forests

Article

Multi-Scale Effects of Landscape Pattern on Soundscape Perception in Residential Green Spaces

Jiang Liu [1,2], Yi-Jun Huang [1,2], Zhu Chen [1,3,*] and Xin-Chen Hong [1,2]

1 School of Architecture and Urban-Rural Planning, Fuzhou University, Fuzhou 350108, China; jiang.liu@fzu.edu.cn (J.L.); yijunhuang_fzu@126.com (Y.-J.H.); xch.hung@outlook.com (X.-C.H.)
2 Fujian Key Laboratory of Digital Technology for Territorial Space Analysis and Simulation, Fuzhou University, Fuzhou 350108, China
3 Institute of Environmental Planning, Leibniz University Hannover, Herrenhäuser Str. 2, 30419 Hanover, Germany
* Correspondence: chen@umwelt.uni-hannover.de; Tel.: +86-18659133048

Abstract: Soundscape quality in green spaces of residential areas directly contributes to residents' quality of life. It has close relationships with landscape characteristics, which should be considered in landscape planning and design processes in residential areas. Accordingly, this study proposed a new perspective on the interrelationships between soundscape perception and landscape pattern on multi-scale, based on a case study of 30 residential green spaces in Fuzhou, China. Percentage of Landscape (PLAND), Patch Density (PD), Landscape Shape Index (LSI), and Patch cohesion index (COHESION) were utilized to represent the landscape pattern of vegetation, buildings, and roads in the residential areas. Soundscape perception was interpreted using the sound dominant degree (SDD) of sound sources and overall soundscape quality. The examined spatial scales range from 20 m to 180 m, with concentric circles spaced 20 m apart for each sampling point. Correlation analyses indicated that most landscape indices of vegetation and buildings were correlated with these soundscape perception indicators, while limited landscape indices of roads were associated with them. Based on the multi-scale landscape indices, multiple linear regression models for the SDD of sound sources and overall soundscape quality were established, confirming that the scale effect of landscape patterns can affect soundscape perception. Expressly, results indicated that these models were chiefly influenced by the landscape indices at a scale less than 120 m, but the scale effect of landscape pattern on the SDD of birdsong, pleasantness, and quietness was not so evident. Furthermore, we found that the number of explanatory variables may somewhat affect the model performance. The overall interpretability of these landscape indices for the SDD of sound sources was better than that of overall soundscape quality, implying the complexity of the latter. This study offers a fresh insight into the relationship between landscapes and soundscapes at varying scales. The findings can provide useful information for the promotion strategies of landscapes and soundscapes, especially in residential green spaces.

Keywords: landscape pattern; sound dominant degree; soundscape quality; residential area; green space; scale effect

Citation: Liu, J.; Huang, Y.-J.; Chen, Z.; Hong, X.-C. Multi-Scale Effects of Landscape Pattern on Soundscape Perception in Residential Green Spaces. *Forests* **2023**, *14*, 2323. https://doi.org/10.3390/f14122323

Academic Editor: Panteleimon Xofis

Received: 24 October 2023
Revised: 15 November 2023
Accepted: 21 November 2023
Published: 27 November 2023

1. Introduction

With rapid urbanization and population growth, noise pollution has become a pertinent issue worldwide. The World Health Organization (WHO) has stated that noise pollution is one of the primary threats to human health and well-being, and a primary cause of deteriorating urban environmental quality [1]. Decision-makers have considered the quality of the acoustic environment as a crucial component of environmental impact assessment and policies [2]. The Environmental Noise Directive (END) [3] demands member countries assess noise and manage key urban functional areas. Many European countries like Ireland have completed the noise mapping [2,4]. In China, the evaluation of the impact of the acoustic environment started relatively late. However, the established assessment approaches only consider controlling the noise levels, which is not equal to improving the quality of the acoustic environment. This is because human perception of the acoustic environment is also affected by the perceived sound sources, the psychological perception of the user, and other non-acoustic factors [5,6]. The soundscape is "an acoustic environment as perceived or experienced and/or understood by a person or people, in context" as defined in ISO 12913-1 [7]. This concept emphasizes the relationship between individuals, environment, and sound, and takes a more comprehensive approach to improve the quality of the acoustic environment [8–11]. Soundscape research aims to shift the focus from equating the acoustic environment with noise to sound as a resource. Currently, multiple approaches are available for exploring soundscape perception, typically through collecting human perception data along with physical and psychoacoustic information regarding the acoustic environment and context [12]. The definition and utilization of various data collection methods have been outlined in ISO 12913-2 [13], including questionnaires, soundwalk, and interview guidelines. Among these methods, the questionnaire has been commonly used for gathering subjective responses from a large sample across various scales [12,14].

The soundscape in the green spaces of residential areas is especially essential for human benefits, because these green spaces are the core areas for the daily life of urban dwellers. The residential green spaces provide residents with places for leisure, recreation, and socialization [15], and offer opportunities for inhabitants to access the natural environment and experience nature-based pleasure conveniently. Furthermore, studies have found the interrelationships between the quality of residential green spaces with children's health [16], residents' body mass index [17], and psychological health [18,19]. The soundscape serves as a key that unlocks the world, offering both normal-sighted and visually impaired inhabitants meaningful experiences and memories [20]. The poor acoustic environment in these areas can negatively affect residents' physiological and psychological states [21]. Moreover, excessive exposure to noise pollution can lead to health risks such as sleep disorders, cardiovascular diseases, increased stress and anxiety, and cognitive impairment in children [22,23]. The soundscapes in residential green spaces are indispensable for providing good environmental quality and reducing the annoyance caused by air pollution and noise [24]. However, they have not received attention as much as the soundscapes in other green spaces like urban parks or forests [25–28].

Many studies have proven that soundscape perception has interrelationships with landscape features [29,30], such as landscape aesthetics, spatiotemporal dynamics, and biodiversity [11]. Notably, landscape patterns representing landscape structures and ecological processes have been recognized as one of the most essential characteristics affecting soundscape perception [31]. Existing soundscape studies generally explored the relationship between landscape patterns and soundscape perception at only one scale. However, the landscape spatial patterns are differentiated across various scales [32]. This difference caused by scale effects may also affect soundscape perception directly or indirectly. The research of acoustic ecology has started to pay attention to this aspect, and the explored scales ranged from local to regional. At the local scale, it has been shown that the strength of the relationship between the acoustic entropy, the centroid, and skewness with vegetation and topographic features is influenced by the scale effect of landscape, especially at 25 m and 50 m [33]. Acoustic metrics also respond to the percentage of natural vegetation cover at different scales, and scale effects can eliminate redundancy in acoustic metrics. Especially at the 100 m scale, the surrounding landscapes are more likely to influence acoustic features [34]. At the regional scale, one study found a strong association between acoustic indices and habitat structure and quality between 1.5 km and 3 km [35]. In addition, the scale effect of landscape patterns may also indirectly affect soundscape composition. For example, tree cover at 20 m and 500 m scales has a direct and significant impact on bird species richness [36], which may indirectly affect the perceived intensity and diversity of birdsongs as well as soundscape restoration in the environment [37,38].

Nevertheless, the scale effects of landscape spatial features on soundscape perception are still under-explored, and relevant research was rarely set in residential green spaces. Accordingly, this study aims to explore the relationships between soundscape perception and landscape pattern at different scales, and then examine the scale effect of landscape pattern on soundscape perception. To this end, this study took 30 green spaces within 20 residential areas in Fuzhou, China, as a case study. These green spaces served as the center to create nine equally spaced concentric circles ranging from 20 to 180 m, representing different spatial scales. This study can provide essential data references and empirical evidence for soundscape planning and management in residential areas.

2. Research Method

2.1. Study Area

This study selected the residential areas on the south side of Jinshan Avenue in Fuzhou, China, as the case study sites, trying to minimize the influence of site location factors and the biases of research results (Figure 1a). The selection of residential areas was based on the following principles: (1) the building time of the residential area should be between ten and fifteen years and have relatively complete facilities; (2) the internal green spaces of the residential area should be well planned with diverse and representative characteristics; (3) the green spaces in the residential area should be away from city roads to avoid abundant external noise interference. Ultimately, 20 residential communities were selected and 30 representative green space samples were chosen for the acoustic data collection on site, labeled from SP1 to SP30 (Figure 1b).

