Effect of the Visual Landscape and Soundscape Factors on Attention Restoration in the Public Space of Old Residential Areas by VR

Zhiyu Zhou and Xiaoqing Ye

School of Architecture and Art Design Hebei University of Technology, Tianjin, China.
Key Laboratory of Healthy Human Settlements in Hebei Province, Tianjin, China.
E-mail: Zhouzhiyu@hebut.edu.cn

Junjie Chen

Langfang Urban and Rural Planning and Design Institute, Langfang 065000, China.

Jian Kang

Institute for Environmental Design and Engineering, The Bartlett, University College /London, London, WC1H 0NN, United Kingdom.

(Received 9 May 2023; accepted 16 August 2023)

The purpose of this study is to analyze the relationship between the visual landscape and soundscape factors of the public spaces in old residential areas and their attention restoration benefits for residents and to determine the main influencing factors. In this paper, the public spaces of six typical old residential areas in Tianjin were selected as the research object, and the restorative benefits of the respondents were analyzed through virtual reality environment, subjective evaluation, and attention testing methods. The results showed that the attention restoration benefits of the central square in the old residential area were better than those of the public space along the street. Second, greenery satisfaction, environmental cleanliness, architectural aesthetics, sky visibility, and soundscape evaluation are all significantly positively correlated with the attention restoration level. Finally, a "visual landscape and soundscape perception evaluation–attention restoration level" structural equation model was constructed. According to the model, both the visual landscape factors and soundscape evaluation factors in old residential areas had a direct positive impact on the attention restoration level, with a greater impact exerted by visual landscape factors than by soundscape evaluation factors. The findings from this study can provide significant information for the renewal of old residential areas.

1. INTRODUCTION

With the ever-increasing size and density of cities, the negative emotions and mental pressure of urban residents cannot be ignored. According to relevant surveys, 73.6 % of Chinese urban residents had a mental subhealth status in 2017, and only 10.3 % of them qualified as mentally healthy.[1] The outbreak of COVID-19 has also had a negative impact on people's mental health.[2] According to a WHO report, COVID-19 has increased the prevalence of global anxiety and depression by 25 %.[3] In the context of the normalization of epidemic prevention and control, home offices have become a very common environment for work. Maintaining directed attention for long periods of time readily causes stress and fatigue. Therefore, attention should be given to whether the built environment of residential areas has the potential to alleviate mental fatigue.

Based on stress reduction theory (SRT)[4,5] and attention restoration theory (ART),[6,7] an increasing number of studies have focused on the restoration effects of the environment on human stress, attention, positive emotions, etc. SRT assumes that when individuals are exposed to an ideal nonthreatening environment, their negative emotions and stress are reduced.[5] ART is a cognitive framework, directed attention fatigue (DAF) related to the restoration of mental fatigue[8] and proposes four characteristics of a restorative environment—being away, fascination, extent and compatibility.[7]

The ideal visual environment can alleviate the mental pressure of residents and effectively restore positive emotions.[5,7] Evans et al. found that factors such as residential density, facility layout and housing conditions have direct or indirect effects on mental health.[9] Ye et al. showed that semi-open spaces that offer a sense of sight encirclement that includes a view of distant scenery are more conducive to positive restorative experiences in urban public spaces.[10] Kimura et al. confirmed through experiments that watching natural scenes such as forests, flowing water and leaves is a beneficial way for people to restore their attention.[11] Berdejo-Espinola et al. investigated the use of green space during COVID-19 in Australia and found that urban green space can effectively relieve people's stress and depression.[12] Lindal et al. found that in residential areas, rich building facades have a positive impact on people's psychological restoration, while taller buildings reduce the feeling of "being away," which exerts a negative impact on psychological restoration.[13] Zhang et al. discussed the relationship between environmental perception and residents' subjective happiness and found that a clean environment has a significant positive impact on residents' positive emotions.[14]

In addition to visual landscape perception, soundscapes are also an important factor affecting residents' relief of mental pressure. In terms of types of sound source, Zhang et al. found that natural sounds such as bird calls and the sound of running water can effectively promote positive emotions, which have

a positive effect in turn on the attention restoration of individuals.[15] Wallenius proposed that the annoyance level caused by road traffic noise is positively correlated with suffering by urban residents.[16] Dzhambov et al. conducted an online survey of college students during the COVID-19 home quarantine period and found that mechanical sounds in the environment reduce the restoration effect, thereby leading to poor self-evaluations of health status.[17] From the perspective of soundscape characteristics, Medvedev et al. showed that a pleasant acoustic environment can help to relieve people's stress more quickly.[18] Guo et al. found that in urban parks, it is the pleasantness of soundscapes that has a high restoration potential rather than their eventuality, and further results showed that audio-visual interactive stimulation has higher restoration benefits than single sensory stimulation.[19] Herranz-Pascual et al. found that sound comfort is associated with a reduction in negative and an increase in positive emotional states.[20] Zhang and Kang analyzed the acoustic needs of the elderly in the outdoor environment of the residential areas, and found that sound preference, quiet and acoustic variability can affect the acoustic comfort. Increasing the coverage of vegetation in the residential areas and the formation of multi-level greening can also significantly improve the comfort of the overall acoustic environment.[21]

Residential areas are an important component of a city, and their environmental conditions directly affect the health level and quality of life of residents. Due to a lack of reasonable planning and routine maintenance, the internal environment of old residential areas has begun to decay. Dense buildings, damaged facades, poor environmental sanitation, and lack of ornamental plant landscapes seriously affect the quality of the visual environment. In the meantime, the acoustic environment in residential areas is of poor quality because of the complex population composition and the disorderly traffic caused by motor vehicles. To improve the quality of life of residents, the Chinese government attaches great importance to the renovation of old residential areas. According to statistics, during the period of 2012–2022, China renovated approximately 163,000 old urban residential areas to the benefit of more than 28 million residents. It is estimated that by 2025, China will basically complete the renovation of 219,000 old urban residential areas built before 2000.[22] However, at present, the renovation direction of residential areas is mainly focused on residential quality improvement, elderly friendly environmental design and other aspects, lacking a consideration of the health and restoration of public space.

Therefore, this study aims to (1) evaluate the restoration benefits of the visual landscape and soundscape in the public spaces of old residential areas, (2) explore the relationship between the visual landscape and soundscape perception factors of the public spaces of old residential areas and their attention restoration level, and (3) apply a structural equation model for extracting the main factors affecting the restoration benefits and propose renovation strategies for the public spaces of old residential areas according to those main influencing factors.

2. METHODS

This study mainly includes four steps. First, we carry out scene video acquisition and sound pressure level measurement in the sampled residential areas. Second, we screen and determine the perception variables of the visual and audio environments and complete the questionnaire design. Third, we conduct the restoration experiment using virtual reality (VR). Finally, we analyze the relationship between the visual landscape and soundscape factors and the attention restoration level and construct a structural equation model.

