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The acoustic designer: Joining soundscape and architectural acoustics in architectural design education

Alessia Milo

Abstract

This article discusses the integration of acoustic design approaches into architectural design education settings. Solving architectural acoustic problems has been for centuries one of the primary aims of theories and experiments in acoustics. Recent contributions offered by the soundscape approach have highlighted broader desirable aims which acoustic designers should pursue, fostering ecological reasoning on the acoustic environment and its perception as a whole. Drawing from the available literature, some examples are brought to show the integration of architectural acoustics and soundscape approaches into the realm of architectural design education, highlighting the significance of specific design situations and aural training techniques in learning contexts.

Keywords

Acoustic design, soundscape, architectural acoustics, education, situated learning, architectural design, building acoustics

Introduction

Theories and experiments in acoustics have been focusing for centuries on the explanation and solution of architectural acoustic problems, driving the technical development of the discipline and its application in the built environment design. In the last decades, the sonic imbalance deriving from the industrial development in urban settings led to the design of a series of regulations to control machine-made noise and reduce sound levels. Urban authorities as well as the construction industry became closely involved in the design and mitigation of sounds which were likely to be found in the built environment, being also responsible for potential effects on future inhabitants.

The development of regulatory measures aimed to contain excessive sound levels reflected a surge in interest in environmental matters and an increasing attention on the effects of *noise*

Media and Arts Technology, School of Electronic Engineering and Computer Science, Queen Mary University of London, London, UK

Corresponding author:
Alessia Milo, C4DM, QMUL, Mile End Road, London E1 4NS, UK.
Email: a.milo@qmul.ac.uk

exposure on health. *Noise* exposure can cause annoyance, sleep disturbance, cardiovascular disease, impairment of cognitive performance in children, stress-related mental health risks and tinnitus.[1,2] It increases systolic and diastolic blood pressure, causes variation in the heart rate and the release of stress hormones.[3] A recent report by the World Health Organization highlighted the relationship between road traffic and the incidence of ischaemic heart disease with high-quality evidence.[4,5] These focused research efforts raise awareness on health risk factors which may become a burden on our society but rarely acknowledge the *positive* diversity of sounds which populate everyday life, making an acoustic environment peculiar and meaningful for a community. As Adams et al.[6] state, ‘not all sounds are unwanted and many add to the sense of vitality of living in an urban area’.

Among the acoustic design objectives to be pursued by practitioners and researchers, alternative strategies to noise-oriented measures have been recently explored by soundscape scholars. The pioneers in soundscape research were musicians who reflected on the learning processes activated by listening, ultimately leading to an increasing awareness of the relationships characterising the environmental sound ecosystem – our acoustic ecology. This original approach weaved together different disciplines concerned with the built environment and its social system, marking the need for acoustic designers to assume creative responsibilities towards the world soundscape and its music. In some architectural design contexts, these approaches have been adopted as an educational method to reflect on the interactions between architectures and the sounds they activate and modulate, expanding the traditional architectural acoustic scopes to other domains, largely social and cultural.

This article aims to discuss, on the basis of an updated literature, those educational strategies engaged in defining the role of the Acoustic Designer. The questions I pose seek to identify (1) the responsibilities of acoustic design practitioners and (2) which educational approaches may lead to the development of acoustic design skills in architectural design education contexts. Before bringing educational examples, I present a series of conceptual standpoints from the disciplines Architectural Acoustics and Soundscape, to clarify what their contribution in shaping future education strategies might be.

Architectural acoustics and acoustic design

Origins of acoustic design theory

It is widely acknowledged that the first person writing about Architectural Acoustics was the architect-engineer Marcus Vitruvius Pollio.[7–9] Vitruvius wrote the acclaimed 10 books on architecture, called ‘De Architectura’, between 40 and 20 BC.[10] This publication has been for many centuries the first and only handbook on architecture and architectural acoustics, fostering interest in the discipline. According to Walden,[11] Vitruvius was aware of the teachings of the father of medicine, *Ippocrate*. When planning new buildings and in the specific theatres, he advises that ‘a site as healthy as possible’ (p. 137) be selected.[12] Vitruvius also acknowledges the expertise of the Greek architects in designing open-air theatres.

> Hence, the ancient architects, following the footsteps of nature, perfected the ascending rows of seats in theatres from their investigations of the ascending voice, and, by means of the canonical theory of the mathematicians and that of the musicians, endeavoured to make every voice uttered on stage come with greater clearness and sweetness to the ears of the audience. For just as musical instruments are brought to perfection of clearness in the sound of their strings by means of bronze plates or horn echeia, so the ancients devised methods of increasing the power of the voice in theatre through the application of harmonics.[12]

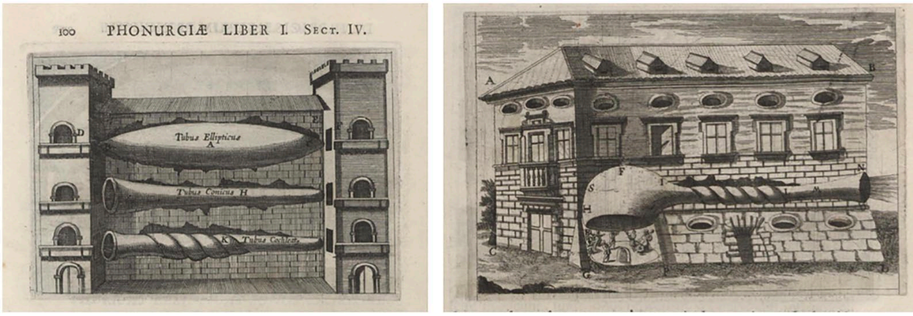

Figure 1. Acoustic Designs by Athanasius Kircher, 1673.

Vitruvius introduced his famous theory on *dis-sonnantes, con-sonnantes, circum-sonnantes* and *re-sonnantes* design solutions, as reminded by Postma et al.[8] and D'Orazio and Nannini.[13] Thanks to his contribution, acoustic design through centuries largely focused on the control of the building shape and the application of the resonant tuning devices called *echeia.*[14]

Acoustic design and medieval tradition

During the Middle Ages, we have no trace of important acoustic developments, although the *echeia* were found in various medieval churches, inserted into the walls, with the belief that they could improve the acoustics of the interior space and the intelligibility of the spoken word.[15] These devices were for example found in Serbian churches spanning from medieval times to the 17th century.[16] However, the measurement of these resonators showed that they would not have any effect on typical choral and preaching production which would take place in these churches, leaving space to the hypothesis that they were installed primarily for oral tradition or as a construction material. These devices were found to achieve diffusion in Swiss churches by Desarnaulds.[17]

Baumann and Haggh[15] demonstrated through the geometrical analysis of reflection paths how in the 15th century the positioning of the organ in Santa Maria del Fiore in Florence might have followed specific acoustic design principles. In the 1500s and the 1600s, architectural acoustics saw a renovated interest, guided by the need to design new playhouses, such as the Elizabethan theatres in London and Opera theatres in Italy.[13] It is nowadays possible to explore this evolution through online resources, such as the website *theatre-architecture* (https://www.theatre-architecture.eu).

Acoustic design and modern science

Shortly after Giuseppe Biancani and Marin Mersenne laid the foundation of the modern science of acoustics, in 1650 the Jesuit scholar Athanasius Kircher published in Rome the *Musurgia Universalis*, followed by the similar *Phonurgia Nova* in 1673.[8,18,19] Kircher charmingly named acoustics as the 'magic art' of the bent sound – *Magia Phonocamptica* – and drafted inventions to amplify sound through pipes in buildings (Figure 1), hydraulic organs, and theories based on geometrical projections and listening experiments with choirs, which he called *Musica per Echo.* (p.50)[20] In these books, he used the word *Architectura Echonica* to describe the study and the controlled design of architectural interactions with sounds. Further insights on the development of the science of Acoustics from its origins can be found in Hunt,[18] who remarked the importance of observation and experiments in such evolution.

Predicting echoes and reverberation times

Architectural acoustics developed as a fundamental part of the design of performance spaces, pushing the limits of innovation.[14,21,22] Recently, Postma et al.,[8] D'Orazio and Nannini[13] and Postma[23] provided an examination of the main design strategies adopted before the discovery of the Reverberation Time (RT60) formula by Sabine, which took place around 1898.[23,24] Pre-Sabinian strategies to solve acoustic design problems involved several methods. Postma et al.[8] differentiated in *design* approaches, such as *copying* or *upscaling* acoustically satisfying buildings and rooms, and *physics-based* design approaches, which can be divided into *undulatory* and *geometrical acoustics*. The *undulatory* approaches were based on the concept of circulation and obstruction of sound, which can be traced back to Vitruvius' suggestions.[8] Vovolis[25] suggested that geometrical methods were already used in Greek open-air theatres to avoid centralised focusing effects.

According to Postma,[23] at the end of the 18th century, an alternative acoustic design guideline emerged, named *echo theory*, based on the 'quantification of the perception threshold between direct and reflected sounds'.[8] Postma et al.[8] have also identified an additional acoustic guideline, based on the undulatory 'circulation of sound' and 'unobstructed propagation' approaches, which employed 'a speaking person and human observer judging audibility/intelligibility as a function of distance and direction', ultimately leading to limiting the size of audience areas.

Designing architectural acoustics

With the formulation of the RT60 by Sabine,[26,27] explaining the influence of volume and absorbent surfaces on the time needed for sound to decay until being inaudible, a rediscovered interest in acoustics spread to the design of everyday spaces. Acoustic consultants, already operating at the time of Sabine,[24,28] could test in real architectural settings their hypotheses aimed at controlling the reverberation phenomenon. In this context, the experimental application of innovative materials, also driving the manufacturing and design industry, made a large number of spaces more absorbent.[24]

Over the course of time, opera houses, theatres, and concert halls had been the primary playground to compare design solutions and test innovations, leading to the standardisation of room acoustics measurement procedures, at the beginning focused mainly on performance spaces. In order to help enable research reproducibility in the field, the standard ISO 3382 was released in 1975 to uniform the measurement of reverberation time, later updated in ISO 3382:1997 to include other acoustic parameters.[29,30] In the recent years, the Building Acoustics Technical Committee (ISO/TC 43/SC 2) has extended the focus of the ISO 3382 from performance spaces[31] to ordinary rooms[32] and open plan offices.[33]

Simulation and auralisation

To be able to demonstrate the reliability of design solutions, practitioners were (and still are) supported by calculation strategies which need to be solid in mathematical and physical theory and guarantee the proposed design outcomes. Theatre acoustic design experimentation developed also through the analysis of sound propagation in scale models, progressively assisted by digital simulation tools, allowing to quickly compare results and organise them in tables and graphs.[34] The combination of computational improvements in both audio signal processing and computer graphics progressively led to the possibility to display information related to acoustic parameters next to the geometrical representation of the digital model. In the last few decades, practitioners have been able to visually inspect critical areas of the design by looking at heat-maps superimposed on the two- (2D) or three-dimensional (3D) views of model, as well as to study reflection paths and their spatial distribution in time.

