

Soundscape in Piazza Garibaldi in Parma, Italy

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Abstract—As a dynamic urban node, Piazza Garibaldi in Parma offers a rich and variable acoustic environment shaped by daily human activity and traffic flows. This study employs a 64-channel spherical microphone array and 360° panoramic video recordings to capture and render a three-dimensional representation of the square's soundscape. Objective psychoacoustic parameters, including loudness, roughness, sharpness, and tonal prominence, are analyzed to characterize the acoustic variability of this high-activity public space. Through directional sound visualization and 3D mapping, the research highlights the spatial complexity and social vibrancy embedded in Garibaldi's sonic environment. Integrated with the AGORA project's immersive playback systems, these recordings enable new forms of public engagement with urban soundscapes and offer a framework for comparing the acoustic identity of historically and functionally diverse city squares.

Keywords—urban soundscape, Piazza Garibaldi, spatial audio mapping.

I. INTRODUCTION

Urban soundscapes offer a rich and underutilized perspective on the cultural and spatial dynamics of cities. Defined as the complete acoustic environment of a location, including human-made, natural, and environmental sounds, a soundscape can reflect patterns of movement, social behavior, and spatial design [1]. While much of the existing research has focused on natural ecosystems or controlled indoor environments, outdoor urban spaces, especially public squares, remain insufficiently studied in terms of their acoustic identities [2].

In Italy, public squares are more than transit areas; they serve as symbolic arenas for public discourse, interaction, and civic identity. Among them, Piazza Garibaldi in Parma stands out as a lively urban node, surrounded by administrative buildings, cafes, and transport routes [3]. Its soundscape is shaped by continuous pedestrian activity and moderate traffic flow, producing a layered and temporally variable acoustic profile. Capturing these dynamics requires not only high-resolution recording equipment but also tools that can map the directional behavior of sound in open, reverberant environments.

The AGORA project responds to this gap by applying immersive 3D audio technologies to the study of urban public squares. Using a spherical 64-channel microphone array and 360° panoramic video, the project captures not only the intensity but also the directionality and movement of sound sources over time [4].

By highlighting the acoustic complexity of a space like Piazza Garibaldi, this research contributes to a broader understanding of sound as both a physical phenomenon and a

cultural resource. Through immersive technologies, urban soundscapes can be experienced in new ways, supporting more inclusive reflections on the meaning of public space in contemporary society [5].

II. HISTORICAL BACKGROUND OF PIAZZA GARIBALDI IN PARMA

Piazza Garibaldi occupies a historically strategic position in the heart of Parma, originally established as the Roman forum at the intersection of the *cardo* and *decumanus*, the two principal orthogonal roads of Roman urban planning. Renamed in honor of Giuseppe Garibaldi after the unification of Italy, the square serves as a symbolic space connecting ancient civic functions with modern national identity [6].

The current urban layout evolved during the medieval period, though substantial transformations occurred in the 19th century, reflecting the city's modernization. Architecturally, the square is anchored by key landmarks, including the Palazzo del Governatore, dating back to the 17th century, which historically functioned as the city's administrative center. Adjacent to it stands St. Peter's Church [6].

On another side of the square rises the City Hall Palace, constructed in 1287. Its design features an arched colonnade at street level and robust brick masonry on the upper floor. Historically significant is the civic tower, once located at the palace's center, which collapsed in 1606, destroying the adjacent Palazzo del Capitano del Popolo. Nearby, the Portici del Grano, originally used for wheat storage, reflects the square's long-standing connection to commerce and supply.

Over time, Piazza Garibaldi has served as a focal point for public life, hosting political demonstrations, civic celebrations, and daily social interactions [7]. The presence of cafés, restaurants, and municipal offices continues to reinforce its role as a vibrant urban hub. Figure 1 shows the aerial view of Piazza Garibaldi.



Fig. 1. Aerial view of Piazza Garibaldi in Parma, Italy (from Google Earth).

