

A Study on the Soundscape Satisfaction Degree of Urban Landscape Garden Parks

Guoqing Di (✉ dgq@zju.edu.cn)

Zhejiang University <https://orcid.org/0000-0001-8779-6838>

Junli Xiang

Zhejiang University

Yao Yao

Zhejiang University

Cong Chen

Zhejiang University

Qinhao Lin

Zhejiang University

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Abstract

Establishing a public response model of soundscape in parks can provide a basis for the optimization of soundscape design. Three representative urban landscape garden parks were selected in Hangzhou, in which a number of evaluation points were chosen along soundwalk paths. Binaural sounds at each evaluation point were sampled by an artificial head and the landscapes of horizontal view and vertical view were obtained by panoramic photos and satellite images, respectively. An evaluation on soundscape of each point was conducted in laboratory based on virtual reality technology, and the correlations between 17 acoustic indicators, 35 landscape indicators and soundscape satisfaction degree were analyzed. The public response model of soundscape satisfaction degree in parks was established. Final indicators entering the model were the loudness level of sound, the aggregation index of water, the largest patch index of water and the landscape shape index of roads, and their standard regression coefficients were -0.666, -0.561, 0.523 and -0.310, respectively. The impact weights of acoustics and landscape factors on the satisfaction were 32.3% and 67.7%. When the percentage of vegetation area in park exceeds 15%, its contribution to satisfaction degree will be close to a fixed value (reflected in the constant term of the model). The soundscape satisfaction can be effectively improved by reducing the loudness level of sound in parks, increasing the area of the largest water patch with scattered water patches around it, and reducing the shape complexity of road patches.

1 Introduction

Urban landscape garden parks are important places for public recreation, and their soundscape qualities directly affect the public satisfaction degree with the parks. Soundscape includes two elements, sound and landscape, which affect public perception experiences through audition and vision, respectively (Cassina et al., 2018). Studies showed that sound pressure level, sharpness, loudness and roughness were important acoustic factors affecting auditory perception in parks (Gozalo et al., 2015; Hall et al., 2013; Jeon et al., 2010; Ricciardi et al., 2015; Tse et al., 2012), while the on-site overall landscape composition and local landscape patterns of roads, water, vegetation and buildings were closely related to visual perception (Kang, 2001; Liu et al., 2013a; Luo et al., 2019; Matsinos et al., 2008; Ode et al., 2009). The effects of acoustics and landscape factors on soundscape can be quantitatively studied through questionnaires, soundwalks and laboratory evaluations, among which laboratory evaluations can better control variables effectively and are widely used in soundscape researches (Hong et al., 2013; Jeon et al., 2018; Kim and Shelby, 2011; Lindquist et al., 2016). Previous studies (Maffei et al., 2016; Hong et al., 2019) showed that using virtual reality (VR) technology to reproduce on-site soundscape was a reliable method of performing the laboratory evaluation of soundscape, which could effectively replace soundscape surveys on site.

In previous studies, acoustic comfort, soundscape preference, soundscape quality or soundscape satisfaction degree was used as a dependent variable to establish soundscape models, while landscape preference, sound preference, visual amenity of subjects were usually used as independent variables in these models, and the impact degree of acoustics and landscape factors on soundscape perception has

not reached a consensus conclusion (Cassina et al., 2018; Gan et al., 2014; Liu et al., 2013b; Ricciardi et al., 2015; Tse et al., 2012; Watts et al., 2013). The values of independent variables in the models reported by these studies above, such as landscape preference, sound preference, visual amenity, etc., need to be obtained by means of questionnaires and interviews instead of direct measurements or calculations. Therefore, these models cannot be applied to the quantitative comparison and selection of soundscape schemes in the soundscape design stage. As a good soundscape model, if the independent variables are all acoustic and landscape indicators which can be determined by quantitative measurements or calculations directly, the soundscape quality of different schemes can be quantified in the design stage. Meanwhile, according to the soundscape model, the targeted strategies improving soundscape (such as changing the noise characteristics in the environment, reasonable layout of landscape elements, etc.) (Brown, 2012; Hall et al., 2013; Li et al., 2018) can be put forward to serve the soundscape design.

Taking urban landscape garden parks as an example, this study aimed to develop a methodology setting up a public response model of soundscape based on virtual reality technology. The independent variables of the model established by this method are all acoustic and landscape indicators, and the independent values can be determined by direct measurements or calculations. Excluding other environmental factors (such as temperature, humidity, wind speed, air quality, etc.), the impacts of acoustic and landscape indicators on soundscape satisfaction degree in parks were quantitatively studied.

