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Indoor Soundscaping of Public Enclosed Space

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Indoor soundscape methodology and analysis techniques have been used for this study on two case public buildings in Sheffield. Sound recordings were carried out in different pre-defined function areas and certain objective and psychoacoustic parameters such as equivalent sound pressure levels (Leq), loudness (N), roughness (R) and sharpness (S) were considered for analyses of architectural and functional properties in each sample area. Analyses on indoor soundscapes were accomplished through post-signal analysis methods in both cases. In order to understand the indoor soundscaping approach, various architectural elements were analysed by architectural theory. The results imply that similarities in architectural and functional properties lead to similar sound environments regarding objective and psychoacoustic parameters. It was found that loudness is better related to indoor soundscape studies than objective parameters such as sound pressure levels and A-weighting. In addition, loudness values were found to have a positive correlation with roughness results in the studied spaces.

Keywords: Indoor soundscaping, public space, psychoacoustics

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1. INTRODUCTION

Architectural and functional properties of indoor spaces should be well defined and analysed for indoor soundscape studies. In a previous study, architectural theory and classification techniques were introduced and stated before studying indoor soundscaping for case areas [1]. Soundscapes in built entities are greatly affected by sound properties of the enclosure and the functions that are held in the spaces. As each type of function has its unique sound key, functions related with human activity defines the sound environment in public spaces. In this study, certain objective acoustic and psychoacoustic parameters were considered in order to understand how architecture and function variances could be effectual on the soundscapes. Equivalent sound pressure level (Leq), roughness (R), sharpness (S), and loudness (N) parameters were evaluated, revealing certain traits with varied architectural and functional characteristics. Using such parameters for soundscape studies began recently from the urge to link subjective evaluation on auditory perception, acoustic comfort and noise annoyance with the analysis of psychoacoustic and acoustic parameters [2, 3].

2. METHODOLOGY

2.1 Sound Recordings

Sound recordings were done for detailed analysis of the sound environment. The KU100 Neumann, artificial head measurement system was used for the recordings. The specific areas with different functions and their soundscapes showed great variances when compared to each other. In order to reveal such differences, sound recordings were carried out in five chosen sample areas of two case sites, which are The University of Sheffield Student Union and Sheffield Winter Gardens. The sound recordings and these audio samples were used to gather detailed information on sound levels and spectrum of the soundscapes. Post-processing of the raw data was carried out using HEAD

Acoustics ArtemiS (advanced research technology for measurement and investigation of sound and vibration) analysis software.

2.2 Architecture and Function

The architectural dissolution and the analysis of the particular functions within the space are presented in Table 1. The analysis and dissolution of the enclosures should be set forth considering present architectural theories and techniques [4] of the two case sites, namely The University of Sheffield Student Union and Sheffield Winter Gardens. These two enclosed public spaces were chosen as main cases and five different sample areas within each case are described in Table 1, regarding their combination of functions and architectural characteristics.

Both case sites are public spaces. This is a classification given by their pre-defined function within the built environment. The main functions that are carried out by the users of the case spaces are; walking through, eating, shopping, talking to others, studying, and leisure. These two cases vary completely regarding their formal organisations, spatial relationships and circulation patterns. The main aim for such a motif was to reveal sound environments of these different indoor public spaces that can act as examples for further indoor soundscape studies.

Table 1. Two architectural cases, their layout plans and architectural analysis criteria

