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Ten questions on the soundscapes of the built environment

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Abstract: Soundscape research represents a paradigm shift from noise control policies towards a new multidisciplinary approach as it involves not only physical measurements but also the cooperation of humanity and social sciences to account for the diversity of soundscapes across countries and cultures, with more focus on how people actually experience the acoustic environments; and it considers environmental sounds as a 'resource' rather than a 'waste'. The ten questions presented in this paper range from the very basic definitions underlying the emerging soundscape 'science', to more applied topics about how to use soundscape as a design approach for the planning and management of the built environments. Although significant research activity has been conducted so far, there is still a need to systematically provide the underpinning science and practical guidance in soundscaping. Thus, the last question aims to identify the most crucial gaps in soundscape research and set the agenda for future advancements in the field.

Keywords: soundscape; acoustic environment; environmental noise; urban sound planning; quality of life

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Introduction

The concept of 'soundscape' is originally rooted in the music and acoustic ecology research areas. It quickly expanded to other disciplines, such as acoustics, architecture, environmental health, psychology, sociology and urban studies, claiming for further attention and a holistic approach to the way we conceive the sound around us and its perception (Schafer, 1977; Truax, 1978). To some extent all the above mentioned disciplines have something in common. They deal with how humans experience the environments and try to establish relationships between the physical world and the human response to it (e.g., Cassidy, 1997; Sörqvist, 2016). Sound is globally acknowledged to be a main component of such experience and ever since soundscape started to emerge as a science, researchers started questioning how cities and the built environment overall should 'sound like' (e.g., Southworth, 1969).

However, over the years, sound was mainly considered in its epidemiological aspects of 'noise' and most of international environmental policies focused on noise control (e.g., World Health Organization, 1999; World Health Organization, 2011; European Parliament and Council, 2002). Reducing sound levels, though, did not necessarily lead to improved quality of life in urban and rural areas (e.g., Yang & Kang, 2005; Andringa, et al., 2013; van Kempen, Devilee, Swart, & van Kamp, 2014; Asdrubali, 2014; Alves, Estévez-Mauriz, Aletta, Echevarria-Sanchez, & Puyana Romero, 2015) and this is why the soundscape multidisciplinary approach to the management of the acoustic environments became more and more relevant, for its focus on how people actually perceive and experience the acoustic environments. Soundscape research represents this paradigm shift as it involves not only physical measures but also the cooperation of human and social sciences to account for the diversity of soundscapes across countries and cultures, and it considers environmental sounds as a 'resource' rather than a 'waste' (COST TUD Action TD-0804, 2013). The environmental noise and soundscape approaches to the management and design of the acoustic environments vary substantially, but they are not mutually exclusive. Following the discussions in the COST action, Brown (2012) summarised what are the most salient differences in terms of how the 'sound'

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is conceived, how it relates to human perception and how it should be consequently measured and managed (see Table 1).

Table 1 - Differences between the Environmental Noise and Soundscape management of the acoustic environments. Adapted from Brown (2012)

Environmental Noise management framework	Soundscape management framework
Sound managed as a *waste*	Sound perceived as a *resource*
Focus on sounds of *discomfort*	Focus on sounds of *preference*
Human response related to sound levels*	Human response often *not* only related to sound levels*
Measures by *integration* across all sound sources	Requires *differentiation* between sound sources
Manages by *reducing* sound levels*	Manages *masking*** unwanted with wanted sounds as well as reducing unwanted sounds

* sound level refers to an equivalent sound pressure level, L_{Aeq} over 10 minutes or more
** masking includes perceptual masking as well as energetic masking

Although soundscape started to be a research field in the late 1960s, it received significant attention mainly in the last fifteen years in the field of community noise and environmental acoustics by researchers, and recently by policy makers and practitioners. This is confirmed by the steadily growing number of people involved in this topic. From a research point of view, a special issue of Acta Acustica united with Acustica (the Journal of the European Acoustics Association) was produced on soundscape in 2006 (Schulte-Fortkamp & Dubois, 2006). Others special issues followed in different journals (see, for instance: Pijanowski & Farina, 2011; Schulte-Fortkamp & Kang, 2013; Davies, 2013), increasing the number of publications in scientific literature of the field, as shown in Figure 1.

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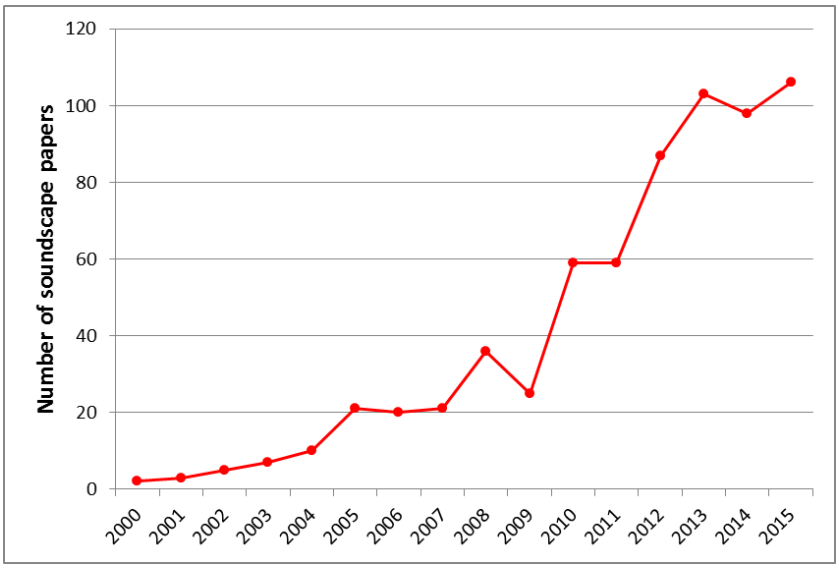

Figure 1 - Number of papers retrieved in the Scopus® database using 'soundscape' as criterion (TITLE-ABS-KEY) in 'Health Sciences' and 'Social Sciences & Humanities' sections

Possibly, this was also in response to the requirements of the Environmental Noise Directive (European Parliament and Council, 2002) about the need to identify and preserve 'quiet areas'. Indeed, the European Environment Agency in its "Good practice guide" acknowledges 'soundscaping' as one of the strategies to identify and manage quiet areas (European Environment Agency, 2014), thus a lot of research efforts focused on this one particular soundscape: quietness and tranquillity (e.g., Pheasant, Watts, & Horoshenkov, 2009; García, Aspuru, Herranz, & Bustamante, 2013; Brambilla, Gallo, Asdrubali, & D'Alessandro, 2013; Brambilla & Gallo, 2016).

