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# Considering Sound in Planning and Designing Public Spaces: A Review of Theory and Applications and a Proposed Framework for Integrating Research and Practice

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**Abstract**

We critically review the literature on the relationship between users of public spaces and their auditory environments, and how this knowledge is integrated in the planning, design, and management of public spaces as well as in technologies for acoustic and spatial data collection, analysis, and communication. To address the gaps identified in the review, we propose an activity-centered framework as a conceptual tool developed to support the integration of different types of knowledge in incorporating sound and the auditory environment in the planning and design of public spaces, by focusing on the activities that users perform in these spaces.

**Keywords**

public space, activity, user, planning practice, urban design, technology, auditory environment, activity-centered framework, soundscape design

## Introduction

> I experience myself in the city, and the city exists through my embodied experience. The city and my body supplement and define each other. I dwell in the city and the city dwells in me.
>
> Juhanni Pallasmaa, *The Eyes of the Skin: Architecture and the Senses* (2005, 40)

Public spaces are the arenas where public life unfolds. In a dynamic urban environment, public spaces should satisfy the needs and expectations of different, multicultural, and connected users (Carr, Francis, and Rivlin 1992). Furthermore, public spaces must adapt to and incorporate rapid changes in technology, from the ubiquitous means of transportation to mobile devices that alter their patterns of use. Understanding how users interact with public spaces and determining and improving the elements of the physical space that may influence their function and use is instrumental in designing spaces that accommodate the complex dynamics of public life. Achieving this is one of the foci of planning and design research and practice.

Many researchers argue that visual aesthetics are paramount for the enjoyment and use of public spaces (Pallasmaa 2005), with some claiming that vision is the "noblest of senses" (viz., Levin 1993; Jay 1993). Mirroring this belief, in the planning of cities, the multisensory aspect of the lived urban experience has been largely considered as an afterthought. For example, the ways in which urban spaces sound or smell were often only addressed by policy makers upon a negative reaction from community members or in the case of a societal problem (for sound, viz., Bijsterveld 2008; for smell, viz., Bijsterveld 2008; Corbin 1986; Henshaw, Cox, and Clark 2011). Despite increasing calls from theoreticians and practitioners to acknowledge and incorporate the complexity of the sensory qualities of a place in their planning and design, professionals remain mostly anchored in a primarily visual tradition (Montagu 1971; Tuan 1977; Holl, Pallasmaa, and Péréz-Gómez 1994; Lynch, Banerjee, and Southworth 1995; Pallasmaa 2005; Zardini 2005; Porteous 2013).

In order to address this gap, in this article, we extend beyond the limitations of a mainly vision-oriented approach to the study, design, and management of public spaces, and investigate *the sense of hearing* as a first step to shift from the dominance of vision to a "democracy of senses" (Berendt 1985, 32), and a more holistic understanding of the human world (Schafer 1993; Bull and Back 2003). We start with the sense

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of hearing not because it is *comparable* with vision or the other senses but rather use it as a *first step* toward a multisensory apprehension of the urban experience. Anthropologists, historians, and soundscape researchers depict an intimate relationship between sound and the ways humans relate to community, to social relationships, and to space and place (Smith 1997; Bull and Back 2003; Feld 2012, *inter alios*).

The emphasis on the auditory "atmosphere" of cities (Böhme 2000) as part of one's holistic experience of urban spaces is not novel. As early as in the 1960s, media theorists Carpenter and McLuhan discussed *acoustic space*, emphasizing the ability of sound to "fill space" (1960, 67) and thus construct it and influence humans' understanding and enjoyment of it. In the late 1960s and early 1970s, Murray Schafer's work on the World Soundscape Project drew awareness to the relationship between humans, sound, and society and particularly to what Schafer considered a "degradation" of the auditory environment due to industrial growth (Torigoe 1982; Schafer 1993). In doing so, he popularized the concept of *soundscape* (coined by Southworth 1969), as an auditory equivalent to *landscape* (Dubois, Guastavino, and Raimbault 2006). He used soundscape to describe *acoustic ecology* as a new area of research centered on the study of the auditory environment by emphasizing the way in which humans relate to and perceive their auditory environments (Schafer 2009). Nearly half a century later, Blesser and Salter (2009) introduced the concept of *auditory spatial awareness* to express "more than just the ability to detect that space has changed sounds; [including also] the emotional and behavioural experience of space" (p. 11), recognizing the aesthetic value of the auditory dimension of spaces and its possibility to stimulate (or discourage) deeper emotional sensations, states, and actions.

Traditionally, researchers tend to focus on narrow conceptualizations of users' auditory environments, largely ignoring their multiplicity of meanings. This may arise from an increasing body of research on the negative effects of sounds that are over particular levels on the well-being of urban space users (World Health Organization [WHO] 2000; Öhrström et al. 2006, inter alios) alongside a long history of complaints about noise[1] (Bijsterveld 2008). Sound has become synonymous with public nuisance, at least in mainstream planning and design practice, and in policy formulation. In the latter, this aspect is addressed through national and international regulations on noise, aiming to ensure the well-being of users of rural and urban spaces (Adams et al. 2006; Goines and Hagler 2007; Weber 2013, inter alios). The norms set forth in these regulations are incorporated in planning and design practices through environmental noise management strategies [ENM] (Bijsterveld 2008). Nonetheless, there are a few studies dedicated to the analysis of the positive effects of specific categories of sounds and environments, particularly so-called natural ones like those of birdsong and waterfalls (Brown and Muhar 2004; Alvarsson, Wiens, and Nilsson 2010; Annerstedt et al. 2013; inter alios), as well as the importance of quiet areas in urban environments (Pheasant et al. 2008; Booi and van den Berg 2012; Shepherd et al. 2013; De Coensel et al. 2013). Despite this work, in planning and design practice and in policy making, the focus remains on sound-as-noise and consequently sound-as-an-afterthought approaches, in which sound/noise is considered a *waste* caused by industry, traffic, or other human activities, and needs to be managed and controlled ex post facto (to be detailed in "The Environmental Noise Management Strategy (ENM)" subsection). Nevertheless, strategies for incorporating users' individual and shared experience of public spaces in the auditory design of such spaces are increasingly developed (e.g., the soundscape design strategy).

