ECHOES OF SUSTAINABILITY: SOUNDSCAPE AND SUSTAINABILITY ASSESSMENT IN A COLLEGE CAMPUS

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Abstract

Despite the existence of legislation and good practice guidelines, environmental noise remains a challenge for most urban environments. While noise control methods have made significant strides in reducing noise levels in urban sound environments, there has been a notable oversight in addressing its perceptual construct known as the 'soundscape.' This oversight is a missed opportunity for urban sustainable development, aiming towards inclusive, safe, resilient, and sustainable cities and human settlements. Several College and University campuses serve as exemplars of well-designed and environmentally conscious sound environments. For this research, a soundscape assessment at Perrotis College in Thessaloniki, Greece has been conducted. Furthermore, noise level measurements and sound recordings were conducted. This approach allowed the combinatory evaluation of soundscape descriptors with noise and acoustic indicators, over a three-month period. The results highlighted a seasonal variation in how campus users perceive the soundscape. The concept of positive soundscapes and the application of soundscape improvement strategies are crucial elements for enhancing urban environments. These approaches not only contribute to reducing noise pollution but also promote a more pleasant and harmonious auditory experience in our cities and support the creation of sustainable urban spaces.

Key words: *Soundscape, Sound environment, Noise, Sustainability, Noise map, Campus*

Introduction

Approximately 75% of European citizens and 57% of the global population reside in urban areas (*World Bank Open Data*, 2018) with an increasing trend. Additionally, the rapid urbanization rate has led to a series of environmental pressures impacting the well-being of urban dwellers (Lal et al., 2017). Alongside the various environmental pressures, noise emerges as a significant factor negatively affecting both human (Riedel et al., 2019) and environmental health (Brumm & Zollinger, 2011; Slabbekoorn, 2013). Sound retains the potential to stand as a proxy of urban sustainability, as changes in the urban environment create acoustic impacts reflecting the environmental condition of a region (Krause & Farina, 2016).

Cities are complex and dynamic systems, in which changes in one area can lead to unexpected effects (Glouberman et al., 2006). The dominance of built infrastructure in cityscapes has shaped a view of urban society that is dissociated from natural ecosystems. Nevertheless, the degradation of rural habitats due to the intensification of agriculture and the promotion of green and circular policies in the urban environment (Tsaligopoulos et al., 2022), has elevated the ecosystemic importance of urban green areas (Fuller & Gaston, 2009; Susskind & Kim, 2022). This paradox builds upon the perception that cities are both the cause of and the solution for local and global climatic crisis phenomena (Byrne, 2022).

Urban green areas offer numerous benefits and ecosystem services to city dwellers. These spaces contribute to noise reduction, support biodiversity conservation, and promote health restoration (Gidlöf-Gunnarsson & Öhrström, 2007). Despite these advantages, limited access to urban green spaces remains a challenge in many cities, affecting the well-being of residents (Chiquet et al., 2013; Kothencz et al., 2017). The United Nations' 11th Sustainable Development Goal (*United Nations*, 2024) underscores the importance of creating inclusive, safe, resilient, and sustainable cities. Therefore, ensuring access to public green spaces, quiet areas (Bartalucci et al., 2019), and restorative environments (Payne, 2013) is an integral part of creating a sustainable and healthy urban environment.

Implementing a strategy that prioritizes acoustic sustainability in urban planning and design can lead to robust and adaptable urban spaces. Acoustic sustainability is defined as "*our ability as a culture to live within a positively functioning soundscape that has long-term viability*" (Truax, 2021). In most cases, university and college campuses serve as exemplars of healthy environments, providing acoustic sustainability (Mohammed et al., 2022). They serve as hubs of innovation, implementing thoughtful design and planning by integrating green spaces and pedestrian-friendly layouts (Colding & Barthel, 2017). Sustainable design and practices are a priority in such environments, aligning with educational missions that promote environmental awareness and responsibility among students and staff.

This research aims to demonstrate that college campuses can serve as models for cities, influencing sustainable practices at urban level. By assessing the sound environment of a college campus, we intend to showcase a sustainable approach, providing an outline for proper design, conservation and promotion of urban green spaces. The objectives of this research are a) to assess the impact of noise in a college campus, b) to assess how the sound environment is perceived over time, c) to assess the interconnection of noise and acoustic complexity.