The importance of soundscape research has been recognised by governmental organisations and national funding bodies in Europe, and a number of national research projects relating to this field carried out in Europe, such as the *Noisefutures* network and the associated *Positive Soundscape* projects funded by the UK EPSRC (Engineering and Physical Science Research Council), the *Soundscape support to health* project funded by the Swedish Foundation for Strategic Environmental Research, the *Eye-Hear Project - Qualitative sound maps for visualization of the urban soundscapes*, funded by the Portuguese Science and Technology Foundation, and a series of soundscape projects funded by the French Ministry of Town Planning, Housing and Construction, as well as the *PREDIT* program (National

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Research Program on Innovation in Transport). In other parts of the world including Australia, Canada, USA, Japan, China, Hong Kong and Korea, considerable attention has also been paid to soundscape research.

Nonetheless, there is still a need to systematically provide the underpinning science and practical guidance in soundscaping. Overall, soundscape research and practice has a huge impact potential in terms of promoting public health and quality of life and conveying cultural uniqueness and diversity to our world. Moreover, the main issue in soundscape is not the focus on quiet areas but on areas where noise is used as a resource.

The ten questions presented in this paper, based on a series of workshops of the COST Action (COST TUD Action TD-0804, 2013), range from the very basic definitions underlying the emerging soundscape science, to more applied topics about how to use soundscape as a design approach for the planning and management of the built environments. Questions 1 to 4 address the issue of defining the soundscape framework and its relationships with socio-cultural contexts and quality of life. Questions 5 and6 deal with 'methods' for data collection and soundscape characterisation, while Question 7 explores how such data could be implemented into planning and design tools. Question 8 offers an historical angle on how soundscapes can be considered part of our 'immaterial cultural heritage'. Eventually, Question 9 provides some insights on current best practices and test sites in soundscape studies and applications, while Question 10 aims to identify the most crucial gaps in soundscape research and set the agenda for future advancements in the field.

1. What is the definition of soundscape?

The concept of soundscape has been applied across widely diverse disciplines since the term, used by Southworth in an urban context in 1969 (Southworth, 1969), was popularized by Canadian composer, Schafer in 1977 (Schafer, 1977). Recently soundscape has been defined by the International Organization for Standardization (ISO) as "[the] acoustic environment as perceived or experienced and/or understood

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by a person or people, in context" (International Organization for Standardization, 2014); 'soundscape' is different from 'acoustic environment' as the former refers to a perceptual construct, and the latter to a physical phenomenon, while both are affected by the context, as schematised in Figure 2. Within the framework of this paper, we will refer to soundscape as defined in the ISO standard. Context is meant as the physical place where the acoustic environment exists, and according to the ISO definition, it "includes the interrelationships between person and activity and place, in space and time […] and may influence soundscape through (1) the auditory sensation, (2) the interpretation of auditory sensation, and (3) the responses to the acoustic environment."

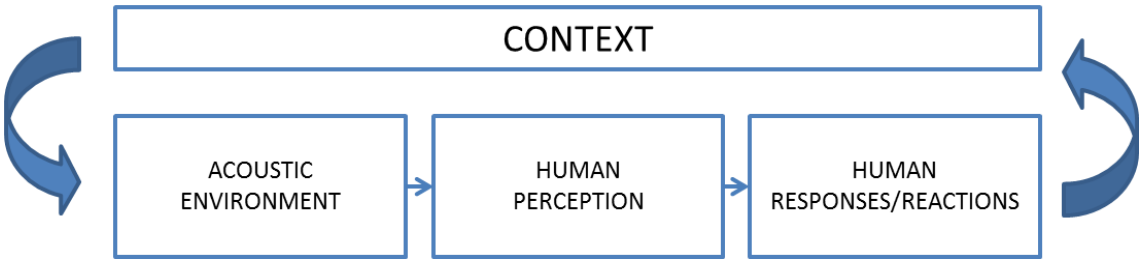

Figure 2 - Elements in the perceptual construct of soundscape. Adapted from (International Organization for Standardization, 2014)

While the ISO definition provides an important, and rigorous, distinction, it is recognized that some, particularly planners, designers, lay persons, and even those primarily interested in management of the acoustic environment through environmental noise control, will find it convenient to use "soundscape" as a synonym for the physical acoustic environment. As long as such equivocal usage of the term soundscape does not introduce confusion in communication, we can be relaxed about the ambiguity.

The soundscape, as a perceptual construct, can also apply to the acoustic environment in memory, to the "assumed acoustic environment" of a historic place or event (e.g., the Forum Romanum in ancient Rome or the Civil War battle at Gettysburg), or even to abstracted acoustic environments such as musical compositions. Even more broadly, the soundscape terminology has variously

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encompassed, for example: the recording of the sounds of nature; the creation of compositions based on, or of, natural sounds; studies of the sounds heard in villages and rural environments; documentation of disappearing sounds; analysis of the way acoustic environments have been described in history and in literature; analysis and description of all types of acoustic environments; and the creation of artistic sound installations.

The term soundscape may be considered in relation to the term landscape. The European Landscape Convention Agreements (Council of Europe, 2000) defined landscape as an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors. Substituting place for area because of the high spatial variability of the acoustic environment over any of the types of outdoor areas in which we are likely to be interested, the analogous definition of soundscape is: soundscape is the acoustic environment of a place, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors. The interpretations that can be placed on the term soundscape can be as diverse as the different interpretations people already have of its namesake landscape—for example, the latter can include: landscape as geographical form; landscape as a system of physical components; landscape as both determinant and reflection of culture (painting, literature and music); landscape as a place for recreational activity; and landscape in the design activity of landscape-planning or architecture. A similar diversity applies to interpretations/applications of the soundscape term.

