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SOUNDSCAPE MAPPING IN THE URBAN CONTEXT: A CASE STUDY IN SHEFFIELD

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Abstract

According to the recently published ISO 12913-1, soundscape differs from the acoustic environment, since the first refers to a perceptual construct, whilst the latter to a physical phenomenon. Noise exposure has been a main concern over the last decades, but from the planning viewpoint limited attention has been given to the perception of the acoustic environment and its representation at a city scale. This paper aims to establish a method for representing soundscape through source-related maps and secondly to correlate the sound sources with the urban context in terms of specific activities. Using a grid-based sampling methodology within the broader area of Sheffield city centre, soundscape data were collected in 90 spots, during morning and evening hours. Afterwards, soundscape variability for technological, anthropic and natural sounds was represented by maps using a Kriging interpolation technique in GIS. Preliminary results show how sound sources' spatial variation in urban soundscapes is closely related to urban contexts and activities, therefore urban activities can be relevant for designing the soundscape of the urban realm. The paper ultimately points out how soundscape mapping can be used as a tool for planning purposes and urges to rethink the design process of the built environment also from the sonic viewpoint.

1. Introduction

Soundscape has recently been defined in an international standard as an "acoustic environment as perceived or experienced and/or understood by a person or people, in context" (ISO, 2014). Such a definition is somewhat comparable to the European Landscape Convention (Council of Europe, 2000) that defines 'landscape' in similar terms (Brown, 2012). Hence, there is a general agreement that soundscape – as well as landscape – concerns human perception of the environment.

The soundscape philosophy implied a paradigm shift from a 'reactive' approach to noise to a 'proactive' attitude towards sound, considering this element as a resource rather than a waste. Indeed, community noise has been a main concern over the last decades, but from the planning and design perspective, limited attention has been given to the perception of the acoustic environment in its positive aspects and its representation at a city scale.

There is a current need to position soundscape management into planning policies (Kang 2007; Andringa, et al., 2013). For this purpose, new operative tools are required to be used by planners and policy-makers. Some researchers investigated the possibility to use spatial analysis to study the sound environment of urban contexts (Ge and Hokao, 2005) and possible ways to record and represent the soundscape (Ge et al. 2009). Furthermore, a number of studies investigated the relationship between soundscape and landscape as well as land use metrics and urban morphology (Hao and Kang 2013; Liu et al. 2013a; Liu et al. 2014a; Liu et al. 2014b; Hao et al. 2015).

Apart from that, numerous studies have started visualising soundscape using GIS tools to map sound sources in urban areas or parks (Irvine et al. 2009; Liu et al. 2013b; Hong and Jeon, 2014). The mapping process is usually performed using various interpolation techniques (Li and Heap, 2008). The most widely known such as Kriging and Inverse Distance Weighting (IDW), have previously been tested for noise assessment purposes (Can et al. 2014). Nevertheless, there is still no clear consensus about what soundscape-related information is relevant and should be collected for planning and design purposes and how soundscape and urban contexts relate to each other.

This paper aims to propose a method for representing soundscape through source-related maps and secondly to correlate the sound sources with the urban context in terms of specific activities. For these purposes, soundscape data and audio recordings were collected in 90 spots in a typical European city, Sheffield (UK), according to a grid-based sampling methodology. Afterwards, a laboratory experiment was carried out with 20 participants, in order to investigate possible relationships between the individual assessments of the acoustic environments and a set of urban activities.

2. Soundscape mapping

2.1 Study area and data collection

A study area was selected in Sheffield city centre, since it combines many different land use characteristics and can also be considered a typical example of a post-industrial average-size European city. Furthermore the area is characterised by a dense and varied network of local and national level of streets as well as transport infrastructures (e.g. railway, tram, buses). The total area extends to 3.6 km^2. A grid of 200 × 200m was implemented, segregating the region in 90 tiles. The measurement points were defined at the centroids of all tiles, as shown in Figure 1. In case a centroid resulted to be non-accessible due to legal or physical restrictions (e.g. buildings), the closest publicly accessible point was selected.

