBA [23].

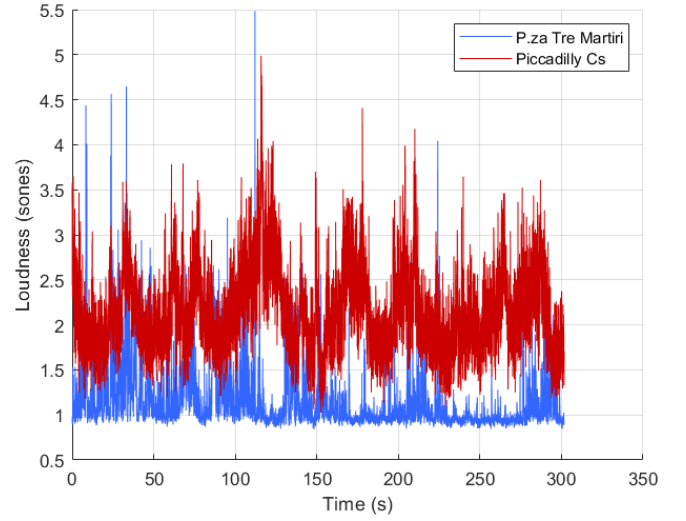


Fig. 5. Loudness outcomes.

Sharpness is another environmental parameter that refers to high-frequency content in a sound signal: the greater the proportion of high octaves, the sharper the sound [20]. This parameter can be compared to the sound of a glass shattering on the floor of a quiet room [23], or to a gunshot/explosion echoing in a forest [24]. In our case, the values of sharpness are around 0.5 acum in Piccadilly Circus, with a peak of 2.5 acum, and around 2 acum in Piazza Tre Martiri. Effectively, the sound recorded in both squares was related mainly to conversations, without any sound characterized by high-frequency content, as could have been a siren. Figure 6 illustrates the sharpness related to the two places [25].

The roughness is a perceptual measurement of modulations in amplitude or frequency that are too narrow to be discerned separately [8]. Usually, the modulations for roughness are between 20 and 300 times per second. In our case, the roughness between the two sites is very similar, around 4 and 11 aspers, respectively, when averaged across the period [26]. However, Piazza Tre Martiri shows peaks around 80 aspers, which is considered very noticeable, as shown in Figure 7. These events correspond to a very loud voice close to the microphone.

The prominence ratio (PR) is an environmental acoustic parameter used to quantify the presence of distinctly audible tones in a sound signal. This type of noise can be assimilated to a train passing by in a quiet environment [27]. The level of the prominent tone must be at least 8 dB above the level of the adjacent octaves representing the masking/background noise level; otherwise, it is not perceived by the listener [21]. The prominence around 1.0 dB, as registered in both sites, is not considered prominent, such that they are inaudible to the listener.

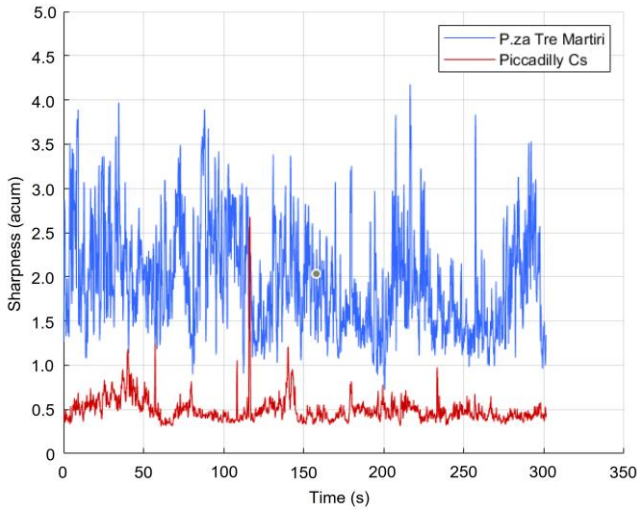


Fig. 6. Sharpness outcomes.

