How Green Landscape Factors Influence Soundscape Evaluation in Urban Fringe Residential Areas

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The ongoing expansion of Chinese cities has led to the growth of urban fringe residential areas. However, green landscapes and soundscapes in these zones are under pressure owing to factors such as housing prices and high-speed traffic. Therefore, the focus of this study is to explore how green landscape factors influence soundscape in urban fringe residential areas. On-site sound environment measurements and a questionnaire survey on perceptions of green landscapes and soundscapes are conducted in the public spaces of 15 typical urban fringe residential areas near Tianjin's outer ring road. The results indicate that: (1) The overall evaluation of soundscape perception in urban fringe residential areas is low, which vary significantly across different spatial types; the core green areas present moderate pleasantness (0.02) and low eventfulness (-0.20), the central squares exhibit high pleasantness (0.05) and moderate eventfulness (-0.15), and public spaces along the streets demonstrate low pleasantness (-0.02) and high eventfulness (0.02); (2) Shannon's diversity index (SHDI) and greening rate (GR) have a positive effect on soundscape pleasantness; the GR and the landscape shape index (LSI) are significantly negatively correlated with soundscape eventfulness; and subjective perception factors have a positive impact on pleasantness; (3) The path analysis of the structural equation model (SEM) support that green landscape perception factors exert a direct positive effect on soundscape pleasantness, whereas objective green landscape factors and spatial environmental perceptions influence pleasantness indirectly through the perception of green landscapes. This study offers theoretical and methodological support for optimizing the green space planning and soundscape of public areas in high-density urban fringe neighborhoods.

1. INTRODUCTION

Noise has emerged as the second-largest urban pollutant, with only air pollution being a larger problem. Prolonged exposure to high-intensity noise can lead to symptoms such as dizziness and neurasthenia, and in extreme cases, may even lead to chronic conditions such as cardiovascular and cerebrovascular diseases.[1,2] According to a report from the Ministry of Ecology and Environment of the People's Republic of China (2021), one-third of cities experience daytime traffic noise levels that exceed the standard limit.[3] Notably, in 2023, approximately one-third of all noise complaints nationwide originated from high-density cities, with noise from social life noise accounting for the largest proportion at 68.4 %.[4] The urban fringe is the transitional zone between urban and rural areas in terms of land use and population characteristics.[5] It has characteristics of both urban and rural areas, and its population density is lower than that of the central urban area but higher than that of the surrounding rural areas.[5,6] Urban fringe residential areas, which are situated on the outskirts of cities, often border urban outer ring roads or industrial parks.[7] These areas are characterized by a fragile ecological environment and subpar internal living conditions.[8,9] A United Nations Environment Programme (UNEP) report highlights that individuals residing near environmental stressors, such as industrial zones or heavily trafficked routes, are more vulnerable to noise pollution.[10] Consequently, addressing noise prevention and control in urban fringe residential areas of high-density cities is imperative.

Previous research has examined how factors such as traffic organization, spatial form, and building layout influence noise attenuation in residential areas.[11–13] However, merely lowering sound pressure levels fails to address residents' broader concerns about noise. Instead, a holistic approach to optimizing the sound environment—considering both subjective experiences and objective measurements—should be prioritised.[14,15] The "soundscape" is defined as an "acoustic environment as perceived or experienced and/ or understood by a person or people, in context",[16] highlighting the importance of environmental perceptions in understanding human–environment interactions. Selecting suitable soundscape descriptors, including loudness, annoyance, quietness, pleasantness and suitability, aids in better comprehending the sound environment.[15] Axelsson et al. introduced a two-dimensional "pleasantness-eventfulness" model for assessing the perceived affective quality of soundscapes, which includes eight adjectives: calm, pleasant, vibrant, eventful, chaotic, annoying, monotonous, and uneventful.[14] ISO has integrated emotional perception dimensions and overall soundscape assessments into the standards for soundscape evaluation, offering standardized questionnaires and analytical methods.[17,18]

As a key element of residential public spaces, green landscapes not only mitigate noise levels through their abundant vegetation but also enhance the soundscape experience.[19–22] The tranquility that people feel in these landscaped areas can alleviate anxiety, reduce irritation, and relieve stress.[23,24] Additionally, green landscapes can reveal patterns within the soundscape. Metrics such as Patch Density, Landscape Shape Index, Shannon's Diversity Index, woodland density, and distance to water bodies are correlated with biological and human sounds to varying extents.[25] Alterations in landscape characteristics, including land use,[26] vegetation density,[27] and the built environment,[28] can impact organism habitats and ecosystem dynamics, subsequently influencing how humans perceive the soundscape.

Recent research has underscored the significance of subjective perceptions of green landscapes, encompassing aspects such as aesthetics, quantity, and quality. In older residential areas, greening satisfaction and architectural aesthetics positively influence the perceived pleasantness and comfort of the soundscape.[29,30] The more green vegetation that individuals observe[28,31,32] and the greater the degree of space openness,[33,34] the more comfortable and pleasant their perception of the soundscape becomes. In an environmental health survey conducted in Helsinki, Finland's capital, Pasanen et al. examined the interactions among road traffic noise, green spaces, tree cover density, views of greenery from homes, noise sensitivity, and noise annoyance. Their findings revealed that when traffic noise levels were less than 60 dBA, homes surrounded by more green spaces and denser tree cover experienced lower levels of traffic noise annoyance.[35] It can be seen that the quality of green landscape plays an important role in the perception of soundscape. However, existing studies that focused solely on the impact of single-dimensional indicators on soundscape may underestimate the comprehensive effects of both objective and subjective green landscape elements. It is essential to examine the objective indicators and subjective perception of green landscape to fully understand the comprehensive effects on soundscape, and such insights are expected to promote the high-quality planning and construction of green space and living environment.

Although the importance of soundscape has been widely recognized, most studies have focused on parks[20,36,37] and streets,[38,39] and few have paid attention to the specific space of urban fringe residential areas. Considering the complexity of urban spaces, soundscape characteristics vary across different functional spaces, and existing research cannot be fully applied to other types of spaces. Since 2000, residential construction in large Chinese cities has followed pronounced suburbanization trends, with urban fringe residential areas emerging in suburbs far from the city center, accommodating both residential and some work-related functions. Unlike residential areas in urban centers, urban fringe residential areas are characterized by a complex demographic mix,[40] a fragile ecological environment,[41] and severe environmental pollution.[42] Noise has become a significant negative environmental problem in this residential area,[10] which seriously affects the residents' soundscape perception. Moreover, due to varying construction periods, the green landscape patterns in urban fringe residential areas vary considerably. Urban fringe residential areas that were built earlier are typically smaller in scale and lack a systematic green landscape, whereas newer developments prioritise comprehensive planning and emphasize a hierarchical arrangement of green spaces. This means that the green landscape of urban fringe residential areas has a special influence on the perception of soundscape, so it is necessary to examine this question.

In conclusion, existing studies lack attention to soundscape in urban fringe residential areas and comprehensive consideration of the impact of both subjective and objective green landscape elements on soundscape. This study aims to fill these gaps by assessing the soundscape features of urban fringe residential areas in high-density cities and the influences of green landscapes on soundscape evaluation. This study investigated:

1. the soundscape characteristics of these urban fringe residential areas,
2. the correlation between green landscape factors and soundscape evaluation,
3. the paths through which green landscape factors influence soundscape evaluation.

2. METHODS

2.1. Selection of Study Sites

Tianjin, the largest coastal city in northern China, exhibits typical high-density urban characteristics. As the city expands outwards from its center, the population in urban fringe residential areas continues to grow steadily. The Seventh National Population Census[43] revealed that the urban population share in the central city dropped from 33.56 % to 29.26 %, while the proportion in the four surrounding districts rose from 19.45 % to 28.05 %. This study selects the four districts of the ring city as the urban fringe, including Beichen District, Xiqing District, Dongli District and Jinnan District, which are the important hub connecting the central and the outer rural areas. Tianjin boasts a considerable number of urban fringe residential areas, predominantly situated near the city's outer ring road and expressways, where noise pollution stands out as a significant drawback. The selection of residential areas follows these principles:

1. the residential areas should be in use and have relatively complete facilities;
2. the public spaces of the residential area should be well planned with diverse and representative characteristics.

As illustrated in Fig. 1(a), this study selected 15 well-developed and operational peripheral residential areas near the outer ring road in the four urban fringe areas. As detailed in Table 1, most of these residential areas were constructed after

2000, spanning areas ranging from 3.0 to 17.5 hectares. The residential types encompass multi-story, high-rises, and a mix of both, with notable variations in internal greening conditions across these areas. According to relevant research, core green areas (G), central squares (SQ), and public spaces along the streets (ST) are primary outdoor activity venues for residents in residential areas.[29,44] As depicted in Fig. 1(b), 30 public spaces are selected as subjects based on their greening quality and spatial type. These include G1–G10 for core green areas, SQ1–SQ10 for central squares, and ST1–ST10 for public spaces along the streets.