Auralisation, 'the creation of audible acoustic sceneries from computer-generated data',[35] has helped in the recent years to listen to acoustic design solutions for architectural spaces and evaluate perceptually their acoustic signature, represented by a room impulse response (RIR). An RIR corresponds to the response of the room to the excitation of a given signal, emitted by a source with a given set of coordinates, as recorded by a receiver placed in a different position. Since 1980, and developing in sophistication in the 1990s, a series of innovative auralisation tools were developed in the audio engineering context.[36–41] Adding another sensory dimension to the potential of computer-aided design (CAD), acoustic simulation software has largely helped through years calculating and hearing – with some limitations – how spaces might sound like, according to their volume, geometry and materials.[42]

Thery et al.[43] recently studied the adoption of auralisation in consulting practices, highlighting how their adoption depends on the size of the practice. While smaller practices seem unable to afford the use of these techniques for a lack of resources which include time, money, and skills, higher budget companies adopted this technology often in combination with immersive visualisations, reporting improvements in the collaboration and communication with other stakeholders participating in the construction process. Most of these tools can be considered too expensive also for the pockets of a student, making the simulation of acoustics design choices a technique viable only in large and established professional contexts, or academic departments engaged in acoustic design research.

To meet the demand for more accessible tools which could foster education and creative experimentation in acoustic design, recent developments saw the emergence of real-time auralisation tools such as the SketchUp plug-in RAVEN,[44–46] the open-source EVERTims based on Blender and Juce,[47] and the recent Project Acoustics by Microsoft.[48,49] In Milo and Reiss,[42] the main technical features of these platforms were reviewed providing some details about their software architecture. Drawing from the results of a survey with 15 architects, their technical potential in educational and architectural practices was also discussed.

We should acknowledge that the more widely adopted simulation platforms, such as Odeon and CATT, have supported the study of valuable heritage buildings,[50–52] as well as public squares.[53] On this hybrid terrain where architectural acoustics and public space design intersect, computer-based simulations[54] and scale-model methods[55] are often employed to research case-specific problems while testing the interplay between acoustic theory and simulation constraints.

Modelling acoustic designs

In the last decade, the construction industry has made large use of parametric design techniques to achieve digital form-finding or optimise design solutions.[56] Non-uniform rational B-spline (NURBS)-based software platform like Rhinoceros offer with the Grasshopper plug-in the possibility to construct design algorithms which create bespoke functions. Pachyderm[57] is a plug-in developed within the Foster + Partners practice to verify acoustic design solution. This tool has been employed for the design of acoustically optimised meeting rooms, as shown by Peters, based at the Architecture faculty in Toronto.[58,59] Another example is Aeolus, a computational design tool used to support the acoustic design of a classical music stage shell (ReS), built every year during an architecture and music workshop.[60] This practice-based experience aims at engaging student architects in the realisation of a functional acoustic design, while teaching them the rationale behind design choices (Villa Pennisi in Musica).

Critical summary

From the review presented, we notice how the evolution of the architectural acoustics discipline was driven by the desire to design architectural spaces with adequate acoustic performance. Thanks to those spaces primarily dedicated to social listening the historical development of investigation and prediction techniques ultimately created the scientific basis of contemporary acoustic design practices. I suggest that in such cases, two main factors were jointly involved: first, the *excitement for higher aesthetic scopes* in the acoustic design discipline, helping the delivery of performing arts content through the design of the architectural space also by means of its *significance as a sonic experience*; second, the will to *fulfil the expectations of the clients*, together with some *apprehension for the future audience judgements*.

Architectural acoustic design is today as once still relying on drawing methods, although these can now be managed by a computer. Predictive tools helping solve the complexity in sound wave propagation will increasingly aid designers in imagining new spatialities and study their acoustic effects, with utilitarian as well as aesthetic purposes. Subjective evaluations are still based on listening, although we can now simulate a trial-and-error process in a virtual environment, taking into account the physical laws which were discovered while founding the science of acoustics. A plethora of new inventions in the realm of audio processing and technical design have accompanied this progress. In the next section, I will present the development of the discipline called *soundscape*, highlighting those cultural aspects of acoustic design which the technical nature of the architectural acoustics discipline might have neglected.

Soundscape and acoustic design

In 2014, the standard ISO 12913-1:2014 has defined the soundscape as 'the acoustic environment as perceived or experienced and/or understood by a person or people, in context', where the acoustic environment is 'sound at the receiver from all sound sources'. Such sound from all sources can be 'actual or simulated, outdoor or indoor, as experienced in memory'.[61]

Nevertheless, the first to write about *Soundscape* was Schafer,[62] when he published *The New Soundscape*, followed by the more famous *Soundscape. Our Sonic Environment and the Tuning of the World.*[63] The New Soundscape was published as a *Handbook for the Modern Music Teacher*. In this book, Schafer describes vividly his experience in a classroom at the School of Communication in Simon Fraser University, also reporting sample dialogues with his students. Students were given exercises to describe and categorise sounds. Shortly after, Schafer succeeded in granting funding to the World Soundscape Project (WSP), whose 'purpose was to study the effects of the changing soundscape on human behaviour' beginning with this information 'to develop the new discipline of soundscape design'[64] (p. xii). The project achieved a large resonance globally, influencing future generations. The *Soundscape*[63] and the *Handbook of Acoustic Ecology*[65] represent some of the outcomes of this experience. This *Handbook*, edited by Barry Truax and accompanied by well-documented field recordings, embodied the core of the later book *Acoustic Communication.*[66] In both books, there are some sections covering the *Acoustic Design* theme, which will be briefly described in the next paragraphs.

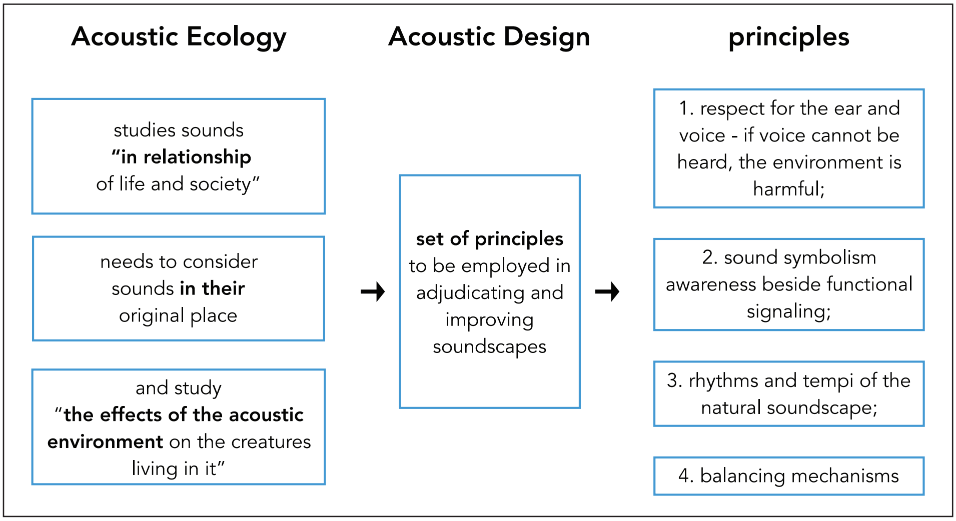

Figure 2. Acoustic ecology and acoustic design principles.[67]

Two perspectives on Acoustic Design

In the *Soundscape*, Schafer argues that the Bauhaus invented the field of industrial design bringing together the fine arts and industrial craft.[63] Similarly, the interdisciplines acoustic ecology and acoustic design can be further developed in a unified framework covering the *science and art of sound*. As illustrated in Figure 2, acoustic ecology studies sounds 'in relationship of life and society' and thus needs to consider sounds in their original place and study 'the effects of the acoustic environment on the creatures living in it'. The study of this discipline is preliminary to acoustic design practice. For Schafer, 'Acoustic design does not, therefore, consist of a set of paradigms or formulae to be imposed on lawless or recalcitrant soundscapes, but is rather a set of principles to be employed in adjudicating and improving them' (p. 238). These principles, also shown in Figure 2, are listed as follows:[67]

1. A respect for the ear and voice – when the ear suffers a threshold shift or the voice cannot be heard, the environment is harmful.
2. An awareness of sound symbolism – which is always more than functional signalling.
3. A knowledge of the rhythms and tempi of the natural soundscape.
4. An understanding of the balancing mechanisms by which an eccentric soundscape may be turned back on itself.

Schafer goes on to explain that the soundscape of the world unfolds around us as a huge musical composition of which we are audience, performers and composers. He advocates for Acoustic Design not to be controlled from above but to work towards the retrieval of a *significant aural culture* with the contribution of anyone with good ears. He sees *composers as the architects of sounds*, although they seem not ready for the task. Finally, he argues for the acoustic designer to have training in acoustics, psychology, sociology, music, and more, although such schools do not exist and need to be created. Basic modules in such disciplines concern the human ear and the human voice, to know the world by experience and comprehend extrahuman sounds with respect to our own. *Ear cleaning exercises* is the name given to listening activities in support of the aural training process. Students should be engaged in recording practices, documenting their sounds, and exploring new places to notice variations which the familiarity with a place would not trigger. Sound and listening walks can support the aural training of the students, using maps as scores for the soundscape exploration.

In the chapter Acoustic Design, from the book *Acoustic Communication*, Truax argues that criteria for acoustic design are obtained from the analysis of positively functioning soundscapes.[66] In addition to governmental legislation and consultants, listeners and sensitive experts can help supporting the goal in aiming at public awareness. The dualism between science and art is solved through the *communication paradigm* which describes the relationship of the individual and the environment as *mediated* by sound. Acoustic Design, therefore, 'represents an understanding of the processes of acoustic communication and seeks to redirect the mediating influence of sound in relationships that are observed to be malfunctioning'.