2.1. Site Selection and Audio-Visual Data Collection

As the largest coastal city in northern China, Tianjin has conducted large-scale planning and construction for residential areas since the 1980s. In the central area of the city, there were more than $3,000$ residential areas that had been built before 2000, with their land area accounting for 59 % of the total residential land area of the city and covering approximately 3 million residents.*23* The residential area is dominated by multistorey unit houses arranged in rows. The land scale is mostly between 3 ha and 15 ha, which gradually increases from the urban center to the outer edge, and the plot ratio is between 1.2 and 3.0, showing a gradient decreasing trend from the urban center to the outer edge.[24]

In this study, six representative residential public spaces in six districts of Tianjin were selected as the research objects. As shown in Table 1, R1–3 display the central squares of the residential areas, and R4–6 display the public spaces along the streets of the residential areas. The residential areas where the sampling public spaces were located were built before 2000, with land areas between 3.0 ha and 8.0 ha, plot ratios between 1.2 and 2.4, and building densities between 20 % and 40 %. The buildings are mainly multistorey and arranged in a row or enclosed layout.

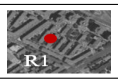
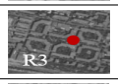
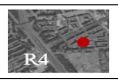
On a sunny day in December 2020, the visual and audio environment data of each public space targeted were collected during two peak hours of crowd activities: 9:00–12:00 and 14:00–17:00. For the visual landscape, GoPro Max was used, and panoramic video was recorded at 60 Mbps in 5.6K Ultra HD resolution and 30 fps resolution. All of which included the surrounding buildings, natural vegetation, sports facilities, roads, and other landscape factors. For the soundscape, 4-channel HEAD acoustics 2019 binaural earphone was applied to capture sound recordings on the spot. Simultaneously, the sound pressure level was measured with a HS5671B-type sound-level meter for 5 min per measurement. During measurement, the microphone was kept more than 1 m away from the external wall of the building and read an A-weighted sound-pressure level every 10 s. Acoustic environment characteristics were obtained by calculating the A-weighted sound-pressure level (SPL, LAeq) and percentile SPLs (L10 and L90). The mean LAeq of the six sites was distributed in the broad range of 53.7˘67.5 dBA. LAeq was the lowest at Site R2 (central square) and the highest at Site R6 (roadside).

All visual and audio environment data were measured from a height of 1.5 m. The corresponding visual and audio environment characteristics and panorama of each space are shown in Table 1.

2.2. Measurement of Attention Restoration Level

In this study, the attention restoration level was determined by the Schultz tables test, which has been widely used in attention tests and evaluations and has been demonstrated to have good reliability and validity.[25,26] The 55 Schulter grid matrix was used in this experiment, with 25 numbers from 1-25 in the

Table 1. Visual and audio environmental characteristics and panorama of the sampled public spaces.

The name of old residential area	Visual landscape features	Acoustic environment characteristics (dBA)			Plan	Panorama
		LAeq	L10	L90		
Fengguangli	Open space, moderate number of trees, clean and tidy environment	55.6	57.4	46.8		
QingchunNanli	Open space, lots of trees, clean and tidy environment	53.7	57.0	45.6		
Ziyali	Open space, lots of trees, less paving	62.1	63.0	50.6		
JiayuanDongli (Southern)	Open space, moderate number of trees, proximity to road	54.6	56.0	51.2		
JiayuanDongli (Eastern)	Open space, a few trees, proximity to road	62.4	65.2	53.2		
Dunhuanglou	Open space, moderate number of trees, proximity to road	67.5	70.8	55.8		

grid. Subjects were instructed to click these numbers in ascending order, and if the subject clicked the incorrect number midway through the session, they would then be immediately asked to select the correct number and continued the experiment until the end of the experiment, and the time spent was recorded. After the experiment, the difference in the test time between the two attention levels before and after the subject's attention recovery experiment was measured as the ΔAt, as shown in Eq (1).

$$\text{Level of attention recovery}\Delta At = A_{t1} - A_{t2}; \qquad (1)$$

where, A_{t1} and A_{t2} are the time of attention recorded in the test before and after the restoration experiment, respectively. $\Delta At > 0$ means that the time is shortened, and the restoration benefit is positive, whereas $\Delta At = 0$ means the time is equal and affords no restoration benefit, and $\Delta At < 0$ means that the time is extended and the restoration benefit is negative.

2.3. Questionnaire Design

The questionnaire includes two parts: the basic information regarding the subjects and the environmental perception evaluation scale. The basic subject information mainly captures the subjects' sex, age, educational major and other information. The environmental perception evaluation scale focuses on visual landscape factors and soundscape evaluation factors. As shown in Table 2, the visual landscape factors include greenery satisfaction, environmental cleanliness, architectural aesthetics, sky visibility, and spatial openness, and they are evaluated as "poor–good." The soundscape evaluation factors include quietness, pleasantness and comfort, which are evaluated by "noisy–quiet," "annoying–pleasant" and "painful–comforting," respectively. In the experiment, the corresponding parameters were scored on a 5-point Likert scale.

2.4. Experimental Procedure

Virtual reality (VR) technology presents subjects with an immersive experience by constructing 3D digital scenes with immersive, realistic and three-dimensional elements. Relevant studies have confirmed that the virtual environment is effective in cognitive competence,[27] emotional health[28] and physiological stress restoration.[29] Therefore, this study uses audio-visual data to create a VR environment in the laboratory and combines the attention restoration level test to evaluate the attention restoration benefits of the visual landscape and soundscape in the public spaces of old residential areas.

To calibrate the equivalent continuous A-weighted sound pressure level, the HEAD acoustics 2019 binaural earphone was worn to the Dummy head. The audio was then played and the sound pressure level of the audio was measured segmented using a sound-level meter (Bk type2270). Specifically, the sound pressure level of three 10 s segments of the front, middle and back audio measurements were taken, and the average value was calculated. Taking the audio of the R3 scene as an example, the sound pressure level measurements for the three time periods were 60.3 dBA, 56.5 dBA and 63.3 dBA. After calculating the average value, it is found that the result is 2.1 dBA different from the error of the field measurement, and the error is small, indicating that the recording of HEAD acoustics 2019 binaural earphone can express the actual sound situation and meet the requirements of the experiment.

Relevant studies have shown that students usually experience anxiety in English or other foreign language environments.[30] Therefore, this experiment consumes subjects' attention through an English listening test. In this experiment, 200 college students were recruited as subjects, with a male to female ratio of 1 : 1, who are majoring in urban and rural planning, architecture, design, etc. All subjects had normal hearing and vision (including with correction) and did not suffer from color blindness.

