Evaluation of the Acoustic Environment of Urban Recreational Trails

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Abstract: The acoustic environment state of four recreational trails in Taichung was investigated. First, the basic forms, spatial proportions, characteristics of the trail interfaces, and sound sources of the recreational trail spaces were investigated. Second, sound pressure level measurement and a questionnaire survey were conducted in relation to the four trails. The measurements demonstrated that the sound levels of the four trail spaces are lower than the permissible exposure limit 90 dB(A) recommended by the Occupational Safety and Health Administration. Meanwhile, the results of the factor analysis show that the perception of the acoustic environment of recreational trails has five dimensions: likability, intensity, communication, joyfulfulness, and richness. Compared with the acoustic environments of other cities, the perception of the acoustic environment of the recreational trails in this city was characterized by more dimensions and a more balanced structure.

Keywords: recreational space; objective indicator; soundscape perception; sound field comfort

1. Introduction

Nowadays, all the major metropolises are crowded with people. In addition to the sound energy emanating from transportation-related activity, the effects of the distribution and exposure of the sounds of daily life and of recreational activities, and the auditory perception of the people occupying the urban recreation spaces act as direction indicators of current soundscape research. Among the indicators of urbanization, actively pursuing the creation of a recreational living and pedestrian environment with low sound energy and high perception is an important reference for habitable cities. In recent years, most international environmental policies pertaining to the relevant economic activity and social science research have focused on noise control, with a specific research focus on the energy–time domain and the spectral domain, while it is conceded that lowering the noise level does not necessarily improve the quality of urban life [1–4]. Both the World Health Organization and various governments have attempted to comply with regional specifications by decreasing the high-decibel sound energy emanating from transportation and industrial production activity [5–7]. However, due to the hidden multidimensional sound energy characteristics of the sound field of recreational spaces, noise source processing or passive noise suppression structures cannot present evidence pertaining to the urban acoustic environment. Changing the intensity and distribution of the sound energy, mitigating the undesirable noise by creating a specific urban soundscape and acoustic environment, and collecting the relevant data are especially important for the patterns of construction in residential areas [8–10]. Many governments are encouraging their urban residents to walk or use public transport to reduce urban carbon emissions and enhance sustainable operations, decreasing the undesired sound energy from transportation-related activity [11]. The sounds emanating from road traffic, nature, and human life are significant and characteristic of the acoustic environment, thus reflecting relevant information. However, the dynamics of such sounds must be considered, which essentially means that the concepts “soundscape” and “acoustic...
“soundscape” are different, with the former mainly composed of human perceptions and the latter largely referring to a physical phenomenon. Most importantly, the soundscape is presented through people’s perception of the acoustic environment. Furthermore, the correlation between urban recreational spaces and the environment tends to be complex and relates to the relationship between the pleasant sounds generated in the environment and the physical quantity of the sound field when occupying these spaces, as well as the recording of objective measurement data. For example, the pleasantness of the sound environment induces the sound field quality indicator to define the high-quality urban soundscape field [12–14]. Attention must be paid to the actual experience of the senses and the experience of hearing based on the data on the sound diversity among different cultures and customs. Thus, urban sound energy can be regarded as an available “resource” rather than a “pollutant”. The urban soundscape triangle theory developed by Schafer in 1977 [15] includes foreground sound, main tone, and acoustic landmarks. Here, the foreground sound refers to the signal sound that, unlike background noise, attracts people’s attention and can be consciously heard by them, and it tends to be organized into sequences of sounds to convey information. Meanwhile, the concept of “main tone” highlights the representative or key tone in a series of sounds, which, although not necessarily consciously perceived, abstracts or condenses the features of a string of sounds. Finally, acoustic landmarks are the sources of distinctive sounds, be they real or imagined, such as the sounds from activities or events.

In the domain of geography and architectural urbanism, the urban soundscape has sparked widespread attention. For the urban soundscape, data for objective and subjective evaluations must be collected. In addition, the perceptual characteristics of acoustic environments are acoustic and psychoacoustic indicators that are now established as prediction factors or soundscape indicators. Whether emotion measures agree with evaluation processes should be standardized for analysis [16,17]. In the sound field investigation conducted in the present study, measurements and explorations were performed based on these concepts of foreground sound, main tone, and acoustic landmarks, with a sequential sound field distribution developed to reproduce the characteristics of urban soundscape spaces. Specifically, the urban soundscape system was explored in relation to four recreational space patterns, namely: Trail A, pedestrian spaces involving the streets in shopping districts and markets; Trail B, shady recreational trail spaces; Trail C, small-strip waterfront recreational spaces; and Trail D, large-strip waterfront recreation spaces, as listed in Table 1. The measurements pertain to the sound energy characteristics and subjective assessment perceptions, and are discussed in relation to the patterns and classifications of recreational spaces.

Table 1. A column table of the classification of the sound field characteristics of urban recreational spaces in this study.

| Urban Soundscape Locations | Soundscape Field Category | Soundscape Characterization | Urban Soundscape Triangle Type |
|---------------------------|---------------------------|-----------------------------|-------------------------------|
| A. Sound field of pedestrian space along the street of the market in the business district | Business district market Pedestrian space | Crowd and mall combined soundscape | foreground sound |
| B. Tree-shaded recreational trail space | Recreation tree shade Pedestrian space | Greenbelt Trail Soundscape | acoustic landmark |
| C. Small strip-shaped waterfront recreational space (Green River) | Water trail space system | Sound Street Valley Waterfront Soundscape | main tone |
| D. Large and small strip-shaped waterfront recreational space (Yagawa) | Water trail space system | Sound Street Valley Waterfront Soundscape | main tone |
dimensional structure. In this research field, soundscape evaluation consists of multiple terms or features at once, such as sound preference, communicative, interesting review, richness, and sound level evaluation. Soundscape research requires a multi-dimensional structure. Researchers in this field are working hard to generalize soundscape perception into multiple dimensions, so that the weights of certain situations can be quantified [18,19]. Early research focused on the context of a single sound source [20], while later research covered more complex sound scenes. Berglund, for example, highlights four key elements of the residential area’s perception, emotional and expressionless [21]. Zeitler proposes four additional crucial factors in the analysis of the whole urban space, including evaluation, timber, power, and temporal change [22].

The purpose of this research is to see if there is a correspondence between the distribution of spatial sound field energy of recreational trails and subjective factors (including preference, communication, interest, richness, and level).