III. ACOUSTIC MEASUREMENTS

To capture and analyze the complex soundscape of this highly frequented space, an advanced multichannel audio-visual setup was deployed. Measurement setup included [8]:

- 64-channel spherical array microphone (MH-Acoustics Eigenmike) [9].
- 360° video camera (Qoocam 3 Kandao, 8K resolution) [10].
- Personal computer for synchronized audio-video data acquisition.

The Eigenmike was positioned at 1.7 meters above ground level, with the camera mounted directly above it to maintain vertical alignment. The microphone array, consisting of 64 omnidirectional capsules distributed over a rigid sphere, allows encoding of the sound field into Higher-Order Ambisonics (HOA), enabling precise directional and spatial analysis [11]. The system operates with a 48 kHz sampling rate and covers the 50 Hz–8 kHz range with a near-flat frequency response, appropriate for urban acoustic monitoring [12].

The recordings, each lasting five minutes, were conducted during daytime hours (11:00–17:00) in April, under consistent environmental conditions (temperature 20–24 °C; wind speed below 1.2 m/s) [13]. The collected audio primarily featured pedestrian movement, traffic flow, and overlapping human conversations typical of a central square. Sound events were captured passively.

Audio signals were processed using Plogue Bidule [14], with spatial analysis carried out through the O3A Flare plugin, transforming the multichannel data into third-order Ambisonics for detailed spatial rendering. The accompanying video was processed using Qoocam Studio, enabling panoramic control and spatial rotation. Final synchronization and overlay of spatial audio directionality onto the video were performed in Adobe Premiere Pro, yielding immersive audiovisual content enriched with dynamic color-coded sound vectors [15].

IV. ANALYSIS OF RESULTS

A. Environmental acoustic parameters

The analysis of psychoacoustic parameters reveals higher variability and greater intensity across all metrics. The audio recording have been carried out during weekdays, between 1200 and 1400, as the busiest time of the day, in accordance with ISO/TS 12913 [16]. The overall duration is 5 minutes for each place.

The acoustic parameters analysed for the outdoor soundscapes refer to the environmental parameters like Loudness [17], Sharpness [17], Roughness [18], and Prominence [19].

As shown in Figure 2, loudness levels in Piazza Garibaldi are considerably elevated, with an average around 1.3 sones and several spikes exceeding 7 sones [17]. These peaks are likely associated with the frequent passage of vehicles and larger pedestrian flows, particularly along the adjacent Via Mazzini, which intersects the square. The variability in

amplitude over time suggests a dynamic and stimulus-rich environment.

In terms of sharpness, this parameter can be compared to the sound of a glass shattering on the floor of a quiet room [20], or to a gunshot echoing in a forest. Figure 3 illustrates relatively stable values near 1 acum, with occasional narrow peaks. The sharpness remains moderate overall, indicating that high-frequency components (such as voices, brakes, or clattering sounds) are present but not dominant. This spectral balance reflects the typical blend of human and mechanical sources in a city-center square.

Roughness, depicted in Figure 4, is the most prominent distinguishing factor. Piazza Garibaldi exhibits fluctuations around 5-10 aspers and frequent spikes exceeding 25 aspers. These rapid amplitude modulations are characteristic of noise generated by moving traffic and are perceptually associated with agitation or harshness, underscoring the square's acoustical complexity [21].

Finally, the prominence ratio plot in Figure 5 highlights numerous tonal components spread across the Bark scale, with peaks reaching approximately 1.5 dB. Although most values remain below the 6 dB threshold for clear audibility, their recurrence across bands suggests a soundscape enriched with semi-tonal mechanical elements. The prominence ratio is associated with high-peak noise, and can be assimilated for instance to a train pass-by in a quiet environment to be clearly audible and perceptible [22].

In summary, the soundscape of Piazza Garibaldi is acoustically active, shaped by regular vehicular activity and fluctuating crowd dynamics. Its higher loudness, roughness, and spectral richness reflect a typical urban environment.