In this article, we aim at enabling the integration of scientific knowledge on sounds, auditory environments, soundscapes, and activities with the professional knowledge of practitioners (particularly planners and designers of public spaces) in order to develop spaces that respond to the auditory needs and expectations of users. We contend that the theoretical, methodological, and technological approaches to understand or model the relationship between users of public spaces and their auditory environments is insufficiently integrated in urban planning and design practice, largely due to different conceptualizations of the auditory environment. We synthesize knowledge from the scholarship and practice related to public spaces as well as on recent developments in soundscape research to develop an activity-centered framework that can bring together the expertise and interests of researchers as well as policy makers, planners, and designers. To this end, we first ask the following question:

> How do different types of scientific fields, policies, and planning and design practices address the relationship between users of urban public spaces and their auditory environments and what technologies were employed to address this relationship?

To address this research question, we performed a cross-disciplinary literature review that contrasted different strands of literature (including psychology, psycholinguistics, social sciences, history, urban planning, acoustics, and psychoacoustics), covering scientific research, policy, planning and design practice, and technological development. For clarity, we first define two terms used hereinafter: the "acoustic environment," to refer to characterizations of sounds and the environment relying first on physical measurements with a device, and the "auditory environment," to refer to the characterization of sounds and the environment relying first on descriptions of the human experience and afterward related to physical measurements. As a background to the rest of the article, we introduced and grounded in the literature our understanding of the notion of "public space", and of its relationships with its roles and users. We separated our review process and output into three sections, whose methodologies are outlined in the third section and their findings in the fourth, fifth, and sixth sections, respectively. First, we reviewed different strands of sound research, incorporating findings from the soundscape tradition (including studies embedded in psychology, linguistics, social sciences, and history) as well as from acoustics and psychoacoustics. Second, we performed a systematic review of the implications and implementation of such research in policy and practice, with a focus on how sound has been integrated in the design and planning of public spaces. Third, considering the growing role that technological tools have in the collection and analysis of acoustic, auditory, and spatial data as well as the creation and implementation of sound-related policies, we offered a synthesis of the technologies used by both researchers and practitioners to measure and represent the auditory and acoustic environment. The seventh section summarizes three gaps that we have identified in our reviews related to the way in which sound and the auditory environment have been addressed in research and practice, and how addressing them could contribute to integrating research and practice in the future. We conclude with a framework (see "Framework for Future Research" section), a conceptual tool developed to support the integration of different types of knowledge in incorporating sound and the auditory environment in the planning and design of public spaces, by focusing on the activities that users perform in these spaces.

## Background

Public spaces satisfy many roles, including aesthetic, psychological, social, symbolic, economic, and political, and must cater to the needs and expectations of increasingly diverse stakeholders (C. W. Thompson 2002). As "interlinkage[s] of geographic form, built environment, symbolic meanings and routines of life" (Molotch 1993, 888), they are the arenas on which day-to-day public life unfolds and where varied groups and individuals engage in various activities, depending, for example, on their purpose in using the space (Gehl 1987). Extensive studies show that the way in which public spaces are designed, the function they are designed to perform and the amenities that they offer have a strong influence over their actual function and their appropriation[2] by different users in their everyday practices and activities (Jacobs 1961; Lynch 1976; Whyte 1980; Jarvis 1980; Lynch 1984; Lefebvre 1991; Kayden 2000; Gehl and Gemzøe 2001; Dines and Cattell 2006; Carmona and Tiesdell 2007; Franck and Stevens 2007; Carmona et al. 2010, inter alios). Besides observing the dynamics of use and the patterns of activities that actual users perform in their spaces, it is considered crucial to understand and identify the different profiles and characteristics of potential users and ultimately engage with them as part of a participatory process instrumental in the research, planning, and design of used and usable spaces (Carr, Francis, and Rivlin 1992; Pain 2004; Carmona and De Magalhães 2006; Carmona et al. 2010, inter alios). Potential users can be and have been defined according to a large number of characteristics, both individual and collective (viz., Holland et al. 2007), among which we include *age* (Dunnett, Swanwick, and Woolley 2002; Hopkins and Pain 2007), *gender* (Massey 1995; Scraton and Watson 1998; Pain 2001; Garcia-Ramon, Ortiz, and Prats 2004), *familiarity* with the space (Lynch 1960; Jackson 1998; Blokland and Rae 2008), and *needs and expectations* from the space (Jarvis 1980; Carr, Francis, and Rivlin 1992; Carmona and Tiesdell 2007).

## Review Methodology

This literature review was performed in three parts: (1) studies on the relationship between humans, sounds, and the auditory environment; (2) strategies used to incorporate sound in urban planning and design research and practice; and (3) information technologies and systems used to support policy and the urban planning process when dealing with sound concerns.

### *The Relationship between Humans, Sounds, and Their Auditory Environments*

The literature review on sound, the auditory environment, soundscapes, and activities was based on a combination of review strategies. We began with the publications of three influential scientists in the field of soundscape studies, who also collaborate with acousticians and psychoacousticians, namely, Dr. Daniele Dubois, Prof. Dr. Brigitte Schulte-Fortkamp, and Prof. Jian Kang. They were identified either as action chairs or main contributors to the European Cooperation in Science and Technology (COST) action called "About Soundscape of European Cities and Landscapes." [3] Based on their publications, we performed a backward and forward search, by reviewing both the publications they cited and the publications in which they were cited (Webster and Watson 2002). We consulted the overall contents of the journals in which the aforementioned publications were published (e.g., *Acta Acustica united with Acustica, Journal of the Acoustical Society of America*) and the published proceedings of topical conferences (e.g., International Congress on Acoustics, International Congress and Exposition on Noise Control Engineering, Forum Acusticum). We reviewed publications in English, French, and Spanish.

