DOI: 10.61782/fa.2025.0387

FORUM ACUSTICUM EURONOISE 2025

EXPLORING PEDESTRIAN PERCEPTIONS OF SAFETY THROUGH SHARED SPACE SOUNDSCAPES

Frederico Pereira[1,2*] **Raul Almeida**[2] **Dario Machado**[1]
Emanuel Sousa[3] **William L. Martens**[4] **Elisabete Freitas**[5]
[1] CCG/ZGDV Institute, Campus de Azurém, 4800-058 Guimarães, Portugal
[2] University of Minho, ISISE, Department of Civil Engineering, Campus de Azurém, 4800-058 Guimarães, Portugal
[3] CCG/ZGDV Institute, Centro Algoritmi, Campus de Azurém, Guimarães, 4800-058 Portugal
[4] Faculty of Medicine, Health and Human Sciences, Macquarie University, NSW 2109, Australia
[5] University of Minho, ISISE, ARISE, Department of Civil Engineering, Campus de Azurém, 4800-058 Guimaraes, Portugal

ABSTRACT[*]

Pedestrians often avoid areas they perceive as unsafe. Negative feelings of safety undermine the goals of urban planning initiatives such as shared spaces that are designed to promote pedestrian mobility and social interaction.
The soundscape - defined as the acoustic environment as perceived by individuals - has the potential to shape pedestrians' perceptions of urban settings, while its impact is at the same time influenced by specific pedestrian context and expectations.
This study explores the impact of soundscapes on pedestrians' feelings of safety in dynamically interactive shared spaces, where pedestrians and vehicles coexist.
Using interactive virtual reality (VR) simulations, participants are immersed in realistic urban shared space scenarios, where they are exposed to different acoustic environment conditions. The simulations integrate acoustically defined natural, human-made and mechanical sounding elements. Participants engage with the simulations from a pedestrian perspective, where they may be engaged as a walking pedestrian or as one engaging in leisure activities.
The study examines the interplay between auditory stimuli and participants' perceived safety from their subjective assessments. Findings suggest difference between walk and leisure conditions dominated participants' perceptions.
Insights from these evaluations aim to identify shared space design interventions that enhance pedestrians' perception of safety as influenced by auditory percepts.

Keywords: *shared space, pedestrian safety, soundscape, urban planning, virtual reality,*

1. INTRODUCTION

In recent years, the purposes, design, and use of urban public spaces have evolved to prioritize city center regeneration, introducing a new approach to road safety in which pedestrians take center stage. Modern design concepts encourage walking and promote healthier lifestyles [1]. Efforts to reclaim urban spaces for pedestrians have driven the adoption of one such concept: the shared space.
Shared space is an urban design model in which pedestrians and motorized vehicles coexist within the same physical environment. Its goal is not only to enhance accessibility and sustainable mobility, but also to enrich public life, making urban areas more inclusive and enjoyable for all [2].

[*] ***Corresponding author***: Frederico.Pereira@ccg.pt.
Copyright: *©2025 Frederico Pereira et al. This is an open-access article distributed under the terms of the Creative Commons Attribution 3.0 Unported License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.*