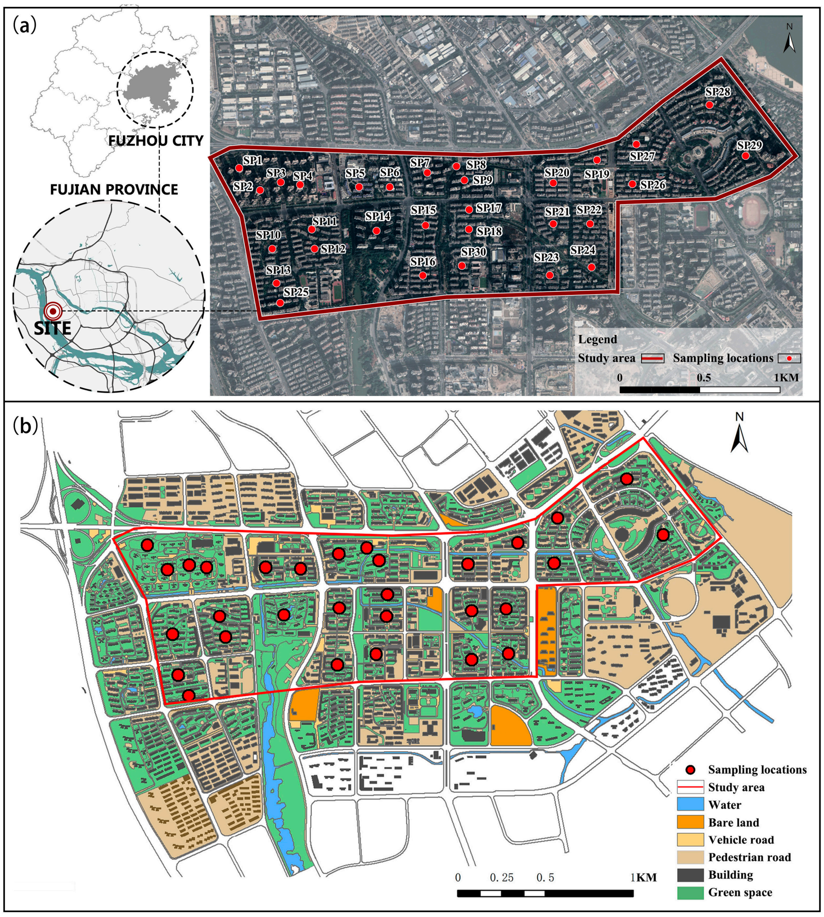

Figure 1. (**a**) Location and (**b**) land use types of the study area.

This study analyzed the landscape pattern based on three land use types: buildings (BD), vegetation (VT), and roads, including vehicular roads (VR) and pedestrian roads

(PR). The previous study indicated that the landscape pattern of these three land use types significantly determines the landscape spatial characteristics within the region [39]. The category of typical sound sources in the study area is outlined in Table 1. The classification and identification are based on the pilot study in the study area and adapted from relevant literature [40,41].

Table 1. Category of typical sound sources.

Primary Sound Category	Sound Source	Abbreviation
Natural Sound	Bird song Leaves rustling	BS LR
Human Sound	Surrounding speech Children playing	SS CP
Traffic Sound	External traffic Internal traffic	ET IT

A nine-scale circular buffer zone centered with each sampling site was created to reflect different spatial scales. The scale radius was set from 20 m to 180 m. The scales cover 20 m, 40 m, 60 m, 80 m, 100 m, 120 m, 140 m, 160 m, and 180 m. The set size refers to previous studies [30,32,34] and China's Standard for urban residential area planning and design [42]. We further assigned these scales into three relative ranks for better analysis and understanding (Table 2).

Table 2. Relative scale ranks for the study area.

Relative Rank	Scale
Small scale	20 m, 40 m, and 60 m
Medium scale	80 m, 100 m, and 120 m
Large scale	140 m, 160 m, and 180 m

2.2. Data Collection and Measurement

2.2.1. Landscape Spatial Data

The status quo of the three land use types within the study area was vectored in ArcGIS10.2, including buildings, vegetation, and vehicular and pedestrian roads, based on Google satellite imagery of the study area, topographic maps of residential areas provided by the Natural Resources Bureau of Cangshan District, as well as street view maps, and on-site investigations. Subsequently, the nine-scale concentric circular zone of each sampling site was used to extract the corresponding landscape types.

This study selected four landscape metrics from two aspects, landscape composition and spatial pattern, deduced from the literature exploring the relationship between landscape features and soundscape perception [26,30,31]. The indices included Percentage of Landscape (PLAND), Patch Density (PD), Landscape Shape Index (LSI), and Patch cohesion index (COHESION), as shown in Table 3. Fragstats4.2 was employed to calculate such landscape indices (see Supplementary Materials).

2.2.2. Soundscape Perception Data

The soundscape perception data was obtained through a questionnaire survey conducted in November 2021 for 15 non-rainy days. Data were collected between 8:00–11:00 am and 3:00–6:00 pm. These two periods were the active times for most residents, which was practical for engaging participants. In addition, these timeframes can relatively ensure that we capture diverse and dynamic natural, human, and traffic sounds in the morning and afternoon. The questionnaire consisted of two parts: (1) demographic, social, and behavioral characteristics of the participants, including gender, age, education level, activity frequency, and purpose of visit; and (2) participants' evaluation of sound sources and overall soundscape quality of the green spaces. This study was approved by the Institutional Review Board (IRB) of Fuzhou University. All subjects were informed of the purpose and content of the questionnaire before the survey. They were able to quit this survey at any time without any reason if they wanted to

Table 3. Land use types and selected landscape indices.

Land Use Type	Landscape Index	Abbreviation	Explanation
Vegetation	Percentage of landscape index of vegetation.	PLAND_VT	The relative proportion of vegetation patches in the entire landscape.
	Patch density of vegetation.	PD_VT	The number of vegetation patches per unit area reflects the intensity of patch density.
	Landscape shape index of vegetation	LSI_VT	The degree of regularity of the shape of vegetation patches.
	Patch cohesion index of vegetation.	COHESION_VT	The connectivity of vegetation patches.
Building	Percentage of landscape index of building.	PLAND_BD	The relative proportion of building patches in the entire landscape.
	Patch density of building.	PD_BD	The number of building patches per unit area.
	Landscape shape index of building.	LSI_BD	The degree of regularity of the shape of building patches.
	Patch cohesion index of building.	COHESION_BD	The connectivity of building patches.
Road	Percentage of landscape index of vehicular road.	PLAND_VR	The relative proportion of vehicular road patches in the entire landscape.
	Patch density of vehicular road.	PD_VR	The number of vehicular road patches per unit area.
	Landscape shape index of vehicular road.	LSI_VR	The degree of regularity of the shape of vehicular road patches.
	Patch cohesion index of vehicular road.	COHESION_VR	The connectivity of vehicular road patches.
	Percentage of landscape index of pedestrian road.	PLAND_PR	The relative proportion of pedestrian road patches in the entire landscape.
	Patch density of pedestrian road.	PD_PR	The number of pedestrian road patches per unit area.
	Landscape shape index of pedestrian road.	LSI_PR	The degree of regularity of the shape of pedestrian road patches.
	Patch cohesion index of pedestrian road.	COHESION_PR	The connectivity of pedestrian road patches.

The sound source perception was evaluated by perceived occurrences of sounds (POS) with a 5-point scale (1—never, 2—occasionally, 3—normal, 4—often, 5—frequently), and perceived loudness of sounds (PLS) also scored by a 5-point scale (1—very weak, 2—weak, 3—normal, 4—strong, 5—very strong). The overall soundscape quality assessment consisted of the following 6 adjectives: pleasant, harmonious, vibrant, comfortable, eventful, and quiet [25,43], which were also rated on a 5-point scale (from 1-strongly disagree to 5-strongly agree). Furthermore, we also calculated the sound dominant degree (SDD) based on POS and PLS, as shown in Equation (1), which refers to the dominance of a specific sound source [44].

$$SDD_{Ji} = POS_{Ji} \times PLS_{Ji} \tag{1}$$

in this equation, POS denotes perceived occurrences of individual sounds, and PLS denotes the perceived loudness of individual sounds. Similarly, j represents the jth sample, and i represents the ith sound source.

2.3. Statistical Analysis

On the 30 survey sites, 350 questionnaires were distributed, with 338 returned. After eliminating questionnaires with incomplete or false information, there were 308 valid questionnaires, resulting in an effective rate of 91.1%. The reliability and validity of the collected questionnaire were examined, with the results indicating a Cronbach's alpha coefficient of 0.751, indicating acceptable reliability. The Kaiser-Meyer-Olkin (KMO) value is 0.796, more significant than the recommended 0.7 threshold. In addition, the significance value of the Bartlett test was 0.000, which is less than the standard 0.05 level, suggesting that the data had good validity. The demographic characteristics of the respondents are presented in Figure 2.

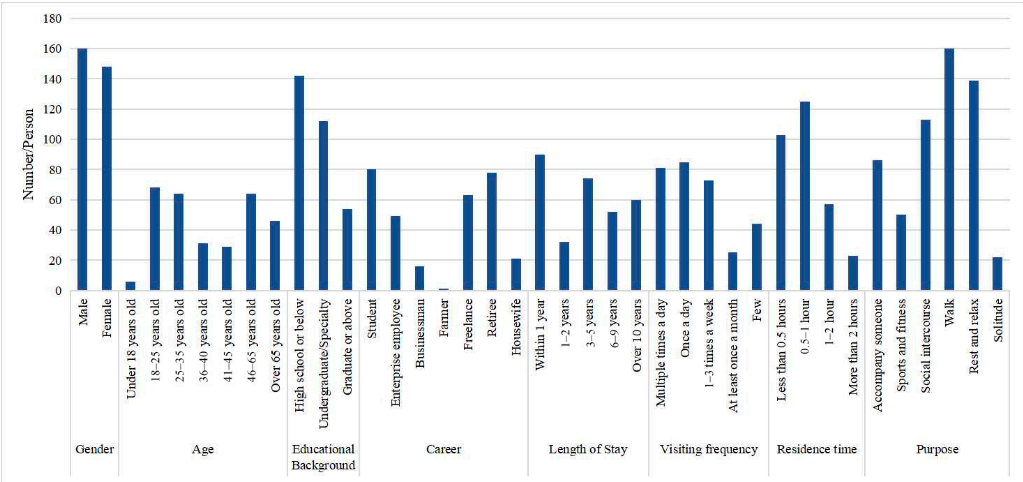

Figure 2. Statistical sample information (n = 308).

