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Urban Blue-Green Spaces and tranquility: a comprehensive review of noise reduction and sensory perception integration

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ABSTRACT

Urbanization has led to a significant increase in noise pollution, severely impacting the psychological well-being of urban dwellers. This review critically evaluates the effectiveness of urban blue-green spaces in mitigating noise pollution and enhancing tranquility experiences. Initially, this study utilizes CiteSpace visualization software for bibliometric analysis to scrutinize the current research landscape and pinpoint emerging trends. We systematically searched the Web of Science (WoS) database with the following parameters: Topic = (("noise" OR "tranquility") AND ("soundscape" OR "green space" OR "blue space" OR "blue-green spaces")), 2015 to 2024. Through meticulous screening, 1504 articles were selected as the final research sample. We discuss both subjective and objective methods for assessing tranquility, and we categorize and thoroughly review the various factors influencing perceptions of urban tranquility. These factors include the interplay between natural and anthropogenic soundscapes, the authenticity of visual environments, and the unique auditory characteristics of human activities. Additionally, our review highlights the pivotal role of individual behavioral propensities and cultural frameworks in crafting tranquility experiences, and proposes a shift from reactive noise prevention to proactive tranquility exposure research. The insights provided here lay a foundation for future academic exploration and offer practical guidance for planning and management of blue-green infrastructure.

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KEYWORDS
Tranquility; soundscape; urban blue-green spaces; acoustic environmental perception

1. Introduction

Urbanization has driven the rapid expansion of transportation, construction, and social activities, leading to an increase in noise pollution, which is now widely recognized as a significant environmental contaminant (Europe 2018). This pervasive noise can severely impact mental health, precipitating psychological anxiety, and perceptual and emotional-behavioral disturbances (Araújo Alves et al. 2020; van Kamp et al. 2020). In recent years, noise has been acknowledged as influencing health, biodiversity, economic conditions, aesthetics, and educational outcomes (Miller 2008; Votsi, Kallimanis, and Pantis 2017). Tranquil spaces, as vital environmental resources, have shown efficacy in mitigating noise pollution and enhancing the quality of life and well-being of residents (Shepherd et al. 2013). Exposure to such tranquility not only alleviates fatigue but also diminishes stress, fostering a state of comfort and mental ease (Hunter et al. 2010). Consequently, an increasing number of national organizations are prioritizing the planning and design of quiet zones and formulating associated related management policies (Hewlett et al. 2017; Watts 2017).

The Environmental Noise Directive (END 2002/49/EC) marked the European Union's inaugural policy to explicitly delineate quiet zones. According to the directive, a quiet zone is an area free from disturbances caused by traffic, industrial, or recreational noises. However, the interpretations of what constitutes a quiet zone vary significantly (Pheasant et al. 2008; Shepherd et al. 2013). Tranquility, inherently subjective, is a subjective experience that cannot be fully captured by sound pressure levels alone, as these measurements do not adequately reflect the perceptual quality of tranquility. From a subjective standpoint, Herzog and Bosley (1992) describe tranquil environments as places that "encourage relaxation, inner peace, and freedom from life's stresses." The concept of tranquility is fundamentally composed of two elements: pleasantness and a sense of tranquility itself (Watts and Pheasant 2015). Prior research has pinpointed two critical factors influencing tranquility perception: the level of anthropogenic noise, predominantly from traffic, within the soundscape, and the proportion of natural elements within the visual environment. This understanding has led to the

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development of the Tranquility Rating Prediction Tool (TRAPT), a pragmatic approach for evaluating tranquility (Pheasant et al. 2008). Collectively, these studies underscore that a synthesis of objective acoustic measurements and subjective perceptual assessments yields a more refined understanding of tranquility perception.

Research on urban tranquility areas predominantly examines perceptions related to the acoustic environment, visuospatial elements, and geospatial characteristics (Yan et al. 2024). Acoustically, tranquility spaces are typically characterized by soundscapes enriched with natural sounds and minimal anthropogenic noise. Studies demonstrate a general preference for natural over man-made soundscapes, noting that natural sounds of varying acoustic properties can markedly influence tranquility perception, emotional intensity, and arousal, particularly in individuals with anxiety disorders (Ge et al. 2023). Furthermore, the presence of vegetation and wildlife is identified as a crucial element contributing to tranquility (Hu et al. 2021). Visuospatially, the perceived naturalness of a space (Watts and Marafa 2017) and landscape preferences significantly shape tranquility experiences (R. J. Pheasant et al. 2010). Audio-visual interplay also critically defines quiet zones, as the integration of auditory and visual stimuli can modify the focal point of sensory perception, thereby altering the conscious experience of soundscapes (Southworth 1969). Geospatial factors, such as the type, size, and location of spaces, also indirectly shape perceptions of tranquility (Yan et al. 2024).

Urban blue and green spaces play a pivotal role in delivering a range of ecosystem services, which can be broadly classified into provisioning, regulating, and cultural services. Provisioning services encompass essential needs such as food security, poverty alleviation, and access to clean water and energy. Regulating services include critical functions such as water and heat regulation (Liu et al. 2024), reduction in energy consumption, carbon sequestration (Dong, Xu, and Zhen 2023; Fan et al. 2022) air quality improvement, and climate regulation. Cultural services, meanwhile, provide a variety of benefits, including recreational opportunities, aesthetic value, and biodiversity conservation (Gupta and De 2024). As urbanization continues to accelerate globally, noise pollution increasingly affects a wider range of populations, highlighting the growing importance of tranquility as an essential ecosystem service. Urban blue and green spaces, a fundamental concept in urban planning and ecology, integrate diverse open space systems – comprising water bodies such as rivers, lakes, wetlands, and other natural and artificial water features, as well as green spaces like farmland, forests, and parks – within the national territory (Wang et al. 2025). These spaces, crucial for providing tranquility, serve as valuable ecosystem services by fostering tranquility zones through their noise attenuation capabilities and enhancement of positive soundscape experiences (Fang and Ling 2003; Van Renterghem, Botteldooren, and Verheyen 2012). The presence of natural sound sources in these areas significantly boosts perceptions of tranquility and emotional resonance (Liu et al. 2019).

Despite the breadth of Blue-green space elements impacting urban tranquility, systematic reviews in this domain remain scarce, underscoring a notable gap in the literature. Most existing reviews of urban tranquility perception have concentrated on the methodologies and indicators for assessing soundscapes (Kong and Han 2024; Li and Lau 2020; Nieto-Mora et al. 2023) as well as predicting soundscape experience (Lionello, Aletta, and Kang 2020). These reviews have explored the impact of audiovisual elements and their interactions on soundscape evaluations. Additionally, research emphasizing the positive health impacts of soundscapes suggests the potential for expanding soundscape methodologies into the fields of environmental and public health (Aletta, Oberman, and Kang 2018). The health benefits of urban blue and green spaces have been reviewed by many scholars (Labib, Lindley, and Huck 2020; Zhou et al. 2024), including aspects such as combating anxiety and depression (Bray et al. 2022) and cooling effects (Yu et al. 2020). However, there is no systematic review focusing on the benefits of tranquility in urban blue-green spaces. Bibliometric method refer to the quantitative analysis of the measurement data in the literature (Jing et al. 2024) and qualitative descriptions of scientific activities are also possible (Wang, Dai, and Xu 2022). However, few of the above studies have applied this methodology. Consequently, this review combines bibliometric analysis to thoroughly assess the existing research methodologies and evaluate the impact of blue-green spatial elements on the perception of tranquility in urban settings. Therefore, this study aims to: (1) analyze the current state and emerging trends in research on the tranquility benefits of urban blue-green spaces through bibliometric analysis; (2) based on these findings, clarify both subjective and objective methods for assessing tranquility and identify the key factors influencing urban tranquility perception through a detailed literature review; (3) discuss the process from tranquility perception to experience, highlighting the roles of individual behavior, contextual factors, and the physical environment, and provide insights for the planning and management of blue-green infrastructure.

2. Methods

2.1. Data sources

2.1.1. Search parameters

To explore the progression of soundscape research in the context of the rapid development of urban blue-green spaces and their influence on tranquility perception, we selected publications from the Web of Science (WoS) Core Collection as our primary data source. The publications in the WoS Core Collection are widely recognized for their high quality and global reputation, making them a reliable foundation for our research and ensuring that our findings are credible, universally applicable, and representative. Secondly, compared to other databases, the WoS provides more suitable data for CiteSpace analysis (Ding and Yang 2022), minimizing potential issues related to data integrity, such as corruption or missing fields, and thus safeguarding the completeness of Step 2 in Figure 1.

Once the data sources were confirmed, we designed specific retrieval strategies that balanced the breadth and accuracy of the coverage. his approach aimed to encompass all relevant literature on the topic while excluding unrelated studies. Moreover, the retrieval strategy was crafted to ensure that the selected articles focused on the environmental elements of blue-green spaces and their tranquility benefits. After several iterations, the final retrieval strategy was defined as TS = (("noise" OR "tranquility") AND ("soundscape" OR "green space" OR "blue space" OR "blue-green spaces")), with a time span from January 2015 to December 2024. The search was conducted as of 7 January 2025, and the article type was limited to "Articles." A total of 1,543 journal articles were retrieved.