2. How can acoustic environments become soundscapes?

Understanding human auditory scene analysis and the important role of auditory attention allows us to outline better soundscape assessment methods and to come to enhanced methodologies for designing desirable soundscapes within a specific context and for a specific use. Environmental sound by definition is not the primary focus of attention of a person submerged in it. Rather, specific sounds that stand out,

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that are salient, attract attention and become auditory objects as the listener starts paying attention to them (Botteldooren, et al., 2015). Not only the composition of the acoustic environment determines what sounds are noticed but also the attentiveness, current activities, and expectations of the listener and its prior knowledge of the sounds that could be heard. As attention is largely multisensory and multisensory stimuli can partly be bound into a single percept even prior to attention, the visual context and visibility of the source play a significant role.

These noticed sounds are associated to a broader set of mental objects or representations, they are recognised, and become meaningful. The meaning that is given depends on prior experience of the individual or on public discourse concerning these sounds. The common experience and discourse within a society are strongly culturally loaded. As such, the meaning given to noticed sounds is both individually and culturally determined. The sounds extracted from the acoustic environment could be labelled sound marks. A few sound marks are often sufficient to identify one's own living environment and to give the soundscape an identity (Oldoni, De Coensel, Bockstael, Boes, De Baets, & Botteldooren, 2015). Yet the noticed sounds are nothing more than the chords in the soundscape composition.

The sequence of sounds both consciously noticed and subliminal may influence appraisal of the acoustic environment. Predictability leads to positive appraisal because the prediction success which causes an aesthetic emotion (Leder, Belke, Oeberst, & Augustin, 2004), is misattributed to the sound itself (Huron, 2006). A moderate degree of expectation violation is also experienced as pleasurable. This may be explained by the award found in learning: extremely unpredictable sequences of sound as well as extremely predictable sequences afford reduced opportunity for learning (Pearce & Wiggins, 2012). But, completely unexpected sound events that are inoffensive in a way that they do not limit behavioural options may cause laughter or awe and thus contribute to the pleasant eventfulness of the soundscape. Sequences in sounds occur because of actual changes in the acoustic environment or because the user of a space wanders from one part to another. Hence the soundscape also depends in the path followed by the user of the space.

Implementing a desired soundscape matching the designer's vision by modifying the acoustic environment thus faces important challenges. Knowing the users and their cultural heritage is a key factor in deciding what sounds give the desired meaning. Exploiting saliency of each sound in its context, attention can then be focussed on these sounds. Finally expectation and surprise, repetition and novelty have to be explored to create a pleasurable experience. This is probably the main challenge of them all.

3. How are soundscapes related to socio-cultural backgrounds and context?

The first and main message is that the soundscape approach is holistic, meaning that we are looking at the assessment of the acoustic environment based on the contribution from different disciplines. Moreover, soundscape is a construct of human perception, which is influenced by the socio-cultural background, as well as by the acoustic environment in context (International Organization for Standardization, 2014). Among others, the meanings of sound, the composition of diverse sound sources, the listener's attitude and expectations towards the acoustic environment is most important with regard to the soundscape concept. Previous experiences of individuals with the acoustic environment are significant to completely comprehend the different perceptions and assessments of the environment. For instance, previous research shows that people who grew up in a small town will have a different understanding of sounds than people who grew up in a metropolitan area (Schulte-Fortkamp, 1994; Nitsch, 1997; Farina, 2014). Moreover the lifestyle and understanding of rules is also an important contribution with regard to socio-cultural background. Considering the socio-cultural background is important to understand the assessment of any acoustic environment.

According to Kull (2006), a soundscape is the entire acoustic environment resulting from natural and man-made sound sources. Every environment is different and the contribution of sound sources varies. Therefore, when considering the built environment and modelling or analysing dependencies within soundscapes, it may be useful to consider sound sources which range from completely urban on one end

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to extremely natural on the other. Lercher and Schulte-Fortkamp (2003) pointed out that contributors of soundscapes include geography, climate, wind, water, people, buildings, and animals. In other words, soundscape assessments should consider other sensory systems, including visual aesthetics (visual cues), geographic, social, psychological and cultural aspects. With this in mind it becomes clear that soundscapes do more than just describing the sound level or audibility of ambient and intrusive sounds. Indeed, response to sound depends on the listener's mental, social and geographical relation with the sound source and the context.

Given the strong influence from socio-cultural backgrounds and context as discussed above, when perception is "measured", "we are referring to a heterogeneous *field of research*" (Hollstein, 2010) and among them are different forms of observation, interviewing techniques with low level of standardization (such as open-ended, unstructured interviews, partially or semi-structured interviews, guided or narrative interviews), and the collection of documents or archival records (e.g., from libraries or public repositories) is also commonly used. In spite of their differences, those approaches all share a common ground, as advocates of the 'interpretive paradigm' agree on certain ideas about the nature of social reality (Hollstein, 2010). Social reality is always a 'meaningful' reality, and by representing meaning, refers to a context of action in which actors organize actions (Hollstein, 2010).

4. How are soundscapes influencing health and quality of life?

Access to high quality acoustic environments may positively affect well-being, quality of life (The Whoqol Group, 1998), and environmental health through some restorative or health and wellbeing promoting mechanism (van Kamp, Klæboe, Brown, & Lercher, 2015). Two types of restoration can be discerned: Type 1 restoration refers to a high quality acoustic environment providing restoration directly; Type 2 restoration refers to the effect of availability (knowledge) of a high (better) quality acoustic environment to a person who otherwise is subject to adverse effects of noise. Type 2 includes availability of a quiet place or access to nearby green areas.

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Epidemiologic evidence on the intrinsic positive value of areas with high acoustic quality such as green areas/wilderness/water is limited. For restoration by way of mediation, several studies (e.g., de Kluizenaar, Janssen, Vos, Salomons, Zhou, & van den Berg, 2013) showed that access to quiet in or near the home reduce annoyance at home and also has a beneficial effect on sleep quality and blood pressure. Temporary respite from exposure to unwanted environmental noise at home can mitigate the negative effects on health and wellbeing. Different features of the immediate physical environment play together: e.g., access to green space in the immediate vicinity of dwellings moderates the effect of the availability of a quiet side of the dwelling and annoyance. Also, a need for quiet space in the wider area is felt more by people who live under noisy conditions (e.g., high traffic noise equivalent levels) and by people who are noise sensitive (Booi & van den Berg, 2012). We still need to advance our understanding of the process by which these different mechanisms may operate.

