
# Overall environmental assessment with soundscape and landscape indices in urban parks

Hyun In Jo[1], Jin Yong Jeon[1,2]

[1] Hanyang University, Department of Architectural Engineering, Seoul 04763, Korea

[2] Hanyang University, Department of Medical and Digital Engineering, Seoul 04763, Korea (Corresponding author)

Corresponding author's e-mail address: jyjeon@hanyang.ac.kr

## ABSTRACT

In this study, soundscape and landscape indices that can be used for overall environment assessment of urban parks are proposed, and the effects of audiovisual interactions are examined. In a virtual reality evaluation environment reproduced based on audio-visual data collected from three parks in Paris, audio-visual element identification, perceived affective quality, and overall environmental assessment for a total of 30 subjects. Based on this, reference indices (Green soundscape index (GSI), Red soundscape index (RSI), Green landscape index (GLI), Red landscape index (RLI)) are defined based on the ratio of the audio-visual perception of nature and traffic or nature and people. In addition, Revised reference indices were proposed. Finally, environmental awareness models using structural equation model were presented. As a result, it was found that acoustic and visual satisfaction had 79 % and 21 % effect on overall environmental satisfaction, respectively. In addition, in order to increase acoustic and visual satisfaction, GLI should be increased and RLI should be decreased, and it was found that visual satisfaction can be improved when GSI is additionally increased.

## INTRODUCTION

Urban parks contribute to a healthy, cultural city life and public welfare by creating a pleasant urban environment [1]. Because of the negative effects of urban environmental noises on urban residents, sound is now a key element in urban design [2], Nonetheless, environmental factors such as energy efficiency and air pollution mitigation have been prioritized by urban designers and stakeholders; thus, there remains a large academia–practice gap [3].

To minimize this gap, studies have examined multi-sensory interaction between sound and other senses (visual, smell, and thermal) in urban environments [4-6]. Attempts have been made to analyze the interaction of soundscapes and landscapes, to create design suggestions from the perspective of audio-visual interaction [6,7]. Overall environmental assessment indicators for soundscapes and landscapes that make up the ecological entity of urban environments exist and have been evaluated in various studies.

As overall environmental assessment is closely related to the interaction between soundscape and landscape [6], various perception models have been proposed to predict soundscape perception in urban environments. In addition to various physical and psychological parameters, spatial metric parameters were used and linear or non-linear equation models applied [8]. For example, some studies have applied structural equation modeling to examine the relationship between factors influencing soundscape and landscape perception or indirect influence through latent variables [9-11]. However, most perception model studies emphasize only the sound environment aspects and only consider the degree of overall preference (visual esthetic and visual comfort) from a visual perspective. Thus, it is difficult to apply these approaches to urban planning. Additionally, research on audio-visual interactions in urban parks is insufficient. Therefore, the academia–practice gap can be narrowed if the response to the audio-visual elements constituting urban parks is included in the perception model through a more fundamental approach.

Accordingly, this study examines the perception of the overall environmental assessment of urban parks in terms of audio-visual interaction and presents design guidelines that can reduce the academia–practice gap based on the elements constituting the soundscape and landscape. The research aims are as follows: (1) develop an index that can quantify the response to audio-visual elements that constitute the soundscape and landscape; (2) based on this, use a structural equation model (SEM) to propose an overall environmental model for urban parks; and (3) design guidelines for pleasant urban parks based on the relationship between audio-visual elements and environmental satisfaction.

## METHODS

### Soundscape and landscape index

In this study, various soundscape and landscape indices were defined (Table 1) to quantify the subjects' perception of the audio-visual factors that constitute urban parks. The representative reference indices were defined as the soundscape index (SI) and landscape index (LI). SI comprises GSI, which is the ratio of the perceived extent of natural sounds (PNS) to the perceived extent of traffic noise [12], and RIS, which is the ratio of PNS to the perceived extent of human sounds [13]. The natural sound was divided into the perceived extent of birdsongs and the perceived extent of water sounds to create sub-indices of GSI and RSI. Similarly, LI was divided into the green landscape index (GLI), which is the ratio of the perceived extent of natural elements (PNE) to the perceived extent of vehicle elements, and the red landscape index (RLI), which is the ratio of PNE to the perceived extent of people elements. LI was divided into the perceived extent of greenery and perceived extent of water elements to create sub-indices. As the reference index is a ratio for the perception of each audio-visual element category, there is a limitation in that it cannot reflect the loudness of the sound or the visual density. Thus, to supplement the reference index, a revised index dividing SI and LI into perceived loudness and perceived crowdedness was proposed.