2.2. Soundscape Evaluation

2.2.1. Selection of Evaluation Indicators

The first part of the soundscape questionnaire focused on types of sound sources. Drawing from the soundscape evaluation standard[17] and considering the sound environment characteristics of urban fringe residential areas, in this study, four types of sound sources were used: traffic noise, human sounds, natural sounds, and other noise.[17] The respondents were presented with five response options (not at all, a little, moderately, a lot, and dominants completely), each corresponding to a score of “1, 2, 3, 4, or 5”. The median values should be reported as the measure of central tendency in ISO 12913-3:2025.[18]

The second section of the questionnaire focused on the perceived affective quality of the soundscape. The respondents were asked to rate the emotional dimensions of the soundscape using eight adjectives: pleasant, annoying, eventful, uneventful, calm, chaotic, monotonous, or vibrant. They indicated the extent to which each dimension applied, with options of “strongly agree”, “agree”, “neither agree, nor disagree”, “disagree”, and “strongly disagree” corresponding to scores of “5”, “4”, “3”, “2”, and “1”, respectively. According to ISO 12913-3,[18] the results were processed to derive the values on two dimensions for each response—pleasantness (P) and eventfulness (E). Results can be reported in a two-dimensional scatter plot with coordinates for the two dimensions P and E. The coordinates for P were plotted on the x axis, and the coordinates for E on the y axis, using the following formulas:

$$P = \frac{1}{\lambda_P} \sum_{i=1}^{8} \cos(\theta_i) \cdot \xi_i; \tag{1}$$

$$E = \frac{1}{\lambda_E} \sum_{i=1}^{8} \sin(\theta_i) \cdot \xi_i; \tag{2}$$

where i indexed each circumplex scale moving counterclockwise around the circumplex. When applying Eqs. (1) and (2), it is recommended to use the adjusted angles given in ISO 12913-3[18] to ensure the accuracy of soundscape assessment. θ was the angle for the circumplex attribute, and "ξ" was the response value for the attribute in the range. Since this study was conducted in China, the adjusted angles for Chinese (Mandarin) are given below: $\theta_1 = 0°$ is pleasant, $\theta_2 = 18°$ is vibrant, $\theta_3 = 38°$ is eventful, $\theta_4 = 154°$ is chaotic, $\theta_5 = 171°$ is annoying, $\theta_6 = 196°$ is monotonous, $\theta_7 = 217°$ is uneventful, $\theta_8 = 318°$ is calm.

In Eqs. (1) and (2), $\cos(\theta_i)$ was used as a trigonometric projection function to adjust for the $45°$ rotation in the two-dimensional model. λ provides a scaling factor to bring the range of P and E values to $[-1, +1]$:

$$\lambda_P = \frac{\rho}{2} \sum_{i=1}^{8} |\cos(\theta_i)|; \tag{3}$$

$$\lambda_E = \frac{\rho}{2} \sum_{i=1}^{8} |\sin(\theta_i)|; \tag{4}$$

where ρ was the range of the response values $(5 - 1 = 4)$.

The third part of the questionnaire involved an overall assessment of the on-site sound environment. The respondents were asked, “Overall, how would you describe the present surrounding sound environment?” They were then instructed to select a rating from 5 to 1, where 5 represented “very good”, 4 “good”, 3 “neither good, nor bad”, 2 “bad” and 1 “very bad”.

2.2.2. Soundscape Survey

The soundscape survey took place from November 29, 2024, to December 15, 2024, between 9 a.m. and 5 p.m. During this period, the weather was favorable, with comfortable temperatures and no wind. The surveyors adhered strictly to the guidelines set forth in the soundscape survey standard to document the physical parameters of each sampling space.[17] As respondents completed the questionnaire, staff members used BHS II headphones for audio recording and an HS5671B noise spectrum analyzer to measure sound pressure levels. The testing equipment was positioned 1.6 meters above the ground and at least 1 meter away from any reflective surfaces. Each measurement session lasted for 5 minutes. Prior to the measurements, both the BHS II headphones and the sound level meter were calibrated using a HS5620 calibrator. Following the measurements, the SQobold SQP 01 FFT software was used to report the acoustic environment. Parameters such as the Loudness Average (Navg), Loudness Cubic Mean (Nrmc), N_5, N_{95}, $L_{Aeq,T}$, $L_{Ceq,T}$, $L_{AF5,T}$, and $L_{AF95,T}$ were extracted and output for further evaluation. This study aims to reveal the important influence of subjective and objective greening landscape factors on soundscape perception. The physical acoustic parameters, which are important indicators to describe the objective sound environment, will be presented in the descriptive analysis in Section 3, but will not be used as the observation variables in the SEM.

2.3. Selection of Green Landscape Indicators

2.3.1. Selection of Objective Green Landscape Indicators

The status quo of the three land use types within the study area was vectored in ArcGIS10.6, 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 Tianjin Urban Planning and Design Research Institute, as well as street view maps, and on-site investigations. Drawing on the public space morphology and greening characteristics of urban fringe residential areas, three indices—the greening rate (GR),[21,45] Landscape Shape Index

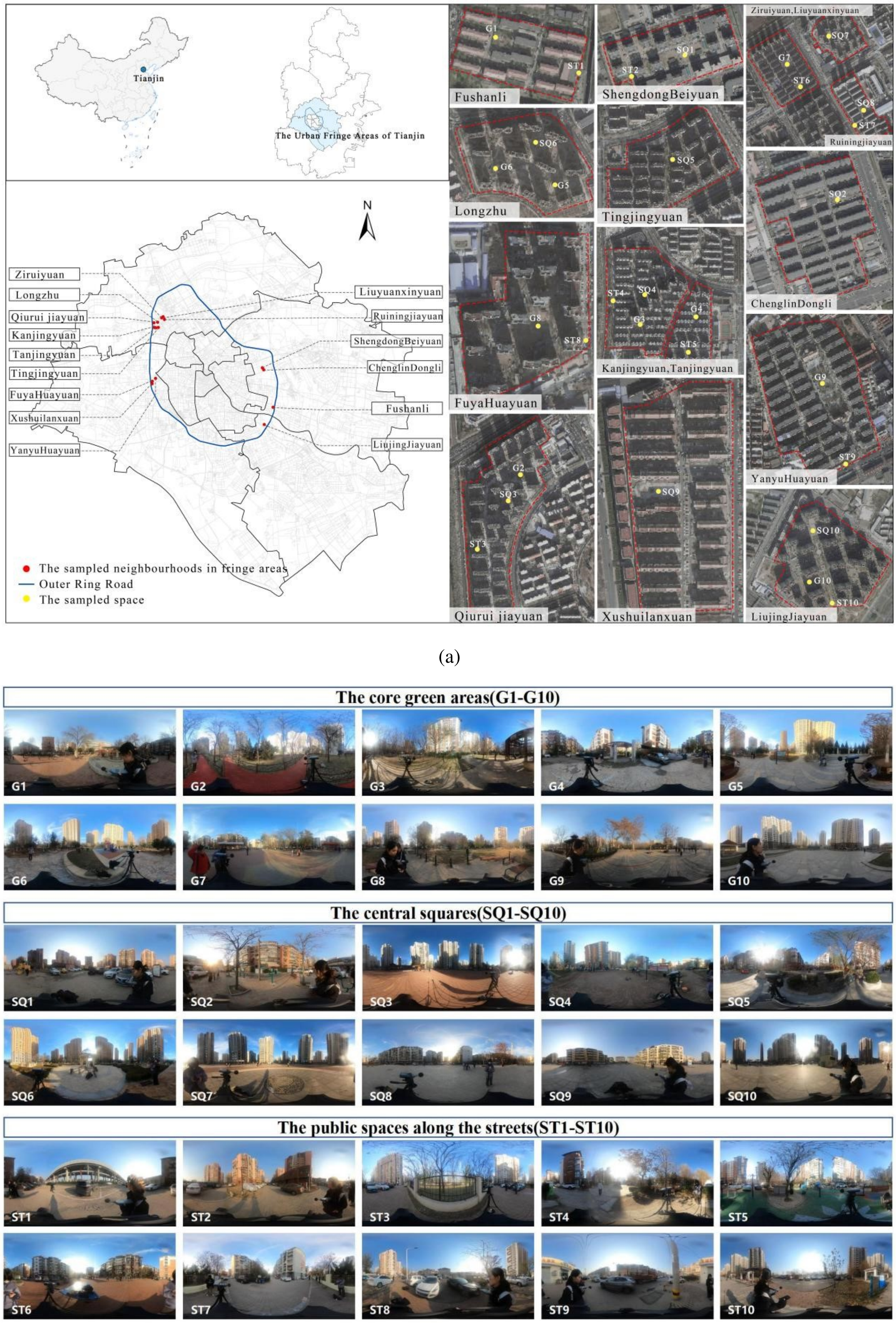

Figure 1. Selection of typical urban fringe residential areas and sampled space: a) the location of the sampled residential areas and b) sampled space photos.

Table 1. Information on the sampled urban fringe residential areas.

The name of neighbourhood	Administrative division	Building construction age	Land area (ha)	Layer number (F)	Plot ratio	Greening rate
Qiuruijiayuan	Beichen District	2006	16.08	8–17	2.0	30%
Kanjingyuan		2008	11.44	6–18	1.3	20 %
Liuyuanxinyuan		2008	6.73	11/18	2.0	38 %
Ruiningjiayuan		2006	7.6	6/20	1.9	45 %
Ziruiyuan		2007	12.27	6/18	1.7	38 %
Longzhu		2015	9.86	18–30	2.0	65 %
Tanjingyuan		2006	6.18	6/11	1.3	36 %
Tingjingyuan		2008	10.24	6/11	1.6	46 %
Xushuilanxuan	Xiqing District	2004	9.74	6/15	1.12	30 %
Yanyuhuayuan		2002	16.1	6	1.22	36 %
Fuyahuayuan		2005	7.5	11–18	3.2	30 %
Shengdongbeiyuan	Dongli District	2012	7.48	13	1.2	25 %
Chenglindongli		2003	9.04	6	1.6	15 %
Fushanli		1996	3.25	6	1.55	15 %
Liujingjiayuan	Jinnan District	2004	17.5	18–27	3.0	30 %

(LSI),[12] and Shannon's Diversity Index (SHDI)[46]—were selected for evaluating the green landscape pattern. Table 2 outlines the descriptions and calculation formulas for these indicators. To accurately capture the green landscape features of the sampled areas, a 100-metre buffer zone was designated as the study unit, taking into account the sound propagation characteristics and insights from prior research.[47–49] The landscape pattern indicators were computed using Fragstats 4.2 software.

Figure 2 displays the statistics of the green landscape pattern indicators for the sampled spaces. The average GR across these spaces ranges from 40 % to 60 %, with core green areas exhibiting the highest rate, followed by central squares, and public spaces along the streets showing the lowest rate. Notably, there are substantial differences in the LSI among the various space types. Square spaces register the highest values for this index, followed by core green areas, whereas the public spaces along the streets have the lowest values. In contrast to the GR and LSI, public spaces along the streets have the highest SHDI, followed by square spaces and core green areas having the lowest.