Laboratory studies and controlled field experiments (e.g., (Hartig & Staats, 2003; Hartig, Evans, Jammer, Davis, & Gärling, 2003; Hartig, Mitchell, de Vries, & Frumkin, 2014) have shown repeatedly positive effects on mood, perceived quality of life and wellbeing, when subjects were exposed to predominantly natural sounds in parks, forests, urban areas, work environments or dynamic, virtual environments including both nature and sounds.

The majority of these findings may, however, have been confounded by other qualities of the experienced environment. In the rare studies, where experimental control was provided, parasympathetic activation was observed in the group subjected to sounds of nature but not in the virtual nature group without sound. These findings indicate physiological stress recovery and restoration effects by natural sounds through balancing the autonomous nervous system (Annerstedt, et al., 2013). The sustainability and repeatability of the observed effects is less clear.

There is increasing evidence of a reduction of adverse effects of noise exposure (annoyance, sleep, blood pressure) when the residential soundscape is judged of higher overall quality (quiet facades, quiet courtyards, visual attractiveness, green space, ecological features) (e.g., Dzhambov & Dimitrova, 2014; Van Renterghem &

Botteldooren, 2016). In addition, however, positive valued soundscapes were associated with higher vitality, less need for quiet and greater satisfaction with access to quiet areas (Lercher, van Kamp, von Lindern, & Botteldooren, 2015). Likewise, these studies cannot distinguish the effect sizes attributable to the sound quality from other features of the neighbourhood.

Few studies investigated systematically restorative effects. The observed findings indicate some evidence of positive effects on general health indicators when sound environments provide sufficient restorative qualities (von Lindern, Hartig, & Lercher, 2016). Even if some further knowledge on the relationship between soundscape and quality of life is still needed, future research should go towards the full integration of the wider environmental, social, psychological and ecological context to guide soundscape design in planning processes at various decision levels. The soundscape approach offers further options to improve health and quality of life under unfavourable acoustic environments at medium and smaller geographical scales (Andringa, et al., 2013).

5. How can we ‘measure’ soundscapes?

The main challenge with respect to measuring soundscape is that soundscape is a multifaceted phenomenon and hence cannot be measured with few single numbers. In general, soundscape must be measured, assessed and evaluated through human perception of the respective acoustic environments (International Organization for Standardization, 2014). Therefore, all measurement procedures, whether collecting physical or perceptual data, have to be strongly related to the way humans perceive the acoustic environment. This is the central tenet of the soundscape approach and guides the way soundscapes are measured. Following this notion, for the purpose of characterisation, it is desirable to perform recordings of acoustic environments with binaural technology enabling to re-experience the acoustic environment in an aurally accurate way and to determine acoustical quantities mimicking human auditory sensation. To describe and analyse those noise measurements appropriately, psychoacoustics parameters covering several dimensions of basic auditory sensations must be applied. In general, psychoacoustics deals with the quantitative

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link between physical stimuli with their caused hearing sensations (Fastl & Zwicker, 2007). Psychoacoustic parameters, like loudness, roughness, sharpness, fluctuation strength, enable to describe the character of an acoustic environment in detail and allow relating the physical phenomenon (acoustic environment) to the perceptual construct of the acoustic environment (soundscape). Detailed information about psychoacoustic parameters including definitions, meaning and applications, can be found in Fastl and Zwicker (2007). Moreover, since the classical psychoacoustic parameters cover only basic auditory sensations, further hearing-related parameters have to be introduced to detect and characterise temporal and spectral patterns adequately. A hearing-related parameter that has shown its significance in several surveys (Fiebig, Guidati, & Goehrke, 2009) is the relative approach parameter, which is related to perceivable patterns in acoustic signals. This parameter allows for quantifying the amount of temporal and spectral patterns and largely ignores absolute values (Genuit & Bray, 2006).

While physical metrics with close connections with the human hearing are essential to characterise the acoustic environment in a perceptually relevant way, in soundscape studies it is necessary to 'measure' perception, thus gathering individual data about the responses to the acoustic environment. Aletta *et al.* (2016) reviewed the most typical methods and corresponding operational tools used to collect soundscape data, as shown in Figure 3. The most typical methods are: soundwalks, laboratory experiments, behavioural observations and narrative interviews. The authors observed that even if some methods tend to recur more often than others, and they are often used in a combined way, the methodological approach largely depends on the way researchers decide to analyse the perception of the acoustic environment; i.e., whether it is experienced on site or virtually reproduced.

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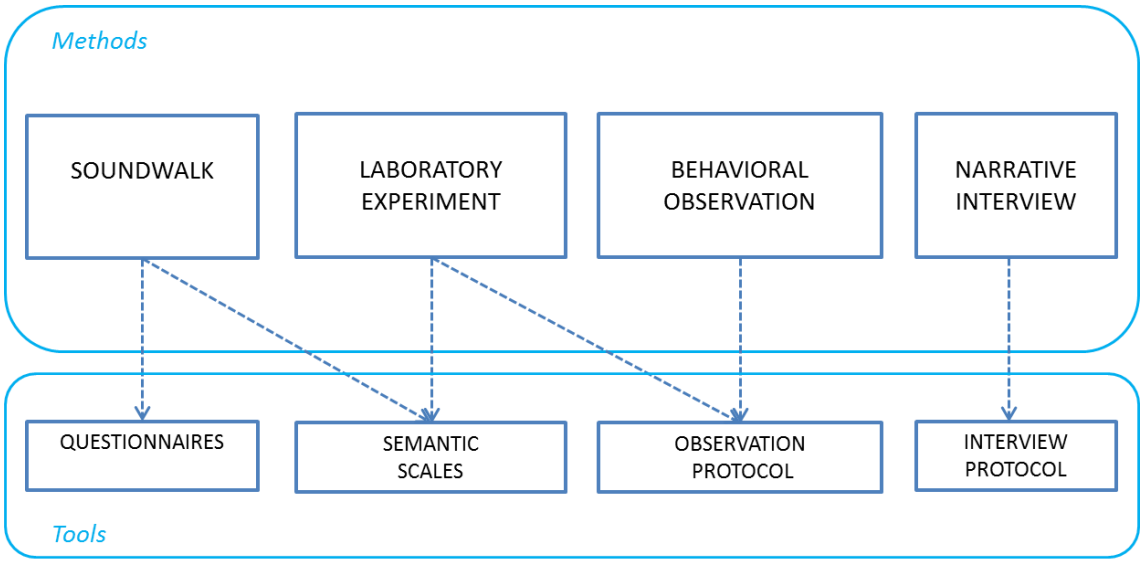