Having identified the journals and conference proceedings that regularly publish academic work on the relationship between humans, sounds, and their auditory environments, we selected both theoretical and empirical articles that outline the larger debates in soundscape research, as well as studies that focus on or discuss the influence of various variables on the aforementioned relationship (including user characteristics, user activities, etc.), of which there were forty. These publications were then reviewed qualitatively, using content analysis (Bryman 2015).

### *Sound in Policy and Urban Planning and Design Practice*

This systematic literature review was performed to offer an overview of how sound is dealt with in policies and legislation as well as how research strategies or empirical case studies address auditory concerns in urban planning and design practice. This review goal influenced the key word selection for a SCOPUS database search (Table 1), focused on noise legislation, soundscape design, and quiet areas. We reviewed publications published between 2000 and July 2015, in English, French, and Spanish. The abstracts of 195 publications (including conference and journal papers) were reviewed. We further selected the publications discussing sound-related policies and conceptual or applied strategies to integrate sound in the planning and design

**Table 1.** Key word–based Systematic Search.

| Search keywords | Filter (title, key words, abstract): Total documents | Documents (without double counting) |
|---|---|---|
| Noise legislation | | |
| "Urban planning," "noise policy" | 35 | 35 |
| "Urban design," "noise policy" | 6 | 0 |
| "Urban planning," "noise legislation" | 58 | 51 |
| "Urban design," "noise legislation" | 2 | 2 |
| "Environmental noise management" | 46 | 5 |
| Soundscape design | | |
| "Soundscape design" | 57 | 47 |
| "Soundscape planning" | 14 | 9 |
| "Acoustic design," "urban" | 44 | 16 |
| Quiet area | | |
| "Quiet area," "policy," "urban" | 36 | 30 |

*Source*: Scopus database. Languages: English, French, and Spanish. Period: January 2000–July 2015.

process of public spaces, resulting in twenty-five publications that were reviewed. Relevant policies and official technical reports cited in the selected publications have been included to show the current policy framework in which sound-related policies and design interventions occur. Findings are provided in the "Implementation of Scientific Knowledge on Sound in Policy and Urban Planning and Design Practice" section.

### *Technologies for Acoustic, Auditory, and Spatial Data Collection, Analysis, and Communication*

For the review of technologies that have been used by researchers in scientific studies as well as in projects in collaboration with practice, we relied on the publications resulting from "The Relationship between Humans, Sounds and Their Auditory Environments" and "Sound in Policy and Urban Planning and Design Practice" sections. We identified a number of technologies referred to in the aforementioned publications and offered short descriptions of each of them. We selected and offered a nontechnical overview of the following technologies: auralization technologies, noise mapping, ambisonics (e.g., Dubois, Guastavino, and Raimbault 2006), and binaural technologies (e.g., Basturk, Maffei, and Masullo 2012). Considering our focus on users of public spaces and their knowledge of and engagement with public spaces, we also reviewed publications detailing approaches to integrate participatory sensing technologies in their collection and analysis of acoustic and auditory data (e.g., participatory noise mapping: Rana et al. 2010; D'Hondt, Stevens, and Jacobs 2013).

## Relationship between Humans, Sounds, and Their Auditory Environments

In researching the relationship between humans, sounds, and their auditory environments, different communities of scientists consider sound as their object of study, but research it from different perspectives focusing for instance on the physical (acoustics), semantic (psychology), or sociocultural (social sciences) characteristics. The literature distinguishes two overarching scientific approaches—object-centered and human-centered—informed by either methods from physical sciences or human/social/behavioral sciences (viz., Polotti and Rocchesso 2008). More specifically, the *object-centered approach* relies on the physical properties of sounds (viz., Marquis-Favre, Premat, and Aubrée 2005 for a synthesis of methods and strategies for researching sound-related concerns), while the *human-centered approach* starts from how humans experience sound(s) and their auditory environments, including individual and shared knowledge, experience, and expectations (viz., Raimbault and Dubois 2005; Dubois, Coler, and Wörtche 2014; Bruce and Davies 2014, inter alios). Despite the different angles for researching sound concerns, the two approaches are complementary and can often be found together in studies offering a complex understanding of the relationship between humans and sounds.

### *Object-centered Approach to Sound Research*

The object of study of the object-centered approach to sound is the sound as described in physical or technical terms (Hansen and WHO 1995; Kinsler et al. 1999; Crocker 2007, inter alios) and measured using methods, tools, and metrics agreed upon by a scientific community of acousticians (including psychoacousticians) and computer scientists (Porteous 2013, 31; Dubois, Coler, and Wörtche 2014). Research following this approach includes controlled experiments, in a laboratory setting, that test or answer a variety of research questions on the physical properties of sounds that, for example, are more likely to drive the way in which humans evaluate sound producing objects (Giordano, Susini, and Bresin 2013) or classify sounds into categories (Gygi, Kidd, and Watson 2007; Lemaitre and Heller 2013). Object-centered studies produce knowledge on the physical attributes of sounds that, for instance, affect the level of annoyance caused by traffic noise (Lercher 1996; Fujii, Atagi, and Ando 2002). Multidisciplinary endeavors are not rare among object-centered scientists; they often collaborate with medical experts to tackle issues like the effects of road traffic noise (Ising and Kruppa 2004; Babisch 2008; Sorensen et al. 2012) and aircraft noise (Hygge, Evans, and Bullinger 2002; Eriksson et al. 2007, inter alios) on human health. Furthermore, their findings fuel policy development and regulations on noise levels and spatial delineations, and influence the choice of methods and tools for the planning and design of urban public spaces (see "Implementation of Scientific Knowledge on Sound in Policy and Urban Planning and Design Practice" section).

