Soundscape for European Cities and Landscape - Understanding

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Introduction

Working group 1 of the COST project TD0804 Soundscapes for European Cities and Landscapes has focussed on creating deeper understanding on the relationship between the sonic or acoustic environment and soundscape. For this purpose, WG1 organised or co-organised several workshops across Europe and stimulated exchanging of scientists via STSM.

This report discusses the main conclusions. It attempts to relate the somewhat vague concept "soundscape" to findings from psycho-physics, psychology, hearing system physiology, and auditory cognition. This often requires extrapolating lab findings to environmental sound and everyday context. This is not a trivial task by far and it will be shown where additional research might be needed.

The results of this theoretical exercise are of importance for measuring but also can give guidance to better design practice.

From sonic environment to soundscape

Soundscape

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 or acoustic 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 [42]– 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 [6] and health [31] of the population.

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 as a mediator in creating mood and appraisal of the sonic environment.

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 narrative or story listening focusing attention on one particular sonic story within the multitude of sounds.

Auditory scene analysis

The sonic environment of interest in the context of soundscape consists a multitude of individual sounds. One of the first tasks of the auditory system is to analyse this auditory scene and to identify its building blocks, a process referred to as auditory scene analysis (ASA). ASA involves decomposing a complex mixture of incoming sounds, originating from different sources, into individual auditory streams, using different auditory, but also visual and other cues [59]. Part of this decomposing happens in a pre-attentive phase. Identification of auditory objects based on spectro-temporal features is a learned process that relies on co-occurence of these features. The importance of temporal coherence in auditory scene analysis and learning in humans has recently been confirmed on a neurological basis [52]. As such, the familiarity of the listener with a sound may contribute to the ability to distinguish this sound in a complex sonic environment. Prior experience therefore could even have an influence on this low level ASA and lead to inter-individual differences in perceiving the sonic environment and in the soundscape experience.

In general however, one could expect that a sonic environment where various auditory streams can easily be formed is appreciated as a high-fidelity soundscape. More complex situations that cannot easily be “read” by the average listener may be perceived as too complex and mentally stressing. Like in the Attention Restoration Theory (ART) and the associated “fascination” urban environments, with too complex stimulations, could be a source of attentional fatigue [31][63]. If on the contrary, ASA results in a single auditory stream the sonic environment may be perceived as boring.

The role of attention

Let us now focus on the attention mechanism in more detail. The role of selective attention is to allow part of the sensory input to be evaluated it in the context of specific knowledge while preventing sensory signals from overloading the higher level cognitive system. For experiencing the sonic environment, not attentively listening to the sounds is the default state. However, as the auditory system always stays alert, sounds within the sonic environment could draw attention. The proposed theoretical model foresees a two stage mechanism to account for this: auditory stimuli may draw attention because of specific features they possess but they don’t necessarily get attended. This two stage mechanism is supported by neuroscience: sounds with high saliency trigger early brain response [47] while inhibition of return [48] and general attentiveness to sound determine whether a late response corresponding to actual attending is observed. Identifying sound features that increase saliency [49] and attract attention is an important aspect of the proposed soundscape theory. It is well known [49] that spectral and temporal variations and modulations – sometimes referred to as ripple – increase saliency for human observers. However, the auditory brainstem, which is responsible for these specific sensitivities, has a much higher plasticity than one might expect. On the basis of this, one could expect a common basis for auditory saliency, but in addition some specificity for different (groups of) people.

Auditory streams are classically regarded as existing in a pre-attentive phase. Although this view is appealing because of its conceptual simplicity, recent findings suggest that attention also plays a role in the formation of auditory streams [50][52]. Overall, it can be stated that the process of auditory scene analysis draws on low-level principles for segmentation and grouping, but is fine-tuned by selective attention [53]. Sound objects within the sonic environment are thus formed with the help of selective attention.

The listener embedded in a real environment – in contrast to experimental conditions – relies on all senses to structure a representation of the environment [51]. One sensory modality could draw spatial attention also to a different modality and even influence the perception itself strongly. This raises the question whether attention resources are controlled by a supramodal system or by many modality specific attention systems. In focused attention conditions, judging each signal (sound and vision) separately when incongruent sensory signals occur at the same location is difficult, at least much more difficult than when the incongruent signals come from different spatial location and attention is divided [54]. A multilevel mechanism of attention with a multimodal component overarching the single sensory component seems the most plausible model given today’s knowledge. In the context of assessing the sonic environment, this could be interpreted as a stronger emphasis on visible sources but at the same time a lower identification of deviant sound experience if it comes from the same location.