Figure 3 - Typical methods and corresponding tools to collect soundscape data. Adapted from (Aletta, Kang, & Axelsson, 2016)

The soundwalk method as an empirical method for identifying a soundscape and its components is the most frequently method applied to collect data to explore areas by minds of local experts opening a field of data for triangulation. The soundwalk methodology is a common measurement method for the evaluation of soundscapes (Jeon, Hong, & Lee, 2013). The essential purpose of a soundwalk is to encourage participants to listen discriminately and to make judgments about the sounds heard (Adams, et al., 2008), but the protocols can vary in various aspects, such as the way of performing acoustical measurements, way of questioning, sampling of participants, sample size, soundwalk duration, instruction, collection of visual information. However, the core of the soundwalk methods is that local experts experience and evaluate the soundscape under scrutiny in its real context (Figure 4).

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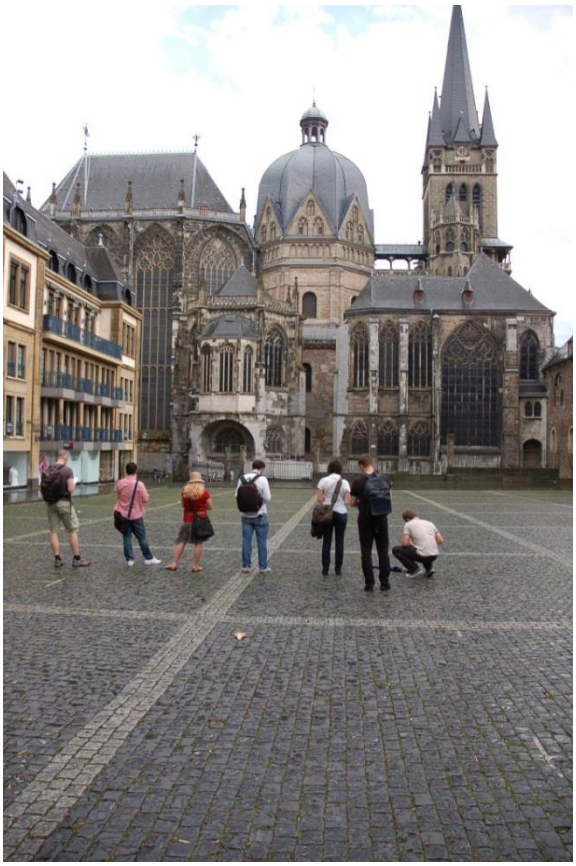

Figure 4 - Example of a soundwalk. Participants visited an urban square, listened at least three minutes to the acoustical environment and filled out an evaluation sheet (Fiebig, 2015). The soundwalks were performed within the framework of the COST network on soundscapes

The need to measure soundscape raises the question of how to define its 'quality' from a perceptual point of view. It is necessary to identify and to agree on relevant soundscape descriptors and attributes to be included in questionnaires, semantic scales, and observation and interview protocols (i.e., the tools reported in Figure 3), in order to gather individual responses against those criteria.

Some studies proposed to assess soundscape quality using general descriptors for 'soundscape quality,' addressing the overall perception of the acoustic environment, i.e., measuring whether a soundscape is 'good' or 'bad' (Aletta, Kang, & Axelsson, 2016). However, 'good' is contextual; thus, such general descriptors are not always likely to be suitable for all circumstances. For instance, the sound of a children playground might be good for a context (e.g. a park), but not necessarily good for another (e.g. a residential area). Consequently, since in everyday life sounds are processed on the basis of semantic features rather on abstracted perceptual (sensory) properties only, further perceptual dimensions must be considered. For

example, tranquillity has been considered, which is constructed through sensory information received by the auditory and visual modalities. A tranquil environment is one that is considered to be quiet, a peaceful place to be, i.e. a place to get away from everyday life (Pheasant, Watts, & Horoshenkov, 2009). Axelsson *et al.* (2010) developed a model to perform a perceptual characterisation of a soundscape. They observed two orthogonal components, pleasantness and eventfulness in the context of soundscapes. Andringa and van den Bosch (2013) used the dimensions 'pleasure' (valence) and 'activation' (arousal) to characterise soundscapes. These dimensions putting emphasis on emotion are linked to the appraisal of soundscapes and should be considered when collecting perceptual data.

Although several methods in the context of measuring soundscapes are widely used and established, it must be noted that research on measuring soundscape is still ongoing and this will be discussed further in Question 10.

6. How can we 'represent' soundscapes?

Soundscape data should be 'visible' and communicable. This is needed both for characterising soundscapes that 'already exist' and for pre-visualising soundscapes that 'might exist' in the future. Over the years, researchers often used spectrograms (i.e., time vs frequency) to represent the acoustic environments (often recorded from soundwalks) in soundscape studies (e.g., Genuit & Fiebig, 2006; Semidor, 2006; Aletta, Axelsson, & Kang, 2014). While spectrograms do not represent 'soundscapes' on their own, they might be viable tools to inform soundscape analysis as they provide further insights into the sound sources composition over time at a given place, as shown for example in Figure 5, which is essential for the sound sources differentiation (see also Table 1, in the Introduction). However, from a planning and design point of view, it would be useful to conceptualise the spatial distribution of certain sound sources and the soundscape variability in relatively large areas for potential soundscape information for users. Thus, visual representations (e.g., two-dimensional maps) of how the acoustic environment is perceived become useful tools both for understanding the soundscape composition and for design. At a strategic level, the European Environmental Noise Directive (END) requires L_{den} and

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L_{night} maps to be computed. Although, these only consider noise sources, and the corresponding exposures for people, but they only contain very partial and indirect information on people's perception of the acoustic environments and completely lack temporal resolution. In soundscape studies the full range of perceptible sounds in a given context at a given time is usually considered. Therefore, soundscape researchers are aiming to broaden the mapping process to other sources, both positive and negative (e.g., Hao, Kang, & Krijnders, 2015; Aletta & Kang, 2015).

