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CLUSTERING RESIDENTIAL SOUNDS BASED ON SOUNDSCAPE ATTRIBUTES

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ABSTRACT

This study performed clustering of residential sounds using soundscape attributes data. Residential sounds in apartments were defined as primarily consisting of noise from neighbors and outdoor sources, as well as natural sounds such as birdsong and water sounds. The evaluation of soundscape attributes for residential acoustic environment was conducted in a laboratory setting with 67 participants, using 8 soundscape attributes specified in torresin *et al*. indoor soundscape. The soundscape attribute data used for clustering consisted of evaluation results for the eight descriptors, transformed into two soundscape dimensions. Clustering was conducted using the k-means algorithm, and the optimal number of clusters k was determined through the silhouette coefficient and elbow method. The analysis revealed that each cluster exhibited unique soundscape attributes and acoustic characteristics, which were comprehensively evaluated to systematically classify the sound characteristics of residential environments.

Keywords: *residential sound, soundscape monitoring, soundscape attributes*

1. INTRODUCTION

Noise generated in multi-family housing has a direct impact on residents' quality of life. In South Korea, complaints related to inter-floor noise have been steadily increasing, affecting both the psychological and physiological well-being of residents. While physical measurements have been used to enhance the sound insulation performance of buildings in an effort to reduce noise, these efforts have not led to a decrease in noise-related complaints [1-2]. To address this issue, it is necessary to move beyond simply blocking unwanted sounds and instead adopt an approach that involves understanding and managing the characteristics of residential sounds. Recently, the field of soundscape research has expanded to include investigations of both outdoor and indoor acoustic environments [3-7]. Soundscape assessments are based on how individuals perceive, understand, and experience the sounds in a given environment [8]. Drawing on this perspective, various attempts have been made to transform the negative perception of soundscapes into more positive ones within indoor and outdoor environments. In particular, studies have begun to explore how introducing positive sounds can improve soundscapes in both indoor and outdoor settings of multi-family housing [9]. For practical applications, it is essential to investigate the characteristics of residential sounds by soundscape data and evaluating the acoustic environment both inside and outside dwellings. Research on classification of sounds sharing similar soundscape characteristics and in order to provide residents with a positively perceived acoustic environment is therefore necessary. Accordingly, the present study investigates the soundscape of residential sounds through auditory perception experiments and classifies them using clustering techniques based on soundscape data. Differences in soundscape perception and psychoacoustic parameters across residential sound clusters are analyzed to provide

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insights into the acoustic characteristics of multi-family housing environments.

2. METHODS

2.1 Laboratory experiment

In this study, a listening experiment was conducted to investigate residents' perceptual responses to sounds occurring in residential environments. A total of 67 participants living in multi-family housing were recruited for this test. The experiment involved the evaluation of 92 sound samples, including residential noise, natural sounds (e.g., birdsong, water sounds), combined natural sounds (birdsong and water), noise and natural sounds, and noise and multiple natural sounds (residential noise and multiple natural sounds (birdsong and water sounds)). Soundscape assessments were carried out using a five-point Likert scale (from "not at all" to "very much"), based on the indoor soundscape attributes proposed by Torresin et al. The experiment was conducted in a controlled laboratory setting, where sound stimuli were played back using a subwoofer speaker (Dynaudio BM14S) and headphones (Sennheiser HD600). The playback order of the sound samples was randomized for each participant.

2.2 Clustering

In this study, clustering was performed using the k-means algorithm based on the soundscape evaluation data of residential sounds. The optimal number of clusters (k) was selected from a range of 2 to 10 by identifying the value that yielded the smallest deviation between the overall average silhouette coefficient and the mean silhouette coefficients of individual clusters. All analyses were conducted using Python.

3. RESULT

3.1 Clustering based on indoor soundscape indicators

Clustering based on the eight indoor soundscape attributes revealed three distinct clusters, as determined using the elbow method and silhouette coefficient. As shown in Table 1, cluster 1 primarily included sound samples categorized as natural sounds, combinations of noise and natural sounds, and combinations of various natural sounds.

Figure 1 presents the median ratings for each soundscape attribute across the three clusters. Sounds in cluster 1 exhibited higher values for full of content, engaging, comfortable, and private/controlled compared to those in other clusters. In contrast, sounds in cluster 3 showed higher ratings for detached and empty than the other clusters. Table 1 displays the number of sound samples assigned to each cluster. Cluster 1 contained the highest proportion of natural sounds and included several combinations of noise and natural sounds. Cluster 2 was characterized by a greater presence of combinations of noise and natural sounds compared to clusters 1 and 3. Cluster 3 encompassed various combinations not found in the other clusters, including noise, pure natural sounds, and hybrid natural sounds.