Although for Schafer 'any classification system or taxonomy is surrealistic', he suggests that sounds can be classified according to their physical characteristics (acoustics), how they are perceived (psychoacoustics), focusing on their function and meaning (semiotics and semantics), or on their emotional or affective qualities (aesthetics) (p. 133).[67] In explaining why this activity might be beneficial, Schafer cites Truax, for whom the act of 'disintegrating a total sound impression into its component parameters' is 'a skill that must be learned', probably necessary for acoustic design. In this quoted passage, Truax clearly reminds that 'a soundscape cannot be understood merely by a catalogue of such parameters', 'but only through the representations formed mentally that function as a basis for memory, comparison, grouping, variation and intelligibility'. Before detailing how different classification approaches may help qualifying soundscapes, Schafer explains *the aim* of these comparison activities:[67]

> If soundscape study is to develop as an interdiscipline, it will have to discover the missing interfaces and unite hitherto isolated studies in a bold new synergy. This task will not be accomplished by any one individual or group. It will only be accomplished by a new generation of artist-scientists trained in acoustic ecology and acoustic design.

Many classification systems have been proposed so far, one example being Krause's[68] division in Geophony, Biophony and Antropophony. The soundscape standard ISO 12913-2[69] *Data collection and reporting requirements* proposes a classification system which focuses on the Urban Acoustic Environment, based on the framework by Brown et al.[70]

From these two summaries, we can observe how the environment is considered as an *ecosystem* (an ecological system), in constant relationship with the listener. The listener, who can be considered an ever-learning open-minded and open-eared student, is invited to explore these relationships with the acoustic environment through a *reflexive* process which includes (1) *exploration*; (2) *auditory observation*; (3) the *association with semantic constructs* such as words; and (4) the *documentation* through the means available, including recording practices. The last step allows the experience gathered by the listener to be communicated to other human beings through further discussions which should include the perspectives of other social sciences to evaluate the perceived quality of the situations examined.

Developing acoustic ecologies

Being the founders of the acoustic ecology movement composers, *soundscape composition* further developed into a genre which is mainly constructed on sounds which preserve the features which make them recognisable.[71–73] However, the weight of the contribution of the WSP was also felt in other disciplines. Throughout the years, the development of the soundscape community was supported by the interdisciplinary contribution of cognitive and environmental psychologists and social sciences theorists. Discussions among researchers largely pointed to ecological themes and awareness motifs, adopting co-creation processes such as participatory mapping practices, often supported by an attention to psychoacoustics phenomena.[74,75]

Sonic experiences and effects. In Grenoble, the interdisciplinary research group CRESSON (Centre de recherche sur l'espace sonore et l'environnement urbain), based at the school of architecture, brought forward 'this attention to earwitness accounts in concrete contexts' that with some phenomenological influences 'led to an emphasis on exploring the dynamic interaction between the physical environment, the socio-cultural milieu, and the individual listener'[64] (p. xiii). Their practice aimed to 'compare the physical characteristics of urban settings with the perceptual awareness of its inhabitants and users' (p. xiii), developing through years a vivid discourse on concepts such as 'atmospheres' and 'ambiances'[76] based on several sensorial dimensions.[77] The group, founded in 1979 by Augoyard, has collected a series of urban sound effects, published in the book *Sonic Experience*.[64,78] This book is the outcome of an interdisciplinary collaboration and can be considered particularly helpful for those who want to approach the acoustic environment from aesthetic, sociological and geographical perspectives. Augoyard and Torgue[64] (p. 4) frame their question as follows, appearing also in Harvey (p. 27):[79]

> What instruments are available to technicians and researchers, administrators and users, designers and inhabitants? What is the sonic instrumentarium of urban environments?

Soundwalking and listening skills. The listening practices advocated by the WSP were chiefly aimed to rediscover our sense of hearing, making them extremely suitable in learning contexts.[80,81] In particular, the *soundwalking* method, poetically described by Westerkamp,[82] and discussed by Drever[83] in its historical lineage, can be considered as an environmental educational practice which achieves two effects. It helps us, through listening and soundmaking, to reflect on how we relate to the environment[84–87] and provides additional training in listening skills, fundamental for composers and performers.[81,88] Recently, soundwalking has also been standardised as a valid and advisable way to characterise soundscapes[69,89] and suggested as a form of training in acoustics for interior design students.[90]

Environmental Psychology and place. Among the satellite disciplines contributing to soundscape research, Environmental Psychology (EP) seems to be close in aims.[91] This field aims to improve the understanding of the interrelationships between people and their built and natural surroundings, helping to create environments responsive to human needs.[92] The discipline gathers psychologists and architects sharing the same interests, producing research which could inform directly Architecture, Town and Regional Planning, Landscape Architecture, and Interior Design.[92] EP officially arose in Proshansky et al.,[93] one year after Southworth[94] published his work on *The Sonic Environment of Cities* in the Journal *Environment and Behaviour*. From this attention to the human–environment relationship arose the idea of a *Psychology of Place*[95] and the field called Architectural Psychology, now considered ended.[96] On this matter, Philip[97] suggested that interactions between individuals and architectures were represented with too rigid behavioural models and there was scarce attention to the emerging scientific findings from architectural design education contexts. Similarly, Canter[98] noticed that the research attention in the architectural theoretical field moved progressively from the relationship between individuals and their environments to pure formal research.

Place attachment, qualities and expectations. At the core of EP research, there is an interest for the relationships between human beings and *place*. For Morgan,[99] 'the concept of place refers to the subjective experience of embodied human existence in the material world'. The term *place identity* was introduced by Proshansky et al.[100] to highlight how the physical environment significantly shapes the human sense of self.[99] *Place attachment*, largely discussed in Giuliani,[101] can be considered for Manzo[102] the set of 'emotional bonds that form between people and their physical surroundings'. These bonds are also related to patterns of use and their meaning for the community, providing additional interpretation layers which influence the soundscape evaluation from a semiotic point of view, as suggested by Dokmeci Yorukoglu and Onur.[103] These layers also depend on listening modes and the atmospherical qualities and the geographical character of a place, defined by Norberg-Schulz's[104] *genius loci.*[103] In soundscape research, local experts are considered the principal source of information to investigate these emotional bonds with the place[69] exemplified by the work of Liu and Kang[105] with local residents in Sheffield.

Besides place attachment, EP discusses broader themes such as stress, restorative environments, and the health benefits of nature.[106–109] It well integrates with soundscape approaches studying our interpretation of the soundscape and its perceived restorativeness,[110] ultimately influencing our quality of life.[2,111] Researching what gives a *sense of place* to a location also has large implications on environmental education.[112–114]

Influencing factors in soundscape evaluation. In soundscape research, the attention to the context and the perception of the individual is paramount.[61] Qualitative approaches to soundscape assessment have shown that expectations and sound preference play a key role in the contextual understanding of a soundscape.[115,116] Aletta et al.[117] reviewed eight soundscape descriptors involved in the perception of an acoustic environment: *noise annoyance, pleasantness, quietness or tranquillity, music-likeness, perceived affective quality, restorativeness, soundscape quality*, and *appropriateness*. Brown et al.[70] identified a large number of outcomes which might determine preference in the assessment of a soundscape. These can be divided in *direct* (e.g. comfort, clarity, sense of control, place attachment) and *indirect* or *enabled* by the soundscape (e.g. communication and nature appreciation).

Developing Soundscape Design. Soundscape researchers have employed simulation tools to test the human response to different soundscape scenarios. Examples are the soundscape simulators by Bruce et al.,[118] Sudarsono et al.[119] and Rossignol et al.[120] and the project DeStress by Payne and collaborators (https://destress.hw.ac.uk/people/). Soundscape research has also started looking at indoor spaces, studying the correlation between acoustic parameters within buildings, the deriving soundscape, and the architectural analysis of a place.[121,122] In addition to physical measurements, qualitative methods can be adopted to investigate the soundscape as perceived by the building occupants.[123,124]

The presence of soundscape topics among research papers in the last years has increased at an extremely fast pace,[125] allowing researchers to identify key priorities and similarities in the methods adopted.[117,126] Within this field, the handbook *Soundscape and the Built Environment*[127] provides well-documented contributions to those approaching the topic.

Critical summary. We examined in this section the inspiration and objectives of those who started soundscape research and launched the World Soundscape Project. Mainly musicians, these pioneers raised among the public awareness on the imbalance of the sonic environment and proposed strategies to ameliorate it through an educational method based on listening and a documenting practice. The authors stress the need for interdisciplinary institutions bridging knowledge from different fields such as psychology and sociology. Acoustic designers are envisioned as artists and scientists engaged with the real world and its social collective problems. The parallel development of EP brought to the attention of the scientific community investigations on the meaning of place and our relationships with it.

The legacy of this movement, such as the CRESSON group or recent soundscape researchers, kept extending the attention from the sole analysis of the sound phenomenon itself, or its control for functional purposes, to the analysis of the sonic environment effects on society. *Expectations* for a given place and its soundscape influence our perception of the situation in which we carry out the listening activity. Design intentions are physically conveyed but implicitly and explicitly mediated through site-specific cultural, social, and geographical constructs. *Sound preference* rely on the individual's experiential history and personality, as well as physiological responses to sound, a sort of cultural and sensorial universe always filtering the environmental scenario.

This important distinction between settings and interpretations may guide acoustic designers in identifying the priorities between *controllable* factors versus those which are found extremely dependent on subjective interpretations. Understanding requirements from specific communities and giving space to the individuals' diversity might help avoid the exclusion or dissatisfaction of some categories of users.

Situated learning and design

The section introduces first an approach to situated practices in learning and design as covered by relevant literature. This grounding might help to highlight how the word *design* in *acoustic design* may carry *situated* implications which make it a process embedded in specific contexts and dependent from them, such as cultures, communities of practices or the domains of applications of specific policies.