The processed landscape index and soundscape perception data were statistically analyzed in SPSS 26. Spearman's rho correlation analysis was applied to explore the significant relationship between landscape index and soundscape perception of different landscape types at multiple scales. Stepwise multiple linear regression analysis was employed to identify further the key landscape indices affecting soundscape perception. The SDD was set as the dependent variable, and landscape indices that show significant correlations with SDD were used as independent variables. The collinearity diagnostic rule was applied to ensure no collinearity issue among the independent variables, as indicated by the variance inflation factor (VIF) being less than 10.

3. Results

3.1. Basic Analysis

3.1.1. Sound Source Perception

The POS and PLS in each sampling point were calculated through statistical analysis of the questionnaire data, as shown in Figure 3. Regarding POS, birdsongs generally had a higher value in natural sounds, while the value of leaves rustling was lower. To some extent, the sounds of surrounding speech and children playing are highly similar. The differences in the PLS values for natural and artificial sounds were identical to their POS. Specifically, the PLS of bird song and surrounding speech were relatively high. Additionally, internal traffic sounds were generally perceived as higher in PLS than external ones.

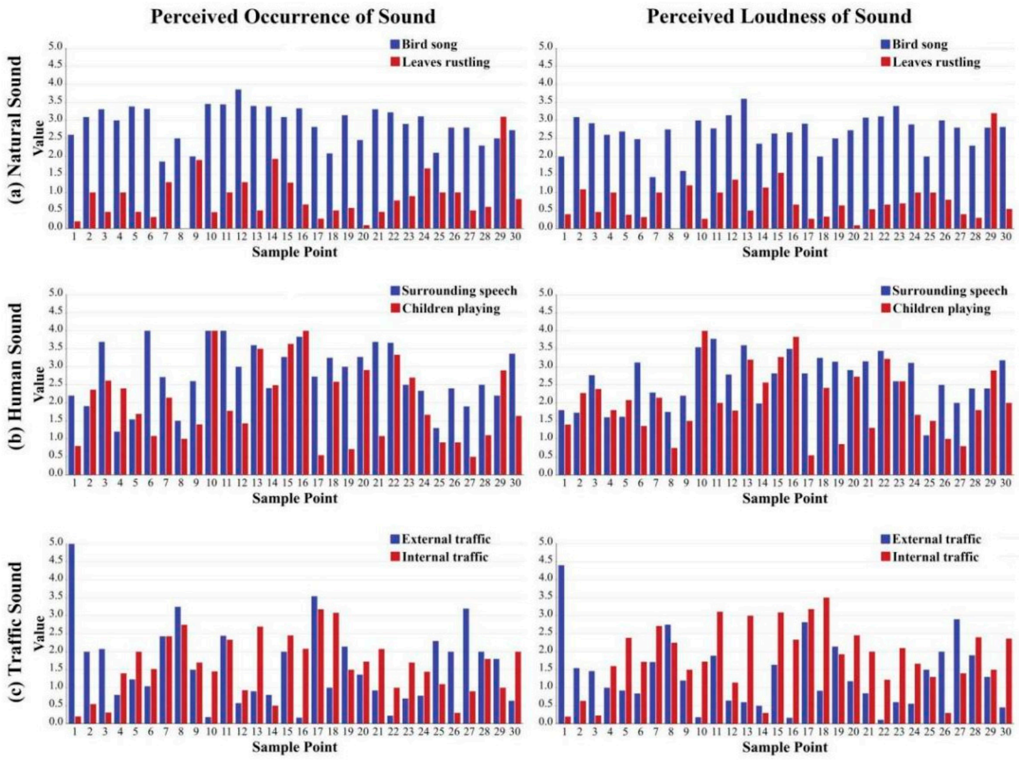

Figure 3. Mean Frequency and Intensity Map of Sound Sources.

3.1.2. Principal Component Analysis of Overall Soundscape Quality

Principal Component Analysis (PCA) was performed on the six soundscape perceptual attributes to synthesize the main character of overall soundscape quality in the study area. Referring to ISO standards and the characteristics of residential areas [7,45], the following three common factors were extracted: soundscape pleasantness, soundscape eventfulness, and soundscape quietness (Table 4). This outcome is similar to the results of previous studies [45]. The cumulative variance contribution rate of the three factors was 73.873%, indicating that they can capture relatively comprehensive information on the overall soundscape quality.

Table 4. PCA results of soundscape perception factors.

Common Factor	Factor	Component		
		1	2	3
F1 (soundscape pleasantness)	pleasant	0.879		
	harmonious	0.729		
F2 (soundscape eventfulness)	eventful		0.840	
	vibrant		0.747	
F3 (soundscape quietness)	quiet			0.934
	comfortable			0.632

Note: Extraction method: principal component analysis. Rotation method: Kaiser normalized varimax method. Rotation converged in 4 iterations.

3.2. Correlations between Landscape Indices of Different Land Use Types and Soundscape Perception Indicators

3.2.1. Vegetation

Figure 4 shows many correlations between landscape indices of vegetation and sound source SDD and soundscape quality. The SDD of natural sounds is only related to LSI_VT and PD_VT. Specifically, the SDD of both bird song and leaves rustling positively correlates with LSI_VT at all examined scales except for 20 m. Furthermore, the SDD of bird song also has a positive relation to PD_VT at the scale from 40 m to 180 m. The SDD of human sounds has correlations with all landscape indices of vegetation. The SDD of both human sounds only correlates with PD_VT at 40 m–100 m, and the SDD of surrounding speech has more correlations at 120 m–180 m. The SDD of surrounding speech presents negative correlations with PLAND_VT and COHESION_VT ranging from 40 m to 180 m; however, apart from the scale of 100 m with the former. The SDD of children playing showcases two correlations with LSI_VT at 80 m and 100 m. Similarly, the SDD of external and internal traffic also exhibits significant relationships with the four indices, all of which are negative. Notably, only LSI_VT correlates with the SDD of these two traffic sounds. The SDD of external traffic correlates with PD_VT at 40 m–160 m. Both PLAND_VT and COHESION_VT are related to the SDD of internal traffic at 40 m–120 m and 40 m–100 m, separately. Regarding the correlations between the soundscape quality indicators and the landscape indices, soundscape pleasantness and eventfulness are positively related to LSI_VT at 80 m, 100 m and 140 m, and 80 m–160 m, respectively. PLAND_VT and COHESION_VT only have relationships with soundscape eventfulness at 60 m to 180 m and 80 m to 180 m, respectively. Nevertheless, soundscape quietness only correlates with COHESION at the 20 m scale among all indices.

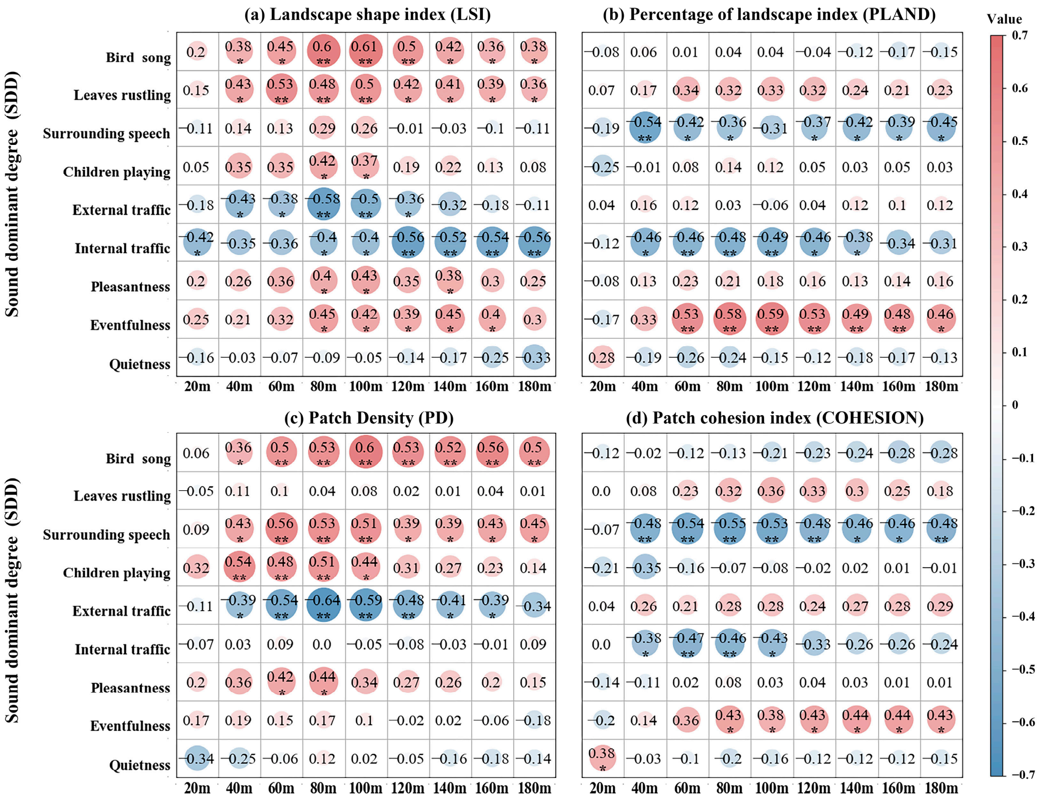

Figure 4. Correlations between landscape indices of the vegetation and the sound dominant degree (SDD) of sound sources and overall soundscape quality (* indicates $p < 0.05$, ** indicates $p < 0.01$).