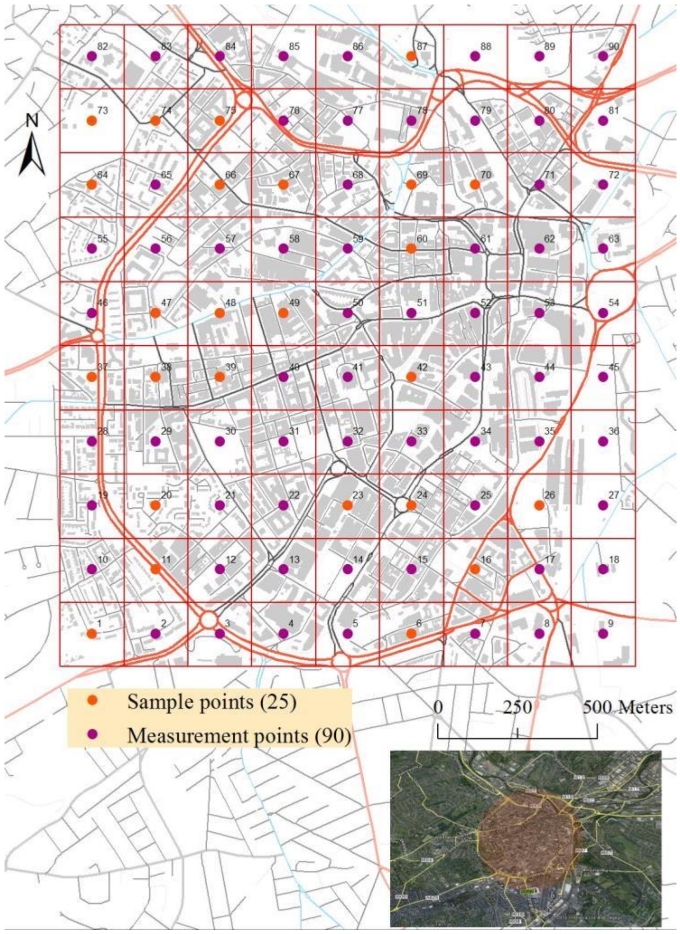

Figure 1. Study area with measurement and sampling points in Sheffield

A researcher collected data at each spot twice over 4 working weeks: during mornings (09:00–12:00) and afternoons (14:00–17:00). For each measurement session the researcher recorded the equivalent sound level (L_{Aeq}-2min) with a sound level meter (MicW i436 - class 2) and carried out 2-minute audio recordings of the sound environment by means of a binaural kit connected to a portable recording device (Edirol R-44). Furthermore, the researcher reported "what sound sources it was possible to hear" by ticking off on a form with possible sound sources selected during a pilot on site campaign, as shown in Table 1.

Table 1. List of sound sources used during the soundscape data collection

Category	Sound sources	
Technological	Cars	Alarms
	Buses	Grass Mowing
	Trucks	Industries - Fans
	Trains	Industries - Other Machines
	Airplanes	Construction
	Bicycles	Domestic
	Fireworks	Recreation
		Miscellaneous
Natural	Wind	Rain
	Trees Rustling	Birds
	Grass Rustling	Dogs
	Water Sounds	Insects
	Thunder	Frogs
		Miscellaneous
Anthropic	Human Speech	Roller-skating
	Human Singing	Music - Live
	Human Laughter	Music - Recorded
	Crowd of People	Music - Shops
	Footsteps	Church Bells
		Miscellaneous

2.2 Mapping methods

After the data collection was finalised, all the information related to the audible sound sources was transferred in the ArcGIS software (v.10.1) for further processing. The audible sources' occurrences were aggregated per type and these values were averaged over the morning and afternoon conditions. Then a prediction surface was created using the kriging interpolation method for the technological, natural and anthropic sound sources accordingly. The surfaces were created based on the Ordinary Kriging method and the spherical semivariogram model, considering all the 90 points of the study area.

