Understanding urban and natural soundscapes

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Summary

The concept of soundscape has garnered increasing research attention over the last decade for studying and designing the sonic environment of public spaces. It is therefore critical to advance knowledge on how the soundscape of a place is evoked by its sonic environment, given visual, cultural, and situational contexts. Working Group 1 of the COST action "Soundscapes of European cities and landscapes" revolves around this question. In our current understanding the sounds that are heard during normal activities in a place trigger meaning and emotions based on the matching with expectations of the people using and acting in that place. This complete package of human experience in relation to the sonic environment can be named the soundscape. In terms of design, this understanding opens several opportunities. The designer can decide which sounds should be heard and try to make this happen by guiding the attention to particular sounds or simply remove, add or shape sounds. In doing so, he or she should keep in mind expectations of the local users. Expectations and meaning might be changed by suitable design of non-sonic features of the environment including besides the obvious visual context also the openness, lighting, local climate, etc. Bringing these concepts to practice requires new tools and methodologies.

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1. Introduction

Working Group 1 of the COST action "Soundscapes of European cities and landscapes" focuses on increasing our knowledge on how the soundscape of a place is evoked by the sonic environment, given the visual, architectural, functional… and more generally cultural context.

2. The soundscape concept

The term soundscape has been used by different communities of practice (e.g. acousticians, composers, architects, ecologists, psychologists), giving rise to several definitions (see working group 2 of the same COST action). A standardized definition may not be required nor wanted but it is useful to summarize generally accepted views on this concept:

- The soundscape is evoked by the physical sound environment henceforth called the sonic environment, but it is not equal to it and therefore cannot be measured using classical sound measurement equipment alone.
- The soundscape is formed within a context. This context is shaped by all sensory stimulations – of which visual observations are most important [11] – and by the knowledge people have accumulated about the space, its use, its purpose, its cultural meaning, his or her own and others motivations and purposes to be there, the associated activities, etc.
- The soundscape concept tends to be used mostly in relation to open outdoor spaces, but has also applications for indoor settings, mainly public but also private. But it always entails a sense of spaciousness. Environmental sounds intruding in private spaces result in effects following different mechanisms with control as an important factor.
- The timescale related to soundscapes is in the order of minutes to hours. The quality of the soundscape in some parts of the living environment can nevertheless have long term effects on the quality of life [14] and health of the population.

3. From sonic environment to soundscape

Although the sonic environment on its own does not define the soundscape that is evoked, it plays a crucial role in the process. Hence it is useful to try and better understand the mechanism connecting this physical environment to the soundscape mental concept.

3.1. Listening

Listening is a complex process which involves multi-leveled attention and higher cognitive functions, including memory, template matching, foregrounding (attentive listening) and backgrounding (holistic listening) [1][2]. Attentive, analytic, descriptive listening has been identified as the most important listening style in the construction of the soundscape based on investigations where persons are asked about their aural experience in a place and often mention particular sounds – by naming the source of these sounds. One should however not underestimate the potential role of holistic listening or even simply hearing – that is the preconscious process that determines global characteristics and directs attention to salient events [44][45] – as a mediator in creating mood and appraisal of the sonic environment. Merely focusing attention of the participants in the above mentioned investigations on the environmental sound might trigger them to adopt an analytic listening mode.

As the listening experience in a sonic environment evolves, the listener switches between different listening styles: from the more holistic *listening in readiness* waiting for familiar or important sounds to emerge (expected or not), to *listening in search* expecting particular sounds in a context, or even to *story listening* focusing attention on one particular sonic story within the multitude of sounds.

With this definition, listening is part of a multi sensory experience. Visual information – and to a lesser extent other sensory information – may trigger the expectation for a sound to occur and therefore facilitate attention being drawn to it. Other senses may however also distract attention from the sonic environment or even put so much stress on the organism that some forms of listening become rare. In addition outward processes from the person's knowledge or expectations may also change listening style (see Section 3.2 and 3.3).