2 Research Methods

2.1 Research object and soundscape data sampling

In order to quantitatively study the impacts of acoustics and landscape factors on satisfaction degree in urban landscape garden parks, Lakeside Park, Taiziwan Park and Xixi Wetland-Hongyuan Park characterized by waterfront, garden and wetland were selected separately in HangZhou. Fig. 1 showed the overall aerial views of three parks from Google maps. 10, 12 and 13 evaluation points (see Fig. 2) with great differences in soundscapes were chosen in three parks, respectively. To control environmental variables such as temperature, humidity and wind speed, ten sunny days with the temperature of $26^{\circ}\text{C} \pm 3^{\circ}\text{C}$, humidity of $65\% \pm 3\%$ and the wind speed of less than 3 m/s were selected in the summer of 2018. In the morning (8:00 ~ 10:00) of each day, binaural sounds and panoramic videos at each evaluation point were sampled by an artificial head (Head Acoustics GmbH) and a panoramic camera (GoPro). Sampling point was 1.5 m above the ground and sampling duration was 5 min.

2.2 Evaluations on soundscape satisfaction degree

The software Autopano Video Pro 2.5.3 and Autopano Giga 4.0.2 were used to synthesize panoramic videos from the videos sampled by 6 cameras of the panoramic camera at each evaluation point. The software ArtemiS 10.0 and Adobe Premiere Pro CC 2018 were used to synchronously extract a clip of 30 s in each sample of sound and panoramic video from evaluation points as an evaluation sample (Ren and Kang, 2015). Meanwhile, an interval of 7 s (5 s for evaluation, 1 s for playback of a prompt tone and 1 s for blank) was inserted between any two evaluation samples to form a series of evaluation samples of

sounds and panoramic videos from all evaluation points. A professional sound playback system including PEQ V equalizer (Head Acoustics GmbH), HDA IV.1 headphone splitter (Head Acoustics GmbH) and Sennheiser HD 600 headphones was used to play sound samples from evaluation points, which has no distortion in the frequency band of 20 Hz ~ 20000 Hz. A head-mounted display system (HTC Vive) of VR was used to synchronously play the panoramic videos of corresponding evaluation points.

An evaluation experiment of soundscape satisfaction degree was conducted in a professional evaluation room (3 m × 2 m × 3 m), where indoor background noise was less than 25 dB (A). During the experiment, indoor temperature and humidity were controlled at the range of 26°C ± 3°C and 65% ± 3%, respectively, which were close to the ambient temperature and humidity during sampling on site. Referencing the minimum number of subjects (20) specified in ISO/TS 12913-2 (2018), twenty-four college students (12 males, 12 females, average age 25 ± 3 years) with normal hearing and vision (or corrected vision) were randomly recruited as subjects. Each subject wore a VR head-mounted display and put on a pair of headphones in the experiment. Subjects experienced extra two soundscape samples sampled from Lakeside Park before experiment, then a formal experiment began after they raised hands to show everything right. Each experimental sample was played in turn and subjects could turn their heads autonomously in the process of experiencing each sample. Then, a 7-level Likert Scale was used to evaluate soundscape satisfaction degree of each sample. In Likert Scale, 1, 2, 3, 4, 5, 6 and 7 represented extremely dissatisfied, dissatisfied, slightly dissatisfied, moderate, slightly satisfied, satisfied and extremely satisfied, respectively. In each satisfaction evaluation experiment, 35 experimental samples were evaluated by one subject and the duration was about 30 minutes. Grubbs criterion was used to eliminate abnormal values (Grubbs, 1969) and the mean soundscape satisfaction degree of each evaluation point was calculated by formula (1).

$$s = \frac{\sum_{i=1}^7 (n_i \times i)}{\sum_{i=1}^7 n_i} \quad (1)$$

In formula (1), s was the mean soundscape satisfaction degree, i was the satisfaction level in 7-level Likert Scale and n_i was the number of subjects who chose level i .

2.3 Extraction of soundscape indicators

2.3.1 Acoustic indicators

In order to analyze the correlations between sound pressure, temporal characteristics, spectrum distribution, human auditory sensation and soundscape satisfaction degree, 17 acoustic indicators were selected considering sound characteristics of physical acoustics and psychoacoustics (Di et al., 2018, Gozalo et al., 2015, Hall et al., 2013, ISO/TS 12913-2, 2018, Ricciardi et al., 2015). These acoustic indicators included sound pressure level (SPL), A-weighted equivalent continuous sound pressure level (L_{Aeq}), percentile values for sound pressure level ($L_5, L_{10}, L_{50}, L_{90}, L_{95}$), $L_{10} - L_{90}$, difference between C-weighted equivalent continuous sound pressure level and L_{Aeq} ($L_{Ceq} - L_{Aeq}$), low frequency (20 Hz ~ 200

Hz) sound pressure level (L_L), medium frequency (200 Hz ~ 2000 Hz) sound pressure level (L_M), high frequency (2000 Hz ~ 20000 Hz) sound pressure level (L_H), loudness level (L_N), fluctuation (F), roughness (R), sharpness (S) and tonality (T). These acoustic indicators of each evaluation sample (30 s) were analyzed by Artemis 10.0.

2.3.2 Landscape indicators

The landscape of horizontal view focuses on the characteristics of on-site landscape composition while that of vertical view focuses on the characteristics of landscape patterns. Both are closely related to soundscape perception (Liu et al., 2013b, Shum et al., 1997, Schirpke and Szeliski, 2019, Wergles and Muhar, 2009).