Listening in search or story listening involves voluntary (endogeneous) attention focusing grounded in higher level cognition. It can be shaped by expectations about the place based on prior experience or knowledge or it can be initially triggered by involuntary attention focusing. In the latter case, incongruence of the sound in the scene can enhance detectability [16]. Event Related Potential measurements confirm the deviant processing also with complex sounds but also show that familiarity with the sound has an effect [55]. A foundation for rapid extraction of meaning from a familiar environmental sound was observed even when sounds were not consciously attended. Thus the soundscape theory has to account for this dual effect: congruent and familiar sounds are less likely to trigger attention but they are also to most probably object of voluntary attention focusing during listening is search or story listening.

Until now we did not consider the relationship between attention and binaural hearing. Inhibition of return on location [56] could explain why moving sources or groups of sources of the same kind popping up at different locations might be less easily inhibited by the auditory system and thus continue to attract attention longer than a stationary source. It is known that identity information predominates over location information in auditory memory [57] thus soundscape appraisal (see the following sections) in itself – in contrast to unmasking – may be less sensitive to aspects of binaural hearing.

The reaction of the brain to sensory stimuli depends on its current state. According to the attention to memory model hypothesis, very similar attention mechanism are involved in memory tasks at the one hand and sensory processing tasks at the other [58]. Part of the neural circuitry even seems to overlap. This implies additional modulation of overall attention devoted to the sonic environment. Conversely, it also implies that sensory input in general and sound in particular can distract from memory (and cognitive) tasks. Soundscape perception can therefore be different for the same person at different instances dependent on current activity.

Giving meaning to sound(s)

The role of audition is not mere information processing but re-cognition, resulting from bottom-up (signal-driven) and top-down (knowledge-driven) processing. It also contributes to meaning giving through activating behavioural options, of which the best can be selected [43]. Meaning is given in a context for a person at a given time. The sensory perception could even be regarded as a factor correcting and fine-tuning the mental representation of the (sonic) environment. As such, meaning of sound(s) could be determined as much by the current status of the mind (emotions included) as it is by the stimulus per se.

Meaning could be given to the sound itself but it is more likely that it is given to the event it stands for, or is a cue for some previous more global representation in memory. This implies some form of mapping from the sound to an event before meaning is given. In case of nomic mapping the sound and events present consistent information. The event itself produces the sound, e.g. a car approaching. In this case the sound source (e.g. the car) will often be the most important factor in creating meaning. Symbolic mapping relates a sound to an event that does not produce the sound. Furthermore symbolic representations (and mainly those referred in languages) allow sharing individual experiential meaning and contribute to the elaboration of social (conventional) meaning. E.g. police siren indicates a warning signal alerting of some kind of misfortune for someone. E.g. church bells are mapped to an event that is not the ringing of a bell per se but a socially defined event such as celebration, in a specific culture. Through meaning production, an acoustic stimulation can be at the same time an individual experience as well as a shared one. This accounts for very different preference amongst different cultures or communities. Soundscape thus has to be evaluated taking into account the corpus of population involved, and the psychological context of people.

The meaning given to a sound or the event or source it stands for, relies on complex process such as categorisation and naming, where one category does not depends exclusively on its intrinsic properties but also on its resemblance and differences with other categories within the whole classificatory system. Therefore the same signal can be categorised at different levels of categorisation (more or less specific, e.g.. as traffic, car, sport car, human voices, or child voice, my child calling!) or along different principles of categorization (source, event such as car breaking or starting [27], global appraisal, wanted versus unwanted sound)[64]. This vague meaning is sharpened by knowledge on the place [28] and by the most recent meaning attached to the auditory stream. The latter could explain why the path followed by the person experiencing a sonic environment matters for the interpretation and appraisal of a sonic environment.

Appraisal

Recently, Kuppens et al. [44] reported highly ecologically valid research into the bidirectional relationship between the way we appraise our (current) environment and how that influences how we feel, plan, and act. Kuppens studied this relationship in the context of core affect, which is defined as an integral blend of the dimensions displeasure-pleasure (valence) and passive-active (arousal) [45]. Unlike emotional episodes, which are relatively infrequent, core affect is continually present to self-report.

The concept of core affect and the associated appraisal of the sonic environment appear in a number of soundscape studies. Depending on the choice of the researchers, the main appraisal dimensions are either termed pleasantness and eventfulness (which match the dimensions of core affect) [2] or a combination of these dimensions rotated by 45 degrees. Cain [9], [46] reports the dimensions vibrancy (interpreted as combination between pleasant and eventful) and calmness (combining pleasant and uneventful). Axelsson [2] proposes to interpret the vibrancy dimension as a continuum from monotonous to exiting and the calmness dimension spanning from calm to chaotic. One could argue that these dimensions of core affect are related to the person rather than to the sonic environment but with soundscape interpreted as an object in the mind, this does not pose any problem.

