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MEASURING SHORT-TERM CHANGES IN PERCEIVED SOUNDSCAPES DUE TO LOCALIZED INTERVENTIONS

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ABSTRACT

Soundscape assessments are now an established method to evaluate the perceived acoustic climate in a location. In most cases, however, these methods are used to evaluate long-term acoustic judgements, over large areas.
In this study, we created a localized, movable quiet area in the shape of an acoustic gazebo. We used acoustic metamaterials (SonoBlind), instead of traditional solutions, to maintain the structure transparent to light and lightweight, so that it could be removed every day. After checking that the structure allowed a 10 dB change between inside and outside, we installed it in selected service stations along a motorway in Italy and we asked volunteers to assess the change using a brief sound walk (inside and outside). The resulting change in perception was described using the metrics suggested by ISO 12913. Results show the potential impact on perception-focused action plans of small, localized interventions.

Keywords: *soundscape, metamaterials, quiet areas*

1. INTRODUCTION

The outdoor area of a motorway service station is often a place with high noise levels, given its proximity to the infrastructure. Traditionally, standard acoustic barriers are rarely used in these locations, either because the outdoor is designed to be an area of transit (a "park-and-go" location) or because the barriers would block landscape views.
According to a previous study, however, a large-scale intervention may not be necessary. Looking at how the outdoor environment of service stations is perceived by end-users, using measurements and semi-structured interviews, Memoli et al. [1] concluded that, in certain situations, creating a localized "quiet area" may be more effective than a noise-management intervention affecting the whole service station. In 2021, however, such solutions were too expensive to realize in a non-permanent way. By now, four years later, the situation has changed. On the demand side, end-users are now looking for respite from noise in these outdoor areas while they wait for their electric vehicle charging or while stopping for a video call. And solution offering has evolved too: novel solutions are now commercially available as ready-to-use products.

Figure 1. The metamaterial structure used in this study, mounted at the service station *Peretola Sud*.

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In this study, we went back to the service stations investigated in 2021 – i.e. *Peretola Sud* and *Arno Est*, near Florence, Italy – and used the emerging technology of acoustic metamaterials to create a movable, semi-transparent quiet area in the shape of a gazebo (Figure 1). We then used traditional acoustic measurements and semi-structured interviews to assess the local soundscape inside and outside the gazebo. Our study, therefore, constitutes an example of how the methods of ISO 12913 can be used to measure change, also in short-term perception.

2. THE METAMATERIAL GAZEBO

The gazebo in Figure 1 is based on a standard pop-up unit (All Seasons Gazebos, L: 4500 mm, W: 3000 mm), with its sides substituted by acoustic panels: four along the short side and five along the long side. The acoustic panels were made of SonoBlind®: an acoustic metamaterial commercialized by Metasonixx Ltd (UK) and optimized for reducing transmission between 125 Hz and 6000 Hz [2]. Acoustic metamaterials are standard materials, engineered at sub-wavelength level to achieve uncommon acoustic properties [3-4]. SonoBlind® panels are labyrinthine metamaterials, made by assembling smaller cuboidal modules ("bricks", L: 270 mm, H: 27 mm and T: 25 mm in size), each designed to achieve noise-cancellation over a wide range of frequencies. A SonoBlind panel acts therefore like an interferential filter would operate in optics and, for a thickness of 25 mm, it achieves the insertion loss in Table 1 with a weight of approximately 10 kg/m² [2, 5].

Table 1. Insertion loss (in dB) of a SonoBlind panel, compared to other commercial materials: rockwool (Safe and Sound by Rockwool) and mineral wool (DryTherm 37 by Knauf). Measurements were conducted with the procedure described in [5], which is an adaptation of ISO 7235:2003 [6].