Videos and images can reflect real landscapes and reproduce on-site overall landscape composition effectively (Dunn, 1976, Dandy and Rene, 2011, Luo et al., 2019, Tveit, 2009). Considering the impacts of all on-site landscape elements, a panoramic photo was extracted in the panoramic video of each evaluation point, which was regarded as the landscape of horizontal view at each evaluation point. Five kinds of landscape elements, vegetation, water, buildings, roads and sky, were extracted from panoramic photos and 5 cm × 5 cm grids were overlaid on these photos (about 200 cm × 100 cm) by Photoshop 7.0. Then, the proportion of each landscape element was calculated to quantitatively obtain 5 on-site overall landscape indicators, namely vegetation proportion (VP), water proportion (WP), building proportion (BP), road proportion (RP) and sky proportion (SP) (Pheasant et al., 2008, Sowinska-Swierkosz and Soszynki, 2019).

Local landscape patterns mainly affect on-site soundscape perception in a small area, whose radius is less than 175 m (Dramstad et al., 2006). The landscape of vertical view in each park was obtained based on the images from GaoFen-2 satellite of China (resolution of 1 m) and the plan of the layout of main landscape elements inside and in the vicinity of the park (see Fig. 2) was drawn by ArcMap 10.2.2. Based on Fig. 1, 30 local landscape pattern indicators in each circular area, whose center was the evaluation point and whose radius was 175 m, were calculated by the software of Fragstats 4.2.1 (Liu et al., 2013a). Referencing comparable studies (Peng et al., 2010, Schirpke et al., 2013), these selected local landscape pattern indicators included the percentage of landscape ($PLAND$), largest patch index (LPI), landscape shape index (LSI), cohesion index ($COHESION$) and aggregation index (AI) of each landscape element (grasslands, forest lands, roads, buildings and water), as well as the contagion index ($CONTAG$), Shannon's diversity index ($SHDI$), Shannon's evenness index ($SHEI$), Simpson's diversity index ($SIDI$) and Simpson's evenness index ($SIEI$) of whole landscape.

Furthermore, the mean values of the percentages of area for vegetation (including grasslands and forest lands), roads, buildings, water and other landscape elements (see Fig. 3) in each park were calculated by formula (2).

$$MA_j = 100\% \cdot \sum_{k=1}^n PLAND_{jk} / n \quad (2)$$

In formula (2), j was the serial number of five landscape elements (vegetation, roads, buildings, water and others), k was the serial number of evaluation points, n was the number of evaluation points in each park, $PLAND_{jk}$ was the percentage of landscape for landscape element j in a circular area whose center was evaluation point k and whose radius was 175 m, and MA_j was the mean value of the percentage of area for landscape element j .

2.4 Data analysis method

Pearson correlation coefficient was used to analyze the correlations between each acoustic indicator, each landscape indicator and the mean soundscape satisfaction degree in parks. Considering the main effect of single acoustics and landscape factor as well as the interaction effect of these two types of factors on soundscape satisfaction degree, three public response models of soundscape, in which independent variables were only acoustic indicators, only landscape indicators and both of them significantly correlated with the mean soundscape satisfaction degree, were set up respectively by stepwise regression method. SPSS 20.0 was used for data analysis.

3 Research Results

3.1 Correlation between single acoustic or landscape indicator and soundscape satisfaction degree

By linear fittings, the correlations between each acoustic indicator and the mean soundscape satisfaction degree in parks were listed in Table 1. Table 1 showed that 14 acoustic indicators were significantly correlated with the mean soundscape satisfaction degree in parks. Among these acoustic indicators, L_N had the highest and significantly negative correlation with satisfaction degree. It indicated that soundscape satisfaction degree was closely related to the loudness level of sound.

Table 1 Correlations between each acoustic indicator and the mean soundscape satisfaction degree in parks

Acoustic indicators	Pearson correlation coefficients
<i>SPL</i>	-0.623**
L_{Aeq}	-0.803**
L_5	-0.807**
L_{10}	-0.806**
L_{50}	-0.796**
L_{90}	-0.762**
L_{95}	-0.756**
$L_{10}-L_{90}$	-0.516
$L_{Ceq}-L_{Aeq}$	0.489
L_L	-0.642**
L_M	-0.682**
L_H	-0.767**
L_N	-0.842**
<i>F</i>	-0.345**
<i>R</i>	-0.398**
<i>S</i>	-0.547
<i>T</i>	-0.479**

