Acoustical categorization of urban public places by clustering method

M. Rychtáriková[1,2] and G. Vermeir[1]

[1] K.U.Leuven, Afdeling Bouwfysica en Laboratorium Akoestiek en Thermische Fysica, Celestijnenlaan 200D, 3001 Leuven, Belgium, Emails: Monika.Rychtarikova@bwk.kuleuven.be; Gerrit.Vermeir@bwk.kuleuven.be
[2] STU Bratislava, Katedra KPS, Radlinského 11, Bratislava, 813 68, Slovakia

Introduction

The evaluation of an acoustical situation in the city can be in general be done in two ways. Quantitative assessment, also called "object-related description", uses known methods of statistical noise analysis and is rather straight-forward. Assessing the quality of a soundscape is more difficult, since it does not always lead to the answer "good" or "bad". It rather deals with question "how different" are different soundscapes in their quality, and how they can be classified into categories. An acoustical situation in a city is determined by many different factors and the perception of the urban soundscape by different people also reflects the difference between their subjective judgment criteria. Some places in the city may sound similar and some very different. Some places might be acoustically judged as pleasant and some as annoying. However, the same objective acoustical situation is sometimes judged differently if it occurs in two different places. This observation makes us ask a question: On what does the human perception and evaluation of sound depend?

We presume, that the assessment of a public place by people depends not only on the level of pleasantness/annoyance of the sound itself, but it also depends on the subjective factors (such as relation of a person to the given place, his/her mood etc.), on the objective non-acoustical factors (function of the place, etc) and on the human expectation concerning not only the sound levels but also the temporal and spectral character of the sound, including its context.

In the evaluation of urban public places, we aim at eventually improving their quality while maintaining their diversity. The city might change during the years, but its "heart" must stay the same. This is also one of the reasons, why we prefer to avoid too much acoustical prototyping (e.g. copying features of urban places which are overall appreciated in one city to another city) with the danger of too simplistic or dogmatic proposals. Instead, we aim to development of a set of acoustical parameters for clustering different urban soundscapes into categories, which we try to relate with their non-acoustical descriptions. In this way the defined acoustic typology will be fitted within the framework of a broad urban typology.

The described complexity of urban soundscapes makes the acoustical comfort analysis a cumbersome task, unless we divide the whole problem into two steps, which can be performed independently and subsequently, followed by their final synergy. In our working hypothesis, the first step can be understood as an evaluation of the sites by "experts", while the second steps concerns the assessment of the same places by their "users". This division allows us to reduce the subjectivity of the evaluation during the initial part of the research, working purely with objective sound descriptors and objective non-acoustical factors.

Choice of the acoustical descriptors

Standardized descriptors of the acoustical quality in urban public places does not exist so far and the different quality numbers are under development in the framework of several research projects.[1],[4]. Our approach presented in this paper is based on signal processing of characteristic binaural recordings in situ with a length of 10-15 minutes, where the sound data are collected during the so-called "soundwalk (SW)" [2], using the in-ear microphones. Acoustical parameters calculated from each recording are Sound pressure level L_A [dB] and chosen psychoacoustical parameters: Loudness N [son], Sharpness S [acum], Roughness R [cAsper], and Fluctuation strength F [cVacil]. Estimation of the values is done in the time domain followed by the calculation of statistical values, expressed as a value of the parameter (L_x, N_x, R_x, S_x or F_x) exceeded in x % of time.

Level

Frequency weighting in Sound level calculation was chosen as "A-weighted". The time constants for sound level averaging was selected as „fast", i.e. with the time constant equal to 125 ms.