Theoretical Framework

The issue of noise

The World Health Organization (WHO) defines health as a "*state of complete physical, mental and social well-being and not merely the absence of disease or infirmity*" (*Constitution of the World Health Organization*, 2024). To this end, urban residents exposed to increased noise levels, experience a combination of mental and physical health deterioration (Basner et al., 2014; Mucci et al., 2020). More specifically, noise can cause annoyance, sleep disturbance, hearing impairment and even coronary heart disease, myocardial infractions, strokes, and hypertension (*WHO, Environmental Noise Guidelines for the European Region*, 2019). Additionally, noise impacts avifauna communication efforts, directly and indirectly affecting overall environmental quality (Ey & Fischer, 2009).

The Environmental Noise Directive (END), relating to the assessment and management of environmental noise, underscores the significance of addressing this specific pollutant. In this directive environmental noise is defined as the "*unwanted or harmful outdoor sound created by human activities, including noise emitted by means of transport, road traffic, rail traffic, air traffic, and from sites of industrial activity*" (*END*, 2002). Among these sources, road traffic noise stands out as a major cause of distress.

According to WHO, the recommended threshold for road traffic noise exposure to safeguard human health is a threshold of 53 dB(A). Unfortunately, recent statistics reveal that 40% of the European population is exposed to noise levels exceeding 55 dB(A), with 20% experiencing levels surpassing 65 dB(A) during the daytime, and 30% enduring levels exceeding 55 dB(A) at night. Urgent intervention is pivotal to alleviate this burden (*WHO, Environmental Noise Guidelines for the European Region*, 2019).

One potential solution to noise-related challenges involves creating urban quiet areas, where low levels of environmental noise are preserved (Bartalucci et al., 2019; Tsaligopoulos & Matsinos, 2022). These areas can be established through various noise control measures, including the use of noise barriers. However, the prompt to homogenize all sounds under the prism of their intensity was the reason to shift away from traditional noise control methods towards perceptual approaches similarly to the soundscape approach emphasizing the holistic experience of sound beyond intensity (Kang et al., 2016).

The soundscape approach

The soundscape approach provides a new sound environment interpretation going beyond the concepts of noise and quietness by focusing on negative and positive soundscapes (Axelsson et al., 2012). Soundscape investigations intend to collectively evaluate all sounds perceived in an environment (Mitchell et al., 2022). This phenomenological approach, through which individuals interpret and understand the sounds around them, is reinforced by the objective reality of the natural world.

The definitions provided by the ISO 12913 soundscape series highlight the differentiation between the concepts of the '*sound environment' and the 'soundscape'. The sound or acoustic environment is defined as the 'sound at the receiver level from all sound sources as modified by the environment*', thus emphasizing an objective reality of sound and noise propagation. Additionally, the soundscape is defined as the '*acoustic environment as perceived or experienced and/or understood by a person or people, in context*' (ISO 12913, 2014). This differentiation underscores the fact that the soundscape stands as the perceptual construct of a sound environment that can be assessed individually or collectively.

There are several survey methods for soundscape assessment that involve collecting both qualitative and quantitative data. Survey participants complete soundscape assessment questionnaires to highlight the perceived affective quality of the sound environment (Aletta et al., 2016). These specific questionnaires utilize soundscape descriptors to describe how people perceive their auditory surroundings. One engaging method for perceptual data collection is the soundwalk (Oberman et al., 2020). During a soundwalk, participants actively listen while following a pre-designed route that exposes them to various sound environments. Using the aforementioned descriptors, participants collectively describe the soundscape they experience. The future of soundscape studies lies in establishing soundscape indicators that serve as metrics for predicting the overall soundscape quality. The ultimate goal of the soundscape approach is to move beyond the decibel scale and provide more meaningful outcomes for urban dwellers in terms of soundscape design (Kang, 2017).

However, a common limitation of both noise control and the soundscape approach is the inadequate concern of the ecological aspects within a sound environment. The field of ecoacoustics offers an environmental perspective, acting as a connecting link between the objectivity of noise control and the subjectivity of the soundscape approach (Krause & Farina, 2016).

The ecoacoustics approach

The field of ecoacoustics studies the ecological role of sounds originating from geophysical (geophony), biological (biophony), and anthropogenic (anthropophony) sources (Farina, 2018). Unlike traditional bioacoustics, that focuses solely on isolated animal vocalizations, ecoacoustics scale-up and assess entire animal orchestras (Pijanowski et al., 2011). In recent years, researchers have increasingly turned to passive acoustic methods in order to capture and analyze vocal species dynamics, providing valuable insights into species behavior (Desjonquères et al., 2020). Automated recorders that have been recently developed offer a cost-effective and trusted solution and are now widely used by researchers.