### *Human-centered Approach to Sound Research*

The human-centered approach emerged from a psychological understanding of sound that focused on how sounds are perceived, interpreted, and judged by humans, rather than their physical properties. The emphasis is on *experiential knowledge* and on "human specificities and diversities in practices and know-how" (Dubois, Coler, and Wörtche 2014, 21). Consequently, according to this approach, sound is not reducible only to a quantifiable "signal" (i.e., a potentially audible pressure change as detected by an auditor/receiver) in the same way that perception is not simply "signal processing" (Truax 1995). On the contrary, the *human* is at the center of the *relationship* between humans and sounds, understood from this perspective as an *information exchange* (Truax 1995).

Accounting for the diversity of meanings attributable to the same acoustic signal requires understanding the complex relationships between users, sounds, and their auditory environments, beyond the abstract physical properties of the latter two (Guastavino 2007). This approach was pioneered by psychology and is currently encountered in a variety of human-centered disciplines, including social sciences, history, and linguistics, where the starting point and focus are the meaning of sounds for humans and the factors that may frame or influence their auditory experience (as detailed below).

As mentioned previously, the most widely known concept developed and used to research auditory concerns from a human-centered perspective is "soundscape", considering sounds as part of a whole and not as separate entities that can be researched independently. It was initially defined as "an environment of sound (sonic environment) with emphasis on the way it is perceived and understood by the individual, or by a society. It thus depends on the *relationship* [emphasis added] between the individual and any such environment" (Truax 1978, 126). The concept has been appropriated by members of different communities of scientists and practitioners and a standardized definition has only recently been proposed, defining soundscape as "the acoustic environment as perceived or experienced and/or understood by a person or people, in context" (International Standard Organization 12913-1, 2014). Currently, most soundscape research is performed combining measurements of the acoustic environment with knowledge on the individual auditory experience, attempting to account for the relationship between the physical environment and the mental representation users have of it. In operationalizing this concept in a manner useful for policy makers, designers, and other practitioners, a number of conceptual models of soundscapes have been proposed (Ipsen 2002; Schulte-Fortkamp and Fiebig 2006; and Zhang and Kang 2007; Herranz-Pascual, Aspuru, and García 2010, inter alios) with consequences for the ways in which soundscape research is or could be translated into practice (Raimbault and Dubois 2005; Botteldooren et al. 2011, inter alios).

The preferred research instrument for human-centered studies is the survey, through structured or semistructured questionnaires. They either accompany listening experiments in a laboratory setting (Guastavino et al. 2005; Guastavino 2007; Nielbo, Steele, and Guastavino 2013, inter alios) or are self-administered, at the home of the subject or online, covering topics of annoyance, pleasantness, or overall perception of their auditory environments (Gidlöf-Gunnarsson and Öhrström 2007; Yu and Kang 2008; Booi and van den Berg 2012; Tardieu et al. 2015, inter alios). A number of outdoor techniques have also been developed to offer opportunities for the human-centered in situ documentation, description, and analysis of sounds and soundscapes (viz., Lercher and Schulte Fortkamp 2003). One such empirical technique is the *soundwalk*, also designed and employed first by Schafer in the 1960s. The purpose of this walk, performed by researchers, professionals with diverse backgrounds and everyday users of spaces, is to intently *listen* to the auditory environment (Semidor 2006; Adams et al. 2008).

*Activity, users, and sound.* Nearly half a century ago, Lynch encouraged researchers and practitioners in the planning and design of public spaces to focus on "how the wellbeing of persons and small groups arises as they directly interact with their settings, and not primarily from their role of passive observers" (Carmona and Tiesdell 2007 on Lynch 1976, 30). In public space research and practice, this translated into a concern for the functions of spaces and their use and appropriation. In research on sound, the idea of humans as *sound-producing agents*, namely, as active users and *diverse* appropriators of (auditory) spaces (viz., Rémy 2005), is explored to different extents.

On the one hand, in the majority of psychological studies, this idea is marginal and only recently are studies being sensitive to *activity* as a factor potentially influencing the users' perception of sounds and their auditory environments. The focus is still on a cause–effect type of relationship between humans and sounds, where the human (as user of spaces), is a passive receiver of acoustic stimulations. These studies explore in depth the noise *sensitivity* of urban dwellers, particularly to the types of and extent to which activities can be *affected* (read: *disturbed*) by continuous exposure to unwanted sounds in everyday life (viz., Moch-Sibony 1980; Marquis-Favre, Premat, and Aubrée 2005). Recently, a number of psychological studies indicate that whether users consider soundscapes as quiet (Moch-Sibony 1980; Marquis-Favre, Premat, and Aubrée 2005) or restorative (Payne and Guastavino 2013) depends on the users' characteristics as well as their activities. Furthermore, the evaluation and description of sounds and auditory environments may vary according to the activities that users perform (Nielbo 2015; Bild et al. 2015). Finally, research indicates that users' auditory environments in public spaces are perceived as enabling or discouraging certain categories of activities (Nielbo, Steele, and Guastavino 2013; Steffens, Steele, and Guastavino 2015; Nielbo 2015). Psychological studies are also sensitive to the *diversity* of users, accounting for intragroup differences and user characteristics, particularly to how users of different demographic or socioeconomic or educational background may perceive and evaluate their auditory environments differently (Yu and Kang 2008; Booi and van der Berg 2012).

On the other hand, sociological and anthropological studies on the relationship between users, sounds, and their auditory environments as a whole rely heavily on the ethnographic method (Lewis-Beck, Bryman, and Liao 2003; Pink 2009) to research the social dimension of auditory environments and the social meanings of sounds, as cues to social practices and cultural belonging (Hiramatsu 2006; Féraud 2010; Feld 2012). Historical studies offer extensive knowledge on how perceptions of certain categories of sounds and sound-producing activities changed throughout centuries and how they influence current sound-related policies (Bull and Back 2003; E. A. Thompson 2004; Bijsterveld 2008). Characterizing and studying auditory environments by integrating the individual and collective characteristics of users, their purposes in using the space, familiarity with the space, and auditory expectations as well as ways in which they use and act in the space is currently not part of mainstream scientific approaches to sound research.