The concept of situation

The term *situation* is key in social psychology, arising in the literature with topological psychology from Lewin between the 1930s and 1940s.[128] For Lewin, a person's behaviour depends on two factors – the Person and the Environment – which together represent 'one constellation of interdependent factors'.[129] In 1981, Magnusson distinguished between 'actual environments and situations' and 'perceived environments and situation'.[128] From this concept derived situatedness, applied to the different but related fields of situated knowledges, situated practice, situated learning, and situating contexts (p. 4).[130]

Schön[131] defined *reflection-in-action* the phenomenon of *reshaping design concepts during the process of designing*, declined according to example cases. For the case of architects,

> In a good process of design, this conversation with the situation is reflective. In answer to the situations back-talk, the designer reflects in action on the construction of the problem, the strategies of action, or the model of the phenomena, which have been implicit in his moves.[131]

Situated knowledges

The concept of *situated knowledges* was introduced in 1988 by Donna Haraway, marking the particular, partial and embedded.[130,132] This process allows to ground knowledge with respect to where it is produced and historical contingencies, so that claims can be more aware of partial views and contradictions and keep looking for connections and compromises with other knowledge systems. For Haraway, knowledge is re-created through communities, rather than isolated individuals.[130] In

1989, Brown et al.[133] reflected on *situated cognition in learning* through concepts such as *tools, enculturation, activity, apprenticeship, collaborative learning*, studying examples from just plain folks (JPF), students and practitioners.

Situated learning

In 1991, Jean Lave and Etienne Wenger coined the term *situated learning*, locating this phenomenon in the capacity of learners to access participating roles in skilled performances.[130,134] For the authors, *learning is a situated phenomenon* since it takes place in a *community of practice* which allows 'legitimate peripheral participation', similar to apprenticeship.[130,134] Participation is legitimate since the integral role of the work in *contributing* to the practice is acknowledged by the community. Peripheral means that tasks are initially simple and intended as *learning vehicles* to appreciate the complexity of the whole work.[130,134]

Clancey[135] expanded this concept by arguing that *situated learning* is a theory 'concerned with how learning occurs everyday'. The actions of us as individuals are situated in our *role as community members* and knowledge is dynamically constructed when what happens to ourselves is conceived within a *social matrix* influencing our thinking and behaviour.[135]

Situatedness in design

The concept of situatedness was later applied to design theories, science and practice. Gero[136] argued that situatedness is concerned with the ability to *contextualise* so that both the situation and the situation's construction or interpretation influence the decision-making process. Designers are seen as actors who operate within existing structural constraints, such as *rules, discourses* and *artefacts*.[130,137,138] To understand the extent to which design is situated, other methods can be invoked: (1) *interdisciplinary* methods, which help to understand the relationship between agency and structure; (2) methods to *meta-design*, aimed at improving healthy relationships with institutions or organisations; (3) *reflective* methods, to study how design approaches could be transferred to other domains.[130]

Architectural design education

Architectural design can be considered a form of situated knowledge, bound to geographical regions, legislation systems and locally established working practices. Let us now consider architectural design as a discipline interested in finding design solutions for specific settings and conditions, which we can call the *design situation*. Kowaltowski et al.[139] highlighted how, in the context of architectural design education, the learning process mostly happens through the *design studio*, although the design process often does not follow rigid rules. At the basis of the *design studio* method there is the interaction of students with experienced professionals, allowing unstructured discussions to take place about design problems which are mostly *specific* and *hypothetical*. Kowaltowski et al.[139] identified six main teaching methods for the design process:

1. Studio teaching based on a given architectural programme and site for a specific design project or architectural typology.
2. Studio teaching based on the discussion of an architectural programme, elaborated by students and its appropriate urban setting.
3. Introduction into the studio of an actual, local design problem and the development of a participatory process, with problem analysis and solution justification by students.

4. Teaching design as a combination of architectural theory with practical design activities.
5. Teaching design using 'form generation' methods and formal architectural languages.
6. Teaching design to explore specific CAD design tools.

From this list, we notice that designs and related problems are never generic, but specific, originated according to sites and typologies. Lawson[140] found different approaches in design tasks between fifth-year student architects and fifth-year student scientists, with the former adopting *solution focusing strategies* and the latter adopting *problem focusing strategies*. Architectural design tasks often focus on the design of an original solution, and students are encouraged to justify their solutions, including formal ones. The adoption of CAD tools helps transfer ideas to a digital platform which allows further control on the properties of the design and its communication. From a creative standpoint, a common practice in architectural design teaching is metaphorical reasoning, defined by Welling[141] as four operations: *application, analogy, combination* and *metaphor*.[142] As found by Kowaltowski et al.[139] in a worldwide and Brazil-focused survey, *analogy* is considered the most appropriate method to stimulate the designer's creativity.

Adapting acoustic design education to architectural design schools

Acoustic design handbooks

A large number of courses teaching acoustics to student architects mimics the structure of handbooks of architectural acoustics. Templeton and Saunders[143] include in their book *Acoustic Design* topics such as *Perception of sound, Properties of sound, Sound in the built form, Noise control*, and the last chapter called *Design*. The last chapter includes *Buildings and Building Elements*, such as roofs, ceilings, partitions, accompanied by design details and (outdated) UK Building Regulations.

Similar topics can be found in handbooks on architectural acoustics written in English.[144–149] Some publications have a deeper focus on auditoria,[9,21,150] and some others on modelling and design problems.[151,152] Often, these are directed also towards architects and pre-architects to support their design practice with guidelines accompanied by formulas, calculation procedures and example illustrations.

Among these, we can take as an example the handbook 'Architectural Acoustics' by Marshall Long. The book, designed to support the study of the subject for an introductory academic level, undergraduate or master, is organised as 'a step-by-step progression through acoustic interactions' with practical applications where appropriate. Algorithms are presented to solve real-life design problems and to understand the fundamentals.[146]

According to the chapter order in the book, the student shall start with the fundamentals, including the history of architectural acoustics, physical concepts and quantities, human perception (psychoacoustics), acoustic measurements, and environmental noise. After these five topics, we find a specialised chapter on wave acoustics, followed by eight different cases characterising sound propagation. Finally, we find six chapters on design cases (multifamily dwellings, office buildings, rooms for speech, rooms for music, multipurpose auditoria and sanctuaries, studios and listening rooms), interrupted in the middle by a chapter on sound reinforcement systems and followed by a chapter on computer simulation techniques.

From this overview, we can infer that the Acoustic Designer should fundamentally; (1) master the psychophysiology of hearing; (2) be knowledgeable about sound propagation; (3) understand the different acoustic requirements of common architectural spaces; and (4) be able to apply procedures to achieve acoustic design objectives. These can be considered the core pillars of the discipline regardless of the background of the aspirant designer.

In addition, there are several other topics which help to contextualise the discipline and its evolution. These topics are profoundly entangled with the development of the entire field of acoustics and an attention to sound in the design of the built environment. These can be (1) the historical development of the discipline, (2) the mathematical description of the propagation phenomena; (3) the design and control of electro-mechanical devices producing sound; (4) the design of technological elements able to show fine-tuned passive acoustic properties; and (5) the application of acoustic design knowledge to outdoor settings. Although these paths seem to diverge into many directions, an acoustic designer is expected to have a basic preparation also on each of these topics.

Documenting acoustic design education

The two main methods in acoustic design education could be identified as the *analysis of existing settings* and the *design of new settings*, based or followed in some cases by further analyses. The approach adopted by Berardi[153] belongs to the first method. He reports emergent themes from his experience of teaching acoustics in an architecture school in Canada. He suggests that architecture students have limited attention since acoustics is perceived as an engineering discipline with strong bases into physics, and students consider the course distant from the architectural profession. He introduced new learning practices to help students ‘compare different sound spaces’, in addition to room acoustics descriptions through photos and graphs, and the visit to a performance space. These new practices consisted in the following:

1. Asking the students to visit and describe architecturally and acoustically a performance space, with the goal to collect and share the data in an open-source e-book, accompanied by auralised impulse responses.
2. The in-class experience of a room acoustic simulation.
3. Sound-level measurements conducted in different urban sound environments through smartphone apps, to be done in pairs and from two apps. This helped showing the Sound Pressure Levels of some environments as well as how such systems are *unreliable* as measuring tools.

Some other researchers have supported the adoption of smartphones in environmental acoustics education.[154–156] Kitapci[90] followed a different approach and argued for a teaching module in interior design schools based on four phases addressing Schafer’s principles earlier mentioned: the technical lecture phase, the preliminary research and soundwalks phase, the initial design phase, and the holistic soundscape design phase. Kitapci[90] motivates the criticism to existing courses stating that

> the main objective of the design-oriented architectural acoustics course is to create awareness of the students in the built and natural soundscapes. It is also crucial to emphasize the relationship between conceptual ideas and auditory environments, while delivering adequate levels of theoretical knowledge comprehendible by interior architecture students.

Interesting crossovers were recently initiated by Llorca, looking at two aspects: (1) the potential that architecture students hold in drawing soundscapes[157] and the evaluation of teaching methods for acoustic design through the bipolar ladder assessment (BLA).[158,159] Llorca et al.[158] used the SketchUp plug-in RAVEN to provide an auralised listening experience to architecture students, after the delivery of a theoretical module on acoustics. Comparing theoretical teachings with the experience through the simulation software with the BLA method, Llorca et al.[158] found that the students valued especially the change of paradigm from passive learning to learning by listening. The inclusion of this method for acoustic design teaching could therefore be valuable in architecture and building engineering curricula. They also stressed the importance of covering in an adequate way acoustic theory concepts. Another recent initiative aiming to conduct applied research at the intersection of architecture and acoustics is the European project Acoutect (http://www.acoutect.eu/).

In some cases, acoustic design educators adopt approaches borrowed from architectural acoustics and apply them to architectural design contexts. Trained students can be involved in acoustic surveying to build experiential knowledge based on their perceptions while enhancing observation and reporting skills.[160] For example, Fowler[161] asked his landscape design students to record sonic excerpts from several sites, measure them and write notes in a diary. Students created visualisations of the resulting information on the geographical map showing the area explored, or on architectural drawings such as elevations, plans and sections.

Visualisations of interactions between direct sounds and reflections from architectural elements have been adopted also by Yang et al.[162] to show acoustic design rationales in Chinese listening pavilions. Schafer[63] in general discourages the practice of reducing sound to sole visual signs, as he believes there is a perceptual abyss between a sonic experience and its graphical representation. However, he also acknowledges that visual representations and notation systems such as aerial sonography maps can make it easier for the inexperienced to absorb the salient information.

From aural architecture to architectural soundscapes

In the book *Spaces Speak. Are you listening?*, Blesser and Salter[163] introduce the concept of *aural architecture* – spatial properties which can be experienced through listening. For these authors, the aural architect is usually not an individual but rather an ensemble of roles often unaware of their contributions towards our aural experience of a space, at times resembling the acoustic designer envisioned in Schafer's and Truax's words. Blesser and Salter[163] distinguish the aural architect from the acoustic architect, who is rather a hybrid between the architect and the acoustic engineer.