There is no direct evidence on whether appraisal and core affect are related to the sonic environment as a whole or on the meaning given to the events and sound sources that are heard. In this context the results of the COST summer school in Aachen are worth mentioning [62]. In one particular sonic environment the appraisal differed significantly between two groups of listeners: those that mentioned afterwards that a saxophone player was the dominant sound source, and those that mentioned a fountain as the dominant source. These results seem to indicate that the sound source that received more attention also determined dimensions related to core affect and thus that auditory scene analysis, attention and probably meaning precede appraisal.

The mechanisms connecting at the one hand sound recognition and giving meaning to on the other hand appraisal and core-affect are as yet not fully understood. It has been noticed that familiarity of the listener with the sonic environment explains the way the sound is perceived [2]. In music research, it is known that the familiarity of the sound plays an important role in the process of engaging emotionally and potentially liking it, an observation that was recently confirmed by brain research [60]. Familiarity at a low level processing can be linked to how difficult or easy it is to re-cognizing – involving previous memorized representations. In this way expectations enter the process for at a low level. Sounds that are expected at a place are more easily recognized.

However, expectations may play a role at another level in the appraisal process. Matching expectations is a key factor in learning. In this context expectation is interpreted as the events that the cognitive system predicts given its knowledge on the place, and thus the sounds that will be heard. If this prediction matches the events that actually occur, the learning brain is rewarded. A sonic environment that results in rewards – thus contains expected sounds –, will in this way lead to a more pleasant experience.

Measuring soundscape

Measuring is a way of representing a reality to allow comparison and making it interpretable by those that had no direct contact with it. This allows proposing designing actions and finding sound variables that must be addressed to improve acoustic comfort. In this broad view, measuring sounsdcape can involve measuring people, measuring with people, or measuring with electronic human-mimicking devices. The difference between measuring people and measuring with people might sound subtle, but we will explain in this section why it is not.

Measuring people

When measuring people, the investigator wants minimal interference with the test persons. The observation is mainly retrospective unless subtle bio-monitoring can be used. This kind of measuring can attempt to capture general mood, restoration, appreciation, preferences, and overt behaviour, and thus assesses the soundscape as a whole within a context. This type of measurement fulfils the role of creating a representation perfectly but it is rather difficult to obtain results that allow comparing between areas. Moreover, this type of measurement should respect the way people are experimenting their environment. So the measurements should not only characterize locations one by one, but also paths between different locations. In that case, the adapted measurements should follow to the listener movements.

Measuring people is the only possible way to assess the whole path from sonic environment to soundscape, including the processes of giving meaning to sound(s) and appraisal.

This assessment is holistic in the sense that it covers all auditory streams and in the sense that it covers all other context variables such as visual stimuli, expectation, etc. It is not certain when the holistic experience that is reported by persons is constructed. Part of it might certainly be triggered by the questioning of the subject. A fast intuitive response may be more useful than a well thought of answer given later. In the latter case a cognitive process aggregating the analytic results that tries to match the expectations of the person asking the question might be generated: “I heard birds so I am expected to say this is more pleasant”. To apply this holistic approach interviews and/or questionnaires are the most commonly used tool. To use the results in a planning process, information on the processes discussed above may be gathered: what sounds did they hear (attention process), what these sounds mean to them, how this relates to expectations concenring the place, etc. This information should be collected after the main appraisal questions in order not to stear the process.

As stated above, one of the most important drawbacks of measuring people is that the selected methodology may influence the results.

Measuring with people

Measuring with people implies that the sensory and cognitive capabilities of humans are used to assess the (sonic) environment. The participants are usually in an attentive, analytic listening mode. To obtain measurements with high comparability one either has to rely on statistical averaging of the personal factors that might influence the human observation or a master scaling [24] has to be used to eliminate some of these personal factors by first asking the participants to judge a set of standard stimuli. These stimuli could either be classical pink or white noise samples, but they could also be reference sonic environments explicitly exhibiting the soundscape features that the research is trying to explore. The latter comes down to calibrating the human as measurement equipment.