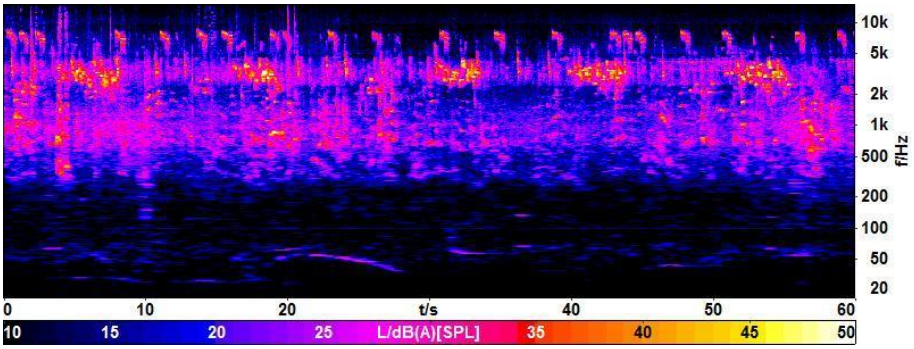

Figure 5 - A spectrogram from where 'birdsong' is clearly noticeable as a sound source standing out from the background noise

In order to represent existing soundscapes, two-dimensional maps could be developed as additional layers of landscape information. For instance, attempts have been made to map directly some soundscape dimensions (e.g. 'calmness', like in Figure 6), starting from individual data collected on site through soundwalks (e.g., Liu, Kang, Luo, Behm, & Coppack, 2013; Liu, Kang, & Behm, 2014; Aletta, Margaritis, Filipan, Puyana Romero, Axelsson, & Kang, 2015; Aletta & Kang, 2015; Aiello, Schifanella, Quercia, & Aletta, 2016). The hypothesis for developing such maps is that based on the soundscape information on certain locations in an area, the soundscape of the whole area could be predicted with spatial interpolation analysis method in GIS platforms.

Figure 6 - Example of 'Calmness' map in Brighton & Hove, UK. Adapted from (Aletta, Margaritis, Filipan, Puyana Romero, Axelsson, & Kang, 2015)

On the other hand, under a planning and design perspective, researchers have been exploring the possibility of using computer-based models, like Artificial Neural Networks (ANNs), to predict the soundscape quality evaluation of potential users in urban open spaces at the design stage (Yu & Kang, 2009). Such an approach requires large amount of data for the models to be likely to generalise and further research in this direction would be desirable.

The sounds' meaning within the context was also shown to be an important element in soundscape, for sounds that people notice. Therefore, an important step in mapping soundscape is mapping the sounds that users of the space are likely to notice. A sound's capability to attract attention depends on its characteristics, such as changes in time and frequency, often referred to as its saliency (De Coensel, Botteldooren, De Muer, Berglund, Nilsson, & Lercher, 2009). A sound's capability to receive attention and to get noticed also depends on the activity of the person. For mapping models inspired by human auditory processing, the latter can only be included in a general, person-independent way. Grouping of sounds into increasingly complex auditory objects (cars becoming traffic, bird chirps becoming a dawn chorus) is an example of such a common factor that can be included in a model (Oldoni, et al., 2013).

7. How can we 'plan' and 'design' soundscapes for the built environment?

Soundscape management and planning must always be part of the design of any place, either new or redeveloped, and taken as early as possible at the design stage,

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in the same way as visual or lightening aspects usually are. Even when noise is not a serious issue (if noise sources are not relevant), the sonic experience of the people using the place should be as enjoyable as possible, as it certainly will contribute to the overall appreciation of the site and of its quality. As discussed above, soundscape usually results from a complex structure of sounds, in their specific context. Sound components, of natural or of anthropogenic origin, will be heard and understood (except where masked), even completely or rationally identified, according to their topologies and meaning. The degree of appreciation will result from the experience of the user, from the interaction with information from all senses, and from confrontation with his/her expectations in view of the uses of the place. All these aspects will guide the soundscape planning and design.

The soundscape designer must then understand not only which sound sources correlate well with the users' expectations but also know the areas where the sounds of interest should be audible. These sounds of preference have to be well identified, together with those that are unwanted. The basic key for the designer here is to put the human listener/perceiver at the centre of the listening process and consider sound perception as a measurement. Care must be taken to put the listener and his sonic interests at the forefront of the design process with his preferences and expectations according to location, human activities, and local culture.

A number of paths and criteria should be followed, each using different techniques, which fall under three main broad steps (Brown & Muhar, 2004; Bento Coelho, 2015): to define the acoustic character of the place; to plan; and to design and optimize.

Defining the acoustic character requires a physical (i.e., through physical parameters and sound sources taxonomy) as well as a perceptual characterisation of the place (i.e., through targeted individual responses), using the methods discussed in Question 5. This characterisation includes the visual forms, the materials, the lights, the odours, and the people using it. This character is then to be well established, taking into account the current and foreseen purpose of the place, the uses, the activities, the variations in time (along the day or the week), but also the local culture and history, so as to define the objective acoustical goals (Brown, 2012).

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Planning the soundscape implies planning the physical features of the environment to achieve a specific acoustic objective (Brown & Muhar, 2004) and to support the desired perceptual outcome. The planning step will thus carefully identify: the areas of listening and the users' itineraries; the sound components, both existing and new, their sources and topologies; the sonic interests; and context. The dominant sounds, either wanted or unwanted, as well as time and geographical variations must be found and integrated in the plan. The sound component topologies can be defined by evaluating their limits of audibility in the whole area of interest, by perceptual measurement and mapping (Aletta & Kang, 2015). Overall, the soundscape planning stage requires the capability to anticipate to some extent what the above mentioned perceptual outcome will be. For this purpose, soundscape predictive models will be needed, which is one of the future challenges also discussed in Question 10.

