

3D Soundscape in Piazza Duomo of Parma, Italy

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Abstract—Urban soundscapes reflect the cultural and spatial dynamics of public life, yet their acoustic characteristics remain underexplored. This study presents a high-resolution 3D acoustic analysis of Piazza Duomo in Parma, using a 64-channel spherical microphone coupled with a 360° video camera. The soundscape was recorded and analyzed in terms of environmental psychoacoustic parameters, including loudness, sharpness, roughness, and tonal prominence, as well as through spatial visualization techniques that identify the directionality and distribution of sound energy. Piazza Duomo in Parma, characterized by its architectural symmetry and restricted vehicular access, exhibits a notably stable and quiet acoustic profile. The resulting data contributes to the preservation of urban acoustic heritage and support immersive playback for public engagement through the AGORA project’s modular audio systems. This research underscores the potential of 3D sound mapping as both a scientific tool and a medium for cultural reflection in historically significant civic spaces.

Keywords—soundscape analysis, Piazza Duomo, immersive audio, environmental acoustics.

I. INTRODUCTION

In recent years, soundscape analysis has gained recognition as a valuable, non-invasive method for examining both natural and built environments. A soundscape encompasses the full acoustic composition of a place, including human, biological, and environmental sounds, and provides insight into spatial character and activity. While this approach has primarily been applied in ecological monitoring and noise control, its potential for cultural heritage research remains underexplored, particularly in outdoor urban settings [1].

Public squares in Italy, and especially in the Emilia-Romagna region, represent not only architectural and historical landmarks but also acoustic environments shaped by centuries of civic life. These spaces, traditionally associated with dialogue and congregation, exhibit distinct sonic signatures that emerge from their geometry, materiality, and modes of use [2]. Unlike enclosed venues such as theaters or churches, the acoustics of open-air squares are rarely documented, despite their cultural significance [3].

This paper presents part of the work carried out within the AGORA project, which aims to investigate the acoustic identity of historical urban squares through multichannel immersive audio recordings. By employing a 64-channel spherical microphone array and high-resolution video capture, the project develops spatial sound maps and dynamic

soundscape representations of selected squares. Among these, Piazza Duomo in Parma offers a particularly instructive case due to its preserved medieval structure and relatively low ambient noise levels [4].

Beyond technical documentation, AGORA seeks to reframe sound as a form of cultural expression. The recorded environments are intended not only for analysis, but also for public playback experiences, realized through both fixed installations—such as the Casa della Musica in Parma—and portable systems adapted for various spatial settings. In doing so, the project extends acoustic heritage preservation into the realm of participatory cultural engagement, offering new tools to perceive, reflect upon, and reconnect with shared urban spaces through sound [5].

II. HISTORICAL BACKGROUND OF PIAZZA DEL DUOMO IN PARMA

Piazza Duomo is the historic core of Parma, celebrated for its outstanding medieval architecture and artistic treasures. Dominating the square is the Parma Cathedral, a Romanesque landmark consecrated in 1106, renowned for its richly decorated interior and Correggio’s fresco of the *Assumption of the Virgin*, one of the masterpieces of Renaissance ceiling painting. The cathedral is further distinguished by its 67-meter bell tower, topped with a gilded angel that also functions as a lightning conductor [6].

Next to the cathedral rises the Baptistry, begun in 1196 under the direction of Benedetto Antelami. This octagonal structure, clad in pink Verona marble and adorned with refined sculptural details, exemplifies the stylistic passage from Romanesque to Gothic. Completing the square is the Bishop’s Palace, a simpler yet historically important residence that once housed the bishop and diocesan administration [6].

The serene atmosphere, harmonious proportions, and intact medieval plan of Piazza Duomo embody the strong interconnection between civic and religious life in Parma, making it one of the most evocative historic squares in Italy [7]. Figure 1 offers a view of this remarkable piazza.



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

III. ACOUSTIC MEASUREMENTS

Audio recordings were carried out using a 64-channel spherical microphone array (Eigenmike em64, mhAcoustics). Measurements took place on 28 May during weekday rush hour, between 12:00 and 13:00, under stable conditions with wind speeds below 0.4 m/s and a temperature of approximately 29 °C [8]. Each recording lasted for a total of five minutes.