Shared spaces have gained increasing traction in urban centers although their overall acceptability has produced mixed results. Research on pedestrian perceptions of shared spaces has revealed considerable concern regarding safety, particularly relating to potential collisions with motorized traffic [3,4]. Indeed, fear of collisions remains a critical determinant of perceived safety [5].
Perceived safety significantly shapes how individuals assess, use and navigate public spaces [6] and is related to overall user comfort [7]. However, there are currently no clear design guidelines for shared spaces that effectively tackle safety perception related to the unregulated coexistence of pedestrians and motorized vehicles.
Implementing shared spaces poses significant challenges regarding both safety and functionality. They can involve more potential conflicts than segregated conventional streets, with pedestrian-vehicle interactions often relying on awareness state, politeness, and common sense.
Notably, pedestrians' subjective sense of safety not always aligns with objective safety, however it remains a key factor influencing willingness to regularly use a space. It is then important to understand how these new designs are perceived, and the factors that shape these perceptions.
Soundscape is a perceptual construct arising from human experience and interpretation of an acoustic environment in context. It is well established that soundscapes play a crucial role in urban space perception [8], with environmental noise significantly affecting pedestrian safety by influencing their ability to detect vehicles—both in terms of localization (i.e., where the vehicle is) and identification (i.e., what the vehicle is) [9]. Providing pedestrians with adequate auditory cues is therefore vital in vehicle detection tasks, particularly when vehicles approach from outside the visual field or are partially or completely obstructed [9].
Detectability concerns become even more critical given the challenges posed by the transition to low-noise electric vehicles (EVs), which predominantly emit rolling noise and can be particularly difficult to detect at low speeds [10].
Although the ability to detect approaching vehicles is closely tied to collision risk [11] —a factor that is especially relevant in unsegregated shared spaces where vehicles may approach from multiple directions simultaneously—research into how the built environment influences traffic awareness and perception remains limited. This gap is even more pronounced for highly reverberant environments, such as streets surrounded by reflective building façades ("urban canyons"), which are often characterized by high ambient noise and acoustic diffuseness—factors likely to exacerbate detection challenges [12].
Often-overlooked measures, such as the acoustic properties of strategically placed vegetation, can potentially enhance the soundscape by serving as sound-absorbing elements and natural noise barriers [13]. Moreover, vegetation contributes positively to the soundscape by introducing natural sounds, which have been shown to elicit pleasurable experiences for road users [14]. Integrating vegetation into shared spaces may leverage its acoustic properties to improve soundscape attributes promoting a greater sense of safety.
This study examines acoustic environment design strategies—specifically, building facade reflective properties and the integration of natural sounds—and their impact on perceived safety within a simulated shared space. Considering the multifunctionality of shared spaces, the study further explores the influence of its context of use by road users.
The study proposes a perceptually plausible VR-based framework where participants take the role of virtual actors in a shared-street urban simulation. Adopting an evaluation approach similar to soundwalk field studies, the method allows for both, objective and subjective data collection [15].
Outcomes of the study aim to identify soundscape design interventions that enhance pedestrians' perceptions of safety.

2. MATERIALS AND METHODS

2.1 Research methodology overview

The study employed a 2 (façade reflections) × 2 (nature sounds) × 2 (context) repeated-measures factorial design, resulting in eight experimental conditions.
A virtual environment simulating an urban shared zone was developed with sound elements corresponding to electric vehicles' rolling noise, general urban background ambience, and natural sounds such as birdsong, rustling foliage, and flowing water.
Tire-road rolling noise recordings were selected from a Close Proximity (CPX) measurement campaign conducted in accordance with [16]. Measurements were made with a Brüel & Kjær Pulse Analyzer (type 3560-C) and two type 4189 microphones. For this study, a CPX recording corresponding to a constant speed of 20 km/h on an asphalt concrete surface (AC14) was used.
For the background urban ambience noise, a first-order ambisonic recording of a pedestrian zone was sourced from the Eigenscape database [17]. The recording was segmented into eight 2-minute excerpts, with each corresponding to one of the eight experimental conditions.

2.2 Audio stimuli

Sound signals were integrated into the VR environment to create a perceptually plausible urban setting. Acoustic propagation effects (including reflections) and sound source spatialization were computed using the Steam Audio engine built into Unreal Engine 4. Details regarding the performance of Steam Audio's physically based propagation effects can be found in [18].

For reflections, an 8th-order image-source computation method (ray-based) was applied, with reflection surfaces including building façades and the ground plane. Direction-dependent Head Related Transfer Functions (HRTFs) filtering was applied for the direct and for each reflected path. Vehicle rolling noise is modeled from four individual omnidirectional virtual sources at a height of 0.01 m, each corresponding to one tire-road contact patch. Sources reproduce distinct CPX recording excerpts in loops of different durations to introduce variability (approx. 10 s). Rolling noise sound power levels were estimated using the Harmonoise method for the asphalt concrete surface [19] (80.5 dBA, 1-min LA,eq).