By discussing possible options for soundscape management and design with stakeholders (such as residents, citizen groups, or transport authorities), planning technicians (architects, engineers, urban planners, consultants involved), and decision makers (local authorities, for example) light might be shed on the best applicable solutions and on the users expectations. Noise control measures and strategies are used to reduce or eliminate unwanted sounds where possible. Masking techniques may be adopted by making use of the psychoacoustic phenomena, by enhancing or introducing sounds of preference that will mask unwanted sound components or will divert the attention of the listener to other more pleasant sounds. When new sounds are introduced they must correlate with the place and with the human activities and expectations so as to assure overall coherence and context.

8. How are soundscapes shaping our history?

Human beings integrate, in real or imaginary situations, the sensorial stimuli that surround them. So buildings, panorama, and in general all cultural and natural heritage cannot be described, appreciated, and consequently, valorised using a mono-sensorial component analysis essentially based on vision. Many times, in fact,

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our ability to recognize the intrinsic value of elements that surround us is unconsciously guided by the presence of sound.

The tolling of the bells in a square, the reverberant atmosphere inside a church, the quietness sense in a cloister, the voices of the shopkeepers in a crowded historical market, the rattle of an old tram, but also the stadium chant and the yells on a recreation ground, are all examples of sound marks or iconic sounds and, as such, they are an intrinsic part of a specific context. They can stimulate our sphere of emotions and they can influence our global sensation in experiencing that specific context (Burgess & Wathey, 2000).

When for the population the feature of hearing in a scenario, now, as in the past, is important, and in some cases predominant then the soundscape of that scenario should be considered an intangible cultural element, linked to the social and cultural heritage of the community and part of our history. As a consequence, it should be preserved and valorised, just like the other artefacts (Brambilla & Maffei, 2010; Huang & Kang, 2015; Zhang, Zhang, Liu, & Kang, 2016).

In the larger scale such as the urban scale, the soundscape of a city across space, time and society, is the result of several stratified factors: human activities, transport technologies, culture, geographic position, town planning, human habits and way of life. Although processes of globalization and new technologies can change the urban soundscape making its recognition harder, this intangible element does not always lose its intrinsic characteristics as recognized and felt by the population and it becomes one of the signs of the identity of a city (Maffei, Iannace, & Lembo, 2004; Brambilla, De Gregorio, Maffei, Yuksel Can, & Ozcevik, 2007; Gómez Escobar, et al., 2012; Brambilla, Maffei, Di Gabriele, & Gallo, 2013).

In details in the same city we can recognize areas in which, although the people's lifestyle and some details were modified, the actual soundscape can be assumed to be similar to the one in the past (Fernandez Álvarez, Pascale, Masullo, Maffei, & Puyana Romero, 2014), areas in which the presence of a specific sound source has altered the original soundscape, which is, however, still present in the background, and areas that had a radical urban and social transformation and in which all past sound sources disappeared and were replaced by new ones (Zhou, Kang, & Jin,

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2014). Besides all, the soundscape of these areas takes over and accompanies our daily life as residents and impresses us as tourists during our visits. On the other side the variety of stimuli favours the concept of mixophilia and encourages the possibility of living peacefully and happily with difference (Maffei, Brambilla, & Di Gabriele, 2015).

9. What examples of soundscape practices do we have so far?

While there are still relatively few soundscape improvement projects, some examples are available to represent a range of practical soundscape applications.

The project *Nauener Platz: Remodelling for Young and Old* (Schulte-Fortkamp, 2010) represents a successful implementation of the soundscape approach to the management and design of the urban sound environment. Data were triangulated through measurements on sound propagation, traffic censuses, binaural recordings, and qualitative evaluations such as soundwalks and open interviews introducing the local experts' perspective. The soundscape intervention included installing a gabion wall along one of the main roads to protect against noise around the playground and a number of 'audio islands' integrating sounds that people would listen to when using the place (see Figure 7). The resulting solutions reduced residents' exposure to low frequency noise in Nauener Platz and provided novel approaches to enable the most wanted sounds in the area to be heard so that the desire of the residents to escape road traffic noise through hearing natural sounds was realised creating a relevant and usable green space and city park for the area. The improvement of the residents' soundscape experience was measured using soundwalk and narrative interviews methods. The redevelopment of the Nauener Platz was awarded the in 2012 with the European Soundscape Award by the European Environment Agency and the UK Noise Abatement Society.

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Figure 7 - Example of the soundscape intervention in Nauener Platz, Berlin (Germany), using a gabion wall (right) to protect park goers from noise around the playground area; audio islands (left and centre) were also installed to provide areas of restoration

A citywide approach using soundscape principles has been conducted in Brighton & Hove in the United Kingdom (Easteal, Bannister, Kang, Aletta, Lavia, & Witchel, 2014). The City Council and The Noise Abatement Society worked together on a series of demonstration projects (Lavia, Dixon, Witchel, & Goldsmith, 2015), including: *West Street Story* (Lavia, Easteal, Close, Witchel, & Axelsson, 2012), *West Street Tunnel* (Witchel, Lavia, Westling, Healy, Needham, & Chockalingam, 2013; Lavia, Witchel, Kang, & Aletta, 2016) and *Valley Gardens* (Aletta & Kang, 2015). The *West Street Story* project was the first night noise soundscape intervention pilot: a three-dimensional curated ambient audio installation in a clubbing district. The project resulted in better crowd behaviour and reduced need for police presence in the area, which was proved through observational and body language analysis, and video footage. The *West Street Tunnel* project was a follow-on experiment in a pedestrian subway which had been closed due to anti-social behaviour and noise. Curated added sounds were proven to help minimise public disorder and increase feelings of safety amongst those passing through the tunnel. In the *Valley Gardens* project, soundscape analyses were conducted to implement the management of the acoustic environment in a broader urban regeneration scheme. The interventions helped residents to feel safer, suffer less from noise pollution, and increased a sense of social cohesion through citywide collaboration.

