DOI: 10.61782/fa.2025.0337

FORUM ACUSTICUM EURONOISE 2025

EMERGENCE OF INDOOR SOUNDSCAPE STUDIES FOCUSING ON NOISE MITIGATION: A BIBLIOMETRIC REVIEW

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ABSTRACT

Soundscape methodologies are increasingly recognised as effective approaches to address noise-related challenges. This study presents a bibliometric analysis of soundscape research focusing on the emerging domain of indoor soundscapes. Data were retrieved from the Scopus database using the keywords: "noise" AND ("noise barrier*" OR "noise control*" OR "noise reduction") AND "soundscape". After applying inclusion and exclusion criteria, 188 documents were selected for analysis, which included trend analysis, keyword co-occurrence mapping using VOSviewer (v1.16.19), and distribution analysis of indoor soundscape studies across different settings. Results show a notable growth in publication activity beginning in 2010. The highest number of studies was recorded in 2014 (n = 16), and citations peaked in 2016 (n = 518). Keyword analysis reveals that indoor soundscape remains an emerging topic, represented in only three papers (5.4%), mostly linked to terms such as "health" and "well-being" without a direct connection to "soundscape" as the central term. Further analysis identified 23 studies directly addressing indoor soundscapes, with open-plan offices being the most underrepresented setting, with only one study, followed by commercial spaces (e.g., retail shops, restaurants, cafes), with two studies.

Keywords: *Indoor soundscape, Indoor Acoustic Research, Noise control, Bibliometric analysis, soundscape research trends*

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1. INTRODUCTION

Noise is considered one of the most widespread environmental pollutants, with the World Health Organization (WHO) and European Environment Agency (EEA) identifying it as a significant public health concern [1]. Exposure to community noise has been associated with hearing discomfort, cardiovascular issues, sleep disruption, reduced cognitive and work performance, and increased annoyance [2]. Traditional noise management in buildings has focused mainly on airborne and structural noise transmitted through building elements or generated by activities and operations within the building [3], with treatment approaches primarily aimed at reducing or isolating noise through physical interventions and active noise control systems.

Various standardised methods are available to evaluate noise reduction or isolation performance, such as sound absorption coefficient, transmission loss, sound transmission class, weighted sound reduction index, and weighted normalised impact sound pressure level [4], [5], [6], [7]. However, researchers have long questioned whether these objective parameters adequately reflect human perception of acoustic comfort [3]. This gap has prompted a shift towards more holistic, user-centred approaches to acoustic design, notably the soundscape approach.

Within this context, the present study is conducted as part of the INNOVA Doctoral Network, a collaborative research initiative that addresses noise challenges in encapsulated structures. This doctoral project, titled *"Noise Barriers with a Soundscape Approach,"* aims to extend the traditional concept of noise barriers by integrating soundscape principles with a focus on indoor applications. Rather than treating noise barriers solely as physical structures that block sound propagation, this project adopts a soundscape perspective to explore broader strategies that not only

reduce noise but also enhance how users perceive and experience the acoustic environment [8].

The soundscape concept bridges the divide between physical measurements and subjective experience by considering the perceptual and contextual dimensions of sound [9]. Defined by ISO 12913 as the *"acoustic environment as perceived or experienced and/or understood by a person or people, in context* [10]*,"* soundscape studies integrate both objective measurements and subjective evaluations [10], [11], [12]. This approach recognises that the impact of sound is not solely determined by its intensity but also by how listeners interpret and appraise it.

Over the past two decades, soundscape research has marked a significant shift in environmental acoustics, extending beyond traditional noise control engineering [13]. While early studies focused on urban and outdoor settings, recent years have seen growing interest in indoor soundscapes to address perceived acoustic quality in interior environments [3].

To explore the positioning of this emerging area, the present study conducts a bibliometric review of soundscape research applied to address noise-related challenges. The review includes a trend analysis to examine how the focus of publications has evolved over time, a keyword co-occurrence mapping to identify recurring concepts and relationships between research topics, and a distribution analysis to investigate how indoor soundscape studies are represented across different settings.