The intrinsic link between sound and ecological processes, as explored in ecoacoustics, highlights that sound environments are fundamental components of ecosystems (Sueur & Farina, 2015). This has led to the development of new indices that quantify acoustic properties, similar to complexity and diversity. These indices shed light on various ecological aspects based on assumptions about the frequency attributes of animal vocalizations (Sueur, 2018).

One commonly used acoustic index is the Acoustic Complexity Index (ACI). ACI operates under the assumption that biotic sounds exhibit variability in intensities, while human-generated noise maintains constant intensity values (Farina & Li, 2021). Its purpose is to measure acoustic complexity by assigning greater importance to sounds that demonstrate amplitude modulation.

Numerous studies have revealed an inverse relationship between noise indicators and acoustic complexity (Haselhoff et al., 2022; Tsaligopoulos et al., 2023). This implies that noise producing human activities tend to simplify complex sound environments, thus providing additional evidence of the effects of noise on environmental health.

Methodology

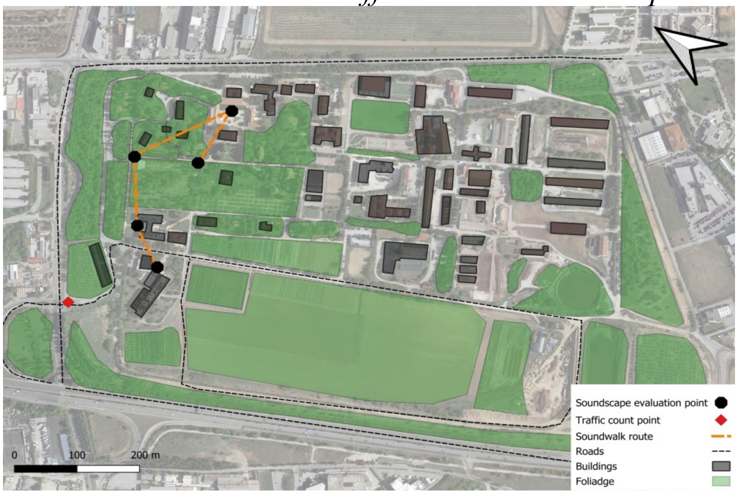
Case study area

For this research we focused on a large section of Perrotis College campus located in the outskirts of Thessaloniki, Greece. The specific campus incorporates green spaces, agricultural land, and pedestrian areas, prioritizing sustainable infrastructure in order to align with the educational mission of the college.

Amongst the numerus plant species found in the premises of the campus, Pine trees (Pinus brutia) are abundant. Furthermore, numerous bird species including robins (*Erithacus rubecula*), white wagtails (*Motacilla alba*), doves (*Columpa liva*), common blackbirds (Turdus merula), warblers (*Sylvia melanocephala*), great tits (Parus major), sparrows (Paser domesticus), goldfinches (*Carduelis carduelis*), hooded crows (*Corvus corone cornix*), and medium-sized rose-ringed parakeets (*Psittacula krameri*).

This research was conducted during the daytime hours (10:00 a.m.–11:00 a.m.) of October, November, and December 2023. As can be seen in Figure 1, a soundwalk route containing five soundscape evaluation points was planned to enable simultaneous sound level measurements and sound recordings. The five evaluation points represent diverse environments and were selected because they are frequently used by college students for studying, leisure, and even educational activities. In total 10 students, aged between 18 and 25 years, completed the soundscape evaluation questionnaires for each period. For every questionnaire a sound level measurement and a sound recording were simultaneously conducted. Participants utilized a 5-point Likert evaluation scale to depict their perceived affective quality data, using the available soundscape descriptors such as annoying, calm, chaotic, eventful, monotonous, pleasant, uneventful, and vibrant.