The experiment was conducted in the following order in a closed office environment, with a single experiment lasting approximately 30 min. The specific steps are as follows:

a A listening test was conducted on CET-4 (College English Test Band 4) for approximately 25 minutes, producing stress in all subjects and putting them into a state of attention consumption.

b The Schultz Tables attention level test was conducted under the consumption state, capturing the time of A_{t1}, which takes approximately 1 min.

c Subjects wore VR helmets and HEAD acoustics with 2019 binaural earphones to become immersed in a virtual scene rendering the sound-vision integration in the central square of the residential area or the public space along the street for approximately 3 min.

Table 2. The visual and audio environment perception evaluation scale.

Type	Evaluation dimension		Very	Slightly	Neutral	Slightly	Very	
Visual landscape factors	Greenery satisfaction	Poor	1	2	3	4	5	Good
	Environmental cleanliness	Poor	1	2	3	4	5	Good
	Architectural aesthetics	Poor	1	2	3	4	5	Good
	Sky visibility	Poor	1	2	3	4	5	Good
	Spatial openness	Poor	1	2	3	4	5	Good
Soundscape evaluation factors	Quietness	Noisy	1	2	3	4	5	Quiet
	Pleasantness	Annoying	1	2	3	4	5	Pleasant
	Comfort	Painful	1	2	3	4	5	Comforting

Table 3. Basic information of the subjects.

The central square group of the residential area (N=134)			The public space group along the street (N=122)		
Indicators		Number of samples (%)	Indicators		Number of samples (%)
Gender	Male	63 (47.01 %)	Gender	Male	60 (49.18 %)
	Female	71 (52.99 %)		Female	62 (50.82 %)
Age	≤20	72 (53.73 %)	Age	≤20	74 (60.66 %)
	21-25	57 (42.54 %)		21-25	47 (38.52 %)
	>25	5 (3.73 %)		>25	1 (0.82 %)
Major	Urban and Rural Planning	95 (70.90 %)	Major	Urban and Rural Planning	87 (71.31 %)
	Architecture	35 (26.12 %)		Architecture	32 (26.23 %)
	Design Science	4 (2.98 %)		Design Science	3 (2.46 %)

d Another attention level test was conducted on subjects, recording the time of A_{t2}, and then the visual and audio environment perception evaluation scale results were captured.

During the experiment, 60 subjects participated in two tests of attention recovery level in different groups. It is worth noting that the second test of the 60 subjects was one week between the first test, and the stress stimulation and recovery test questions were not repeated to avoid interference with the results of the subjects or familiarity with the specific content of the test in advance. Finally, a total of 260 questionnaires were collected in the experiment (Table 3), including 134 valid questionnaires regarding the central square group of the residential area and 122 valid questionnaires regarding the public space group along the street, with an effective rate of 98.46 %.

2.5. Data Analysis

In this study, the data collected from the experiment were entered into SPSS 23.0 for statistical analysis, and the relationship between the visual landscape and soundscape factors in old residential areas and the attention restoration level was analyzed by Spearman correlation. The R system is widely used for statistics and calculation, where the software package Lavaan implements the construction of structural equation models. Lavaan is an acronym for latent variable analysis, which provides a range of tools to explore, estimate and understand a wide range of potential variable models, including factor analysis, structural equations, multi-level, potential classes, project responses, and missing data model.[31] Therefore, in this study, the Lavaan software package in the R system was used to construct the structural equation model to analyze the impact mechanism of visual landscape and soundscape factors on the attention restoration level.

To construct the structural equation, the reliability and validity test and exploratory factor analysis (EFA) of the visual landscape and the soundscape evaluation results of the subjects were first conducted, and then confirmatory factor analysis (CFA) was conducted based on the visual landscape and soundscape evaluation results. The goodness of fit of the CFA was evaluated using the maximum likelihood estimation method. The visual landscape and soundscape perception evaluation–attention restoration level structural equation model was constructed after fit modification.

Table 4. Paired-sample t-test results for the level of attention recovery before and after the experiment.

	Paired difference					t	df	Sig.
	AVG	SD	Standard error mean value	95 % confidence interval of difference Lower	Upper			
ΔAt (R1-R3)	2.01254	5.12468	.44270	1.13688	2.88819	4.546	133	.000
ΔAt (R4-R6)	-.77943	4.27867	.38737	-1.54633	-.01252	-2.012	121	.046

3. RESULTS

3.1. Comparison of the Restoration Benefits of the Audio-Visual Landscape in the Public Spaces of Old Residential Areas

To compare the effects of different audio-visual scenes on the degree of recovery of subjects, this study performed a paired sample T-test for two test times before and after the experiment. As shown in Table 4, the level of attention recovery was significantly different before and after viewing the scene in the central square (R1-3) and the public space along the street (R4-6). Among them, the test time of the central square group was shortened by 2.0 s ($P < 0.01$), while the test time of the public space group along the street was increased by 0.8 s ($P < 0.05$).

In order to deeply analyze the differences in the effects of different scenarios on subjects' attention recovery, this study compared the test time difference value (ΔAt) of each scenario, and the results are shown in Figure 1. The average attention recovery benefit of the subjects after watching the scene in the central square of the old residential areas was positive, while the average attention recovery benefit of the scene in the public space area along the street was negative. Specific analysis found that the recovery level was the R1 group, with a difference of 2.4 s, while the R4 group was obviously negative with a difference of -1.3 s. This shows that the audio-visual landscape in the central square of the old residential areas has a positive impact on the recovery level of residents' attention, which may be related to the relatively open space in the central square, good landscape maintenance, clean environment, and low traffic noise level.

3.2. Evaluation of Audio-Visual Landscape Perception Factors and Their Relationship with Attention Restoration Level

Figure 2 a displays the evaluation chart of the visual landscape factors of the public space in the sampled residential ar-