## Implementation of Scientific Knowledge on Sound in Policy and Urban Planning and Design Practice

The two approaches to sound-related research reviewed in fourth section informed the development of two dominant strategies for addressing auditory issues in urban planning practice and in policy: (1) the *environmental noise management strategy* (ENM) and (2) the soundscape design strategy (SSD), where we also include initiatives to identify, develop, and manage "quiet areas." While the motivation of both strategies stems from concerns about human well-being, the differences between them arise from their opposing conceptualizations of sound. ENM focuses on sound as a *waste* that must be managed to protect users of spaces from its deleterious effects. Contrastingly, SSD addresses sound as a *resource* and thus focuses on the purposeful design and improvement of users' auditory environments for it to be perceived as pleasant *to* and enjoyable *by* users (Brown 2011, 2014).

### The Environmental Noise Management Strategy

Rooted in environmental impact studies, ENM arose from the concern of international organizations (e.g., the European Union and the WHO) and national governments with the well-being of users of rural and urban spaces exposed to different categories of *noise*, that is, unwanted sounds that are considered disruptive and damaging for everyday life. Therefore, ENM aims at developing actions for the management and control of outdoor noise as defined in public policies. Among these, aircraft, industrial, and traffic noise has been regulated in a number of regional and national policies such as the European Directive 2000/14/EC and the European Directive 2002/49/EC. Due to the findings of studies on the negative effects of noise on human health from a physical and physiological perspective (described in the "Object-centered Approach to Sound Research" subsection), these policies establish outdoor noise-level recommendations and solutions to enforce them and offer humans exposed to potentially dangerous levels of noise instruments to file complaints on noise annoyance.

Traditionally, the implementation of ENM strategies has two distinct phases, formalized and described in the late 1980s. First, there is the *diagnosis*, consisting of measurements in areas where sound levels are considered unpleasant and providing an overview of measured levels. Second, the *prescription* phase identifies the sources of sounds perceived as unpleasant and limits their effects (Gaver 1988, 7). The conventional strategy to incorporate acoustic concerns in planning and design practice is therefore to measure, monitor, and visualize urban and rural noise levels using methods object-centered and instruments and afterward implement a series of strategies to respect the various noise regulations (viz., Botteldooren et al. 2008). The tools and expertise of acoustic experts are sought in both stages of ENM and, inspired by the findings in the diagnosis stage a number of prescriptions are made to try and address the complaints. The following are some of the common prescription instruments: zoning (e.g., establishing zones alongside roads and railways that act as a spatial separator between noise sources and noise-sensitive recipients), traffic management (e.g., altering the infrastructure of cities to ensure a more fluid, less noise producing traffic flow), and physical alterations to space (e.g., erecting noise barriers, integrating noise exposure and sound absorption and insulation standards when planning/redeveloping both residential areas and roads and railways; viz., Weber 2013, 224–27, for a detailed overview).

In this process, the emphasis is on the physical properties of (unpleasant) sounds and marginally, if at all, on how humans experience and describe these sounds. As a result, current ENM strategies are often unable or insufficient to reconcile the knowledge from noise measurements with that from noise complaints that urban dwellers make (viz., Raimbault and Dubois 2005, 344–45). In using globally established indicators of sound levels which may not be relevant or adequate for local contexts, this strategy is not able to do justice to the meanings of sounds, the idea of auditory comfort (viz., Raimbault and Dubois 2005) or preferred auditory qualities of spaces, understood here not as a quality of the space per se but as referring to "certain qualities of the relations between sounds, space and social practices" (Rémy 2005, 7).

### The Soundscape Design Strategy

Studies within the human-centered approach discussed in "Human-centered Approach to Sound Research" subsection indicate that the perception of sound depends not only on the physical properties of the sound but also on humans' psychological and sociocultural characteristics, their personal history, and their previous experiences of (auditory) spaces (Raimbault and Dubois 2005; Yang and Kang 2005; Féraud 2009). Also, according to this strand of literature and the findings in "The Environmental Noise Management Strategy" subsection, ENM strategies are inadequate to address human-centered issues of auditory expectations of spaces and the auditory quality of outdoor spaces. In this context, SSD has been initially developed to complement ENM efforts and it aims at the "management or manipulation of the acoustic environment of a place to change the way that its acoustic environment is perceived by humans" (Brown 2011, 73). It is a strategy that incorporates both physical and perceptual components, combining knowledge, theories, and methods from the object and human-centered approaches to sound research. In doing so, it integrates knowledge and methods from ENM with user's experiential knowledge on their sounds and auditory environments. Accordingly, it supports the evaluation and (re)design of auditory environments based on so-called aesthetic dichotomies (M. S. Thompson 2014): unwanted/unpleasant/undesirable versus wanted/pleasant/desirable sounds (Sasaki 1993; Brown and Muhar 2004; De Coensel et al. 2010; Brown 2011; Asdrubali et al. 2014).

The criteria and steps for SSD vary according to the expertise of those involved in the process, and the interests, needs, and expectations of the stakeholders initiating or funding the initiative. Currently, SSD is promoted by the European Environment Agency (EEA). The EEA describes soundscape design as an alternative, "creative" solution to managing sound as noise and has given a number of scientists a platform to propose different models for incorporating sound concerns in the early stages of urban planning, with a focus on the human experience of the auditory space. The models have either been tested in real-life scenarios of soundscape redesign (De Coensel et al. 2010; Asdrubali et al. 2014; Aspuru et al. 2014) or remained at the development stage (Brown and Muhar 2004; Cain et al. 2008; Adams, Davies, and Bruce 2009; Jennings and Cain 2013).