2. METHODS

This study employed a literature search to identify relevant publications for inclusion in the bibliometric review. All records were retrieved from the Scopus database using the following search query:

"noise" AND "noise barrier*" OR "noise control*" OR "noise reduction" AND "soundscape"

The search was conducted on January 28, 2025, resulting in an initial dataset of 264 documents. Subsequently, preliminary filtering was applied directly within Scopus by limiting the results based on subject area, document type, and language, which reduced the dataset to 199 documents. Further screening was performed by reviewing the titles and abstracts to assess their relevance, specifically focusing on studies addressing soundscape and noise control. After this screening process, 188 documents were identified and selected for inclusion in the bibliometric analysis. The document selection process is illustrated in Figure 1.

The dataset was manually analysed to identify trends and examine indoor soundscape studies across various settings. A keyword co-occurrence analysis was performed using VOSviewer (version 1.16.19) to visualise the network of authors' keywords. The full counting method was applied, where each keyword occurrence was counted equally. A minimum threshold of three keyword occurrences was set to refine the analysis and focus on the most significant terms. This approach produced a keywords network map highlighting the selected authors' keyword relationships and research clusters.

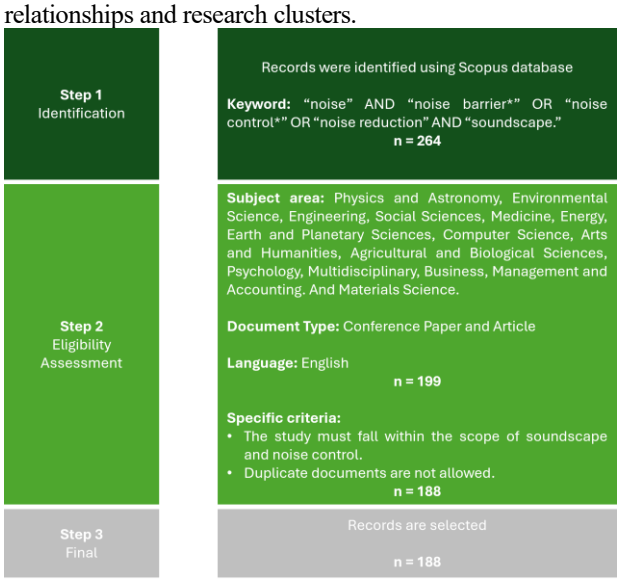

Figure 1. Study selection process

3. RESULTS AND DISCUSSIONS

This section presents and discusses the results of the bibliometric analysis, highlighting key trends, research clusters, and the distribution of indoor soundscape studies across various settings. These findings offer insights into the evolution and current state of research in the field.

3.1 Trends in Studies and Citations Over Time

The trend of soundscape research addressing noise issues shows a gradual increase in studies and citations over time, as illustrated in Figure 2. Early activity was limited, with only a few publications in the 1990s and early 2000s—for instance, just two studies appeared in 1993, and some years, such as 2001 and 2006, recorded only a single study.

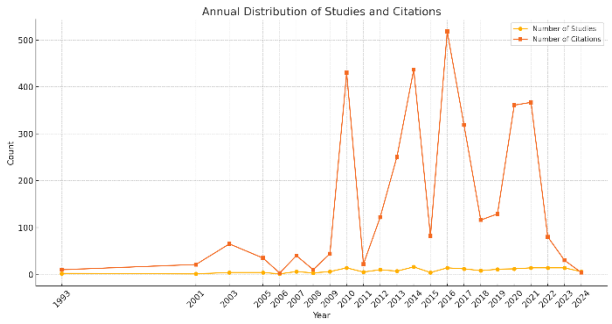

Figure 2. Annual distribution of studies and citations in soundscape and noise control research.