	Frequency/Hz							
	80	125	250	500	1000	2000	4000	8000
SonoBlind (25 mm)	4	8	11	21	25	26	29	35
Rockwool (80 mm)	0	3	14	20	20	23	30	35
Glasswool (100 mm)	0	1	4	8	10	15	20	24

The SonoBlind modules used in this study were injection-molded from semi-transparent polycarbonate (Protolabs, UK) and mounted on 30 mm square aluminum profiles (Phoenix Mecano, Germany), for a total height of 1930 mm from a levelled ground (Figure 2) and a total maximum weight of 20 kg per panel. The panels were secured from wind using sand ballast on their feet (100 kg per panel). The risk of accidental falls during testing was minimized by joining (with bolts) each panel to its side neighbor and by using ground pegs on the four corners of the gazebo.

In each of the two service areas in this study, the gazebo was oriented with one of its sides parallel to the motorway and, in order to maximize the differential level between inside and outside, the effective acoustic height of the panels was increased in two ways:

a. Three of the sides had a T-shaped top, extending 115 mm in both directions. According to the literature, this type of barrier adds an interferometric effect to edge diffraction and should give an additional insertion loss (*IL*) of 2-4 dB [7-8].
b. In the case of *Peretola Sud*, the panels closer to the motorway were extended by an additional 260 mm. This modification also improves the expected *IL* [12].

Two of the panels on one of the short sides were used as a door, which was kept closed during the measurements inside. The height of the pop-up gazebo was adjusted so that its structure was in contact with the aluminum panels. It is expected that the fabric of the gazebo roof contributes to insertion loss only minimally.

Figure 2. Details of the inside of the gazebo, highlighting the roof of the gazebo and the panel extensions.

3. TESTING PROTOCOL

The gazebo was mounted every morning and dismounted every evening, with the support of specialized operators selected by MOVYON. Acoustic measurements (5 minutes, with 0.125 sec resolution) were taken in 1/3rd octaves using a Bruel & Kjer sound-level meter (model 2270) and 1/2" microphone (model: 4192), mounted on a tripod at 1500 mm from the ground. The insertion loss was measured along a path inside the gazebo (see Figure 3), in periods when traffic was established. For each position in the path, we measured the insertion loss as follows: (1) the distance from the road was measured for the selected position; (2) a 5-minute measurement was taken inside, at the selected position; (3) and additional 5 minutes measurement was taken outside, at 3 m from the gazebo, but at the same distance from the motorway – e.g. in Figure 3, the red dot shows where this last measurement was taken for positions 1,1 1,2 and 1,3. The insertion loss was calculated from the difference between these two measurements.

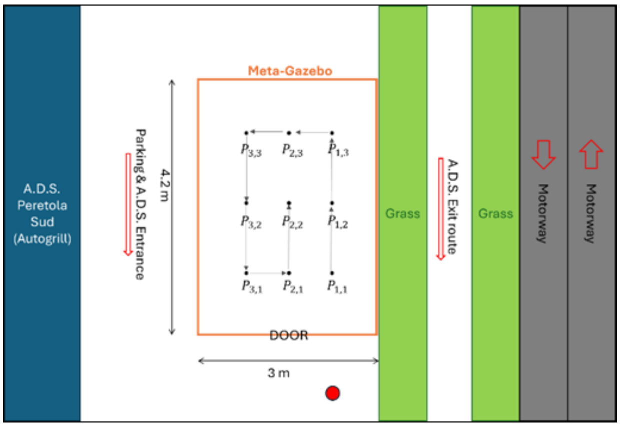

Figure 3. The path used in both cases to check the insertion loss of the gazebo and, later, for guiding the soundwalk inside it (here for *Peretola Sud*).