General urban background ambience was presented at reference levels as measured by the authors in a pedestrian zone in Guimarães Portugal. In the simulation, no propagation attenuation is applied to background ambience, remaining at a constant level independent of virtual listener position (54 dBA, 1-min LA,eq). Audio stimuli are binaurally rendered to participants through headphones.

Headphone playback levels were calibrated using Sennheiser *HD650 open-back* headphones placed on a head-and-torso simulator (Brüel & Kjær *type 4128C*) equipped with two calibrated ear simulators (*types 4158/4159*). Levels were monitored using a Brüel & Kjær *type 2270* sound level meter. A Varjo *XR-3* head-mounted display (HMD) and Sennheiser *HD650* headphones were used to present the stimuli to participants.

Natural sound sources, including birdsong, rustling foliage, and water fountains, were obtained from publicly available recordings (freesound.org). Their playback levels were set for plausibility, determined based on pilot testing sessions. These sounds were then positioned in the simulated environment at spatially distributed locations, anchored to corresponding visual objects.

Absorption coefficients for modeled reflecting surfaces were set as to represent applied materials. Brick absorption properties for reflective façade condition or a *green wall* [13] facade for the absorptive façade condition. Ground surface was modeled as concrete.

In addition to perceptual data, a physical characterization of the binaural signals was conducted for both moving and seated conditions. For these measurements dummy trials with no participants were run and the audio output signal from HMDs was recorded directly into *Audacity* software (including calibration signal) using an RME *babyface Pro* soundcard at 48 kHz 24-bit. Sound pressure levels Loudness (Zwicker method [20]) were computed (see Tabs.2 and 3). Finally, Early Decay Time was measured from impulse responses at a source-receiver reference position to compare absorptive and reflective façade properties (see Tab.4).

2.3 Visual stimuli

The visual scenario was developed in Unreal Engine 4.0. It features a typical shared space layout, integrating green elements and street furniture, and with no physical demarcations between vehicle and pedestrian zones. An outdoor café seating area is modeled, and the scene is populated by animated virtual pedestrians. Vehicle movements are pre-programmed to simulate traffic along a two-way carriageway, represented only by light passenger vehicles (see Fig. 1 for a depiction of the visual scenario).

All visual elements remain unchanged across experimental conditions.

Figure 1. Visual model of the simulated shared space environment (21 m width between building facades). Green-wall facades are not visually represented.

2.4 Participants

Participants were primarily recruited from among University of Minho staff and students, as well as colleagues from CCG/ZVDG Institute. Inclusion criteria required normal hearing and vision (self-reported), and a minimum age of 18 years. In total, 20 participants completed the experiment.

2.5 Procedure

Upon entering the laboratory, participants were greeted by a researcher who provided an overview of the study. Each participant received a set of paper forms, including instructions, written consent form, a demographic survey, and a Weinstein Noise Sensitivity test to identify participants who may be abnormally vulnerable to negative effects of noisy environments. The forms were completed before proceeding to the actual experiment in VR. Instructions included a concise description of *soundscape* and the shared-space design concept highlighting its implications for pedestrian users.

Participants were informed that they would interact with a VR simulation of an urban shared space, assuming the role of a virtual pedestrian. They would either explore the area by moving through it or remain in a fixed position, acting as a seated user at an outdoor café table.

While moving, participants were free to rotate their heads (thus rotating the viewpoint of the virtual character), but translational movement followed a predetermined path mimicking walking dynamics. They were instructed to embody the perspective of the virtual character and be aware of the surrounding (simulated) environment as they would in the real world.

The researcher then guided each participant to a reference position marked on the floor and ensured proper setup of the VR equipment. Prior to data collection, participants completed a familiarization session in which they freely explored the simulated street environment using a keyboard to control their translational movement, while head rotation was tracked by the HMD. No vehicles were simulated during this session, and only general background sound was presented. After completion the actual experiment commenced.