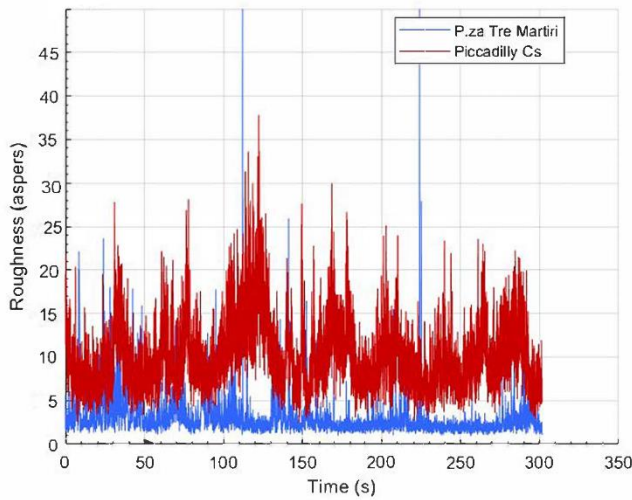


Fig. 7. Roughness outcomes.

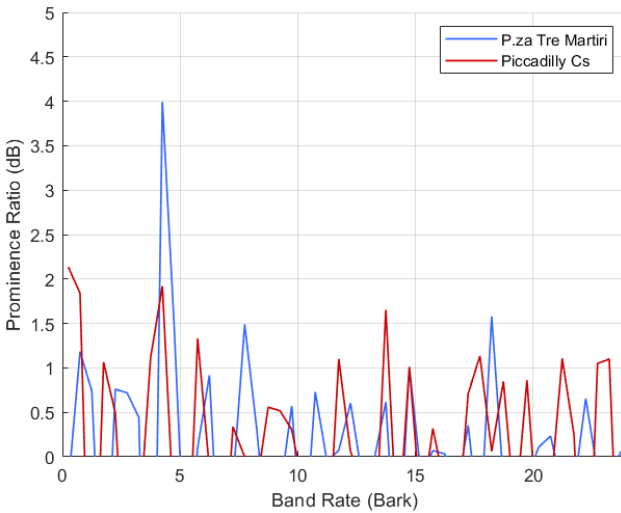


Fig. 8. Prominence Ratio outcomes.

VIII. CONCLUSIONS

This research study is focused on the analysis of the external soundscape through an immersive experience given by the recordings captured by a multi-channel spherical array microphone. The technical challenge consists of creating a

3D audio for detecting the arrival of sound from all directions when the microphone is recording. The high level of capsules over a microphone probe allows for achieving a high-order Ambisonics (HOA). Specifically, the outdoor measurements have been performed by using a 64-channel microphone [27].

Despite the limited duration of the audio recording, which, if extended, could have contributed to more comprehensive conclusions, the analysis of the environmental acoustic parameters indicates that the soundscapes recorded at the two sites are not significantly affected by specific sound sources that could be considered annoying [28]. However, these conclusions are valid only for the period during which the recordings were made and cannot be considered absolute, as the dynamics of squares and other outdoor public spaces are influenced by events and social gatherings, which are inherently unpredictable. It can be observed that the main source of noise was the conversations of transient individuals in Piazza Tre Martiri, and road traffic in Piccadilly Circus [29].

Future research will focus on the possibility of building seating areas with a breathing enclosure made of metamaterials, providing both privacy and shielding the public from traffic noise, which is inevitable in urban contexts [30]. According to the literature, approaches using 2D scatterers have already been studied and show promise in increasing absorption at mid-to-high frequencies [31].

ACKNOWLEDGMENT

This research has been granted by the Emilia-Romagna European Regional Development Fund (ERDF) Programme 2021-2027 under AGORA project (un Atelier sonoro per il Gioco, la Ricerca, l'Acustica – progetto innovativo per l'inclusione delle persone vulnerabili tramite il suono immersivo 3D delle piazze), CUP E97G22000580007.