2. Methods and Calculation

Given that the acoustic characteristics and spatial scale of specific interfaces can significantly affect the sound field characteristics of recreation trails, to ensure that more trail forms were covered, four different recreation trails in Taichung were selected for assessment and measurement. These trails were labeled Trails A–D, as shown in Figure 1. Trail A (Wenhua Road; Figure 2) is around 1300-m long, with minimum and maximum widths of 6 and 11 m, respectively, while the building/street height ratio is 1.2–1.15, with a similar scale to that of many commercial streets. Trail B (Caowu Road; Figure 3) is around 1000-m long, with 10-m one-way paths on both sides and a pedestrian recreational road of 40 m, while the building/street height ratio street is 1:0.3–1:1.5, with a fairly unique street scale. Trail C (Green River Waterfront Trail, Liuchuan Road West [East] section; Figure 4) is around 500-m long and 10-m wide, while the riverbank/street height ratio is 1:0.5–1:2, and the waterfront/river bank height ratio is around 1:2. Finally, Trail D (Luchuan Waterfront Trail; Luchuan Street East [West]; Figure 5) is around 650-m long and 10-m wide, while the building/street height ratio is 1:0.5–1:2, similar to many commercial streets, with the trail close to the waterfront. Clearly, each of the trails is significantly different in terms of spatial scale and interface form.

This study investigated the basic forms, spatial scales, street interface characteristics, and noise source characteristics of the urban streets using field tests, a questionnaire survey, statistical analysis, and various other methods, with the aim of providing a research basis and a reference model for subsequent analyses. First, the methods for the acoustic environment data collection, monitoring, investigation, and data processing were selected, with the acoustic environment of the four sample trails investigated on this basis to ensure that the data collected were authentic and reliable. Second, the effects of the differences in the width, height, plane closure, section closure, and street interface around specific measuring points were studied and analyzed with the spatial geometry of the urban streets as the breakthrough point.

On-Site Measurement Method

The measuring instruments adopted included noise and vibration analyzers (Rion NA-27), cameras (iPhone 10), camcorders, and various other tools. The noise and vibration analyzers were used to record accurately the noise level and the spectrum of the ambient noise, while the cameras and camcorders were used to record the street environment status during the measurement process. The measurements were performed during the daytime (10:00–22:00) on several working days from September to November. To ensure the accuracy and representativeness of the acoustic environment data, the measurements were performed under rainless weather conditions with a wind speed not greater than 5 m/s. During the measurements, the instruments were placed on the sidewalk, 2 m from the curb of the roadway and 1.5 m above the ground, with the time weighting of the acoustical instruments set to “fast” response. The measurement period for one point was 1 min of sampling time, with the measurements performed at the hours of 10.00, 15.00, and 22.00. The camcorders and cameras were simultaneously used to record the on-site environment.
Figure 1. Trail distribution map.

Figure 2. Current condition and 1–49 measuring points of Trail A (EX: photo direction was set as (A1, A2)).
**Figure 3.** Current condition and 1–47 measuring points of trail B (EX: photo direction was set as (B1,B2)).

**Figure 4.** Current condition and 1–36 measuring points of trail C (EX: photo direction was set as (C1,C2)).
2.1. On-Site Measurement Method

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3. Data Processing Method

3.1. Universality Indicator of Noise Sources

The audio recordings sampled were replayed to record the times of the noise sources that appeared on each street during the three selected time points, with the universality indicator of these noise sources obtained on this basis. Taking traffic noise as an example, a total of 20 audio recordings obtained on a single day were replayed. Here the appearance of traffic noise in any recording counted as 1, with the number of audio recordings containing traffic noise subsequently totaled before the corresponding percentage (out of 20) was calculated. For example, if traffic noise appeared in 15 of the 20 audio recordings, the universality indicator of traffic noise in the sample was 75%.

A total of eight sound sources across six categories (Table 2) were obtained alongside the measured results of the acoustic environment through the further subdivision of the noise sources of the four trail systems in Taichung. As presented in Table 2, traffic noise was the main noise source for the streets, followed by the noise from social activities, while construction noise was fairly rare, and industrial noise was never heard. In the category of traffic noise, the universality indicator of the different noise sources differed across the four trails, with the noise of vehicles the most common source. However, as the trail type changed from living trail to greenbelt trail, the universality indicator of the above noise sources decreased accordingly. Among the noise pertaining to social activities, commercial propaganda was the most universal source, followed by crowd noise, while noise related to music was fairly rare. Unlike traffic noise, the commercial propaganda noise and crowd noise indicators increased as the trail type changed from greenbelt trail to living trail, while the music noise indicator decreased. The construction-related noise mainly included municipal road construction noise and building decoration/construction noise, while industrial noise was not a factor in this investigation, which was due to the scope of the study area, i.e., the urban center and the residential areas where no industrial enterprise exists.
Table 2. Noise Classification Results.

| Category          | Sound Source       | Time     | Average Commonality Index |
|-------------------|--------------------|----------|---------------------------|
|                   |                    |          | Trail A | Trail B | Trail C | Trail D |
| Traffic Noise     | Vehicle Sound      | Morning  | 43.9%   | 38.3%   | 30.6%   | 34.3%   |
|                   |                    | Afternoon| 51.2%   | 55.3%   | 44.4%   | 48.6%   |
|                   |                    | Night    | 24.4%   | 25.5%   | 27.8%   | 25.7%   |
| Social Life Noise | Commercial Sound   | Morning  | 14.6%   | 12.8%   | 0.0%    | 11.4%   |
|                   |                    | Afternoon| 24.4%   | 25.5%   | 0.0%    | 28.6%   |
|                   |                    | Night    | 53.7%   | 8.5%    | 0.0%    | 17.1%   |
| Social Life Noise | Crowd Talking      | Morning  | 19.5%   | 25.5%   | 16.7%   | 28.6%   |
|                   |                    | Afternoon| 29.3%   | 46.8%   | 27.8%   | 45.7%   |
|                   |                    | Night    | 61.0%   | 10.6%   | 33.3%   | 22.9%   |
| Natural Sound     | Wind               | Morning  | 4.9%    | 21.3%   | 27.8%   | 11.4%   |
|                   |                    | Afternoon| 9.8%    | 42.6%   | 33.3%   | 28.6%   |
|                   |                    | Night    | 9.8%    | 38.3%   | 33.3%   | 17.1%   |
| Natural Sound     | Wind Blowing Leaves| Morning  | 0.0%    | 12.8%   | 16.7%   | 8.6%    |
|                   |                    | Afternoon| 0.0%    | 34.0%   | 22.2%   | 17.1%   |
|                   |                    | Night    | 4.9%    | 17.0%   | 22.2%   | 11.4%   |
| Natural Sound     | Water Sound        | Morning  | 4.9%    | 4.3%    | 22.2%   | 14.3%   |
|                   |                    | Afternoon| 4.9%    | 4.3%    | 16.7%   | 11.4%   |
|                   |                    | Night    | 0.0%    | 0.0%    | 36.1%   | 20.0%   |
| Construction Noise| Building/Road      | Morning  | 0.0%    | 4.3%    | 0.0%    | 0.0%    |
| Noise             | Construction       | Afternoon| 0.0%    | 4.3%    | 0.0%    | 0.0%    |
|                   |                    | Night    | 0.0%    | 0.0%    | 0.0%    | 0.0%    |
| Industrial Noise  | Industrial Noise   | Morning  | 0.0%    | 0.0%    | 0.0%    | 0.0%    |
|                   |                    | Afternoon| 0.0%    | 0.0%    | 0.0%    | 0.0%    |
|                   |                    | Night    | 0.0%    | 0.0%    | 0.0%    | 0.0%    |

3.2. Statistical Sound Level of the Acoustic Environment

The equivalent continuous average sound level (LAeq) in each measurement period was calculated based on the measurements obtained via the sound level meter to express the acoustic environment quality of each sample. The LAeq value reflects the magnitude of noise by averaging the energy in the measurement period.