The authors state that *auditory spatial awareness* is the fundamental skill that aspiring aural architects should develop through listening experiences and sonic practices. They further explain that three related disciplines are involved in investigations on auditory spatial awareness, creating methodological complexity through their combination. These are '*physical science*, which represents physical acoustics with mathematical equations; *perceptual psychology*, which describes perceptual acoustics with subjective measurements; and *cultural anthropology*, which understands cultural acoustics in phenomenological terms'. Following this triadic organisation, they argue that the experience of acoustics can be categorised in *physical acoustics, perceptual acoustics* and *cultural acoustics*.[163]

Sound, space, and architecture. In his doctoral thesis, Harvey[79] argues for the integration of soundscape design methods in the School of Architecture and Design in Melbourne. He achieved this goal through the development of the SIAL Sound Studios, 'a multi-disciplinary facility, incorporating a wide range of investigations into auditory spatial awareness'. Embedding his spatial sonic practice in the department, he produced a number of installations and engagement events, providing in his research a discussion of the variegated meanings underlying the concept of acoustic design. In his arguments, Harvey[79] first mentions the work of Robyn Lines, who investigated in her Masters' thesis the use of acoustic knowledge in architectural design practice. Lines[164] formulates six categories of acoustic design knowledge, reported in Harvey:[79]

- The acoustic design repertoire: known acoustic solutions or partial solutions relating to forms of construction or materials.
- Experience of sound in space: prior concrete experience, which could be practical, evocative or archetypal.
- Visual images of sound behaviour in space: images that depict the movement of sound in space as a wave or ray and visualising the movement of building elements in response to sound impact.
- Function and sound: using knowledge of the building programme and the behaviour of users and equipment to predict possible sound events.
- Spatial relations for sound management: usually involving relationships of volume to reverberation time and role of absorbent materials.
- Existing design as reference: drawn from architecture, and other disciplines such as sculpture and musical noise-making artefacts.

As Harvey[79] reports (pp. 62–63), Lines'[164] conclusion (pp. 118–119) is that

> [. . .] didactic approaches to acoustic education have largely failed to contribute to designers' ability to tackle acoustic design tasks. These attempts to teach a domain of design knowledge separate from design have resulted in poorly remembered learning experiences often associated with dislike, anxiety and a perceived lack of relevance. The treatment of acoustic education is indicative of its place in the shared appreciative system of architecture designers. Hearing has been the poorly regarded second sense by a visual culture working as a visual medium.
>
> An educational design experience needs to require of students that they can apprehend the design situation, make qualitative judgments about a desirable acoustic environment for the subject space, design an acoustic solution in concert with design intentions and confidently judge the success of the acoustic design. (pp. 118–119).

Harvey[79] openly poses the question:

> if the research into the acoustic environment, auditory spatial awareness and electroacoustic music are ways of thinking about the sounding world, then why are they not formally part of schools of spatial studies? (p. 63)

He justifies his arguments by bringing well-known examples based on a geographically co-located cross-fertilisation: (1) the WSP, part of the communications department at Simon Fraser University, now adjacent to the School of Geography; (2) the departments CRESSON and Irec51, part of architecture schools. He also argues that 'various schools of architecture and design employ composers or sound designers, or run sound-based design studios as part of their teaching programs'. Harvey[79] further explains his position as follows:

> It would appear that for an auditory pedagogy to take hold in the practice of designers will require teaching and learning exercises that embody the experience of auditory space; include critical exercises through which to understand the scope of auditory perception and its relation to other sensory systems, the development and application of aural memory, and the discovery of generative acoustic design methods. (p. 66)

and

> the contemporary convergence of electroacoustic practices with spatial studies might be the catalyst to generate new concepts of spatial design and experiences in built and digital space. However, for such a renegotiation of spatial concepts to occur, design pedagogy must embrace the unique needs of an aural training for architects.

Six categories of design studios are brought as an example:

- Sonic-based form generators: sound or music is used to generate a graphic (2D or 3D mapping). Design by parameter-to-parameter selection.
- Acoustic design: sound can be understood as data/numerical-based for distinct auditory programme (e.g. signal-to-noise ratio for lecture theatre).
- Acoustic communication: spatial design to achieve particular auditory communication or experience.
- Heightening auditory awareness: resonant objects or materials, sound installations or wind chimes (e.g. design for blind people).
- Virtual acoustic spaces: sound design for/in other media (e.g. animation, virtual reality or games engines).
- Soundscape studies: analysis and documentation through recording, observation and interviews of interior, urban or natural environments.

Conversational territories between these fields are well represented by the topics of the conference 'Architecture, Music, Acoustics', in which Harvey was involved: (1) Acoustic Ecology, (2) Situated Sonic Practices, (3) Spaces for Performance, (4) Intersections of Music and Architecture, (5) The Poetics of Closure, (6) Sound in Architectural Education and (7) The Architectural Representation of Sound.

Lacey, another sound practitioner and researcher from SIAL, proposed a categorisation for the acoustic design of *architectural soundscapes*, dividing them in *incidental*, arising from sonic infrastructures, and *intentional*, creating sonic architectures.[165] Students engaged in aural training workshops are encouraged to achieve more nuanced perceptions of the site with respect to the capability of the lo-fi concept, especially in thinking how the social and the acoustic relate to each other.[166] In learning activities, Lacey[166] gives emphasis to soundmaking, researching three of the acoustic effects categorised by Augoyard and Torgue:[64]

- Mask: 'the presence of a sound that partially or completely mask another sound' (p. 66).
- Drone: 'the presence of a constant layer of stable pitch in a sound ensemble with no noticeable variation in intensity' (p. 40).
- Filtration: 'a reinforcing or weakening of specific frequencies of a sound' (p. 48).

Lacey[166] argues that these effects could be perceived on site and analysed, helping the students inform their interventions. Soundwalking, listening, and sound mapping are considered acoustic ecology exercises to be employed with the aim to 'obtain a deeper appreciation of each sound effect as a site-specific visceral experience'. 'Imaginative cues and listening exercises of acoustic ecology' were used 'while applying the structural analysis tools offered by CRESSON for the creation of a more diversified sound environment'. Sound art approaches were considered helpful in leading to 'more imaginative listening environments' than those based on shutdowns, attenuation and masking.

Hellström[167] similarly proposes the employment of acoustic design artefacts, such as sound art installations in the city, to promote specific sounds and social interactions in urban spaces. For Hellström,[168] the sound effects categorised by Augoyard and Torgue[64] are seen as 'conceptual tools to depict the context of sound in the sense that it embraces the interaction between human, spatial and physical dimensions'.[166]

Table 1. Sound-based studies within schools of architecture and design, as reported by Harvey.[79]

	University	School/Department	Programme/Centre
FR	University of Grenoble	School of Architecture	CRESSON
CH	School of Polytechnic, Lausanne	Department of Architecture	Institut de Recherche sur l'Environnement Construit (IREC)
US	Rensselaer Polytechnic, New York	Department of Architecture	Graduate programmes in Architectural Acoustics
AU	University of Sydney	Faculty of Architecture, Design and Planning	Master of Design Science (Audio and Acoustics) and single subjects
AU	University of Auckland	National Institute of Creative Arts and Industries	Acoustics Research Centre
UK	University of Edinburgh	School of Arts, Culture and Environment	Master in Sound Design and MSc/ Dip in Sound Environments

Access to education and resources. In developed research contexts, students can explore, through different methods, physical, technical, psychological and cultural aspects of acoustics and be taught how to design by taking into account acoustic properties of architectural environments. The positions of Harvey and Lacey enhance the need for acoustic ecology exercises in architectural design schools and acknowledge as fundamental the contribution from CRESSON's researchers. The student is seen as a critical thinker able to playfully explore the sonic environment and conceptualise phenomena based on situated observations. A deeper attention to music is advocated by those practitioners who see potential in the exchanges between the arts though sound and space. The coverage of topics focusing on acoustic properties of materials, insulation and basics of reverberation seems available in some architectural schools with an engineering focus, embedded in either *building physics* or *architecture technology* courses, as shown by Berardi.[153]

Table 1 reports a list of educational settings showing the integration of sound-based studies within schools of architecture and design, from Harvey;[79] Table 2 reports a list of acoustic courses in Canadian architectural schools, from Berardi;[153] Table 3 reports a compiled list of acoustics departments, within or outside architecture schools, teaching acoustics or providing research supervision and equipment. Table 4 shows the contribution from Kitapci,[90] who reviewed the teaching of acoustics within interior design courses in Turkey.

The teaching of soundscape-related themes, which could be beneficial in the development of the aural awareness needed to communicate with acousticians, for now is still limited geographically and in number of examples. To our knowledge, there is no dedicated master's programme focusing only on soundscapes, which could bridge architectural design, acoustics and recording, and social sciences, mirroring the interdisciplinary school envisioned by the WSP. A solution adopted throughout the years is to connect schools from different countries through large-scale research projects, facilitating the exchange of knowledge. Examples are (1) 'TD0804 – Soundscape of European Cities and Landscapes' within the COST framework (European Cooperation in Sound and Technology); (2) 'Hosanna – HOlistic and Sustainable Abatement of Noise by optimised combinations of Natural and Artificial means';[169] (3) 'FP7 SONORUS – Urban Sound Planning', aimed at discussing urban sound topics and training the new generation of researchers on urban acoustic design strategies.[170–173]

The outcomes of these projects are applicable design guidelines which local authorities and spatial planners or designers can adopt.[174,175] Alves et al.[176] provided a systematic review of

Table 2. Acoustic courses in Canadian architectural schools as reported by Berardi.[153]

	University	Degree	Course
CA	University of British Columbia	Masters of Architecture	Architectural Technology II, Acoustics and Noise Control, Industrial and Environmental Acoustics and Vibration, Advanced Engineering Acoustics, Acoustics
CA	University of Waterloo	Bachelor of Architectural Studies	Interior Environments: Acoustics and Lighting
CA	Universite de Montreal	Bachelor of Science in Architecture	Lighting Engineering and Applied Acoustics
CA	Carleton University	Bachelor of Architecture	Theatre Production
CA	Dalhousie University	Master of Architecture	Acoustics
CA	McGill University	Master of Architecture	Environmental Acoustics
CA	Athabasca University	Post-Baccalaureate Diploma in Architecture	Architectural Design: Acoustics

Table 3. Acoustics research groups collaborating with architecture schools.