Each participant performed eight trials divided into two blocks as summarized in Tab. 1. Presentation order of blocks and individual trials within them was randomized. After each trial, participants verbally responded to a perception-related questionnaire presented in the simulated environment using a 5 point-Likert scale (ordered from 1-*strongly agree* to 5-*strongly disagree,* displayed on the HMD). The researcher recorded their answers. The following 5 statements were presented for participant assessment:

Q1. *I felt comfortable in the shared space.* [5 point-Likert scale].

Q2. *I felt safe in the shared space* [5 point-Likert scale].

Q3. *I was aware of surrounding vehicles' movement* [5 point-Likert scale].

Q4. *I feel that sound had an influence in my sensation of safety* [5 point-Likert scale].

Q5. *The sound category that dominated the soundscape was:* categorical multiple-choice: a) Motorized transport; b) Human-made; c) Nature sounds

Each trial lasted approximately two minutes. Upon completing the fourth trial, a five-minute rest is given, before beginning the second block. The experimental sessions lasted for about 40 min, and were conducted in a quiet room at the CCG/ZVDG Institute building, located in the University of Minho Campus of Guimaraes, Portugal.

Table 1. Blocks and trials summary. (L. refl. = Low reflection, H. refl. = High reflection; No Nat.= No nature sounds, Nat.= with nature sounds). Blocks and trials presentation order were randomized.

Blocks	Trials and conditions id			
1	W1	W2	W3	W4
	Walk H. refl. Nat.	Walk L. refl. Nat.	Walk H. refl. No Nat.	Walk L. refl. No Nat.
2	S1	S2	S3	S4
	Seat L. refl. No Nat.	Seat L. refl. Nat.	Seat H. refl. No Nat.	Seat L. refl. No Nat.

3. RESULTS

3.1 Virtual acoustic environment characterization

Table 2. Acoustic parameters calculated from trials' binaural recordings of 2 min duration (no head movement). Max. of the two channels used as the single representative value [21]. Levesl in [dBA].

Cond. id	W1	W2	W3	W4	S1	S2	S3	S4
LAeq	67.3	65	67	64.9	67.3	65	67.1	64.9
LA5	71.5	70.3	71.3	70.3	72.7	71.5	72.3	71.5
LA95	61.1	55.7	60	55.1	61.6	56.9	61	55.9

Table 3. Psychoacoustic parameters calculated from trials' binaural recordings, 2 min duration (no head movement) Max. of the two channels used as the single representative value [21]. Loudness in [sone]

Cond. id	W1	W2	W3	W4	S1	S2	S3	S4
Navg	19.8	15.6	18.6	14.7	20.1	15.8	18.5	14.7
N5	26.7	24.1	25.9	23.6	27.5	25.7	26.9	25.4
N95	14.6	9.8	12.9	8.7	15.2	11	12.6	9.3

Table 4. EDT [s] estimation from impulse response (Dirac delta) with source position at egocentric coordinates (az=30º (right), el=0, d=6 m).

Cond	EDT (1kHz)
High refl.	0.55
Low refl.	0.15

3.2 Questionnaire Statistical Analysis

To investigate the influence of experimental conditions on participants' responses, a two-part statistical analysis was conducted. First, descriptive statistics and visualizations were used to summarize the distribution of responses to each question across all conditions. This included boxplots for Questions 1–4 (measured on a five-point Likert scale), as shown in Fig.2, and bar plots for Question 5 (categorical multiple-choice: A, B, or C, see Fig. 3).