3.3. Geometric Parameters of Street Spaces

Figure 6 shows a diagram of the street-facing facades of specific streets. Unlike an ideal street model, real streets have buildings with irregular heights on both sides, as well as different-sized and diversely located street openings. The samples shown in Figure 6 (1–4) feature similar building heights but different-sized and differently distributed street openings, with all the samples presented in Figure 6 having buildings on one side with different heights and street openings. Clearly, ideal street space parameters, such as building height and aspect ratio, are not applicable for describing real streets, which means that the parameters of real street spaces must be adopted in the corresponding studies. The specific parameters used in the present study are outlined below.
3.4. Width

Street width (the spacing between the building facades on both sides of the street) is the most important spatial morphological parameter for studies on urban street sound propagation. Figure 7 shows a partial plan of a street with a width of 40 m. As the figure shows, urban streets with the same width may have different sidewalk widths and vehicle lane widths, which causes changes in the difference from the building facades to the sound sources and receiving points. Therefore, in this study, a total of three parameters, i.e., street width (W), vehicle lane width (Wv), and sidewalk width (Ws), were selected to obtain the width information of a given street.

3.5. Height

In this study, the average facade height (H) was used instead of the building height adopted in the idealized model. Here, the average facade height was calculated by averaging the total height of the street-facing facades in the test area on both sides of the street. Figure 8 and Formulas (1) and (2) present specific calculation examples. However, all the facade information could not be sufficiently expressed simply by the average facade height. As shown in Figure 8, the facade area is unevenly distributed in the propagation area due to inconsistent local facade heights and the existence of street openings, among other things. As a result, the standard deviation of the facade height (σ[H]) was used in this study to reflect whether the facade area is evenly distributed in the propagation area. The standard deviation of the facade height relates to the standard deviation of the facade...
height on both sides of all sections extracted from the test area with an interval of 6 m. Figure 8 and Formulas (3) and (4) show calculation examples.

\[ H_{\text{Near}} = \frac{1}{(30 \times 2)} \sum_{i=1}^{5}(FS_i + TS_i) \]  
(1)

\[ H_{\text{All}} = \frac{1}{(60 \times 2)} \sum_{i=1}^{10}(FS_i + TS_i) \]  
(2)

\[ \sigma(H_{\text{Near}}) = \sqrt{\frac{1}{5} \sum_{i=1}^{5}[(FS_i + TS_i)/2 - H_{\text{Near}}]^2} \]  
(3)

\[ \sigma(H_{\text{All}}) = \sqrt{\frac{1}{10} \sum_{i=1}^{10}[(FS_i + TS_i)/2 - H_{\text{All}}]^2} \]  
(4)

where \( H_{\text{Near}} \) is the average facade height of the near field, M; \( H_{\text{All}} \) is the average facade height of the full field, M; \( \sigma(H_{\text{Near}}) \) is the standard deviation of the facade height of the near field, M; \( \sigma(H_{\text{All}}) \) is the standard deviation of the facade height of the full field, M; \( FS_i, TS_i \) are the facade heights of the building on both sides of the \( i \)-th trail, M.

Figure 7. Samples with the same street width.

3.5. Height

As noted above, Kang [23] demonstrates that the existence of street openings can reduce the sound propagation by 2–3 dB, which is especially the case when the street openings are close to the sound sources. Therefore, in this study, the plane closure (\( C_p \)) and the standard deviation of the plane closure (\( \sigma[C_p] \)) were used to express information regarding whether the size and the location distribution of the street openings are balanced. Formulas (5)–(8) are calculation examples of the plane closure and the standard deviation of the plane closure with the sound sources of specific points.

\[ C_{p\text{Near}} = \frac{1}{30 \times 2} \sum_{i=1}^{5}(a_i + b_i) \]  
(5)

\[ C_{p\text{All}} = \frac{1}{60 \times 2} \sum_{i=1}^{10}(a_i + b_i) \]  
(6)

\[ \sigma(C_{p\text{Near}}) = \sqrt{\frac{1}{5} \sum_{i=1}^{5}[(a_i + b_i)/12 - C_{p\text{Near}}]^2} \]  
(7)

\[ \sigma(C_{p\text{All}}) = \sqrt{\frac{1}{10} \sum_{i=1}^{10}[(a_i + b_i)/12 - C_{p\text{All}}]^2} \]  
(8)

\[ C_{v\text{Near}} = \frac{1}{6} \sum_{i=1}^{5}(a_i + \beta_i)/180 \]  
(9)

Figure 8. Mean facade height and standard deviation of facade height.

3.6. Plane Closure

As noted above, Kang [23] demonstrates that the existence of street openings can reduce the sound propagation by 2–3 dB, which is especially the case when the street openings are close to the sound sources. Therefore, in this study, the plane closure (\( C_p \)) and the standard deviation of the plane closure (\( \sigma[C_p] \)) were used to express information regarding whether the size and the location distribution of the street openings are balanced. Formulas (5)–(8) are calculation examples of the plane closure and the standard deviation of the plane closure with the sound sources of specific points.
was later extended to include more complex soundscapes, with the SD method found to allow for effectively summarizing the soundscape perception structure under different sources of specific points.

\[
C_{vAll} = \frac{1}{16} \sum_{i=1}^{16} (\alpha_i + \beta_i) / 180
\]  

(10)

where \( C_{pNear} \) is the plane enclosure degree of the near-field, \( \% \); \( C_{pAll} \) is the plane enclosure degree of the full field, \( \% \); \( \sigma (C_{pNear}) \) is the standard deviation of plane enclosure degree of the near field, \( \% \); \( \sigma (C_{pAll}) \) is the standard deviation of plane enclosure degree of the full field, \( \% \); \( \alpha_i, \beta_i \) are the facade lengths of the building on both sides of the \( i \)-th trail, M. where \( C_{vNear} \) is the plane enclosure degree of the nearfield, \( \% \); \( C_{vAll} \) is the plane enclosure degree of the full field, \( \% \); \( \alpha_i, \beta_i \) are the angles between the facade of the building on both sides of the \( i \)-th trail and the road axis.