<table>
<tr><td>Architectural Cases</td><td colspan="2">1. The University of Sheffield Student Union
</td><td colspan="2">2. Sheffield Winter Gardens
</td></tr>
<tr><td>Pre-defined Functions</td><td colspan="2">Public Space: Student union building
Walking (pass through), Eating, SHopping, Talking, STudying, Leisure</td><td colspan="2">Public Space: Greenhouse
Walking (pass through), Eating, SHopping, Talking, Leisure</td></tr>
<tr><td rowspan="5">Sample areas + Sub-functions</td><td>1. Entrance</td><td>W, T</td><td>1. Entrance</td><td>W, T</td></tr>
<tr><td>2. Food-court</td><td>E, T, L</td><td>2. Green zones</td><td>W, E, T, L</td></tr>
<tr><td>3. Café area</td><td>E, T, L</td><td>3. Café area</td><td>W, E, T, L</td></tr>
<tr><td>4. Union shop</td><td>SH, T</td><td>4. Museum shop</td><td>W, SH, T</td></tr>
<tr><td>5. Computer study space</td><td>ST, T</td><td>5. Central foyer</td><td>W, T</td></tr>
<tr><td>Formal organisation
- Order:
- Layout:</td><td colspan="2">Clustered organisation
-Order: Orientation of parts
-Layout: Complex</td><td colspan="2">Linear organisation
-Order: Symmetry
-Layout: Basic</td></tr>
<tr><td>Spatial Relationships:
- Elements defining single volume
- Unit Associations
- Whole-body complementation</td><td colspan="2">-Several varied planes and types of opening
-Relation: Spaces linked by a common space (foyer) + interlocking and adjacent spaces
-Reference: Juxtaposition; overlaid but conceptually separate spaces
-Containment: Cell + Court + Domain</td><td colspan="2">-Single volume (space), no additional planes – planes contouring one main domain.
-Reference: Interpenetration; spaces being resolved into harmony</td></tr>
<tr><td>Circulation Patterns:
- Act:
- Configuration:
- Form:
- Relation with Spaces:</td><td colspan="2">
- Through + enter
- Network + composite
- Open on several planes
- All 3 relations with spaces</td><td colspan="2">
- Through + Roam
- Linear
- Open
- Through space</td></tr>
</table>