3.2. Meaning

In a particular context and for a particular person, the sounds heard in the sonic environment are meaningful. Meaning can be regarded as the collections of associations that are triggered or evoked in the person's mind by hearing the sounds. These associations influence (and determine) how we interpret the world around us and also depend on other sensory inputs, knowledge about the environment, and expectations grounded in current intentions and previous experience [28]. From this viewpoint one can assume that associative memory plays an important role driving top processes involved in any perception. It is known that recent observations, thoughts, and emotional states influence recall.

Relevant meaning – associations with important consequences for the person's action – induces listening in search and even story listening. As the origin of the sound is more closely related to the listener it can be expected that stronger and more relevant associations are evoked and thus more attentive listening styles are provoked. This partly explains the special meaning of the sound of human voices [3].

3.3. Appraisal

As the potential for survival of an individual depends on an adequate behaviour which requires predicting the immediate future, expectations became a crucial mechanism in functioning. Non-matched expectations generate negative emotions that accentuate the need for adaptation.
Cognitive appraisal of the sounds heard within the sonic environment together with the meaning they convey [42], could lead to reinforcement of positive or negative emotions triggered by the sonic environment. This may in turn focus listening in search of the positive or negative sounds within the sonic environment.

3.4. Long term effects

A human can endure high levels of stress – part of which might be caused by extensive noise exposure – for short time periods as long as these periods are interrupted by restoration moments. Because of its focus on open space, soundscape design may contribute primarily to restoration [5]. The mechanism linking sonic environment to inner world that is described above directly implies that perfect silence is not necessarily the best option: attention should be drawn to sounds that trigger new associations that contribute to positive appraisal. It might even be necessary for the sonic environment to create opportunities for focusing attention away from everyday thoughts for optimal restoration [29][40].

4. Consequences for design

The understanding of how soundscapes work discussed above has practical consequences for the design of future sonic environments through soundscape planning. A few key concepts are discussed below.

4.1. Matching expectations

A good sonic design should match expectations of the current or intended users of the space. Therefore designers need to identify the target population of users and involve a representative sample of them in the early stages of design to determine their needs and expectations as a crucial step in the soundscape design process. Visual setting and general design and use of the space, as well as prior knowledge of the users should be accounted for.

4.2. Creating realistic expectations

As the sonic design of an urban public space is often the result of compromise between people engaged in activities producing sound and those hearing it, it may be advantageous to indicate clearly what can be expected in a pragmatic approach. Urban planning and landscape planning in accordance with the intended uses of the space can indicate to the user that high levels of transportation sound, recreation, children or sports sounds can be expected in certain areas. Hiding sound sources from direct view without removing the accompanying sound might not be a good option for this reason, although the same measure might help to distract attention as explained in Section 4.3.

4.3. Directing attention and listening

As the perception of a soundscape to a large extend depends on analytic or focused listening, a suitable design should avoid sounds that evoke negative meanings for the typical users of that space. If these sounds – which are often produced by mechanical sources – cannot be avoided, the designer can attempt to distract attention away from these sounds, for example by adding more sounds that are generally appraised as positive in the environment and context of the design [4][6][8][10][12]. A term (too) often used in this respect is attention masking.

5. Indicators

Indicators are intended to create an impression of existing or future sonic environments that is accurate enough to allow a person who has not been exposed to these environments to imagine the soundscape. As such, indicators do not need to capture aspects of the sonic environment that have little or no influence on the soundscape. They need to form a set that is as complete as possible, yet practical in use.

5.1. Holistic verbal descriptors

A first set of indicators borrowed from the classical investigations in sensory sciences [30][31][32], attempts to describe the soundscape experience as a whole. Multiple attribute profiling using attributes such as *soothing* and *pleasant* or *annoying* and *noisy*, has been used in previous research [17]**Error! Reference source not found.**[33]. The multitude of attributes collapses into principle components that can be labeled *pleasantness* and *eventfulness* [34]. A third component, *familiarity*, is sometimes significant [24][35]. In view of the theoretical model relating the sonic environment to soundscape, it is not surprising that these principle components quite neatly match the two axes: valence and arousal commonly found in psychological analyses concerning affective and emotional state (e.g. [41]). Indeed, the overall appraisal of the sonic environment is expected to lead to an overall affective state. Holistic indicators give little detail in their description of the soundscape. Moreover this description is valid for the particular group of people studied and to the particular context the study was conducted in. More detailed descriptions are useful to move between context and subgroup of the population.