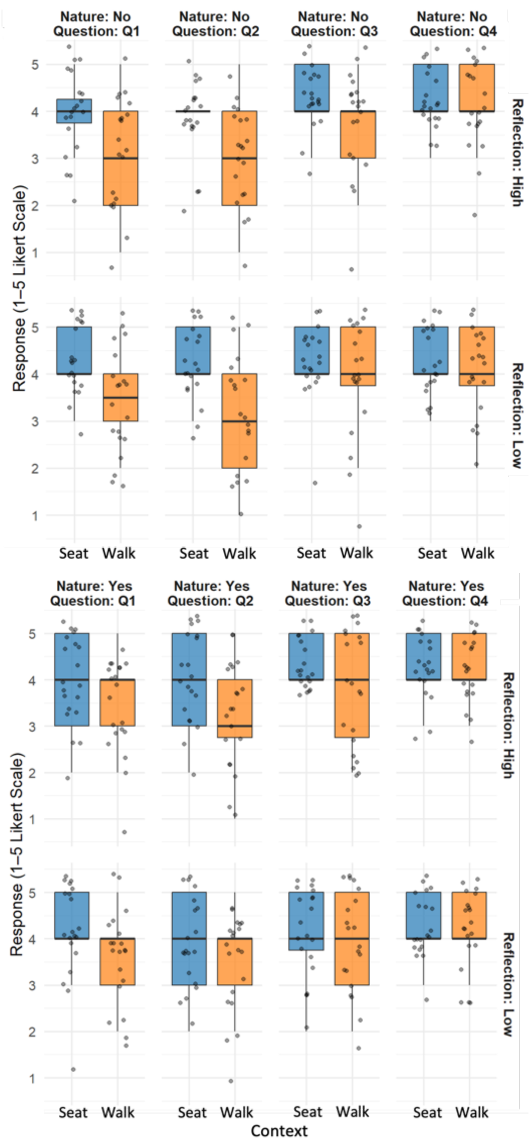

Figure 2. Descriptive statistics box plots for Questions 1–4.

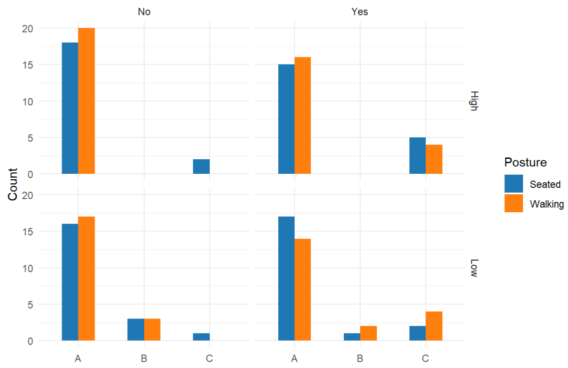

Figure 3. Descriptive statistics bar plots for Q5.

Second, inferential statistical tests were performed to evaluate whether context (Seated vs. Walking), reflection level (High vs. Low), and presence of nature sounds (Yes vs. No) had a significant effect on the participants' responses.

To assess whether context, reflection, and nature sound conditions influenced participant responses, we ran linear mixed-effects models (LMM) for each question (Q1–Q4), with Participant as a random effect to account for repeated measures within subjects. This allowed us to estimate the fixed effects of the three experimental factors and their interactions on each question independently.

For Question 5, due to the categorical nature of the responses and the small sample size in some subgroups, a Fisher's Exact Test was employed rather than Chi-square tests, as it provides more reliable results for contingency tables with low expected cell counts.

All statistical analyses were conducted using R software (version 4.4.3), and the results are presented below by question. Significance was determined at the $\alpha = 0.05$ level.

3.3 Summary of Results

Q1 (comfort): Context had a significant effect: participants rated the comfort lower when walking compared to seated ($\beta = -0.90$, $p < .001$). No significant effects were found for Reflection or Nature sounds, nor for their interactions ($p > .05$).

Q2 (safety): Posture again had a significant effect: safety ratings were lower during walking than seated ($\beta = -0.85$, $p < .001$). Although Low Reflection had a positive (but non-significant) effect, none of the interactions reached significance.

Q3 (awareness): Walking posture again resulted in significantly lower Q3 scores ($\beta = -0.55$, $p = .017$), showing diminished awareness. No other fixed effects or interactions were statistically significant.