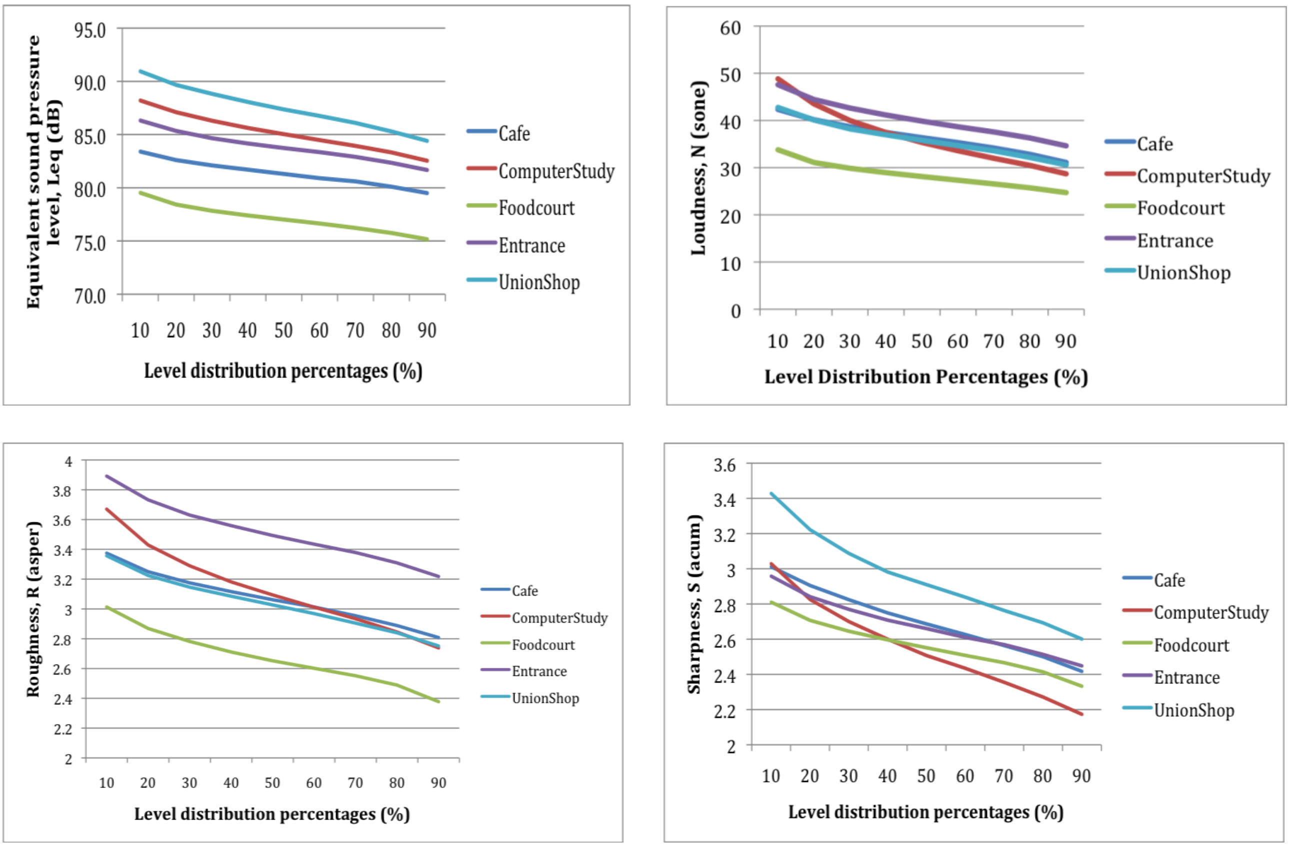

Figure 1. Level distribution percentage of Leq, N, R, S for Case 1: Student Union Building.

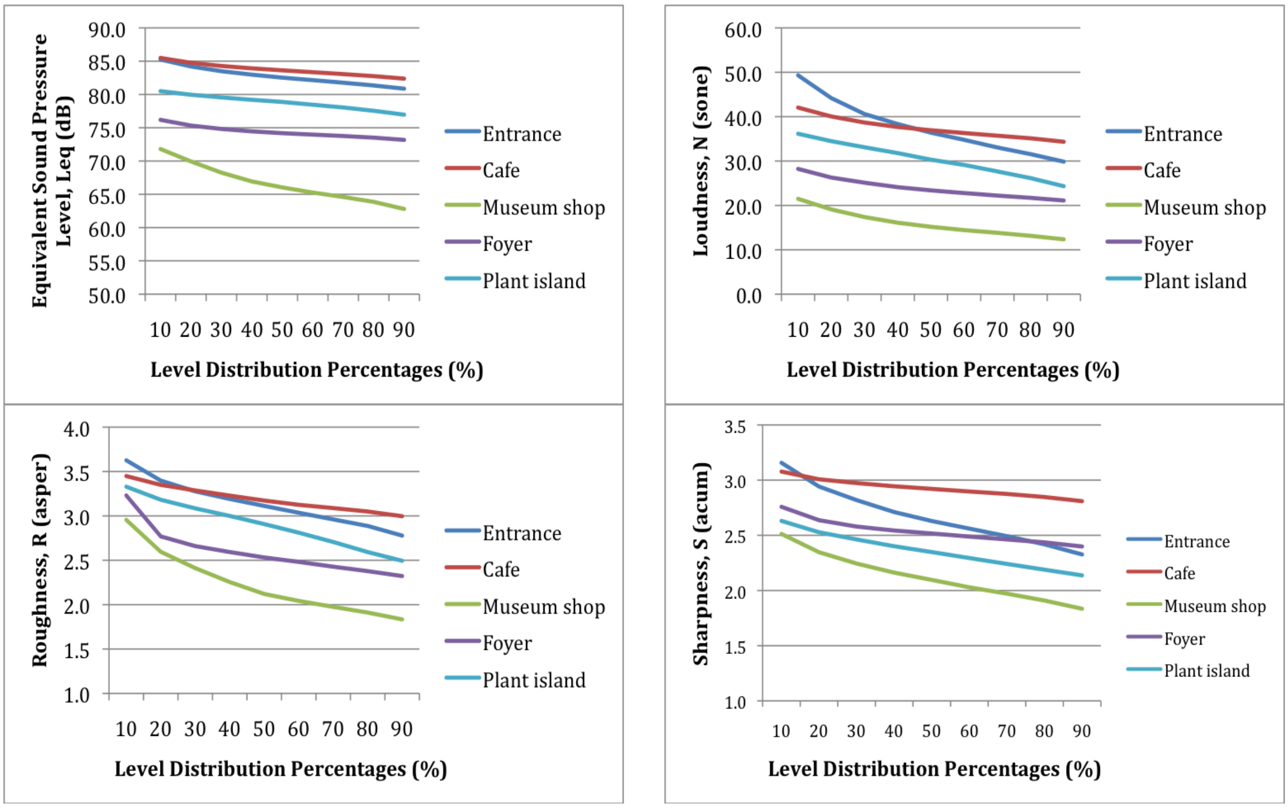

Figure 2. Level distribution percentage of Leq, N, R, S for Case 2: Winter Gardens.