2.1.2. Inclusion and exclusion criteria

Manual screening of retrieved articles is important to ensure the reliability and validity of the study. In this

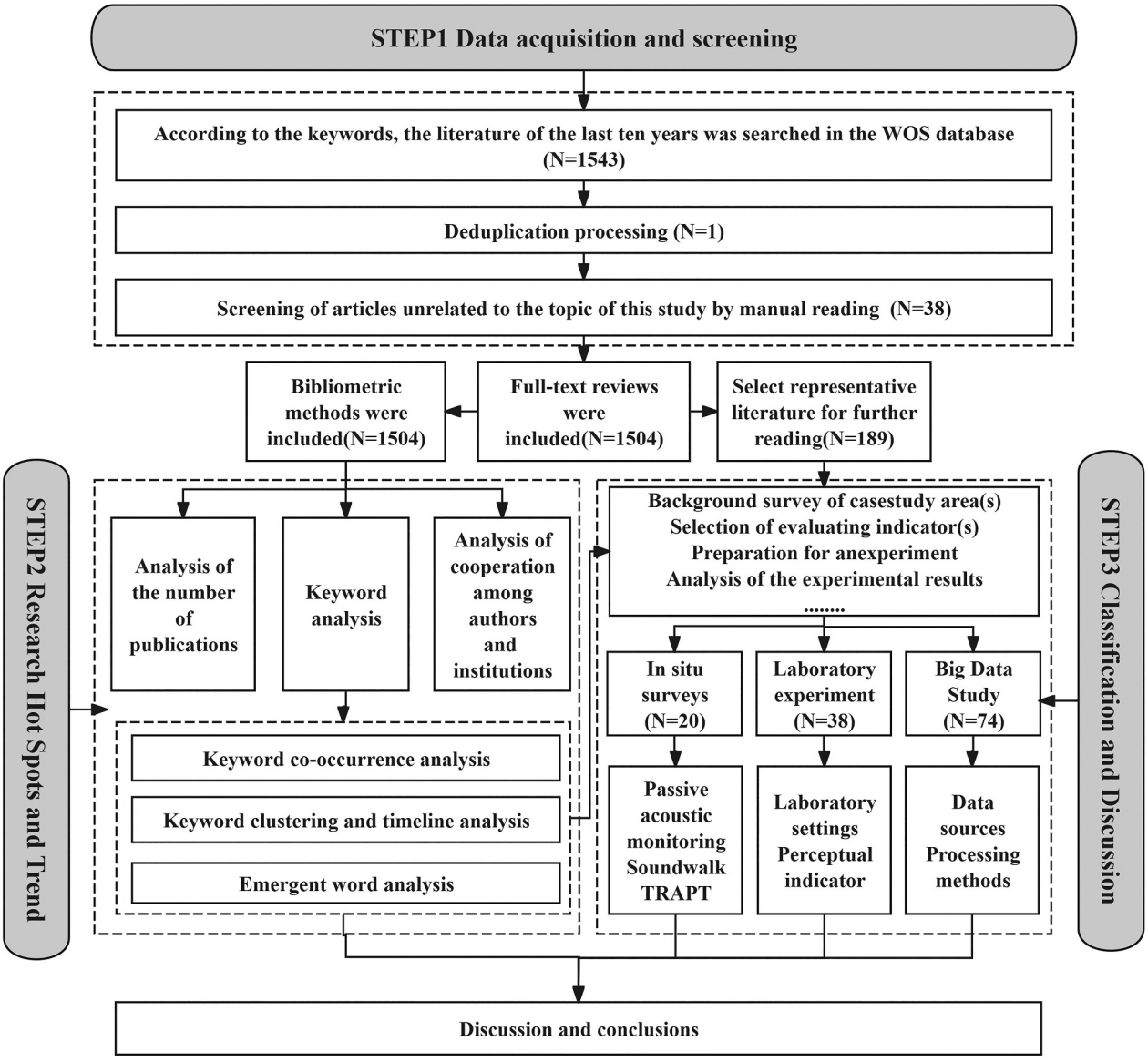


Figure 1. The framework of the research methods.

study, the retrieved articles were screened according to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) (Moher et al. 2009). Initially, duplicate articles were removed through a four-step process: "search", "primary screening", "inclusion", and "synthesis". Subsequently, three researchers read the titles, abstracts, and keywords of the retrieved articles to exclude book reviews, literature reviews, and other types of literature. The remaining articles were then manually examined to exclude those that were unrelated to the focus of this study, ensuring that all selected articles addressed the tranquility benefits of urban blue-green spaces. Furthermore, it was stipulated that the articles must include both blue and green elements, or at least one type of environmental element. Following this rigorous screening process, 1,504 articles were retained as the final research sample. The data filtering process is illustrated in Step 1 of Figure 1.

2.2. Data analysis and categorization

2.2.1. Review of systems supported by CiteSpace software

A bibliometric approach was employed in this study to analyze the research landscape. Two widely used bibliometric software tools are VOSviewer (van Eck and Waltman 2010) and CiteSpace developed by Chen (2004). While VOSviewer is useful for understanding the strength of collaborations and identifying frequently cited publications and journals, it is not the primary focus of this study. Instead, CiteSpace was selected due to its superior ability to uncover patterns, hotspots, and emerging trends in the field of research (Wu et al. 2025). The analysis was visualized and conducted using CiteSpace version 6.3.R1, covering data from countries, institutions, authors, and keywords. The parameters for CiteSpace were set as follows: time slices from January 2015 to December 2024, with each slice representing one year; and a selection criterion of the g-index, with a threshold of $k = 12$.

2.2.2. Literature categorization based on research object and setting

Utilizing CiteSpace, this study mapped the overall structure and dynamics of the research field. However, it also highlighted a gap in the in-depth interpretation of specific content and methodologies. To bridge this gap, representative literature that had high citation counts and strong relevance to the research topic was selected for further examination, based on the analysis of research trends and hotspots. The selected literature was categorized according to research focus and methodology. Key reference categories included the selection of research objects or study sites, choice of assessment indicators, experimental preparation, and evaluation of research outcomes. Based on these findings, the study discusses the methodological differences across various types of studies on the tranquility benefits of urban blue-green spaces, offering deeper insights into their results. Step 3 in Figure 1 illustrates the foundation and outcomes of the literature classification. The categorization was as follows: (1) Field investigation, which included passive acoustic monitoring, questionnaire survey, and serenity ratings; (2) Laboratory experiments and experimental environment design, which encompassed laboratory setups, and evaluation dimensions; and (3) Big data research, focusing on data sources and processing methods. Subsequently, the results from these studies were thoroughly analyzed and discussed, providing a nuanced understanding of each category's contributions to the field of urban tranquility and soundscape research.

3. Current status and trends

3.1. Keyword analysis

3.1.1. Keyword co-occurrence analysis

As shown in Figure 2 and Table 1, the keyword co-occurrence analysis revealed 229 nodes and 260 connecting lines with a network density of 0.01. The size of each node reflects the frequency of keyword occurrences, while the thickness of the connecting lines demonstrates the strength of the associations between keywords. Keywords with a centrality greater than 0.1 are deemed significant. In the context of urban quiet zones, 8 of the top 20 high-frequency keywords exhibited a centrality exceeding this threshold, including: quality, air pollution, perception, anthropogenic noise, ambient noise, landscape, physical activity, annoyance. These keywords anchor the primary research trajectories in the field, indicating enduring academic interest as evidenced by their sustained centrality and frequency over time. The pivotal research directions identified through this analysis encompass: (1) Tranquility perception: Investigating human responses to environmental factors such as green space and noise interference, focusing on their impact on mental health, stress alleviation, emotional regulation, and concentration enhancement; (2) Sound environment monitoring and assessment: Analyzing sound sources, propagation characteristics, and environmental influences, with an emphasis on forecasting acoustic trends; (3) Health risks of noise exposure and combined exposure to other environmental pollutants: Conducting quantitative assessments of the risks associated with noise and other environmental pollutants, guiding interventions for environmental and public health protection; (4) Noise control: Investigating noise origins, propagation dynamics, and mitigation strategies such as sound insulation, damping, and absorption to minimize the negative impact of noise on human tranquility.