	University	School/Degree	Acoustics Research Group
UK	University of Liverpool	School of Architecture	Acoustics Research Unit
UK	University College London	Faculty of the Built Environment	Acoustics Group–Institute for Environmental Design and Engineering
UK	Sheffield	School of Architecture	Acoustics Group
DE	RWTH Aachen	Faculty of Architecture	Institute for Technical Acoustics
NL	Eindhoven University of Technology	Building Physics and Services	Building Acoustics
IT	Turin Polytechnic	Faculty of Architecture	DENERG – Department of Energy – Laboratory of Applied Acoustics
IT	University of Bologna	School of Engineering and Architecture	DIENCA: Acoustics Research Group
IT	University of Rome Sapienza	School of Engineering. Building Engineering Architecture	Department of Astronautic, Electric and Energetic Engineering: Acoustic Laboratory
IT	University of Campania Vanvitelli	Architecture and Industrial Design	Acustica, Vibrazioni e Interazioni Multisensoriali
BR	University of Campinas	Faculty of Civil Engineering, Architecture and Urbanism	LACAF: Laboratory of Applied Physics and Environmental Comfort
BR	Universidade Federal de Santa Maria	Engenharia Acústica	Grupo de Pesquisa Acústica
BR	Universidade de São Paulo	Faculdade de Arquitetura e Urbanismo	Departamento de Tecnologia da Arquitetura

European projects which address urban sound planning topics and an overview of research results that can be applied by practitioners. With the presence of acoustics groups in architecture schools, as – for example – in Sheffield,[54,105,177–179] good research synergies seem to be activated, with valuable outcomes for the civic community.

Table 4. Proposed acoustics course based on interior design studio course by Kitapci.[90]

Week	Proposed acoustics course structure	Interior design studio course structure	Traditional acoustics course structure
1	Introduction to architectural acoustics	Introduction to the course	Origins of sound theory
2	Research presentations	Research presentations	Fundamentals of acoustics
3	Soundwalks	Conceptual presentations	Human perception and reaction to sound
4	Studio critiques on the initial aural design ideas: keynotes	Studio critiques on the initial design ideas	Sound absorption
5	Studio critiques on the initial aural design ideas: keynotes	Studio critiques on the initial design ideas	Room acoustics I
6	Evaluation jury	Evaluation jury	Room acoustics II
7	Evaluation jury	Evaluation jury	Midterm
8	Studio critiques on the improved aural designs: signals	Studio critiques on the improved designs	Sound isolation
9	Studio critiques on the improved aural designs: soundmarks	Studio critiques on the improved designs	Mechanical system noise and vibration
10	Evaluation jury	Evaluation jury	Design of rooms for speech and music
11	Evaluation jury	Evaluation jury	National holiday
12	Studio critiques on the holistic soundscapes	Critiques on the detailed designs	Electronic sound systems
13	Studio critiques on the holistic soundscapes	Critiques on the detailed designs	Regulations, standards, and guidelines
14	Studio critiques on the holistic soundscapes	Critiques on the detailed designs	The soundscape theory
Final examinations			

Discussion

In Figure 3, a framework is proposed to bridge the architectural acoustics scopes with the soundscape ones. This framework suggests that Architectural Acoustics is concerned primarily with the physical and technical dimensions of Acoustic Design, while the Soundscape approach offers a stronger focus on social and cultural aspects. Nevertheless, we can construct a relationship between these disciplines based on dialogue and a common vocabulary. To do so, we shall highlight common aspects, which can be in the first place analytical, for example – an attention to the perceptual and cognitive aspects of sound situations, and empirical comparison activities. Embodied practices can generate new experiential knowledge which can better support abstract theoretical concepts. At the centre of the framework proposed there is the idea of the design of architectural sonic environments. The design activity could involve traditional architectural tasks, as well as the familiarisation with added layers of sounds, such as compositions or installations.

Educational research projects could be situated in key buildings to study how different users interpret soundscapes also in a longitudinal way, helping create a database on how acoustic environments are perceived with respect to how they are acoustically designed. These projects could take advantage of existing research centres providing education on these topics. Student architects, engineers and acousticians could learn in practice to acoustically design a space by studying in a design-studio-context real-life scenarios. Figure 4 suggests a progression of topics which could be covered in an Acoustic Design module. Students could be involved in the following:

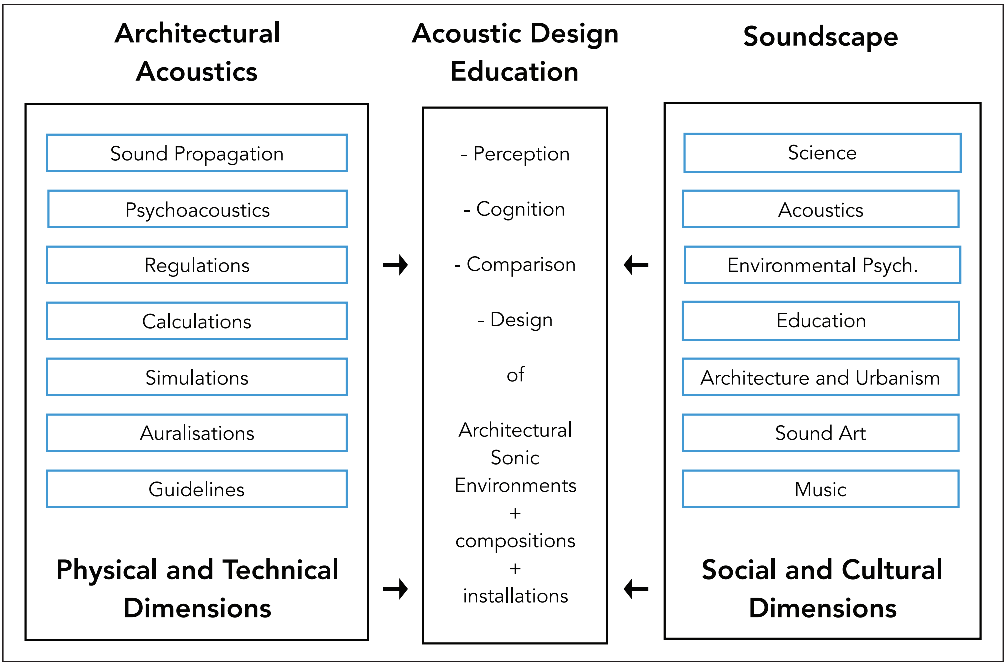

Figure 3. Proposal for an acoustic design unified framework.

1. Listening practices based on both acoustic ecology principles and scientific research protocols, having as outcomes soundscape surveying and design.
2. Designing technical solutions to specific acoustic problems – real or hypothetical – while discovering the efficacy and the limitations of the auralisation methods.
3. Critical reflections on the impact of different regulatory contexts on design practices, which could ultimately lead to the improvement of design standards through a bottom-up approach.

In the progression proposed, the first step is based on practices such as listening activities, soundwalks, and a design process relying on case studies. The practical study of architectural solutions should be finalised to the identification of acoustic objectives and effects, and be addressed creatively through design strategies which include soundscape design. The creative practice is supported by previous analysis of sound sources, taxonomies and atmospheres. Soundscape design can be supported by the study of acoustic effects and sound-based activities such as recording and composition. The adoption of certain strategies is researched through a simulation process based on theory and the verification of the efficacy of the design idea. Among the learning outcomes, the development of aural awareness would take place during the listening experience and the design process, eventually resulting in presentations to be shared with others, such as auralisations and sonic narratives.

To transfer research to design practice through guidance documents, the most important step is to identify what are *common and shared soundscape design goals, according to use cases*. The analysis and comparison of existing studies to new ones, adopting soundscape approaches together with traditional measurements, may help to define design requirements for pedestrian walkways,

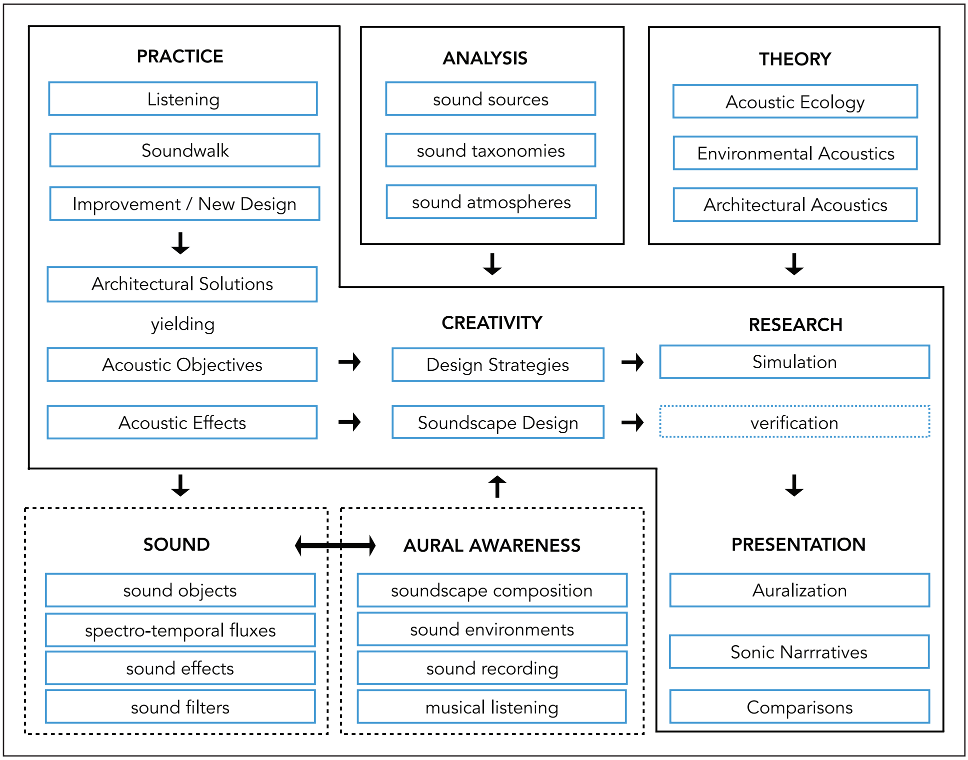

Figure 4. Topics progression for an acoustic design module.

cafes, libraries, atria, offices and so on. Performance spaces could be studied in dedicated acoustic design modules, while other acoustic requirements could be covered in the design studio settings, which are often typology-based. Among the architecture schools, acoustic design practitioners could be involved with the role of experts in design studios, providing feedback case by case on the acoustic design strategies suggested by the students.