2.3.2. Selection of Green Landscape Perception Indicators

The relevant studies have summarized the natural,[50] aesthetic,[39] openness,[39] cleanliness[30] and diversity[30,50] as the important landscape perception quality. These indicators, as the basis of perception evaluation, are widely used in landscape assessment and planning design and have been verified.[51] Considering the spatial characteristics of urban fringe residential areas, this study selected five indicators for evaluation: greening satisfaction, greening diversity, environmental cleanliness, architectural aesthetics, and spatial openness. Greening satisfaction measures respondents' overall perception of green landscape; green diversity indicates the richness of greenery configuration; environmental cleanliness reflects the overall quality and hygiene standards of spaces; architectural aesthetics assesses the style and visual appeal of public spaces; spatial openness evaluates the openness and obstruction of visual environments in public spaces. The respondents rated these dimensions on a 5-point Likert scale, where 1 indicated "very poor" and 5 indicated "very good."

Figure 3 shows the statistics of the scores for each perceived factor. Overall, only about 30 % of respondents reported positive perceptions of green landscape, with all spaces rated as "neutral" in perceived quality. In greening diversity, the central squares(SQs) received only 21 % positive ratings("good"=4, "very good"=5), while the public spaces along streets(STs) scored merely 17 %. In greening satisfaction, the core green areas(Gs) performed better at 45 %, whereas the other two showed lower levels, due to their lack of vegetation coverage and predominantly artificial construction. In terms of environmental cleanliness, STs received the lowest positive ratings at just 23 %. For architectural aesthetics, all sampled points across spaces averaged around 30 %, with each space maintaining consistent openness.

2.4. Respondent Characteristics

During the survey, questionnaires were randomly distributed to the residents in the sampled spaces on a voluntary basis. A total of 462 valid questionnaires were collected from 30 sampling points, with 15-20 questionnaires distributed per site. Table 3 outlines the basic information of the respondents. The survey reveals a balanced gender ratio among respondents, with the majority being middle-aged and elderly individuals. In terms of education, more than 30 % of the respondents had completed high school or junior college. Most residents reported frequent activity in the sampled areas. Regarding the duration of their visits, the largest proportion falls within the "0.5–1 hour" range, followed closely by the "1–2 hours" category.

2.5. Statistical Analysis

Firstly, IBM SPSS Statistics 26 was used to investigate the basic characteristics and overall trends of the data. Secondly, Spearman's correlation analysis was applied to assess the relationship between green landscape factors and soundscape perception. Finally, based on exploratory factor analysis and confirmatory factor analysis, a structural equation model (SEM) was constructed to reveal the influence path between variables and the direct and indirect effects. The statistical software package IBM SPSS AMOS 26 was used to analyze SEM. The SEM serves as an advanced form of multiple regression model, effectively analyzing the interrelationships among variables. It has been extensively applied across disciplines such as psychology, sociology, and economics.[52–55]

Table 2. Calculation of objective green landscape indicators.

Indicators	Description	Formula	Explanation
Greening Rate (GR)	The proportion of green space in the unit	$GR = \frac{\sum_{i=1}^{n} a_i}{A}$	n is the number of green patches, a_i is the area of patch i, and A is the total area of the study unit
Landscape Shape Index (LSI)	The complexity of the shape of a green landscape in the unit, indicating green landscape fragmentation	$LSI = \frac{0.25 \times \sum_{i=1}^{n} e_i}{\sqrt{A}}$	e_i is the total length of the boundary of patch i
Shannon's Diversity Index (SHDI)	The diversity of landscape types in the unit	$SHDI = -\sum_{i=1}^{n}(P_i \times \ln P_i)$	P_i is the proportion of the total area of green space in the unit

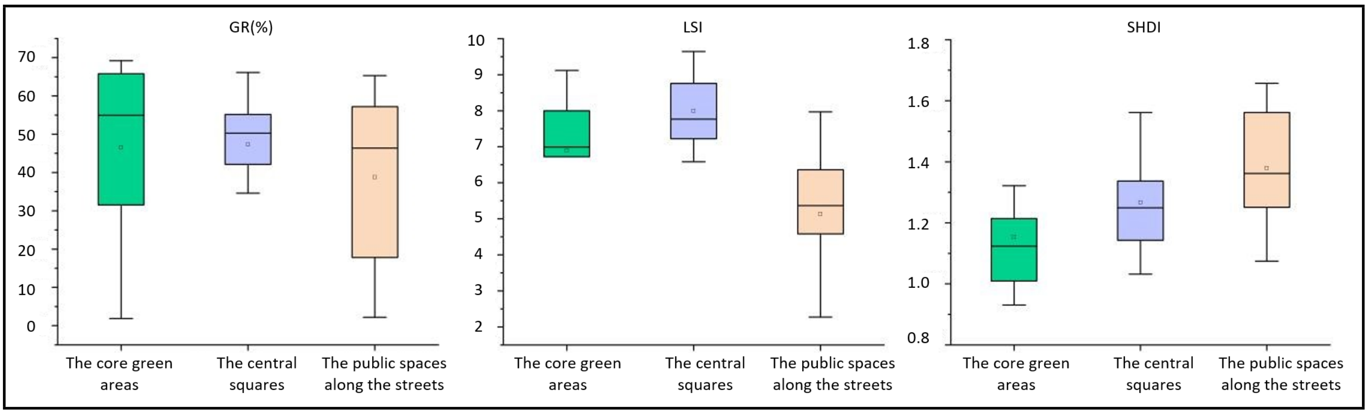

Figure 2. Results of the objective green landscape indicators.

Table 3. Descriptive statistics of participants' demographic characteristics. ($N = 462$)

Description	Division	Total / Proportion (%)
Gender	Male	197 (42.6 %)
	Female	265 (57.4 %)
Age	< 18	12 (2.5 %)
	18–35	90 (19.5 %)
	35–60	198 (42.9 %)
	> 60	162 (35.1 %)
Education level	Junior high school and below	69 (15 %)
	High school / technical secondary school	140 (30.3 %)
	Junior college	146 (31.6 %)
	Undergraduate	97 (21 %)
	Postgraduate	10 (2.1 %)
Activity frequency	First time	12 (2.6 %)
	Sometimes	125 (27 %)
	Often	210 (45.5 %)
	Always	114 (24.7 %)
	Never	1 (0.2 %)
Length of stay	< 0.5 h	73 (15.8 %)
	0.5–1 h	215 (46.5 %)
	1–2 h	122 (26.4 %)
	> 2 h	52 (11.3 %)

3. RESULTS

3.1. Soundscape Characteristics of Urban Fringe Residential Areas

3.1.1. Statistics of Sound Source Perception and Acoustic Indicators

Figure 4 displays the statistics of the sound sources in each sampled space within urban fringe residential areas. The percentages indicate the ratio of subjects who responded "a lot" or "dominates completely" for each sound source. Because the locations of urban fringe residential areas are closer to roads, traffic noise in general is most prominent, followed by human sounds, other noise and nature sounds. The results of one-way ANOVA showed that there were significant differences in the perceived scores of traffic noise ($p < 0.01$, $\eta^2 \approx 0.08$) and human sounds ($p < 0.01$, $\eta^2 \approx 0.04$) among three types of public spaces, while no significant differences are found in natural sounds and other noise. At G1, G2, G10, SQ2 and most public spaces along the streets (STs), the perception rate of traffic noise exceeded 60 %, with 93.3 % of respondents identifying it as the predominant noise. A closer examination of specific spaces reveals that in spaces such as G3, G5, G7, G9, SQ5, SQ7, SQ9, SQ10, ST6, and ST10, human sounds surpass traffic noise. This is attributed to activities such as square dancing and singing that occur in these locations.

Figure 5(a) shows the equivalent sound pressure levels recorded in each sampled space within urban fringe residential areas. The Kruskal-Wallis test revealed statistically significant differences in equivalent sound pressure levels ($p < 0.001$) across spatial types. The equivalent sound pressure level ranged for the core green spaces (G1-G10) was $50.7-66.7$ dBA, with a mean value of 55.1 dBA; while the central squares (SQ1-SQ10) show $53.5-59.3$ dBA (mean = 56.2 dBA) and public spaces along the streets (ST1-ST10) $45.1-64.6$ dBA(mean = 58.0 dBA). Approximately 60 % of sampled spaces exceed the 55 dBA threshold, which is the maximum daytime noise level required for quiet residential areas as stipulated in the Environmental quality standard for noise, issued by Ministry of Ecology and Environment of the People's Republic of China.[56] This indicates widespread noise pollution in urban fringe residential areas during daytime. A more detailed examination of specific spaces identified G9, ST1, and ST9 as having relatively high sound pressure levels. In G9, this was attributed to recreational activities such as square dancing, whereas in ST1 and ST9, the primary cause was traffic noise.