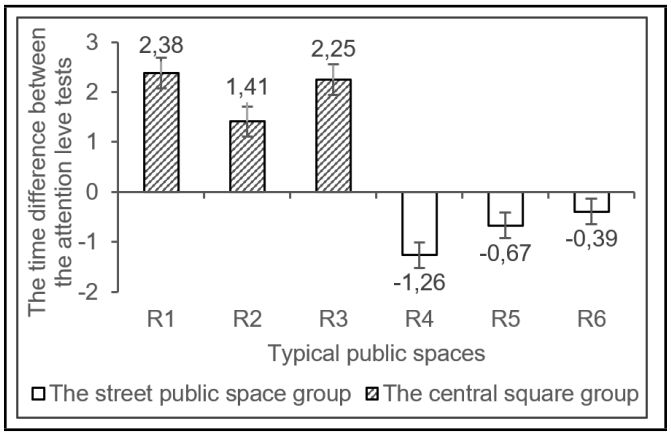
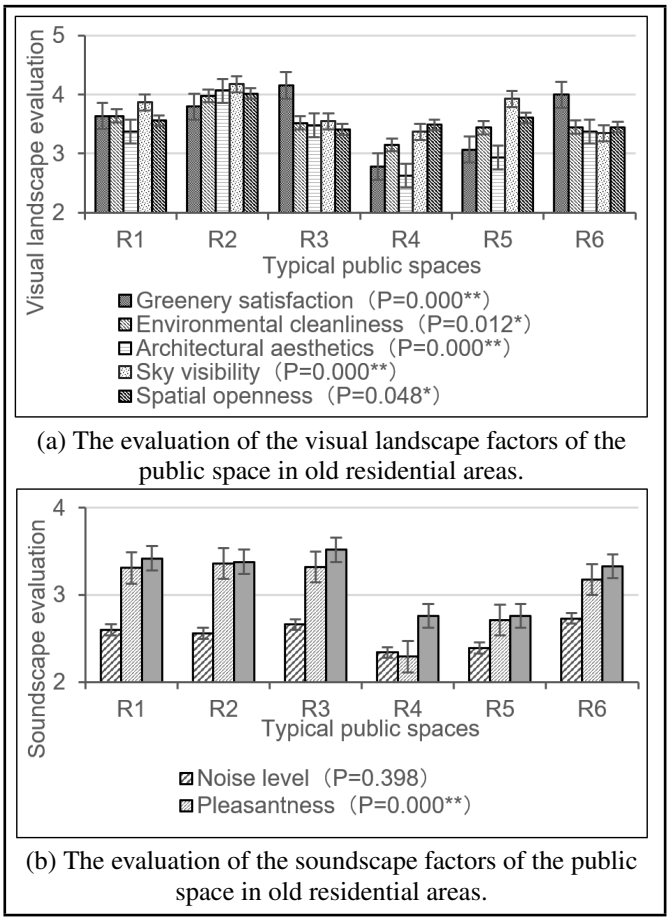


Figure 1. Attention recovery benefits of the public spaces in old residential areas.

eas. As shown in the figure, the subjects' evaluation values for the visual landscape factors of the central square (R1–3) are all above 3.30, while the evaluation values for the public space along the street (R4–6) are only 2.50˘3.50, and the average value of the architectural aesthetics, which is only 2.97, is particularly low. After conducting a one-way ANOVA, we found that the subjects' evaluation values for the visual landscape factors of different public spaces contained significant differences.

Figure 2 b shows the evaluation of the soundscape factors of the public space in the sampled residential areas. As shown in the figure, the subjects tend to select "noisy" in their evaluation of the quietness of the central square in old residential areas (R1–3) and the public space along the street (R4–6), with an average score of 2.30˘2.80. After conducting one-way ANOVA, we found that there was no significant difference in the evaluation results. In contrast to the evaluation of quietness, the evaluation of soundscape pleasantness and comfort level of the central square in residential areas and the public space along the street showed great differences, among which the central square in residential areas has values between 3.30 and 3.60, while the public space along the street has values between 2.20 and 3.40. Applying one-way ANOVA, we found that the evaluation of soundscape pleasantness and comfort among different public spaces had significant differences ($P < 0.01$). For the purpose of exploring the impact of visual landscape and soundscape factors on the attention restoration level, this study conducted a correlation analysis between the evaluation of audio-visual landscape perception factors and the attention restoration level. As shown in Table 5, except for spatial openness, the visual landscape and soundscape factors are significantly positively correlated with the attention restoration level. Among them, the correlation coefficient of greenery satisfaction is the highest at 0.358, followed by the soundscape evaluation factors, which ranged from 0.273 to 0.288, and the correlation coefficient of environmental cleanliness, architectural aesthetics and sky visibility is lower, ranging from 0.195 to 0.251. This shows that a beautiful visual landscape and comfortable acoustic environment can be conducive to the restoration of people's attention following attention consumption, especially natural landscapes such as green plantscapes. This result is consistent with the existing research results; that is, the natural environment can have restorative effects, such as reducing stress or stimulating positive emotions.[32]



(a) The evaluation of the visual landscape factors of the public space in old residential areas.

(b) The evaluation of the soundscape factors of the public space in old residential areas.

Figure 2. The evaluation of audio-visual landscape perception factors of the public space in old residential areas.

Table 5. Relationship between audio-visual landscape perception evaluation and attention restoration level.

Visual landscape factors	Attention restoration level	Soundscape factors	Attention restoration level
Greenery satisfaction	.358**	Quietness	.277*
Environmental cleanliness	.251**	Pleasantness	.288**
Architectural aesthetics	.241**	Comfort	.273**
Sky visibility	.195**		
Spatial openness	.104		

* Correlation is significant at the 0.05 level
** Correlation is significant at the 0.01 level

3.3. Building A Structural Equation Model For The Evaluation Of Audio-Visual Landscape Perception And Attention Restoration Levels

3.3.1. Reliability And Validity Tests

In this study, SPSS 23.0 software was utilized to carry out reliability analysis, and the results showed that Cronbach's alpha coefficient was 0.765, with good internal consistency and a high level of reliability of the data. The validity analysis of the data was mainly achieved through an analysis of the KMO value and Bartlett's test of sphericity. After calculation, the KMO value was 0.733 ($KMO > 0.60$), indicating that the visual landscape and soundscape perception evaluation data can be applied in factor analysis. The significance was 0.000 ($P < 0.001$), suggesting that the data passed Bartlett's test of sphericity.

Table 6. Principal factors in the visual landscape and soundscape evaluation factors that were extracted via EFA.

No	Common factor	Observed variables	Factor loading	Explained variance (%)
1	Visual landscape factors	Greenery satisfaction (X1)	.839	18.577
		Architectural aesthetics (X3)	.782	
2	Spatial factors	Environmental cleanliness (X2)	.636	24.838
		Sky visibility (X4)	.782	
		Spatial openness (X5)	.858	
3	Soundscape evaluation factors	Quietness (X6)	.741	26.086
		Pleasantness (X7)	.818	
		Comfort (X8)	.826	

Table 7. The values of goodness-of-fit indices for the meta and modified models.

Model fit index	Recommended values	Initial values	Modified values
P-value	>0.05	0.110	0.510
GFI	>0.90	0.977	0.985
CFI	>0.90	0.988	1.000
RMSEA	<0.08	0.040	0.000

3.3.2. EFA Of Visual Landscape And Soundscape Factors

There are 8 variables applied in the visual and audio environment perception evaluation scale: greenery satisfaction (X1), environmental cleanliness (X2), architectural aesthetics (X3), sky visibility (X4), spatial openness (X5), quietness (X6), pleasantness (X7), and comfort (X8). SPSS 23.0 was used for principal component analysis, and the factor loading matrix was calculated to obtain the rotated principal component matrix through maximum variance analysis. The results are shown in Table 6. Finally, three common factors were extracted, with a total explanation degree of 69.50 % (a good explanation degree exceeds 60 %). The three common factors were summarized as visual landscape factors, spatial factors and soundscape evaluation factors.