SSD strategies of addressing sound in policy and urban planning and design practice reviewed in this article follow similar theoretical and methodological principles (Siebein 2011), specifically employing a participatory planning approach that includes the opinions, needs, and expectations of different stakeholders, using different acoustic measurement strategies, developing and presenting simulation models of proposed redesigned soundscapes to interested parties, and finally implementing active and passive measures to transform the (auditory) space (De Coensel et al. 2010). Such measures range from maintaining or enhancing sounds deemed wanted by humans and encouraging activities that generate these sounds, on the one hand, to physically altering the environment to reduce the level or overall presence of sound deemed unwanted, on the other. Modifications may include so-called masking techniques, like constructing water fountains or planting trees, or implementing acoustic installations (Licitra, Brusci, and Cobianchi 2010; Hellström 2012; Asdrubali et al. 2014). Unlike ENM, that promotes and implements a top-down process of management of noise (used here to mean that acoustic strategies are outlined by decision makers at a national and supranational level and are implemented as such by local actors), SSD relies on and integrates insight from different stakeholders, through sociological methods: performing interviews or focus groups, administering questionnaires to users of spaces (Vogiatzis and Remy 2014; Aspuru et al. 2014) and to a comparatively less extent, performing field observation, and behavior mapping (Vogiatzis and Remy 2014; Aspuru et al. 2014).

*Quiet areas.* The concept of "quiet area" has been formalized in European legislation as part of Directive 2002/49/EC, to refer to both "quiet areas in urban agglomerations" and "in open country," for which different definitions are provided. For urban environments, a quiet area is defined as "an area, delimited by the competent authority, for instance which is not exposed to a value of $L_{\mathrm{den}}$ or of another appropriate noise indicator greater than a certain value set by the Member State, from any noise source" (*L.* 189/14). The generic definition refers to the physical properties of the acoustic environment in the area and it relies on inaccurate assumptions on the capabilities of existing technologies to differentiate between sound sources and measure the sound pressure levels of "unwanted" sound sources, separately from those of "wanted" sources (EEA 2014).

Such a definition remains open to interpretation, as it points to no standardized methodology or process through which to achieve the development or maintenance of quiet areas and therefore is difficult to implement in practice. Despite this shortcoming, the social and economic importance of such spaces for urban dwellers has led to the implementation of various actions that explored many facets of the aforementioned definition to develop and maintain quiet areas in diverse European urban contexts (see EEA 2014 for an overview). The multiple ways in which quiet areas have been empirically understood and selected in these actions (driven by both policy makers and other experts, including researchers) show the relativeness of labels such as "quiet" (and "calm," "tranquil," etc.) as well as the idea that sound pressure measurements are insufficient to indicate "quietness." Consequently, the methodologies used to evaluate selected quiet areas differ on a project-per-project basis, ranging from object-centered to mixed or hybrid approaches including, for example, on site questionnaires, observations, sound recordings, and so on (e.g., Carfagni et al. 2014). The results of such analyses have also led to SSD interventions for the redevelopment of the existing areas according to local quietness needs (e.g., Carfagni et al. 2014).

A key question outlined in the "Good Practice Guide on Quiet Areas" (Carfagni et al. 2014) is that of functionality of spaces and the relationship between activity and auditory environments, in terms of appropriateness for activity. Specifically, "what sounds enable and what sounds interfere with activities? What activities and sounds are appropriate to a quiet area?" (Carfagni et al. 2014, 26). While this is a topic for future research, the focus of existing initiatives on use of space and functionality (even if only in relation to quietness for now) indicates a change in perspective that could become mainstream for SSD strategies in general.

## Technologies for Acoustic, Auditory, and Spatial Data Collection, Reproduction, Analysis, and Communication

In the process of studying various components of the relationship between humans, sounds, their auditory environments, and their public spaces, technology has supported the collection, analysis, and use of data and knowledge from different communities of scientists, professionals (including planning and design practitioners, policy makers), and users. We review technologies that help study each component of the relationship between users, sounds, auditory environments, and public spaces. As spatial data collection and analysis technologies are quite well documented (viz., Jensen, Gatrell, and McLean 2007; Longley et al. 2015, inter alios), we focus on the state of the art in acoustic technologies and on the how sound visualization technologies incorporate spatiotemporal aspects and user-driven knowledge.

Acoustic technologies record and process acoustic signals. The quality and precision of the systems and tools—particularly microphones—used to perform these tasks is of paramount importance to both sound researchers and practitioners (Pohlmann 2011; Rumsey and McCormick 2012, 2014, inter alios). Two such technologies for recording and reproduction of the environment have been used extensively in laboratory settings to aid in the study of spatial sound perception (Guastavino et al. 2007): ambisonics (used in e.g., Dubois, Guastavino, and Raimbault 2006) and binaural recording techniques (used in e.g., Basturk, Maffei, and Masullo 2012). While both technologies support the recording and reproduction of sound three-dimensionally (Gerzon 1985; Møller 1992), studies indicate that there are perceptual differences between their reproductions, in terms of, for example, sense of immersion, realism envelopment, and localization of sound sources (Guastavino et al. 2007), making them preferred for different types of laboratory tests.

Due to the increase in commercially available compact and portable mobile devices with higher processing speeds and more accurate global positioning capabilities, a larger array of acoustic and spatial data collection tools are being developed, allowing to research, document and map acoustic and auditory environments in real time or near real time and in situ (Steele, Krijnders, and Guastavino 2013; Davidovic and Stoimenov 2014; Lavandier, Delaitre, and Ribeiro 2015). Mobile phones in particular have been used to crowdsource data collection for the monitoring of noise pollution indicators (Rana et al. 2010; Kanjo 2010; Maisonneuve, Stevens, and Ochab 2010; D'Hondt, Stevens, and Jacobs 2013) or for capturing the way in which users of public spaces describe and assess their auditory environments while documenting their activities and geographic position in real time (Steele, Steffens, and Guastavino 2015; Steffens, Steele, and Guastavino 2015).