3.2.2. Buildings

Figure 5 shows the correlations between the landscape indices of buildings and the SDD of sound sources and overall soundscape quality. LSI_BD has a relatively weaker correlation with the SDD of sound sources than other landscape indices, especially for the relations with the SDD of natural sounds. Apart from LSI_BD, all the building landscape indices exhibit significant positive correlations with the SDD of bird song at the scale of 140 m–180 m. However, the SDD of leaves rustling is unrelated to the four landscape indices at all tested scales. The relationships between the SDD of surrounding speech and the four building landscape indices are significant, mainly at medium and large scales. The SDD of children playing is found to have very weak correlations with the building indices, which appear only on one scale of each index. In addition, negative correlations are located between the SDD of external traffic and PLAND_BD and PD_BD at 120 m–140 m and COHESION_BD at 140 m–180 m. The correlations between the SDD of internal traffic and the four indices are found generally at small and large scales. The soundscape quality components are found to have rare correlations with the building landscape indices. Soundscape pleasantness and soundscape quietness are not associated with any of these indices. Correlations between soundscape eventfulness and the indices are chiefly below 100 m but not too much.

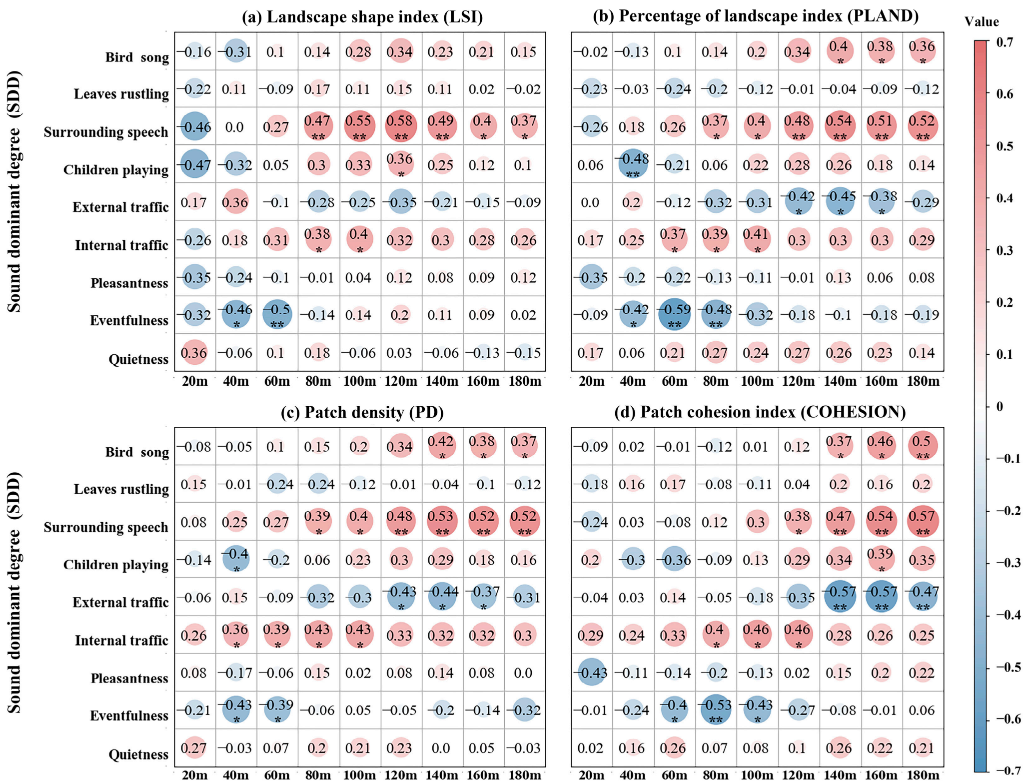

Figure 5. Correlations between building landscape indices and the sound dominant degree (SDD) of sound sources and overall soundscape quality (* indicates $p < 0.05$, ** indicates $p < 0.01$).

3.2.3. Roads

Figures 6 and 7 indicate that only a few landscape indices representing vehicular and pedestrian roads at specific scales significantly correlate with the SDD of sound sources. Compared to vehicular landscape indices, pedestrian landscape indices showcase more correlations with the SDD of sound sources and soundscape quality. Notably, PLAND_PR exhibits the most correlations with the SDD of surrounding speech at each scale ranging from 40 m to 180 m and with the SDD of internal traffic from 80 m to 180 m except for 160 m. Likewise, COHESION_PR has continuous correlations with the SDD of leaves rustling at the scale ranging from 20 m to 80 m. Soundscape pleasantness presents only two correlations with vehicular road landscape indices, including PLAND_VR and COHESION_VR; both are found at 80 m. Soundscape eventfulness is related to PLAND_PR at most scales among the three components, from 80 m to 140 m. Interestingly, the four landscape indices of pedestrian roads are all positively correlated with soundscape quietness at the 20 m scale. However, no significant correlation was found between the landscape indices of vehicular roads and soundscape quietness.

Figure 6. Correlations between vehicular road landscape indices and the sound dominant degree (SDD) of sound sources and overall soundscape quality (* indicates $p < 0.05$, ** indicates $p < 0.01$).

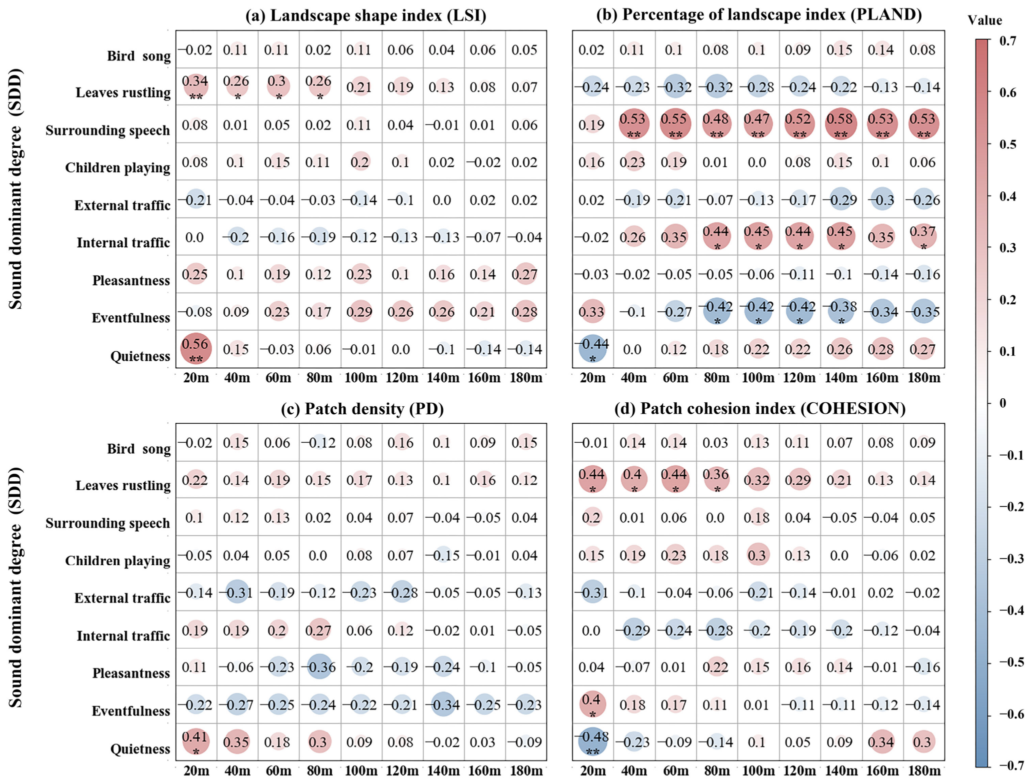

Figure 7. Correlations between pedestrian road landscape indices and the sound dominant degree (SDD) of sound sources and overall soundscape quality (* indicates $p < 0.05$, ** indicates $p < 0.01$).