### Audio-visual data collection

Three parks located near the Seine in Paris, France, with different sizes and functions were selected as assessment targets: Arènes de Lutèce (Park A), Champ de Mars (Park C), and Jardin des Tuileries [14]. A total of 18 assessment locations representing various audio-visual characteristics were selected for each park. Measurements were taken for 2 min 30 s for each location. The visual information was collected using a 6-channel 360-degree camera (Insta360

Pro). Auditory information was collected using a four-channel first-order ambisonic (FOA) microphone (SoundField SPS200), and set up in A-format.

### Virtual reality environment

A VR environment was created based on audio-visual data to assess the environment of urban parks. First, to realize the visual environment, video recorded in six channels was edited into a single 360-degree video using stitching software (Insta360 Stitcher) and provided through a head-mounted display (HMD; VIVE Pro). Next, to implement a sound environment, the sound source recorded in A-format FOA was converted to B-format FOA using an ambisonic plug-in (sound devices). To implement a headphone-based sound, 4-channel sound sources were down-mixed with a binaural track using spatial audio SDK (Spatial Audio API). The real-time direction of sound according to the head rotation was identified using the head-tracker built into the HMD. The sound information was provided through an open-type headphone (HD-650, Sennheiser).

### Questionnaire

The questionnaire for environmental assessment consisted of three parts [14]. First, to explore the audio-visual element identification for each evaluation stimulus, the participants were asked to respond to the degree of magnitude perceived for three sound categories (traffic noise, sounds from human beings, natural sounds) and three visual categories (vehicles, people, nature) with a 5-point Likert scale. Natural sounds were divided into birdsongs and water sounds, and natural elements were divided into greenery and water. Next, the participants were asked to score the degree to which the audio-visual stimuli were in line with eight semantic expression words (pleasant, chaotic, vibrant, uneventful, calm, annoying, eventful, monotonous) on a 5-point Likert scale to investigate the perceived affective quality of urban parks. Finally, for the overall environmental assessment, they were asked to respond on a 5-point Likert scale regarding the three assessment factors (satisfaction, loudness, and crowdedness). To examine the audio-visual interaction, they were asked to respond by dividing satisfaction into overall, acoustic, and visual aspects. Additionally, the perception of loudness for the sound factor was evaluated as loudness, and the sense of density of the visual factors was evaluated as perceived crowdedness.

### Procedure

A total of 30 subjects (17 men and 13 women) participated in this experiment, and the age range was 20–31 years (mean age: 25.20, standard deviation: 2.11). To examine the difference in environmental assessment over time within the same location, each of the 18 stimuli recorded for 150 s was divided into 30 s segments, and a total of 90 stimuli (18 locations × 5 times) were created. The same audio-visual stimulation was provided to all subjects, and the subjects signed a consent form before the experiment. All playback orders were provided in the same sequence, and the stimulus was provided repeatedly as required. Consequently, 2,700 responses (30 participants × 90 stimuli) were collected for each questionnaire evaluation item.