Easy access to these widely available technologies permits the active integration of users of spaces and their knowledge in the data collection and analysis processes through participatory sensing initiatives by connecting users' mobile devices in a network that enables researchers to collect local data (Paulos, Honicky, and Hooker 2008; Rana et al. 2010; Hondt et al. 2013). Through this, researchers directly engage with users of spaces as active generators of knowledge, acoustic, and geocoded information (for participatory noise mapping, viz., Maisonneuve, Stevens and Ochab 2010; Hondt et al. 2013, for more participatory spatial mapping, viz., user-generated street maps—Haklay and Weber 2008, collaborative planning process—Kyttä 2011). Additionally, faster and wired technologies support more dynamic and real-time mapping of urban noise, a considerable departure from standard noise maps, that aggregate average sound levels, usually alongside main arteries, over longer periods of time, and make use of complex simulations on traffic flows.

Noise maps, for instance, created through advanced noise models, are widely used tools to graphically and spatially represent urban noise. They are not only used as a research instrument but are also a standard requirement as part of complying with national and international noise regulations and are therefore actively incorporated both in ENM and SSD (De Coensel et al. 2010; Guedes, Bertoli, and Zannin 2011; Booi and van den Berg 2012; Gulliver et al. 2015; Wu et al. 2015; Erwin and van Banda 2015). They have also been used extensively in processes of urban development and more recently as part of simulation technologies and interactive virtual reality platforms as communication, visualization, and auralization means to support the evaluation of suggested alterations to the physical space, particularly in the process of soundscape design (Drettakis et al. 2007; Brambilla et al. 2009; De Coensel et al. 2010; Basturk, Maffei, and Masullo 2012). In this context, auralization technology is particularly relevant, as an auditory analogue to visualization, as "the technique of creating audible sound files from numerical (simulated, measured, or synthesized) data" (Vorländer 2007, 3), to create a virtual sound environment used as a simulation.

While technological advances have been made in the fields of remote acoustic sensing, noise and sound mapping, and modeling and participatory data collection as described, mainstream urban planning and design practice still largely rely on technologies that fall short of incorporating user knowledge and their activities and portray an incomplete "image" of users' auditory environments.

## Gaps Identified

The aim of this review is to answer our research question through a comprehensive literature review on research, policy, and practices addressing the relationship between humans, space, sounds, and their auditory environments. By putting knowledge gathered from different scientific fields and disciplines in discussion with each other, we identified *activity* and *user characteristics* as two key variables that have the potential to change the conditions under which the relationship between users and their spaces occurs. Applying this perspective to the reviewed literature, we identify three gaps:

### *While Activities and User Characteristics Are Present in the Discourses of Scientists Working on Sound, Studies on the Relationship between Users and Their Auditory Environments Have yet to Systematically Consider the Two as Variables Influencing the Relationship*

Based on the reviewed knowledge on how humans interact with their auditory environment, we hypothesize that there is a two-way relationship between activities and the user-auditory environment relationship. On the one hand, users' auditory environments, their physical features, and the meanings they have for different users of spaces in a moment in time may influence the activities users perform. On the other hand, the activities that users perform affect their auditory environments and transform it in ways that other users may find suitable or not for their purpose for using the space, their needs, and expectations. While sound is addressed in a small number of soundscape studies from an activity perspective (as seen in ''Human-centered Approach to Sound Research'' subsection), a systematic conceptual and methodological framework allowing for an integrated research of the relationship, considering both how users' auditory environments affect their activities *and* how users and their activities affect their auditory environments is still lacking. In this two-way relationship, research should also consider user characteristics beyond demographics which, based on insight from public space research and practice, could include knowledge on the expectations of users in appropriating the space, the purpose for which they are using it, and their familiarity with the space and their auditory environments.

### *Incorporation of Auditory Issues in Urban Planning and Design Practice Beyond the ENM Strategy Is Not Standardized, Sound Being Considered Mainly as a Waste and Not as a Resource*

In the strategies for the integration of auditory issues in the planning and design of public spaces reviewed in fifth section, sound remains mostly an afterthought and SSD strategies are the exception rather than the rule. Particularly because of the focus on activity and functionality, planning and design initiatives could benefit from accounting for the relationships between users and spaces, as part of an iterative process that affects both users and their auditory environments. To this end, such initiatives should integrate knowledge *on* and *of* users, their needs, expectations, their purpose for using the space and their familiarity with it, as well as their patterns of use of space, manifested through the activities that they perform. Building upon, for example, methodologies developed for quiet space design and management, such an approach for incorporating auditory issues in planning and design initiatives would account not only for users as passive receivers of sounds but also as active producers of it. To this end, the approach would focus on the *variety* of activities that *different* users expect to and are expected to perform in public spaces. It also offers an innovative approach for studying the suitability for action of designed public spaces from an auditory perspective, identifying potential gaps between intended function and actual use of spaces.

### *Policy Makers, Planners, and Designers Mostly Rely on Reductionist Acoustic Measurements and Technologies to Achieve Their Acoustic Goals in Practice*

Despite an increasing array of measuring, recording, and reproduction technologies employed by researchers, planners and designers are only marginally benefiting from these technologies, usually as part of pilot projects. This is not only due to the limited collaboration between research and practice but also because of the use of sophisticated technologies, often inaccessible, and opaque to nonexperts. This is problematic because, as legislation on noise and sound is influenced profoundly by various measurement and visualization technologies (e.g., the reliance on noise maps or various sound pressure level measurements), planners and designers prefer to rely on purely acoustic measurements (and technologies) to achieve minimum noise regulations in their plans and designs, rather than engage with more complex technologies (like auralization) that require either extensive training or expert knowledge. This minimizes the potential uses of such technologies beyond the academic field.

## Framework for Future Research

To conclude, we propose a framework as a tool to research the relationship between users of spaces, their activities, and their auditory environment, that can help address the gaps identified above, specifically the integration of scientific knowledge on sounds, auditory environments, soundscapes, and activities with the professional knowledge of practitioners (particularly planners and designers of public spaces) in order to develop used and usable public spaces.

