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Soundscape characterization in selected areas of Central London

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The Mayor of London's Ambient Noise Strategy 'Sounder City' is the first UK public policy document to promote, not just noise reduction, but positive soundscape management. For its prescriptions to be put into full effect, psychoacoustic methods are needed to characterize existing areas where action may be needed to counteract existing noise pollution. To this aim, the soundscape characterization of two different areas in Central London will be presented in this work, where the two selected parks have in common the presence of a heavily trafficked road nearby. The acoustical experience of passers-by will be mapped using an indicator related to the time history of sound energy, related in previous studies to people's perceptions. Comparison with the same description performed by classical psychoacoustic parameters and perspectives for innovative, positive soundscape based actions will be discussed.

1 Introduction

One of the specific objectives of the 2002/49/EC Environmental Noise Directive (END) is "preserving environmental noise quality where it is good", so increasing attention is being given to protecting "quiet areas" as well as reducing noise levels where they are high.

However, the END has left to the Member States the task to identify and define quiet areas. Since 2002, many experiences can be found across Europe on Noise Mapping and Action Plans applied to Quiet Areas. There are also some general recommendations drawn by Working Groups established by European Commission to support the END [1][2]. However the definition, identification and protection of Quiet Areas in urban locations and in the countryside are still under discussion, not only with respect to acoustic criteria (when an area can be defined as "quiet"), but also to such items as future land use and public access.

Particularly difficult, in this framework, is the design of solutions for urban parks, district green spaces and natural areas, often exposed to a high level of noise pollution because of their location, while typically expected to be "quiet". In these areas, a wide range of requirements must be met at the same time, as different users could require and expect a different level of "quietness". As an example, older people are generally more open to sounds related to nature or human activities. By contrast, young people are more favourable or tolerant to sounds like street music and mechanical sounds. Also, the expected "quietness" that a jogger expects is very different from what a family would like to enjoy during a picnic on the grass.

The expectation of the people involved, then, appears to be of primary importance: the problem of identifying Quiet Areas resolves into the challenge of finding suitable indicators to map and design the outdoor environment from a psycho-acoustical point of view. If the first step is describing the different areas of a city by their acoustical "fingerprint" (e.g. on the scale of perception, but using quantitative indicators), other considerations and criteria must follow.

1.1 Soundscape based action plans

The interest in action plans based on "positive" soundscapes is growing across Europe and in particular in UK. Projects have been funded by the UK EPS Research Council (NoiseFutures, Positive Soundscapes, ISRIE) to promote emerging psychoacoustic research, andpublic authorities are also moving in this direction.

An example is the London Plan (Spatial Development Strategy) [4], published for the first time in February 2004, which calls for a higher profile to "abating the adverse effects of noise, and maintaining or enhancing soundscape quality" in design and management and, in its latest version, explicitly refers to protecting/enhancing relative tranquillity (section 4A.20) among its goals.

Another example is the Mayor of London's Ambient Noise Strategy 'Sounder City' [5], published in March 2004. This document puts forward general policies and proposals aimed at promoting best practice and innovation in noise management and acoustic design, in the context of positive soundscape design (e.g. paragraphs 4F.28-32, 5.32-3, Policies 78 and 97, and Proposal 26).

The Mayor's Ambient Noise Strategy 'Sounder City' is the first UK public policy document to promote, not just noise reduction, but positive soundscape management. This reflects developing psychoacoustic research showing that, for example, the presence of sounds which people regard as generally positive can reduce negative perceptions of noise.

This is probably one of the reasons why fountains have traditionally been such popular architectural features in public spaces. More generally, sounds which people regard as generally positive, often associated with the history and cultural heritage of the city ("soundmarks"), have proven to be effective in reducing negative perceptions of noise [6]. As an example, the sounds of Big Ben's chimes create a distinctive local character in some areas of London [4].

One possible approach is to design actions that, maybe at the cost of a slight increase in overall sound level, modify the soundscape in an area, in such a way as to transform the perception of its users. An existing polluted soundscape would be supplemented by appropriate sound compositions, the characteristics of which are related to the needs of end users of the area.