3. SOUNDSCAPE ANALYSIS

3.1 Sound Environment in Each Case

The soundscape is described based on four main parameters, including equivalent sound pressure level (Leq), loudness (N), roughness (R) and sharpness (S). They were considered for each sample area in both cases [5, 6]. Each parameter's level distribution percentages in time domain are presented in Figure 1 for different space types. From these results, variances of the sound environment depending on architectural characteristics and functions of the sample areas can be discussed.

In Figure 1, 10% implies the high value achieved, 50% implies the mean value achieved throughout the sample time period, and 90% implies the overall background value that is dominantly present throughout the sample time period.

When the chosen parameters of Case 1 are considered (see Figure 1), the equivalent sound pressure level and sharpness values of the union shop are found to be higher in comparison to other sample spaces. For loudness and roughness values, the union entrance shows higher values. This variance is mainly due to the functions of the space as well as the noise composition. When all four parameters are considered, the food-court has the lowest values. The computer study area follows the food-court for the sharpness value. Interestingly, loudness and roughness values of all five different sample areas have similar patterns.

In order to carry out further analyses, functional and architectural characteristics should be discussed in detail according to the framework as mentioned previously. The entrance shows different properties regarding both function and architecture when compared to other four sample areas. Firstly, it is the only space that holds walking as a main function. The entrance space is integrated with the main atrium, which acts as a common element for other adjacent spaces. These affect the occurrence of higher values regarding loudness and sharpness.

The union shop, located adjacent to the main atrium and the entrance, has different functions from other sample areas. Therefore, it has a different soundscape. Architecturally, it is enclosed within itself yet gives circulation access from three points, all connected with the main circulation of the building. The computer study space, which shows low values for all four parameters, holds the function of study, again different from the other spaces. In addition, it is located adjacent to an inner atrium on the second floor, which acts as a buffer zone and attenuation chamber for overall noise from the main atrium and function areas. The areas that hold eating as the main function tend to have similar values located at central parts of the plots.

The values of the considered parameters for Case 2 are given in Figure 2. For all parameters, the café area has the highest values and the museum shop has the lowest. Similar to the Case 1 graphs, the loudness and roughness plots of the five sample areas are very similar. The entrance follows the cafe with high values even exceeding on some parts of low percentages, which means the highest values are achieved in the entrance space, exceeding values of the café area. Yet the overall background noise levels in the café area are higher than that of the entrance. The reason for this is perhaps that the café area is located near the opposite entrance space of the Winter Gardens, so it holds the functions of the entrance as well as the cafe. One crucial characteristic regarding the functions of Case 2 is that all sample areas hold the function of walking through, which affects the overall sound environment and values of all four parameters.