** $p < 0.01$, * $p < 0.05$.

Table 2 listed the correlations between each landscape indicator and the mean soundscape satisfaction degree in parks. Table 2 showed that, in 30 local landscape pattern indicators from the landscape of vertical view, 25 indicators were significantly correlated with soundscape satisfaction degree and the absolute values of correlation coefficients were all greater than 0.35. Especially, the correlations between *ALW*, *PLAND_R*, *LPLR* and soundscape satisfaction degree ranked top three among 25 indicators and three indicators were all significantly negatively correlated with satisfaction degree. This indicated that the decrease of soundscape satisfaction degree was related to the increase of the aggregation index of water, the percentage of the area of roads and the largest patch index of roads. Similarly, Table 2 showed that in 5 on-site overall landscape composition indicators from the landscape of horizontal view, only

road proportion was significantly correlated with satisfaction degree (a negative correlation). The absolute values of the correlation coefficients between these 5 indicators and satisfaction degree were all less than 0.36. Besides, Table 2 showed that the vegetation proportion in the landscape of horizontal view was weakly correlated with soundscape satisfaction degree, while that including grassland and forest lands (*PLAND_R* plus *PLAND_F*) in the landscape of vertical view was moderately related. Clearly, compared with that in the landscape of horizontal view, the vegetation proportion in the landscape of vertical view could better reflect the impact of landscape indicators on soundscape satisfaction degree.

Table 2 Correlations between each landscape indicator and the mean soundscape satisfaction degree in parks

	Landscape indicators	Pearson correlation coefficients
Local landscape patterns (the landscape of vertical view)	<i>PLAND_G</i>	0.538**
	<i>LPL_G</i>	0.610**
	<i>LSL_G</i>	0.559**
	<i>COHESION_G</i>	0.470**
	<i>AI_G</i>	0.457**
	<i>PLAND_R</i>	-0.651**
	<i>LPL_R</i>	-0.646**
	<i>LSL_R</i>	-0.463**
	<i>COHESION_R</i>	-0.433**
	<i>AI_R</i>	-0.435**
	<i>PLAND_B</i>	-0.471**
	<i>LPL_B</i>	-0.312
	<i>LSL_B</i>	-0.044
	<i>COHESION_B</i>	-0.018
	<i>AI_B</i>	-0.102
	<i>PLAND_F</i>	0.588**
	<i>LPL_F</i>	0.611**
	<i>LSL_F</i>	0.054
	<i>COHESION_F</i>	0.421*
	<i>AI_F</i>	0.350*
	<i>PLAND_W</i>	-0.427*
	<i>LPL_W</i>	-0.436**
	<i>LSL_W</i>	0.567**
	<i>COHESION_W</i>	-0.440**
	<i>AI_W</i>	-0.710**
	<i>CONTAG</i>	0.472**
<i>SHDI</i>	-0.606**	
<i>SIDI</i>	-0.629**	

	<i>SHEI</i>	-0.570**
	<i>SIEI</i>	-0.603**
On-site overall landscape composition (the landscape of horizontal view)	<i>VP</i>	-0.093
	<i>WP</i>	-0.077
	<i>BP</i>	0.182
	<i>RP</i>	-0.358*
	<i>SP</i>	0.259

** $p < 0.01$, * $p < 0.05$ (*PLAND_G*, *PLAND_R*, *PLAND_B*, *PLAND_F* and *PLAND_W* refers to the percentage of landscape of grasslands, roads, buildings, forest lands and water, respectively).

3.2 Public response model of soundscape satisfaction degree in parks

Considering only acoustic indicators, only landscape indicators and both of them, three models of soundscape satisfaction degree established by stepwise regression method were shown in formula (3), formula (4) and formula (5), respectively. The results of stepwise regression analysis were detailed in Table 3. It could be seen in Table 3 that the determination coefficient of regression model ($R^2 = 0.895$) considering both acoustic and landscape indicators was higher than that considering only acoustic indicators or only landscape indicators (R^2 was 0.775 and 0.734, respectively). This indicated that the stepwise regression model considering both acoustic and landscape indicators could better quantify public soundscape satisfaction degree (s).

$$s = 18.007 - 0.115L_N - 0.072L_L \quad (3)$$

$$s = 62.814 - 0.609AI_W + 0.063LPI_W - 0.073LPI_R - 1.958RP \quad (4)$$

$$s = 43.180 - 0.110L_N - 0.234LSI_R - 0.317AI_W + 0.045LPI_W \quad (5)$$

Final indicators entering the model of formula (5) were loudness level (L_N), the aggregation index of water (AI_W), the largest patch index of water (LPI_W) and the landscape shape index of roads (LSI_R). As independent variables of this model, L_N reflects the sound strength perceived. AI_W reflects the aggregation degree of water patches. LPI_W refers to the percentage of area of the largest water patch in the landscape of vertical view and LSI_R reflects the shape complexity degree of road patches. It could be seen in Table 3 that L_N , LSI_R and AI_W all had significantly negative correlations with the mean soundscape satisfaction degree in parks. It indicated that soundscape satisfaction degree would be decreased if the loudness level of sound was higher, the shape of road patches was more complex and the aggregation of water patches was higher in parks. It could also be seen in Table 3 that LPI_W had a significantly positive correlation with soundscape satisfaction degree in parks, which indicated that

soundscape satisfaction degree in parks would be improved when the area of the largest water patch increased.