3.7. Plane Closure

As shown in Figure 6, since the section morphology of streets cannot be unified and there exist building facades on only one side of certain streets, the numerical value of the aspect ratio of the street spaces could not be determined. As such, the more universal parameter, section closure, was used instead of the aspect ratio. Figure 9 and Formulas (9) and (10) show calculation examples of the section closure with the sound sources of specific points.

![Figure 9. Cross-sectional enclosure degree (a and b are the truncated planes on both sides).](image)

4. Questionnaire Survey

Over the past 20 years, a psychology-based method known as the semantic differential (SD) method has been widely applied in the field of acoustic research [24]. This method initially involved determining how subjects evaluate specific aspects quantitatively through a series of pairs of descriptive words (antonyms) before the subjective description (i.e., how things are perceived) is summarized into several dimensions via a statistical method [25]. The SD method has subsequently been applied within the field of soundscape research to analyze the structure of soundscape perception through summarizing the main perception factors [26]. The attendant research can be divided into several stages. While most of the early studies focused on soundscapes with a single sound source [27], the study scope was later extended to include more complex soundscapes, with the SD method found to allow for effectively summarizing the soundscape perception structure under different soundscape forms. Berglund [27] proposes four major perception factors for residential areas, i.e., adverse, reposing, affective, and expressionless. Meanwhile, according to Zeitler [28], a further four major factors, i.e., evaluation, timber, power, and temporal change, are proposed across various studies. In terms of urban public open spaces, Professor Kang Jian proposes four further factors in a comparative study between Chinese and English, i.e., relaxation, communication, spatiality, and dynamics.
Table 3 presents the data related to the background information of the respondents who took part in the questionnaire survey. All the respondents were randomly selected and included both local residents and first-time tourists. A total of 360 questionnaires were distributed, with 338 returned. It should be noted that studies indicate that the sample size for a survey using the SD method should be no smaller than 150 [22]. To ensure the reliability of the sample size in this study, the results of later statistical analysis were compared when the sample size reached 200 and 300. The results indicate that the factors extracted became stable when the sample size reached 300, suggesting that the sample number used in this study was sufficient.

Table 3. Sample trail.

| Sample Trail | Trail A | Trail B | Trail C | Trail D |
|--------------|---------|---------|---------|---------|
| Number of respondents | 108     | 107     | 55      | 68      |
| Gender |          |         |         |         |
| Male | 42%     | 36.5%   | 36.4%   | 42.6%   |
| Female | 58%     | 63.5%   | 63.6%   | 57.4%   |
| Age 21–60 | 63%     | 65.4%   | 72.8%   | 70.5%   |
| Purpose |          |         |         |         |
| Shopping | 22%     | 9.3%    | 0%      | 13.2%   |
| Entertainment | 16.7%   | 42.9%   | 9.1%    | 32.4%   |
| Play | 26.9%   | 38.3%   | 38.2%   | 33.8%   |
| Walk | 19.5%   | 3%      | 32.7%   | 7.4%    |
| Other | 14.9%   | 6.5%    | 20%     | 13.2%   |
| Frequency |          |         |         |         |
| First | 0%      | 14%     | 7.2%    | 7.4%    |
| Occasionally | 44%     | 53.3%   | 43.6%   | 60.3%   |
| Frequently | 56%     | 32.7%   | 49.2%   | 32.3%   |

As presented in Table 3, among all the selected trails, the distribution of male and female respondents was largely balanced, with around 20% more females than males overall. In terms of age distribution, the 21–30 age group accounted for 65%, while there was a certain difference in age distribution among the different areas. The proportion of 21–30-year-old respondents in Trail A was the lowest due to the comparatively higher proportion among the other age groups, which meant the age distribution in this trail was more balanced.

Questionnaire Design

One of the main aspects of surveys involving the SD method is the questionnaire design, with the selection of the semantic word pairs being especially important. The word pairs used in terms of different soundscapes in previous studies tend to differ significantly in terms of content and number, directly affecting the results of the final analysis. Therefore, a reasonable selection of semantic word pairs is a precondition for the accurate description of a soundscape. Here, to ensure the accuracy of the results, multiple methods were adopted to obtain the word pairs to be used for the soundscape description. Figure 10 shows the process, which is described below.

The first step involved collecting the word pairs for the soundscape description. First, ten descriptive word pairs (e.g., like–dislike, quiet–noisy, single–diverse) were obtained with reference to the word pairs used in similar studies. Second, around 16 descriptive word pairs were obtained by conducting interviews. However, there was some intersection between the word pairs obtained using the two approaches, with a total of 12 descriptive word pairs finally selected following an assessment of the overlap.
The first step involved collecting the word pairs for the soundscape description. First, ten descriptive word pairs (e.g., like–dislike, quiet–noisy, single–diverse) were obtained with reference to the word pairs used in similar studies. Second, around 16 descriptive word pairs were obtained by conducting interviews. However, there was some intersection between the word pairs obtained using the two approaches, with a total of 12 descriptive word pairs finally selected following an assessment of the overlap.

Meanwhile, the second step involved screening the word pairs for an accurate soundscape description, with the 12 descriptive word pairs collected screened and refined using a pre-experiment involving a total of 10 subjects. The results indicate that six of the word pairs had ambiguous meanings or were difficult to evaluate quantitatively, and were thus removed. The final formal questionnaire consequently contained ten descriptive word pairs: quiet–noisy, interesting–boring, comfortable–uncomfortable, friendly–unfriendly, like–dislike, simple–complex, artificial–natural, single–diverse, orderly–chaotic, and sharp–gentle.

The SD-based questionnaire adopted a seven-point numerical scale evaluation, as presented in Table 4. Moreover, it should be noted that the pre-experimental samples were only used to analyze the reliability of the word pairs selected for the questionnaire, with the attendant data not included in the 338 samples used in the formal experiment.

| Extreme | Very | A Bit | Neither | ABit | Very | Extreme |
|---------|------|-------|---------|------|------|---------|
| Noisy   | −3   | −2    | −1      | 0    | 1    | 2       | 3       | Quiet     |
| Boring  | −3   | −2    | −1      | 0    | 1    | 2       | 3       | Interesting |
| Uncomfortable | −3 | −2    | −1      | 0    | 1    | 2       | 3       | Comfortable |
| Unfriendly | −3 | −2    | −1      | 0    | 1    | 2       | 3       | Good     |
| Dislike | −3   | −2    | −1      | 0    | 1    | 2       | 3       | Like     |
| Complicated | −3 | −2    | −1      | 0    | 1    | 2       | 3       | Innocent |
| Artificial | −3 | −2    | −1      | 0    | 1    | 2       | 3       | Nature   |
| Single  | −3   | −2    | −1      | 0    | 1    | 2       | 3       | Diverse |
| Chaotic | −3   | −2    | −1      | 0    | 1    | 2       | 3       | Ordered |
| Sharp   | −3   | −2    | −1      | 0    | 1    | 2       | 3       | Peaceful |

Table 4. Questionnaire scale table.