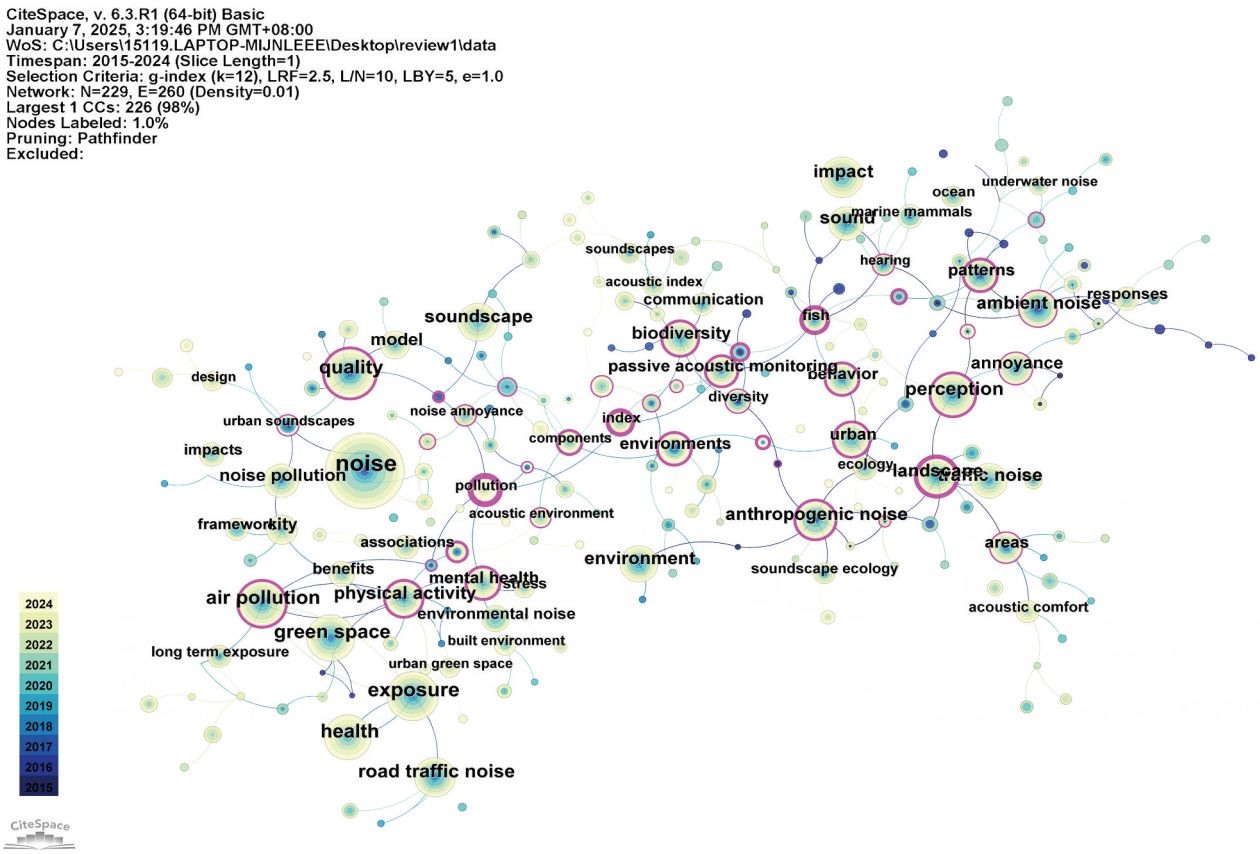


Figure 2. Keyword co-occurrence analysis.

Table 1. Keywords (top 20) with a centrality greater than 0.1.

Count	Centrality	Year	Keyword
162	0.23	2015	quality
138	0.21	2015	air pollution
127	0.26	2015	perception
102	0.26	2015	anthropogenic noise
102	0.18	2015	ambient noise
98	0.47	2015	landscape
95	0.35	2015	physical activity
83	0.1	2015	annoyance

3.1.2. Keyword clustering and timeline analysis

The log-likelihood-ratio (LLR) algorithm, implemented in CiteSpace software, is utilized for clustering keywords, focusing on the top 15 clusters. As depicted in Figure 3 each cluster is represented by a distinct color block. The numbering of clusters is inversely proportional to their size, with the largest cluster denoted as #0. There is also observable interlacing among cluster labels, which highlights the interconnections between related clusters. The modularity (Q) of the English literature clusters is 0.8194 (>0.4), and the silhouette score (S) is 0.9402 (>0.5). These metrics indicate a robust clustering structure, signifying well-defined, homogeneous clusters with high reliability within the analyzed corpus.

The keyword clustering analysis identifies several pivotal themes within the study of urban blue-green spaces and tranquility. #0 passive acoustic, monitoring as the largest clusters, are closely linked to #5 perceptual assessment and #7 quiet areas, indicating that the assessment and monitoring of the urban soundscape are fundamental to the study of urban tranquility areas. Acoustic indices aid in evaluating soundscapes and analyzing noise impact mechanisms. Acoustic monitoring technologies such as sound source localization, sound imaging, and noise monitoring are applied to the surveillance and integrated management of the urban soundscape, leading to the formation of urban noise maps, early warning systems for noise exceedance, and a variety of innovative noise control and management methods. #8 Acoustic design emphasizes the creation of high-quality auditory experiences through active acoustic strategies that effectively mitigate the adverse effects of noise. These methods include optimizing reverberation time, sound diffusion, and reflection. In contrast, themes such as #1 noise pollution, #12 mental health, and #4 noise exposure focus on the negative health impacts of noise. Noise exposure can disrupt an individual's psychological state, diminishing environmental tranquility. Prolonged exposure to noise is linked to heightened anxiety, irritability, and stress, which in turn impair cognitive functions. This disruption makes it difficult for individuals to accurately perceive and assess their environment, thereby hindering their ability to experience tranquility. On the other hand, attributes of urban green spaces, as identified by #2 and #3,

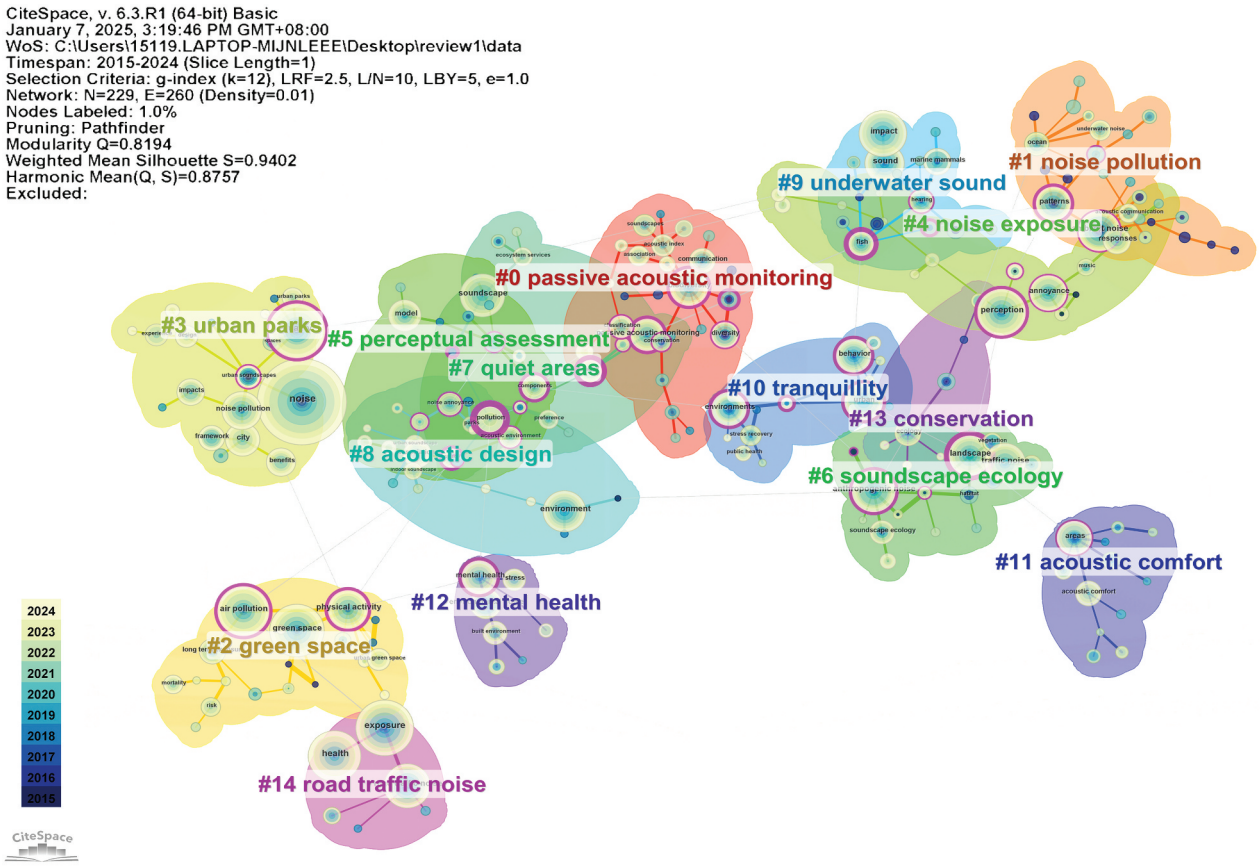


Figure 3. Keyword clusters.

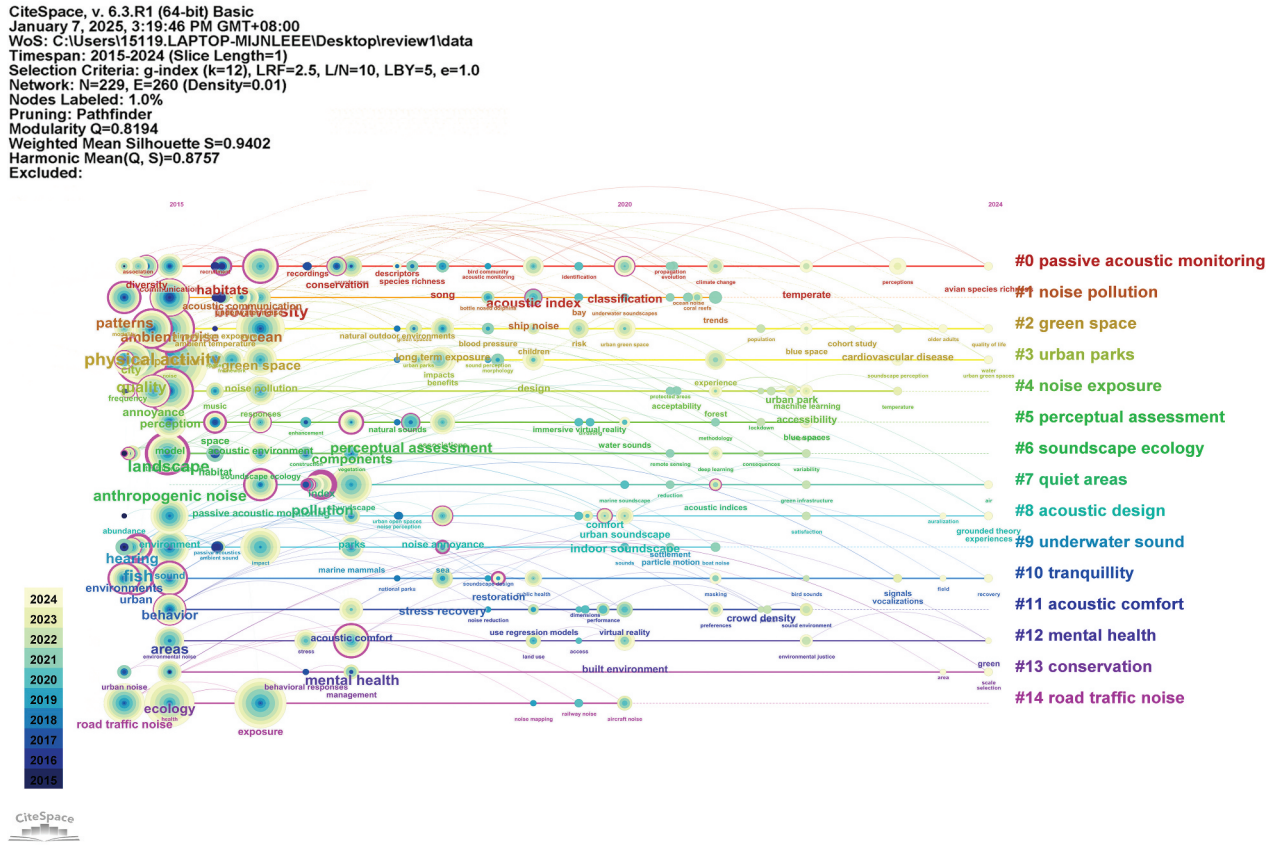


Figure 4. Keyword timeline analysis.