The framework thus centers on activity, while also emphasizing the importance of user characteristics and contextual factors, as variables that may affect the user-auditory environment relationship (Figure 1). In this understanding of the relationship between users of spaces and their auditory environments, the former are both passive receivers/perceivers and producers of sounds, through the activities they perform in the public space. Also, the users are defined by a number of characteristics, which in this figure include demographics, familiarity with the space (and their auditory environments), needs and expectations from the space, and their overall purpose for using the space. Similarly, their auditory environments can also be characterized through their perceptual features (e.g., how users describe and discuss about their auditory environments in language) as well as their physical features, measurable using various acoustic devices. Third, we refer to contextual factors that may influence the parameters of the relationship between users and their auditory environment. Such factors include environmental conditions (e.g., weather), spatiotemporal aspects (e.g., day of the time, week, etc.), and the amenities existent in the public space (e.g., benches, trees, and lighting).

The framework brings together the expertise of researchers and practitioners by emphasizing the idea that activity is a variable influencing the way in which users relate to their auditory environments and therefore their public spaces (and whether they consider their environments suitable or not for their activities). While the relationship between activity and urban form is not a novel insight for public space planners and designers, emphasizing the importance of users' auditory

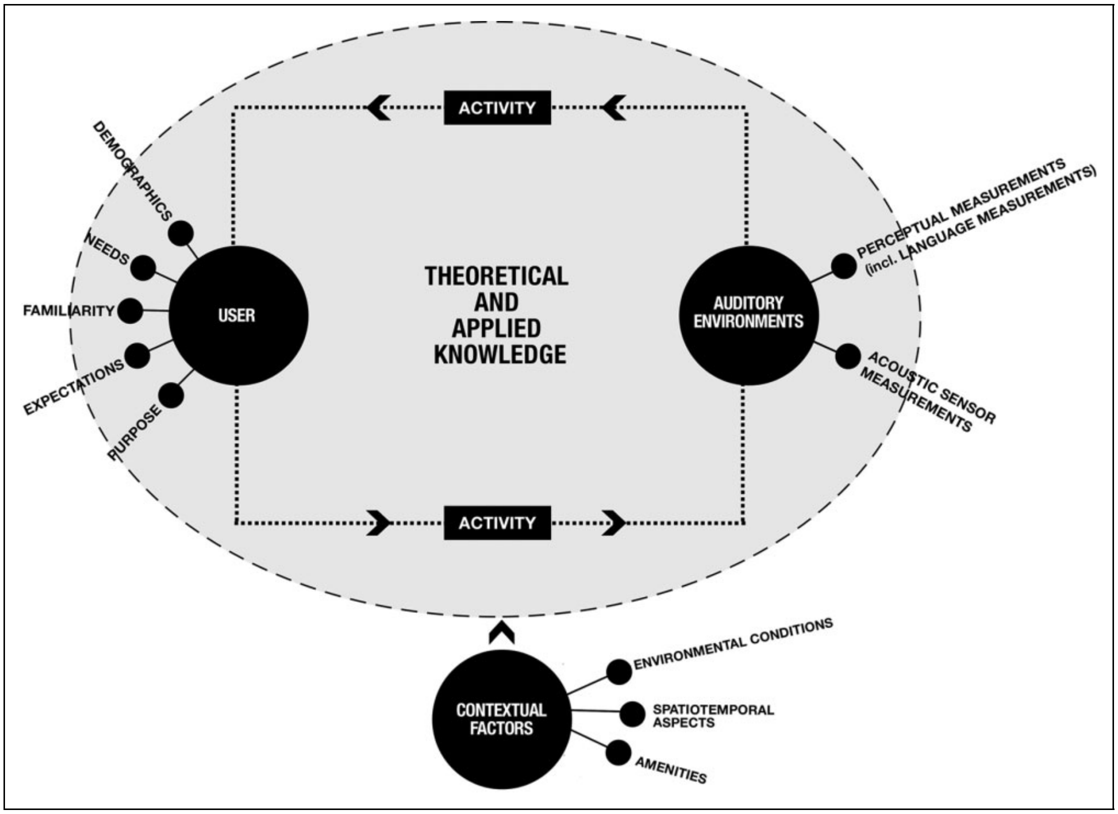


**Figure 1.** Activity-centered framework for the integration of sound research and practice.

environments for their engagement with and use of public spaces could illustrate the need to consider sound as more than a waste in their planning and design initiatives, but as a resource that could encourage certain categories of activities for some categories of users, while interfering with others.

One avenue in which the conceptual framework can be implemented concerns bringing together researchers, practitioners and technology developers to design a metric to systematically investigate potential correlations between some contextual factors (e.g., the amenities of the space), the characteristics of its users, the activities users perform, and the properties of their auditory environments (perceptual and physical). To this end, we could support the development of technologies that can incorporate different types of data and knowledge, thereby integrating the human (perceptual and behavioral), spatial, and auditory dimensions of public spaces, for a more holistic analysis and understanding of use of spaces.

The findings of this multidisciplinary initiative, the technologies developed in the process, and the aforementioned metric may provide policy makers and planners with an instrument offering insight into the relationship between users of public spaces and their auditory environments, as influenced by their activities and patterns of use of the space.

We argue that the process of collecting and systematizing the knowledge needed for the development of such a planning and design instrument facilitates and mediates communication between different stakeholders. It does so by integrating the know-how and the spatial and acoustic and auditory data collection and analysis technologies of researchers and technology developers with the knowledge and expectations of planners, designers, and users, therefore supporting and furthering an informed participatory planning process.

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## Notes

1. *Noise* is a term used in policy and research as well as in everyday discourses of users of urban and rural spaces to refer to sounds considered or perceived as *unwanted* (Directive 2002/49/EC; Carmona et al. 2010, 179; Hondt et al.2013; Dubois, Coler, and Wörtche 2014, *inter alios*).
2. We understand *appropriation* as the interactive process through which humans take over their physical settings, through different

means in order to make these spaces their own (viz., Feldman and Stall 2004; De Haan 2005).

3. European Cooperation in Science and Technology action website. Accessed June 20, 2016. http://soundscape-cost.org/.

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