Figure 10. Questionnaire process.
5. Results and Discussion

Objective characteristics of the acoustic environment.

Trail A: The measurement results are evaluated and recorded using the physical quantity LAeq (dB). As shown in Figure 11, forty-nine groups of measurement points completely examined the sound field distribution. On weekdays and weekends, measurements were taken to determine the distribution of street sound energy at three different times: 4:00 p.m. (market opening), 9:00 p.m. and 1:00 a.m. (market closing). On average, the sound level of the recreational trails along the street in the business district ranged from 55 to 80 dB(A). Different sections showed a difference of more than 20 dB(A), indicating the uniqueness of recreation at nighttime. Moreover, the sound field energy increases steadily over time; nevertheless, it dives at the T-shaped intersection at the corner, showing that the sound energy decreases when the linear space is turned, according to the measurement results. The sound energy attenuation varies depending on the type of linear street.

Figure 11. Trail A LAeq value.

Trail B: Based on the measurement results, the average sound energy is roughly 69.5 dB(A) from 10:00 a.m. to 7:00 p.m., 65.5 (A) at 10:00 p.m. near the sound field of residential areas, and 61 dB(A) at nightfall. Although the maximum sound energy of the main traffic node road can reach up to 80 dB(A), it is adequate for roaming in the leisure space environment. The study shows that its noise is mainly concentrated between 25 to 33 point positions (with music, radio, frolic, and talking as its main sound sources), and its sound field energy declined steadily at 35 point positions during the day and at night. Figure 12 shows the measurement results of the 47 groups of measurement points.

Figure 12 shows the measurement results of the 47 groups of measurement points.

Trail C: The sound field distribution is discussed for the main pedestrian street of Luchuan Road West and the riverside trail at different time nodes based on the measurement results. The sound sources of the Luchuan riverside recreation trail are divided into two categories: the first is the sound of mechanical equipment, such as traffic noise, motor vehicles, and music; the second are the sounds of life, such as human voices, footsteps, frolics, and talking. Measurements were taken at 10:00 a.m., 3:00 p.m., and 9:00 p.m. According to the measurement results, the average is 67 dB(A) during congested and peak hours. At peak afternoon hours, the differences between the riverside and ground measuring points can reach 7 dB(A) at maximum and 2 dB(A) at minimum. According to measurement results, regarding the main road section point (7–16), the average Leq value of the river bank at (6–21) points is 61 dB(A) for the whole day, while the Leq value of the water bank at (22–36) points is U-shaped, with low energy in the middle section, and high Leq values on both ends, possibly affected by Taiwan Avenue and Minquan Road traffic nodes. Figure 13 shows the measurement results for the 36 groups of measurement points.
Figure 12. Trail B LAeq value.

Figure 13. Trail C LAeq value.

Trail D: Measurement results show that the base is adjacent to the surrounding residential area. The Leq(A) value rises as night falls due to traffic spikes and frequent exchanges. For secondary traffic, roads also witness the same condition. The afternoon Leq(A) value is higher than the evening value. To be more specific, the average of four major junctions is 72 dB(A) throughout the day, and the Leq(A) value at the river bank is 68 dB(A), indicating that the sound field at the river bank is significantly affected by activities, whereas the sound energy distribution of the riverside landscape trail is maintained by its embankment and subsidence topography. According to the above field average measurement data, the sound field distributions of the ground walkway and riverside trails at different time nodes are discussed. To gather sound energy at varied times and fixed positions, 21 groups of test points (measuring points 1–21) and 15 groups of test points (measuring points 22–36) are selected along the water bank walking space and riverside trail space. Figure 14 shows the measurement results of 35 groups of measurement points.

Overall, the sound pressure level (SPL) of the acoustic environments of the selected trail spaces was between 55 and 80 dBA, with the difference among the different trails as high as 20 dB(A). Trail A had the highest SPL at 77 dB(A), while the SPL of Trails B, C, and D was comparatively low at around 65 dB(A). According to the Environmental Quality Standard for Noise, urban trails pertain to Category 2 of the acoustic environment function division, including areas where commercial finance and market trading are the
main functions, or areas with residential, commercial, and industrial functions where the noise level of the residential areas should be maintained at a low level, with the noise level limit in the daytime set at 60 dBA. Here, it was clear that only one of the sample trails fully met this requirement, while two almost met the requirement. However, the noise level of the other trail was far higher (up to 20 dB(A)) than the required standard.

Figure 14. Trail D LAeq value.

5.1. Spatial Morphological Parameters

Table 5 presents the spatial parameters of all the streets selected for the point sound source model, which include the width information, the plane information, the height information, and the section information regarding the spatial form of the streets. According to the data, the street width ranged from 15 to 80 m; the lane width and sidewalk width were 5–40 and 3–40 m, respectively; the full-field and near-field average facade heights were 5–62.6 and 1–57.5 m, respectively; the full-field and near-field section closures were 6.7–69.8% and 1–57.5%, respectively; the full-field and near-field plane closures were 36.8–100% and 5.0–100%, respectively; the standard deviation of the full-field and near-field plane closures was 6.7–69.8% and 1–57.5%, respectively; the full-field and near-field plane facade heights were 5–62.6 and 1–57.5 m, respectively; the full-field and near-field section closures were 0–5% and 0–5.67%, respectively.

Table 5. Street spatial parameters of point source model.

| Spatial Morphological Parameters | Unit | The Audience | Near Field |
|--------------------------------|------|--------------|------------|
|                                |      | Short Name   | Data Range | Short Name   | Data Range |
| Trail width                    | M    | W            | 5–80       |             |            |
| Lane width                     | M    | Wv           | 5–40       |             |            |
| Sidewalk width                 | M    | Ws           | 3–40       |             |            |
| Average elevation              | M    | $H_{\text{All}}$ | 5–62.5     | $H_{\text{Near}}$ | 1–57.5     |
| Section enclosure              | %    | $C_{p\text{All}}$ | 6.7–69.8   | $C_{p\text{Near}}$ | 1–69.8     |
| Plane enclosure                | %    | $C_{p\text{All}}$ | 36.8–100   | $C_{p\text{Near}}$ | 5–100      |
| Standard deviation of elevation height | M     | $\sigma(H_{\text{All}})$ | 0–95.52 | $\sigma(H_{\text{Near}})$ | 0–125.65 |
| Standard deviation of plane enclosure | %  | $\sigma(C_{p\text{All}})$ | 0–5 | $\sigma(C_{p\text{Near}})$ | 0–5.67 |
5.2. Dimension Structure of Commercial Street Soundscape Perception