Q4 (sound influence on safety): No fixed effects or interactions reached statistical significance. Posture, Reflection, and Nature all had negligible effects.
Overall, the results suggest that walking posture negatively influenced participant experiences across Q1 to Q3, particularly in terms of comfort, safety and awareness. In contrast, neither Reflection nor Nature sounds had statistically significant main or interaction effects in any model.
Q5: Categorical Choice Analysis (vehicle/people/nature).
There was no significant association between context and Q5 responses ($p = 0.900$), indicating that whether participants were seated or walking did not influence their final selection. However, statistically significant associations were found for both reflection condition ($p = 0.0039$) and nature sound exposure ($p = 0.0077$). These results suggest that participants' choices on Q5 were influenced by both the level of reflection (High vs. Low) and the presence of natural sounds during the task.
Reflection ($p = 0.0039$): There is a significant association between the level of reflection (High/Low) and the sound participants preferred at the end. This suggests the reflective framing influenced their auditory preference.
Nature Sound ($p = 0.0077$): The presence or absence of natural sounds during the experience had a significant effect on participants' final choice.
Posture ($p = 0.90$): There is no significant difference in Q5 responses between seated and walking participants. Posture did not influence which sound they preferred.

4. DISCUSSION AND CONCLUSIONS

This study assessed the effects of acoustic reflections, natural sounds, and context of use on pedestrians' perceived safety in shared spaces

4.1 Walking vs. Seated

Results across the first three subjective measures (Q1–Q3) revealed statistically significant differences between postures. When walking through the shared space, participants reported lower comfort (Q1), reduced feelings of safety (Q2), and diminished awareness (Q3) compared to when seated. The seated condition—representing a passive, stationary user—was consistently associated with higher comfort and a stronger sense of safety, suggesting that the simple act of moving through the space increased perceived vulnerability.
A plausible explanation is that seated participants may have perceived themselves in a more observational role, detached from the risk of direct interaction with vehicles. In contrast, walking participants actively traversing the shared carriageway were more likely to feel exposed, needing to monitor vehicles approaching from multiple directions. This likely imposed a greater cognitive load, reducing participants' capacity to absorb environmental details—an effect supported by previous research on attention and spatial complexity.[22].
Importantly, these differences are unlikely to stem from acoustic intensity alone. As shown in Tables 2 and 3, both Loudness (a strong correlate of annoyance [23]) and sound pressure levels (SPL) remained comparable across walking and seated conditions, suggesting that the subjective differences were not driven by increased noise levels. This further supports the interpretation that related differences reflect a behavioral context effect rather than acoustic exposure.
These findings affirm a crucial point in soundscape research: the behavioral mode of interaction fundamentally shapes environmental perception [24]. Moreover, they validate adequacy of our proposed VR framework, which successfully elicited decreased perceived safety while participants moved through the simulated space—mirroring real-world shared street experiences.

4.2 Ambient Sounds

Neither the level of façade acoustic reflections nor the presence of natural sounds produced statistically significant main effects on participants' comfort, safety, or awareness ratings (Q1–Q3). This was true even under high-reflection conditions, which introduced greater acoustic complexity and higher Loudness values (Tables 3 and 4). These findings suggest that, in active contexts like walking, situational dynamics—such as the presence of vehicular traffic—predominated over background acoustic factors in shaping perceived safety.
These findings carry important implications for the design of shared urban spaces and the strategic planning of their soundscapes. In practical terms, this means urban designers should first and foremost ensure tangible safety measures in shared spaces providing a baseline of security.
From a design perspective, this implies that soundscape interventions alone may not suffice in enhancing perceived safety in shared spaces. Instead, foundational safety measures must be prioritized to establish a baseline of comfort. Only then can secondary interventions (such as the introduction of nature sounds) contribute meaningfully. This view aligns with existing literature indicating that in high-engagement settings, primary risks must be addressed before secondary cues become effective [25].

That said, our findings appear to diverge from prior studies that report positive effects of natural sounds on comfort and safety perceptions [8]. One explanation may lie in the simulation set sound levels. The intentional addition of sound sources such as natural sounds in shared spaces must be exerted with caution, as they may amount to masking noise to vehicles' acoustic cues for detectability. Aware of this risk, the present study calibrated nature sound levels to avoid noticeable increases in overall Loudness, aiming for subtle integration.