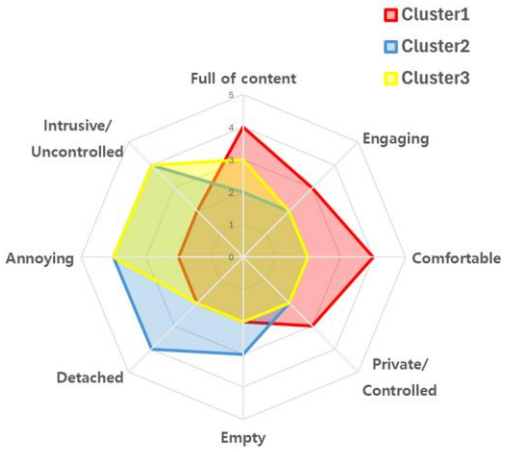


Figure 1. Evaluation of soundscape attributes by cluster

Table 1. Number of residential sound by cluster

Sound source	Cluster		
	1	2	3
Noise	0	9	2
Natural	22	4	3
Noise + Natural	7	15	9
Noise + Natural + Natural	0	0	12
Natural + Natural	4	0	0

3.2 Clustering based on the comfortable and full of content axis

The values for comfortable and full of content dimensions were calculated based on the methodology proposed in ISO/TS 12913-3 [10]. Clustering analysis using the comfortable and full of content axis resulted in three distinct clusters, as determined by the elbow method and silhouette coefficient. Figure 2 shows the distribution of all sound samples in the two-dimensional space derived from soundscape evaluations. The residential sounds examined in

this study were found to be distributed within the range of approximately [–0.75 to 0.75] on the comfortable axis and [–0.50 to 0.50] on the full of content axis. Table 2 presents the sound samples grouped by cluster based on the two dimensions. Cluster 1 included a higher number of natural sounds compared to the other clusters. While clusters 2 and 3 contained an equal number of combined sounds (noise and natural sounds), cluster 3 uniquely included complex mixtures containing both noise and two types of natural sounds. Figures 3(a), 3(b), and 3(c) show the distribution of comfortable and full of content values for each cluster. Cluster 1 sounds were distributed within the range of [0.00 to 0.75] on the comfort axis and [–0.15 to 0.50] on the full of content axis. Cluster 2 sounds fell within [–0.75 to 0.15] on the comfortable axis and [–0.45 to 0.00] on the full of content axis. Cluster 3 sounds were located between [–0.75 to 0.00] on the comfortable axis and [0.00 to 0.45] on the full of content axis.

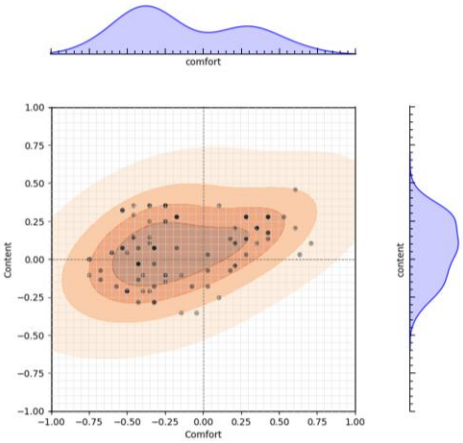
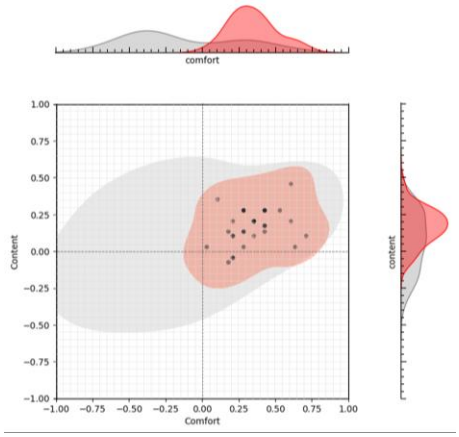


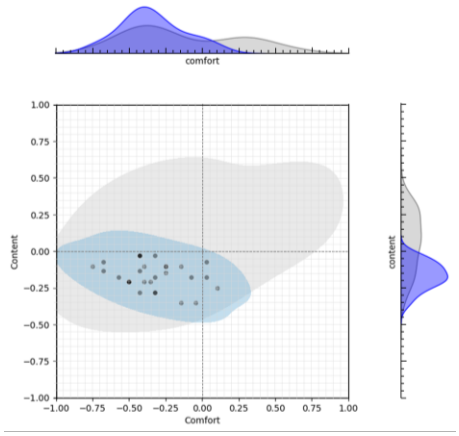
Figure 2. The visualization of residential sounds on the comfort–full of content axes