are frequently associated with positive contributions to urban tranquility perception. Urban parks, as key sites of tranquility exposure, improve urban environmental quality by establishing quiet zones and restorative soundscapes, which mask urban noise and mitigate its impact on biological communication. In addition to their tranquility benefits, the broader value of urban green spaces lies in their provision of multidimensional ecosystem services – an area of growing interest in research. #8 Soundscape ecology, a field that integrates acoustic principles and technological tools, plays a critical role in understanding the relationship between sound and ecosystems. By combining ecological and acoustic data, soundscape ecology contributes to enhancing environmental management and conservation strategies, with strong ties to #10 tranquility and #13 conservation. This discipline underscores the importance of preserving and restoring natural sounds, such as birdsong and flowing water, which are integral to tranquility. Furthermore, soundscape ecology emphasizes the reciprocal relationship between sound and human well-being, focusing on how soundscapes can strengthen the human-nature connection and provide restorative benefits.

A timeline analysis of keyword clustering conducted via CiteSpace provides insight into the evolving research hotspots and trends within the field revealing several keywords with persistent clustering that indicate ongoing research interest (Figure 4). Notably, the terms "passive acoustic, monitoring" (#0), "green space" (#2), and "tranquillity" (#10) exhibit the longest periods of clustering, underscoring continued examination of city soundscape monitoring and evaluation. The continued focus on "green space" (#2) and "urban parks" (#3) in particular demonstrates the importance of urban blue-green spaces for the perception of tranquility. Conversely, the clustering of "noise pollution" (#7) and"road traffic noise" (#8) suggests these topics were more prevalent earlier on, with a noticeable decline in related publications post-2020. This reduction could reflect the maturation of these research areas or a pivot towards newer, emerging topics within the field. In contrast, "mental health" (#12) and"conservation" (#13), though later entries into the research timeline, maintain a steady presence, signaling enduring academic and public interest. This shift in focus reflects a broader trend in contemporary research, which increasingly prioritizes human perception over mere physiological responses to noise, gradually moving towards a deeper exploration of psychological needs for tranquility.

3.1.3. Keyword bursts analysis

The analysis of emergent terminology related to the creation of urban quiet zones elucidates key terms and the evolution of research priorities within the field. Figure 5 presents 25 significant emergent terms, with "ambient noise," "urban soundscapes," and "urban noise" standing out prominently. Notably, "ambient noise" was a dominant focus from 2015 to 2017, and "urban soundscapes" sustained interest from 2015 to 2019, highlighting early innovative directions in studies on urban tranquility. The synthesis of this timeline analysis identifies 2015 and 2022 as critical years marking significant shifts in the research landscape. Around 2015, novel keywords such as "hearing," "diversity," "urban soundscapes," and "sound production" appeared. While these terms did not significantly increase publication volumes, they signaled emerging trends in the field. During this period, urban sound planning began to integrate acoustic considerations into the initial phases of urban planning. This approach represented a paradigm shift from traditional noise control strategies, incorporating soundscape analysis and naturalization techniques to enhance urban environments (Alves et al. 2015).

By 2020, new research hotspots such as "virtual reality","acoustic comfort," and "experience" have significantly influenced the development of urban quiet zones. Technological advancements in big data and computing have ushered in innovative methodologies and perspectives for exploring tranquility in urban settings. Developments in mobile and communication technology have revolutionized urban noise management, facilitating cost-effective strategies for sustained acoustic monitoring. Audio-visual soundscape mapping has significantly enhanced public engagement, providing a critical tool for urban sound planning. This technique has elevated sound management issues to a prominent position within community discussions and policy considerations (Lacey and Harvey 2011). Additionally, the social perception research paradigm introduces a novel approach to understanding urban tranquility zones. Residents' perceptions become an important basis for planning and designing blue-green spaces.

3.2. Analysis of cooperation network

From 2015 to 2024 (Figure 6a), Jian Kang emerged as the most prolific figure in the field, authoring 95 publications, significantly outstripping Francesco Aletta, who produced 39 papers. Kang's contribution extends beyond sheer volume; he has spearheaded the formation of multiple research teams and developed extensive collaborative networks that have broadened the scope of soundscape research. Conversely, despite his productivity, Aletta's research has not had a comparable impact on the field. Meanwhile, the research group led by Dick Botteldooren, which was once highly active, experienced a noticeable decline in output after 2020. Despite these collaborations, the analysis identifies a pronounced lack of connectivity between various

Top 25 Keywords with the Strongest Citation Bursts

Keywords	Year	Strength	Begin	End	2015 - 2024
ambient noise	2015	9.05	2015	2017	
urban soundscapes	2015	5.67	2015	2019	
patterns	2015	4.6	2015	2018	
sound production	2015	4.29	2015	2016	
diversity	2015	3.67	2015	2017	
urban noise	2015	3.62	2015	2018	
hearing	2015	3.18	2015	2016	
habitat	2016	6.01	2016	2017	
passive acoustics	2016	4.66	2016	2017	
space	2016	3.89	2016	2019	
habitats	2016	3.71	2016	2018	
vegetation	2017	4.99	2017	2020	
conservation	2017	4.41	2017	2018	
perceptual assessment	2018	4.36	2018	2021	
song	2018	3.39	2018	2019	
ship noise	2019	4.96	2019	2021	
virtual reality	2020	4.19	2020	2022	
experience	2021	3.83	2021	2024	
climate change	2021	3.74	2021	2022	
sound environment	2022	4.06	2022	2024	
urban park	2022	3.65	2022	2024	
acoustic comfort	2017	3.63	2022	2024	
risk	2020	3.62	2022	2024	
urban green space	2020	3.43	2022	2024	
comfort	2020	3.2	2022	2024	

Figure 5. Burst time map.

research networks, highlighting a prevailing issue of limited inter-team collaboration and a tendency towards reliance on intra-institutional partnerships, which may impede the integration and broader application of research findings.

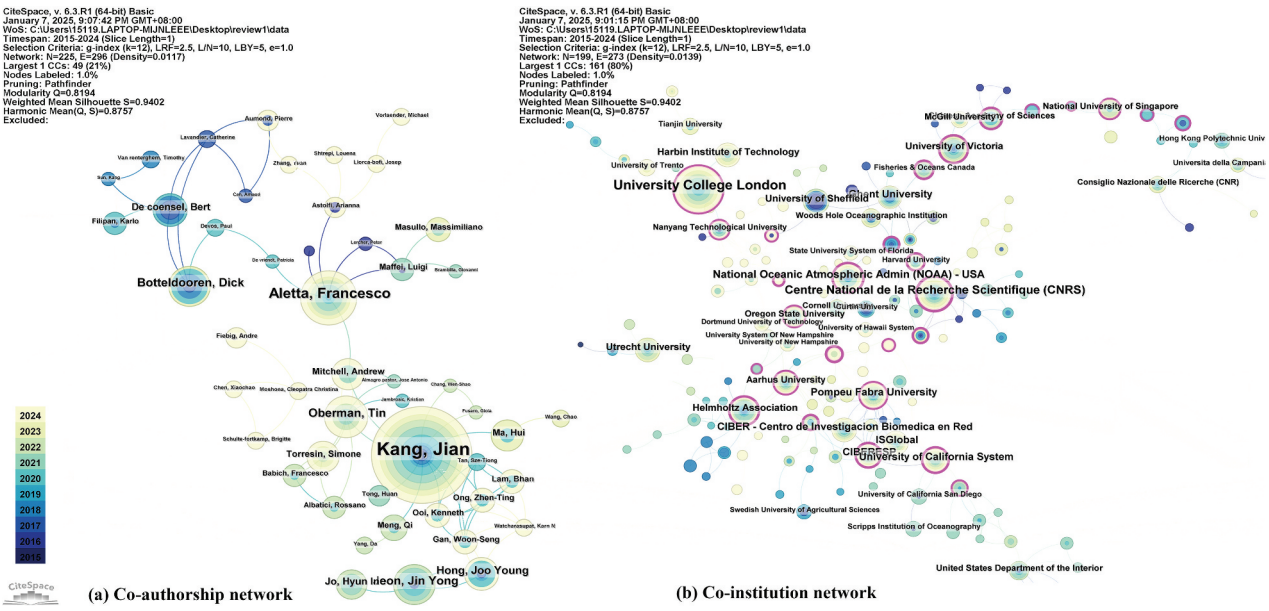


Figure 6. Co-authorship network and Co-institution network.