Loudness

The loudness analysis in this paper was computed as loudness versus time (DIN 45631 and ISO 532B.) The loudness calculation according to Zwicker was applied, that uses the calculation of 20 approximated critical bands, for each time interval the sound levels. Data are stored with a temporal resolution of 2 ms. [6]

Roughness and Fluctuation strength

The temporal variation of sound causes two kinds of impressions: the fluctuation strength, which expresses slow variations of the loudness (< 20 Hz), and the roughness. The perceived sensation of fluctuations reaches a maximum at 4 Hz and then decreases for higher frequencies. Above 10 Hz, a new sensation appears. The loudness is perceived to be constant and a feeling of roughness appears, which reaches a maximum for a frequency of 70 Hz. The unit for fluctuation strength can be understood as follows: a 1 kHz signal modulated in amplitude by a signal of frequency $f_{modulated} = 4$ Hz with a modulation depth of 100% and a level of 60 dB yields a fluctuation strength of $F = 1$ Vacil. [7]

To calculate roughness, more methods are known. In our research the method developed by Zwiker and Aurès, is used which calculates a specific roughness by critical band, the global roughness being the sum of all specific roughnesses. The calculation of roughness is based on the determination of the relative fluctuations of the envelop of excitations levels of the 24 critical bands. A 1 kHz signal modulated by a signal of a frequency $f_{\text{modulated}}$ = 70 Hz with a modulation depth of 100% and a level of 60 dB yields a roughness of R = 1 Asper. [7]

The Time Interval that defines the interval in which the psychoacoustic parameters are computed and written to a file was for all calculation of psychoacoustical parameters chosen as 2 ms (the loudness computation time interval). The roughness sequence length was chosen to be 500 ms and the fluctuation strength sequence length 1000 ms. These values define the length of the (loudness) data window which is used to compute specific roughness or fluctuation strength) and overall roughness (or fluctuation strength) for a point in time. The data windows overlap by a certain amount because the sequence length is always longer than the time interval.

Sharpness

Sharpness expresses the centre of gravity of the spectral envelop. However, the detailed spectral structure, as well as the level difference, have very little influence to the calculation.

Binaural parameters

The importance of the binaural aspects of hearing on perception of the acoustical comfort in the urban environment has been shown in several studies [3], but almost never introduced as an acoustical parameter which can be expressed by a number. For our research, the parameter called "urban interaural level difference" (*uILD*) was developed. This parameter is based on the comparison of the acoustical situation in the left ear and right ear with a respect to the level difference. Proposed $uILD_1$ and $uILD_2$ are defined as:

$$uILD_1 = \frac{\sum_{i=1}^{n}\left(L_{Li} - L_{Ri}\right)}{n} \qquad (1)$$

$$uILD_2 = \sum_{i=1}^{n}\sqrt{\frac{\left(L_{Li} - L_{Ri}\right)^2}{n}} \qquad (2)$$

where L_{Li} is a value of sound pressure level in the left channel in the time i, L_{Pi} is a value of the sound pressure level in the right channel in the time i and n is the number of the values.

Clustering of the sound samples

Research presented in this paper deals with categorization of streets by using the multi-parameter analysis, namely the hierarchical agglomerative clustering by using the SPSS® software. Hierarchical clustering analysis is based on calculation of the Euclides distances, which is then followed by agglomerative or divisive methods. In our case, agglomerative methods was used. This method is based on treating each object as a separate cluster, and then grouping them into bigger and bigger clusters.

Our previous research [1] has shown the behavior of the statistical values of five chosen parameters (*L, N, R, S* or *F*) in the example of 20 soundwalks and some examples of calculated urban interaural level differences *uILD* defined by (1) and (2). However the clustering by using only 5 parameters (e.g. L_{95}, N_5, F_5, R_5, and S_{50}) has been shown as not successful enough. Our recent research uses 27 parameters for the clustering experiment: L_5, L_{10}, L_{50}, L_{90}, L_{95}, N_5, N_{10}, N_{50}, N_{90}, $N_{95,}$ F_5, F_{10}, F_{50}, F_{90}, F_{95}, R_5, R_{10}, R_{50}, R_{90}, $R_{95,}$ S_5, S_{10}, S_{50}, S_{90}, $S_{95,}$ $uILD_1$ and $uILD_2$.

Results and Analysis

The 91 "soundwalks", recorded in Leuven, Namur and Brussels, were analyzed with a respect to chosen 27 parameters.