2.3 Characteristics of sound sources

According to the perceptual data, 3 soundscape maps were created for the study area. Figures 2–4 show the spatial variability of audible technological, natural and anthropic sound sources respectively.

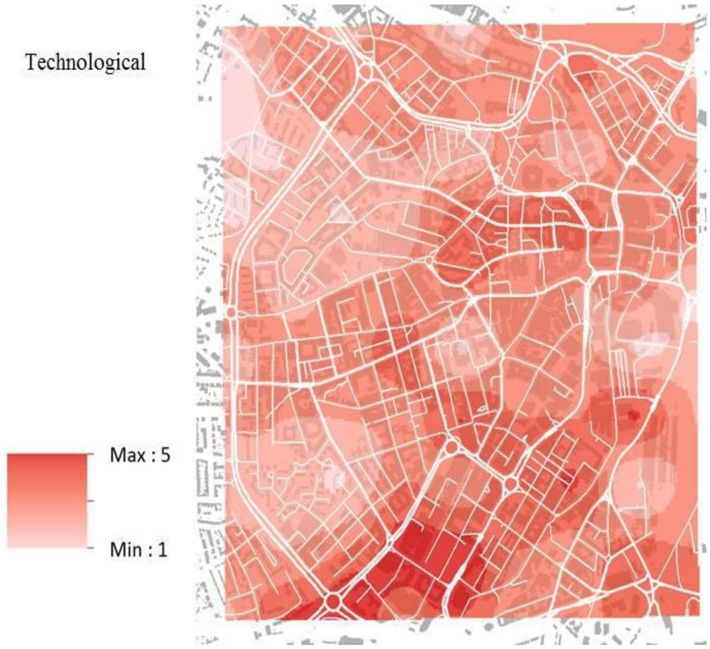

Figure 2. Spatial variability of the audible technological sound sources

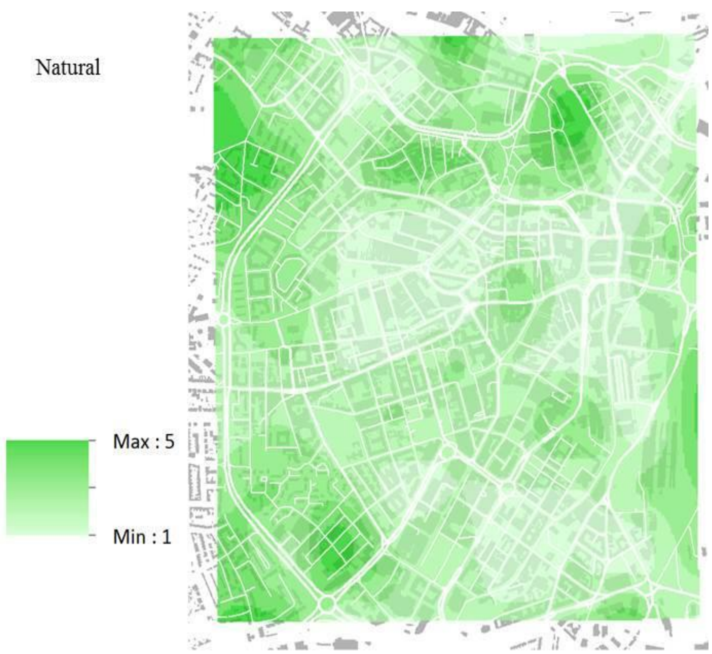

Figure 3. Spatial variability of the audible natural sound sources

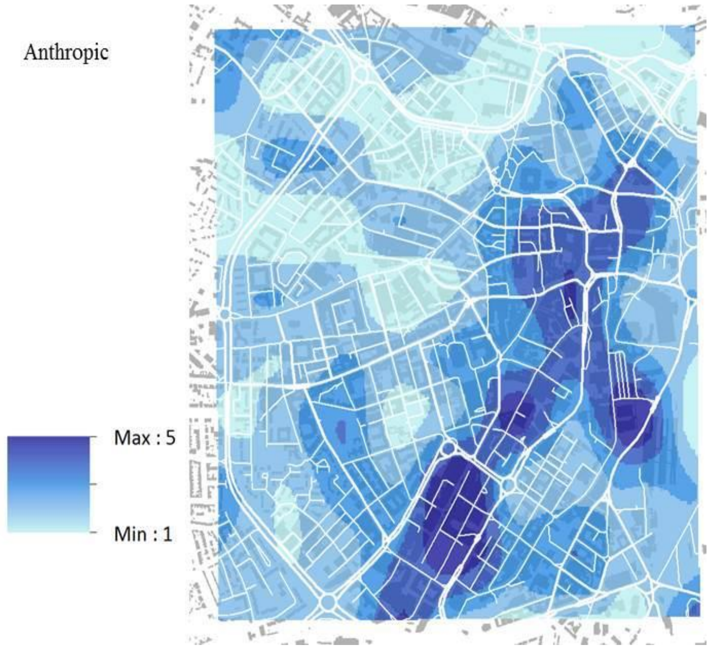

Figure 4. Spatial variability of the audible anthropic sound sources

According to Figure 2, areas on the north-west side of the ring road – mainly covered by University buildings, parks and residential houses – present low level of technological sources. The same happens on the south-west side of the ring road, which is a purely residential area. Low technological sources are also present in the east side, close to the train station because of the natural area on the east. Similarly, another small area with absence of technological sounds can be identified in the city center, with many pedestrian areas. High concentration of technological sources was observed in the roundabouts of the ring road and along the main roads in the central zone of the study area. The highest number of sources was observed in the southern part, which was expected due to the combination of traffic and light industrial activity.

From Figure 3 it can be seen that increased number of natural sources is evident in specific areas around the ring road which constitute parks, exclusive residential areas or places close to the river on the north. The west side of the study area is more privileged in terms of natural sounds because of the proximity to urban green spaces and playgrounds, while the house type with backyards or front yards enhances the presence of birds and animals. The city center presents the lowest aggregation of natural sounds with a small presence in various squares. It is also surprising that most of these places are along the main highway creating a contradictory soundscape environment with increased number of technological and natural sources very close to one another.