3.3. Regression Models for Soundscape Perception Utilizing Multi-Scale Landscape Indices

3.3.1. Models for the Sound Dominant Degree of Sound Sources

The results of stepwise multiple linear regression analysis are shown in Table 5. Most independent variables are at medium scales (80 m, 100 m, and 120 m), followed by the indices at small scales (20 m, 40 m, and 60 m). The number of significant landscape indices at large scales (140 m, 160 m, and 180 m) is the least. Only 100 m-PD_VT has a considerable impact on the SDD of bird songs. The SDD of surrounding speech is affected by landscape indices of vegetation and buildings at medium and large scales. PD_VT and PD_BD at 80 m, and LSI_BD at 160 m have positive effects on it, while PD_VT negatively affects it at 120 m. The 40 m-COHESION_BD has a negative impact on the SDD of children playing, but its intensity (Beta) is higher than the other two significant variables, 40 m-PD_VT and 120 m-LSI_BD. The SDD of external and internal traffic is influenced by building landscape indices that are 140 m-COHESION_BD and 100 m-LSI_BD, respectively. There are no landscape indices found to have a significant influence on the SDD of leaves rustling. However, according to the results of the correlation analysis below, there were correlations between the SDD of leaves rustling and landscape indices of vegetation and roads.

Table 5. Multivariate stepwise regression models for the sound dominant degree (SDD) of sound sources using multi-scale landscape indices.

Dependent Variable	Independent Variable	Beta	VIF	t	R^2	F
Bird song SDD	100 m-PD_VT	0.53	1	3.311 **	0.256	10.963 **
Surrounding speech SDD	80 m-PD_VT	1.082	2.973	7.736 **	0.849	23.013 **
	80 m-PD_BD	0.672	1.571	6.607 **		
	160 m-LSI_BD	0.418	1.156	4.797 **		
	120 m-PD_VT	−1.046	3.862	−6.564 **		
Children playing SDD	40 m-PD_VT	0.396	1.207	2.86 **	0.540	12.367 ***
	40 m-PLAND_BD	−0.535	1.291	−3.739 **		
	120 m-LSI_BD	0.478	1.496	3.104 **		
External traffic SDD	20 m-COHESION_VR	0.460	1.012	2.703 **	0.598	11.429 **
	140 m-COHESION_BD	−0.619	1.012	−3.632 **		
Internal traffic SDD	100 m-LSI_BD	0.363	1.003	2.242 **	0.399	8.646 **
	120 m-LSI_VT	−0.586	1.003	−3.620 *		

Note: * indicates $p < 0.05$, ** indicates $p < 0.01$, *** indicates $p < 0.001$.

3.3.2. Models for the Overall Soundscape Quality

The regression models for the overall soundscape quality indicators show that not many landscape indices have a significant relationship with them (Table 6). The scale effect of the landscape pattern on overall soundscape quality does not seem to be obvious, especially for pleasantness and quietness. Both pleasantness and quietness are only affected by one metric, 80 m-PLAND_VR and 20 m-PD_PR, separately. Eventfulness is negatively affected by 60 m-PLAND_BD and 100 m-COHESION_VT, while positively affected by 140 m-PLAND_VT.

Table 6. Multivariate stepwise regression models for overall soundscape quality using multi-scale landscape indices.

Dependent Variable	Independent Variable	Beta	VIF	t	R^2	F
Pleasantness	80 m-PLAND_VR	−0.506	1	−2.988 **	0.227	8.927 **
Eventfulness	60 m-PLAND_BD	−1.023	1.828	−5.431 **	0.728	13.492 **
	100 m-COHESION_VT	−0.948	2.647	−4.182 *		
	140 m-PLAND_VT	0.467	2.242	−2.238 *		
Quietness	20 m-PD_PR	0.406	1	2.354 *	0.135	5.543 *

Note: * indicates $p < 0.05$, ** indicates $p < 0.01$.

4. Discussion

4.1. Typical Landscape Characteristics Associated with Soundscape Perception

The correlation results in vegetation indicated that LSI_VT and PD_VT significantly impacted soundscape perception at 80 m and 100 m scales. In contrast, other landscape indices had a relatively weaker effect on sound source perception. A possible reason is that landscape types and spatial configurations at scales lower than 80 m are relatively simple. People's perception of landscape elements weakens after over the scale of 100 m. On the impact of the SDD of different sound sources, LSI_VT, PLAND_VT, and PD_VT, they strongly promoted the SDD of bird song. This result indicates that the common birds in residential areas prefer vegetation with relatively complex and irregular shapes, similar to previous research [46,47]. However, some scholars have found that birds survive in regularly shaped urban green spaces [48], highlighting the uniqueness and value of studying the soundscapes of residential green spaces. In contrast, the above three landscape indices negatively impacted the SDD of surrounding speech and internal transportation noise, which may be attributed to the relatively complex vegetation structures that help to reduce anthropogenic noise [49]. Regarding overall soundscape quality, both LSI_VT and PD_VT had substantial impacts on soundscape pleasantness at the 80 m scale, while LSI_VT, PLAND_VT, and COHESION_VT had significant implications on soundscape eventfulness at the 100 m scale. This result may be due to the promoting effect of bird songs on soundscape pleasantness [50,51], and people were more likely to perceive various sound sources in vegetation at this scale. Based on such, it is suggested that the scale from 80 m to 100 m is more suitable for landscape creation by establishing a diverse and well-structured vegetation, which can not only enhance the perception of positive sound sources and weaken the impact of negative sound sources, but also improve the overall soundscape quality.

For the relationship between the landscape indices and the SDD in building land use, the SDD of surrounding speech and internal traffic had the strongest positive correlation with PD_BD and PLAND_BD. This finding indicates that in densely built areas, sound propagates perhaps through multiple reflections from walls [52,53], because the buildings in high-density urban areas can obstruct the free propagation of road traffic noise, leading to lower noise levels within residential areas and the formation of sound shadow zones [54,55]. This suggests that the layout of buildings can be utilized in residential planning to create sound shadow zones for improving acoustic environment quality. For example, high-density or high-rise buildings can be arranged on the side of external roads or residential areas combined with commercial building layouts to form strong sound shadow zones. In comparison, PD_BD and PLAND_BD had positive effects on the SDD of internal traffic sound at the scale of 100 m–120 m, which may be due to the increase in building area and density leading to the proximity of roadways to vegetation, thereby enhancing the perception of traffic sound. For overall soundscape quality, there was no significant correlation between the various landscape indices of buildings and soundscape pleasantness, while LSI_VT, PLAND_VT, and COHESION_VT were all positively correlated with soundscape eventfulness. However, we found that at the scale of 60 m–80 m, the size of building patches increases, and patch clusters become more aggregated, leading to soundscape eventfulness decreases. This result may be due to the relatively low area percentage of vegetation at that scale, thereby reducing the attractiveness of the place to birds and negatively impacting bird abundance [56], further affecting soundscape eventfulness. Additionally, LSI_BD negatively affected soundscape eventfulness at 40–60 m, possibly due to the complex architectural forms that affect sound propagation, decreasing soundscape eventfulness. These findings indicate that the pattern of buildings in residential areas significantly impacts sound perception. Therefore, increasing the height and density of buildings near urban roads is advisable while reducing the distance between buildings along the streets. These strategies are beneficial in creating good sound shadow areas, thereby reducing the permeability of noise. Moreover, designing relatively diverse forms of individual buildings can also effectively minimize external traffic sound, and adopting a simple arrangement method in the overall layout can promote the perception of positive soundscapes inside the residential area.

Regarding the analysis of road land use, results showed that the PLAND was more closely related to the SDD of surrounding speech and internal traffic compared to other landscape indices. The relationship between the SDD of bird song and landscape indices of roads was not as significant. This finding differs from other studies that indicated a negative correlation between bird abundance and road exposure [57,58]. Regarding overall soundscape quality, PLAND_VR and PLAND_PR had significant negative effects on soundscape pleasantness and eventfulness, respectively. These findings indicated that visual exposure to residential roads, including vehicle and pedestrian roads, may decrease the perception of overall soundscapes. From the perspective of acoustics, the sound reflection effect of road surfaces could also be a reason that increases the difficulty of perceiving natural sounds, thus reducing the overall soundscape quality. This study found a significant correlation between the quietness of soundscapes and the landscape indices of pedestrian roads, particularly at a scale of 20 m. The PD_PR and LSI_PR were found to positively impact the quietness, consistent with previous research [59]. These findings suggest that the landscape pattern of pedestrian roads is a crucial factor affecting the quietness of residential areas at the 20 m scale. Therefore, increasing the complexity of road forms, such as meandering and scattered footpaths, can be a helpful design strategy to help create a quiet environment in residential areas. In addition, previous studies have shown that paving materials can also impact the quality of soundscapes, with grass having more silent proposed background noise, making it more popular than gravel [60]. Therefore, in addition to adjusting the layout of pedestrian roads, sound-absorbing materials such as grass and wooden boards can also be considered paving materials to optimize the sound environment further [61].