Volunteers for the perception assessments were recruited from among the customers of the service station. After consent was recorded, a numerical ID was assigned to the participant, and they were asked to stand outside the gazebo for 6 minutes before answering a set of questions (see below). The person then moved inside, the door was closed, and they were asked to explore the acoustic environment inside the gazebo for 6 minutes, at least along the path used for the measurements, before answering the same questions on their experience inside. To simplify data management for a non-EU country, the responses were treated anonymously, and no confidential data was acquired.
The questionnaire was constructed (in Italian) as follows:

1. One question checking whether the participant was a music professional. In [1], this was found to be more relevant than questions on noise sensitivity, for this context.
2. Two questions on how long the participant usually spends at this service station and whether this is indoor/outdoor.
3. Three questions, taken from questionnaires historically used to measure annoyance [9], trying to assess the sounds heard and their perceptive value. These questions were modified to use "sounds" instead of "noise" and repeated twice: first outside and then inside.
4. One group of questions to investigate the degree of agreement to some descriptive keywords from ISO 12913-2 [10]. These questions were repeated twice: first outside and then inside.
5. Two questions on whether the participant felt a difference between inside and outside, and on the nature of the latter, if present, followed by the possibility of adding an open comment.

Figure 4. The service stations of *Peretola Sud* (left) and *Arno Est* (right) with the position of the gazebo highlighted by an orange rectangle.

4. ACOUSTIC RESULTS

Acoustic measurements were conducted at the service area *Peretola Sud* over three days (2-5 December 2024) and at *Arno Est* on 9th December 2024.
On average, the sound pressure measurements confirmed what had been already observed in 2021. The soundscape appeared more repeatable at *Arno Est* (Figure 4, right), which sits between a high-traffic motorway and a high-speed railway track. Here, perception was dominated by traffic at high sound pressure levels. The A-weighed equivalent sound pressure level measured over 5 minutes ($L_{Aeq,\ 5min}$) for traffic was within 72±1 dB(A) at *Arno Est*. Conversely, the soundscape at *Peretola Sud* (Figure 4, left) was more

variable. This was due to a less-continuous traffic flow, probably influenced by a speed camera nearby, and by occasional aircraft overflights, due to the proximity of Florence-Peretola Airport. Additionally, bird chirping was distinctly audible in the late afternoon hours (i.e. near sunset), adding a natural element to the acoustic environment, and machinery sounds were present on one of the days, since a team was carrying out seasonal maintenance of the green areas. At *Peretola Sud* we measured $L_{Aeq,\,5min}$ = 66±1 dB(A) for motorway traffic.

In this context, it was necessary to measure in situ the acoustic insertion loss with the different sources. First, acoustic diffraction at the upper border of any acoustic barrier impacts on its performance, and this effect depends on the frequency content of the source. Second, in absence of a roof, the gazebo simply did not work for some sources (e.g. aircraft noise or strong wind). Figure 5 shows therefore the insertion loss measured at *Peretola Sud* along the middle line of the gazebo, perpendicular to the motorway (i.e. in points $P_{n,2}$ with n=1…3). Also reported in Figure 5 is the insertion loss (*IL*) calculated using the classical formula of Kurze and Anderson for a barrier with a superficial mass of at least 10 kg/m^2 [11]:

$$IL = K + 20\,log\frac{\sqrt{2\pi N}}{tanh\sqrt{2\pi N}} \qquad \text{for } -0.2 < N < 12.5$$
$$IL = 24\ dB \qquad \text{for } N > 12.5 \qquad (1)$$

where $N = 2\ \delta/\lambda$, δ is equal to the difference in the path between the diffracted path length and the direct line of propagation and λ is the wavelength of sound. In Figure 4 we measured the road to be 35 m away and at a height of 300 mm from the floor of the gazebo. The constant *K*, which accounts for the effect of the terrain on the propagation and for the diffraction due to the lateral size of the barrier, has a value of 5 for a semi-infinite barrier on a reflecting surface. In Figure 5, we report the curves for *K=0* (i.e. the value for a finite barrier, according to ISO 9613-2) and *K=3* (the value for a semi-infinite barrier with a mixed terrain). In Figure 5:

- Above 1000 Hz, the metamaterial gazebo used in this study follows a similar trend to the one of a mass-based barrier (eq. 1), with a height between 1.9 m and 2.2 m (see the curves with *K*=0).
- Alternatively, the data above 1000 Hz fall within the values predicted by equation (1), when the height is set at 1.9 m, and *K* varies between 0 and 3.
- The trend above 1000 Hz shows a resonant behavior that, in the case of sonic crystals, has been explained with internal resonant behaviors [12]. In our case, this is probably due to the Tee-shaped top of the barrier [7-8].
- Below 800 Hz, the IL of the metamaterial gazebo is superior to the one predicted by equation (1). This effect is due to using a metamaterial, and in particular to SonoBlind (see Table 1).