In this paper the authors outline an action plan approach, which, like the more "classical" ones (aimed at reducing noise levels) requires three basic steps:

1. an initial assessment (e.g. of the existing soundscape and, ideally, of the expectations of future users);
2. a prediction of the soundscape after the action is completed (with consequent optimization of the sound compositions, of the location and appearance of emitters and of the interactions between the different emitters and the noise source);
3. evaluation of the soundscape after the installation is in place (e.g. assessed by questionnaires).

For reducing the noise level at a dwelling (like building a barrier), the three steps above are usually measured on the numerical scale of equivalent sound pressure level (L_{Aeq}), sometimes using percentiles (L_{10} L_{50} L_{90} etc.). Similarly, the

Type of sound/locations to be characterised	Value of the indicator
Quiet locations	Greater than -1
Music	Close to -1
White noise and MLS	Close to -2
Disturbed locations	Lower than -2

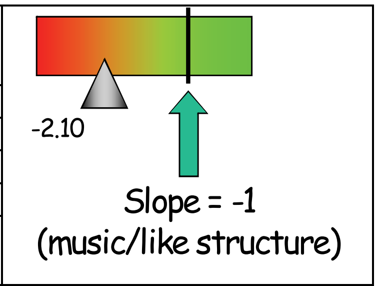


Fig. 1 Values of *Slope* for some environmental and artificial sounds and a graphical representation of the scale defined by this indicator.

optimization step of a soundscape based plan, to be effective, requires the use of a numerical indicator related to user perception. This paper will characterize two urban parks in London, using energy-based and perception-related indicators. Differences between the two approaches, and the perspectives they open in terms of possible actions, will be discussed.

Due to the multi-disciplinary nature of such a project, however, a more detailed method is needed that integrates these steps into a larger framework where anthropology, music, landscape design, visual art, architecture and choreography can work together. Such a method has been investigated in other works [7][8].

1.2 Existing indicators

A recent document by the Department for Environment, Food and Rural and Rural Affairs (DEFRA) [9], confirms that one of the main problems in putting the END into practice is the lack of a good set of indicators for the identification of quiet areas. The Defra document also underlines how the END suggests a purely acoustical criterion in agglomerations, e.g. a threshold like $L_{den} \leq 55$ dB for identification of quiet areas.

An example of a more complex approach to the characterization of open spaces in urban environments can be found in the final report of the RUROS-FP5 project [7]. In the part dealing with acoustic aspects, the authors point out the importance of L_{90} as an index, but conclude that the acoustic comfort is more related to the "perceived sound level" and to the presence of "soundmarks".

The Soundscape Support to Health project [10] further specified the conceptual differentiation between acoustic soundscapes and perceived soundscapes. Noting that in many cases perception of the sound environment works as an intervening variable between acoustic impact and health impact is thus a key factor in devising cost-effective actions. In addition, Soundscape Support to Health [10] was the first step (to the authors' knowledge) to devising a more comprehensive technique for classifying soundscape quality from the acoustical point of view, identifying the non-linear nature of the process.

Interesting considerations also come from the ORUS project [11], which emphasized the limitations of the energy-based indicators (like L_{den} or L_{night}) in reflecting citizens' perceptions of their sonic environment.

1.3 The Slope indicator

The Environmental Protection Agency of Tuscany (IT), in collaboration with the INTEC group at the University of Ghent (B) and the Institute for Chemical and Physical Processes of CNR (IPCF-CNR) has conducted in the past four years studies on the identification of quiet areas. The main outcome of this research has been the definition of a numerical indicator (called Slope hereafter) for acoustical "quality", calibrated on people's perception using questionnaires [12].

The *Slope* indicator is related to time history of the SPL and measures how often events appear in it and how they emerge from the background [13]. The typical value of *Slope* in a few significant cases can be found in Fig. 1.

Previous studies allowed the creation of a "scale of perceived quietness" with ticks corresponding to different numerical values of Slope: a dose-response curve, effectively. Also reported in Fig. 1 is a graphical representation of the scale defined by *Slope*, where the colour represent the degree of quietness, as assessed by questionnaires during calibration, and the arrow points at the relative numerical value.