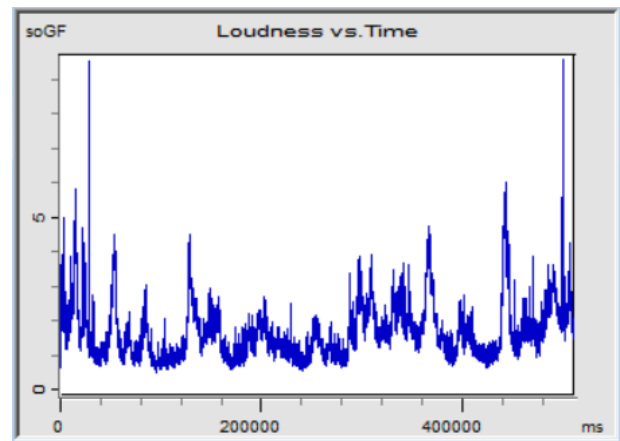


Fig. 2. Measured Loudness in Piazza Garibaldi, Parma, Italy.

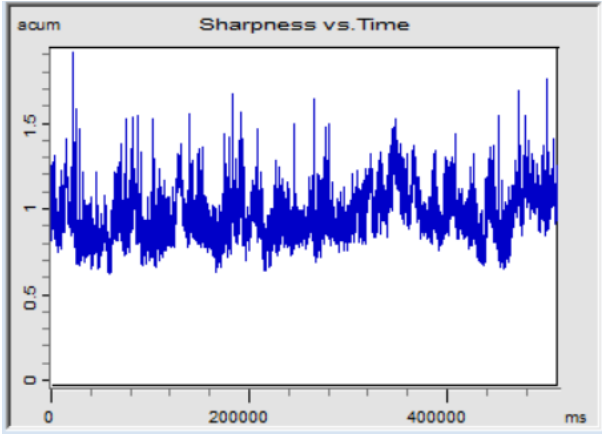


Fig. 3. Measured Sharpness in Piazza Garibaldi, Parma, Italy.

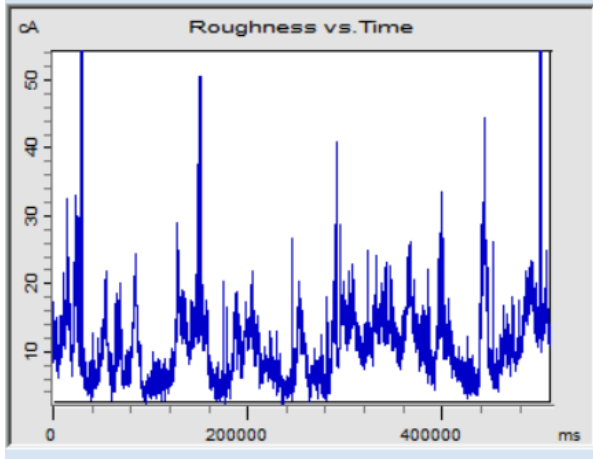


Fig. 4. Measured Roughness in Piazza Garibaldi, Parma, Italy.

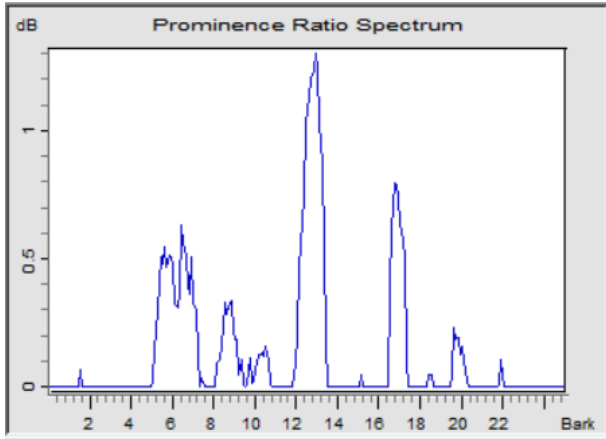


Fig. 5. Measured Prominence Ratio in Piazza Garibaldi, Parma, Italy.