REFERENCES

- [1] A. Farina, A. Amendola, L. Chiesi, A. Capra, S. Campanini. "Spatial PCM sampling: A new method for sound recording and playback". In Proceedings of the 52nd AES International Conference, Guildford, UK, 2-4 September 2013.
- [2] R. Yan, L. Tronchin. "Acoustic characteristics and objective evaluation of acoustic quality in historical Italian theaters". *Applied Acoustics*, 2025, 233, 110483.
- [3] R.J. Pheasant, K. Horoshenkov, G. Watts, B.T. Barret. "The acoustic and visual factors influencing the construction of tranquil space in urban and rural environments: tranquil spaces-quiet places?" *J. Acoust. Soc. Am.* 2008, 123, pp. 1446–1457.
- [4] M. Manfren, P.A. James, V. Aragon, L. Tronchin. "Lean and interpretable digital twins for building energy monitoring – A case study with smart thermostatic radiator valves and gas absorption heat pumps". *Energy and AI*, 2023, 14, 100304.
- [5] L. Tronchin, K. Fabbri, M.C. Tommasino. "A Comparison of Thermal Insulation with Interstitial Condensation in Different Climate Contexts in Existing Buildings in Europe". *Energies*, 2023, 16(4), 1979.
- [6] V. Barbi, G. Ginocchini, C. Sponza. "Co-Designing the Accessibility: from Participatory Mapping to New Inclusive Itineraries Through the Cultural Heritage of Bologna". *European journal of creative practices in cities and landscapes*, 2020, 3(2). <https://doi.org/10.6092/issn.2612-0496/12587>.
- [7] N. Dines. "The politics of the piazza: The history and meaning of the Italian square", by Eamonn Canniffe, *Modern Italy*, 2010, 15(1), 115 – 118. (In Italian) <https://doi.org/10.1080/13532940903478011>.
- [8] S. Hoare. "Piccadilly - London's West End and the Pursuit of Pleasure". The History Press: London, UK, 2021.