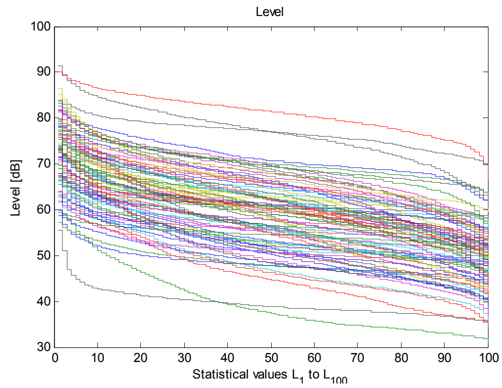

Figure 1: Sound pressure level data of 91 analyzed sound samples

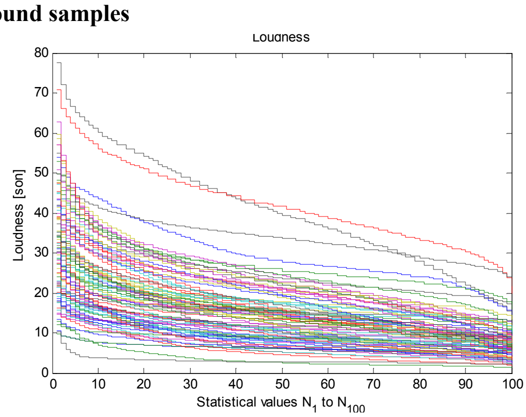

Figure 2: Loudness data of 91 analyzed sound samples

Figure 1 shows that the spread of the data used for the analysis ranges between the silent samples, with L_{50} that ranges between 40 - 85 dB. Curves have also different slopes what expresses differences in the temporal structure and so also differences in "peaks-to-basic sound level" that can be express as L_5, - L_{95}.

Roughness and Fluctuation strength data show also relatively broad spread in values and slopes mainly in peak values. Spread of Sharpness values are is keeping normal distribution, except of few samples.

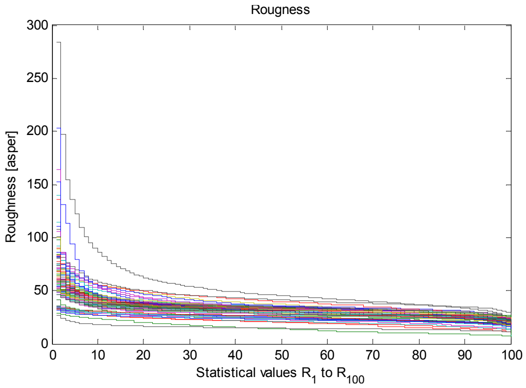

Figure 3: Roughness data for 91 sound samples

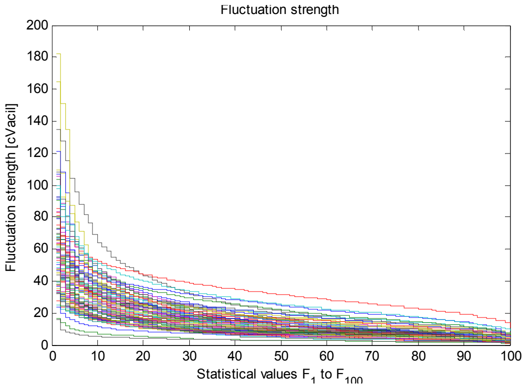

Figure 4: Fluctuation strength data of 91 sound samples

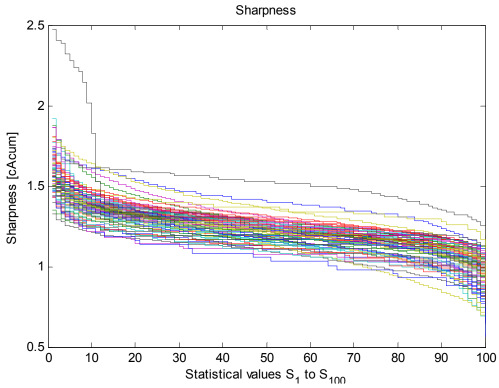

Figure 5: Sharpness data of 91 sound samples

After the linear normalization of the values (0-100), these soundwalks were divided into 20 clusters. Figures 6 - 10 show the average values per cluster and average overall values. Observed common acoustical and non-acoustical features of urban places within each category can be described as follows:

Cluster 1 consists of recordings made in the city-parks in the spring and summer time during the day. Cluster 2 includes all recordings made at the balcony (on the 5th floor) in the suburban area of Leuven city during the day- and evening-hours. Cluster 1 and 2 have relatively similar acoustical properties and values of all parameters are smaller than the average values. L_{95} = 48dB in cluster 1 and 43dB in cluster 2 and L_5 is ca 60dB in both clusters. Airplanes, buses, cars and human voices can be heart, but they sound distant. In the cluster 1, one out of seven and in the cluster 2, one out of fourteen samples was following the non-acoustical features clustered unsuccessfully.