A noticeable rise began around 2010, when the number of studies reached 14, accompanied by 430 citations, marking a turning point in research interest. This upward trend continued, with 2014 standing out as the year with the highest number of studies (n=16) and 437 citations, indicating increased productivity and strong academic attention. The peak in citations occurred in 2016, with 518 citations across 14 studies, suggesting the presence of influential works that gained wide recognition.

The years 2017 to 2021 showed consistent research activity, with publication counts ranging from 12 to 14 studies per year and high citation levels, maintaining the visibility of the field. However, a decline is observed in the most recent data: while in 2023 sustained high output with 14 studies, citation counts dropped to 30, and in 2024, the number of studies decreased sharply to 6, with only four citations. This drop may reflect the limited time for newer publications to accumulate citations and the possibility that many 2024 studies have yet to be indexed or published.

3.2 Keyword Co-occurrence Analysis

This section presents a keyword co-occurrence analysis to explore the relationship between authors' keywords in soundscape research addressing noise issues. The analysis helps identify central themes, research clusters, and potential gaps in existing literature.

Figure 3 illustrates the network visualisation of each cluster, distinguished by colour coding. The colours used include red, green, blue, yellow, purple, light blue, orange, brown, and pink. In the keyword co-occurrence network, coloured circles represent individual keywords, with their node size corresponding to their frequency of occurrence. Keywords with higher frequencies appear with larger text and circles [14]. The bibliometric mapping of studies addressing noise challenges and innovative soundscape approaches yielded ten clusters, as shown in Table 1.

The central node, "soundscape", is the most frequently occurring term, underscoring its centrality in the analysed research. Closely related terms such as "noise", "environmental noise", "health", and "noise control" are prominently connected, reflecting their strong relevance to the field. Table 1 shows that the cluster with the fewest cluster occurrences is Cluster 9. However, its close proximity to the central node suggests that, despite its lower frequency, it holds significant conceptual relevance [15].

The next smallest is Cluster 7, whose relative distance "soundscape" highlights its position within an emerging subfield of soundscape research—distinct from outdoor or urban studies. This cluster centres on subjective evaluations, linking annoyance to perception and connecting health and well-being to environmental noise and control strategies. Notably, the keyword "indoor soundscape" is not directly linked to "soundscape" but instead connected through "health" and "well-being". This indirect pathway suggests a conceptual gap, indicating that indoor soundscape research has yet to be fully integrated into the broader soundscape discourse. Addressing this gap could help establish more holistic frameworks for designing health-supportive acoustic environments, particularly in indoor settings.

While limited in number, the three studies identified within the "indoor soundscape" theme provide valuable insights into how indoor soundscapes are perceived and evaluated. These works employ different methodological approaches—from experimental setups to qualitative inquiry and interventions using materials and active noise control—but share a common emphasis on subjective perception, acoustic comfort, and well-being.

- Lam, Bhan, et al. (2023) conducted an experimental study to assess the effectiveness of an anti-noise window using Active Noise Control (ANC) and biophilic maskers (birdsong and water sounds) in naturally ventilated urban dwellings. The findings revealed that ANC significantly reduced perceived loudness and annoyance, even with minimal objective sound level reduction. The addition of birdsong was more effective than water in further reducing annoyance, and perceptual metrics better predicted subjective comfort than by physical acoustic data alone [16].