Lastly in Figure 4, anthropic sources seem to create a corridor from north to south starting from the river and continuing along the commercial and former industrial area of the city center. These are areas with many shops, services, entertaining activities and active social life during the greatest part of the day. Another vital point is the train station on the east as well as the corridor on the west close to the student's accommodation houses and the Devonshire Green square. The presence of human sources is limited on the rest of the study area apart from some small exceptions close to the river on the north and the green area of Ponderosa on the north-west.

3. Relationship between soundscape and urban context

In order to investigate the relationship between the soundscape of a place and the urban activities that are likely to occur in such a place, an audio-visual laboratory experiment was designed. For the experiment, 25 out of the initial 90 spots were selected around Sheffield (See Figure 1). The first selection criterion was to choose sites representative of all the possible land use categories according to the Local Plan of Sheffield within the study area. Consequently, areas appropriate for residential, industrial, open green space, commercial and educational purposes were selected. The second criterion accounts for the availability of the street view option in Google Earth in order to create the videos.

3.1 Experimental set-up and procedure

Twenty undergraduate and postgraduate students from the University of Ghent (Belgium) aged between 23 and 33 years old, took part in the experiment (16 males, 4 females; M_{age} = 27.5 years, SD = 2.82). All of them were citizens of Ghent, while 16 participants had previously visited England at least one time in the past. However none of them had been to Sheffield before. The auditory conditions were the same for the total duration of the experiment, since it took part in a listening room using specific equipment. Each participant received a reward of 5 euros in cash after completing the experiment.