More technically, it is worth remembering that the numerical value of *Slope* represents the exponent S of a power function fitted, using a least squares method, to the power spectrum $G(f_0)$ of the L_{Aeq} time history in the interval [0.02, 0.2] Hz, so that

$$G(f_0) = A \cdot f_0^S \quad (1)$$

$$G(f_0) = \hat{L}_{Aeq}(f_0) \cdot \hat{L}^*_{Aeq}(f_0) \quad (2)$$

where $\hat{L}_{Aeq}(f_0)$ is the Fourier transform of $L_{Aeq}(t)$

and $\hat{L}^*_{Aeq}(f_0)$ its complex conjugate.

Under the previous definitions, the obtained "frequency of occurrence" (f_0) is not related to the signal emitted every second, but to the time history of L_{Aeq} over a fixed amount of time: a peak in the spectrum evidences a repetitive event during the selected acquisition time. The exponent S, then, measures the correlation between events appearing in the time history [12].

The relationship of *Slope* with statistical levels [13] and with classical psycho-acoustical indicators has also been studied. Some tests were conducted at the Sonic Garden *La Limonaia dell'Imperialino* in Italy: a park in Florence where sound/music/noise compositions could be superimposed on the noisy background from a nearby road, de facto altering the soundscape perceived by visitors. Questionnaires distributed to visitors to this Garden in summer 2007 assessed that, when the sound was ON, the average visitor perceived an improvement in the soundscape [14]. This change towards "perceived quietness" could not be detected using the classical psycho-

(a) Wild Garden (b) Knot Garden (c) St. Thomas' Hospital Garden

Fig. 2 Photographic views of the Museum of Garden History (a,b) and of St. Thomas' Hospital Garden (c).

acoustical indicators (like loudness, sharpness, fluctuation strength, roughness).

2 Description of the measurements

At the start of the project, the Greater London Authority selected two locations in central London to be characterized in terms of soundscape quality. The two selected sites are:

- the Museum of Garden History (MGH), in Lambeth Palace Road, which is divided into two main areas (Fig. 2a,b);
- the square in front of St. Thomas' Hospital (Fig. 2c), at the centre of which Naum Gabo's fountain is placed, currently not working but being consideredfor reactivation.

The location of the Museum of Garden History also includes a public park that has been recently refurbished by the Lambeth Borough, containing a small fountain.

Seven measurements were taken in each location: in 3 of them acquisitions lasted 45 minutes (for characterization of the overall site) while the other 4 had a 15 minutes' duration (for characterizing particular effects). In all cases the microphone was at 1.5 m from the ground and close to areas normally used by visitors (benches, paths etc.).

Measurements were taken in good weather conditions and absence of relevant wind. Sound pressure levels were acquired in 1/3-octaves with 1 s time resolution. Statistical values and other relevant sound pressure levels have been calculated, after eliminating exceptional events. Audio recordings have been acquired for future studies.

2.1 The Museum of Garden History

The main source of unwanted sound affecting the Museum area is Lambeth Road (on the south), ending in the roundabout. Other features in the close surroundings include Lambeth Palace Road, followed by the river and a pier (west) and the London residency of the Archbishop of Canterbury (north and east border). Since the traffic did not change much during the measurements (taken between 10am and 2pm on weekdays), the soundscape was relatively simple to describe.