Figure 5(b) presents the loudness values for each sampled space. Overall, the average loudness across all the sampled spaces is 10.7 soneGF. The N_5, N_{95} and Nrmc ranged

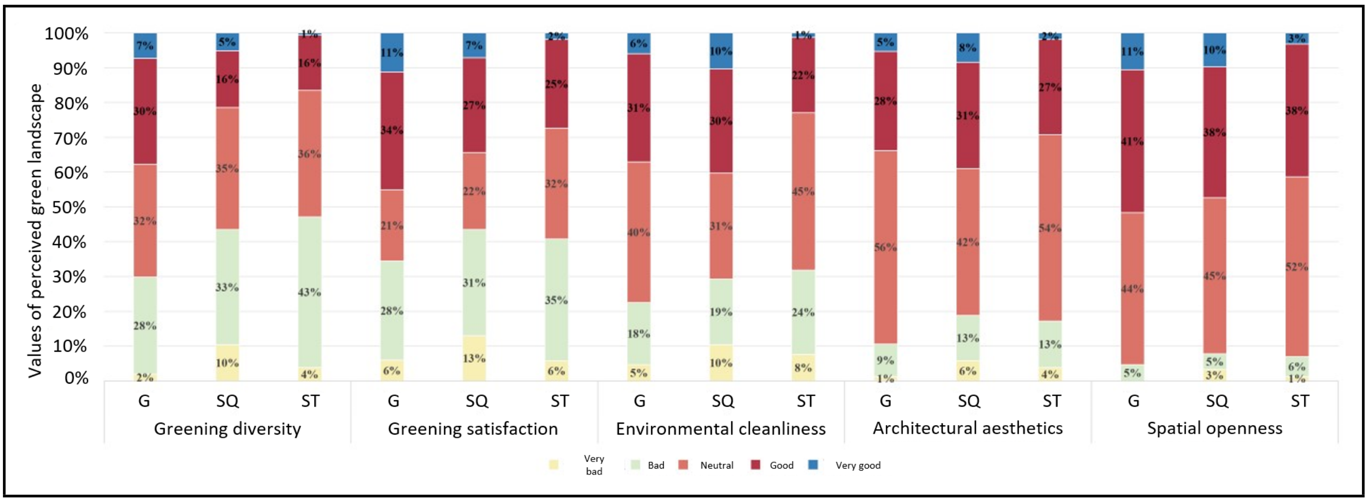

Figure 3. Green landscape perception factor scores.

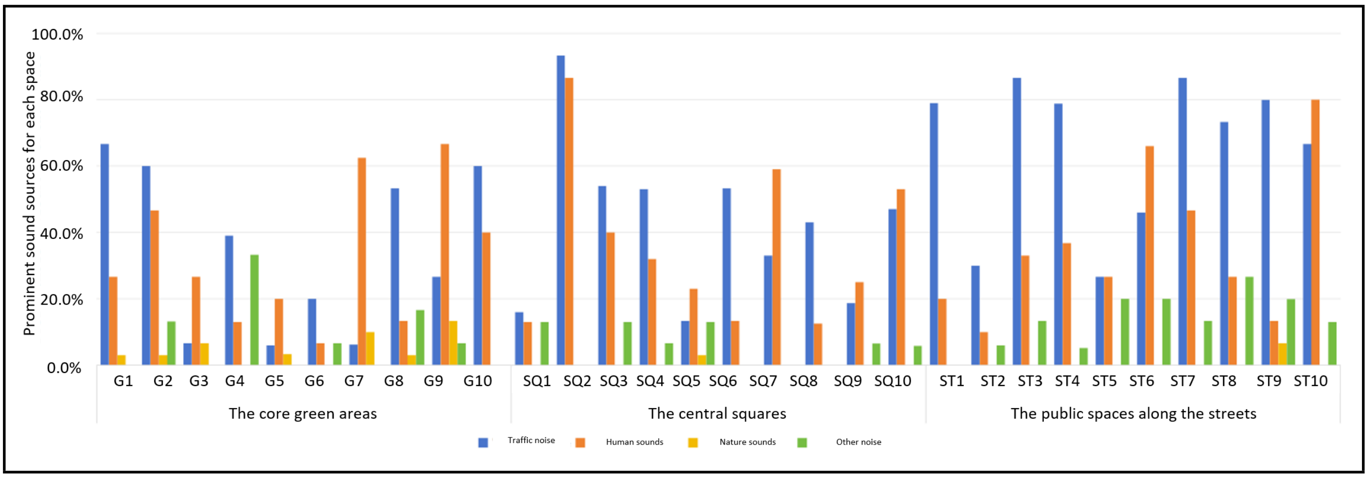

Figure 4. Prominent sound sources for each place.

from 6.98 to 29.5 soneGF, 2.85 to 12.5 soneGF and 5.42 to 21.7 soneGF, respectively. N_5 and N_{95} represent loudness at intervals exceeding 5 % and 95 %, respectively, and Nrmc is the root-mean-square loudness, which is used to describe the intensity of sound perceived by the human ear. Public spaces along the streets have the highest average loudness at 12.9 soneGF, followed by core green areas, with an average of 10.0 soneGF. The central squares have a slightly lower average loudness than the core green areas at 9.2 soneGF. Notably, G7 and G9, which are popular venues for residents' square dancing, also have relatively high loudness values.

3.1.2. Soundscape Perception Evaluation

According to recommended statistical analysis and visualization methods as described in ISO 12913-3:2025, A.3.2,[18] Fig. 6 displays the soundscape evaluation of the sampled spaces. The Kruskal-Wallis test revealed statistically significant differences in pleasantness ($p < 0.001$) and eventfulness ($p < 0.001$) across spatial types. After calculation by standard formula,[18] the soundscape pleasantness scores across all spaces ranged from -0.36 to 0.27, with median of 0.03. The central squares have the highest score of 0.27, with median of 0.06; followed by the core green areas with median of 0.05; whereas the public spaces along the streets have the lowest score of -0.36, with median of 0.02. A detailed analysis of specific spaces revealed that G5, G7, and SQ3 achieved higher pleasantness scores. These areas are characterized by lush green landscapes and well-maintained facilities that accommodate a diverse range of recreational activities for residents, which can promote residents' positive evaluation of pleasantness. Conversely, SQ2, ST7, and ST9 had lower pleasantness scores. These spaces are situated near industrial parks and major urban thoroughfares and experience frequent traffic from various vehicles, leading to elevated noise levels. Moreover, they lack sufficient greenery and suffer from poor sanitary conditions.

In terms of the soundscape eventfulness dimension, the eventfulness scores of the sampled spaces range from -0.35 to 0.17, with an average score of -0.11 and median of -0.17. Public spaces along the streets have the highest score of 0.17, with median of 0.03; followed by the central squares, with median of -0.18; and the core green areas have the lowest score of -0.35, with median of -0.21. G1, G4, G5, SQ3, SQ4, and ST2 had relatively low eventfulness scores. This can be attributed to their abundant green landscapes and relatively limited activities. Conversely, ST8, ST9, and ST10 presented higher eventfulness scores because they are equipped with more recreational facilities, attracting residents of all ages for various entertainment activities and enhancing the eventfulness.

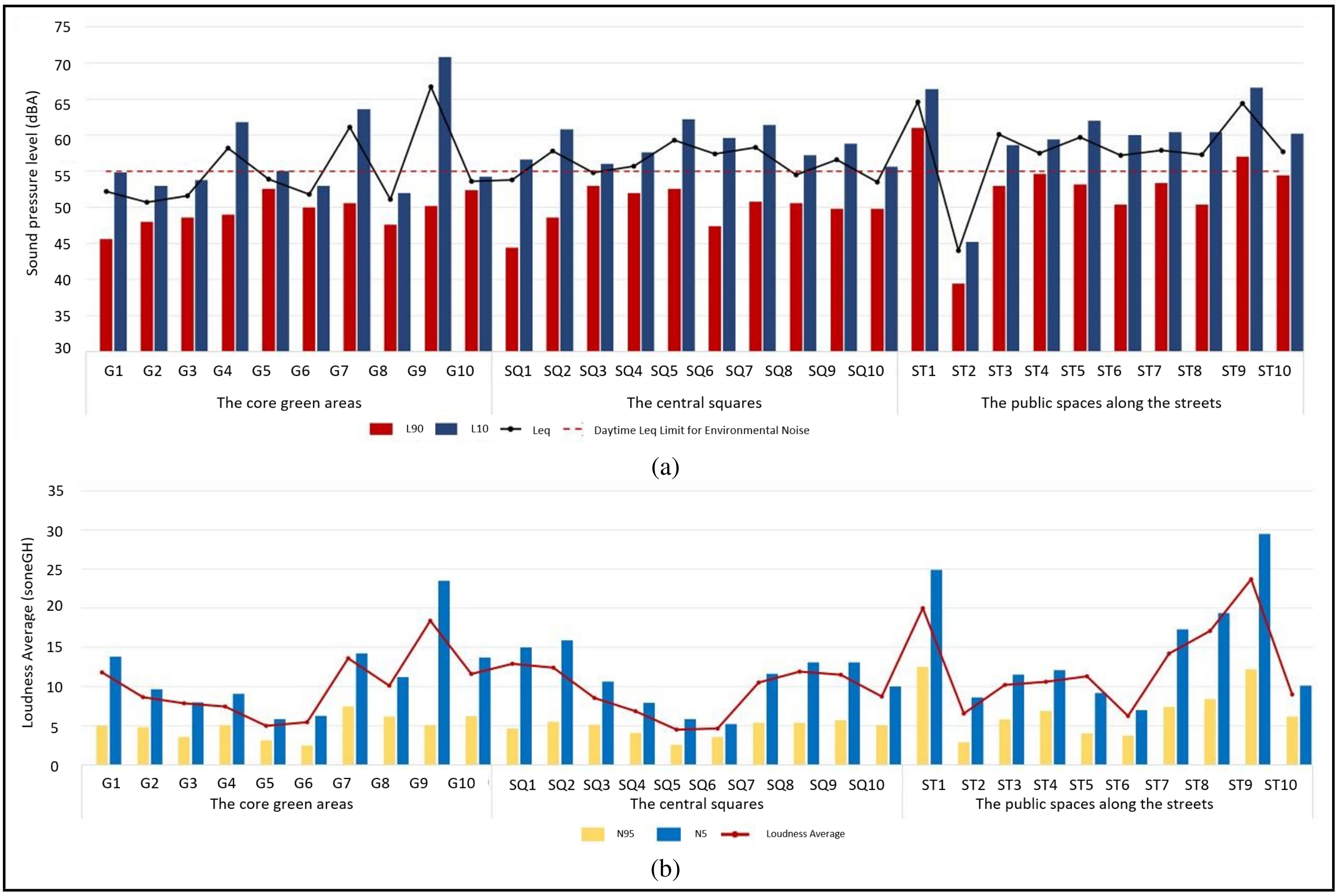

Figure 5. Acoustic environment of the sampled space: a) sound pressure level (55 dBA is the maximum daytime noise level required for quiet residential areas[56]); b) loudness.