The soundscapes were evaluated according to the descriptive word pairs, after which the main dimensions could be summarized and analyzed in terms of specific factors, i.e., the principal factors of people’s perceptions of the commercial street soundscape. Table 6 presents the twiddle factor matrix obtained via factor analysis. The results indicate that there were a total of five main perception factors: likability (accounting for 24.89% of the variance and including word pairs such as like–dislike, comfortable–uncomfortable, and friendly–unfriendly), communication (accounting for 22.01% of the variance and including word pairs such as sharp–gentle, artificial–natural, and chaotic–orderly), intensity (accounting for 13.54% of the variance and including word pairs such as noisy–quiet), interestingness (accounting for 11.98% of the variance and including word pairs such as complex–simple and boring–interesting), and richness (accounting for 8.35% of the variance and including word pairs such as single–diverse). These five principal factors account for 80.77% of the overall sample variance, which is a relatively high level compared with similar studies in the field of soundscape research. However, the Kaiser–Meyer–Olkin value of up to 0.88 means that the validity of the factor analysis applied in this sample was high, and that the results of the factor analysis were consistent.

Table 6. Sample factor analysis matrix.

| Main Factor                  | 1 = 24.89% | 2 = 22.01% | 3 = 13.54% | 4 = 11.98% | 5 = 8.35% |
|-----------------------------|------------|------------|------------|------------|------------|
| Dislike–Like                | 0.794      |            |            |            |            |
| Uncomfortable–Comfortable   | 0.784      |            |            |            |            |
| Unfriendly–Friendly         | 0.791      | 0.925      |            |            |            |
| Noisy–Quiet                 |            |            |            | 0.925      |            |
| Sharp–Peaceful              |            |            | 0.836      |            | 0.925      |
| Artificial–Natural          |            | 0.505      |            |            | 0.836      |
| Chaos–Order                 |            | 0.831      |            |            |            |
| Single–Variety              |            |            |            |            | 0.947      |
| Complex–Simple              |            |            |            |            |            |
| Boring–Interesting          |            |            |            |            | −0.561     |
|                             |            |            |            |            | 0.69       |

The results reveal the similarities and differences in the perception structure between the acoustic environment of urban recreational trails and other urban soundscapes. Compared with previous studies on soundscapes pertaining to other urban spaces, the principal factors summarized in this study have essentially the same connotations and cover several major aspects of the acoustic environment, including intensity, content, and variability. However, the results of this study also reveal some specific characteristics of commercial street soundscapes.

The research findings reveal some characteristics of the acoustic environment of recreational trails. Table 7 compares the results of the semantic segmentation method of the acoustic environment in different cities. Based on this, two factors are extracted from the study to explore the effect of limitations in the recording research, and three to four factors are the main factors extracted from the study’s field survey. This study extracts five main factors from the on-site investigation that are conducive to the study of subjective evaluation. In addition, in prior studies, one or two factors with much higher weights than other factors explain most of the variance. Since the weights of the five factors in this study vary insignificantly, the variance of the total sample is almost the same. This indicates that the structure of soundscape perception is more complex, with more factors affecting subjective evaluation in the acoustic environment of urban recreational trails. Furthermore, a single factor (such as level) has a great influence on the overall perception of other urban soundscapes, which can heavily influence people’s evaluation results. However, various factors in the acoustic environment of recreational trails are equally important.
It also demonstrates that more elements and design methodologies can be used in the construction and improvement of recreational trail acoustics. When the sound pressure level cannot be adjusted, changing the composition of the soundscape (for example, by introducing natural sounds) might effectively improve the soundscape evaluation.

Table 7. Comparison of research results of semantic segmentation methods in different urban acoustic environments.

| Researcher | Environmental Classification | The Main Factor Taken and the Corresponding Explained Variance | Research Method |
|------------|-----------------------------|---------------------------------------------------------------|-----------------|
| Kawai      | Garden                      | Preference (25%)                                             | Recording       |
|            |                             | Activity (16.8%)                                             |                 |
|            |                             | Daily life (9.2%)                                            |                 |
| Rebecca    | Square                      | Calmness (52%)                                               | Recording       |
|            |                             | Vibrancy (21%)                                               |                 |
| Deboeah    | Various                     | Vibrancy (48%)                                               | Recording       |
|            |                             | Content (24%)                                                |                 |
| Kang       | Parks and Plazas            | Relaxation (30%)                                             | Site investigation|
|            |                             | Communication (13%)                                          |                 |
|            |                             | Spatiality (7%)                                              |                 |
|            |                             | Dynamics (3%)                                                |                 |
| Lin, Wu    | Recreational trail          | Preference (24.89%)                                          | Site investigation|
|            |                             | Communication (22.01%)                                        |                 |
|            |                             | Loudness (13.54%)                                            |                 |
|            |                             | Playfulness (11.98%)                                         |                 |
|            |                             | Richness (8.35%)                                             |                 |

Based on the evaluation average of various perception factors (Figure 15), the evaluation average of four of the five perception factors, namely, likability, communication, intensity, and interestingness, was negative, with only the average of the richness factor found to be “complicated”. This indicates that people’s overall satisfaction with commercial street soundscapes is low and that their overall impression of such soundscapes is “unlikeable”, “chaotic”, “noisy”, “boring”, and “messy”. However, it should also be noted that the average of most of the evaluations, especially the negative evaluations, was extremely close to the overall variance, indicating that there were large individual differences among the respondents and that the evaluation average cannot fully reflect the distribution of users’ evaluations.

5.3. Influence of Functional Formats of Streets

To analyze the influence of the functional format of the commercial streets on soundscape perceptions, the formats of the four sample trails were first classified into two categories for comparison: (1) trails where shopping is the dominant function, and (2) trails where entertainment is the dominant function. Following this, the soundscape perception factors were analyzed in terms of the two datasets, and the results are presented in Tables 8 and 9.

First, on comparing the tables, the characteristics of the acoustic environment perception of the recreational trails were clearly reflected in the two dominant categories. Here, two categories of samples had five soundscape perception factors, while the semantic descriptive word pairs pertaining to each perception factor were highly similar and appeared to be common to the sound environment of recreational trails. However, the influence of the functional formats on the acoustic environment evaluation of the trails
was mainly reflected by the ranking of the various perception factors. With the percentage of the sample variance used as the basis for the order of importance, the most important perception factors for trails where pleasure is the main purpose followed the following sequence: likability, communication, intensity, richness, and interestingness. Meanwhile, the most important perception factors for trails where recreation is the main purpose followed a slightly different sequence: communication, preference, intensity, interestingness, and richness. Here, it can be inferred that in trails where recreation is the main purpose, people have higher aesthetic requirements for the acoustic environment, which means that the importance of soundscape likability and communication was enhanced, while in trails where pleasure is the main purpose, people tend to pay more attention to the functional requirements. Therefore, the communication of the soundscape was found to be the most important perception factor, while preference, richness, and intensity were less important.