5.2. Analytic descriptors

It is also possible to describe soundscape experience focusing on sound sources that organize the acoustic environment [19]. Each source can be described with attributes such as proximity, prominence or presence. These attributes are respectively connected to space, energy and time [36].

5.3. Narrative

Listening to the sonic environment involves a sequence of focused listening and story listening instances intermingled with more holistic listening moments. In that sense the soundscape experience can become a story, a narrative on its own. This is what probably led researchers to use narrative interviews [21] when asking persons to recall a soundscape. The spatial component may be added by combining the narrative with a sound walk.

The narration mainly captures the meaning persons give to the various components of the sonic environment. One simple linguistic procedure to account and communicate for the meaning given to a sound is by naming its supposed source, which seems to occur quite often in the narrative. Some graphical procedures can also capture the soundscape experience in a narrative way. The graphical modes can be figurative (sound sources with or without context), cartographic or abstract [25][37].

5.4. Acoustic summary and auralisation

Whereas narratives try to evoke the soundscape by verbal description (oral or written), an acoustic summary or sonic summary tries to record typical and atypical sound and present it aurally in combination with a suitable description of context to suggest the soundscape in the listeners mind. Today, mainly composers and artists use a technique called soundscape composition to bring together the sounds of a city or an area [26].

When future designs are concerned, auralisation is used to combine expected sounds with urban propagation to create a sonic environment that is as ecologically valid as possible [9][22].

An important drawback of aurally presenting the sonic environment is the large amount of semi-technical work involved in collecting sound samples manually. Soundscape description tools that automatically recognize (salient) events and that can be used to describe the contribution and temporal distribution of individual sources and automatically extract a summary of common sounds from long recordings [46] could therefore be helpful. The big challenge lies in imitating the listener that occasionally focuses attention and changes to story listening style in a model. Since binaural listening is a crucial part in auditory stream formation, binaural recordings seem beneficial for this purpose.

5.5. Holistic measures for the sonic environment

The indicators described above rely on measuring with humans. There are however plenty of situations where indicators based on microphone recordings or simulations are the only option: monitoring, creating maps, quick scanning, etc.

Holistic measures of the sonic environment do not necessarily imply that holistic listening is assumed – with the exception maybe of overall L_{Aeq} that merely estimates loudness. At first sight one may expect that measures of amplitude fluctuation such as L_{A50}, L_{A95}, or a peak level indicator; measures of spectral content such as the spectral centre of gravity; measures of sudden changes such as relative approach [20] or saliency; measures of complexity such as music likeness [15][18][23] are related to holistic listening since there is no mentioning of the individual sounds. However, each of these measures can be related to the presence and audibility of particular sources given the particular context. For example, high frequencies in urban parks could indicate the presence of bird sounds and human sounds rather than the sound of distant slow traffic. More pronounced is the interpretation of complexity measures or saliency measures that can be related directly to the number of attention attracting auditory events present in the sonic environment. The latter may however distinguish less between sources and therefore perform less than expected in categorizing sonic environments.

Interpreting holistic measures with the importance of analytic listening and assigning meaning (discussed in Section 3) in mind could improve understanding the outcome of experimental work in this area.

5.6. Analytic measures for the sonic environment

Analytic measures of the sonic environment that already follow more closely the emergence of soundscape, should theoretically better perform than holistic measures. However they are difficult to derive from the microphone signal. The common approach starts from a detailed analysis of the audio signal picked up by the measurement microphone trying to extract from it a number of features that correspond as closely as possible to the features used by the human listener to discriminate between sounds. The next steps should group activation of features over time to extract auditory streams, a process referred to as auditory scene analysis (ASA) [43]. Chopping streams into “sounds” is not a trivial process that depends also on the meaning or source recognition (e.g. identifying traffic or individual cars). In the context of soundscape research either features are directly linked to sounds that have been labeled by referring to their source [46] or a self learning system is included to extract commonly occurring combinations of features in a given context [48]. Although these measures are still being developed, they could eventually allow to: automatically extract a summary of common sounds from long recordings, indicate how often certain sounds are dominating or even how often certain sounds are heard within a given context.