**Table 1:** Definitions of soundscape and landscape indices. [15]

| Reference | Definition | Formula | Range |
|---|---|---|---|
| **GSI** | **Green soundscape index [12]** | $\frac{<PNS>}{<PTN>}$ | **0.2–5.0** |
| *BGSI* | *Birdsong-based green soundscape index* | $\frac{<PBS>}{<PTN>}$ | 0.2–5.0 |
| *WGSI* | *Water sound-based green soundscape index* | $\frac{<PWS>}{<PTN>}$ | 0.2–5.0 |
| **RSI** | **Red Soundscape Index [13]** | $\frac{<PNS>}{<PHN>}$ | **0.2–5.0** |
| *BRSI* | *Birdsong-based red landscape index* | $\frac{<PBS>}{<PHN>}$ | 0.2–5.0 |
| *WRSI* | *Water sound-based red landscape index* | $\frac{<PWS>}{<PHN>}$ | 0.2–5.0 |
| **GLI** | **Green Landscape Index** | $\frac{<PNE>}{<PVE>}$ | **0.2–5.0** |
| *GGLI* | *Greenery-based green landscape index* | $\frac{<PGE>}{<PVE>}$ | 0.2–5.0 |
| *WGLI* | *Water-based green landscape index* | $\frac{<PWE>}{<PVE>}$ | 0.2–5.0 |
| **RLI** | **Red Landscape Index** | $\frac{<PNE>}{<PPE>}$ | **0.2–3.0** |
| *GRLI* | *Greenery-based red landscape index* | $\frac{<PGE>}{<PPE>}$ | 0.2–5.0 |
| *WRLI* | *Water-based red landscape index* | $\frac{<PWE>}{<PPE>}$ | 0.2–2.5 |
| **Revised** | **Correction** | **Formula** | **Range** |
| **R_GSI** | ***Perceived Loudness- based correction for reference index*** | $\frac{<PNS>}{<PTN>} \times \frac{1}{<PL>}$ | **0.05–5.0** |
| *R_BGSI* | | $\frac{<PBS>}{<PTN>} \times \frac{1}{<PL>}$ | 0.04–5.0 |
| *R_WGSI* | | $\frac{<PWS>}{<PTN>} \times \frac{1}{<PL>}$ | 0.04–5.0 |
| **R_RSI** | | $\frac{<PNS>}{<PHN>} \times \frac{1}{<PL>}$ | **0.05–5.0** |
| *R_VRSI* | | $\frac{<PBS>}{<PHN>} \times \frac{1}{<PL>}$ | 0.04–5.0 |
| *R_PRSI* | | $\frac{<PWS>}{<PHN>} \times \frac{1}{<PL>}$ | 0.04–3.0 |
| **R_GLI** | ***Perceived Crowdedness-based correction for reference index*** | $\frac{<PNE>}{<PVE>} \times \frac{1}{<PC>}$ | **0.05–3.5** |
| *R_GGLI* | | $\frac{<PGE>}{<PVE>} \times \frac{1}{<PC>}$ | 0.05–5.0 |
| *R_WGLI* | | $\frac{<PWE>}{<PVE>} \times \frac{1}{<PC>}$ | 0.05–3.0 |
| **R_RLI** | | $\frac{<PNE>}{<PPE>} \times \frac{1}{<PC>}$ | **0.05–1.5** |
| *R_GRLI* | | $\frac{<PGE>}{<PPE>} \times \frac{1}{<PC>}$ | 0.05–2.5 |
| *R_WRLI* | | $\frac{<PWE>}{<PPE>} \times \frac{1}{<PC>}$ | 0.04–1.0 |

## RESULTS

### Environmental perception model

The SEM, including SI and LI, the environmental perceptual dimension (potential variable), and the overall environmental assessment, were analyzed to present an audio-visual interaction-based perception model for urban park environments. For the SEM analysis, the following five main hypotheses were established based on previous studies, and 24 specific hypotheses were developed:

- $H_1$: Soundscape and landscape indices influence environmental perceptual dimensions.
- $H_2$: Soundscape and landscape indices influence acoustic and visual satisfaction.
- $H_3$: Environmental perceptual dimensions affect acoustic and visual satisfaction.
- $H_4$: Environmental perceptual dimensions positively affect overall satisfaction.
- $H_5$: Acoustic and visual satisfaction positively influences overall satisfaction.

The SEM model results using the main index are illustrated in Figure 1, divided into the reference index ($I_1$) and the revised index ($II_1$). In both Model $I_1$ and Model $II_2$, all CMIN/DF, GFI, RMR, AGFI, CFI, and RMSEA values were at an appropriate level, indicating that they are an acceptable model.

In examining $H_1$ among all paths, GSI had the most significant importance for pleasantness, followed by RSI, GLI, and RLI. For eventfulness, RSI was the most significant, followed by GSI, GLI, and RLI, reflecting a negative effect. Regarding $H_2$, different relationships were observed between the variables depending on the model. In Model $I_1$, regarding acoustic satisfaction, GLI was the most significant, followed by GSI. Simultaneously, GLI was found to be an important factor for visual satisfaction. In Model $II_1$, RLI had the most significance for the acoustic satisfaction, followed by GLI, and for the visual satisfaction, GLI had the most significance, followed by GSI and RLI. Regarding the $H_3$ path, the pleasantness of the park environment was found to have the most positive effect on acoustic satisfaction, followed by visual satisfaction. In contrast, the eventfulness of the park environment was found to have the most negative effect on acoustic satisfaction, followed by visual satisfaction. The $H_4$ path confirmed that pleasantness is an important factor influencing overall satisfaction. Lastly, the contribution of acoustical satisfaction and visual satisfaction to the overall satisfaction of urban parks was explored through the $H_5$ path. On average, acoustic satisfaction and visual satisfaction contributed approximately 79% and 21%, respectively.