B. 3D acoustic maps for a more comprehensive soundscape

A more varied acoustic environment was observed in Piazza Garibaldi, as confirmed by the spatial distribution of directional sound energy. The same 3D sound mapping methodology was applied: multi-channel Ambisonics audio was spatially decoded and aligned with 360° video, using Plogue Bidule and Qoocam Studio. The resulting visual product integrates directional audio information into the panoramic video, using a color overlay to represent temporal and spatial sound intensity [23].

In Figure 6, two regions with orange-red coloration appear across the image. Notably, a bright area on the center-left corresponds to a moving vehicle, while a similar cluster on the right-hand side marks the presence of active pedestrian conversations. These sound sources are spatially distinct and vary over time, revealing the square's acoustical dynamism [24].

Piazza Garibaldi is exposed to frequent transient events, pedestrian crossings, short-term gatherings, and vehicular movement, resulting in a heterogeneous sound field. The visualization effectively communicates not only the strength but also the directionality and changing nature of sound sources [25].



Fig. 6. Color mapping of the 3D soundscape in Piazza Garibaldi in Parma.

V. STRATEGIES FOR IMMERSIVE PLAYBACK OF URBAN SOUNDSCAPES

Recent developments in audio-visual reproduction technologies have opened up multiple options for experiencing spatial recordings in immersive formats. A commonly adopted solution involves the use of a virtual reality headset combined with binaural playback via headphones, often supported by head-tracking functionality [26]. This setup is relatively low-cost and capable of delivering convincing spatial realism, allowing users to explore acoustic environments interactively.

In addition to personal devices, fixed playback installations offer enhanced spatial resolution. The Casa della Musica in Parma represents one such facility. It features a hemispherical loudspeaker array comprising 25 speakers arranged to support 4th-order Ambisonics. A listening position at the geometric center allows for precise spatial rendering of sound fields, making the space well-suited for public demonstrations and research applications.

CONCLUSIONS

The investigation of Piazza Garibaldi's soundscape through immersive audio technology reveals the acoustic complexity typical of a multifunctional urban square. As a site of continuous movement and interaction, Garibaldi exhibits a rich array of sonic elements, from vehicular traffic and pedestrian activity to intermittent conversations, captured effectively through high-resolution Ambisonics and panoramic visual integration [27].

Acoustic indicators such as elevated loudness and roughness values, as well as temporal fluctuations in tonal prominence, reflect the square's dynamic role within the city's social and commercial network. The 3D spatial audio visualization reinforces this variability, with color-mapped

sound fields showing multiple concurrent sources of activity and directional shifts across time.

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 [28].

Future research development 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 [29]. According to the literature, approaches using 2D scatterers have already been studied and show promise in increasing absorption at mid-to-high frequencies [30].