Furthermore, in the light of Table 3, the sum of the absolute value of the standard regression coefficients (-0.310, -0.561, 0.523) of all the landscape indicators (LSL_R , AI_W and LPI_W) is 1.394 in the model of formula (5), which represents the impact degree of landscape indicators on soundscape satisfaction. Similarly, the sum of the absolute value of standard regression coefficients (-0.666) of all the acoustic indicators (L_N) is 0.666 in the model, which represents the impact degree of acoustic indicators on soundscape satisfaction. By calculating the ratio of each value to the sum (2.06) of two values (0.666, 1.394), the impact weights of acoustic indicators and landscape indicators on soundscape satisfaction degree were determined as 32.3% and 67.7%, respectively.

Table 3 Results of statistical analysis on three models of soundscape satisfaction degree

Indicators	Model parameters	Coefficients	Standard errors	Standard regression coefficients	T-test value	p value	R^2
Only acoustic indicators	Constant term	18.007	1.483	/	12.145	<0.001	
	L_N	-0.115	0.016	-0.694	-7.182	<0.001	0.775
	L_L	-0.072	0.024	-0.297	-3.077	0.004	
Only landscape indicators	Constant term	62.814	10.267	/	6.118	<0.001	
	AI_W	-0.609	0.108	-1.077	-5.630	<0.001	
	LPI_W	0.063	0.016	0.732	3.985	<0.001	0.734
	LPL_R	-0.073	0.029	-0.310	-2.540	0.017	
	RP	-1.958	0.798	-0.250	-2.453	0.020	
Both acoustic and landscape indicators	Constant term	43.180	7.409	/	5.828	<0.001	
	L_N	-0.110	0.016	-0.666	-6.950	<0.001	
	LSL_R	-0.234	0.052	-0.310	-4.461	<0.001	0.895
	AI_W	-0.317	0.085	-0.561	-3.747	0.001	
	LPI_W	0.045	0.011	0.523	4.218	<0.001	

4 Discussion

According to the soundscape satisfaction degree model (see formula 5) established in this study, the loudness level of sound (L_N), the landscape shape index of roads (LSL_R), the aggregation index of water (ALW) and the largest patch index of water ($LPLW$) were important factors affecting soundscape satisfaction degree of urban landscape garden parks. Among these factors, L_N had a negative correlation with soundscape satisfaction degree, which indicated that the greater sound strength got, the worse public soundscape perception got. This result was consistent with relevant research results (Gozalo et al., 2015, Nilsson and Berglund, 2006). In general, when the start point, end point and width of roads (not walkways) are the same, the increase of the shape complexity of roads means that the area of roads will be increased. Accordingly, the impact of road traffic noises will be increased and soundscape satisfaction degree will be decreased. As shown in Table 3, the landscape shape index of roads (LSL_R) in this model of formula (5) was indeed negatively correlated with soundscape satisfaction degree. In fact, relevant studies (Luo et al., 2019, Ode et al., 2009, Schirpke et al., 2019) also showed that public preferred landscape elements with lower shape complexity. Normally, the more water patches with a small area gather, the more tourists are attracted by waterscape per unit area. Correspondingly, sounds from tourists' activities (such as children's shouting, talking and walking) will be increased. Waterscape sounds will be partially masked by the noise from tourists' activities. As public's preference on sounds from tourists' activities is lower than waterscape sounds (Liu et al., 2013b, Pilcher et al., 2009), soundscape satisfaction degree in parks will be decreased. This is consistent with the conclusion in this study that the aggregation index of water (ALW) was negatively correlated with soundscape satisfaction degree in the model of formula (5). What's more, the largest patch index of water ($LPLW$) in this model was positively correlated with soundscape satisfaction degree, which indicated that designing a single water patch with a large area in parks was conducive to the improvement of soundscape satisfaction degree.

Relevant studies showed that vegetation was an important landscape element to improve soundscape perception, but the landscape indicators relating to vegetation (including grasslands and forest lands) in this study did not enter the model of soundscape satisfaction degree. The reasons can be explained as follows. According to the result analysis in 3.1, the vegetation proportion in the landscape of vertical view could better reflect the impact of landscape indicators on soundscape satisfaction degree compared with that in the landscape of horizontal view. In this study, the mean value of the ratio of vegetation area (including grasslands and forest lands) to a circular area at each evaluation point, whose center was the evaluation point and whose radius was 175 m, all exceeded 15% in each park (see Fig. 3). In the model of soundscape satisfaction degree established in this study (see formula 5), the constant term (43.180) could be regarded as the comprehensive impact of other indicators (including the percentage of vegetation area) on soundscape satisfaction degree except the acoustic and landscape indicators entering the model. From this perspective, the reason why the landscape indicators relating to vegetation did not enter the model should be related to that the mean value of the percentage of vegetation area all exceeded 15% in each park. Furthermore, it can be speculated that when the percentage of vegetation area in park reaches a critical value (no more than 15%), the contribution of vegetation area to soundscape satisfaction degree will be a fixed value and will be reflected in the constant term of the model. A further increase of the percentage of vegetation area in park will not improve soundscape

satisfaction degree. Lin et al. (2019) found that tourists preferred lower per capita area of green space when sitting than when walking. Du et al. (2016) found that landscape preference was not inevitably correlated with vegetation proportion as it was closely related to the type and structure of vegetation. Clearly, blindly increasing vegetation proportion cannot effectively improve soundscape perception. With the increase of the percentage of vegetation area in urban landscape garden parks, the contribution of vegetation area to soundscape satisfaction degree will tend to be a fixed value. The critical value of the percentage of vegetation area is worthy of further investigation.