3.1.3. Overall Perception Evaluation of the Sound Environment

Figure 7 presents the rating statistics for the overall perception evaluation of the sound environment in each sampled space. The overall assessment of the sound environment in urban fringe residential areas is generally unfavorable, with only 29.3 % of respondents rating it as "good" or "very good". Notably, over 50 % of respondents give "bad" or "very bad" ratings to spaces such as G8, SQ2, SQ7, and ST9. These areas are predominantly located in squares or public spaces along the streets of older residential areas, characterized by subpar green landscapes.

3.2. Correlation Analysis Between Green Landscape Factors and Soundscape as Well as Overall Sound Environment Assessment

Figure 8 presents the correlation between green landscape factors and soundscape perception and overall sound environment assessment (SEA), based on Spearman's correlation analysis. The GR and Shannon's diversity index (SHDI) are significantly positively correlated with soundscape pleasantness (P) and overall SEA. Additionally, the LSI is significantly positively correlated with SEA. Conversely, the GR and LSI are significantly negatively correlated with E. Among the green landscape perception factors, greening diversity (GD), greening satisfaction (GS), environmental cleanliness (EC), spatial openness (SO), and architectural aesthetics (AA) have positive impact on P and SEA, but are not significantly correlated with E. These findings indicate that a rich, tidy, aesthetically pleasing, and open landscape environment can enhance respondents' pleasantness and improve their evaluation of the overall sound environment. Furthermore, the ratings of traffic noise (TN) and human sounds (HS) are significantly negatively correlated with P and SEA but significantly positively correlated with E.

3.3. The Influence Paths of Green Landscape Factors on Soundscape

This section analyzes the comprehensive influence paths of green landscape factors on soundscape evaluation by employing factor analysis and constructing a SEM. Initially, exploratory factor analysis (EFA) was conducted to identify the underlying factor dimensions. Subsequently, confirmatory factor analysis (CFA) was used to determine the effective factor structure. Finally, a SEM was developed to elucidate the influence paths among the various factors.

3.3.1. Exploratory Factor Analysis

Before the factor analysis, a Kaiser-Meyer-Olkin (KMO) test was performed on the questionnaire data, yielding a KMO value of 0.763 ($p < 0.001$), which exceeds the recommended threshold of 0.7. After standardizing the indicators, principal component analysis (PCA) was used to extract four common factors, accounting for a cumulative variance of 75.876 %. The factor loadings ranged from 0.666 to 0.894. As shown in Ta-

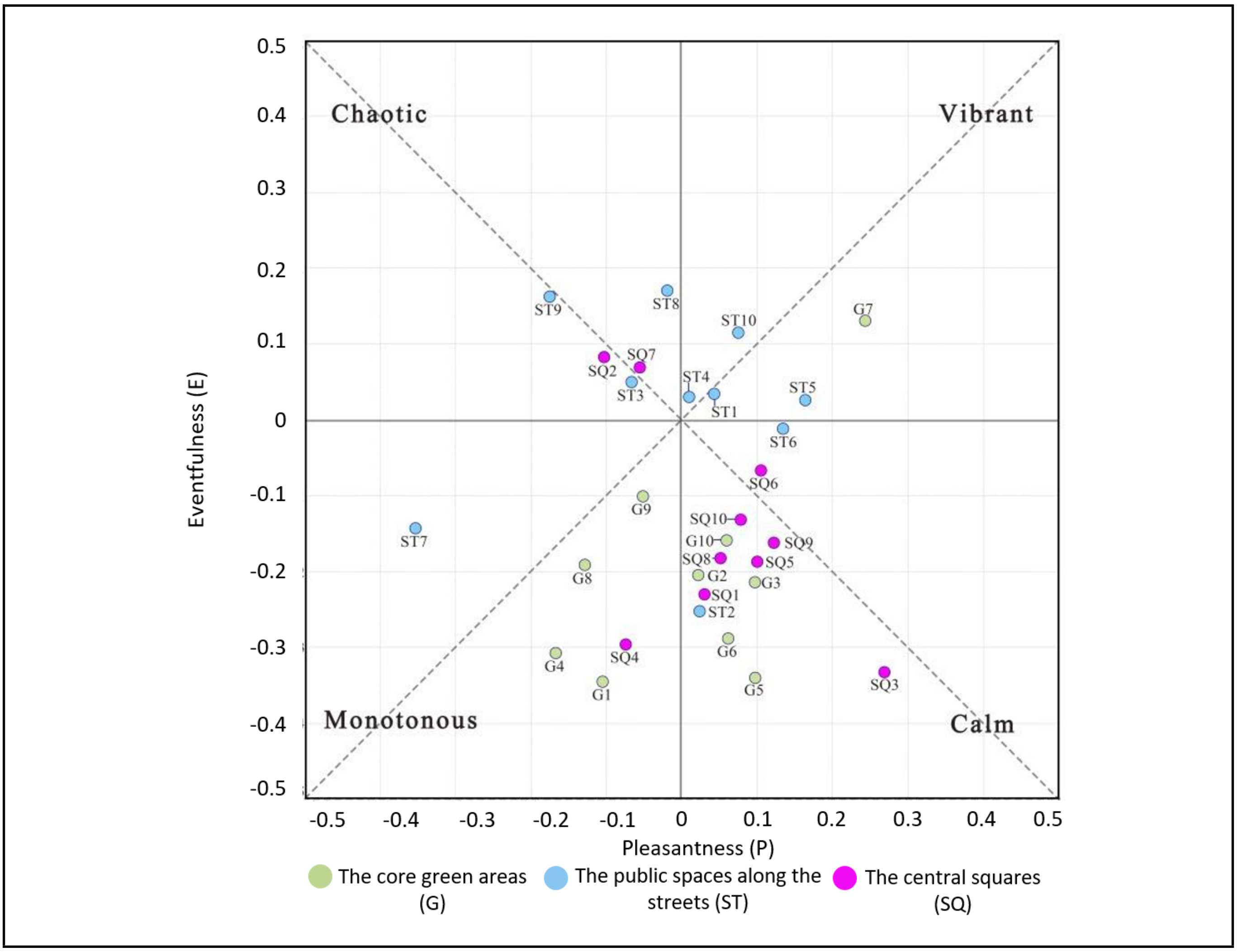

Figure 6. Pleasantness and eventfulness scores at 30 sampled spaces.

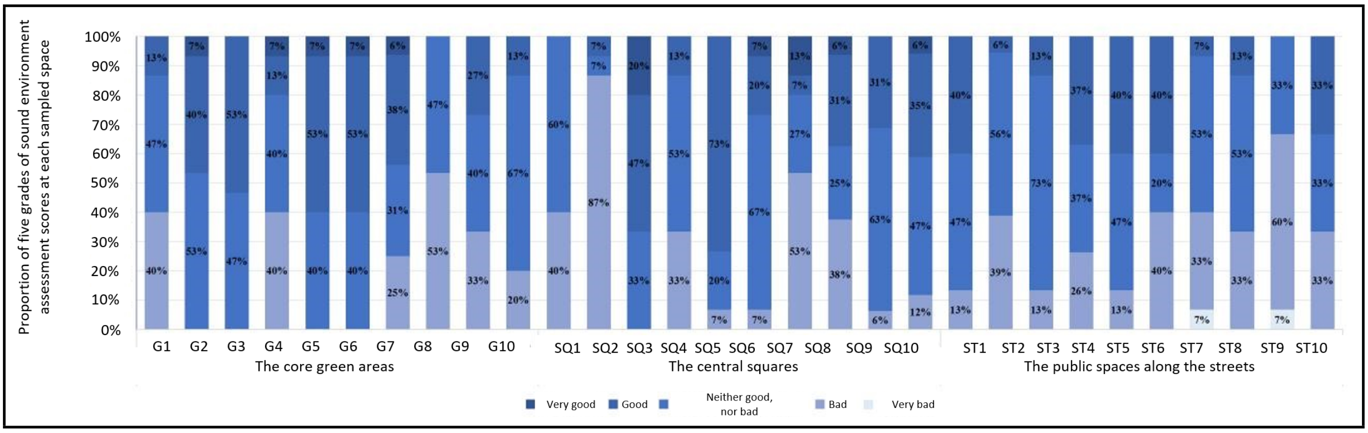

Figure 7. Proportion of five grades of sound environment assessment scores at 30 sampled spaces.

ble 4, common factor 1 includes greening satisfaction, greening diversity, and environmental cleanliness, which can be summarized as perception of green landscapes, and accounts for 24.544 % of the variance. Common factor 2 includes the Greening rate, the Landscape shape index, and Shannon's diversity index, summarized as objective green landscape indicators, explaining 21.359 % of the variance. Common factor 3 includes human sounds and traffic noise, summarized as sound source perception, explaining 15.617 % of the variance. Common factor 4 includes spatial openness and architectural aesthetics, summarized as spatial environment perception, explaining 14.353 % of the variance.