Figure 1: Perrotis College Campus showcasing the soundscape evaluation points, the soundwalk route and the traffic count observation point



Soundscape evaluation methods

The 01 dB Fusion class 1 smart noise monitor, paired with the GRAS 40AE free field microphone, gathered noise data at a 51.2 kHz sampling frequency and a 1 s logging interval, positioned 1.5 m above ground level. Preceding data collection, the device was calibrated, aligning with the requirements for Class 1 measuring instruments and EN61326-1:1997 + A1:1998 specifications. The dBTrait v. 6.3.0 software (ACOEM, Limonest, France) was used to process the environmental noise data, focusing on A-weighted levels of L_{eq}, L_{min}, and L_{max} noise indicators. L_{eq}, also referred to as Equivalent Continuous Sound Level, quantifies the average sound level over a designated timeframe (Namba & Kuwano, 1984).

Stereo sound recordings were simultaneously conducted using a TASCAM DR-05x digital sound recorder positioned at the same height above ground level. Programmed to record at a 44.1 kHz sampling rate, the recorder captured 24-bit uncompressed WAVE audio files through its built-in omni-directional microphones. These audio files were analyzed in R statistics software (*R: The R Project for Statistical Computing*, 2024), using the seewave and soundecology packages (LJ Villanueva-Rivera, 2013; SUEUR et al., 2008) to compute the Acoustic Complexity Indicator (ACI).

Noise modeling and noise mapping

A detailed cartographic representation of the college campus was essential. We collected structural information, including building height and exact locations, as well as details about vegetation. Additional data on road type classification, surface conditions, and width were gathered to create accurate noise maps.

Following the CNOSSOS-EU road traffic noise model guidelines (Kephalopoulos et al., 2012), vehicles entering the campus were counted and categorized. A researcher manually collected traffic flow data at a strategically chosen location for one hour (Figure 1). Using the CadnaA noise prediction and noise mapping software, noise maps were created (*CadnaA – State-of-the-Art Noise Prediction Software - Datakustik GmbH*, 2024). The specific approach considers the digitized roads as sources of noise and the digitized urban structures (buildings) as obstacles. Therefore, traffic flow data were assigned for each road. This included counting light vehicles, medium-heavy vehicles, heavy trucks, and two-wheelers (Kephalopoulos et al., 2014; Khan et al., 2021) simultaneously with the other data collection activities during each measurement period.

Results and discussion

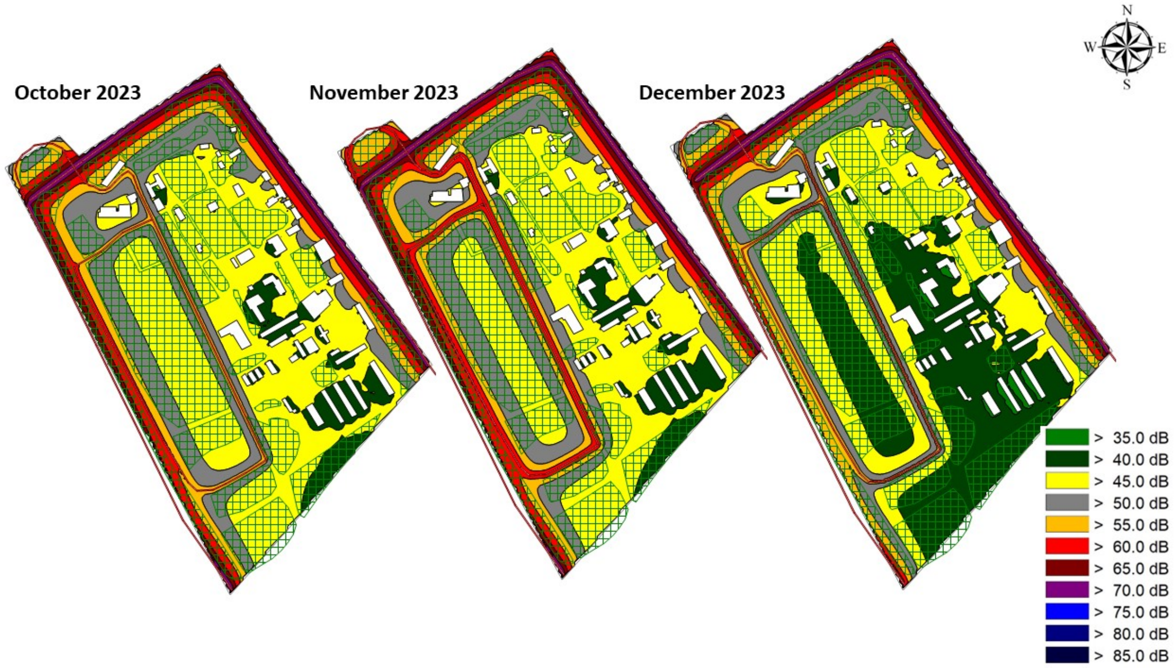
The manual traffic count and categorization revealed a fleet of vehicles using both the local road within the college campus and the major road surrounding it. As shown in Table 1, the total number of vehicles and the percentage within each category fluctuate during the measurement periods. As anticipated, the local road is used to a lesser extent during December.