Colavita (1974) found that visual stimulation dominated the stimulus response in the experiment of visual and auditory stimulation simultaneously, which was called “visual dominant effect”. This study established the model of soundscape satisfaction degree using objective acoustic and landscape indicators. According to this model, the impact weights of acoustic and landscape indicators on soundscape satisfaction degree were 32.3% and 67.7%, respectively. That was to say, the impact weight of visual stimulation on soundscape satisfaction degree was about 2.1 times that of auditory stimulation, which was in line with the “visual dominant effect” above. Ricciardi et al. (2015) established a linear regression prediction model of sound quality in parks through questionnaires. The standard regression coefficients of acoustic factors (overall loudness, loudness of car/light vehicles and time ratio of voices) in that model were -0.22, -0.13 and 0.12, respectively, while that of visual factors (visual amenity) was 0.53. It showed that the sum of the absolute value of the standard regression coefficients of acoustic factors (0.47) was lower than that of visual factors (0.53) and the impact weight of visual stimulation on sound quality was about 1.1 times that of auditory stimulation. In conclusion, landscape factors have a greater impact on soundscape perception than acoustics factors and the impact weight ratio of these two factors is 1.1 ~ 2.1 according to these studies above.

It can be seen from the model of soundscape satisfaction degree established in this study that, soundscape satisfaction degree in parks could be effectively improved by reducing the loudness level of sound in parks, increasing the area of the largest water patch with scattered water patches around it and reducing the shape complexity of road patches. However, as the resolution of the landscape images of vertical view obtained by the GaoFen-2 satellite of China was 1 m, this study failed to analyze the impact of walkways on soundscape satisfaction degree. In fact, walkways usually shuttled between grasslands and forest lands and had a high public preference (Echevarria et al., 2017). Therefore, reducing the shape complexity of road patches to improve the soundscape satisfaction degree in urban landscape garden parks was only applicable to wide roads in parks except walkways.

Especially, a limitation of this study should be noted. Although three parks with different soundscapes were selected, only the soundscape of summer were studied in lab. Thus, the values of acoustic and landscape indicators from all evaluation points could not fully cover the range of variables, which could affect the accuracy of the model.

5 Conclusion

Taking urban landscape garden parks as an example, a new methodology setting up a public response model of soundscape based on virtual reality technology was developed. On the basis of the experimental research on soundscape satisfaction degree in urban landscape garden parks, the correlations between acoustic indicators, landscape (including the landscape of horizontal view and vertical view) indicators and soundscape satisfaction degree were analyzed. The public response model of soundscape satisfaction degree of parks was established, and the impact weights of acoustics factor (auditory factor) and landscape factor (visual factor) on soundscape satisfaction degree were determined according to this model. Several targeted strategies improving soundscape satisfaction degree in parks were suggested.

Declarations

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Conflicts of interest/Competing interests

The authors have no relevant financial or non-financial interests to disclose.

Availability of data and material

Due to regulations, the authors cannot disclose the data of this study.

Code availability

Not applicable.

Ethics approval

Approval was obtained from the Institute of Environmental Processes of Zhejiang University. The procedures used in this study adhere to the tenets of the Declaration of Helsinki.

Consent to participate

Informed consent was obtained from all individual participants included in the study.

Consent for publication

The participant has consented to the submission of the case report to the journal.

Compliance with ethical standards

First, the authors have no relevant financial or non-financial interests to disclose. Second, ethics approval was obtained from the Institute of Environmental Processes of Zhejiang University and the procedures used in this study adhere to the tenets of the Declaration of Helsinki. Moreover, informed consent was obtained from all individual participants included in the study and the participant has consented to the submission of the case report to the journal.