The city of Sheffield is a good example where water features have been embedded in urban design to enhance the perception of the acoustic environment's quality

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(Kang, 2012). Particularly, at the central train station, a complex system of fountains and noise barriers, as shown in Figure 8, implements a masking strategy for the traffic noise coming from the nearby major road. Different water features provide spectral variety and different frequency ranges resulting in an effective masking of the traffic noise. The interventions demonstrate the importance of utilising diversity when designing soundscapes and created spaces with a cultural meaning (the water of the fountains and the metal of the barrier stand for the river and the steel industry, which are key symbols of Sheffield's history) to enhance residents' and visitors' enjoyment of the areas and reduced noise annoyance.

Figure 8 - Example of soundscape intervention in Sheffield (UK), using water features for masking and noise barriers for sound level reduction

A soundscape intervention was developed in St. Knuts Torg on a central square in the city of Malmö in southern Sweden (Cerwén, 2016). The intervention was organised as a quasi-experiment on an urban square, where noise barriers covered with ivy where installed and forest sounds were added through loudspeakers to form an 'arbour' with an improved soundscape. One finding of the study in Malmö was that the quietest acoustic environment was not perceived as the best condition, confirming that carefully curated added sounds might be useful tools in soundscape design.

There have also been soundscape studies and interventions outside the urban realm, which focus more on acoustic ecology and soundscape preservation in rural and natural areas (e.g., Pheasant, Horoshenkov, Watts, & Barret, 2008; Pilcher, Newman, & Manning, 2009; Siebein & Skelton, 2009; Pijanowski & Farina, 2011). The National Park Service (NPS) in the USA has developed a comprehensive soundscape policy to be applied in its sites for the protection and management of the parks' acoustic environments (Miller, 2008). The policy acknowledges the importance of preservation of the acoustic environment for both enhancing the visitors' experience and protecting animal communication and encompasses a broad range of strategies, including: measuring reference acoustic conditions, limiting human-made sounds, setting acoustic management goals and objectives and how to address them by management. These projects benefit all species that interact with them, and aid the protection and conservation of soundscapes of special interest for conservation, restoration, and protection.

10. Conclusions: what are the challenges of soundscape research for the next years?

The previous questions provided an overall picture of the current state of soundscape research and pointed out that there are still several gaps in this field that need to be addressed by researchers and practitioners.

In 2008 the International Organization for Standardization (ISO/TC 43/SC 1) established a new expert working group on soundscape (WG54) working on "Perceptual assessment of soundscape quality". The work of the WG 54 led to the Part 1 of the standard discussed in Question 1 (International Organization for Standardization, 2014), which provides basic definitions and framework for soundscape research. However, Question 5 pointed out that research on methods for collecting soundscape data and ways to process them is still in progress (Brown, Kang, & Gjestland, 2011). The WG 54 is currently working on the Part 2 of the standard, titled "Acoustics — Soundscape — Part 2: Data collection". This will provide information about minimum reporting requirements for soundscape studies and methods and protocols for physical (e.g. binaural recordings, ambisonics) and

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perceptual data collection, both on site (e.g. soundwalks) and off site (e.g. laboratory experiments). Thus, more studies about the optimisation of soundscape data collection in an ecologically valid way that does not disturb the usual context of perceiving the acoustic environment are desirable, as there are relatively few studies dealing with these methodological aspects of soundscape research (Payne, Davies, & Adams, 2009; Axelsson, Nilsson, & Berglund, 2009; van Kempen, Devilee, Swart, & van Kamp, 2014).

It is still not clear what kind of analysis is best to use for soundscape data. Over the years, researchers have sought correlations between physical and perceptual data (e.g., Lercher & Schulte-Fortkamp, 2003; Brambilla, Gallo, & Zambon, 2013; Rychtáriková & Vermeir, 2013). However, such correlations are not necessarily useful *per se*. In order to use soundscape data to inform planning and design, it is also essential to involve all related stakeholders but also to solve the soundscape 'predictability' issue. Thus, more effort should be directed to developing predictive models for the perception of the acoustic environment starting from physical features of the environment, according to a descriptor-indicator(s) framework (Aletta, Kang, & Axelsson, 2016). On the one hand, this might provide actual operative 'tools', closing the gap between soundscape research, policy-making, and design practice; on the other hand, predictive models can also provide further insights into the origins of the perceptual constructs. As mentioned in the introduction, numerous studies have investigated the 'calmness' dimension of soundscape and several models have been proposed to predict this construct using physical indicators (e.g., Watts, Miah, & Pheasant, 2013; Brambilla & Gallo, 2016). However, other dimensions of soundscape might be more relevant in different contexts, like urban streets or commercial districts (Yu, Kang, & Ma, 2016). Therefore, there is a need to agree on what kind of descriptors (i.e., perceptual dimensions) are more suitable for what kind of contexts, and for this purpose further semantic scales should be developed and standardised.

Question 7 addressed the 'soundscape design' topic, which is possibly the most relevant for the built environment practitioners. While one could argue that perception itself cannot be 'designed', it is true that the built environment can be designed to elicit perception. As soon as the current acoustic environment (and the

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corresponding soundscape) of a place has been characterised as discussed in Question 5, the design process can start. According to the different 'acoustic objectives' (Brown & Muhar, 2004) several design strategies might be proposed. For instance: using water features to mask unwanted sounds (as discussed in the introduction); exploiting the saliency (as discussed in Question 2) of wanted sounds (e.g., birdsong in urban parks) to provide attentional masking; exploiting non-acoustical (e.g., visual) factors to modulate perception of both wanted and unwanted sounds; controlling the characteristics of unwanted sounds to make them less noticeable. In cases where poor acoustic design is pre-existing added sounds or music may be the most pragmatic soundscape design intervention (Eastel, Bannister, Kang, Aletta, Lavia, & Witchel, 2014), but active systems (e.g., loudspeakers) should not be the default solution in urban public spaces or act as a substitute for good design. For this reason, there is a need to investigate more systematic design strategies for soundscape which can be sustainable and integrated in long term planning for the future of urban areas.

Overall, soundscape research needs more scientific evidence of its potential to promote healthy urban environments through cognitive restoration. This will help to disseminate the outcomes from soundscape research and eventually to integrate this scientific field in the broader framework of policy-making and urban planning.

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