Table 1. Vehicles counted and categorized during the three months of measurments

October 2023					
Local Road	**N**	Percentage	**Major Road**	**N**	Percentage
Light Vehicles	25	66%	Light Vehicles	155	34%
Heavy Vehicles	2	5%	Heavy Vehicles	120	26%
Heavy Trucks	1	3%	Heavy Trucks	55	12%
Motorcycles	10	26%	Motorcycles	130	28%
Total	**38**	100%	Total	**460**	100%
September 2023					
Local Road	**N**	Percentage	**Major Road**	**N**	Percentage
Light Vehicles	29	60%	Light Vehicles	160	39%
Heavy Vehicles	5	10%	Heavy Vehicles	95	23%
Heavy Trucks	1	2%	Heavy Trucks	40	10%
Motorcycles	13	27%	Motorcycles	120	29%
Total	**48**	100%	Total	**415**	100%
December 2023					
Local Road	**N**	Percentage	**Major Road**	**N**	Percentage
Light Vehicles	5	45%	Light Vehicles	155	36%
Heavy Vehicles	1	9%	Heavy Vehicles	90	21%
Heavy Trucks	0	0%	Heavy Trucks	35	8%
Motorcycles	5	45%	Motorcycles	150	35%
Total	**11**	100%	Total	**430**	100%

The total number of vehicles and the percentages of each category were the input variables of the road traffic noise model and the resulted noise maps. As it can be seen in figure 2, the obvious change in noise propagation is the result of traffic flow fluctuations.

Figure 2. Noise maps for the three periods of measurement as a result of traffic flow assessment



Tables 2, 3 and 4 showcase the descriptive statistics providing information on the mean and standard deviation of the resulting values, as well as measures of shape and symmetry of the distribution for both the L_{eq}, L_{min} and L_{max} noise indicators and also for the Acoustic Complexity Index.

Table 2. Descriptive statistics of the October 2023 measurement period

Descriptives October 2023						
	Min.	*Max*	*Mean*	*SD*	*Skewness*	*Kurtosis*
L_{eq}	47,7	62,5	54,4	5,0095	,429	-,171
L_{min}	43,1	50,3	46,4	2,2353	-,061	,218
L_{max}	49,8	72	61,6	7,7146	-,362	-,511
ACI	956	2679	1328,4	686,40	1,765	1,405

Table 3. Descriptive statistics of the November 2023 measurement period

Descriptives November 2023						
	Min.	*Max*	*Mean*	*SD*	*Skewness*	*Kurtosis*
L_{eq}	46,6	63,4	56,1	5,6251	-,811	-,077
L_{min}	42,1	49,3	45,2	2,3900	,846	-,004
L_{max}	49,8	73	63,4	8,2210	-,849	-,328
ACI	975	2520	1304,1	532,79	1,744	2,223

Table 4. Descriptive statistics of the December 2023 measurement period

Descriptives December 2023						
	Min.	*Max*	*Mean*	*SD*	*Skewness*	*Kurtosis*
L_{eq}	49,3	66,3	59,3	5,7685	-,957	,112
L_{min}	42,3	51,2	47,1	2,7970	-,190	-,586
L_{max}	50,6	74,2	64,9	8,5654	-,938	-,278
ACI	950	2045	1302,8	488,7921	1,027	-1,210

As Figure 3 illustrates, the mean values of the noise indicators exhibit significant statistical differences, with the presence of outliers. In contrast, the ACI values measured (Figure 4) during each period show only a minor degree of statistical differences. This specific outcome serves as initial evidence that the acoustic communities and the acoustic characteristics contributing to complexity maintain stability over time, potentially emphasizing the sustainable approach of campus management.