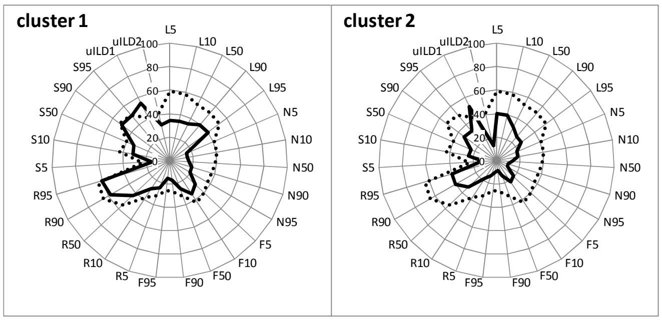

Figure 6: Example of clusters 1 and 2. Black lines express the average value per parameter within each cluster and dotted line shows the average values from all soundwalk data

Cluster 3 and 13 contain mainly the main streets in the city center of Leuven during the night hours and roads in the suburb of the city during the noon and evening (excluding the peak hours of the traffic) with values of L_{95} = ± 50dB, and L_5 > 70dB. Recordings made in the Londenplein in Brussel appear in this cluster as well. It is due to the small size of this square which is also accessible for vehicles. Cluster 3 and 13 contain together 30 elements, from which 6 are wrong.

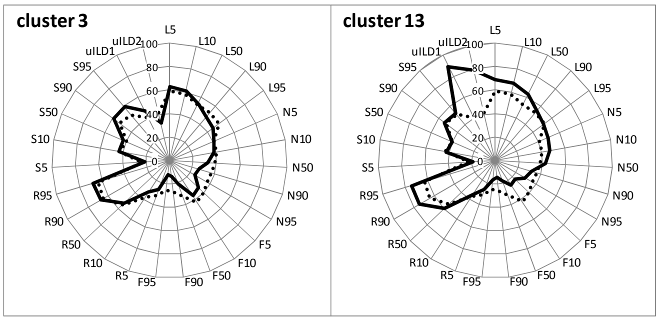

Figure 7: Cluster 3 and 13

Streets in the residential suburban areas with family houses and gardens in front of the house were grouped together with roads for bicycles in the park in the cluster 4. Number of samples in this group is six and no other, e.g. wrongly clusters samples appear here.

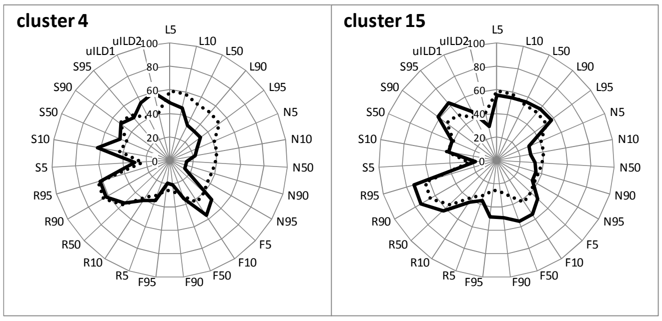

Figure 8: Cluster 4 and 15 Black line - average value per parameter within each cluster

Acoustical recordings made in the squares with restaurants and pubs in the city centre of Leuven during the nice sunny days and recordings in the wide streets full of people after the street theatre festival were grouped together in the cluster 15. (L_{95} = 55dB and L_5 = 68dB) Prevailing sounds in this cluster are human voices and human steps etc. confirmed by values of fluctuation strength.