The human observer has some capabilities that are hard to mimic using electronics and computational intelligence, for example the capability to segregate the auditory environment into streams and objects. Thus questions such as identifying the dominant sound source can easily be answered. Measuring with people, because of the attentive analytic listening mode, is particularly suitable for analytic description of the soundscape. An analytic description of the soundscape includes an inventarisation of the sounds and the sources producing these sounds. It may also include a description of the quality of the sound , the meaning for that particular group of people, and an indication of congruency. The latter require the definition of a clear context –sketched in lab or influenced by the place in field studies – that generates particular expectations. The description can be complemented by the level, perceived or physical.

In the first section of this paper, the importance of attention mechanisms in the soundscape concept has been stressed. Measuring with people puts very strict requirements on managing the attention processes. If the objective is to assess how often certain sounds would be heard in the environment, attention should not be focussed on sound during the measurement. The human (binaural) auditory system is capable to unmask sounds effectively down to strongly negative L_{Aeq} based signal to noise ratios. However, this does not mean that a sound would have been given any attention in a natural setting while attending everyday business. Thus many different distraction methods have been suggested. When such techniques are effective, the sounds and number of sound events reported are sometimes surprisingly different from the assessment based on attentive listening and counting [61].

Measuring in a human mimicking way

Electronic equipment embodying computational intelligence can mimic the listening capabilities of humans. For the easiest indicators based on level, temporal variability of the level, spectrum, and loudness, each measurement tool produces the same outcome and comparability between sonic environments becomes trivial. However, the representation of the soundscape that is created is rather poor. Information on level, spectrum, and loudness are not sufficient to allow the evaluator or designer to imagine the soundscape. More advanced, smart sound meters [4] allow to give information on the sounds that could be heard at the measurement location [23] but at the same time there is no gold standard and comparability of measurements becomes worse.

Using electronic equipment has the clear advantage over measuring people that it allows for long term monitoring. Such monitoring is necessary to study diurnal and seasonal variations in the soundscape. It is also an essential tool to detect novel and unexpected soundscape elements.

It should be stressed that research on measuring soundscape either with people or with human mimicking equipment is ongoing.

Triangulation

Triangulation refers to the process of combining different views, different measurement methods to improve the knowledge on a concept or object. In soundscape measurement, one often combines the three measurement approaches described above to obtain a clearer picture of the soundscape. Connecting the deep understanding of the whole obtained from measuring people with more focussed measuring with people and human mimicking physical measurement, allows to gain insight in how the local soundscape “works” and to use this knowledge for improving design.

More aspects of the holistic approach, apart form sound variables, must be considered to have a soundscape understanding that provides information for decision making process to improve it. Since visual, thermal and general satisfaction with the place influences soundscape, these aspects must be considered for a deeper understanding of soundscape in the place and the moment that is perceived.

Lessons learned for soundscape design

The goal of soundscape design is to create environmental comfort by influencing the mood, the emotion, the appraisal, and the restoration of persons visiting the place. From the theoretical discussion on how the sonic environment results in a soundscape experience several guidelines for future designs can be extracted:

- At the detailed level of composing, attention should be purposely directed to certain components of the sonic environment, to certain sounds, while keeping attention away from unavoidable sounds that are not wanted by the designer. Sounds can be analysed for their saliency, but also their familiarity for the most likely users in determining the probability that they will be paid attention to.
- Multimodal aspects – visual, thermal, … - should, should considered. Spatial aspect of audio-visual matching should be taken into account. Visual stimuli can help to draw attention to wanted sounds but at the same time they can cause conflict when creating incongruence between visual and auditory stimuli. The probability that an undesired sound will attract attention anyhow is crucial here.
- The path usually followed by people visiting the place has to be taken into account since recent experience has a strong influence on listening style, attention paid to sound, recognizing, meaning and appraisal.
- In setting the goals, expectations based on the intended or actual use and functions of a place should be considered carefully since it has been shown theoretically that these expectations may influence the soundscape appraisal or even the mere perception to a very high degree.
- The soundscape architect should try to balance familiarity and novelty in the sonic environment design to obtain the desired amount of vibrancy and calmness matching the use and function.

For the above to be possible, architects and city planners should be provided with the tools for understanding soundscape and for its integration as a design variable from the earliest stages of design

Conclusion

Over the past four years the COST exchange program has allowed our knowledge and understanding of the soundscape to grow in different areas. WG1 in particular has focussed discussions on mechanism. The results of these fruitful discussions as yet still have only partly been condensed into scientific writing and laymen publications.

Smart sound meters embedding this knowledge are under construction as well as calculation and mapping methods that could be used by architects and city planners. Some fundamental research however still needs to be done on connecting multidisciplinary knowledge and on validating many of the theoretically expected relationships discussed in this report and the hypotheses formulated.

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