Figure 3. Box-plots of the noise indicators measured for each period

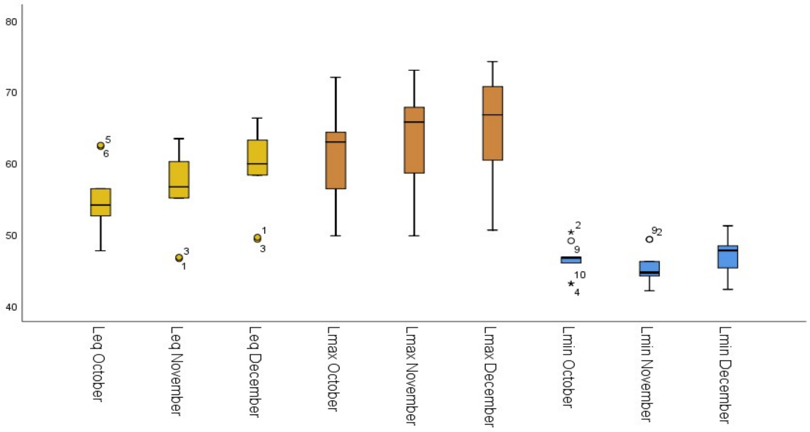
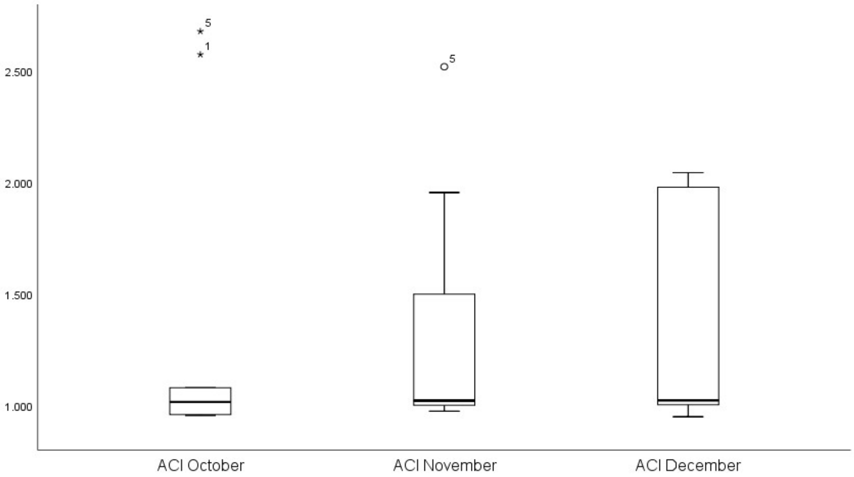


Figure 4. Box-plots of the Acoustic Complexity Index results for each period



Upon further analysis of the resulting indicators, an inverse relationship between the noise indicator Leq and the Acoustic Complexity Index (ACI) emerges across all periods. Specifically, a non-parametric Spearman rank-order correlation reveals significant negative correlations between these indicators in October (r = -.723, sig. = .018), November (r = -.915, sig. = .000), and December (r = -.912, sig. = .000). This inverse relationship has also been observed in various studies across a variety of soundscapes. Consequently, this result serves as additional evidence that noise adversely impacts the complexity of the sound environment, potentially leading to the deterioration of biodiversity.

Following the ISO 12913 guidelines the soundscape evaluation responses were analyzed, and radar plots were produced. As can be seen in figure 5, the perceived affective quality of the participants appears to be influenced by seasonality. More specifically, during the November measurement period the campus soundscape was perceived as pleasant and calm. During the month of October it was perceived as eventful and pleasant. Finally, during December it was perceived as monotonous, uneventful and calm. Such an outcome was expected as student activities on campus tend to decrease during December.

Figure 5. Radar plots showcasing the perceived affective quality of the campus soundscape

In Tables 2, 3, and 4, we observe a gradual increase in noise levels during the studied periods. Consequently, it is reasonable to assume that the elevated noise levels measured in December 2023 may have contributed to the development of a monotonous and uneventful soundscape.

Conclusions

In conclusion campuses have the potential to provide a healthy sound environment, a positive soundscape and contribute to sustainability.

By introducing soundscape indicators sustainable design practices will be reinforced. Furthermore, the inverse relationship between noise and acoustic complexity introduces a novel concern and a new assessment endpoint to be considered in urban planning. Incorporating metrics such as acoustic complexity will re-establish environmental sustainability efforts within noise control strategies.

Rather than a singular focus on noise reduction, the creation of diverse, captivating, and complex soundscapes should be prioritized. Looking ahead, localized smart solutions that promote long term sustainability co-benefits emerge as pivotal considerations.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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