3.3.3. CFA Of Visual Landscape And Soundscape Factors

The common factors obtained from the EFA results were regarded as exogenous potential variables, which were visual landscape factors, spatial factors and soundscape evaluation factors. The difference result of the attention restoration test was regarded as the endogenous observed variable, which was set as the attention restoration level. The visual landscape and soundscape perception evaluation–attention restoration level structural equation model in old residential areas was established. To test the reliability of the model, CFA was carried out with Lavaan in the R system. The results showed that three groups of exogenous observed variables had strong internal correlation, indicating the reliable explanation degree of the observed variables on the latent variables. Parameter estimation was carried out with the maximum likelihood estimation method, with the P value (Chi-square), goodness-of-fit index (GFI), comparative fit index (CFI), root mean square error of approximation (RMSEA) and other parameter values used as a basis for reference to judge the rationality of the model and to modify its internal path.

Relevant studies[33,34] have shown that visual landscape factors, spatial factors and soundscape evaluation factors may affect the attention restoration level of public spaces, and visual landscape factors can also affect their soundscape perception evaluation.[35] Therefore, two main assumptions (Ma, Mb) and five specific assumptions ($Ma1, Ma2, Ma3, Mb1, Mb2$) were proposed to complete the construction of the visual landscape and soundscape perception evaluation–attention restoration level meta-model for old residential areas, as shown in Fig. 3.

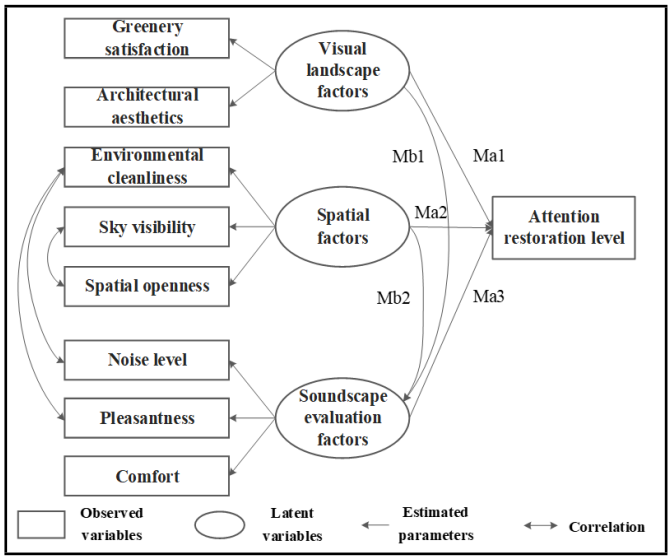


Figure 3. The visual landscape and soundscape perception evaluation–attention restoration level meta-model for old residential areas.

3.3.4. Fit Modification Of The Structural Equation Model

The parameters of the structural equation model were estimated using the maximum likelihood estimation method on the basis of the preliminary structural equation. Based on the modification index (MI) values and $P(>|z|)$ values of the paths in the output results, and on the premise of reasonable model logic, the modified path with MI$>$ 3.0 was added, which entailed architectural aesthetics positively correlated with spatial openness and greenery satisfaction negatively correlated with environmental cleanliness. Furthermore, the paths $Ma2$ and $Mb2$, which did not reach statistical significance, were deleted. Thus, the GFI of the model was further optimized after modification, the correlation of all paths was significant, and the model fit was improved (Table 7), indicating that using the visual landscape and soundscape perception evaluation–attention restoration level relationship model in old residential areas after modification was more reasonable. According to the model paths of visual landscape factors $\rightarrow$ attention restoration level, soundscape evaluation factors $\rightarrow$ attention restoration level and visual landscape factors $\rightarrow$ soundscape evaluation factors $\rightarrow$ attention restoration level, visual landscape factors and soundscape evaluation factors have a significant impact on the attention restoration level in the public spaces of old residential areas. In addition, visual landscape elements can also indirectly promote attention recovery by influencing soundscape assessment.

3.3.5. Visual Landscape And Soundscape Perception Evaluation–Attention Restoration Level Structural Equation Model

Figure 4 shows the visual landscape and soundscape perception evaluation–attention restoration level structural equation model in old residential areas after modification, and Table 7 shows its paths and parameter results. As shown in Figure 4 and Table 8, visual landscape factors and soundscape evaluation factors have a significant direct impact on the attention restoration level, and the standardized path coefficients

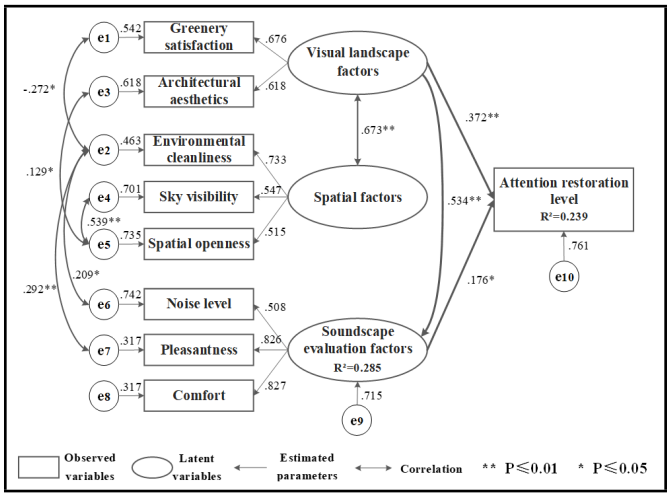


Figure 4. Modified model of the visual landscape and soundscape perception evaluation–attention restoration level in old residential areas.

are 0.372 ($P \leq 0.01$) and 0.176 ($P \leq 0.05$), respectively. Visual landscape factors are the main factors that affect attention restoration. The observed variables of greenery satisfaction and architectural aesthetics make similar contributions to visual landscape factors, with factor loadings of 0.616 and 0.678, respectively. The soundscape evaluation factors are the secondary factors affecting attention restoration, and the observed variables of pleasantness and comfort make greater contributions, with factor loadings of 0.826 and 0.827, respectively.

Visual landscape factors have a positive impact on soundscape evaluation, and the standardized path coefficient is 0.534 ($P \leq 0.01$). Therefore, visual landscape factors can further affect the attention restoration level through soundscape evaluation, indicating that the improvement of the visual landscape not only improves the restoration level, but also optimizes people's acoustic environment experience, induces positive emotions, and enhances the level of attention restoration.

Spatial factors have no direct impact on the attention restoration level but do have a significant positive correlation with visual landscape factors ($P \leq 0.01$), and the standardized path coefficient is 0.673, indicating that a comfortable space improves people's satisfaction with the visual landscape and thereby affects the attention restoration level.