From the initial audio file, a 30sec audio part was extracted representative of the sound environment at each spot. Then the audio excerpts – previously recorded on site – were combined with the visual excerpts in order to create 25 audio-visual representations of 360^o view. This process was performed using Camtasia Studio software. The audio excerpts were also calibrated so as to be as representative as possible with the on-site conditions. For the calibration, a test sound of 30 seconds was used from the initial recordings. The dB value of the test sound was measured using Matlab and the calibration was made based on the dB level of the original signal. Then the volume was adjusted based on calibrated equipment and a dummy head with 0.1" microphones, as shown in Figure 5.

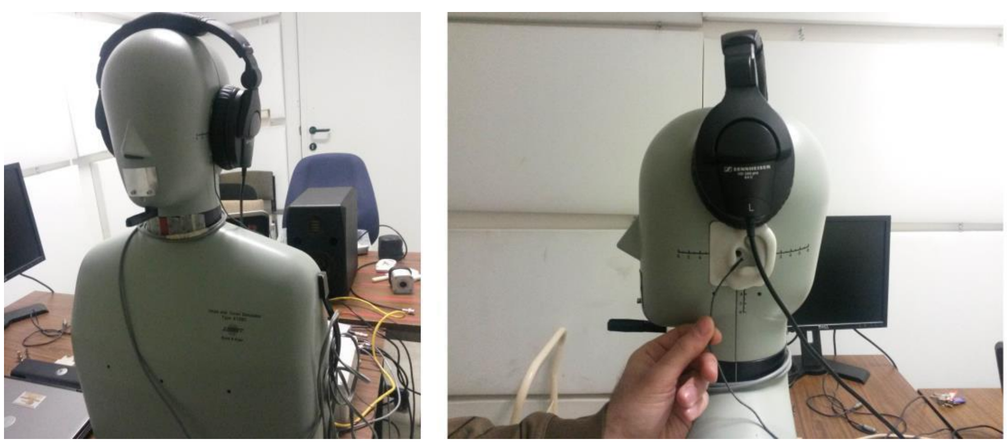

Figure 5. Calibration test on the left ear of the dummy head and the 0.1" microphones

A structured questionnaire consisting of two main questions was prepared based on the soundscape model proposed by Axellson et al. (2009, 2010). On one hand there was a list of 23 urban activities;

namely: outdoor informal games, walking, jogging or running, socialising-conversing-chatting, picnic or barbecue, experiencing active street life, individual outdoor activities, spending time with friends or family, escaping city stress, experiencing peace and quiet in general, nature appreciation, school and student work, residence, offices, shops, shopping, restaurants or cafés, industrial activity, road or rail transportation, parking a car, appreciating inland water, boating or fishing, swimming or bathing, appreciating cultural heritage. For each urban activity participants were required to assess on a scale ranging from 0 to 100 its suitability (i.e. kind of activities that would fit in this place), as shown in Figure 6. On the other hand, a list of 4 sound sources types was presented to participants; namely: traffic sounds, sounds from people, natural sounds, and construction sounds. Similarly, the participants were asked to assess the audio stimuli by defining on a 0-100 scale the extent to which they could hear each sound source type (0 = "Do not hear at all", 100 = "Dominates completely"). The audio-visual stimuli were presented to participants using the SurveyGizmo software, with randomized answers for both questions and different video sequences for each participant. The numbers in the scale bar for all the answers were invisible so as to avoid possible rounding tendencies from the participants. The average duration of the experiment was one hour, while the participants were able to watch the videos more than one time in order to answer the questions.