- [9] A. Bevilacqua, L. Tronchin. "On the acoustic track of the Teatro del Maggio Musicale of Florence". 2023 Immersive and 3D Audio: from Architecture to Automotive (I3DA), Bologna, Italy, 5-7 September 2023.
- [10] D. Poirier-Quinot, M. Lawless. "Impact of wearing a head-mounted display on localization accuracy of real sound sources". *Acta Acustica*, 2023, 7, DOI: 10.1051/aacus/2022055.
- [11] L. Tronchin, A. Bevilacqua. "3D Acoustic Map Analysis of the National Theatre of Zagreb". *Appl. Sci.* 2024, 14, 4365. <https://doi.org/10.3390/app14114365>.
- [12] A. Bevilacqua, F. Merli, E.A. Piana, L. Tronchin. "Exploring the acoustics of the "Teatro Grande" of Brescia". 2021 Immersive and 3D Audio: from Architecture to Automotive (I3DA), Bologna, Italy, 8-10 September 2021.
- [13] R. Yan, C. van Tonder, L. Tronchin. "An Exploration of the unique acoustic characteristics of Mantua's Teatro Bibiena". *Proceedings of Forum Acusticum*, Turin, Italy, September 2023.
- [14] R. Yan, C. van Tonder, L. Tronchin. "Measurements of Room Acoustics with Two Different Methods - A Case Study". 2023 Immersive and 3D Audio: from Architecture to Automotive (I3DA), Bologna, Italy, 5-7 September 2023.
- [15] M. Manfren, M.C. Tommasino, L. Tronchin. "Parametric simulations to evaluate occupants' behavior incidence on building energy performance - A Passive House case study". *Proceedings 2023 IEEE International Conference on Environment and Electrical Engineering and 2023 IEEE Industrial and Commercial Power Systems Europe Eeeic I and Cps Europe 2023*.
- [16] C. van Tonder, R. Yan, L. Tronchin. "Teatro India Sala B: acoustic analysis and descriptions". 2023 Immersive and 3D Audio: from Architecture to Automotive (I3DA), Bologna, Italy, 5-7 September 2023.
- [17] R. Yan, C. van Tonder, L. Tronchin. "Characteristics of the Teatro India Sala A of Rome: new acoustic perspectives". 2023 Immersive and 3D Audio: from Architecture to Automotive (I3DA), Bologna, Italy, 5-7 September 2023.
- [18] M. Manfren, M.C. Tommasino, L. Tronchin. "Energy Signature Modeling Towards Digital Twins – Lessons Learned From a Case Study With TRV and GAHP Technologies" *Building Simulation Applications (BSA)*, 29 June - 1 July 2022, pp. 243–247.
- [19] F. Merli, L. Tronchin. "On the influence of thermo-hygrometric conditions in 3D acoustic measurements". 2021 Immersive and 3D Audio: from Architecture to Automotive (I3DA), Bologna, Italy, 8-10 September 2021.
- [20] ISO 532-1:2017(E). "Acoustics – Methods for calculating loudness – Part 1: Zwicker method." International Organization for Standardization.
- [21] E. Zwicker, F. Hugo. "Psychoacoustics: Facts and Models". Springer Science & Business Media, 2013, 22.
- [22] ECMA-418-1. "Psychoacoustic metrics for ITT equipment — Part 1 (prominent discrete tones)". Ecma International. <https://ecma-international.org/publications-and-standards/standards/ecma-418/>.
- [23] L. Tronchin, A. Bevilacqua, S. Ferucci. "Best selection of adhesive for restoration of archaeological glasses through the modal analysis of its acoustic and vibrational response". *J. Cultural Heritage*, 2025, 73, pp. 426–433.
- [24] H. Saito, A. Pensabene, L. Tronchin, A. Bevilacqua. "Acoustic characteristics of harpichord plectra materials". 30th Int. Congress on Sound and Vibration (ICSV), Amsterdam, Netherlands, 8-11 July 2024.
- [25] G. Iannace, G. Amadasi, A. Trematerra, A. Bevilacqua. "City-Train noise reduction in urban area by using acoustic mini-screens made of metamaterials". *Internoise*, Chiba, Tokyo, 20-23 August 2023.
- [26] A. Bevilacqua, G. Iannace, L. Gomez-Agustina, A. Trematerra. "Racing in Kart Dromes: Laboratory and Site Assessment of Noise Levels from Competition and Rental Karts". *Acoustics* 2024, 6, pp. 1180–1192. <https://doi.org/10.3390/acoustics6040064>.
- [27] L. Gomez-Agustina, A. Bevilacqua, P. Vazquez-Barrera. "Noise exposure and auditory risk from air-filled balloon bursts". *Applied Acoustics*, 2025, 232, 110568.
- [28] A. Farina, A. Bevilacqua, M. Fadda, L. Battisti, M.C. Tommasino, L. Tronchin. "Immersive 3D Soundscape: Analysis of Environmental Acoustic Parameters of Historical Squares in Parma (Italy)". *Urban Sci.* 2025, 9, 259. <https://doi.org/10.3390/urbansci9070259>.
- [29] G. Iannace, G. Amadasi, A. Bevilacqua, M. Cairolì, A. Trematerra. "Resonant Acoustic Metamaterials". *Appl. Sci.* 2024, 14, 5080. <https://doi.org/10.3390/app14125080>.
- [30] A. Bevilacqua, G. Iannace, I. Lombardi, A. Trematerra. "2D Sonic Acoustic Barrier Composed of Multiple - Row Cylindrical Scatterers: Analysis with 1:10 Scaled Wooden Models". *Appl. Sci.* 2022, 12, 6302, <https://doi.org/10.3390/app12136302>.
- [31] A. Trematerra, A. Bevilacqua, G. Iannace. "Noise Control in Air Mechanical Ventilation Systems with Three-Dimensional Metamaterials". *Appl. Sci.* 2023, 13, 1650. <https://doi.org/10.3390/app13031650>.