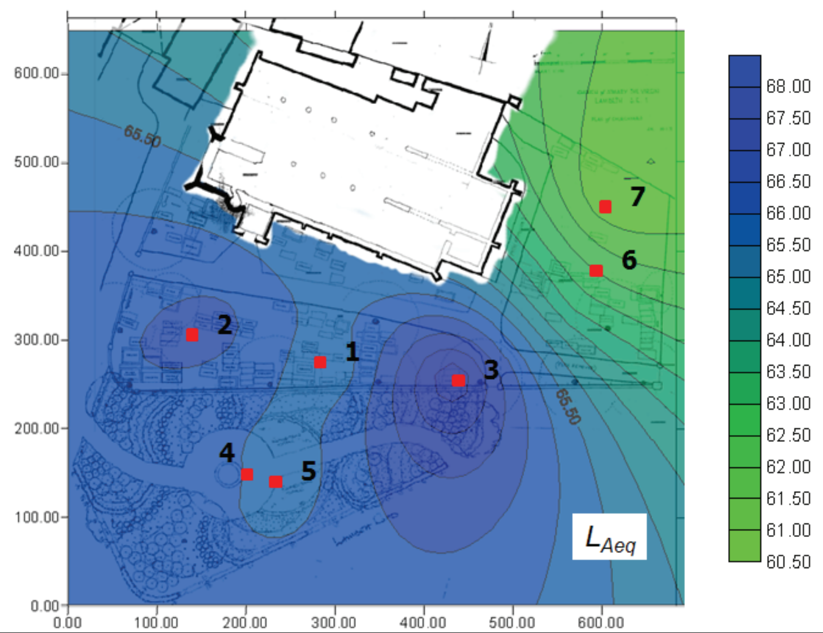
Fig. 3 shows the results of the analysis at MGH in terms of equivalent sound pressure level (L_{Aeq}) and *Slope*. The L_{Aeq} analysis confirms calculations shown in the London Noise Map, which imply that the soundscape quality is similar across most of the area, with some improvement in the inner part of the Knot Garden (Positions 6 and 7). However, the values of *Slope* show that:

- The site at the centre of the Knot Garden (Pos 6) has the lowest value of *Slope* and thus appears to be the location most sensitive to the traffic noise. The uncertainty on *Slope*, however, barely allows this location to be distinguished from the others: *Slope* alone is not sufficient to say more.
- The measurements closer to the fountain (Pos 4 and Pos 5) register a slightly more "positive" value of *Slope* than those characterizing the other locations in the area. The fountain partially masks the traffic noise, enriching the soundscape with messages in the frequencies typical of human speech. Listening to the audio recordings, the running water is distinctly audible in Pos 4 and almost negligible in Pos 5.

A sonogram analysis of Position 6 showed that peaks are effectively clearer relative to background than in other positions (the most exposed one being Pos 3). This is probably because the traffic in front of the Knot garden is of the accelerating/decelerating type (Lambeth and Wild gardens experience the traffic light queue, near the roundabout), superimposed on a lower intensity background (due to partial cover from the Museum's building).

This demonstrates that the analysis of sonograms [10] may give information complementary to what is achieved by *Slope*. In particular, the sonogram also shows that positive sound emission should target the range between 200 Hz and 2 kHz, which is currently only populated by traffic noise.

Recent studies [6] have shown that the speed of the running water and the configuration of the jets in a fountain may be designed to have different frequency spectra, thus colouring the soundscape in a different way. Analysis of the sonogram in Pos 4 and Pos 5 show that, in this case, the effects of the fountain can be distinguished at frequencies above 2 kHz (characteristic emission of most fountains, coming from the water splash itself), whereas low frequency components can be generated when a large flow of water is raised to a very high level and then dropped to a



Slope		
Position number Location	Period 1	Period 2
1: Wild garden	-1.9 ± 0.2	-1.8 ± 0.2
2: Wild garden	-1.9 ± 0.6	
3: Wild garden	-1.9 ± 0.2	-1.9 ± 0.2
4: Lambeth garden, near the fountain	-1.8 ± 0.15	
5: Lambeth garden, near a bench	-1.7 ± 0.4	
6: Knot garden	-2.1 ± 0.2	-2.0 ± 0.2
7: Knot garden	-1.7 ± 0.2	

Fig. 3 Description of the Museum of Garden History's area in terms of sound pressure levels and *Slope*.

water body or hard surface. To change the soundscape with a fountain alone would then require redesigning it.

2.2 St Thomas' Hospital Garden

St Thomas' Hospital Garden (STHG) is divided in two parts connected by steps and is surrounded by the River Thames (west), Westminster Bridge Road (north) and St. Thomas' Hospital (south and east). The largest part of the garden contains a stainless steel fountain of 1972-3 by Naum Gabo, designed to revolve, but currently not working. The existing soundscape in St. Thomas' Hospital Garden is characterized by three main sources: the road traffic, the car park below the garden and, periodically, by the chimes of Big Ben across the river (a clear soundmark).