3.3.2. Confirmatory Factor Analysis

The common factors obtained from the EFA were designated as the latent variables, and the corresponding independent variables were used as observed variables to construct a measurement model within the structural equation model framework in AMOS 26. To assess the reliability of this measurement model, a confirmatory factor analysis (CFA) was per-

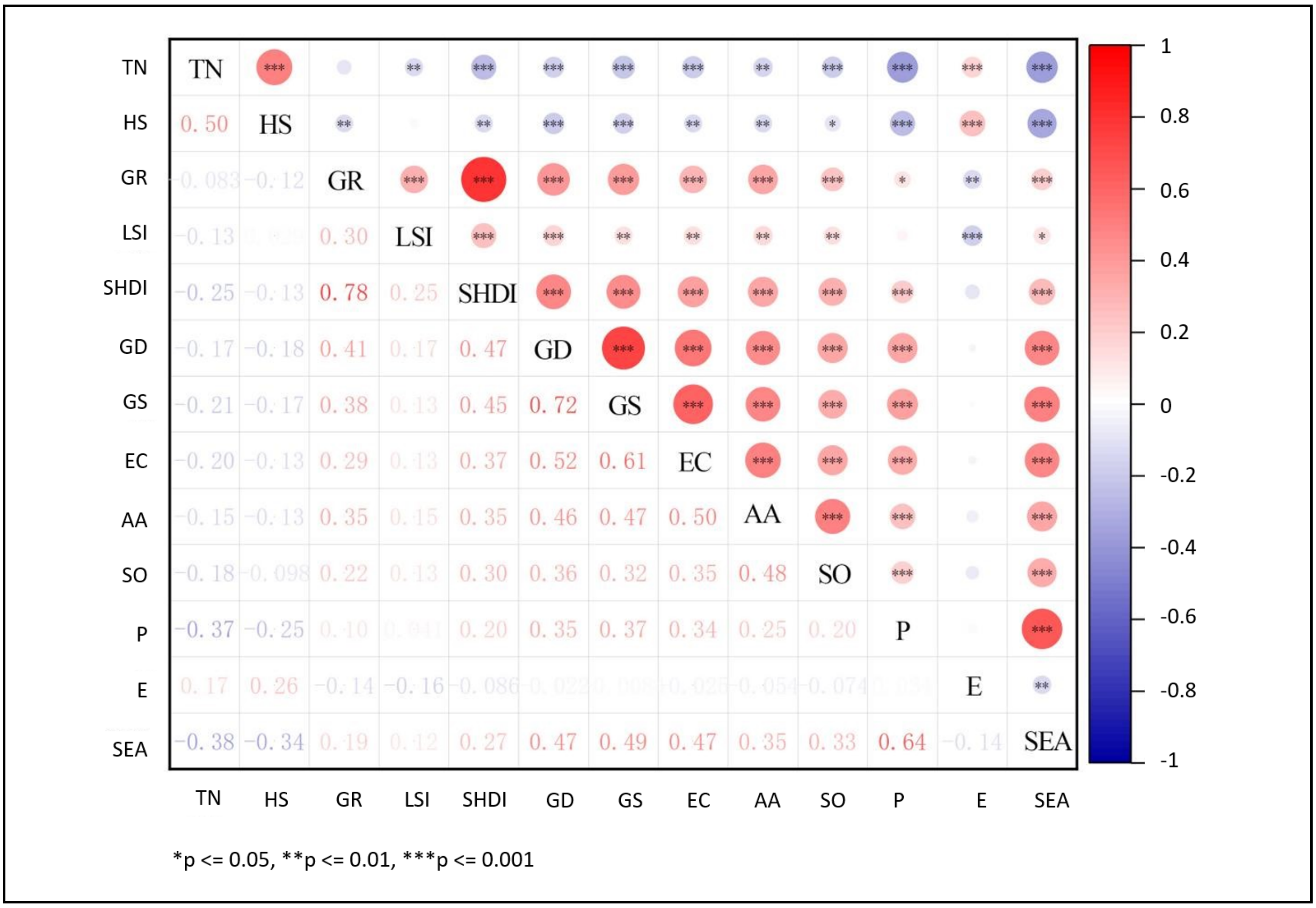

Figure 8. Correlation analysis between green landscape factors and evaluation of soundscape and sound environment.

Table 4. Exploratory factor analysis (EFA).

Factors	Factor loading	Explained variance
Factor 1: Perception of green landscape		24.544 %
Greening satisfaction	0.887	
Greening diversity	0.828	
Environmental cleanliness	0.726	
Factor 2: Objective green landscape		21.359 %
Greening Rate	0.862	
Landscape Shape Index	0.820	
Shannon's Diversity Index	0.759	
Factor 3: Sound source		15.617 %
Human sounds	0.875	
Traffic noise	0.854	
Factor 4: Perception of spatial environment		14.353 %
Spatial openness	0.894	
Architectural aesthetics	0.666	

Table 5. Results of confirmatory factor analysis (CFA) for AVE and CR.

Factors	Factor loading	AVE	CR
Factor 1: Perception of green landscape		0.643	0.843
Greening satisfaction	0.864		
Greening diversity	0.822		
Environmental cleanliness	0.711		
Factor 2: Objective green landscape		0.608	0.818
Greening Rate	0.896		
Landscape Shape Index	0.581		
Shannon's Diversity Index	0.826		
Factor 3: Sound source		0.560	0.714
Human sounds	0.646		
Traffic noise	0.838		
Factor 4: Perception of spatial environment		0.533	0.691
Spatial openness	0.620		
Architectural aesthetics	0.826		

formed. Cronbach's alpha was 0.713, which exceeded the recommended threshold of 0.7, showing high data reliability. The convergence validity of the measurement model was then evaluated using factor loadings, Average Variance Extracted (AVE), and Construct Reliability (CR). As depicted in Table 5, all observed variables exhibit factor loadings greater than 0.5, suggesting that they effectively explain the latent variables. Additionally, the AVE values for all latent variables surpass 0.5, indicating satisfactory convergence validity. Furthermore, the CR values for all latent variables exceed 0.6, demonstrating good internal consistency among them. According to the discriminant validity test results presented in Table 6, the standardized correlation coefficients between the four dimensions are all lower than the square roots of their respective AVE values. This finding indicates that each dimension possesses good discriminant validity.

3.3.3. Construction of the Initial Structural Equation Model

Based on the above study, the initial SEM was constructed. As illustrated in Figure 9, the model comprises four latent variable dimensions: sound sources, objective green landscapes, perception of spatial environment, and perception of green landscape. Furthermore, the soundscape evaluation variables were categorized into three dimensions: pleasantness (P), eventfulness (E), and sound environment assessment (SEA). As outlined in Table 7, the study proposes three primary hy-

Table 6. Results of discriminant validity.

	Perception of green landscape	Objective green landscape	Sound source	Perception of spatial environment
Perception of green landscape	**0.643**			
Objective green landscape	0.51	**0.608**		
Sound source	-0.334	-0.235	**0.560**	
Perception of spatial environment	0.725	0.49	-0.317	**0.533**
Square root of AVE	0.802	0.780	0.748	0.730

potheses (H_a, H_b, and H_c) along with 20 specific hypotheses to explore these relationships in detail.

3.3.4. Results of the SEM

The SEM was drawn in AMOS 26. As shown in Table 8, all the fitting indices, including the χ^2/df, Root Mean Square Error of Approximation (RMSEA), Goodness of Fit Index (GFI) and Comparative Fit Index (CFI) of SEM meet the recommended ranges, indicating a high overall fit and good model adaptation. Furthermore, before analysis, the SEM's identity across three types of public spaces was verified through multiple-group analysis. Following Tsai et al.' s criterion,[57] a comparison between the constrained model and unconstrained model with a difference in fit indices (ΔCFI) ≤ 0.01 was considered statistically significant. The results demonstrate that the proposed SEM exhibits cross-group congruence (ΔCFI= $0.004 \leq 0.01$), indicating that the influence pathways of green landscape elements on soundscape perception remain consistent across three types of public spaces. Therefore, the analysis results will be reported based on this SEM.

Figure 10 illustrates the SEM of "green landscape factors–soundscape evaluation." As shown in Table 9, among the 20 specific hypotheses in the model, 16 hypotheses are statistically significant. With respect to the main hypothesis Ha, objective green landscape has a significant negative influence on soundscape pleasantness ($\beta = -0.13$, $p < 0.005$) and eventfulness ($\beta = 0.20$, $p < 0.001$), with a greater influence on eventfulness than on pleasantness. Conversely, perception of green landscapes has a significant positive influence on soundscape pleasantness ($\beta = 0.338$, $p < 0.001$), eventfulness ($\beta = 0.191$, $p < 0.05$), and overall SEA ($\beta = 0.35$, $p < 0.001$). Compared with objective indicators, green landscape perception indicators have a greater influence on soundscape pleasantness. Traffic noise and human sound perception have a significant negative influence on soundscape pleasantness ($\beta = -0.423$, $p < 0.001$) and overall sound environment assessment ($\beta = -0.199$, $p < 0.001$) and a significant positive influence on eventfulness ($\beta = 0.278$, $p < 0.001$).

Consistent with the results of hypothesis Hb, objective green landscape has a significant negative influence on sound source perception ($\beta = -0.247$, $p < 0.001$) but a significant positive influence on spatial perception ($\beta = 0.496$, $p < 0.001$) and green landscape perception ($\beta = 0.185$, $p < 0.01$). Additionally, sound source perception has a significant negative influence on green landscape perception ($\beta = -0.147$, $p < 0.01$), whereas spatial perception has a significant positive influence on green landscape perception ($\beta = 0.605$, $p < 0.001$).

In line with the results of hypothesis Hc, soundscape pleasantness ($\beta = 0.411$, $p < 0.001$) has a significant positive influence on sound environment assessment, whereas soundscape eventfulness ($\beta = -0.101$, $p < 0.01$) has a significant negative influence. Moreover, the influence of soundscape pleasantness is much larger than that of eventfulness. This implies that, compared with reducing eventfulness, enhancing the pleasantness of sound events is more important for optimizing the quality of urban sound environments. Eventfulness has a positive influence on pleasantness ($\beta = 0.127$, $p < 0.01$). An eventful environment is busy with human activity, whereas an uneventful environment is completely devoid of human activity.[18] This may depend on individual differences in acoustic perception and the alignment between the acoustic environment and the surrounding environment. A high eventfulness stems from rich social activities (such as conversation, sports, etc.), which typically elevate positive emotions and enhance pleasantness.[58]

3.3.5. Mediation Analysis

A mediation analysis was conducted to clarify the influence mechanism of factors on the soundscape evaluation of urban fringe residential areas.[59,60] The Bootstrap method was employed with 5000 repetitions to test for mediating effects, and the significance of the effect was determined by whether the 95 % confidence interval (CI) crossed zero. Table 10 shows the observed and standardized direct and indirect effects of the mediation analyses. In the dimension of soundscape pleasantness, sound source($\beta = -0.423$, $p < 0.001$) and green landscape perception($\beta = 0.338$, $p < 0.01$) are the direct variables that affect the evaluation of pleasantness, while objective green landscape factors($\beta = 0.305$, $p < 0.001$) indirectly affect the evaluation of pleasantness through the sound source and landscape perception factors. Spatial perception factors($\beta = 0.212$, $p < 0.01$) affect the evaluation of pleasantness through green landscape perception indirectly. In the dimension of soundscape eventfulness, both subjective($\beta = 0.191$, $p < 0.05$) and objective($\beta = -0.201$, $p < 0.01$) green landscape factors, as well as sound source, primarily exerted direct effects on eventfulness evaluation. The results of the mediation analysis show that the reasonable greening structure and the perceived greening landscape can improve the soundscape experience.