Over the past decade (Figure 6b), a review of scholarly output reveals that the leading institutions by publication count include University College London (UCL) (92), Centre National de la Recherche Scient fique (CNRS) (52), National Oceanic

Atmospheric Admin (NOAA) – USA (37), CIBER – Centro de Investigation Biomedical en Red(33), Ghent University(29), University of California(28), University of Sheffield(24), Harbin Institute of Technology (23), among others. The geographical distribution of these entities highlights a predominantly European collaborative cluster centered around the UK and France, alongside a US-centric network. The European cluster, spearheaded by UCL and CNRS, is characterized by a robust volume of internal publications but exhibits limited inter-institutional collaboration. In contrast, the collaborative network in US encompasses several large institutions that maintain extensive links with numerous smaller, interconnected entities, facilitating a broader scope of collaborative research efforts.

3.3. Volume analysis

As depicted in Figure 7 (a), our analysis indicates a notable increase in scholarly activity within this domain beginning in 2019, underscoring a dynamic and rapid expansion in the field. The volume of literature peaks between 2021 and 2022, then declines slightly before picking up in 2024.

Geographically, the distribution of research literature encompasses 79 countries and regions, with Figure 7(b) enumerating the top 30 contributors by publication volume. Collectively, these nations represent more than 80% of the total body of literature, with a significant concentration North America, Europe, and Asia. The U.S.A. leads the field in urban tranquility perception research, contributing 360 articles, which account for 23.4% of the total. Notably, U.S.A. exhibits low mediated centrality, suggesting a predominance of domestic research and relatively limited engagement in international academic collaborations. China follows with 273 publications (18.1%), while England holds the third position with 256 documents (17.1%). Canada, Germany, France, Spain and Italy each contribute approximately 5% to the global publication output. Countries ranked from the 20th to the 30th place each account for roughly 2% of the total publications.

4. In situ surveys

4.1. Tranquility evaluation methodology

4.1.1. Acoustic indices and quantitative description of urban soundscape

Acoustic indices are predominant tools in soundscape processing, widely recognized for their objectivity in urban tranquility perception studies (Turlington et al. 2024). Traditional urban sound assessments predominantly rely on objective noise quantification, typically measured through equivalent sound level parameters such as LA_{eq}, L_{day}, $L_{evening}$, L_{night}, and $_{Lden}$. However, these parameters alone may not sufficiently encapsulate the complexity of the soundscape (Raimbault and Dubois 2005). Additional metrics like Perceived Loudness of Individual Sounds (PLS), Perceived Occurrences of Individual Sounds (POS), Soundscape Diversity Index (SDI), and the Normalized Difference Soundscape Index (NDSI) are crucial for enhancing the quantitative description of urban soundscapes. Notably, the NDSI, sensitive to human interference, serves as a robust indicator for analyzing human-generated sounds in urban and peri-urban environments (Machado, Aguiar, and Jones 2017). Building

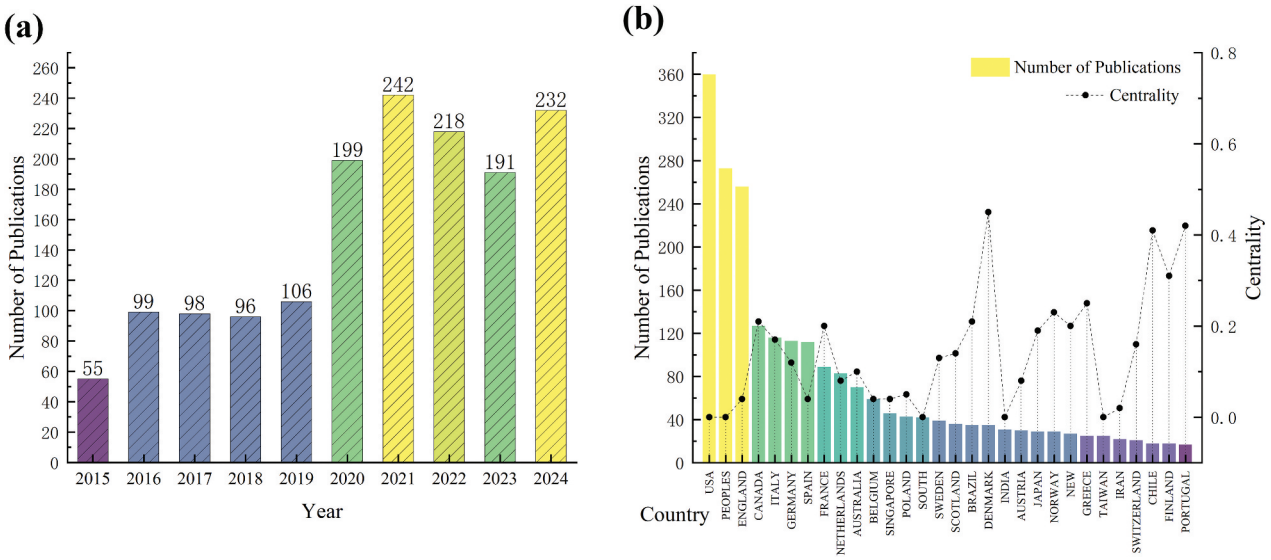


Figure 7. Number of publications by year and publication status by country.

on these methodologies (Xu, Feng, and Kong 2020), has conducted significant research into the potential impacts of anthropogenic noise on endangered species within nature reserve habitats.

4.1.2. Perceived tranquility: an integrated assessment from objective measurements to subjective experience

Human perception of noise is significantly influenced by the meaning attributed to the sound, which is dependent on both the noise source and the individual experiencing it (Raimbault and Dubois 2005). Soundwalks, a prevalent method in environmental acoustic studies, involve groups of participants following a predetermined route and assessing the soundscape quality via questionnaires designed to gauge detailed sound perception. These questionnaires typically include both closed questions, using a Likert scale, and open-ended questions to capture nuances in acoustic comfort, annoyance levels, and serenity perceptions. Moreover, R. R. J. Pheasant et al. (2010) developed the Tranquility Rating Prediction Tool (TRAPT) as a method to quantitatively assess tranquility. This tool objectively integrates audio and visual stimuli by combining A-weighted sound pressure levels with the proportion of Natural and Contextual Features (NCF) visible in the environment, applying a rating scale from 0 to 10 (Marafa et al. 2018). Research indicates that the maximum sound pressure level (LAmax) and the percentage of natural features are critical determinants of serenity (Yan et al. 2024). To address the complexity of the subjective soundscape perceptions, additional questionnaires are employed to ensure that the predicted tranquility levels align with actual experiences (Leereveld, Estévez-Mauriz, and Margaritis 2024). Furthermore, individual differences in noise sensitivity can also significantly impact tranquility perceptions, underscoring the need for personalized approaches in soundscape evaluations.

4.2. Tranquility perception in different scenarios of urban blue-green spaces

4.2.1. National parks

National parks preserve ecosystems of global and national importance. Yet, they face the challenge of noise pollution, which complicates efforts to balance development with the preservation of tranquility. Research into serenity perceptions within these parks is both groundbreaking and exemplary. A study across five major U.S. national parks demonstrated that air, ground traffic, and human noise significantly diminish serenity ratings, especially in scenic areas (Benfield et al. 2010). Further research in Sequoia National Park, located near military installations, suggested that providing educational information to visitors can increase their tolerance for noise (Taff et al. 2013). New Zealand national parks have focused on wildlife's behavioral responses to noise. In Australia, research indicates that mechanical noises are especially bothersome to campers. Additionally (Xu, Feng, and Kong 2020), emphasized that the impact of anthropogenic noise on endangered black-necked cranes inhabiting national park offers valuable management insights. Collectively, these studies underscore the critical role of soundscape research in national parks, enhancing our understanding of both human and wildlife responses to noise.

4.2.2. Urban parks

Urban parks, as vital components of urban green space system, play a significant role in mitigating both the subjective and objective impacts of noise, attributed to their abundant vegetation and diverse landscape elements. (Szeremeta and Zannin 2009) examined four urban parks located near busy streets and discovered variations in noise levels based on the proximity of park boundaries to these streets. The findings indicated that traffic noise significantly degrades the soundscape quality within these parks. However, the presence of natural soundscape environments in urban parks also fosters greater tolerance to traffic noise, thereby diminishing its adverse effects (Taff et al. 2013). Further illustrating the variable responses to noise, a survey by (Tse et al. 2012) targeting individuals over the age of 60 revealed that vehicular noise exerted considerable stress on this demographic, reducing their acoustic comfort and highlighting age-related differences in noise tolerance (Tse et al. 2012). This underscores the nuanced perception of noise across different age groups. Research not only focuses on urban parks in general but also investigates how specific elements within parks influence soundscape quality. For example, Axelsson et al. (2014) found that the sound of water fountains in a central park in Stockholm significantly alleviated the negative perceptions of road traffic noise, enhancing the overall acoustic environment. Cohen, Potchter, and Schnell (2014) compared the effects of urban parks, city squares, and street canyons on air quality and noise in Tel Aviv, further elucidating the multifaceted role of urban parks in urban environments.