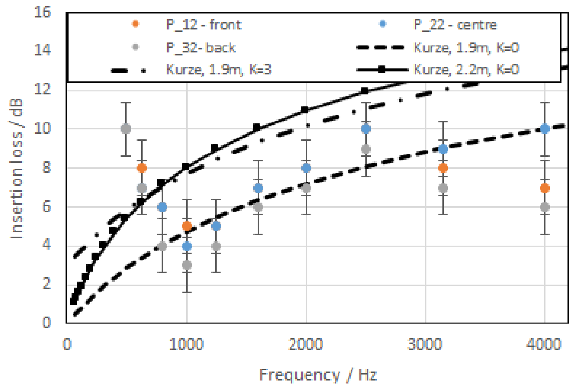

Figure 5. Performance of the metamaterial barrier as a function of frequency, compared with the trend expected from a barrier of similar density and height.

Equally important was to determine the spatial performance of the metamaterial shielding within the gazebo, to verify that the latter was an acoustically uniform space. Even when the orientation of the gazebo was different with respect to the road.

Table 2. Spatial distribution of the insertion loss in the gazebo for the two service stations. "Source side" means on the side of the motorway, with respect to the center of the gazebo.

Position	Broadband insertion loss / dB	
	Peretola Sud	*Arno Est*
P1,1	8.2 (source side)	6.1 (source side)
P1,3	9.5 (source side)	5.5 (away side)
P2,2	10.6 (center)	5.8 (center)
P3,1	8.0 (away side)	6.1 (source side)
P3,3	11.1 (away side)	4.8 (away side)

The broadband IL recorded in five of the locations from Figure 3 can be found in Table 2. These values show that the IL recorded in *Peretola Sud* (average: 9.5 dB) was between 3 dB and 4 dB higher than the one measured in *Arno Est* (average: 5.7 dB). This result is probably due to the orientation of the gazebo, which in *Arno Est* had its short size parallel to the motorway. In addition, the IL has a standard deviation across the gazebo that was as large as 1.5 dB(A) in *Peretola Sud* and as little as 0.5 dB(A) in *Arno Est*. This further difference is probably due to the nature of the traffic in *Peretola Sud*, which was not continuous. According to the Respite Research for Heathrow airport [13], a differential of 6 dB is the minimum value to have a measurable effect on perception. In the rest of this article, we will thus focus on the results obtained at *Peretola Sud*.

5. QUESTIONNAIRE RESULTS

Figure 6 summarizes the participants' opinion on where the incoming sounds come from: both inside and outside the gazebo, most of them were perceived to come from the nearby road. It is worth noting that there is a potential difference between "inside" and "outside" for the other causes of noise, but the difference is not statistically significant.

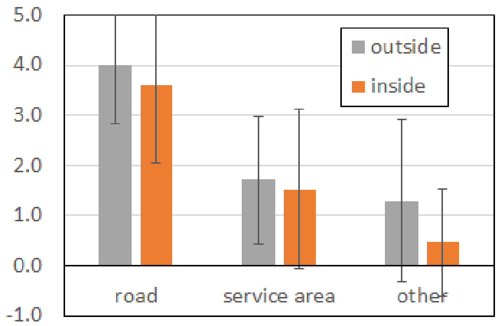

Figure 6. Participants' answers to the question: "where do the sounds come from?". The vertical scale reports in numerical format the 5-point Likert scale from 1="not at all" to 5="very much".