Figure 15. Influencing factors for perception structure of commercial street soundscapes.

Table 8. Acoustic environment perception factors for different purposes.

| Entertainment Purpose | 1       | 2       | 3       | 4       | 5       |
|-----------------------|---------|---------|---------|---------|---------|
|                       | 24.92%  | 23.28%  | 14.83%  | 10.57%  | 10.31%  |
| Dislike–Like          | 0.844   |         |         |         |         |
| Unfriendly–Friendly   | 0.83    |         |         |         |         |
| Uncomfortable–Comfortable | 0.764 |         |         |         |         |
| Sharp–Peaceful        | 0.818   |         |         |         |         |
| Artificial–Natural    | 0.581   |         |         |         |         |
| Chaos–Order           | 0.761   |         |         |         |         |
| Complex–Simple        |         | 0.528   |         |         |         |
| Noisy–Quiet           |         | 0.89    |         |         |         |
| Single–Variety        |         |         |         | 0.98    |         |
| Boring–Interesting    |         |         |         |         | 0.983   |

KMO = 0.82

Explain total variance = 83.91%
Table 9. Acoustic environment perception factors for different purposes.

| Factor                               | For the Purpose of Play |
|--------------------------------------|-------------------------|
|                                      | 1  | 2  | 3  | 4  | 5  |
|                                      | 22.04% | 18.92% | 15.27% | 15.03% | 14.28% |
| Dislike–Like                         | 0.801       |
| Unfriendly–Friendly                  | 0.78        |
| Uncomfortable–Comfortable            | 0.897       |
| Sharp–Peaceful                       | 0.594       |
| Artificial–Natural                   | 0.549       |
| Chaos–Order                          | 0.702       |
| Complex–Simple                       | 0.905       |
| Noisy–Quiet                          | 0.894       |
| Single–Variety                       | 0.921       |
| Boring–Interesting                   | 0.585       |

KMO = 0.85

Explain total variance = 85.35%

As shown in Figure 16, in terms of the evaluation average, the soundscapes evaluations of trails where recreation is the main purpose are more “extreme” than those of the trails where pleasure is the main purpose. In fact, the two different purposes exhibited a similar trend in terms of evaluation but, differed in terms of the likability factor, while the evaluation of the communication and intensity factors was largely negative. However, the absolute value of the evaluation of the trails where recreation is the main purpose was significantly smaller than that pertaining to trails where pleasure is the main purpose. These differences in the evaluation of the trails with different purposes were not related to the objective environment, but by people’s different needs regarding the acoustic environment. In the trails where recreation is the main purpose, the respondents tended to have higher requirements for the acoustic environment, due to the comparative weakening of the shopping function. As a result, those seeking entertainment had a more negative evaluation of the soundscapes and lower satisfaction.
acoustic environment evaluation were assessed using the analysis of variance (ANOVA) technique. Table 10 presents the significant coefficients among the factors assessed via ANOVA, where the * symbol represents a significant difference at the 95% confidence level. Here, it was clear that the factors, i.e., age, gender, and frequency of use, had significant effects on several soundscape perception factors.

### Table 10. Variance analysis of respondents’ background information and evaluation of acoustic environment perception factors.

|                              | Liking | Communicative | Loudness | Interesting | Richness |
|------------------------------|--------|----------------|----------|--------------|----------|
| Respondent’s age             | 0.000 *| 0.126          | 0.000 *  | 0.002 *      | 0.238    |
| Respondent’s gender          | 0.190  | 0.508          | 0.939    | 0.362        | 0.135    |
| Usage frequency              | 0.148  | 0.257          | 0.100    | 0.543        | 0.003 *  |

Note: * indicates a significant difference at the 95% level.

### 5.4. Effects of Age

Figure 17 shows the evaluation trend in relation to age. Here, it was clear that age had a significant effect on the factors of likability, intensity, and richness.

In terms of the effect on the likability factor, interestingly, the lowest age group (below 20) and the highest age group (above 61) reported an opposite evaluation of the acoustic environment of the attendant recreational trail, while the middle age group (20–60) had a largely neutral view regarding the likability aspect. These results indicate that the lower age group is relatively satisfied with the acoustic environment of recreational trails, while the higher age group has failed to adapt to and is dissatisfied with the high SPL and complex sound source composition of the acoustic environment of recreational trails. However, as the main user of trail spaces, the middle age group appeared to have greater tolerance to the current acoustic environmental conditions. Meanwhile, the communication and intensity evaluations returned interesting results, with the communication value decreasing with the increase in age and the intensity increasing with the increase in age. Clearly, as shown in Figure 18, significant differences were found between the low age group and the high age group.

![Figure 17. The effect of age on preference evaluation.](image-url)
In terms of the effect on the likability factor, interestingly, the lowest age group (below 20) and the highest age group (above 61) reported an opposite evaluation of the acoustic environment of the current recreational trails.

5.5. Effects of Gender

It was found that gender had limited effects on soundscape perception, with the effects mainly related to the factor of “interestingness”. As shown in Figure 19, the evaluation was fairly balanced between males and females, and tended toward “interesting”. This further indicates the generally low level of satisfaction with the acoustic environment of the current recreational trails.

5.6. Effects of Frequency of Use

In the survey, the respondents’ “frequency of use” of recreational trails was classified into three categories: first, occasional, and frequent. As shown in Figure 20, while the frequency of use factor had consistent effects on the evaluation of intensity and richness, overall, the effects of this factor were largely insignificant, with the richness evaluation the most affected. In short, as the frequency of use increases, people become more and more familiar with the acoustic environment of the recreational trails, and thus find the acoustic environment increasingly “boring”. This indicates that the acoustic environment of recreational trails requires constant development and renewal to avoid aesthetic fatigue on the part of the users.
were proposed using the semantic segmentation approach and factor analysis. Meanwhile, five main factors account for 80.77% of the total variance explained, level (13.54% of variance explained, including loud and quiet word pairs), communicative (22.01% of variance explained), richness (8.35% of variance explained) and interestingness (11.98% of variance explained). These five main factors account for 80.77% of the total sample variance, which is a higher level than in previous studies in the field of soundscape research. The KMO value is 0.88, indicating that the sample is highly effective in the application of factor analysis, producing consistent results. Based on the comparison with previous studies, it is apparent that the perceptual characteristics of the acoustic environment of urban recreational trails are multi-dimensional factors. On the one hand, the large number of perceptual factors indicates that residents have diverse needs for soundscape aesthetics; on the other hand, the five factors have a similar importance, with the level factor having a low impact, explaining that lowering the acoustic pressure level does not necessarily improve the inherent flexibility of soundscape evaluation. The functional position of the urban recreational trail affects the relative importance of several evaluation dimensions,
although it may not affect the characteristics of the evaluation dimension, indicating the importance of spatial function and soundscape coordination. It is also suggested that other evaluation dimensions could be used to improve overall soundscape satisfaction. According to additional investigation, the structure and evaluation of the acoustic environment perception of urban recreational trails are also highly affected by a variety of factors. The acoustic pressure level has a significant impact on the communicability ratings. Individual factors such as age, gender, and frequency of use also have varying influences on soundscape evaluation.