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Figures

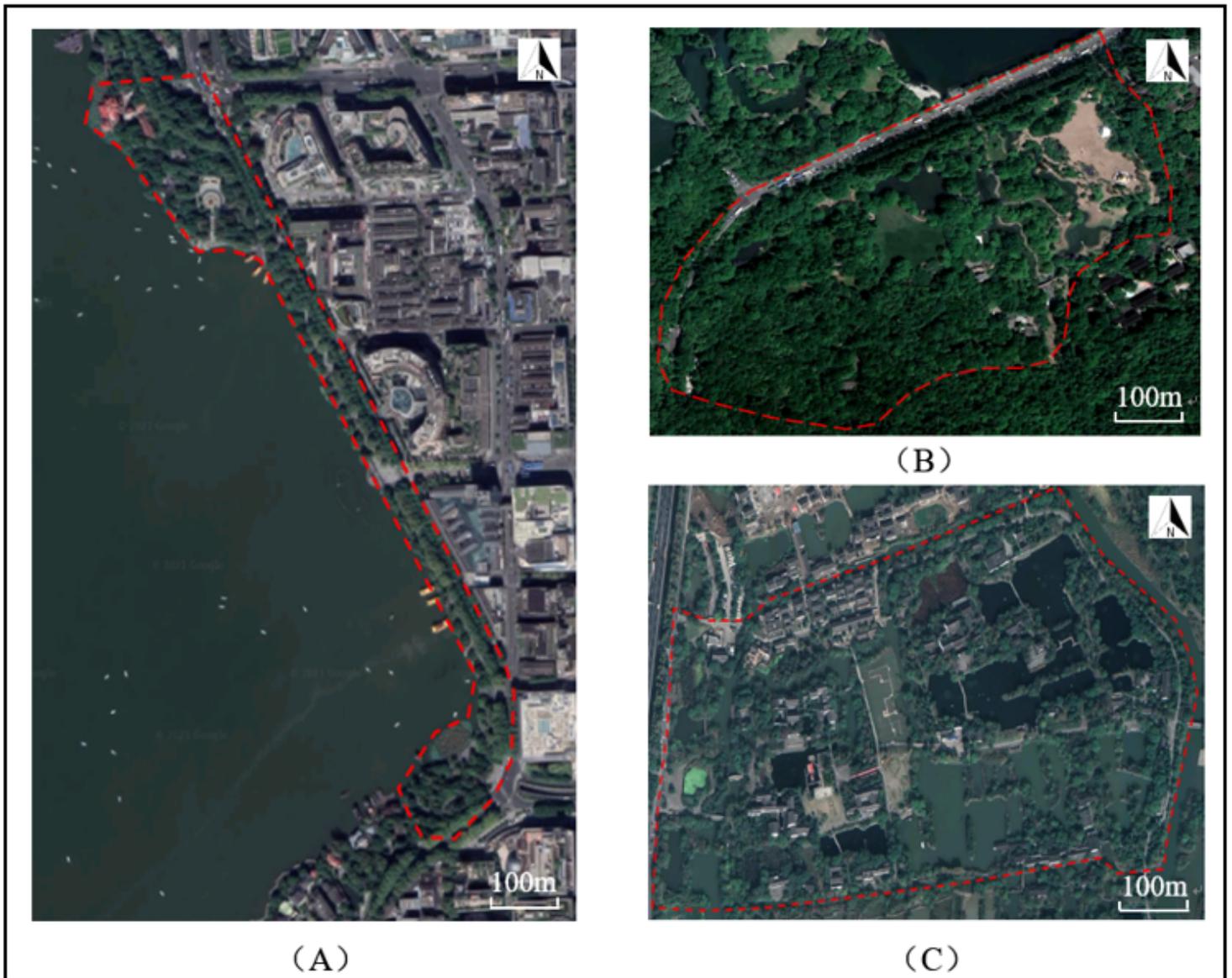


Figure 1

The overall aerial views of three parks from Google maps. (A) Lakeside Park, (B) Taiziwan Park, (C) XiXi Wetland-Hongyuan Park. The dotted areas indicate the scope of parks. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