When Gabo's fountain is reactivated, another soundmark will contribute to the overall sound pressure level (slightly, given the fountain's very fine spray) and the noise due to visitors will probably increase. However, it may have a bigger effect on the perceived soundscape. In particular, it is possible that the benches on the south side, having the fountain between them and the road, will experience a definite improvement of the soundscape. However, in terms of the factors outlined in section 2.1, the other parts of the Garden will probably be unaffected and will require a different intervention.

Fig. 4 shows the results of measurements at STHG in terms of equivalent noise levels and *Slope*. According to L_{Aeq}, the "quietest" area is the SE corner of the garden, corresponding to the most shielded area and leading to the entrance to the hospital. The measurement in Pos 4 has been taken two times, to analyse the controversial effect on the soundscape of playing children (useful in estimating the effect of an increased number of visitors on the soundscape).

According to measured L_{Aeq} values , the area of the STHG experiences very different noise levels, partly due to its size, but also because of the partial shielding due to buildings in the SE corner (Fig. 4). Maximum exposure was measured in Pos 7, while it might have been expected to be at Pos 1 (which is the closer to the road, in front of a bus stop, but better screened by parapet walls).

The values of Slope, calculated in the different locations at the STG and reported in Fig. 4, partly confirm this initial analysis, showing a complex and varying soundscape. The values in Fig. 4 also show that:

- Many positions have a value of *Slope* = -1.9, which places them on the same point of the scale as most of the MGH. As already stated in previous works [13], a value close to -2.0 is typical of many locations "on the edge", where noise can be tolerated for short periods. As already discussed, the fountain divides an area where prospective visitors would not be attracted (e.g. where annoyance is high, closer to the road), in need of action, from another, where noise can be tolerated.
- According to *Slope*, Pos 1 is "worse" than Pos 7 on the scale of quietness determined by *Slope*. The behaviour of visitors (who prefer the area of Pos 7 to the benches in Pos 1) seems to confirm this conclusion much more than the one obtained by only using L_{Aeq}. This is an example where a higher value of L_{Aeq} does not necessarily correspond to a worse perception.
- One issue for further research would be the impact of schoolchildren playing (there were 20 of them, giggling and shouting sporadically). Previous studies [15] suggest that the presence of voices mixed in a sound composition greatly improved its effectiveness in terms of an "artificial" soundscape. Also, "children playing" has been recorded as a "positive sound" [6]. However, it would be useful to establish if there is a threshold to the number of children where this sound loses its positive character, and to investigate differences between reactions of open space users and nearby residents.
- The result for Pos 5, relating to the path along the river, is due to the presence of engineering works in the area (hammers, lift for workers, alarms in the background etc.). These effects were recognized using the audio recording, which may become crucial for unattended measurements. A new analysis in this position will be needed in the future.

3 Conclusion

Two urban parks have been characterized in Central London using energy-based and perception-based indicators. Results have been discussed in terms of an ideal three-step action plan process (characterization, optimization and evaluation) aimed at modifying a soundscape to improve user perceptions. The importance of having a correct indicator for designing such actions from the acoustical point of view has been underlined. Actual design of soundscape interventions should be by a multi-disciplinary team, able to take into account other factors, more related to human activities than to technique. The challenge to find suitable indicators for this part of soundscape-based action is still open.

Acknowledgement

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References

[1] Sysmonds Group, Definition, Identification and preservation of Urban & rural Quiet Areas, Final Report under Service Contract ENV, C 1/SER/2002/0104R of the European Union, East Grinstead, UK (2003).

[2] WG-AEN and WG-HSEA, Quiet areas in agglomerations, Interim Position Paper (2004).

[3] Details respectively at www.noisefutures.org; www.positivesoundscapes.org and www.epsrc.ac.uk.

[4] http://www.london.gov.uk/mayor/strategies/sds/london_plan/lon_plan_all.pdf for more information.

[5] See http://www.london.gov.uk/mayor/strategies/noise/ for more information.

[6] Kang J., Urban Soundscape, Proceedings of the Spring Meeting of the Institute of Acoustics 2008 in Reading, UK (2008). See also references therein.

[7] VV. AA., Designing Open Spaces in the Urban Environment: a Bioclimatic Approach, report of the RUROS FP5-project (2002).