4.2. Scale Effects of Landscape Pattern on Soundscape Perception

The SDD models reveal that most landscape indices with significant impacts are at small to medium scales, namely less than or equal to 120 m. However, the SDD of bird song appears unaffected by scale differences in landscape pattern, as it has only one explanatory variable at 100 m. The SDD is primarily influenced by landscape indices related to vegetation and buildings at various scales, with the only significant road landscape index being PD_VT. Vegetation landscape indices considerably impact the SDD of bird song, surrounding speech, and internal traffic at medium scales. This suggests that structurally rich vegetation is more effective at attracting birds and people and reducing internal traffic noise at medium scales [51]. However, the 120 m-PD_VT has a negative impact on surrounding speech, which we speculate might be due to residents within the surveyed neighborhoods preferring to visit nearby vegetation compared to those further away. The building landscape indices significantly affect all the SDD of sound sources at various scales except for birdsongs. Building landscape indices positively affect surrounding speech (primarily from adults) at medium and large scales, indicating that human activities are influenced by building density and complexity. This phenomenon was also observed in previous research [62]. Interestingly, the SDD of children playing is negatively impacted by PLAND_BD at a small scale (20 m), in contrast to the surrounding speech. We speculate that children's activities within the surveyed residential areas may often occur without adult supervision, as guardian behavior is associated with child behavior [63]. Furthermore, the explanatory variables are at medium and small scales, indicating that the activity range of children may be smaller than that of adults. The SDD of traffic noise model results show that building landscape indices at medium and large scales also influence the propagation of internal and external traffic noise to some extent. Specifically, buildings that are both distant from vegetation (greater than or equal to 100 m) and densely built help mitigate the transmission of external traffic noise inward. Conversely, internally uniform building forms within the residential areas assist in controlling internal traffic noise [64]. The road landscape index COHESION_VR only significantly impacts the SDD of external traffic at a small scale (20 m), indicating that adjacent urban roads outside the residential areas contribute significantly to noise pollution in internal green spaces. Therefore, in residential planning, it is crucial to address areas near urban roads on the periphery of residential areas to mitigate the negative impact of external roads on the residential soundscapes. Additionally, at a medium scale (120 m), LSI_VT has a negative impact on internal traffic noise. This suggests that designing structurally diverse vegetation within residential areas at a 120 m distance can effectively reduce internal traffic noise intensity. Such design can be implemented through plant arrangements within green spaces by enriching plant species or structural combinations such as tree-shrub-grass plant configuration [65].

Similarly, soundscape quality is primarily influenced by landscape indices at small to medium scales. This suggests that landscape design within a radius of 100 m or more minor can more effectively enhance the overall soundscape quality of residential green spaces. Among the three components, only eventfulness is influenced by landscape indices at different scales (Table 6), including 60 m-PLAND_BD, 100 m-COHESION_VT, and 140 m-PLAND_VT. This indicates that, at small scale, soundscape eventfulness is mainly affected by building density, while at medium and large scales, it tends to be influenced by vegetation structures and areas. This is because, on the one hand, vegetation can create favorable habitat conditions, attracting various sound-producing organisms, such as birds and insects, to inhabit them [66]. On the other hand, low-density building layouts provide more space for sound propagation, reducing the frequency of sound reflections on building surfaces [67]. Only 80 m-PLAND_VR has a significant negative impact on pleasantness (Beta = −0.506). Combining this result with the findings of the external traffic SDD model, we found that adjacent external roads to the surveyed residential areas may generate significant traffic noise, thereby diminishing the inside soundscape quality. This is consistent with previous research findings [64,68]. However, for urban residential area planning, the proportion of external roads is often challenging to alter. Therefore, to ensure or enhance the pleasantness of the residential internal soundscape, special attention should be paid to controlling the areas near the edges of residential neighborhoods adjacent to urban roads. For example, this can be achieved by increasing vegetation density in these areas or constructing water features to create masking effects through water sounds [69,70], reducing the perceived intensity of external noise. Quietness is only positively influenced by 20 m-PD_PR, indicating that moderately increasing the density of pedestrian roads at a small scale can promote soundscape quietness. This finding suggests that, for instance, a modest increase in the density of pedestrian roads or paths with varied forms within the interior or adjacent residential green spaces can allow residents to experience a quieter sound environment.

In addition, we found a correlation between the number of explanatory variables and the R^2 of the regression models for the SDD and overall soundscape quality indicators. Regression models with multiple significant independent variables exhibited better fit than models with only one independent variable. Furthermore, landscape pattern indices at different scales demonstrated more substantial explanatory power for the SDD than for overall soundscape quality. The analysis results confirm our research hypothesis that landscape spatial characteristics at different scales significantly influence soundscape perception. However, our analysis results also indicate room for improvement in the performance of regression models. Among the SDD models, except for the SDD model of bird song (which had only 25.6% of explained variance), the other models exhibited relatively good fits. Based on previous research, we speculate that this could be due to additional factors affecting the SDD, such as landscape diversity [51]. High landscape diversity in green spaces can provide better habitat quality, attracting more birds and enhancing the richness and perceptual intensity of birdsongs. However, landscape diversity, such as Shannon's Diversity Index (SHDI) or Simpson's Diversity Index (SIDI), is typically measured at the landscape scale [71]. Thus, this landscape feature may influence the SDD of birdsong at larger scales. The SDD model of surrounding speech achieved the best fit with an R^2 of 84.9%. This suggests that combining landscape structural characteristics of medium- or large-scale vegetation and buildings can effectively predict the SDD values of surrounding speech. Among the three regression models for overall soundscape quality indicators, only the eventfulness model exhibits good explanatory power at 72.8%. In contrast, the models for pleasantness and quietness have less satisfactory fits at 22.7% and 13.5%, respectively. This indicates that influencing factors and processes may be more complex than individual sound perception for the overall sound quality. Moreover, other factors besides landscape spatial characteristics may play a more decisive role. Previous research found that sound characteristics and cultural background influence soundscape quality. The factors, such as natural sound occurrence, sound preferences, noise intensity, and people's cultural and cognitive backgrounds, can significantly impact people's perception of soundscape pleasantness and quietness [11]. Therefore, the results of this study confirm that only incorporating landscape spatial characteristics at different scales may be insufficient to fully explain the variability in soundscape quality [30].

4.3. Limitations and Future Study

The present study has several limitations. Firstly, it only focused on the residential areas of a typical southern coastal city, Fuzhou. However, the soundscape perception and its effects on human well-being may vary across locations [72,73]. Thus, the results may not fully reflect the acoustic characteristics of residential areas in other regions. In addition, this study only considered the landscape elements within the residential areas. Still, it did not include the impact of the urban land cover types outside residential areas, such as urban roads. The perception of sound sources near the boundaries of residential areas can be affected by external noise sources outside the residential area. To overcome such shortcomings, follow-up studies could supplement typical case studies in different regions. In addition, researchers could consider the impact of urban land cover types on the soundscape of residential areas, select sampling points as far away as possible from external noise sources, or conduct time-segmented studies. Additionally, this study only reflected the soundscape characteristics in one season, and future research could also investigate and compare the acoustic environments of residential areas during different seasons. Furthermore, the participants in this study were not trained before the survey. They were randomly selected and asked in the field. This might affect the integrity of their responses to some extent because some of them may not recognize the sound types and features in their daily life. This offers the opportunity for further improvement in future research. Also, we encourage a combination of acoustic measurement with the questionnaire method in the subsequent investigation. Some interesting results could be found if the acoustic features (e.g., spectral contents [74]) and human responses are explored and compared simultaneously. Finally, the dimensions of indicators in this study were considered only in terms of spatial scale, shape, and aggregation degree. In the future, other indicators, such as the proximity index, should be included to enrich the dimensions of the indicators.

5. Conclusions

This study analyzed the relationship between soundscape perception and landscape indices at multiple scales within 30 residential green spaces in Fuzhou, China, which offers an innovative insight into soundscape planning and management in urban green spaces. Soundscape perception was captured from the SDD of the sound source and overall soundscape quality indicators. Landscape indices relating to vegetation, buildings, and roads ranged from 20 m to 180 m. Results showed that most landscape indices at different scales were correlated with the SDD and overall soundscape quality in vegetation and building land use. In contrast, fewer landscape indices in road land use were related to the soundscape perception. This indicates that the multi-scale patterns of vegetation and buildings play more critical roles in forming soundscapes in residential areas. Regression models illustrated that the SDD and overall soundscape quality were affected primarily below the 120 m scale. This suggests that landscape planning and design strategies for promoting soundscape quality can be more useful within this scale. However, the scale effects of landscape patterns on the SDD of birdsong, pleasantness, and quietness seemed insignificant. Furthermore, we found that the multi-scale landscape indices can better explain SDD variance than overall soundscape quality. This means that the components determining soundscape quality are more complex. They can hardly be explained only by landscape spatial features, and therefore variables such as sound features and context factors should also be included for interpreting the soundscape quality. We further argue that such variables may account for more important positions than landscape spatial patterns according to the model's explanatory ability. We are confident that our findings can help planners better understand the useful scales for landscape planning and management to improve soundscape perception in residential areas. Moreover, such results can also advance the state of knowledge regarding the relationships between landscapes and soundscapes. This study serves as helpful data support and empirical evidence for urban soundscape planning and design and related studies in the future.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/f14122323/s1.

Author Contributions: Conceptualization and methodology, J.L. and Z.C.; formal analysis, Y.-J.H. and Z.C.; investigation, J.L., Y.-J.H. and X.-C.H.; writing—original draft preparation, J.L., Y.-J.H. and Z.C.; writing—review and editing, J.L., Z.C. and X.-C.H.; supervision, J.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China (52378049, 52208052), and the Program of Humanities and Social Science Research Program of Ministry of Education of China (Grant No. 21YJCZH038).