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**References**

1. Alves, S.; Estévez-Mauriz, L.; Aletta, F.; Echevarria-Sanchez, G.M.; Romero, V.P. Towards the integration of urban sound planning in urban development processes: The study of four test sites within the SONORUS project. *Noise Mapp.* 2015, 2, 57–85. [CrossRef]
2. Andringa, T.C.; Weber, M.; Payne, S.R.; Krijnders, J.D.D.; Dixon, M.N.; Linden, R.V.D.; de Kock, E.G.L.; Lanser, J.J.L. Positioning soundscape research and management. *J. Acoust. Soc. Am.* 2013, 134, 2739–2747. [CrossRef] [PubMed]
3. Asdrubali, F. New frontiers in environmental noise research. *Noise Mapp.* 2014, 1, 1–2. [CrossRef]
4. Van Kempen, E.; Devilee, J.; Swart, W.; Van Kamp, I. Characterizing urban areas with good sound quality: Development of a research protocol. *Noise Health* 2014, 16, 380. [CrossRef] [PubMed]
5. Schwela, D. World health organization guidelines on community noise. *Present. TRB Sess.* 2001, 391, 193–198. [CrossRef]
6. King, E.A.; Murphy, E. Environmental noise—‘Forgotten’or ‘Ignored’ pollutant? *Appl. Acoust.* 2016, 112, 211–215. [CrossRef]
7. World Health Organization. *Burden of Disease from Environmental Noise;* WHO Regional Office for Europe: Copenhagen, Denmark, 2011.
8. Can, A.; L’Hostis, A.; Aumond, P.; Botteldooren, D.; Coelho, M.; Guarnaccia, C.; Kang, J. The future of urban sound environments: Impacting mobility trends and insights for noise assessment and mitigation. *Appl. Acoust.* 2020, 170, 107518. [CrossRef]
9. Bello, J.P.; Silva, C.; Nov, O.; Dubois, R.L.; Arora, A.; Salamon, J.; Doraiswamy, H. Sony: A system for monitoring, analyzing, and mitigating urban noise pollution. *Commun. ACM* 2019, 62, 68–77. [CrossRef]
10. Brambilla, G.; Pedrielli, F. Smartphone-Based Participatory Soundscape Mapping for a More Sustainable Acoustic Environment. *Sustainability* 2020, 12, 7899. [CrossRef]
11. King, E.A.; Murphy, E.; McNabola, M. Reducing pedestrian exposure to environmental pollutants: A combined noise exposure and air quality analysis approach. *Transp. Res. Part D Transp. Environ.* 2009, 14, 309–316. [CrossRef]
12. Catherine, L.; Defrèville, B. The contribution of sound source characteristics in the assessment of urban soundscapes. *Acta Acust. United Acust.* 2006, 92, 912–921.
13. Ricciardi, P.; Delatitre, P.; Lavandier, C.; Torchia, F.; Aumond, P. Sound quality indicators for urban places in Paris cross-validated by Milan data. *J. Acoust. Soc. Am.* 2015, 138, 2337–2348. [CrossRef] [PubMed]
14. Jo, H.I.; Jeon, J.Y. Effect of the appropriateness of sound environment on urban soundscape assessment. *Build. Environ.* 2020, 179, 106975. [CrossRef]
15. Schafer, R.M. *The Soundscape: Our Sonic Environment and the Tuning of the World*; Destiny Books: Rochester, VT, USA, 1997.
16. Kang, J.; Aletta, F.; Oberman, T.; Erfanian, M.; Kachlicka, M.; Lionello, M.; Mitchell, A. Towards soundscape indices. In Proceedings of the International Congress on Acoustics. International Congress on Acoustics, Aachen, Germany, 9–13 September 2019.
17. Tsaligopoulos, A.; Kyvelou, S.; Votsi, N.-E.; Karapostoli, A.; Economou, C.; Matsinos, Y. Revisiting the Concept of Quietness in the Urban Environment—Towards Ecosystems’ Health and Human Well-Being. *Int. J. Environ. Res. Public Health* 2021, 18, 3151. [CrossRef]
18. Jo, H.I.; Jeon, J.Y. Compatibility of quantitative and qualitative data-collection protocols for urban soundscape evaluation. *Sustain. Cities Soc.* 2022, 74, 103259. [CrossRef]
19. Dias, F.F.; Ponti, M.A.; Minghim, R. A classification and quantification approach to generate features in soundscape ecology using neural networks. *Neural Comput. Appl.* 2021, 34, 1923–1937. [CrossRef]
20. Kerrick, J.S.; Nagel, D.C.; Bennett, R.L. Multiple ratings of sound stimuli. *J. Acoust. Soc. Am.* 1969, 45, 1014–1017. [CrossRef]
21. Margaretten, E. A Place on the Point: South African Street Youth and Informal Street Shelters. Ph.D. Thesis, Yale University, New Haven, CT, USA, 2007.
22. Kang, J.; Zhang, M. Semantic differential analysis of the soundscape in urban open public spaces. *Build. Environ.* **2010**, *45*, 150–157. [CrossRef]
23. Kang, J. Numerical modelling of the sound fields in urban streets with diffusely reflecting boundaries. *J. Sound Vib.* **2002**, *258*, 793–813. [CrossRef]
24. Kawai, K.; Kojima, T.; Hirate, K.; Yasuoka, M. Personal evaluation structure of environmental sounds: Experiments of subjective evaluation using subjects’ own terms. *J. Sound Vib.* **2004**, *277*, 523–533. [CrossRef]
25. Osgood, C.E.; Suci, G.];; Tannenbaum, P.H. *The Measurement of Meaning*. No. 47; University of Illinois Press: Champaign, IL, USA, 1957.
26. Zhang, M.; Kang, J. A cross-cultural semantic differential analysis of the soundscape in urban open public spaces. *Tech. Acoust.* **2006**, *25*, 523–532.
27. 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]
28. Zeitler, A.; Hellbrück, J. Semantic attributes of environmental sounds and their correlations with psychoacoustic magnitude. In Proceedings of the 17th International Congress on Acoustics [CDROM], Rome, Italy, 2–7 September 2001.