4.2.3. Vegetation zones

Vegetation zones, though smaller than national parks and city parks, play an essential role in mitigating road noise, particularly due to their proximity to highways. Scholars have extensively researched their noise-reducing effects. Early research by (Reethof 1973) highlighted that dense strips of trees and shrubbery could substantially reduce highway noise, with a noise reduction of 5 to 8 decibels (dB) for every additional 100 feet of planting depth. Subsequent studies have further

explored the characteristics of vegetation strips, including different plant species, planting depths, heights, lengths, ranges, and densities, to clarify their effects on traffic noise attenuation. For example (Kragh 1979), found that a 25-meter-wide mixed forest belt could decrease noise by 6 to 7 dB compared to open fields, corroborating (Reethof 1973) findings. However (Van Renterghem 2014), noted potential drawbacks of overly dense plantings, such as impaired growth quality of vegetation. He proposed rectangular planting schemes that balance growth quality with effective noise reduction, advocating for non-deep forest strips as an efficient solution for mitigating road traffic noise (Fang and Ling 2003). expanded this research by analyzing the noise reduction capabilities of 35 evergreen tree belts of a single species across different villages, demonstrating variability in effectiveness depending on the locale. Additionally, research in urban centers has also underscored the value of vegetation strips. Pathak et al. (2008) conducted studies in Varanasi, a tropical city, monitoring noise levels and evaluating the noise reduction capabilities of vegetation strips of varying widths and heights, affirming their significance in noise attenuation. Similarly (Wickramathilaka et al. 2022), investigated the statistical relationship between green zones and traffic-related vehicle noise in São Carlos, Brazil, further confirming the crucial role of vegetation zones in noise reduction.

Research has consistently emphasized the influence of blue and green spaces on tranquility perception. Leung et al. (2017) investigated how different landscapes, such as sea views, urban rivers, and greenery, affect the annoyance responses of high-rise apartment residents in Hong Kong, discovering that greenery serves as a more effective buffer against traffic noise annoyance compared to sea or urban river views. In another approach, Van Renterghem, Botteldooren, and Verheyen (2012) utilized three-dimensional Finite Difference in Time Domain (FDTD) calculations to assess how vegetation strips affect road traffic noise propagation, discovering that vegetation strips as low as 1–1.5 meters could match the efficacy of traditional noise barriers in noise reduction. Further contributing to the field, Aletta, Renterghem, and Botteldooren (2018) conducted a field study along a noise-exposed bike path surrounded by green space, which demonstrated that while greenery significantly enhances the positive perceptions of the soundscape, it has a limited effect on actual sound propagation. More recently, Liu et al. (2023) investigated the correlation between vegetation cover and noise reduction in Shenzhen, finding that a 1% increase in green belt vegetation cover could reduce noise levels by an average of 0.4 dB. This suggests that strategic increases in vegetation coverage in green belts could variably reduce traffic noise across different road classes. Overall, soundscape studies in both national and urban parks underscore that traffic and human voices are primary disruptors of tranquility. Globally, studies continue to highlight the critical role of soundscape management in preserving natural environments and improving urban life quality.

5. Laboratory research

5.1. Experimental methodology

5.1.1. Data collection methods for laboratory studies of urban tranquillity and noise reduction

Data collection for laboratory research in the field of urban tranquility and noise reduction typically encompasses both in situ and web-based acquisitions. In situ data collection environments are classified into artificial, semi-artificial, and natural settings. Artificial scenarios often include urban plazas, walkways, streets, and highways, where studies investigate a range of urban scales and their acoustic impacts. Semi-artificial settings such as urban parks, residential green spaces, street green spaces, and waterfront parks offer a broader array of audiovisual elements, resulting in a higher prevalence of studies in these environments due to their diverse sensory stimuli. In artificial settings, studies predominantly focus on the interplay between audiovisual elements on the sound environment, examining factors such as human soundscape preferences and the extent of noise annoyance. Conversely, natural settings, which include forest parks, coastal areas without traffic, and urban rivers, typically concentrate on exploring the interactions between the audiovisual components of the environment and their contributions to perceived tranquility and restorative benefits. This distinction underscores the varying impact of environmental contexts on soundscape perceptions and the effectiveness of noise mitigation strategies.

Concurrently, several scholars have leveraged internet data to gather experimental insights. The validity of online surveys has been affirmed in previous research, illustrating that audiovisual data collected via the web can be as reliable as that obtained in laboratory settings (Roth 2006). For instance, data from public resources such as the International Soundscape Database (ISD) have been utilized for constructing laboratory scenarios. Additionally, Liu, Hu, and Zhao (2019) have employed online questionnaires to ascertain tourists' soundscape preferences before conducting field studies. Compared to in situ collection, online data acquisition offers greater convenience, provides access to larger sample sizes, and allows for dynamic updates. Nevertheless, researchers must also consider potential data quality issues and the possible interference these might pose to experimental integrity.

5.1.2. Subjective and physiological indicators for the assessment of perceived tranquility in laboratory environments

In laboratory settings, the metrics for evaluating perception are divided into subjective perception metrics and physiological data metrics. Subjective data are predominantly gathered through questionnaires employing Likert scales, which enable subjects to express their perceptions and psychological responses to sound attributes. These responses are typically analyzed using the semantic differential method. The standard TS 12,913–2:2018 recommends simplifying evaluation dimensions to eight specific parameters, although adherence to this standard remains limited in extant research. Moreover, the Perceived Restorative Soundscape Scale (PRSS) and the Depression-Anxiety and Stress Scale (DASS) are utilized to evaluate the restorative potential of environments and individuals' anxiety levels, respectively. Additionally, some studies have explored the impact of soundscapes on task performance using cognitive tests.

Previous studies have indicated weak correlations between physiological indicators and subjective perceptions of soundscapes (Li and Kang 2019). Consequently, it is recommended to integrate physiological responses to achieve a more comprehensive assessment of serenity perception (Guo et al. 2022). Notably, changes in electrical skin activity (EDA) and heart rate (HR) are sensitive to external stimuli, reflecting physiological recovery effects (Hedblom et al. 2019). Skin conductance level (SCL) and high-frequency heart rate variability (HF HRV) are indicators of sympathetic and parasympathetic activation, respectively. Additionally, α- and β-EEG brainwave signals, associated with mood and stress levels, provide further insights into emotional states; an increase in α-EEG typically signifies relaxation, while an elevation in β-EEG correlates with active attention and either positive or anxious thinking (Fachner, Gold, and Erkkilä 2013). For instance, the restorative effect of α-EEG is more pronounced in environments dominated by birdsong compared to those affected by traffic noise (Li, Ba, and Kangz 2021). Eye-tracker metrics also contribute valuable data, measuring the subject's level of concentration and mental load (F. Liu et al. 2022). These findings collectively affirm that physiological indicators are reliable measures for reflecting human perceptions of tranquility in various environments.

5.1.3. Methods for simulating blue-green space in laboratory

Historically, still images and sound simulations were employed to assess the impact of urbanization levels depicted in images and the presence of various landscape elements on the perception of serenity (Hong and Jeon 2014; Viollon, Lavandier, and Drake 2002). Advancements in audiovisual recording and reproduction technology have significantly enhanced the fidelity of soundscape assessment tools. The evolution of audio equipment from basic cassette recorders to sophisticated devices capable of stereo and surround sound, including binaural recordings, has transformed auditory data collection. Similarly, the progression in visual presentation technology – from slide shows of film images to digital photos, videos, and eventually virtual reality (VR) technology – has greatly facilitated the accurate reproduction and manipulation of audiovisual environments in experimental setups (R. J. Pheasant et al. 2010). This technological advancement has enabled researchers to more precisely control and replicate audiovisual elements within urban waterfront spaces, for instance. By manipulating various degrees of artificiality in a virtual environment, studies have shown that natural waterfront spaces are perceived as more restorative (Liu et al. 2022). Additionally, some scholars have embraced a visually immersive approach to soundscape research, employing Immersive Virtual Reality (IVR) that allows for scene switching, control, and the deployment of questionnaires within a virtual reality setting. Others have explored Augmented Acoustic Reality (AAR) scene building to simulate the soundscape experience of walking through a woodland, effectively enhancing participants' recognition and knowledge of bird calls using natural soundscapes combined with sound walking methods (Lawton, Cunningham, and Convery 2020). Moreover, field experiments utilizing Mixed Reality Helmeted Display have investigated the effects of natural sound types, background traffic noise levels, and visual representations of the sound source (depicted as holograms) on soundscape attributes. Findings from these studies indicate that the introduction of natural sounds can significantly diminish the perceived loudness of traffic noise and enhance overall soundscape quality in real-world settings (Hong et al. 2021).

The advent of networked audiovisual AR environments heralds a shift toward more interactive and immersive approaches in future soundscape evaluations. The evolution of these technologies not only enhances the precision and dependability of soundscape analyses but also offers participants a lifelike experience that significantly influences their perceptions and evaluations of soundscapes. As VR and AR technologies continue to advance, they promise to revolutionize soundscape studies by enabling more thorough simulations and assessments of soundscapes in both natural settings and urban contexts, poised to yield deeper insights critical for urban planning and environmental design. Moreover, the integration of

these innovative technologies is likely to extend beyond traditional applications, finding new uses in education, entertainment, and healthcare. This expansion will open up novel pathways for research into soundscape perception, potentially transforming how auditory environments are studied and understood.

5.2. Influence of blue-green space on the perception of tranquility

5.2.1. Perceived tranquility of waterfronts

Hydroacoustic play a critical role in enhancing urban soundscapes, with their effectiveness influenced by the morphology and extent of water bodies. Studies have demonstrated that waterfronts with irregular perimeters, such as ocean fronts and promenades, are associated with higher soundscape ratings (Puyana Romero et al. 2016). The levels of water sounds not only impact affective states and provide anxiety relief but also influence heart rate variability, with louder water sounds generally deemed more beneficial for regulating the autonomic nervous system (Hsieh et al. 2023). Variation in sound type and proximity to water sources also significantly affect soundscape perception. For example, the presence of children's playful sounds near water features enhances acoustic comfort, whereas traffic noise proximate to these areas tends to diminish it (Ren and Kang 2015). Furthermore, the perception of tranquility in natural waterfront spaces has been found to surpass that in semi-artificial or fully artificial environments (Liu et al. 2022). The congruence of audiovisual elements also plays a moderating role in perceptions of waterfront soundscapes, with sounds linked to human activities in artificial settings often preferred over those in natural landscapes.