Future directions

The efforts from the research community are already directed towards the amelioration of critical acoustic environments as well as the protection of positive ones which locals and planning authorities consider valuable and meaningful. Outcomes produced by the large-scale projects, which combine scientific acoustic research with the identification of design requirements and the development of design tools, could be better exploited if tested in planning contexts. In professional contexts, acoustic design intentions are always situated, being their accomplishment dependent on enforced regulations which guide professionals in guaranteeing acoustic comfort standards. Design decisions are taken every day in the communication between clients, acoustic consultants and architects, contextualised in a certain policy framework.

In the professional practice, the possible synergies between acoustic engineering and architectural design still seem rather unexplored. To reduce this academia–practice gap identified also by Aletta and Xiao,[180] research outcomes need to be transformed into policies, so that design practices may become fruitfully effective in creating healthy sustainable environments and improving those which are perceived as critical. Reflective research methods should be invoked to investigate common practices in design environments and understand which rationales they follow. Studying professional acoustic design collaborations through qualitative methods may help understand what could be improved in the educational field, and from a regulatory perspective. Quantitative methods could in turn help study the impact on acoustic research centres on the development of acoustic design practices.

Conclusion

The long-lasting legacy of architectural acoustics has paved the way to provide fine techniques to simulate the propagation of sound sources in building enclosures and urban spaces. Although more recent, the soundscape framework has produced widely adopted aesthetic and scientific methods to study the effects that everyday soundscapes yield on inhabitants. I suggested that in order to train acoustic design skills these two frameworks could be combined to pursue common objectives. These include the design of acoustic environments promoting an attention to the diversity and identity of everyday sounds and the creation of high-quality sonic experiences, ultimately influencing our perceived quality of life.

In order to achieve these objectives, the key aspects that every fields could leverage were highlighted and discussed with respect to their application in architectural design education contexts. In such places, where practice-based research is developed primarily through the design studio, the adoption of creative strategies might be the key of success towards the development of an interest in acoustic design and its ecological implications. Future acoustic designers could learn to develop a sound-based vocabulary starting from listening and documenting sonic environments in combination with soundscape design tasks. These tasks could also be based on the teaching of architectural acoustics design methods, such as modelling and simulation techniques allowing to listen to imagined spatial scenarios, which could exploit the design knowledge of the students and help them in future professional tasks requiring the communication with acoustic consultants. Acoustic Design should thus be considered as a co-creative situated process shared between clients, architects, acoustic consultants, planners and policy makers, reason why – to benefit the collectivity – the education of future acoustic designers should take place also in architecture schools.

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ORCID iD

Alessia Milo https://orcid.org/0000-0003-1862-5087

References

1. Basner M, Babisch W, Davis A, et al. Auditory and non-auditory effects of noise on health. *The Lancet* 2014; 383(9925): 1325–1332.
2. Aletta F, Oberman T and Kang J. Associations between positive health-related effects and soundscapes perceptual constructs: a systematic review. *Int J Environ Res Public Health* 2018; 15(11): 2392.
3. Babisch W. Cardiovascular effects of noise. *Noise Health* 2011; 13(52): 201–204.
4. van Kempen E, Casas M, Pershagen G, et al. Who environmental noise guidelines for the European region: a systematic review on environmental noise and cardiovascular and metabolic effects: a summary. *Int J Environ Res Public Health* 2018; 15(2): E379.
5. World Health Organization (WHO). Environmental noise guidelines for the European region, 2018. http://www.euro.who.int/en/health-topics/environment-and-health/noise/publications/2018/environmental-noise-guidelines-for-the-european-region-2018
6. Adams M, Cox T, Moore G, et al. Sustainable soundscapes: noise policy and the urban experience. *Urban Studies* 2006; 43(13): 2385–2398.
7. Addis B. A brief history of design methods for building acoustics. In: *Proceedings of the 3rd international congress on construction history*, Cottbus, 20–24 May 2009.
8. Postma BN, Jouan S and Katz BF. Pre-Sabine room acoustic design guidelines based on human voice directivity. *J Acoust Soc Am* 2018; 143(4): 2428–2437.
9. Ando Y and Raichel DR. *Architectural acoustics: blending sound sources, sound fields, and listeners*. London: Springer, 1998.
10. Baldwin B. The date, identity, and career of Vitruvius. *Latomus* 1990; 49(2): 425–434.
11. Walden DK. Frozen music: music and architecture in Vitruvius' De Architectura. *Greek Rom Mus Stud* 2014; 2(1): 124–145.
12. Pollio MV. *Ten books of architecture* (trans. Morgan MH). New Delhi, India: Lector House, 1960.
13. D'Orazio D and Nannini S. Towards Italian opera houses: a review of acoustic design in pre-Sabine scholars. *Acoustics* 2019; 1: 252–280.
14. Baumann D. *Music and Space: a systematic and historical investigation into the impact of architectural acoustics on performance practice followed by a study of Handel's Messiah*. New York: Peter Lang, 2011.
15. Baumann D and Haggh B. Musical acoustics in the middle ages. *Early Music* 1990; 18(2): 199–210.
16. Mijic M, Sumarac-Pavlovic D and kralja Aleksandra B. Acoustic resonators in Serbian orthodox churches. *Forum Acusticum*, 2002. http://www.sea-acustica.es/fileadmin/publicaciones/Sevilla02_rba05001.pdf
17. Desarnaulds V. *De l'acoustique des églises en suisse–une approche pluridisciplinaire*, 2002. https://www.arauacustica.com/files/publicaciones_relacionados/pdf_esp_124.pdf
18. Hunt FV. *Origins in acoustics*. New Haven, CT: Yale University Press, 1978.
19. Tronchin L, Durvilli I, Tarabusi V, et al. The marvellous sound world in the 'phonurgia nova' of Athanasius Kircher. *J Acoust Soc Am* 2008; 123(5): 3606–3606.
20. Kircher A. *Phonurgia Nova sive Coniugium Mechanico-physicum artis et naturae Paranympha Phonosophia concinnatum*. Kempten: Rudolph Dreherr, 1673.
21. Barron M. *Auditorium acoustics and architectural design*. New York: Routledge, 2009.
22. Forsyth M. *Buildings for music: the architect, the musician, the listener from the seventeenth century to the present day*. Cambridge: Cambridge University Press, 1985.
23. Postma BN. A history of the use of time intervals after the direct sound in concert hall design before the reverberation formula of Sabine became generally accepted. *Build Acoust* 2013; 20(2): 157–176.
24. Thompson A. *Stompbox: a history of guitar fuzzes, flangers, phasers, echoes and wahs*. London: Backbeat Books, 1997.
25. Vovolis T. Acoustical masks and sound aspects of ancient Greek theatre, 2012, https://digitalis-dsp.uc.pt/bitstream/10316.2/36286/1/Acoustical%20masks%20and%20sound%20aspects%20of%20ancient%20Greek%20theatre.pdf?ln=pt-pt
26. Sabine PE. The beginnings of architectural acoustics. *J Acoust Soc Am* 1936; 7(4): 242–248.

27. Sabine WC. *Reverberation, The American Architect and The Engineering Record, 1900*. Reprinted in Collected Papers on Acoustics. Mineola, NY: Dover, 1964.
28. Beranek LL and Kopec JW. Wallace c. Sabine, acoustical consultant. *J Acoust Soc Am* 1981; 69(1): 1–16.
29. Barron M. Using the standard on objective measures for concert auditoria, ISO 3382, to give reliable results. *Acoust Sci Technol* 2005; 26(2): 162–169.
30. Bradley JS. Review of objective room acoustics measures and future needs. *Appl Acoust* 2011; 72(10): 713–720.
31. ISO3382-1. *Acoustics – measurement of room acoustic parameters – part 1: performance spaces. Standard ISO/TC 43/SC 2 3382-1:2009*. Geneva: ISO, 2009. https://www.iso.org/standard/40979.html
32. ISO3382-2. *Acoustics – measurement of room acoustic parameters – part 2: reverberation time in ordinary rooms. Standard ISO/TC 43/SC 2 3382-2:2008*. Geneva: ISO, 2008. https://www.iso.org/standard/36201.html
33. ISO3382-3. *Acoustics – measurement of room acoustic parameters – part 3: open plan offices. Standard ISO/TC 43/SC 2 3382-3:2012*. Geneva: ISO, 2012. https://www.iso.org/standard/46520.html
34. Rindel JH. Modelling in auditorium acoustics. From ripple tank and scale models to computer simulations. *Rev Acúst* 2002; 33(3-4): 31–35.
35. Vorländer M. *Auralization: fundamentals of acoustics, modelling, simulation, algorithms and acoustic virtual reality*. New York: Springer, 2007.
36. Kleiner M, Svensson P and Dalenbäck BI. Auralization: experiments in acoustical cad, 1990. http://www.aes.org/e-lib/browse.cfm?elib=5703
37. Ahnert W and Feistel R. Ears auralization software, 1992. http://www.aes.org/e-lib/online/browse.cfm?elib=6745
38. Dalenbäck BI, Svensson P and Kleiner M. Room acoustic prediction and auralization based on an extended image source model. *J Acoust Soc Am* 1992; 92(4): 2346–2346.
39. Kuttruff KH. Auralization of impulse responses modeled on the basis of ray-tracing results. *J Audio Eng Soc* 1993; 41(11): 876–880.
40. Kleiner M, Dalenbäck BI and Svensson P. Auralization-an overview. *J Audio Eng Soc* 1993; 41(11): 861–875.
41. Dalenbäck BI, Kleiner M and Svensson P. Audibility of changes in geometric shape, source directivity, and absorptive treatment-experiments in auralization. *J Audio Eng Soc* 1993; 41(11): 905–913.
42. Milo A and Reiss J. Designing spaces and soundscapes: integrating sonic previews in architectural modelling applications, 2019. https://www.researchgate.net/publication/334031809_Designing_spaces_and_soundscapes_Integrating_sonic_previews_in_architectural_modelling_applications
43. Thery D, Boccara V and Katz BF. Auralization uses in acoustical design: a survey study of acoustical consultants. *J Acoust Soc Am* 2019; 145(6): 3446–3456.
44. Schröder D and Vorländer M. Raven: a real-time framework for the auralization of interactive virtual environments. In: *Forum acusticum*. Aalborg, 2011, pp. 1541–1546. https://www2.ak.tu-berlin.de/~akgroup/ak_pub/seacen/2011/Schroeder_2011b_P2_RAVEN_A_Real_Time_Framework.pdf
45. Aspöck L, Pelzer S, Wefers F, et al. A real-time auralization plugin for architectural design and education, 2014. https://pdfs.semanticscholar.org/8f93/38fd891cc8611f372e2e6d1f28a537c39383.pdf
46. Pelzer S, Aspöck L, Schröder D, et al. Integrating real-time room acoustics simulation into a cad modeling software to enhance the architectural design process. *Buildings* 2014; 4(2): 113–138.
47. Poirier-Quinot D, Katz B and Noisternig M. EVERTims: Open source framework for real-time auralization in architectural acoustics and virtual reality, 2017. http://www.dafx17.eca.ed.ac.uk/papers/DAFx17_paper_50.pdf
48. Godin K, Gamper H and Raghuvanshi N. Aesthetic modification of room impulse responses for interactive auralization. *Audio Eng Soc* 2019. https://www.microsoft.com/en-us/research/publication/aesthetic-modification-of-room-impulse-responses-for-interactive-auralization/
49. Chaitanya CRA, Snyder J, Godin K, et al. Adaptive sampling for sound propagation. *IEEE Trans Visual Comput Graph* 2019; 25(5): 1846–1854. https://www.microsoft.com/en-us/research/publication/adaptive-sampling-for-sound-propagation/