Evidencing the delicate balance that must be achieved for additional sounds to enhance safety perception without inadvertently exacerbating underlying concerns is possibly reflected in Q4 responses, where these gentle manipulations were, at least consciously, largely unnoticed as safety measures.

Nonetheless, our results underscore the influential role of ambient sound in shaping auditory salience. While comfort and safety ratings (Q1–Q3) were unaffected, responses to Q5 revealed that reflection level and nature sound presence significantly influenced the dominant sound category participants reported. Specifically, environments with high reflections or without natural sounds led to greater prominence of traffic-related sounds, while low-reflection settings and the addition of nature sounds increased the salience of more pleasant or socially meaningful sound sources (e.g., birdsong, human voices).

These findings offer concrete direction for soundscape curation in urban design. By selecting materials with favorable acoustic properties or introducing subtle, contextually appropriate sound sources, designers can shift auditory attention toward more desirable elements of the environment, reinforcing the intended character of the space without overwhelming its functionality.

5. CONCLUSIONS

The present study examined building facade reflective properties, the integration of natural sounds and usage context of use influence on shared spaces safety perceptions by pedestrians. For the experimental work a VR-based framework where participants take the role of virtual actors in a shared-street urban was implemented.

Results indicate the difference between walking and sitting dominated participants' perceptions, overshadowing any subtle benefits that acoustic modifications might have provided. The finding underscores that researchers and designers must consider user engagement level as a key factor in soundscape evaluations.

The study's insights suggest that creating safer shared spaces involves a delicate interplay between managing the practical realities of pedestrian-vehicle interaction (where context and engagement come into play) and crafting a supportive sensory environment.

Further work is planned involving the collection of more comprehensive subjective data, complemented by physiological measures such as skin conductance and heart rate variability to assess participant stress responses. This multimodal approach aims to better capture the interplay between perceived and physiological states. A more integrated analysis of subjective and objective data is considered essential for deepening our understanding of the soundscape determinants of perceived safety.

6. ACKNOWLEDGMENTS

This work was partly financed by FCT/MCTES through national funds (PIDDAC) under the R&D Unit Institute for Sustainability and Innovation in Structural Engineering (ISISE), under reference UIDB/04029/2020 (https://doi.org/10.54499/UIDB/04029/2020); the Associate Laboratory Advanced Production and Intelligent Systems ARISE under reference LA/P/0112/2020; and IMPACT - IMProving users sAfety perCepTion of shared streets: Auditory, visual and geometry-based strategies, under reference 2022.06271.PTDC (https://doi.org/10.54499/2022.06271.PTDC).

7. REFERENCES

[1] Krier, R., Ibelings, H., Meuser, P., & Bodenschatz, H. (2006). *Town spaces: Contemporary interpretations in traditional urbanism: Krier-Kohl-Architects* (2nd rev. ed). Birkhäuser.

[2] Wijayaratna, D. K. (2022). *Evaluation and Implementation of Shared Spaces in NSW - Final Report: Framework for road infrastructure design and operations to establish placemaking Examination of existing Shared Space knowledge.*

[3] Ruiz-Apilánez, B., Karimi, K., García-Camacha, I., & Martín, R. (2017). Shared space streets: Design, user perception and performance. *URBAN DESIGN International*, *22*(3), 267–284.

[4] Methorst, R., Gerlach, J., Boenke, D., & Leven, J. (2007). Shared Space: Safe or Dangerous? *A Contribution to Objectification of a Popular Design Philosophy, 3.*

[5] Aceves-González, C., Ekambaram, K., Rey-Galindo, J., & Rizo-Corona, L. (2020). The role of perceived pedestrian safety on designing safer built environments. *Traffic Injury Prevention*, *21*(sup1), S84–S89.

[6] Rossetti, T., Lobel, H., Rocco, V., & Hurtubia, R. (2019). Explaining subjective perceptions of public spaces as a function of the built environment: A massive data approach. *Landscape and Urban Planning*, *181*, 169–178.