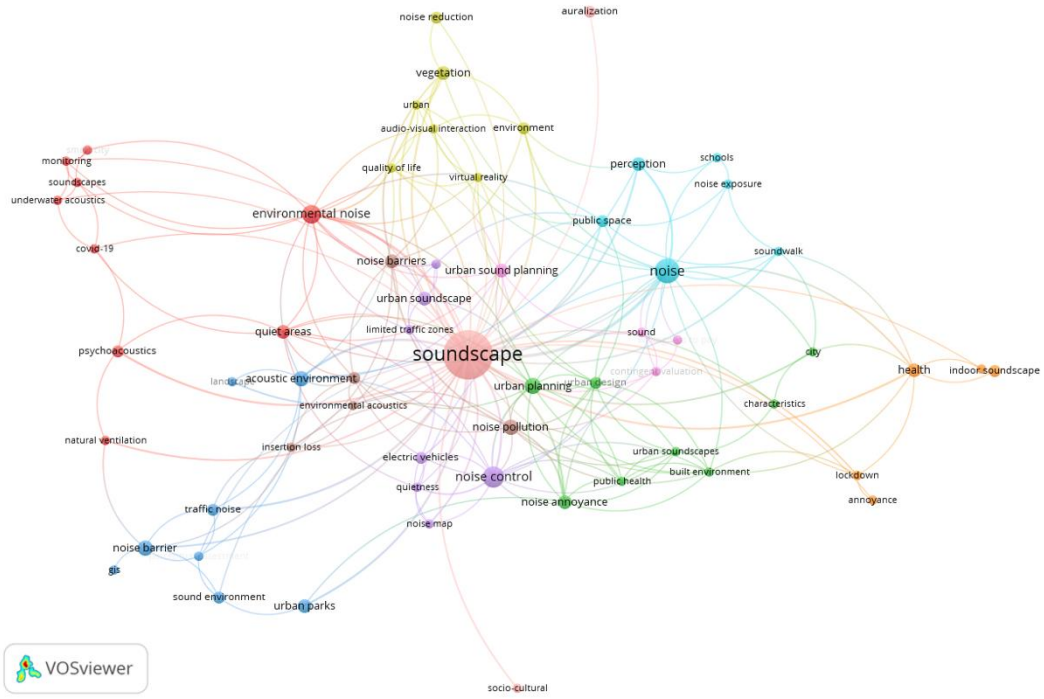

Figure 3. Keywords Network Visualisation

Table 1. Keyword Clusters Identified from Co-occurrence Analysis

Cluster	Keywords	Occurrence (%)
Cluster 1	covid-19, environmental noise, monitoring, natural ventilation, psychoacoustics, quiet areas, smart city, soundscapes, underwater acoustics	11.3%
Cluster 2	built environment, characteristics, city, noise annoyance, public health, urban design, urban planning, urban soundscapes	9.6%
Cluster 3	acoustic environment, GIS, landscape, noise barrier, perceptual assessment, sound environment, traffic noise, urban parks	10.4%
Cluster 4	audio-visual interaction, environment, noise reduction, quality of life, urban, vegetation, virtual reality	7.5%
Cluster 5	electric vehicles, limited traffic zones, noise control, noise map, noise perception, quietness, urban soundscape	10.4%
Cluster 6	noise, noise exposure, perception, public space, schools, soundwalk	10.8%
Cluster 7	annoyance, health, indoor soundscape, lockdown, well-being	5.4%
Cluster 8	environmental acoustics, insertion loss, noise barriers, noise pollution, soundscape design	6.7%
Cluster 9	contingent valuation, sound, urban sound planning, willingness to pay	4.2%
Cluster 10	auralization, socio-cultural, soundscape	23.8%

- Torresin, Simone, et al. (2020) employed a qualitative approach, using expert interviews to explore how user-centred acoustic design can enhance well-being in buildings. Their study identified perceptual dimensions of indoor soundscapes—spanning acoustic, visual, and thermal domains—and promoted the integration of soundscape-based methods into Post-Occupancy Evaluation (POE). They advocated a shift from noise elimination toward strategies that enhance positive sound experiences and increase user agency [17].
- Li, Feng, et al. (2022) presented a case study examining ceramic passive amplifiers as a design-based strategy for improving indoor soundscapes. Their results showed that these amplifiers enhanced pleasant sounds and contributed to multisensory comfort by combining visual and tactile elements. The study highlights that acoustic comfort improvements were influenced by sound level reduction, aesthetic coherence, and emotional resonance [18].