To more closely explore the impact of natural elements on the environmental assessment in urban parks, a SEM analysis was performed based on the sub-model for birdsongs, greenery, and water sound and water features. The results are presented in Fig. 7 and Table 4 and divided into the reference index (Figure 1(c) and (e)) and the revised index (Figure 1(d) and (f)). Overall, the relationships with Models $I_1$ and $II_1$ were similar, but there was a slight difference in the $H_1$ and $H_2$ paths depending on the soundscape and LI. In the $H_1$ path, the effect of BGSI of Models $I_2$ and $II_2$ on eventfulness was valid, while the path of eventful ← WGSI of Models $I_3$ and $II_3$ was not valid. Moreover, the change in eventfulness by water-based RLI (WRLI) was in the opposite direction to greenery-based RLI (GRLI) but in Model $II_3$ it improved with the revised index, there was no significant relationship, and the effect was very small. Furthermore, on examining the effect of RSI on visual satisfaction in the $H_2$ path, BRSI and WRSI were found to be weak, but a significant relationship was found. Additionally, a trend was found in the relationship between RLI and acoustic and visual satisfaction. GRLI was associated with increasing AS, and WRLI was associated with increasing VS.

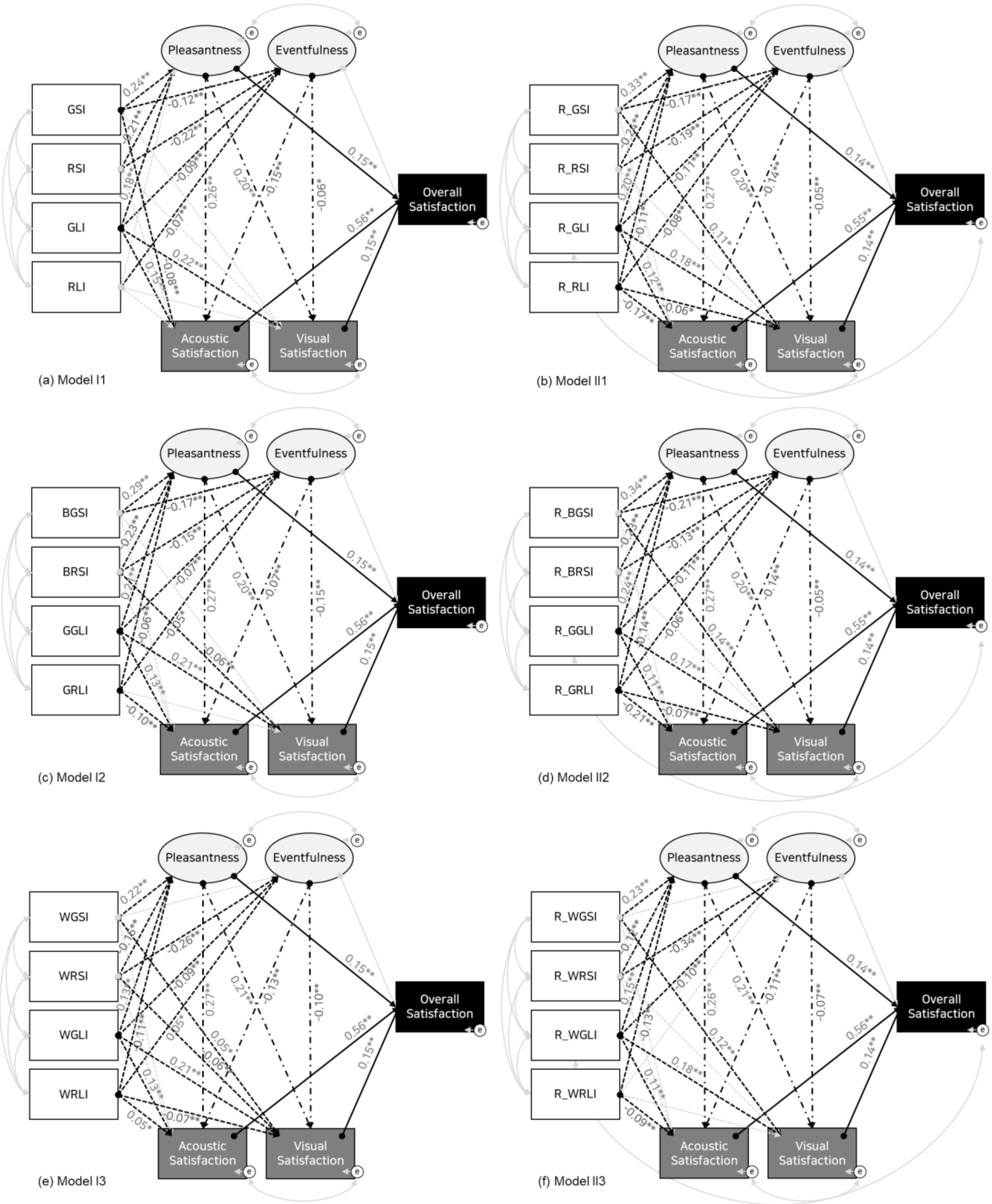


**Figure 1:** Structural equation models by reference index and sub-index ([*p < 0.05, ** p < 0.01]; non-significant paths are marked with gray lines and are not annotated). (a) reference model. (b) revised model. Birdsong and greenery-based (c) reference model and (d) revised model. Water-based (e) reference model and (f) revised model. [15]