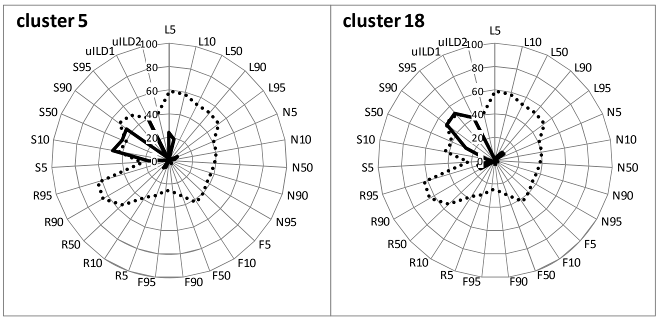

Figure 9: Cluster 5 and 18 Black line - average value per parameter within each cluster

Cluster 5 and 18 consist of recordings made during the night hours in the suburban residential area along one of the main street in Heverlee, where L_{95} was 30dB and L_5 = 54dB (measured around the midnight – cluster 5) and L_5 = 44dB (around 3 a.m. – cluster 18).

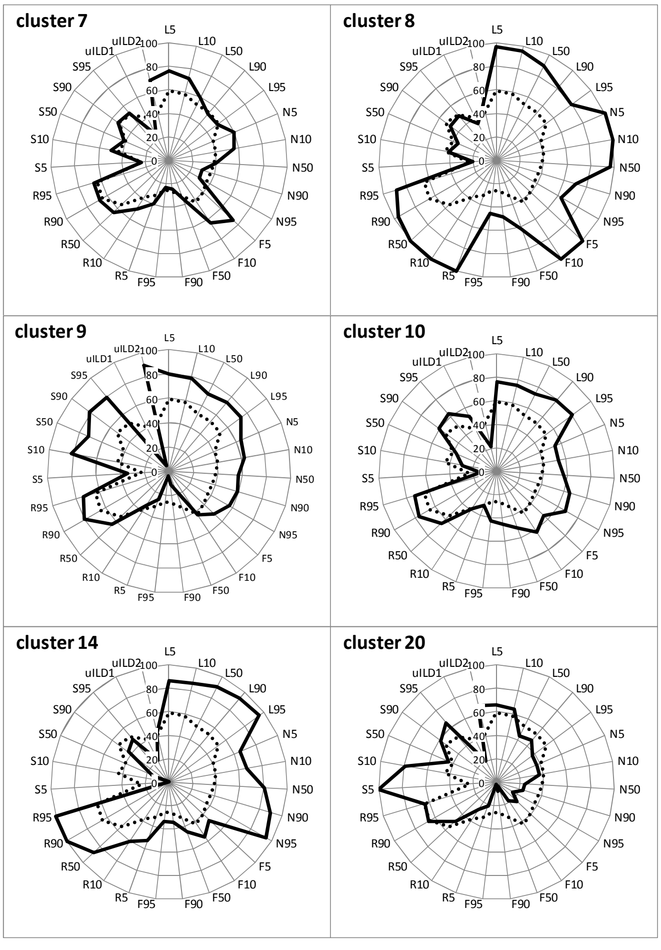

Figure 10: Clusters 7, 8, 8, 10, 14 and 20

To test the reliability of the chosen descriptors, few special sound samples were included in the set of data and some of them were successfully distinguished in individual clusters: Cluster 7 and Cluster 8 with lots of roughness and fluctuation strength due to the loud human voices and helicopter sound, during the cycling competition in Liege, Cluster 9 – recording of a little waterfall, Cluster 10 – celebration of the football match in the main square of Liege, measured while standing in the crowd of football fans, Cluster 14 – a football match in the Old Heverlee, recorded in the nearby pub, Cluster 20 - a sound signal at the railway gates and trains passing by. Interestingly, place d'Armes in Namur was sorted in an individual cluster as well, probably due to the dominant airplane noise and fountain sound in the square.

Conclusions

Majority of the sound recordings were sorted in logical way, however several samples were clustered wrongly. The most successfully were distinguished squares full of people (cluster 15), parks with distant traffic (cluster 1), recordings in the balcony during the day in residential area (cluster 2, 5 and 18), and streets in the residential areas with family houses (cluster 4). Future research in the topic is clearly necessary and should be focused on better differentiation of streets in the centre and roads in the suburban parts, which were not satisfactory, distinguished from each other. Analysis has to be performed on larger set of data, necessary for reliable statistical evaluation.

Acknowledgements

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