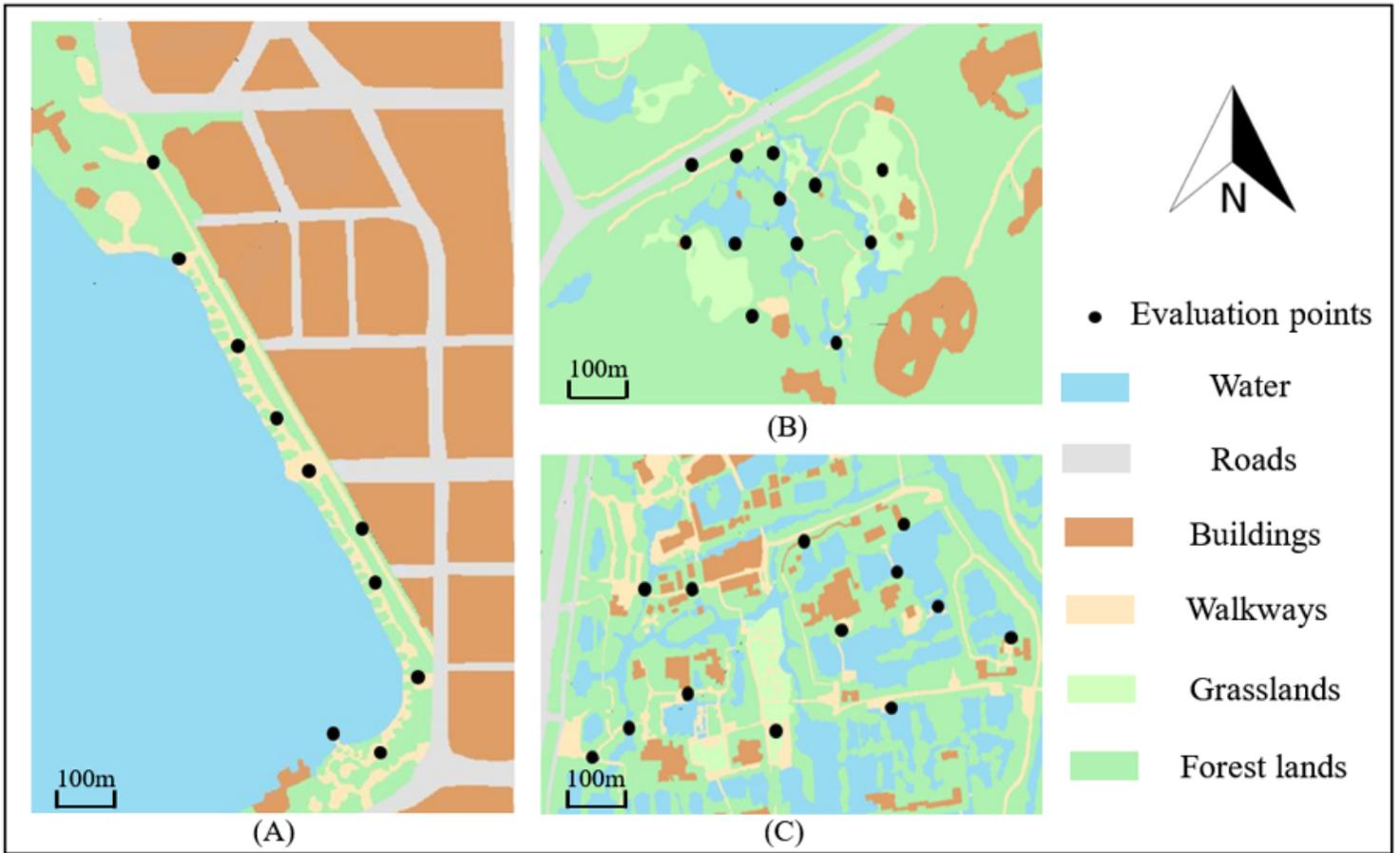


Figure 2

Schematic diagram of the layout of main landscape elements and evaluation points in three parks. (A) Lakeside Park, (B) Taiziwan Park, (C) XiXi Wetland-Hongyuan Park. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

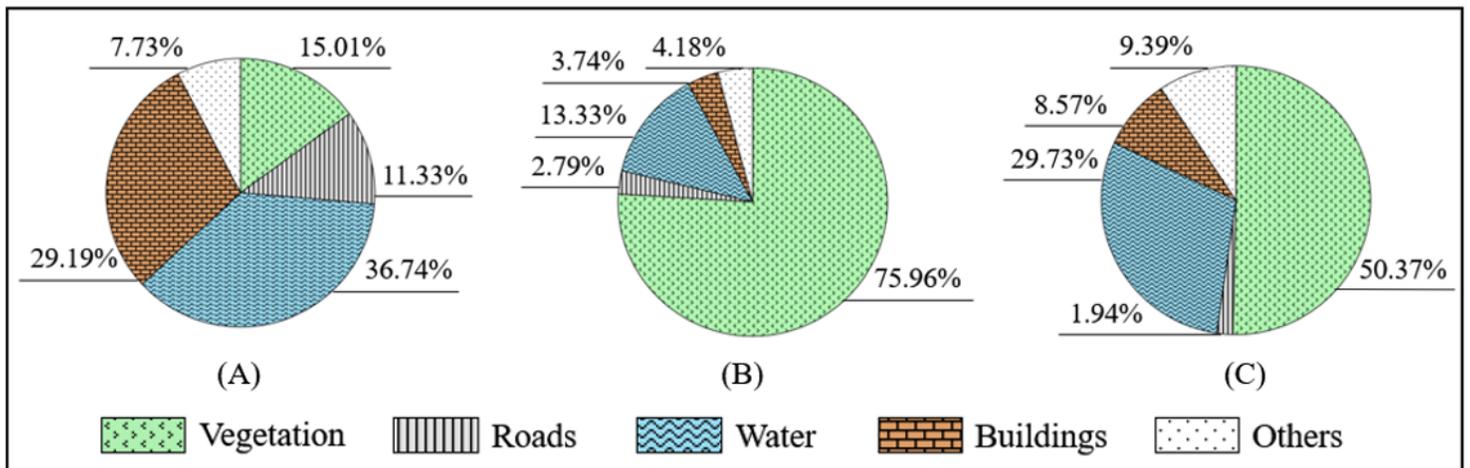


Figure 3

The mean value of the percentage of area in the landscape of vertical view in three parks.