## DISCUSSION AND CONCLUSIONS

This study presented a new SI and LI that can be used for an overall environmental assessment of urban parks and a perception model for overall environmental satisfaction from the perspective of audio-visual interaction. Regarding audio-visual elements, the study presented a reference index based on the ratio of perception for natural-related elements, traffic, and human-related elements, and the revised index using loudness and crowdedness. The results confirmed that the revised index is more advantageous in interpreting environmental assessment through mutual comparison. Next, the study found that primarily securing pleasantness is important and appropriately controlling eventfulness by adding birdsongs or vegetation is effective for increasing the overall environmental satisfaction of urban parks. Finally, it was found that providing greenery and water features is effective in improving visual and sound satisfaction, respectively, and there is a need to induce foot traffic. This study’s findings are expected to be used as design guidelines and supporting data to provide a pleasant urban park environment for urban residents.

### Acknowledgements

This study is a summary of the content of the paper that is submitted to the journal “Overall environmental assessment in urban parks: Audio-visual interaction approaches with a structural equation model based on soundscape and landscape indices” [12]. It is stated that copyrights of all content, figures and tables in this manuscript are owned by the journal.

### Funding

This research was supported by a grant from the National Research Foundation of Korea (NRF), funded by the Korean government (MSIT) (No. 2020R1A2C2009716).

## REFERENCES

[1] Navarrete-Hernandez, P., & Laffan, K. (2019). A greener urban environment: Designing green infrastructure interventions to promote citizens’ subjective wellbeing. Landscape and Urban Planning, 191, 103618.

[2] World Health Organization. (2018). Environmental noise guidelines for the European region. Regional Office for Europe.

[3] Kang, J., & Schulte-Fortkamp, B. (Eds.). (2016). Soundscape and the built environment. Boca Raton, FL: CRC press.

[4] Xiao, J., Tait, M., & Kang, J. (2018). A perceptual model of smellscape pleasantness. Cities, 76, 105–115.

[5] Hai, Y., & Feng, Q. (2018). Thermalscape of Ecological City and its Visualized Evaluation. Energy Procedia, 152, 1139–1144.

[6] Jeon, J. Y., & Jo, H. I. (2020). Effects of audio-visual interactions on soundscape and landscape perception and their influence on satisfaction with the urban environment. Building and Environment, 169, 106544.

[7] Li, H., & Lau, S. K. (2020). A review of audio-visual interaction on soundscape assessment in urban built environments. Applied Acoustics, 166, 107372.

[8] Lionello, M., Aletta, F., & Kang, J. (2020). A systematic review of prediction models for the experience of urban soundscapes. Applied Acoustics, 170, 107479.

[9] Hong, J. Y., & Jeon, J. Y. (2015). Influence of urban contexts on soundscape perceptions: A structural equation modeling approach. Landscape and Urban Planning, 141, 78–87.

[10] Tse, M. S., Chau, C. K., Choy, Y. S., Tsui, W. K., Chan, C. N., & Tang, S. K. (2012). Perception of urban park soundscape. Journal of the Acoustical Society of America, 131(4), 2762–2771.

[11] Tarlao, C., Steffens, J., & Guastavino, C. (2021). Investigating contextual influences on urban soundscape evaluations with structural equation modeling. Building and Environment, 188, 107490.

[12] Kogan, P., Arenas, J. P., Bermejo, F., Hinalaf, M., & Turra, B. (2018). A Green Soundscape Index (GSI): The potential of assessing the perceived balance between natural sound and traffic noise. Science of the total environment, 642, 463-472.

[13] Cao, X., Meng, Q., & Kang, J. (2020). Red Soundscape Index (RSI): An index with the potential to assess soundscape quality. In INTER-NOISE and NOISE-CON Congress and Conference Proceedings (Vol. 261, No. 3, pp. 3527-3539).

[14] Jo, H. I., & Jeon, J. Y. (2020). The influence of human behavioral characteristics on soundscape perception in urban parks: Subjective and observational approaches. Landscape and Urban Planning, 203, 103890.

[15] Jo, H. I., & Jeon, J. Y. (2021). Overall environmental assessment in urban parks: Audio-visual interaction approaches with a structural equation model based on soundscape and landscape indices (Submitted)