Collectively, these studies underscore the multidimensional nature of indoor soundscape research, demonstrating that soundscape quality is shaped not only by objective acoustic parameters but also by contextual, perceptual, and affective factors. This growing body of work supports the development of soundscape assessment frameworks that integrate both quantitative acoustic data and qualitative user experience—advancing more human-centred approaches to indoor acoustic design.

3.3 Distribution of Indoor Soundscape Studies Across Different Settings

A secondary screening was conducted from the 188 studies included in the main analysis to further understand the contextual scope of indoor soundscape research. This step involved selecting studies whose content directly addressed indoor soundscapes, resulting in 23 studies.

Figure 4 displays the distribution of these 23 studies across different indoor settings. The most commonly identified category was general indoor setting (n = 5), which includes studies that explored indoor soundscapes without specifying a particular type of space.

This is followed by residential, educational settings (e.g., schools, universities, libraries), and vehicle-related environments, each with four studies. The hospital category accounts for three studies, while commercial spaces (such as retail shops, restaurants, or cafés) are represented by two studies. Open-plan offices were the least represented, with only one study included. Further exploration of existing soundscape assessments and the factors involved has been conducted through a systematic review carried out by the authors [19].

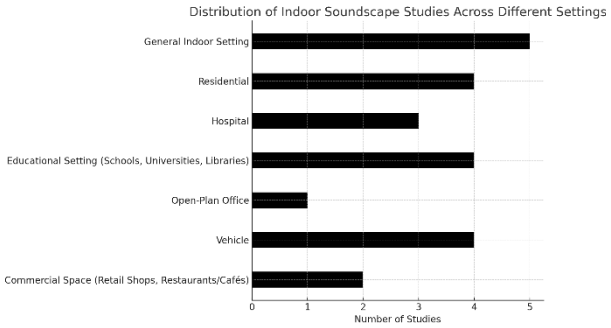

Figure 4. Distribution of Indoor Soundscape Studies Across Different Settings.

The distribution indicates that indoor soundscape research has been applied across various settings with varying degrees of attention. While some environments have received more focus, others—particularly office and commercial spaces—appear underexplored in the existing literature. This suggests potential directions for future research, especially in contexts where sound environments may significantly influence user experience and activity.

4. CONCLUSION

This bibliometric review examined indoor soundscape as an emerging topic in soundscape research, increasingly recognised for its potential to address noise-related issues. Research trends show a notable rise in interest beginning around 2010, marked by an increase in both publications and citations (n = 14 studies, 430 citations). Research productivity peaked in 2014 with 16 studies and 437 citations, while 2016 recorded the highest citation count, with 518 citations across 14 studies. From 2017 onward, research activity remained steady. However, a noticeable decline was observed in 2023, when citations dropped to 30 despite a consistent output of 14 studies. In 2024, the number of publications and citations further declined (n = 6 studies, 4 citations). This decrease may reflect the limited time for newer studies to gain recognition or delays in indexing.

Keyword occurrence analysis further confirms the status of indoor soundscape as an emerging area. The term appeared in Cluster 7 alongside annoyance, health, and well-being, with the second-lowest occurrence rate (5.4%). The “indoor soundscape” node was not directly linked to

the central "soundscape" node but connected through health and well-being. This suggests a conceptual gap and indicates that this area has yet to integrate into the broader soundscape discourse fully. Only three documents represented this node, emphasising the multidimensional nature of indoor soundscape research, which considers both acoustic parameters and contextual, perceptual, and affective factors.

Finally, the distribution of indoor soundscape studies across settings reveals limited exploration in open-plan offices and commercial spaces, represented by only one and two studies. This highlights a research gap and the need for further investigation in these underrepresented environments.

5. ACKNOWLEDGMENTS

This research was supported by the UK Research and Innovation (UKRI) under the IN-NOVA project, Active reduction of noise transmitted into and from enclosures through encapsulated structures (Project reference: EP/X027341/1). The authors gratefully acknowledge this support.

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