4. DISCUSSIONS

This study investigated the soundscape characteristics of public spaces in urban fringe residential areas in high-density cities and explored the complex relationships among subjective and objective green landscape factors and soundscape evaluation, providing a scientific basis for landscape planning and design in urban fringe residential areas.

4.1. Soundscape Characteristics of Public Spaces in Urban Fringe Residential Areas

The soundscapes of urban fringe residential areas in high-density cities were significantly different from those in urban center residential areas and were characterized by higher noise

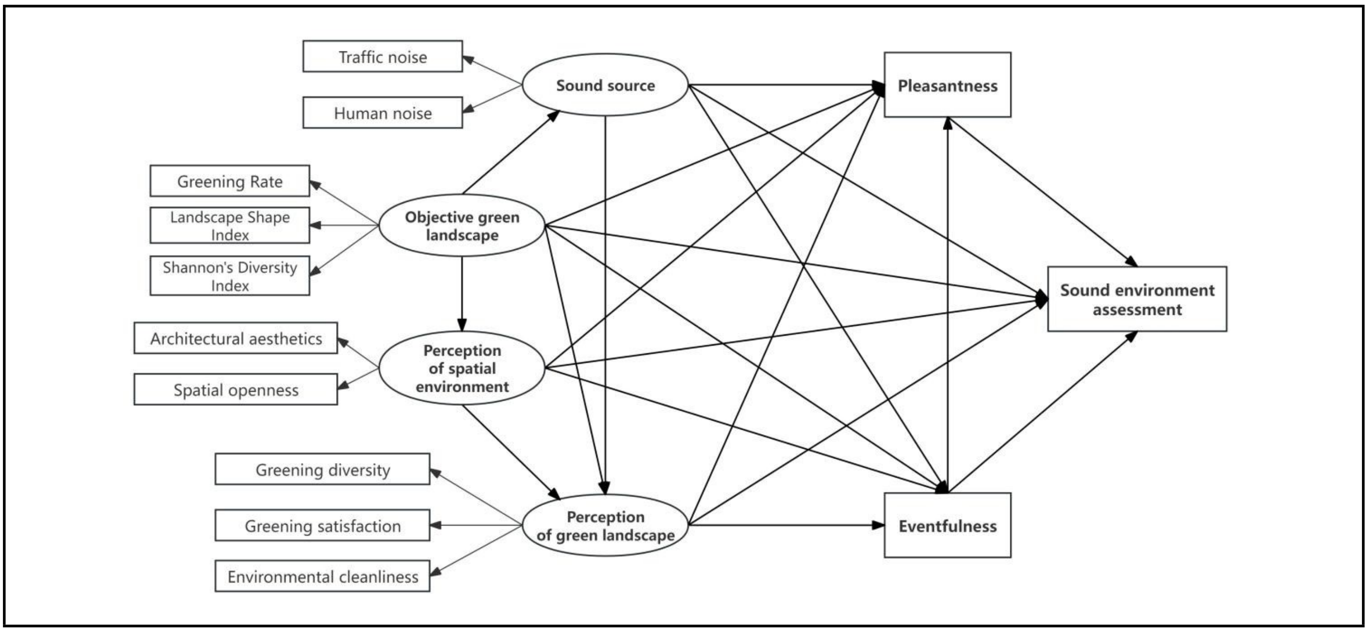

Figure 9. The conceptual SEM of "Green Landscape Factors–Soundscape Evaluation".

Table 7. Hypothetical paths of the conceptual SEM. Note: "+" means positive impact, "-" means negative impact.

Main hypothesis	Specific hypothesis	Influence paths	Impact direction
Ha		Green landscape factors affect soundscape evaluation.	
	Ha1	Sound source → P	-
	Ha2	Sound source → SEA	-
	Ha3	Sound source → E	+
	Ha4	Objective green landscape → P	+
	Ha5	Objective green landscape → SEA	+
	Ha6	Objective green landscape → E	+
	Ha7	The perception of spatial environment → P	+
	Ha8	The perception of spatial environment → SEA	+
	Ha9	The perception of spatial environment → E	-
	Ha10	The perception of green landscape → P	+
	Ha11	The perception of green landscape → SEA	+
	Ha12	The perception of green landscape → E	+
Hb		Factors interact with each other.	
	Hb1	Objective green landscape → Sound source	-
	Hb2	Objective green landscape → The perception of spatial environment	+
	Hb3	The perception of spatial environment → The perception of green landscapes	+
	Hb4	Sound source → The perception of green landscapes	-
	Hb5	Objective green landscape → The perception of green landscapes	+
Hc		Soundscape factors influence each other.	
	Hc1	P → SEA	+
	Hc2	E → SEA	-
	Hc3	E → P	-

Table 8. The values of fit indices of the SEM.

Model fit index	χ^2/df	RMSEA	GFI	CFI
Obtained values	3.805	0.078	0.945	0.945
Recommended values	< 5	< 0.08	> 0.9	> 0.9

levels. In addition to traffic noise,[44,61] human sounds are also a dominant sound source.[62] Field measurements revealed that the sound pressure levels in the sampled spaces of urban fringe residential areas ranged from 51 to 68 dBA. According to the sound environment quality standards, the sound pressure levels in two-thirds of the sampled spaces exceeded the daytime environmental noise limit of 55 dBA for residential areas. This may be due to the unique location and surrounding environment of urban fringe residential areas, which are more likely to be exposed to high-decibel environmental noise.[63,64]

In the soundscape perception evaluation of urban fringe residential areas, both pleasantness and eventfulness scores were low, showing a clear contrast with those of residential areas in the city centre.[29,61,65] Among them, the core green areas presented moderate pleasantness (0.02) and low eventfulness (-0.20). The central squares exhibited high pleasantness (0.05) and moderate eventfulness (-0.15). Public spaces along the streets demonstrated low pleasantness (-0.02) and high eventfulness (0.02). The soundscape pleasantness and eventfulness scores of the central squares were both higher than those of the core green areas. This may be because squares, as centres of public activities, can foster positive social and recreational activities, thereby increasing respondents' positive emotions.[30,66,67] The main noise source in public spaces along the streets was traffic noise. There are many street-side businesses, and the greening quality is poor. Compared with other spaces, residents are more sensitive to noise in these spaces.[33,34,44]

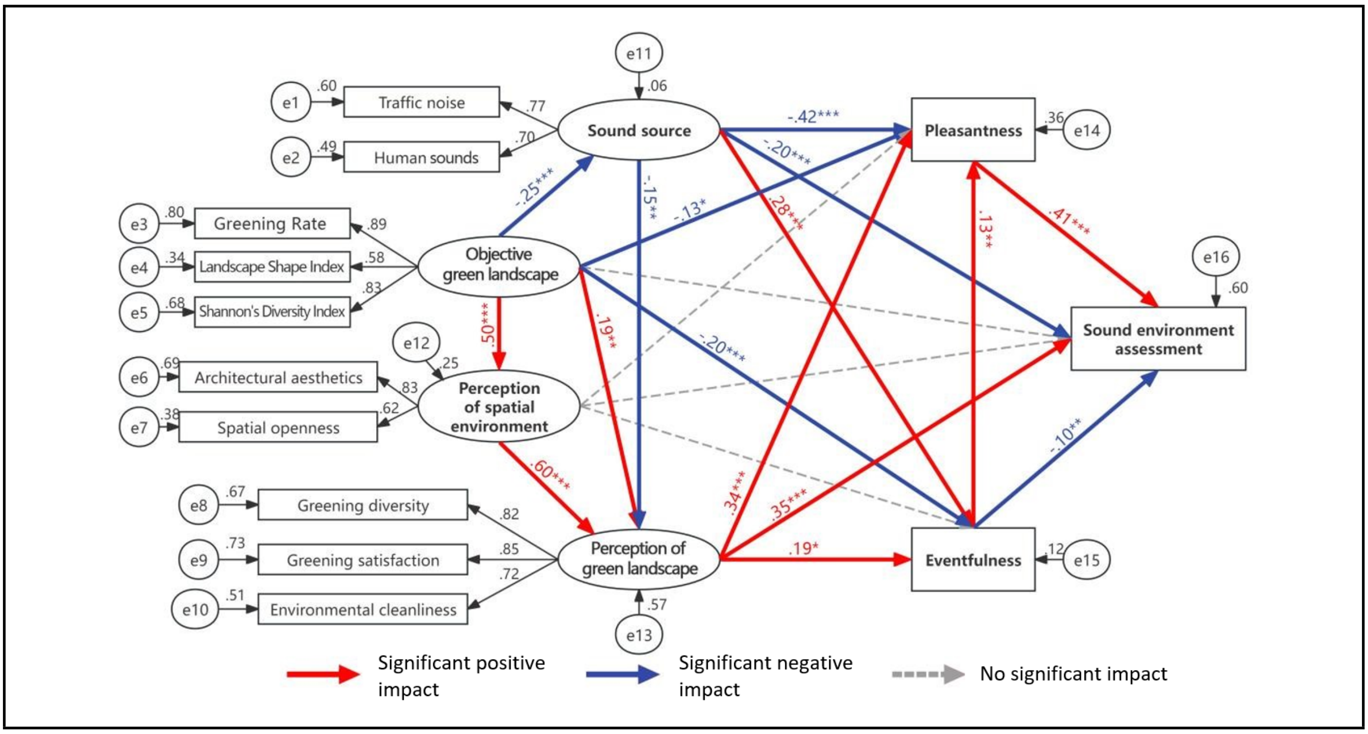

Figure 10. SEM of "Green Landscape Factors–Soundscape Evaluation". (*p<0.05,**p<0.01;***p<0.001)

Table 9. Results of standardized path loadings for SEM. Note: *p<0.05, **p<0.01, ***p<0.001.