[8] VV. AA., Sonic Garden Principles Design Guide, edited by L. Brusci, G. Memoli, T. Borghuis, L. Proli, C. M. Proli, M Veneri/Bianco, London (2008).

[9] DEFRA, Research into quiet areas - Recommendations for identification, UK (2006).

[10] B. Berglund, T. Kihlman, W. Kropp, E. Öhrström, Soundscape Support to Health: A MISTRA Research Programme; http://www.soundscape.nu (1999-2004).

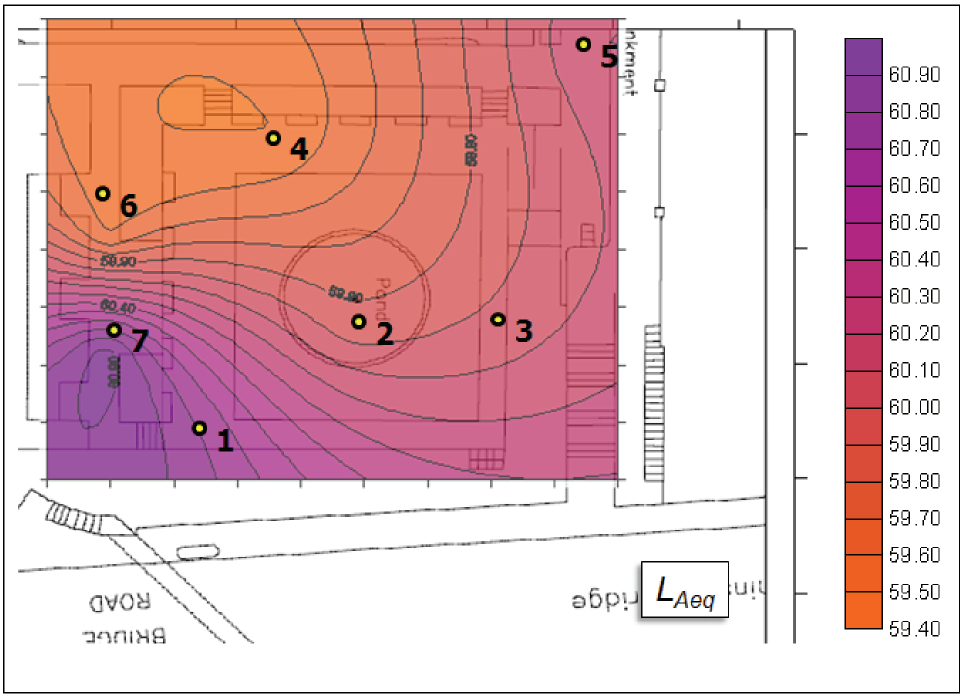
[11] Defréville B., Philippe P., Lavandier C., Roy P., Françoise Y., Objective representation of urban soundscape: application to a Parisian neighbourhood, Proceedings of INTERNOISE 2007, Istanbul (2007).

[12] G. Licitra, G. Memoli, Noise Indicators and Hierarchical Clustering in Soundscapes, Proceedings of INTERNOISE 2005, Rio de Janeiro (2005).

[13] G. Licitra, G. Memoli, D. Botteldooren, B. De Coensel, Traffic noise and perceived soundscapes: a case study, Proceedings of Forum Acusticum 2005, Budapest (2005).

[14] G. Memoli, G. Licitra, M. Cerchiai, M. Nolli, D. Palazzuoli, Measuring soundscape improvement in urban quiet areas, Proceedings of the Spring Meeting of the Institute of Acoustics, Reading UK (2008). See also references therein.

[15] G. Licitra, G. Memoli, Testing new solutions for action plans in quiet areas, Proceedings of Euronoise 2006, Tampere (2006).



Slope		
Position number	Period 1	Period 2
1	-2.4 ± 0.2	-2.3 ± 0.2
2	-1.9 ± 0.2	-2.0 ± 0.2
3	-2.0 ± 0.2	-2.1 ± 0.2
4: with kids	-1.7 ± 0.2	
4: without kids	-1.9 ± 0.2	
5	-2.6 ± 0.2	
6	-1.9 ± 0.2	
7	-1.8 ± 0.2	

Fig. 4 Description of the St. Thomas' Hospital Garden area in terms of sound pressure levels and *Slope*.