Figure 7 shows instead how much different types of sounds were heard "inside" and "outside". With the exception of the "natural sounds", for which there is no difference, all the other sounds were perceived to be less intense "inside" the metamaterial gazebo. By contrast, this explains the comment "I could hear natural sounds better", which was independently shared by 4 participants. Figure 8 reports the average judgement, in terms of annoyance, for the specific sounds heard. It is worth noting that, while all the sources were judged to be less annoying "inside", the change in judgement depends on the source.

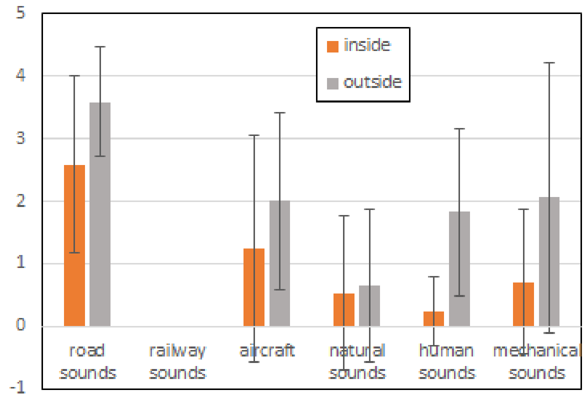

Figure 7. Participants' answers to the question: "which sources did you notice?". The vertical scale reports in numerical format the 5-point Likert scale from 1="not at all" to 5="very much".

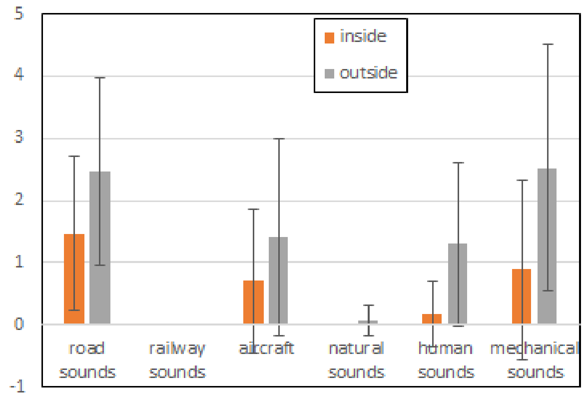

Figure 8. Participants' answers to the question: "how much annoyed were you by this type of sounds?". The vertical scale reports in numerical format the 5-point Likert scale from 1="not at all" to 5="very much".

Mechanical noises (which contain mostly high frequencies) were in fact attenuated more than road traffic or human sounds (see Figure 5), and this was – on average – mirrored by the perceptive judgements. Finally, Figure 9 presents the "inside" vs. outside change in terms of the indicators proposed by ISO 12913 [10]. To make the radar plot, the Likert scale of "agreement" was transformed into a numerical one – i.e. with "I agree completely" = 5 and "I disagree completely" = 1 – and the average value was calculated, before reporting it on the graph. This was sufficient to observe a shift from "annoying" and "chaotic" to "pleasant" and "calm". As assessed by a follow-up question, this change was perceived to be "positive" (59%) or "somewhat positive" (24%) by the majority of the respondents.

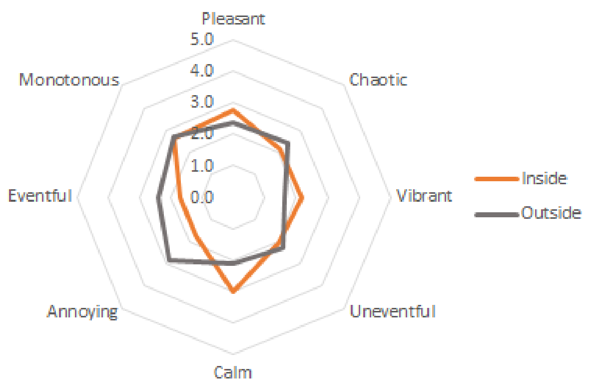

Figure 9. Soundscape assessment in terms of the agreement scale suggested by ISO 12913. The vertical scale reports in numerical format the 5-point Likert scale from 1="Completely disagree" to 5="Completely agree".