5.2.2. Effects of bimodal stimuli on tranquility perception

Both auditory and visual environments significantly shape an individual's overall perception of their surroundings, suggesting that the human experience of tranquility involves a complex interaction between visual and auditory stimuli from everyday environments (Pheasant et al. 2010). Studies have developed regression models incorporating both audiovisual elements and individual soundscape and landscape components, finding that models including both visual and auditory elements exhibit greater explanatory power than those considering only single sensory modalities (Liu et al. 2022). Visual stimuli, particularly those from urbanized environments, tend to negatively influence sound ratings, highlighting the impact of visual context on soundscape perceptions (Hong and Jeon 2014; Hong et al. 2020; Viollon, Lavandier, and Drake 2002). Conversely, auditory stimuli can also affect visual perceptions; for instance, noise from urban infrastructure is known to exacerbate visual annoyance (Ruotolo et al. 2013). Interestingly, visual improvements are more pronounced in artificial waterfront spaces, while auditory perceptions tend to be more favorable in less modified environments (Liu et al. 2022). Regarding the mitigation of ambient noise, several studies have demonstrated that vegetation-covered barriers not only enhance the overall environmental quality but also bolster the performance perception of noise barriers. In contrast, industrial barriers are typically perceived as more unpleasant, and this perception intensifies with escalating noise levels (Hong and Jeon 2014; Liu et al. 2022; Maffei et al. 2013).

5.2.3. Restorative benefits in urban blue-green space

"Restorative environments" are defined as settings that aid an individual's recovery from daily cognitive fatigue, negative emotions, and stress, with urban green spaces, especially parks, often highlighted for their restorative potential due to their enhanced naturalness (Payne 2013). Natural soundscapes, recognized as vital ecosystem services, play a crucial role in alleviating stress, enhancing cognitive function, and fostering positive emotions (Francis et al. 2017). Studies indicates that biodiversity-rich green spaces, resonant with biological sounds such as birdsong, not only enhance the acoustic quality but also increase the ecological resilience of these areas (Ratcliffe, Gatersleben, and Sowden 2020). Furthermore, natural sounds like wind are associated with greater calmness and pleasure compared to anthropogenic noises such as mechanical sounds and human voices (Hedblom et al. 2017). The perception of soundscapes is also affected by factors like the natural environment's characteristics, the presence of people, and the duration of engagement with the space. Importantly, the correlation between sound levels (both subjective and objective) and perceived restorative benefits is not linear, suggesting complex underlying dynamics (Payne and Bruce 2019). Additionally, individual differences such as gender, age, and specific stress relief needs significantly modify how soundscapes are experienced (Gao et al. 2023; Zhu and Chen 2023).

Similar to green space, blue space is recognized as restorative environments and vital public resources. Water sounds can mask urban noise by taking advantage of their distracting effect as "wanted" sounds (Watts et al. 2009). The restorative benefits of soundscapes in blue spaces are significantly influenced by the type of water sound, its loudness, and the congruence between audiovisual elements. The synergy of audiovisual components plays a crucial role in the

restorative quality of blue space soundscapes, with higher decibel levels of water sounds evoking emotional responses, whereas lower decibels are more effective in soothing emotions and alleviating anxiety (White et al. 2010). Further research indicates that waterfront soundscapes with a higher degree of naturalness are more conducive to mental restoration (Han, Kang, and Meng 2023). However, the restorative impact of natural sounds does not invariably surpass that of silent environments; the specific content of the sounds can modify mood dynamics (White et al. 2010). Additionally, the method of reproducing audiovisual environments in laboratory settings impacts subjects' perceived restorative gains. The use of static images and sounds has been shown to evoke greater physiological comfort and subjective restrictiveness, providing valuable physiological insights into the perception of tranquility (Li, Xie, and Woodward 2021).

6. Big data

6.1. Research methodology

6.1.1. Innovation from offline to online and participatory perception

Data within this study are categorized based on their source of collection into two primary types: offline and online collection and crawling; and further differentiated by the collector as either official or unofficial. Offline data collection primarily encompasses objective sound data, with some studies also integrating visual data (Zhao et al. 2023). In contrast, online data collection primarily focuses on social perception data and geographic information data, often enriched with horizontal real-time data such as cellphone signaling and real-time traffic data (Bonet-Solà et al. 2021).

When official data are inaccessible, participatory sensing (PS) emerges as a vital method for data acquisition, leveraging mobile devices and cloud services to collect acoustic data (Li, Liu, and Haklay 2018). Offline data collection often employs sound level meters and smartphones, which are instrumental in soundscape research that requires temporal and spatial mapping. In scenarios where numerous sound level meters must be deployed, it becomes essential to utilize meters equipped with positional coordinates or to pre-record the spatial coordinates of these devices. In the study by (Hernandez-Jayo and Goñi 2021), a real-time, continuous urban soundscape map was created using low-cost sound level meters mounted on shared bicycles, demonstrating an innovative approach to urban sound monitoring. To mitigate the costs associated with constructing urban sound monitoring networks, researchers have begun exploring the development or adoption of more affordable sound level meters. Initiatives include the creation of sound detection devices using less expensive materials and low-accuracy sensors (Karlsson et al. 2021; Celestina, Kardous, and Trost 2021), which represent significant advancements in cost-effective environmental sound recording technology.

Recent studies have demonstrated the potential of using portable smartphones equipped with software to effectively capture sound information by collecting real-time GPS and sound data (Alvares-Sanches, Osborne, and White 2021; Brambilla and Pedrielli 2020). However, employing smartphones for sound data collection presents several challenges. Firstly, privacy concerns may restrict the temporal and spatial parameters of data collection. Secondly, the presence of background noise in the recordings can compromise the accuracy of the data. Thirdly, variations in the microphone sensitivity across different smartphone models can affect the precision of sound pressure level measurements, necessitating calibration, especially for recording high-frequency sounds. Lastly, inconsistencies in how smartphones are carried or positioned can introduce errors in location data (Zipf et al. 2020).

Online data collection in soundscape studies primarily involves comment data crawling, public voice databases, and geographic information systems, where comment data sourced from social media posts with location tags or geographically relevant information are aggregated using machine learning techniques to manage their volume and complexity (Gasco et al. 2019). Subsequently, text detection and dictionary construction are employed to identify content related to sound characteristics, typically through automated machine recognition processes. This review data generally comprises details about sound intensity, sound type, location, and perceptual evaluations, providing a rich source for preliminary spatial-temporal sound analysis. However, the subjective nature and uneven spatial distribution of this data can pose limitations, particularly in small-scale or highly localized studies. Public sound databases feature data actively measured and uploaded by individuals using smartphone applications, enhancing data authenticity and relevance. Popular tools for this purpose include Noise Tube, Noise Map (Schweizer et al. 2012), and Noise Capture (Picaut et al. 2019). Furthermore, some researchers develop bespoke data collection and uploading software tailored to specific study objectives, such as Noise Tube and Noise Spy (Kanjo 2009; Rana et al. 2010).

Overall, the field of soundscape research is increasingly focused on developing more cost-effective data collection methods. These include participatory sensing, the fabrication of affordable devices, and the strategic use of online data sources to circumvent traditional barriers to data access. While concerns regarding privacy and data accuracy persist, the

integration of smartphones and online resources opens new avenues for inquiry and offers fresh perspectives in soundscape analysis.

6.1.2. Big data processing techniques and multiscale analysis of tranquility perception in soundscape research

Big data processing techniques in soundscape research primarily encompass neural networks, machine learning approaches, and the development and management of databases. During the data acquisition phase, traditional statistical analysis methods are prevalently employed, necessitating the calibration of data collected from various devices to ensure precision. For instance, Kardous and Shaw (2016) employed pink noise for calibration, and Asensio et al. (2020) used a range of white noise from 35 dBA to 100 dBA for their calibration processes. In constructing sound dictionaries, Li, Liu, and Haklay (2018) used sound classification framework along with public databases to develop an urban sound dictionary. Which is an urban sound visualization tool that derives from social media data, applying a sentiment lexicon for the sentiment analysis of sound labels. The Audio Set audio event collection serves for the categorical identification of sound types, enhancing urban perception studies through the application of LSTM models to classify sound segments (Verma, Jana, and Ramamritham 2019). Furthermore, the establishment of urban sound databases plays a pivotal role in addressing urban challenges. Due to the point-specific nature of sound data, spatial interpolation methods are essential for creating effective noise maps. However, in scenarios with sparse data points, traditional interpolation methods may fall short. Advanced machine learning techniques, such as Boosted Regression Trees (BRT), have been shown to significantly enhance the accuracy and resolution of noise maps, demonstrating their utility in urban soundscape analysis (Alvares-Sanches, Osborne, and White 2021, Navarro, Tomas-Gabarron, and Escolano 2017).

The challenge of soundscape big data research is to process and analyze large amounts of soundscape data and how to accurately extract useful information from these data. Combining knowledge from the fields of acoustics, ecology, computer science and urban planning in order to fully understand the impacts of soundscapes on humans and ecosystems. Improve the quality and accuracy of data by developing more accurate acoustic sensors and data collection equipment. Utilizing deep learning and artificial intelligence techniques can enhance the automatic classification and identification of soundscape data, while establishing a long-term monitoring network will enable the collection and storage of vast amounts of data, providing essential support for soundscape research.