Through the analysis of observed variables, it is found that there is a positive correlation between spatial openness and architectural aesthetics ($P \leq 0.05$). The reason may be that beautiful and harmonious architectural facades can improve the sense of scale in the public space and make it more comfortable and pleasant.[36] Environmental cleanliness is significantly positively correlated with quietness ($P \leq 0.05$) and pleasantness ($P \leq 0.01$). This shows that an improvement to the environmental sanitation conditions at the site has a positive impact on the soundscape evaluation and thus affects the restoration level. Environmental cleanliness is significantly negatively correlated with greenery satisfaction ($P \leq 0.05$). This may be because the survey time is winter in Tianjin, China, and there are a large number of green plants in the public space with high green satisfaction. Affected by the weather, there are more leaves on the ground, resulting in low environmental cleanliness.

Table 8. Standardized path loadings for the modified model of the visual landscape and soundscape perception evaluation–attention restoration level in old residential areas.

Path	Estimate	Standard Error	P(> |z|)	Standardized Coefficient
Visual landscape factors =∼ Greenery satisfaction	1.000	–	–	0.676
Visual landscape factors =∼ Architectural aesthetics	0.926	0.150	0.000	0.618
Spatial factors =∼ Environmental cleanliness	1.000	–	–	0.733
Spatial factors =∼ Sky visibility	0.715	0.152	0.000	0.547
Spatial factors =∼ Spatial openness	0.669	0.145	0.000	0.515
Soundscape evaluation factors =∼ Quietness	1.000	–	–	0.508
Soundscape evaluation factors =∼ Pleasantness	1.583	0.210	0.000	0.826
Soundscape evaluation factors =∼ Comfort	1.700	0.225	0.000	0.827
Soundscape evaluation factors ∼ Visual landscape	0.399	0.087	0.000	0.534
Attention restoration level ∼ Visual landscape factors	-2.841	0.770	0.000	0.372
Attention restoration level ∼ Soundscape evaluation factors	-1.794	0.870	0.039	0.176
Greenery satisfaction ∼ Environmental cleanliness	-0.136	0.056	0.015	-0.272
Environmental cleanliness ∼ Quietness	0.122	0.049	0.013	0.209
Environmental cleanliness ∼ Pleasantness	0.108	0.039	0.005	0.292
Architectural aesthetics ∼ Spatial openness	0.084	0.040	0.034	0.129
Sky visibility ∼ Spatial openness	0.388	0.072	0.000	0.539
Visual landscape factors ∼∼ Spatial factors	0.190	0.049	0.000	0.673
Note: table uses Lavaan notation (=∼: factor loadings; ∼: regression paths; ∼∼: covariances).				

4. DISCUSSION

With the increasing number of home office residents, the need for psychological restoration is an urgent issue for the renewal of residential areas. Many studies have confirmed that visual landscapes and soundscapes have a significant impact on alleviating residents' mental pressure.[9–11] In this study, the relationship between the visual landscape and soundscape in the public spaces of old residential areas and attention restoration was comprehensively analyzed, and an optimization strategy for the visual landscape and soundscape was proposed.

4.1. Effect of Visual Landscape And Soundscape Factors In Old Residential Areas On Their Attention Restoration Levels

According to the experimental data, 59.38% of the subjects had a shorter time for the second attention level test than for the first test in the central square of the residential areas and the public space along the street, indicating that the visual landscape and soundscape of the public space in old residential areas exert restorative effects. Zhang et al. also carried out similar experiments in urban parks and found that 89.6% of subjects significantly restored their level of directed attention after rest and relaxation.[15] Although the soundscape and visual landscape of the public space in old residential areas and urban parks are very rich, the poor maintenance of the landscape, the damaged and dilapidated buildings, the poor quality

of the soundscape and other phenomena in old residential areas greatly reduce the attraction of the visual landscape and soundscape for the residents, resulting in a limited effect of relieving mental pressure and restoring attention. In addition, compared with the public space along the street, the visual landscape and soundscape of the central square in residential areas play a more positive role in attention restoration. This is because the greening rate is higher and the traffic noise is lower in the central square, enhancing the local attachment and identity of residents.[37]

This study found a relationship regarding attention restoration between the evaluation of visual landscape and that of soundscape perception in old residential areas, and the results showed that greenery satisfaction, environmental cleanliness, architectural aesthetics, and sky visibility evaluation were significantly positively correlated with the attention restoration level of these areas. This conclusion is consistent with the research on urban public space.[38] Although there are differences in the quality of the landscape environment and the degree of space maintenance between old residential areas and that of parks and urban squares, pleasant green landscapes and clean and tidy activity spaces always play an important role in the process of residents' restorative experience. The soundscape perception evaluation is positively correlated with the attention restoration level, and pleasantness is of great importance because a pleasant acoustic environment is thought of as charming, which is a quality that is more likely to stimulate people's indirect attention and reduce stress.[6] By comparing the effect of each factor, it was found that greenery satisfaction had the greatest impact on attention restoration, followed by soundscape factors, while the impacts of environmental cleanliness, architectural aesthetics, and sky visibility were relatively small.

Applying a structural equation model to analyze the relationship between visual landscape and soundscape factors and the attention restoration level of old residential areas, it was found in this study that visual landscape factors and soundscape evaluation factors, especially the improvement of greenery satisfaction, which has a more significant restoration potential, exert a direct impact on the attention restoration level, which is in line with the study of Huang et al.[39] A higher plant richness and diversity in residential areas can create a comfortable visual environment and improve aesthetic quality, thus achieving higher attention restoration potential. Moreover, the model results found that the improvement of architectural aesthetics is also conducive to the quick restoration of consumed attention, which indicates that improving the architectural quality of old residential areas or strengthening the characteristics of its surrounding natural landscape can create a more charming visual landscape, thus restoring attention and reducing mental fatigue.[27]

Spatial factors such as environmental cleanliness, sky visibility and spatial openness have no significant impact on attention restoration. This may be because although a clean space environment can generate positive emotions, it fails to effectively alleviate mental fatigue and does not promote the restoration of attentional competence.[14] Although the spatial openness in urban parks is an effective restorative landscape resource, it is difficult for such public space to provide people with a sense of "being away" in spirit due to the dense buildings and the lack of greening maintenance and management in old residential areas, resulting in no significant relationship between the openness of public space in residential areas and the attention restoration level.[10]

4.2. Landscape Optimization Of Old Residential Areas Based On Restoration Improvement

To improve the environmental quality of the public space in old residential areas, importance needs to be ascribed to the differences in the visual landscape and soundscape among different types of space, especially the public space along the street. First, we can improve the visual environment quality by increasing the interactivity of green space, coordinating the style and color of buildings along the street, and cleaning up the environment. Second, in old residential areas, noise barriers or multilevel green plants can be set up in public spaces along streets, which can effectively absorb noise, but also attract birds, increase natural sound, and reduce the impact of traffic noise on activities of residents.[40]

For landscape design aimed at improving the attention restoration level of old residential areas, designing landscape spaces with charming factors is recommended for relieving the monotony of daily life or addressing the tension of study and work in a restorative way. Due to the problems with crowded buildings, poor landscape quality and low space utilization in old residential areas, it may be difficult to add activity facilities, but the following measures can be taken: reasonably planting arbors, shrubs and grass to enrich the landscape level, planting specific flora that attract birds and incorporating other natural elements, and optimizing the details and continuity of building facades to enhance the restorative potential of the environment and improve residents' life satisfaction and psychological happiness. At the same time, formulating the management system of old residential areas with the goal of alleviating mental fatigue and encouraging people to engage with the natural environment and conduct social exchanges, thus enhancing their inner pleasantness, identity and sense of belonging, is encouraging. It is important to consider the overall optimization and improvement of natural landscapes and artificial environments during the renovation of old residential areas to actuate the more significant restorative potential of public spaces.