6. DISCUSSION

According to the literature [14], during a soundwalk it is essential to pay attention to the different sources. Typically, a soundwalk requires long periods, sometimes even longer than 1 hour. In this study, however, we set the length of our soundwalks to 16 minutes which, according to neurological scans, is the minimum duration to give an acoustic judgement [15]. If confirmed by other studies, 15 minutes may be the minimum time for short-term assessments, but there is no guarantee that results can be extended to long-term. At the end of the tests in *Peretola Sud*, we interviewed 5 additional volunteers while keeping the door of the gazebo open. In these circumstances, only a 6 dB difference could be observed between "outside" and "inside" and questionnaire respondents judged the change to be "neither positive nor negative" or "somewhat positive" (like in *Arno Est*). The lower qualification given to the change is in line with the works that identified "loudness" as the most important indicator in judging the quality of a soundscape [16]. Assuming that loudness is a measure of how much a sound is "noticeable", we therefore looked for a correlation between "noticing" a type of sounds and being "annoyed" by it. As shown in Figure 10, the correlation appears linear "inside" the metamaterial gazebo, and at values of "noticing" up to "neither a little not a lot" (corresponding to value # 3 on the horizontal axis of Figure 10). The linear fit is much worse "outside" the gazebo or at higher values of the "noticing scale". This result suggests that the difference between a source and the background may be equally important i.e. the background sound pressure level must be sufficiently low for listeners to notice a specific sound (and judge whether it is annoying or not). In our case, this was true for "natural sounds": since all the other sounds were lower in volume inside the gazebo, the former dominated. These results highlight the need to consider sound variations in the time domain, and not just in the frequency domain, at least for the qualification of quiet areas over short exposures [17].

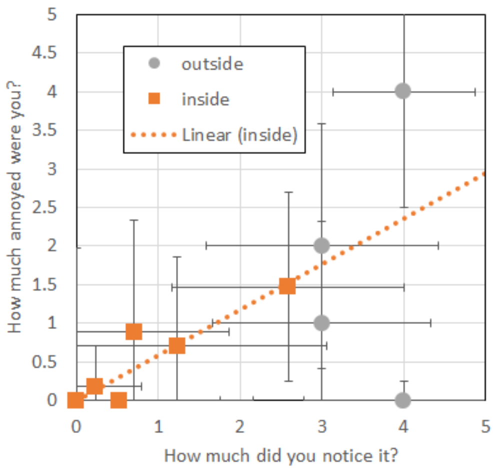

Figure 10. Cross-correlation between how much a type of sound is noticed and how annoying it is perceived to be.

7. CONCLUSIONS

In this work, we have designed, installed and tested a movable quiet area, in the shape of a pop-up gazebo. Portability was ensured by the unique properties of acoustic metamaterials, and in particular the fact that they can reach superior insertion loss with reduced space and weight. We tested our metamaterial gazebo in two service stations near Florence, Italy, where we run acoustic measurements in and out of the structure. We discussed here the case of *Peretola Sud*, where the in/out

difference in sound pressure level (that we called "insertion loss") was approximately 10 dB. In this case, it was possible to qualify the outside/inside change also on the perception scale. We therefore run semi-structured interviews, guided by questions to investigate source identification, weight annoyance judgements (from ISO 15666:2003 [9]) and reach a more neutral description of the soundscape (from ISO 12913-2 [10]).
Our findings may influence the procedures aimed at measuring acoustic changes in a soundscape. The possibility of creating movable acoustic spaces, with a 10+ dB difference with the surrounding world, may be helpful for achieving short term, quick respite in action plans. It may also lead to more immersive environments for soundscape studies.

8. ACKNOWLEDGMENTS

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