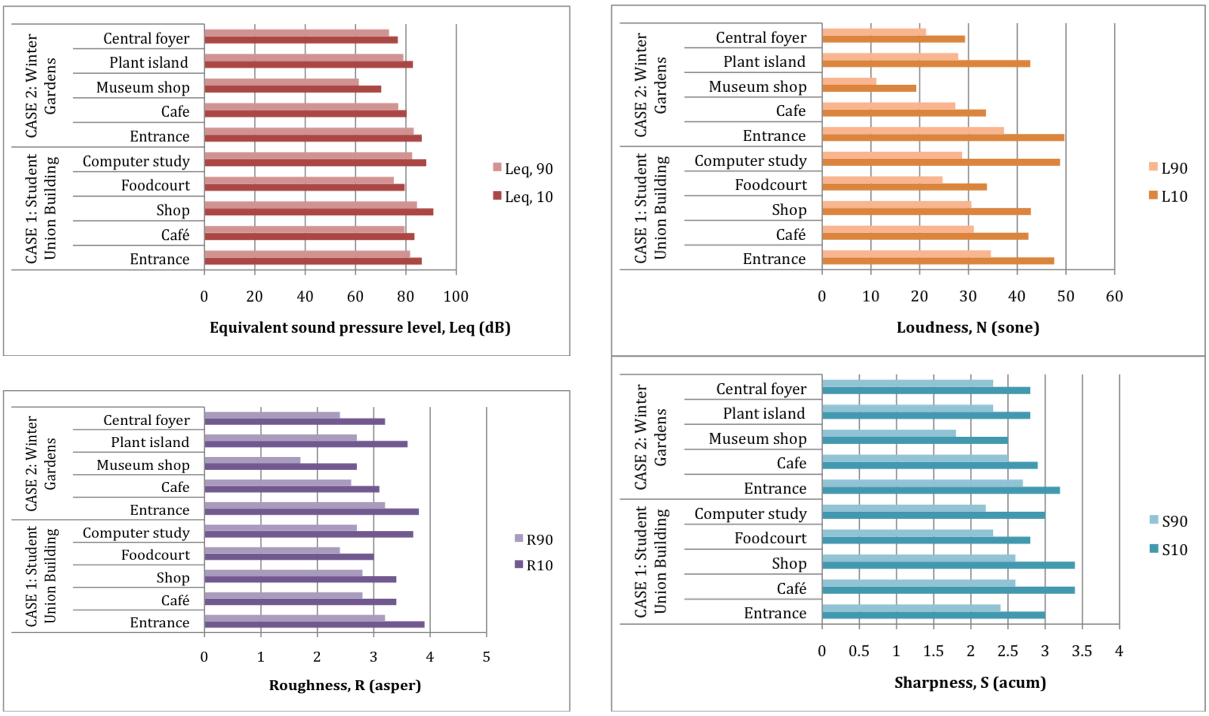

Figure 3. Comparison of peak (10%) and background (90%) values of Leq, N, R, S for both cases.

3.2 Relation between Case Spaces

In order to present the differences between the sample areas in the two cases, distribution percentages of 10 and 90 were considered. When the values of two different cases and sample areas were compared to each other regarding the peak values (10%) and the overall background values (90%), results showed interesting differences. First of all, the difference between the 10% and 90% values of Leq were not great when compared to the other three parameters. This means that the overall sound environment is relatively steady regarding the un-weighted dB levels. On the other hand, N, which is a psychoacoustic measure for human perception of noise, has a great difference between its peak and background values. This suggests that the human hearing of the soundscapes in the sample areas could detect peaks and falls regarding the loudness of noise composition. In addition, R and S showed similar variances between peak and background values like N.

The overall Leq values of the sample areas with similar functions such as the entrance and the café are similar, whereas the union shop (highest dB) and the museum shop (lowest dB) are contrasting. The architectural characteristics and circulation properties play an important role for this contrast.

The background (90%) loudness values of Case 1 deviate less (STD: 3.6 sone) than when compared to the levels of Case 2 (STD: 9.6 sone). This may be due to a significant difference between the two cases' architectural aspects. Case 1 has a clustered organisation with spaces interlocking or adjacent to each other, yet divided with several planes differentiating spaces with different functions and circulation patterns. On the other hand, Case 2 is a linear, single and open volume that holds each function area without separation and the whole volume acts as the main circulation path. However, this interpenetration of Case 2 does not lead to similar values of the chosen acoustic parameters. Instead, the act of walking creates a dynamic environment that leads to higher values in Leq, loudness, roughness, and sharpness, which affects the sound environment in all the other function spaces. When the deviation of R and S is considered for the two cases, they tend to be insignificant. Although the overall R and S can give an effective idea about the characteristics of the space, they should be studied in a more detailed manner considering the R and S values of individual sounds captured within the whole noise composition.

The Pearson's correlation results for the four parameters are very interesting. They indicate a positive correlation between loudness (N50) and equivalent sound pressure levels (Leq50) ($p<0.05$). In addition, a high positive correlation between loudness (N50) and roughness (R50) ($p<0.01$) is indicated, where N50, R50, and Leq50 implies the mean value achieved throughout the sample time period for loudness (N), roughness (R), equivalent sound pressure level (Leq).

4. CONCLUSIONS

Architectural and functional analyses of each case space and sample area, as well as sound environments in comparison with each other, have been presented. It has been revealed that function and architectural characteristics of the spaces have a great impact on the overall sound environment and the noise compositions. Spaces with particular functions show different soundscape characteristics. Architectural elements like atriums and circulation patterns and their configuration are found to be effective in providing variations of sound environments. Variations on loudness values are closely related to the architectural form and integration of the circulation paths. Future work should include more detailed study of the roughness and sharpness characteristics of single sounds and soundscapes. Listening tests and questionnaires including architectural factors are especially important for researchers that concentrate on psychoacoustic parameters, indoor soundscaping, function, and architectural analysis.

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