4.3. Limitations And Future Research

This study conducted an investigation within high-density old residential areas in Tianjin that mainly focused on the relationship between the visual landscape and soundscape perception evaluation in the public spaces of old residential areas and attention restoration, but determining whether the conclusion is applicable to low-density residential areas requires further study. In addition, this study was conducted in autumn and winter, and the subjects were all school students. Considering the seasonal characteristics as well as the psychological characteristics of the population, the subjects' visual landscape and soundscape perception and restorative experience may differ from those of the residents of old residential areas.

Therefore, future research should further explore the restoration benefit principles of the landscape environment of residential areas that are affected by seasonal changes for the purpose of establishing a more complete structural equation model of the relationship between the visual landscape and soundscape perception of resident and their psychological restoration. This can improve the restorative potential of the landscape environment of old residential areas and provide

innovative ideas for the healthy transformation of residential areas.

5. CONCLUSIONS

With the continuous development of urbanization, a large number of old residential areas in the city need to be renewed. As the main space for residents' activities, public space is the key area needing renovation. In the context of the increasing mental pressure on urban residents, it is extremely important to improve the restoration benefits of the visual landscape and soundscape in the public space of residential areas.

This study first evaluated the restoration benefits of the visual landscape and soundscape in the public spaces of old residential areas of Tianjin. There is a significant difference in the visual landscape and soundscape restoration benefits between the central square of old residential areas and the public space along the street. The average test time of the central square group was shortened by 2.0 s, which indicates the positive recovery benefit of the landscape environment in the central square of the old residential area. However, the average test time of the street space group was extended by 0.8 s, indicating that its restorative benefit was negative.

Second, the relationship between the visual landscape and soundscape perception evaluation in old residential areas and the attention restoration level was determined. The visual landscape factors of greenery satisfaction, environmental cleanliness, architectural aesthetics and sky visibility, as well as the soundscape factors of quietness, pleasantness and comfort, are significantly positively correlated with the attention restoration level, among which greenery satisfaction has the highest correlation coefficient with the attention restoration level at 0.358, followed by the soundscape factors, which are between 0.273 and 0.288, and finally those of the environmental cleanliness, architectural aesthetics and sky visibility, which are relatively low, falling between 0.195 and 0.251.

Finally, a structural equation model of the impact of visual landscape and soundscape perception evaluation on the attention restoration level was constructed. According to the structural equation model, the visual landscape and soundscape factors of residential areas have a positive impact on the attention restoration level, and the impact of visual landscape factors is greater than that of soundscape factors. The standardized path coefficients are 0.372 and 0.176, respectively. In addition, visual landscape factors could both directly and indirectly contribute to the attention restoration level, and the indirect effect is realized through its effect on soundscape perception evaluation.

This study confirmed that the visual landscape and soundscape factors in old residential areas are important indicators that affect the attention restoration level of public spaces in old residential areas. Reasonable landscape design can alleviate the mental fatigue of residents and promote attention restoration.

REFERENCES

[1] 2017 *White Paper on the Mental Health of Urban Residents in China. National Population Health Data Center data archive PHDA*, (2020). (Chinese) www.ncmi.cn/phda/dataDetails.do?id=CSTR:A0006.23.A000A.202001.000576-V1.0

[2] Guo F., Cai Y., Wang Y., et al. Emotional health status and social mentality of the Chinese general public during the 2019 novel coronavirus pneumonia pandemic. *Science & Technology Review*, **38**(04): 68-76, (2020). (Chinese) https://doi.org/10.3981/j.issn.1000-7857.2020.04.009

[3] *WHO: World mental health report: transforming mental health for all*.(2022).

[4] Ulrich R. S. Aesthetic and affective response to natural environment. *Behavior and the natural environment*, 85-125, (1983). https://doi.org/10.1002/wps.21018

[5] Ulrich R. S., Simons R. F., Losito B. D., et al. Stress recovery during exposure to natural and urban environments. *Journal of environmental psychology*, **11**(3): 201-230, (1991). https://doi.org/10.1016/s0272-4944(05)80184-7

[6] Kaplan R., Kaplan S. The experience of nature: A psychological perspective. Cambridge university press, (1989).

[7] Kaplan S. The restorative benefits of nature: Toward an integrative framework. *Journal of Environmental Psychology*, **15**(3): 169-182, (1995). https://doi.org/10.1016/0272-4944(95)90001-2

[8] Kaplan S. Meditation, restoration, and the management of mental fatigue. *Environment and behavior*, **33**(4): 480-506, (2001). https://doi.org/10.1177/00139160121973106

[9] Evans G. W. The built environment and mental health. *Journal of Urban Health*, **80**(4): 536-555, (2003). https://doi.org/10.1093/jurban/jtg063

[10] Ye H., Zhu X. Study on the effect of spatial characteristics and health restoration of urban parks in Harbin City in autumn——Taking Zhaolin Park as an example. *Journal of Human Settlements in West China*, **33**(04): 73-79, (2018). (Chinese) https://doi.org/10.13791/j.cnki.hsfwest.20180412

[11] Kimura T., Yamada T., Hirokawa Y., et al. Brief and Indirect Exposure to Natural Environment Restores the Directed Attention for the Task. *Frontiers in Psychology*, **12**: 619347, (2021). https://doi.org/10.3389/fpsyg.2021.619347

[12] Berdejo-Espinola V., Suárez-Castro A. F., Amano T., et al. Urban green space use during a time of stress: A case study during the COVID-19 pandemic in Brisbane, Australia. *People and Nature*, **3**(3): 597-609, (2021). https://doi.org/10.1002/pan3.10218

[13] Lindal P. J., Hartig T. Architectural variation, building height, and the restorative quality of urban residential streetscapes. *Journal of Environmental Psychology*, **33**: 26-36, (2013). https://doi.org/10.1016/j.jenvp.2012.09.003

[14] Zhang Z., Zhang J. Perceived residential environment of neighborhood and subjective well-being among the elderly in China: A mediating role of sense of community. *Journal of Environmental Psychology*, **51**: 82-94, (2017). https://doi.org/10.1016/j.jenvp.2017.03.004

[15] Zhang Y., Kang J. Effects of soundscape on the environmental restoration in urban natural environments. *Noise & health*, **19**(87): 65, (2017). https://doi.org/10.4103/nah.NAH_73_16.