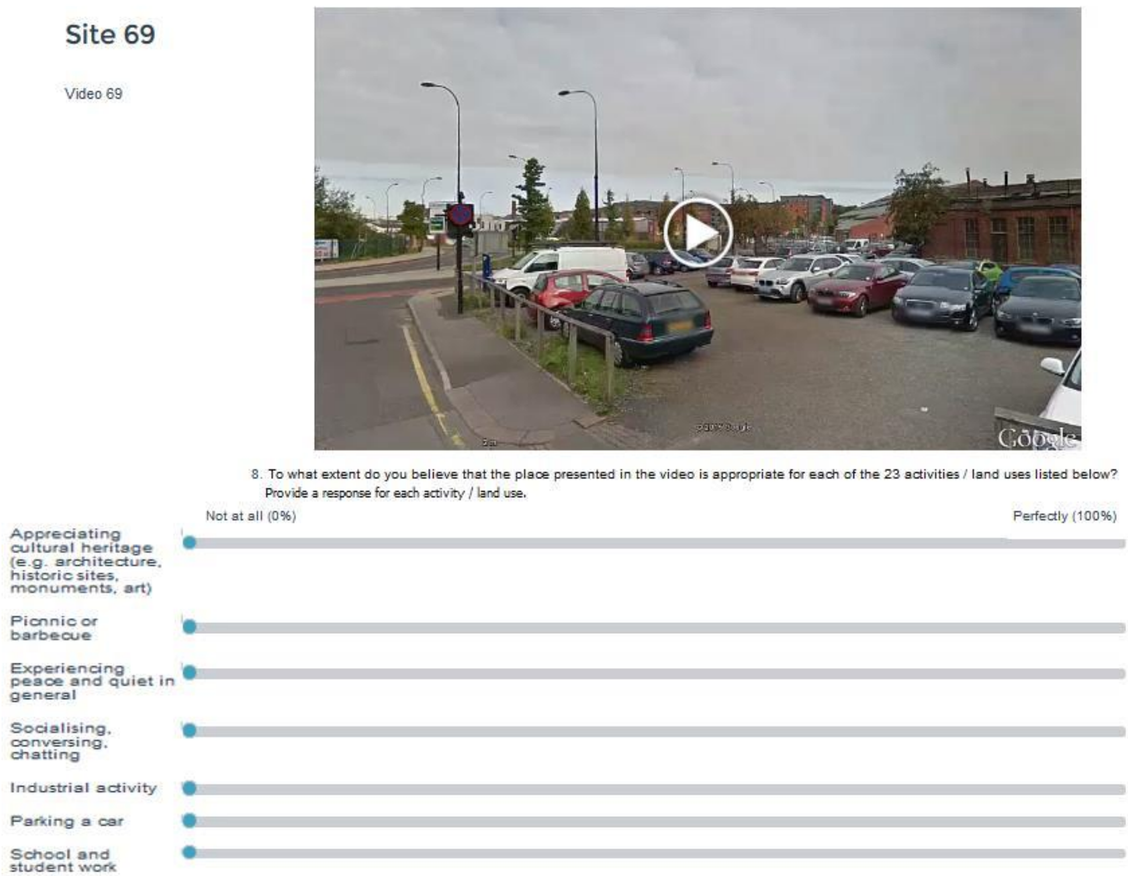

Figure 6. Sample from the questionnaire structure concerning the urban activities assessment

3.2 Clustering of sound sources profiles and urban activities profiles

For the purpose of this study, a cluster analysis was performed on the individual responses using the Ward method. This method is particularly useful when the ideal number of groups to form is not known and needs to be estimated as an output variable. Such a method discriminates attributes based only on their distance from their centroids. In this analysis, the agglomerative hierarchical clustering procedure is applied to the 25 spots. Firstly, the attributes related to the sound sources were used as variables. The algorithm merges two groups at each step, until all elements end up in a single group. The method minimizes the sum of squared distances between the points and the centroids of their respective groups, summed over the resulting groups. The same clustering process was applied considering the urban activities. For both cases, the interpretation of the agglomeration schedule table from the hierarchical analysis (not shown in the paper), suggested that the use of three clusters would be suitable to describe relevant sound sources and urban activities profiles (Can and Gauvreau, 2015). The aim of this process was to identify plausible profiles of sound sources types as well as urban activities' profiles and define the cluster membership to those for the 25 selected spots.