The captured material was processed with *Plogue Bidule*, a platform for real-time audio processing, synthesis, and interactive sound design [9]. Within this environment, VST and other plugins function as modular blocks, which can be interconnected to build audio effects, sequencing tools, and signal routing structures. In this study, the multi-channel recording was loaded into a player and linked to the O3A Flare plugin, enabling real-time detection of the sound field's directional components at the microphone probe [10]. The resulting 19-channel signals were then converted to third-order Ambisonics (O3A), providing a highly detailed rendering of spatial audio [11].

The psychoacoustic parameters have been calculated with dBSonnic software.



Fig. 2. Equipment installed in Piazza Duomo during the survey.

IV. ANALYSIS OF RESULTS

A. Environmental acoustic parameters

To assess the acoustic perception of Piazza Duomo, four psychoacoustic indicators were examined: loudness [12], sharpness [13], roughness [14], and tonal prominence [15]. These descriptors go beyond basic sound pressure level (SPL), offering a more perceptually grounded evaluation of urban sound environments.

Loudness in Piazza Duomo remains consistently low throughout the 5-minute observation window, as illustrated in Figure 3. The time series fluctuates gently around an average of 0.9 sones, with peaks around 12 sones [12]. This aligns with the square's restricted vehicular access and its relatively quiet pedestrian atmosphere.

Sharpness is a parameter comparable to the sound of a glass shattering on the floor of a quiet room [16], or to a gunshot echoing in a forest. Figure 4 indicates a trend of sharpness averaging around 1.3 acum. Several short-lived peaks reach 2.6 acum, suggesting transient high-frequency components, possibly associated with footsteps on stone pavements or distant voices. However, values remain below the perceptual threshold where sharpness becomes clearly unpleasant.

Roughness, depicted in Figure 5, is very minimal, maintaining a near-zero baseline. This supports the observation that Piazza Duomo offers a calm auditory setting, consistent with its historical and religious character [17].

The tonal prominence can be assimilated to a train pass-by in a quiet environment [18]. Figure 6 shows that most frequency bands exhibit low values. The average prominence ratio is approximately 1.4 dB, with occasional narrow peaks, yet none exceeds 4.5 dB. These values suggest that tonal components in the soundscape were not strong enough to stand out against the background noise and are unlikely to cause listener discomfort.

Overall, the psychoacoustic profile of Piazza Duomo reflects a tranquil acoustic environment with low loudness and roughness, slightly elevated sharpness, and no significantly prominent tonal features. This soundscape corresponds to a square shaped more by soft human activity than by mechanized sources, reinforcing its suitability as a quiet cultural and religious urban space [19].

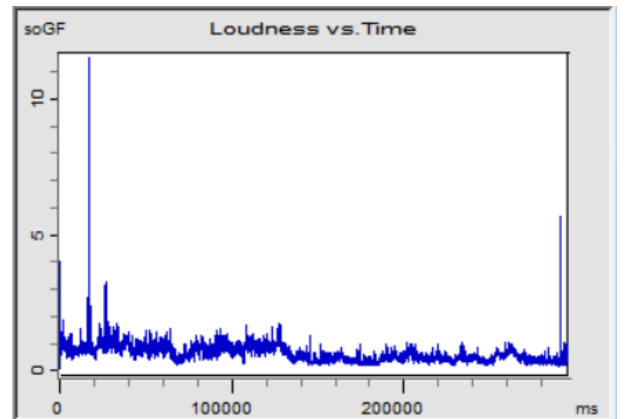


Fig. 3. Measured Loudness in Piazza Duomo, Parma, Italy.

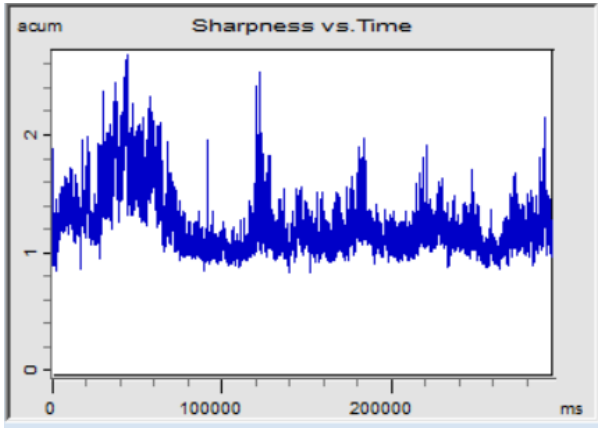


Fig. 4. Measured Sharpness in Piazza Duomo, Parma, Italy.