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REFERENCES

- [1] J. Kang, M. Zhang. "Semantic differential analysis of the soundscape in urban open public spaces". *Building & Environment*, 2010, 45(1), pp. 150-157.
- [2] J. Y. Jeon, J. Hong, C. Lavandier, J. Lafon, Ö. Axelsson, M. Hurtig. A cross-national comparison in assessment of urban park soundscapes in France, Korea, and Sweden through laboratory experiments. *Appl. Acoustics*, 2018, 133, pp. 107-117.
- [3] 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>.
- [4] R. Yan, L. Tronchin. "Acoustic characteristics and objective evaluation of acoustic quality in historical Italian theaters". *Applied Acoustics*, 2025, 233, 110483.
- [5] 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>.
- [6] D. Vera. "Storia di Parma: vol. II: Parma romana". Monte Università Parma Editore: Parma, Italy, 2009 (in Italian).
- [7] A. Bevilacqua, G. Tentoni, A. Martinetti. "Sweet melody: the acoustic analysis of the Auditorium Paganini realized inside a dismissed sugar factory". 2023 Immersive and 3D Audio: from Architecture to Automotive (I3DA23), Bologna, Italy, 5-7 September 2023.
- [8] A. Bevilacqua, F. Merli. "Different Techniques for Measuring Spatial Sound Properties of Auditoria: a Review". *J. Phys.: Conf. Ser.* 1655, 2020, 012111. DOI 10.1088/1742-6596/1655/1/012111.
- [9] Available online. Accessed 23 August 2023. <https://mhacoustics.com/products>
- [10] Kandao Qoccam 3 Ultra 8k. Available online: <https://www.kandaovr.com/qoccam-3-ultra> (accessed on 9 May 2025).
- [11] L. Tronchin, A. Bevilacqua, A. "3D Acoustic Map Analysis of the National Theatre of Zagreb". *Appl. Sci.* 2024, 14, 4365. <https://doi.org/10.3390/app14114365>.
- [12] L. Tronchin, A. Bevilacqua. "How Much Does the Variety of Scenery and the Different Percentages of Audience Occupancy Affect the Indoor Acoustics at the National Theater of Zagreb? *Appl. Sci.* 2022, 12, 6500. <https://doi.org/10.3390/app12136500>.
- [13] L. Tronchin. "Variability of room acoustic parameters with thermohygrometric conditions". *Applied Acoustics*, 2021, 177, 107933, pp. 1-14. <https://doi.org/10.1016/j.apacoust.2021.107933>.
- [14] Available online. Accessed 23 August 2023. <https://www.plogue.com/products/bidule.html>.
- [15] D. Berghi, H. Stenzel, M. Volino, A. Hilton, P.J.B. Jackson. "Audio-visual spatial alignment requirements of central and peripheral object events". 2020 IEEE Conference on Virtual Reality and 3D user Interfaces (VRW), (Atlanta, Georgia, USA, 22-26 March 2020).
- [16] ISO/TS 12913; Acoustics—Soundscape. Part 3: Data Analysis. International Standards Organization: Geneva, Switzerland, 2019.
- [17] ISO 532-1:2017(E). "Acoustics – Methods for calculating loudness – Part 1: Zwicker method." International Organization for Standardization.
- [18] E. Zwicker, F. Hugo. *Psychoacoustics: Facts and Models*. Vol. 22. Springer Science & Business Media, 2013.
- [19] 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/>.
- [20] 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.
- [21] 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.
- [22] 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.
- [23] L. Tronchin, A. Bevilacqua, R. Yan. "Acoustic Characterization and Quality Assessment of Cremona's Ponchielli Theater. *Appl. Sci.* 2023, 13, 4057. <https://doi.org/10.3390/app13064057>.
- [24] A. Farina, A. Amendola, L. Chiesi, A. Capra, S. Campanini. "Spatial PCM sampling: a new method for sound recording and playback". AES 52nd International Conference, Guildford, UK, September 2-4 2013.
- [25] A. Bevilacqua, G. Iannace, L. Tronchin. "Acoustic Competition for the Golden Medal of Crowd Noise Level: Insights on the Stadia and Sport Buildings in Ancient Times. *Appl. Sci.* 2024, 14, 8221. <https://doi.org/10.3390/app14188221>.
- [26] L. Battisti, A. Farina, A. Bevilacqua, L. Tronchin. "Implementation of non-equal partitioned multi-channel convolver". *Internoise 2022 – 51st International Congress and Exposition on Noise Control Engineering*, 2022.
- [27] L. Tronchin, N. Xiang. "Introduction to the special issue on 3D sound reconstruction for virtual auditory displays: Applications in buildings". *Journal of the Acoustical Society of America*, 2023, 154(6), pp. 3941–3942.
- [28] A. Bevilacqua, L. Tronchin, G. Iannace. "Acoustic analysis on alternative use of stadia: from circus maximum of Rome and Hippodrome of Constantinople to San Siro Stadium in Milan. *Architectural Science Review*, 2025, 2, <https://doi.org/10.1080/00038628.2025.2506546>.
- [29] 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>.
- [30] G. Iannace, A. Amadasi, A. Bevilacqua, M. Cairoli, A. Trematerra. "Resonant Acoustic Metamaterials". *Appl. Sci.* 2024, 14, 5080. <https://doi.org/10.3390/app14125080>.