[16] Wallenius M. A. The interaction of noise stress and personal project stress on subjective health. *Journal of Environmental Psychology*, **24**(2): 167-177, (2004). https://doi.org/10.1016/j.jenvp.2003.12.002

[17] Dzhambov A. M., Lercher P., Stoyanov D., et al. University students' self-rated health in relation to perceived acoustic environment during the covid-19 home quarantine. *International Journal of Environmental Research and Public Health*, **18**(5): 2538, (2021). https://doi.org/10.3390/ijerph18052538

[18] Medvedev O., Shepherd D., Hautus M. J. The restorative potential of soundscapes: A physiological investigation. *Applied Acoustics*, **96**: 20-26, (2015). https://doi.org/10.1016/j.apacoust.2015.03.004

[19] Guo X., Liu J., Albert C., et al. Audio-visual interaction and visitor characteristics affect perceived soundscape restorativeness: Case study in five parks in China. *Urban Forestry & Urban Greening*, **77**: 127738, (2022). https://doi.org/10.1016/j.ufug.2022.127738

[20] Herranz-Pascual K., Aspuru I., Iraurgi I., et al. Going beyond quietness: Determining the emotionally restorative effect of acoustic environments in urban open public spaces. *International Journal of Environmental Research and Public Health*, **16**(7): 1284, (2019). https://doi.org/10.3390/ijerph16071284

[21] Zhang H., Kang J. Acoustic Needs of Older People in the Outdoor Environment of Residential Communities: A Case Study in China. *International Journal of Acoustics and Vibration*, **27**: 106-111, (2022). https://doi.org/10.20855/ijav.2022.27.21838

[22] Ding Y., Fan H. The renovation and renewal of old residential areas enhance the sense of gain of the common people. *People's Daily*, **11-16**(018), (2022). (Chinese) https://doi.org/10.28655/n.cnki.nrmrb.2022.012366

[23] Huo B., Liu W., Zhang N. The exploration of the mechanism and the models of residents autonomously collaborate renewal: The way to living quality promotion in Tianjin old residential areas. *Urban Design*, **02**: 06-17, (2022). (Chinese) https://doi.org/10.16513/j.urbandesign.2022.02.009

[24] Bian H. *The study on pattern of small block residential space. Tianjin University*, (2010). (Chinese) kns.cnki.net/KCMS/detail/detail.aspx?dbname=CDFD1214&filename=1013039412.nh

[25] Jing G., Lyu P., Zhao P., et al. Experimental study on the influence of coal mine noise on people's attention. *Journal of Safety Science and Technology*, **13**(10): 164-168, (2017). (Chinese) https://doi.org/10.37155/2811-0595-0203-16

[26] Li W., Ma J., Xie X., et al. The effect of Schulte table training on mental workload of simulated flight multitask. *Chinese Journal of Aerospace Medicine*, **30**(03): 201-207, (2019). (Chinese) https://doi.org/10.3760/cma.j.issn.1007-6239.2019.03.007

[27] Li T., Xue B., Yang X. et al. Research on attention recovery in restorative environment based on wireless physiological sensor and virtual reality technology. *Chinese Landscape Architecture*, **36**(12): 62-67, (2020). (Chinese) https://doi.org/10.19775/j.cla.2020.12.0062

[28] Yin J., Zhu S., MacNaughton P., et al. Physiological and cognitive performance of exposure to biophilic indoor environment. *Building and Environment*, **132**: 255-262, 2018. https://doi.org/10.1016/j.buildenv.2018.01.006

[29] Anderson A. P., Mayer M. D., Fellows A. M., et al. Relaxation with immersive natural scenes presented using virtual reality. *Aerospace medicine and human performance*, **88**(6): 520-526, 2017. https://doi.org/10.3357/amhp.4747.2017

[30] Salehi M., Marefat F. The Effects of Foreign Language Anxiety and Test Anxiety on Foreign Language Test Performance. *Theory & Practice in Language Studies*, **4**(5):931-940, 2014. https://doi.org/10.4304/tpls.4.5.931-940

[31] Rosseel Y. Lavaan: An R package for structural equation modeling. *Journal of Statistical Software*, **48**: 1-36, (2012). https://doi.org/10.18637/jss.v048.i02

[32] Tyrväinen L., Ojala A., Korpela K., et al. The influence of urban green environments on stress relief measures: A field experiment. *Journal of Environmental Psychology*, **38**: 1-9, (2014). https://doi.org/10.1016/j.jenvp.2013.12.005

[33] Van den Berg A. E. From green space to green prescriptions: challenges and opportunities for research and practice. *Frontiers in Psychology*, **8**: 268, (2017). https://doi.org/10.3389/fpsyg.2017.00268

[34] Li Z., Kang J. Sensitivity analysis of changes in human physiological indicators observed in soundscapes. *Landscape and Urban Planning*, **190**: 103593, (2019). https://doi.org/10.1016/j.landurbplan.2019.103593

[35] Van Renterghem T. Towards explaining the positive effect of vegetation on the perception of environmental noise. *Urban Forestry & Urban Greening*, **40**: 133-144, (2019). https://doi.org/10.1016/j.ufug.2018.03.007

[36] Han J., Jiang H., Wang L. Research on the interface of residential street based on semantic analysis and street view data——A case of Xinzhu Road and Fengxiang Road in Nanjing. *Urbanism and Architecture*, **16**(07): 89-94, (2019). (Chinese) https://doi.org/10.19892/j.cnki.csjz.2019.07.018

[37] Liu Q., Wu Y., Xiao Y., et al. More meaningful, more restorative? Linking local landscape characteristics and place attachment to restorative perceptions of urban park visitors. *Landscape and Urban Planning*, **197**: 103763, (2020). https://doi.org/10.1016/j.landurbplan.2020.103763

[38] Ríos-Rodríguez M. L., Rosales C., Lorenzo M., et al. Influence of Perceived Environmental Quality on the Perceived Restorativeness of Public Spaces. *Frontiers in Psychology*, **12**: 644763, (2021). https://doi.org/10.3389/fpsyg.2021.644763

[39] Huang S., Qi J., Li W., et al. The contribution to stress recovery and attention restoration potential of exposure to urban green spaces in low-density residential areas. *International Journal of Environmental Research and Public Health*, **18**(16): 8713, (2021). https://doi.org/10.3390/ijerph18168713

[40] Kang J. Acoustics and Sustainability: A Built Environment Perspective. *International Journal of Acoustics and Vibration*, **25**: 292, (2020). https://doi.org/10.20855/ijav.2020.25.3e97