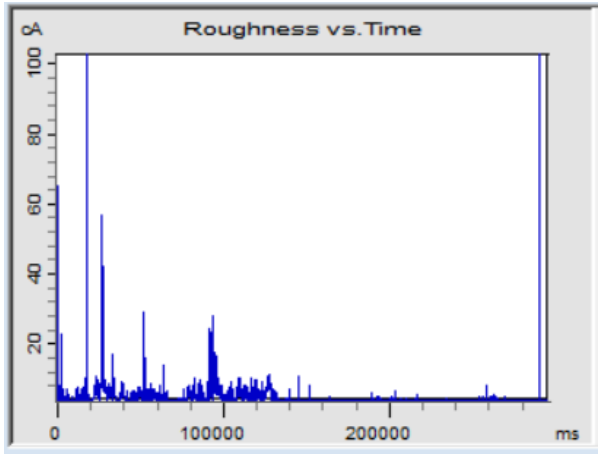


Fig. 5. Measured Roughness in Piazza Duomo, Parma, Italy.

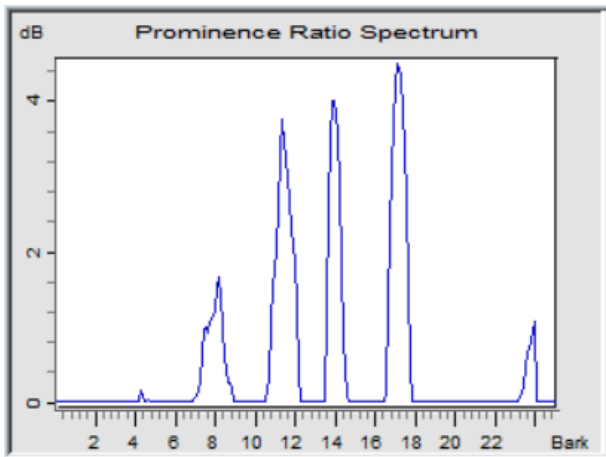


Fig. 6. Measured Prominence Ratio in Piazza Duomo, Parma, Italy.

B. 3D acoustic maps for a more comprehensive soundscape

The video recording, instead, is processed with QoocamStudio [20], software that can elaborate the video, allowing also a 3D panning along the horizontal axis and a rotation around the focal point. Audio and video recording were then synchronized in Adobe Premiere Pro 2024, a software that allows for overlapping audio tracks and video recordings.

As illustrated in Figure 7, the visualized sound field shows a small orange cloud near the center of the square. This corresponds to a localized conversation, likely between a few

individuals. No other intense sources are visible across the mapped area. The rest of the square displays consistently low energy levels, affirming the findings from the psychoacoustic analysis, which showed low loudness, minimal roughness, and no tonal peaks [19].

The spatial uniformity of the acoustic field, combined with the absence of moving sound sources, reflects the calm and static nature of the square's environment during measurement. This result reinforces Piazza Duomo's role as a historically preserved, pedestrian-oriented space, where architectural enclosure contributes to a sense of acoustic stillness and limited directivity [20].



Fig. 7. Color mapping of the 3D soundscape in Piazza Duomo, Parma.

CONCLUSIONS

This study highlights the application of immersive audio technologies to the documentation and analysis of outdoor soundscapes, with a focus on Piazza Duomo in Parma. Unlike the controlled environments of theatres or concert halls, historical urban squares present acoustically open, dynamic settings that require advanced tools for accurate spatial recording and reproduction [21]. Through the use of a 64-channel spherical microphone array and panoramic video integration, it was possible to capture not only the acoustic parameters but also the spatial distribution and movement of sound sources.

Piazza Duomo demonstrated a remarkably stable and tranquil soundscape, with low loudness and roughness values, and minimal tonal prominence. The 3D sound visualization confirmed the absence of intense or rapidly varying sources, reinforcing the square's identity as a calm, reflective civic-religious space [22].

Looking ahead, comparative studies across urban centres, focused on the perceptual and spatial characteristics of public squares, can offer new insights into urban soundscapes, complementing traditional indicators such as traffic data or air quality. As cities face increasing acoustic homogenization due to infrastructure and noise pollution, preserving distinct sound environments like that of Piazza Duomo becomes a matter of cultural urgency. This research contributes to a growing body of work aimed at safeguarding the sonic identity of public spaces within an evolving urban landscape [23].

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 [24]. According to the literature, approaches using 2D scatterers have already been studied and show promise in increasing absorption at mid-to-high frequencies [25].

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