[7] Gill, G., Bigazzi, A., & Winters, M. (2022). Investigating relationships among perceptions of yielding, safety, and comfort for pedestrians in unsignalized crosswalks. *TR_F*, *85*, 179–194.

[8] Sayin, E., Krishna, A., Ardelet, C., Briand Decré, G., & Goudey, A. (2015). "Sound and safe": The effect of ambient sound on the perceived safety of public spaces. *International Journal of Research in Marketing*, *32*(4),

[9] Cai, Y. (2024). Pedestrian auditory perception of approaching vehicles from behind in shared space: The impact of quietness of electric vehicles. *Transportation Research Procedia*, *78*, 594–601.

[10] Karaaslan, E., Noori, M., Lee, J., Wang, L., Tatari, O., & Abdel-Aty, M. (2018). Modeling the effect of electric vehicle adoption on pedestrian traffic safety: An agent-based approach. *TR_C*, *93*, 198–210.

[11] Pardo-Ferreira, M. C., Torrecilla-García, J. A., Heras-Rosas, C. de las, & Rubio-Romero, J. C. (2020). New Risk Situations Related to Low Noise from Electric Vehicles: Perception of Workers as Pedestrians and Other Vehicle Drivers. *International Journal of Environmental Research and Public Health*, *17*(18), 6701.

[12] Badino, E., Manca, R., Shtrepi, L., Calleri, C., & Astolfi, A. (2019). Effect of façade shape and acoustic cladding on reduction of leisure noise levels in a street canyon. *Building and Environment*, *157*, 242–256.

[13] Davis, M. J. M., Tenpierik, M. J., Ramírez, F. R., & Pérez, M. E. (2017). More than just a Green Facade: The sound absorption properties of a vertical garden with and without plants. *Building and Environment*, *116*, 64–72.

[14] Olszewska-Guizzo, A., Sia, A., Fogel, A., & Ho, R. (2020). Can Exposure to Certain Urban Green Spaces Trigger Frontal Alpha Asymmetry in the Brain?—Preliminary Findings from a Passive Task EEG Study. *International Journal of Environmental Research and Public Health*, *17*(2), 394.

[15] Aletta, F., & Xiao, J. (Eds.). (2018). *Handbook of Research on Perception-Driven Approaches to Urban Assessment and Design:* IGI Global.

[16] *EN ISO 11819-2:2017. Acoustics—Measurement of the influence of road surfaces on traffic noise—Part 2: The close-proximity method.*

[17] Green, M. C., & Murphy, D. (2017). EigenScape: A Database of Spatial Acoustic Scene Recordings. *Applied Sciences*, *7*(11), 1204.

[18] Fırat, H. B., Maffei, L., & Masullo, M. (2022). 3D sound spatialization with game engines: The virtual acoustics performance of a game engine and a middleware for interactive audio design. *Virtual Reality*, *26*(2), 539–558.

[19] Jonasson, H. G., Sandberg, U., Blokland, Ejsmont, J., Watts, G., & Luminari. (2004). *Source modeling of road vehicles. Harmonoise deliverable 9*.

[20] *EN ISO 532-1:2017 Acoustics—Methods for calculating loudness. Part 1: Zwicker method.*

[21] *ISO TS 12913-3:2019 Acoustics—Soundscape Part 3: Data analysis*

[22] Dommes, A. (2019). Street-crossing workload in young and older pedestrians. *Accident Analysis & Prevention*, *128*, 175–184.

[23] Lee, J., Francis, J. M., & Wang, L. M. (2017). How tonality and loudness of noise relate to annoyance and task performance. *Noise Control Engineering Journal*, *65*(2),

[24] Hong, J. Y., & Jeon, J. Y. (2015). Influence of urban contexts on soundscape perceptions: A structural equation modeling approach. *Landscape and Urban Planning*, *141*, 78–87.

[25] Cooke, M., Chaboyer, W., Schluter, P., & Hiratos, M. (2005). The effect of music on preoperative anxiety in day surgery. *Journal of Advanced Nursing*, *52*(1), 47–55.