Once the optimal number of clusters was defined, the K-means clustering algorithm was used in order to identify the cluster centres. Regarding the sound sources as presented in Table 2, spots which belong to Cluster 1 are typical of more natural sounds and a balanced combination between traffic and construction. The presence of anthropic sources in these sites is limited mainly due to time variations over the day. Spots which belong in Cluster 2 are highly dominated by traffic and occasional construction sources with a very low presence of people and natural sounds. Finally the presence of people and traffic is highly evident and equally balanced in Cluster 3 with a low contribution of natural or construction sounds.

Table 2. Cluster centers using K-means clustering method

	Clusters		
Sources	**1**	**2**	**3**
Traffic	25.3	81.9	47.6
People	11.3	3.2	63.1
Natural sounds	50.9	6.2	10.4
Construction	20.2	11.3	13.4

From the urban activities perspective, spots which belong in Cluster 1 are placed in areas surrounded by greenery or open spaces as it can be seen in the sample pictures of Figure 7a. These places are primarily suitable for residential purposes, outdoor activities, relaxation, socialising and nature appreciation. To a lesser extent they can also be considered appropriate for educational activities, however they are inappropriate for commercial and industrial amenities or offices.

Spots in Cluster 2 as shown in Figure 7b are mainly appropriate for commercial activities involving shops, restaurants or cafes. They are usually squares; pedestrian or small commercial streets with an active street life where people can spend time shopping, chatting and socializing. Working spaces such as offices are less appropriate there as well as residential and educational facilities. Finally natural green elements and transport have a secondary role in these places.

Points in Cluster 3 presented in Figure 7c indicate a mixture of uses comprising of residential, educational, parking and office facilities. The presence of transportation infrastructure is also obvious in these places combined with small industrial facilities. Overall, commercial and educational services are not suitable there, neither outdoor nor social activities.

Figure 7. Activity profiles: (a) Cluster 1: Residential areas, (b) Cluster 2: Commercial areas, (c) Cluster 3: Mixed land use

3.3 Relationship between soundscape and urban context

A chi-square test of independence was performed to examine the relation between sound sources profiles' membership and urban activities profiles' membership as presented in Figure 8. Results proved that the sound sources profiles were not equally distributed (random) in the activity profiles, χ^2 (4, N = 25) = 11.389, p = 0.023. Detailed results presented in Table 3 denote that the expected frequencies of all sound sources were either higher or lower than the expected ones with a maximum variation of 3.1 in absolute values between the traffic sounds and the mixed class of urban activities. On the contrary, the lowest variation (0.4) was detected between the human sounds and the residential profile.

A comparative analysis of the videos which belong in each cluster revealed that the majority of the places belong to the expected sound profiles. For example residential areas are equally distributed between the natural and the human sound profiles. Mixed activity areas, which include residencies, offices, education and parking spaces; are split among the sound profiles where traffic sounds prevail, while natural or human sounds are present to a smaller extent. Finally, all the places with commercial activities are related to human sounds; denoting an active street life during the recording period. However there were also other places where there was a disparity between the expected and the actual sound classification. In two cases there were activities which were combined with natural sounds, while they were expected to be combined more with traffic. Another example is the prevalence of human sounds in places which were also expected to be combined with traffic such as mixed residential and office spots.