Table 2. Number of residential sound sources cluster based on comfortable-full of content axes

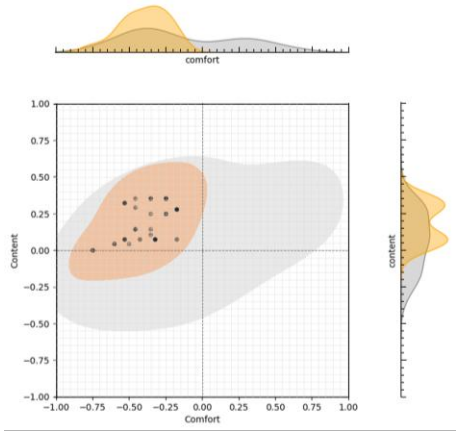
Sound source	Cluster		
	1	2	3
Noise	0	7	4
Natural	20	6	3
Noise + Natural	7	12	12
Noise + Natural + Natural	0	0	12
Natural + Natural	4	0	0



(a) Cluster 1



(b) Cluster2



(c) Cluster 3

Figure 3. Distribution of the comfortable-full of content axes by cluster (gray color: all data)

3.3 Psychoacoustic parameter analysis by cluster

In this study, psychoacoustic parameters were analyzed across clusters identified through soundscape evaluations of residential sounds, using both perceptual attributes and the values derived from axis transformations. Table 3 presents the results of the psychoacoustic analysis for each cluster. The comparison of parameter values was based on the median value within each cluster. The analysis revealed that sound samples in cluster 3 exhibited the highest values for loudness and fluctuation strength. In contrast, sound samples in cluster 1 showed the highest values for sharpness and roughness. Meanwhile, cluster 2 contained sound samples with the lowest sharpness values among the three clusters.

Table 3. Psychoacoustics parameter results by cluster

Psychoacoustic parameter	Cluster		
	1	2	3
Loudness [sone]	7.04	9.16	10.5
Sharpness [acum]	2.56	1.385	1.68
Fluctuation strength [vacil]	0.0157	0.0205	0.033
Roughness [asper]	0.0507	0.025	0.04

4. SUMMARY

This study investigated the soundscape of residential environments by collecting perceptual evaluations of sounds commonly heard in multi-family housing. Clustering was performed using eight descriptors and two derived perceptual axes (comfortable and full of content). As a result, three distinct clusters were identified. Each cluster exhibited differences in both subjective evaluations and psychoacoustic parameters. Sounds in cluster 1, which included a higher proportion of natural sounds compared to the other clusters, were rated more highly on the attributes full of content, engaging, comfortable, and private/controlled. These sounds also showed higher values for sharpness and roughness. In contrast, cluster 3, which primarily consisted of noise combined with natural sounds, exhibited the highest value for loudness and fluctuation strength. This study serves as a foundational effort for monitoring residential soundscapes based on perceptual data. The goal of soundscape monitoring in multi-family housing is to transform residents' negative perception of environmental sounds into a more positive and acceptable interpretation, thus contributing to the creation of a calm and pleasant acoustic indoor environment. In most cases, sounds perceived as noise in multi-family housing originate from other households rather than one's own. This lack of control can lead to negative perceptions of the acoustic environment. To address this, it is necessary to guide residential sounds toward the perceptual space associated with cluster 1, where sounds are positioned closer to the comfortable and full of content axes. The study demonstrated that adding natural sounds (e.g., birdsongs, water) to noise-based samples in clusters 2 and 3 shifted their perceptual positioning toward more favorable soundscape axes. Therefore, it is important to explore ways to transform the soundscape and psychoacoustic characteristics of clusters 2 and 3 toward those of cluster 1 to improve residents' perception of residential sounds. Through such design strategies, it is anticipated that a more tranquil and positively perceived acoustic environment can be achieved in multi-family housing. This study did not cover all types of sounds, such as those generated directly by residents themselves. In addition, a more comprehensive understanding of residential soundscapes should include a broader range of sounds experienced by occupants. Future work will involve expanding the soundscape survey using a mobile application, which will enable continuous and user-driven data collection on residential sounds and their perceptual impacts.

5. ACKNOWLEDGMENTS

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