6.2. Tranquility perception studies at different scales

City-level analyses, in particular, require real-time sound data and often depend on official monitoring networks to obtain this information. For instance, Navarro, Tomas-Gabarron, and Escolano (2017) leveraged open data from Dublin's citywide sound level monitoring network to develop a big data framework aimed at enhancing smart city noise analysis and management.

Despite the invaluable insights provided by governmental data, the accessibility and coverage of urban monitoring networks remain inconsistent across regions. To address these challenges, researchers have implemented innovative solutions, such as deploying automated monitoring devices. For example, the Kinabalu recorder study at Mount Kinabalu Park and smartphone-based sound monitoring efforts exemplify these advancements (Karlsson et al. 2021). Furthermore, several studies have utilized smartphones in a quasi-crowdsourced manner to monitor urban and parkland soundscapes, demonstrating the feasibility of leveraging volunteer contributions for environmental data collection (Zipf et al. 2020). Mora-Araus et al. (2021) explored noise distribution during the Greater Guayaquil Epidemic using student volunteers, while Shim et al. (2016) enlisted 309 volunteers to generate a noise map of Seoul using smartphones. Similarly, Oberman et al. (2023) analyzed the soundscapes of 15 UK national parks through quasi-crowdsourcing. The scale and scope of these studies typically depend on the resources and capabilities of the conducting research organizations. In addition to direct sound level meter deployments, researchers have also embraced socio-perceptual methods to gather sound information on a broader scale. Guo et al. (2022) utilized government noise complaint data for a case study, while Si et al. (2022) collected physical noise monitoring data. Peplow, Thomas, and AlShehhi (2021) and Gasco et al. (2020) have further enriched the landscape of soundscape research by incorporating web comment data and geo-referenced social media images, respectively, to assess public perceptions of quietness.

Nonetheless, sound information gathered through socio-perceptual methods exhibits variable precision and often displays spatial disparities in data density. Consequently, scaling up research efforts, enhancing data precision and density, and minimizing costs have emerged as significant challenges within soundscape research. Future studies will increasingly depend on advanced monitoring techniques, big data analytics, and artificial intelligence algorithms to facilitate comprehensive soundscape monitoring and analysis. The inclusion of public participation and crowdsourced data collection opens new pathways for soundscape

research, though it also introduces critical concerns regarding data quality and consistency that must be promptly addressed. Moreover, while the integration of socio-perceptual data offers fresh perspectives in this field, its accurate interpretation and effective utilization remain formidable challenges. To overcome these hurdles, future soundscape studies will necessitate an interdisciplinary approach that melds acoustics, geographic information science, sociology, and data science, aiming to cultivate a more holistic understanding of urban blue-green spaces and their tranquility.

7. From noise exposure to "tranquility exposure"

7.1. Tranquility exposure in urban blue-green spaces

Tranquility perception is inherently subjective, influenced by an array of factors including sound sources, acoustic environments, climatic conditions, visual scenes, and geographic features. Current research predominantly explores how individuals passively absorb spatial information pertaining to urban quiet zones. Blue-green spaces, such as national parks, urban parks and vegetation zones, are increasingly scrutinized for their contributions to tranquility perception. Notably, urban parks and vegetation zones play a critical role in mitigating traffic noise, prompting studies that examine the interplay between noise levels and human perception.

Contrary to the traditional auditory preference for low noise levels, the richness of natural sounds within quiet urban areas represents a significant area of interest for researchers. Natural sounds, possessing varied acoustic properties, elicit markedly different responses in terms of perceptual tranquility, emotional potency, and arousal in humans (Liu et al. 2019). However, an increase in natural sound sources does not necessarily enhance the soundscape; rather, the complexity of the soundscape can adversely affect subjective perceptions. Greater mixing of sound sources within a natural soundscape tends to diminish subjective quality (Mitchell et al. 2022). Additionally, the sequence of soundscape elements can influence perceptual outcomes (Han, Kang, and Meng 2022). The presence of human activity sounds within tranquil areas, particularly in blue-green spaces near urban centers, also plays a crucial auditory role. Nevertheless, the type and location of human-made sounds significantly influence their impact. For instance, sounds associated with fishing and children playing are found to enhance calmness and restorative perceptions, whereas ship sirens typically have the opposite effect (Zhu et al. 2023).

Prior studies have underscored the significance of visual elements in shaping perceptions of tranquility (Pheasant et al. 2008). Yan et al. (2024) have articulated a forward-looking framework for integrating tranquility theory into the design and development of urban public open spaces. This framework identifies three key visual scenes for tranquility: natural, living, and historical-cultural scenes, which facilitate a visual connection between humans and nature, underscoring the primacy of natural vistas in urban settings. Empirical studies consistently affirm the positive impact of natural elements within urban blue-green spaces on enhancing tranquility, while artificial visual elements tend to exacerbate noise annoyance. The configuration, quantity, placement, and design of these natural elements can significantly influence tranquility perceptions. Conversely, there is a notable paucity of research focused on living scenes and historical-cultural scenes, indicating a crucial area for future exploration. Particularly, crafting a harmonious integration of artificial and natural visual elements within living scenes represents a vital research avenue. Furthermore, understanding the dynamics of people and space in settings frequented by human activity, such as waterfront parks and urban rivers, is crucial for the strategic planning and design of blue-green spaces.

Future research needs to refine the methodologies used to assess the influence of blue-green spaces on tranquility perception, with an emphasis on protecting and amplifying these spaces' tranquil characteristics amidst urban development. The planning and design of blue-green spaces within densely populated urban areas necessitate innovative approaches, including the integration of advanced technologies such as VR and AR. Simultaneously, the design of tranquillity zones regarding urban blue-green spaces should be shifted from passive noise exposure prevention to active tranquillity creation. In this context, this paper introduces the concept of Tranquility Exposure. Tranquility Exposure refers to an individual's passive or active engagement with tranquil environments of varying scales. Rooted in exposure science, exposure ecology, and soundscape theory, this concept encompasses both the duration and quality of an individual's experience in tranquil settings – whether during everyday activities in residential or workplace environments, or while engaging in leisure activities in soundscape-rich areas. Tranquility exposure can be viewed as a form of environmental exposure, akin to the concept of green exposure, with a particular focus on the temporal and spatial dimensions of an individual's immersion in a tranquil environment, ultimately shaping their tranquility experience. These views promise to transform the assessment and design of blue-green spaces by facilitating detailed audio-visual interactions,

potentially setting new benchmarks in soundscape evaluation and enhancing urban living standards.

7.2. Formation of the experience of serenity: a humanistic perspective

The perception and understanding of urban tranquility spaces profoundly shape individuals' experiences of tranquility, influenced by a complex interplay of social, physiological, and behavioral factors. Research increasingly explores how variables such as visit frequency, duration, and physiological attributes like age and gender affect tranquility perceptions. Notably (Liu et al. 2019), highlight that visit frequency and duration significantly correlate with personal sound perception, more so than age or residential status, which nevertheless impact overall soundscape preferences. Moreover, cultural background and psychological state substantially diversify individuals' conceptions of tranquility. For some, tranquility is associated with minimal human activity, emphasizing silence. Others perceive natural sound sources as vital due to cultural connections between nature and serenity, while security and relaxation are paramount, reflecting a need to feel removed from urban stress. Descriptions of tranquility thus vary, centering on natural sounds, social interactions, and the essence of quietness (Lavandier and Delaitre 2015). Theoretical frameworks propose categorizing tranquility experiences into mental relaxation, peace, pleasure, and states of immersion and concentration (Yan et al. 2024). These diverse perceptions highlight the nuanced differences in tranquility experiences across different demographic groups, which are often overlooked in research due to sample size limitations in both in-situ and experimental settings. This variability underscores the need for more targeted social characterizations in the planning and research of tranquility areas, enabling the development of customized quiet zone planning for diverse target groups.

Studies of urban tranquility experiences emphasize the subjective and culturally diverse nature of tranquility experiences across various settings. Future inquiries need to delve deeper into the integration of these demands to foster tranquil spaces that are both inclusive and universally accessible. A key challenge is to reconcile urban development with the preservation of serene environments, particularly within densely populated urban areas. Emphasis should be placed on examining multi-sensory experiences in urban public spaces and investigating how these can be seamlessly incorporated into urban design. Furthermore, sustained attention must be given to the long-term effects of tranquil spaces, ensuring their serene qualities are preserved through continuous management and maintenance.

8. Conclusion

As urbanization intensifies, noise pollution has become a critical issue, with the exposure of individuals to varied scales of serene environments – whether passive or active – becoming crucial for enhancing residents' quality of life through positive soundscape experiences. This review examines the influence of urban blue-green spaces on tranquility perception, highlighting the detrimental impact of noise pollution on mental health and the alleviative role of these spaces. The synergy between natural soundscapes and visual elements is fundamental in augmenting tranquility perceptions. Urban planning of blue-green spaces should therefore encompass both acoustic and visual considerations. Future studies should focus on the tranquility experiences of diverse population segments, aiming to integrate a broad spectrum of cultural and social needs into the design of inclusive urban public spaces. Moreover, leveraging big data and advanced monitoring technologies enables a more comprehensive evaluation of the acoustic characteristics of urban blue-green spaces and their effects on tranquility perceptions. Such approaches not only refine data accuracy but also furnish new perspectives and tools for managing and optimizing urban soundscapes. By integrating machine learning and virtual reality, forthcoming research can probe deeper into the intricate interplay between soundscapes and human behavior.

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