Table 3. Cross tabulation of sound sources profiles and urban activities profiles

			Urban Activities Profiles			
			Residential	Mixed	Commercial	Total
Sound Sources Profiles	Natural sounds	Count	2	2	0	4
		Expected	0.6	2.9	0.5	4
	Traffic sounds	Count	0	11	0	11
		Expected	1.8	7.9	1.3	11
	Human sounds	Count	2	5	3	10
		Expected	1.6	7.2	1.2	10
Total		Count	4	18	3	25
		Expected	4	18	3	25

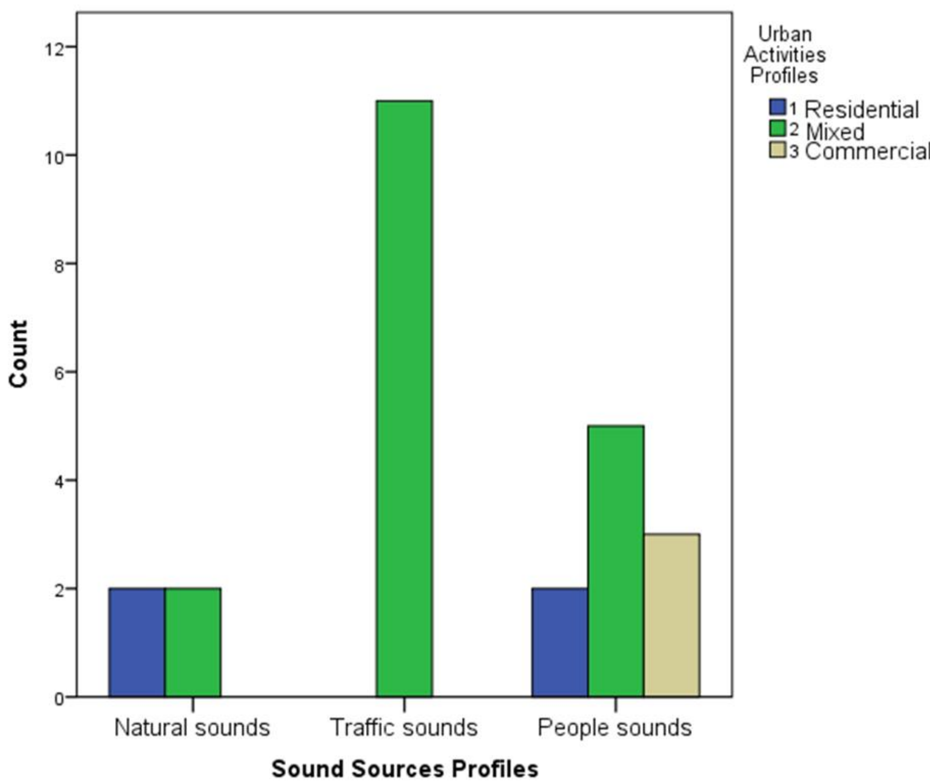

Figure 8. Membership frequency of the urban activities profiles in the sound sources profiles

4. Conclusions

The aim of this paper was initially to describe a methodology for mapping different kinds of sources and visualise their spatial distribution in the study area. From the results it was possible to detect the peaks and lows of each sound source and have a visual representation of the source variability. In spite of the fact that the methodology which was followed can be used only for short time representations; the average of morning and afternoon values provides more robust results for the study area.

Secondly an attempt to correlate sound sources and urban activities was investigated. According to the results the correlation between the sound sources profiles and the urban activities was statistically significant and not random. All the activities corresponded with the expected sound profiles with some exceptions. This happened either because of the time variation in the soundscape during the day or due to the absence of human sources in both recording periods (morning, afternoon). Furthermore, a positive effect in urban design can occur from the correlation between sound sources and activities. Since it is usually difficult to change the land use character of a place; targeted actions towards the modification of one or more sources – such as traffic – can improve the soundscape of a place and change the balance of the perceived sounds. Consequently a defined urban context can be improved according to the balanced combination between the character of the place and the proportion of the audible sound sources.

To conclude, soundscape mapping as a tool should be considered together with the landscape and urban design at a certain stage. As the management of the urban environment is not just a land use process, but also a human-related process, an interdisciplinary approach has to be applied, combining the land use policy with landscape design and human perception.

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