Data Availability Statement: Data available on request due to restrictions, e.g., privacy or ethical.

Acknowledgments: The authors appreciate the help from Zhen Huang in field investigation.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. World Health Organization; Regional Office for Europe. *Environmental Noise Guidelines for the European Region*; World Health Organization: Geneva, Switzerland; Regional Office for Europe: Copenhagen, Denmark, 2018.
2. Murphy, E.; King, E.A. Strategic environmental noise mapping: Methodological issues concerning the implementation of the EU Environmental Noise Directive and their policy implications. *Environ. Int.* **2010**, *36*, 290–298. [CrossRef] [PubMed]
3. European Union. Directive 2002/49/EC of the European Parliament and the Council of 25 June 2002 relating to the assessment and management of environmental noise. *Off. J. Eur. Communities* **2002**, *2002*, L189.
4. King, E.A.; Murphy, E.; Rice, H.J. Implementation of the EU environmental noise directive: Lessons from the first phase of strategic noise mapping and action planning in Ireland. *J. Environ. Manag.* **2011**, *92*, 756–764. [CrossRef] [PubMed]
5. Raimbault, M.; Dubois, D. Urban soundscapes: Experiences and knowledge. *Cities* **2005**, *22*, 339–350. [CrossRef]
6. Zhang, M.; Kang, J. Towards the Evaluation, Description, and Creation of Soundscapes in Urban Open Spaces. *Environ. Plan. B Plan. Des.* **2007**, *34*, 68–86. [CrossRef]
7. *ISO 12913-1*; 2014 Acoustics—Soundscape—Part 1: Definition and Conceptual Framework. ISO: Geneva, Switzerland, 2014.
8. Kang, J. From dBA to soundscape indices: Managing our sound environment. *Front. Eng. Manag.* **2017**, *4*, 184–192. [CrossRef]
9. Abrantes, E. Perceiving, Navigating and Inhabiting: Performance design through sonic strategies. *Perform. Res.* **2021**, *26*, 31–38. [CrossRef]
10. Aletta, F.; Kang, J. Towards an urban vibrancy model: A soundscape approach. *Int. J. Environ. Res. Public Health* **2018**, *15*, 1712. [CrossRef]
11. Chen, Z.; Hermes, J.; Liu, J.; von Haaren, C. How to integrate the soundscape resource into landscape planning? A perspective from ecosystem services. *Ecol. Indic.* **2022**, *141*, 109156. [CrossRef]
12. Mancini, S.; Mascolo, A.; Graziuso, G.; Guarnaccia, C. Soundwalk, Questionnaires and Noise Measurements in a University Campus: A Soundscape Study. *Sustainability* **2021**, *13*, 841. [CrossRef]
13. *ISO/TS 12913-2*; 2018 Acoustics—Soundscape—Part 2: Data Collection and Reporting Requirements. ISO: Geneva, Switzerland, 2018.
14. Tarlao, C.; Steffens, J.; Guastavino, C. Investigating contextual influences on urban soundscape evaluations with structural equation modeling. *Build. Environ.* **2021**, *188*, 107490. [CrossRef]

15. Mygind, L.; Clark, G.M.; Bigelow, F.J.; Fuller-Tyszkiewicz, M.; Knibbs, L.D.; Mavoa, S.; Flensborg-Madsen, T.; Bentsen, P.; Lum, J.; Enticott, P.G. Green enrichment for better mind readers? Residential nature and social brain function in childhood. *J. Environ. Psychol.* **2023**, *88*, 102029. [CrossRef]
16. Ahmed, S.M.; Mishra, G.D.; Moss, K.M.; Mouly, T.A.; Yang, I.A.; Knibbs, L.D. Association between residential greenspace and health-related quality of life in children aged 0–12 years. *Environ. Res.* **2022**, *214*, 113759. [CrossRef] [PubMed]
17. Cummins, S.; Fagg, J. Does greener mean thinner? Associations between neighbourhood greenspace and weight status among adults in England. *Int. J. Obes.* **2012**, *36*, 1108–1113. [CrossRef] [PubMed]
18. Wang, Z.P.; Wang, W. An empirical study on the impact of green spaces in residential areas on the mental health of residents under COVID-19. *Landsc. Archit. Front.* **2020**, *8*, 46–59. [CrossRef]
19. Xiao, Y.; Miao, S.; Zhang, Y.; Chen, H.; Wu, W. Exploring the health effects of neighborhood greenness on Lilong residents in Shanghai. *Urban For. Urban Green.* **2021**, *66*, 127383. [CrossRef]
20. Mediastika, C.E.; Sudarsono, A.S.; Kristanto, L.; Tanuwidjaja, G.; Sunaryo, R.G.; Damayanti, R. Appraising the sonic environment of urban parks using the soundscape dimension of visually impaired people. *Int. J. Urban Sci.* **2020**, *24*, 216–241. [CrossRef]
21. Guo, L.H.; Cheng, S.; Liu, J.; Wang, Y.; Cai, Y.; Hong, X.C. Does social perception data express the spatio-temporal pattern of perceived urban noise? A case study based on 3,137 noise complaints in Fuzhou, China. *Appl. Acoust.* **2022**, *201*, 109129. [CrossRef]
22. Singh, D.; Kumari, N.; Sharma, P. A review of adverse effects of road traffic noise on human health. *Fluct. Noise Lett.* **2018**, *17*, 1830001. [CrossRef]
23. Tobías, A.; Recio, A.; Díaz, J.; Linares, C. Health impact assessment of traffic noise in Madrid (Spain). *Environ. Res.* **2015**, *137*, 136–140. [CrossRef]
24. Dzhambov, A.M.; Markevych, I.; Hartig, T.; Tilov, B.; Arabadzhiev, Z.; Stoyanov, D.; Gatseva, P.; Dimitrova, D.D. Multiple pathways link urban green- and bluespace to mental health in young adults. *Environ. Res.* **2018**, *166*, 223–233. [CrossRef] [PubMed]
25. Guo, X.; Liu, J.; Chen, Z.; Hong, X.-C. Harmonious Degree of Sound Sources Influencing Visiting Experience in Kulangsu Scenic Area, China. *Forests* **2023**, *14*, 138. [CrossRef]
26. Liu, J.; Kang, J.; Behm, H.; Luo, T. Effects of landscape on soundscape perception: Soundwalks in city parks. *Landsc. Urban Plan.* **2014**, *123*, 30–40. [CrossRef]
27. Brambilla, G.; Gallo, V.; Zambon, G. The Soundscape Quality in Some Urban Parks in Milan, Italy. *Int. J. Environ. Res. Public Health* **2013**, *10*, 2348–2369. [CrossRef] [PubMed]
28. Hong, X.C.; Cheng, S.; Liu, J.; Dang, E.; Wang, J.B.; Cheng, Y. The Physiological Restorative Role of Soundscape in Different Forest Structures. *Forests* **2022**, *13*, 1920. [CrossRef]
29. Matsinos, Y.G.; Mazaris, A.D.; Papadimitriou, K.D.; Mniestris, A.; Hatzigiannidis, G.; Maioglou, D.; Pantis, J.D. Spatio-temporal variability in human and natural sounds in a rural landscape. *Landsc. Ecol.* **2008**, *23*, 945–959. [CrossRef]
30. Liu, J.; Kang, J.; Luo, T.; Behm, H.; Coppack, T. Spatiotemporal variability of soundscapes in a multiple functional urban area. *Landsc. Urban Plan.* **2013**, *115*, 1–9. [CrossRef]
31. Liu, J.; Kang, J.; Behm, H.; Luo, T. Landscape spatial pattern indices and soundscape perception in a multi-functional urban area, Germany. *J. Environ. Eng. Landsc. Manag.* **2014**, *22*, 208–218. [CrossRef]
32. Wu, J. Effects of changing scale on landscape pattern analysis: Scaling relations. *Landsc. Ecol.* **2004**, *19*, 125–138. [CrossRef]
33. He, X.; Deng, Y.; Dong, A.; Lin, L. The relationship between acoustic indices, vegetation, and topographic characteristics is spatially dependent in a tropical forest in southwestern China. *Ecol. Indic.* **2022**, *142*, 109229. [CrossRef]
34. Scarpelli, M.D.A.; Ribeiro, M.C.; Teixeira, C.P. What does Atlantic Forest soundscapes can tell us about landscape? *Ecol. Indic.* **2021**, *121*, 107050. [CrossRef]
35. Sangermano, F. Acoustic diversity of forested landscapes: Relationships to habitat structure and anthropogenic pressure. *Landsc. Urban Plan.* **2022**, *226*, 104508. [CrossRef]
36. Mao, Q.; Sun, J.; Deng, Y.; Wu, Z.; Bai, H. Assessing Effects of Multi-Scale Landscape Pattern and Habitats Attributes on Taxonomic and Functional Diversity of Urban River Birds. *Diversity* **2023**, *15*, 486. [CrossRef]
37. Uebel, K.; Marselle, M.; Dean, A.J.; Rhodes, J.R.; Bonn, A. Urban green space soundscapes and their perceived restorativeness. *People Nat.* **2021**, *3*, 756–769. [CrossRef]
38. Hedblom, M.; Heyman, E.; Antonsson, H.; Gunnarsson, B. Bird song diversity influences young people's appreciation of urban landscapes. *Urban For. Urban Green.* **2014**, *13*, 469–474. [CrossRef]
39. Li, J.; Zhang, Z.; Jing, F.; Gao, J.; Ma, J.; Shao, G.; Noel, S. An evaluation of urban green space in Shanghai, China, using eye tracking. *Urban For. Urban Green.* **2020**, *56*, 126903. [CrossRef]
40. Liu, J.; Kang, J.; Luo, T.; Behm, H. Landscape effects on soundscape experience in city parks. *Sci. Total Environ.* **2013**, *454–455*, 474–481. [CrossRef] [PubMed]
41. Hasegawa, Y.; Lau, S.-K. Comprehensive audio-visual environmental effects on residential soundscapes and satisfaction: Partial least square structural equation modeling approach. *Landsc. Urban Plan.* **2022**, *220*, 104351. [CrossRef]
42. *GB50180-2018*; Standard for Urban Residential Area Planning and Design. Ministry of Housing and Urban-Rural Development, State Administration for Market Regulation: Beijing, China, 2018.