Indicators such as number of sound notice events, time of noticing, or level during periods that a sound is noticed can today already be estimated in situations where the sounds are known [47]. Calculation of such indicators is based on signal to noise ratio of the particular sound compared to all other sounds and an inhibition of return mechanism to prevent extensive focusing on continuous sounds.

6. Tools and computational models

Measuring and in particular measuring with people is quite expensive and time consuming. Hence there is a need for models that allow constructing maps either as a form of generalization of local investigations or as a predictive tool. Although source specific L_{Aeq} maps can give some indication, they are in general insufficient for applying a soundscape approach. Several alternatives have been proposed and are under development:

- Sound quality maps showing classical sound quality measures such as sharpness and roughness but also saliency based measures such as relative approach per source have been suggested [49]. As they generally focus on one source they include some aspects of analytical listening but do not explicitly distinguish between sounds.
- Notice-maps [50] go one step further and interpret saliency of foreground and background to come up with an estimate on how often a particular sound will be heard in the sonic environment.
- The maps proposed in [13] calculated using an artificial neural network also include the full context and use of the space, but they rely on prior measurement with people in approximately the same location. One could therefore interpret them as an interpolation technique. This approach does not unravel the sonic environment in its basic components.
- At a low spatial resolution level, land use and landscape may be used to target measurements and cluster areas with comparable soundscapes [27].

A different line of computational modelling aims at mimicking the way that persons perceive the sonic environment, give meaning to its components and come to some appraisal in an itterative way. Although one may argue that it is today almost impossible to mimic in a computer the way that humans think, there are important insights to be gained from building such computer models since they force cognitive scientists to quantify and precisely formulate hypothesis and to accurately test them in computer simulations and specifically designed psychological experiments.

7. The need for future research

While studying the effects of intruding environmental noise on the wellbeing of persons in their private homes, there is large uncertainty concerning the indoor sonic environment. Instantaneous sound insulation is relatively unknown and more importantly, the sound produced by the person's own activities (e.g. television playing) can at the very best be known in a statistical sense. In contrast, in most situations where the soundscape approach is usable, the whole sonic environment can be observed, measured and steered or even controlled. This means that it is worthwhile to study in much more detailed how a sonic environment within a complete sensory context interacts with persons. There seems to be a clear lack of knowledge on what environmental sounds people actually hear when they are not listening in search or listening for the story. A posteriori surveys can only reveal remembered sounds. Attention plays an important role in that process. Fundamental research is complicated because of the importance of context and activities. Trying to measure with persons often includes the risk that the experimenter focuses the participant's attention to the sonic environment in general or to a particular feature of it – thereby ignoring other senses such as visual information. Even more fundamental research is needed to uncover the effects of sounds that are not remembered. Can sounds that a person does not hear affect his or her thinking, mood or other biomarkers?

The influence of restoring environments within reach has been shown as well as the positive effect of the availability of quiet areas [16] and quiet sides [7] on perceived annoyance at home. Nevertheless there is a lack of fundamental knowledge on how exactly the soundscape of these areas influences health and well being. Better knowledge would nevertheless allow more accurately tuning of the sonic environment in combination with the visual setting of these "quiet" areas. Studies linking soundscape quality to epidemiologic effects might be beneficial for this purpose.

Besides these more fundamental research questions, there is a definite need to translate knowledge from the lab to tools and methodologies that can be applied in soundscape analysis and design. They include measurement methods, new measurement equipment for the sonic environment, detailed computational soundscape perception models and alternative mappings. One of the possible outcomes is to describe the influence of different design elements on the soundscape of urban and natural spaces, in order to provide the benefit of different interventions before its implementation.

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