Hypotheses	Influence paths	β	S.E.	C.R.	P
Ha	Green landscape factors affect soundscape evaluation.				
Ha1	Sound source → P	-0.423	0.085	-7.014	***
Ha2	Sound source → SEA	-0.199	0.070	-3.989	***
Ha3	Sound source → E	0.278	0.086	4.606	***
Ha4	Objective green landscape → P	-0.125	0.067	-2.227	0.026*
Ha5	Objective green landscape → SEA	-0.086	0.053	-1.932	0.053
Ha6	Objective green landscape → E	-0.201	0.075	-3.224	0.001***
Ha7	The perception of spatial environment → P	0.100	0.131	1.214	0.225
Ha8	The perception of spatial environment → SEA	0.064	0.102	1.002	0.316
Ha9	The perception of spatial environment → E	-0.053	0.150	-0.569	0.569
Ha10	The perception of green landscape → P	0.338	0.096	4.089	***
Ha11	The perception of green landscape → SEA	0.350	0.077	5.297	***
Ha12	The perception of green landscape → E	0.191	0.107	2.107	0.035*
Hb	Factors interact with each other.				
Hb1	Objective green landscape → Sound source	-0.247	0.051	-4.079	***
Hb2	Objective green landscape → The perception of spatial environment	0.496	0.050	7.393	***
Hb3	Perception of spatial environment → The perception of green landscape	0.605	0.100	8.285	***
Hb4	Sound source → The perception of green landscape	-0.147	0.060	-2.946	0.003**
Hb5	Objective green landscape → The perception of green landscape	0.185	0.061	3.130	0.002**
Hc	Soundscape factors influence each other.				
Hc1	P → SEA	0.411	0.042	9.785	***
Hc2	E → SEA	-0.101	0.034	-2.931	0.003**
Hc3	E → P	0.127	0.043	2.901	0.004**

4.2. Discussion of the Correlation Between Green Landscape Factors and Soundscape Evaluation

In urban fringe residential areas of high-density cities, the positive correlation coefficient between the SHDI and soundscape pleasantness is significantly greater than that of other green landscape factors. This finding indicates that in urban fringe residential areas, green spaces with rich vegetation species and wide distributions can form a multi-layered landscape environment, meeting residents' expectations for the residential environment and thereby eliciting pleasant feelings. Previous research has similarly highlighted that environmental factors within residential spaces substantially influence spatial perception and that designers should prioritize aspects such as vegetation density, type, and layout.[68] In addition, the reasonable configuration of spatial landscapes can influence the propagation of noise and reduce the perceived frequency of traffic noise and human sounds.[28] At the subjective level, all landscape perception factors had strong correlations with soundscape pleasantness and overall sound environment assessment but no significant correlation with eventfulness. The results of this study further emphasize the importance of perceived green landscapes and spatial environments. Especially for urban fringe residential areas with uneven greening quantity and quality, improving residents' satisfaction with the landscape environment of public spaces can increase pleasantness.

Table 10. The results of direct and indirect effects in the mediation analysis.

Pleasantness								
	Direct effect				Indirect effect			
	β	P	95% CI Lower BC	95% CI Upper BC	β	P	95% CI Lower BC	95% CI Upper BC
Objective green landscape	-0.125	0.045	-0.239	-0.004	0.305	0	0.198	0.413
Perception of spatial environment	0.1	0.283	-0.083	0.3	0.212	0.001	0.109	0.336
Perception of green landscape	0.338	0.002	0.163	0.502	0.024	0.02	0.003	0.064
Sound source	-0.423	0	-0.527	-0.305	-0.018	0.457	-0.074	0.033
Eventfulness	0.127	0.001	0.046	0.217	0	0	0	0
Eventfulness								
	Direct effect				Indirect effect			
	β	P	95% CI Lower BC	95% CI Upper BC	β	P	95% CI Lower BC	95% CI Upper BC
Objective green landscape	-0.201	0.006	-0.32	-0.07	0.005	0.965	-0.075	0.069
Perception of spatial environment	-0.053	0.559	-0.249	0.13	0.115	0.036	0.007	0.247
Perception of green landscape	0.191	0.042	0.007	0.378	0	0	0	0
Sound source	0.278	0	0.145	0.402	-0.028	0.022	-0.081	-0.003

Although the correlation between green landscape perception factors and soundscape eventfulness was not significant, eventfulness was still one of the dimensions of the soundscape, and its contribution should not be ignored.[14] Thus, this study comprehensively considered both pleasantness and eventfulness in the SEM.

4.3. The Influence Paths of Subjective and Objective Green Landscape Factors

To explain the different effects of subjective and objective green landscape factors on soundscape, the influence paths of SEM were analyzed and discussed. First, objective green landscape factors significantly reduced the eventfulness of soundscape and had a slight negative influence on pleasantness. Although many previous studies have confirmed that greening can improve soundscape evaluation,[35,69–71] this study revealed that after factors such as vegetation coverage area and the shape of green spaces were comprehensively considered, greening factors do not always increase soundscape quality; it might even have the opposite effect. Schäffer et al.[70] found that greening can mitigate road and railway noise disturbances. However, under high noise levels, increased greenery correlates with heightened aircraft noise annoyance. A study on greening and traffic noise found that residents in areas with higher greening levels experienced more severe annoyance with traffic noise when noise exceeded 60 dBA.[35] In a VR experiment investigating how greenery coverage affected traffic noise exposure, Van Renterghem et al. found that when participants were exposed to a constant noise level of 67 dBA, the optimal greenery coverage to reduce noise annoyance was approximately 30 %. However, higher noise annoyance was observed when the vegetation coverage reached 50 %.[71] These results support our findings. This may align with the consistency hypothesis, which suggests that inconsistencies between auditory and visual stimuli often cause discomfort.[32] In green space with a high noise level and dense vegetation, the pleasant sounds such as natural sounds will be covered by noise, which will weaken the perception of positive soundscape.[72,73] At the same time, the perception difference will be influenced by the individual's psychological expectation, and the individual in different states will have certain expectations for the specific space. When the actual sound conflicts with the expectation, the individual's psychological state and the evaluation of landscape and soundscape will be affected.[74,75]

The results of the mediation analysis revealed that both subjective and objective green landscape factors positively affect soundscape evaluations. However, the objective green landscape factors influenced pleasantness mainly by affecting subjective factors. This finding highlights the pivotal role of subjective landscape perceptions in soundscape evaluation, which is in line with previous research.[32,76–78] Therefore, in the practice of optimizing green landscapes and soundscapes in urban fringe residential areas, the greening structure and subjective green perception should be considered comprehensively; otherwise, a blind increase in the GR or the complexity of landscapes may not effectively improve soundscape quality.

Furthermore, this paper delved into the moderating effect of perceived sound sources.[79] As the dominant noise sources in urban fringe residential areas, traffic noise and human sounds significantly negatively influence pleasantness and the overall sound environment assessment and significantly positively influence eventfulness. This finding indicates that the soundscape experience of residents in urban fringe residential areas is severely affected by urban traffic noise and social sounds. Additionally, a significant negative relationship was found between perceived sound sources and landscape perception, reinforcing the notion that sound and landscape factors in residential environments are closely related.[44]

4.4. Limitations and Further Research

This study has certain limitations. First, this study primarily examines the soundscape characteristics of urban fringe residential areas during daytime in autumn. The applicability of these findings to other seasons requires further investigation. Future research should encompass various seasons and time spans, aiming to develop soundscape perception models adaptable to different temporal sequences. This approach will better capture the dynamic soundscape features and perceptual preferences across diverse environments. Furthermore, this study used a 100-meter radius buffer zone centered on the sampling points as the research unit. While this generally encompasses residents' daily activity spaces, it is worthwhile to further investigate whether the influence patterns of green landscape factors on the soundscape remain consistent across different scales. Future studies could concentrate on examining the influences of green landscape factors on soundscape perception at multiple spatial scales.

5. CONCLUSIONS

The focus of this study was the influence of green landscape factors on soundscape evaluation in urban fringe residential areas of high-density cities. This study has three major findings. First, unlike public spaces in urban centers, over two-thirds of the sampled spaces in these fringe areas present equivalent sound pressure levels that exceed environmental noise limits. Additionally, residents' evaluation of the perceived soundscape tends to be negative. Second, the GR, SHDI, and subjective landscape perception factors are significantly positively correlated with soundscape pleasantness, while the GR and LSI were significantly negatively correlated with eventfulness. Finally, SEM analysis revealed that green landscape perception factors directly positively affect soundscape pleasantness, while objective green landscape and spatial environment perception factors indirectly affect soundscape pleasantness. Traffic noise and human sounds, on the other hand, have negative effects on soundscape pleasantness and overall SEA but positively influence soundscape eventfulness. Public spaces in urban fringe residential areas are the main places for residents' activities. Objective and subjective green landscape factors have different effects on soundscape perception. After considering factors such as vegetation coverage area and the shape of green spaces, a higher proportion of green landscape does not always increase soundscape quality; in fact, it may even have the opposite effect. Based on the findings, this study highlights the importance of utilizing the comprehensive impact of subjective and objective greening landscape factors on soundscape to enhance the perceptual experience of residents, providing scientific guidance for optimizing the green landscape and soundscape quality in urban fringe residential areas.

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