43. Chen, Z.; Zhu, T.-Y.; Liu, J.; Hong, X.-C. Before Becoming a World Heritage: Spatiotemporal Dynamics and Spatial Dependency of the Soundscapes in Kulangsu Scenic Area, China. *Forests* **2022**, *13*, 1526. [CrossRef]
44. Liu, J.; Xiong, Y.; Wang, Y.; Luo, T. Soundscape effects on visiting experience in city park: A case study in Fuzhou, China. *Urban For. Urban Green.* **2018**, *31*, 38–47. [CrossRef]
45. Li, W.; Zhai, J.; Zhu, M. Characteristics and perception evaluation of the soundscapes of public spaces on both sides of the elevated road: A case study in Suzhou, China. *Sustain. Cities Soc.* **2022**, *84*, 103996. [CrossRef]
46. Strohbach, M.W.; Lerman, S.B.; Warren, P.S. Are small greening areas enhancing bird diversity? Insights from community-driven greening projects in Boston. *Landsc. Urban Plan.* **2013**, *114*, 69–79. [CrossRef]
47. Wong, J.S.Y.; Soh, M.C.K.; Low, B.W.; Kenneth, B.H.E. Tropical bird communities benefit from regular-shaped and naturalised urban green spaces with water bodies. *Landsc. Urban Plan.* **2023**, *231*, 104644. [CrossRef]
48. Garizábal-Carmona, J.A.; Mancera-Rodríguez, N.J. Bird species richness across a Northern Andean city: Effects of size, shape, land cover, and vegetation of urban green spaces. *Urban For. Urban Green.* **2021**, *64*, 127243. [CrossRef]
49. Dzhambov, A.M.; Dimitrova, D.D. Urban green spaces' effectiveness as a psychological buffer for the negative health impact of noise pollution: A systematic review. *Noise Health* **2014**, *16*, 157. [CrossRef]
50. Hong, J.Y.; Lam, B.; Ong, Z.-T.; Ooi, K.; Gan, W.-S.; Kang, J.; Yeong, S.; Lee, I.; Tan, S.-T. Effects of contexts in urban residential areas on the pleasantness and appropriateness of natural sounds. *Sustain. Cities Soc.* **2020**, *63*, 102475. [CrossRef]
51. Liu, J.; Kang, J.; Behm, H. Birdsong as an element of the urban sound environment: A case study concerning the area of Warnemünde in Germany. *Acta Acust. United Acust.* **2014**, *100*, 458–466. [CrossRef]
52. Kurze, U.J.; Anderson, G.S.J.N.; Principles, V.C.E. Applications. Outdoor sound propagation. In *Noise and Vibration Control Engineering: Principles and Applications*, 2nd ed.; Wiley: Hoboken, NJ, USA, 2006; pp. 119–144. [CrossRef]
53. Han, X.; Huang, X.; Liang, H.; Ma, S.; Gong, J. Analysis of the relationships between environmental noise and urban morphology. *Environ. Pollut.* **2018**, *233*, 755–763. [CrossRef] [PubMed]
54. Guedes, I.C.M.; Bertoli, S.R.; Zannin, P.H.T. Influence of urban shapes on environmental noise: A case study in Aracaju—Brazil. *Sci. Total Environ.* **2011**, *412–413*, 66–76. [CrossRef]
55. Salomons, E.M.; Berghauser Pont, M. Urban traffic noise and the relation to urban density, form, and traffic elasticity. *Landsc. Urban Plan.* **2012**, *108*, 2–16. [CrossRef]
56. Amaya-Espinel, J.D.; Hostetler, M.; Henríquez, C.; Bonacic, C. The influence of building density on Neotropical bird communities found in small urban parks. *Landsc. Urban Plan.* **2019**, *190*, 103578. [CrossRef]
57. Benítez-López, A.; Alkemade, R.; Verweij, P.A. The impacts of roads and other infrastructure on mammal and bird populations: A meta-analysis. *Biol. Conserv.* **2010**, *143*, 1307–1316. [CrossRef]
58. Cooke, S.C.; Balmford, A.; Johnston, A.; Newson, S.E.; Donald, P.F. Variation in abundances of common bird species associated with roads. *J. Appl. Ecol.* **2020**, *57*, 1271–1282. [CrossRef]
59. Yu, W.L.; Kang, J. Relationship between traffic noise resistance and village form in China. *Landsc. Urban Plan.* **2017**, *163*, 44–55. [CrossRef]
60. Aletta, F.; Kang, J.; Fuda, S.; Astolfi, A. The effect of walking sounds from different walked-on materials on the soundscape of urban parks. *J. Environ. Eng. Landsc. Manag.* **2016**, *24*, 165–175. [CrossRef]
61. Payne, S.R.; Bruce, N. Exploring the Relationship between Urban Quiet Areas and Perceived Restorative Benefits. *Int. J. Environ. Res. Public Health* **2019**, *16*, 1611. [CrossRef] [PubMed]
62. Ren, Z.; Jiang, B.; Seipel, S. Capturing and characterizing human activities using building locations in America. *ISPRS Int. J. Geo-Inf.* **2019**, *8*, 200. [CrossRef]
63. Miller, S.A. Parents' attributions for their children's behavior. *Child Dev.* **1995**, *66*, 1557–1584. [CrossRef]
64. Hong, J.Y.; Jeon, J.Y. Relationship between spatiotemporal variability of soundscape and urban morphology in a multifunctional urban area: A case study in Seoul, Korea. *Build. Environ.* **2017**, *126*, 382–395. [CrossRef]
65. Sakieh, Y.; Jaafari, S.; Ahmadi, M.; Danekar, A. Green and calm: Modeling the relationships between noise pollution propagation and spatial patterns of urban structures and green covers. *Urban For. Urban Green.* **2017**, *24*, 195–211. [CrossRef]
66. Irvine, K.N.; Devine-Wright, P.; Payne, S.R.; Fuller, R.A.; Painter, B.; Gaston, K.J. Green space, soundscape and urban sustainability: An interdisciplinary, empirical study. *Local Environ.* **2009**, *14*, 155–172. [CrossRef]
67. Hewett, D. *Sound Propagation in an Urban Environment*; Oxford University: Oxford, UK, 2010.
68. Wu, J.; Zou, C.; He, S.; Sun, X.; Wang, X.; Yan, Q. Traffic noise exposure of high-rise residential buildings in urban area. *Environ. Sci. Pollut. Res.* **2019**, *26*, 8502–8515. [CrossRef] [PubMed]
69. Ow, L.F.; Ghosh, S. Urban cities and road traffic noise: Reduction through vegetation. *Appl. Acoust.* **2017**, *120*, 15–20. [CrossRef]
70. Coensel, B.D.; Vanwetswinkel, S.; Botteldooren, D. Effects of natural sounds on the perception of road traffic noise. *J. Acoust. Soc. Am.* **2011**, *129*, EL148–EL153. [CrossRef]
71. Wu, J.-G. *Landscape Ecology: Pattern, Process, Scale and Hierarchy*; Higher Education Press: Beijing, China, 2000.
72. Jaszczak, A.; Pochodyła, E.; Kristianova, K.; Małkowska, N.; Kazak, J.K. Redefinition of Park Design Criteria as a Result of Analysis of Well-Being and Soundscape: The Case Study of the Kortowo Park (Poland). *Int. J. Environ. Res. Public Health* **2021**, *18*, 2972. [CrossRef]

73. Hamilton, K.L.; Kaczynski, A.T.; Fair, M.L.; Lévesque, L. Examining the Relationship between Park Neighborhoods, Features, Cleanliness, and Condition with Observed Weekday Park Usage and Physical Activity: A Case Study. *J. Environ. Public Health* **2017**, *2017*, 7582402. [CrossRef]
74. Lauro, E.D.; Falanga, M.; Lalli, L.T. The soundscape of the Trevi fountain in COVID-19 silence. *Noise Mapp.* **2020**, *7*, 212–222. [CrossRef]