50. Garai M, Morandi F, D'Orazio D, et al. Acoustic measurements in eleven Italian opera houses: correlations between room criteria and considerations on the local evolution of a typology. *Build Environ* 2015; 94: 900–912.
51. Suárez R, Alonso A and Sendra JJ. Intangible cultural heritage: the sound of the Romanesque cathedral of Santiago de Compostela. *J Cult Herit* 2015; 16(2): 239–243.
52. Postma BN, Poirier-Quinot D, Meyer J, et al. Virtual reality performance auralization in a calibrated model of Notre-dame cathedral. *Euroregio* 2016; 6: 1–10.
53. Calleri C, Shtrepi L, Armando A, et al. Evaluation of the influence of building façade design on the acoustic characteristics and auditory perception of urban spaces. *Build Acoust* 2018; 25(1): 77–95.
54. Kim MJ, Yang HS and Kang J. A case study on controlling sound fields in a courtyard by landscape designs. *Landscap Urban Plan* 2014; 123: 10–20.
55. Jang HS, Kim HJ and Jeon JY. Scale-model method for measuring noise reduction in residential buildings by vegetation. *Build Environ* 2015; 86: 81–88.
56. Scelo T. Integration of acoustics in parametric architectural design. *Acoust Aust* 2015; 43(1): 59–67.
57. van der Harten A. Pachyderm acoustical simulation: towards open-source sound analysis. *Archit Des* 2013; 83(2): 138–139.
58. Peters B, Burry J, Williams N, et al. Hubpod: integrating acoustic simulation in architectural design workflows. In : *Proceedings of the symposium on simulation for architecture & urban design*, San Diego, CA, 7–10 April 2013. New York: ACM.
59. Peters B. Integrating acoustic simulation in architectural design workflows: the fabpod meeting room prototype. *Simulation* 2015; 91(9): 787–808.
60. Mirra G, Pignatelli E and Di Rosario S. An automated design methodology for acoustic shells in outdoor concerts, 2018. http://www.euronoise2018.eu/docs/papers/354_Euronoise2018.pdf
61. ISO12913-1. *Acoustics–soundscape–part 1: definition and conceptual framework* (Technical Report). Geneva: ISO, 2014.
62. Schafer RM. *The new soundscape: a handbook for the modern music teacher*. Ontario, ON, Canada: Berandol Music Limited, 1969.
63. Schafer RM. *The tuning of the world*. New York: Alfred A. Knopf, 1977.
64. Augoyard JF and Torgue H. *Sonic experience: a guide to everyday sounds*. Montreal, QC, Canada: McGill–Queen's Press, 2014.
65. ARC Publications, Aesthetic Research Centre, World Soundscape Project. *The world soundscape project's handbook for acoustic ecology*. Todmorden: ARC Publications, Aesthetic Research Centre, World Soundscape Project, 1978.
66. Truax B. *Acoustic communication*. Westport, CT: Greenwood Publishing Group, 2001.
67. Schafer RM. *The soundscape: our sonic environment and the tuning of the world*. New York: Simon & Schuster, 1993.
68. Krause B. Anatomy of the soundscape: evolving perspectives. *J Audio Eng Soc* 2008; 56(1–2): 73–80.
69. ISO 12913-2. *Acoustics–soundscape–part 2: data collection and reporting requirements* (Technical Report). Geneva: ISO, 2018.
70. Brown A, Kang J and Gjestland T. Towards standardization in soundscape preference assessment. *Appl Acoust* 2011; 72(6): 387–392.
71. Drever JL. Soundscape composition: the convergence of ethnography and acousmatic music. *Organ Sound* 2002; 7(1): 21–27.
72. Truax B. Genres and techniques of soundscape composition as developed at Simon Fraser University. *Organ Sound* 2002; 7(1): 5–14.
73. Westerkamp H. Linking soundscape composition and acoustic ecology. *Organ Sound* 2002; 7(1): 51–56.
74. Schulte-Fortkamp B. The meaning of annoyance in relation to the quality of acoustic environments. *Noise Health* 2002; 4(15): 13–18.
75. Lercher P and Schulte-Fortkamp B. The relevance of soundscape research to the assessment of noise annoyance at the community level. In: *Proceedings of the 8th international congress on noise as a public health problem*, 2003, pp. 225–231. https://hdl.handle.net/11245/1.274614

76. Thibaud JP. The backstage of urban ambiances: when atmospheres pervade everyday experience. *Emot Space Soc* 2015; 15: 39–46.
77. Kytö M, Rémy N, Uimonen H, et al. *European acoustic heritage*. PhD Thesis, Tampere University of Applied Sciences, Tampere, AZ, 2012.
78. Amphoux P. Sound signatures, configurations and effects. *Arch Comport Arch Behav* 1993; 3: 387–395.
79. Harvey L. The auditory centre: research and design of acoustic environments and spatial sound projects, 2008. http://researchbank.rmit.edu.au/view/rmit:7887
80. Deans J, Brown R and Dilkes H. A place for sound: raising children's awareness of their sonic environment. *Aust J Early Child* 2005; 30(4): 43–47.
81. Tinkle A. Sound pedagogy: teaching listening since cage. *Organ Sound* 2015; 20(2): 222–230.
82. Westerkamp H. Soundwalking. *Sound Herit* 1974; 3(4): 18–27.
83. Drever JL. Soundwalking: aural excursions into the everyday, 2009. http://research.gold.ac.uk/7836/
84. Paquette D and McCartney A. Soundwalking and the bodily exploration of places. *Can J Communication* 2012; 37(1): 135–145.
85. Polli A. Soundscape, sonification, and sound activism. *AI Soc* 2012; 27(2): 257–268.
86. Staśko-Mazur K. Soundwalk as a multifaceted practice. *ARGUMENT: Bian Philosoph J* 2015; 5: 439–455.
87. Brown A. Soundwalking: deep listening and spatio-temporal montage. *Humanities* 2017; 6(3): 69.
88. Oliveros P. *Deep listening: a composer's sound practice*. Bloomington, IN: IUniverse, 2005.
89. Aletta F, Guattari C, Evangelisti L, et al. Exploring the compatibility of 'method a' and 'method b' data collection protocols reported in the ISO/TS 12913-2:2018 for urban soundscape via a soundwalk. *Applied Acoustics* 2019; 155: 190–203.
90. Kitapci K. *Room acoustics education in interior architecture programs: a course structure proposal*, 2019. http://www.sea-acustica.es/fileadmin//INTERNOISE_2019/Fchrs/Proceedings/2135.pdf
91. Seamon D. The phenomenological contribution to environmental psychology 1982; 2(2): 119–140.
92. Edgerton E, Romice O and Spencer C. *Environmental psychology and architecture: putting research into practice*. Cambridge: Cambridge Scholars Press, 2007.
93. Proshansky HM, Ittelson WH and Rivlin LG. *Environmental psychology: man and his physical setting*. New York: Holt, Rinehart and Winston, 1970.
94. Southworth M. The sonic environment of cities. *Environ Behav* 1969; 1(1): 49–70.
95. Canter DV. *The psychology of place*. Hoboken, NJ: Palgrave Macmillan, 1977.
96. Pol E. Blueprints for a history of environmental psychology (ii): from architectural psychology to the challenge of sustainability. *Medio Ambiente y Comportamiento Humano* 2007; 8(1–2): 1–28.
97. Philip D. Essay: the practical failure of architectural psychology. *J Environ Psychol* 1996; 16(3): 277–284.
98. Canter DV. *In search of objectives: an intellectual autobiography*. Lebanon, PA: Dartmouth Publishing Company 1996.
99. Morgan P. Towards a developmental theory of place attachment. *J Environ Psychol* 2010; 30(1): 11–22.
100. Proshansky HM, Fabian AK and Kaminoff R. Place-identity: physical world socialization of the self. *J Environ Psychol* 1983; 3(1): 57–83.
101. Giuliani MV. Theory of attachment and place attachment. In: Bonnes M, Lee T and Bonaiuto M (eds) *Psychological theories for environmental issues*. Aldershot: Ashgate, 2003, pp. 137–170.
102. Manzo LC and Devine-Wright P. *Place attachment: advances in theory, methods and applications*. New York: Routledge, 2013.
103. Dokmeci Yorukoglu PN and Onur AZU. Semiotic interpretation of a city soundscape. *Semiotica* 2019; 2019(226): 73–87.
104. Norberg-Schulz C. *Genius loci*. Milano: ELECTA ED, 1979.
105. Liu F and Kang J. A grounded theory approach to the subjective understanding of urban soundscape in Sheffield. *Cities* 2016; 50: 28–39.

106. Ulrich RS. Aesthetic and affective response to natural environment. In: Altman I and Wohlwill JF (eds) *Behavior and the natural environment*. New York: Springer, 1983, pp. 85–125.
107. Ulrich RS, Simons RF, Losito BD, et al. Stress recovery during exposure to natural and urban environments. *J Environ Psychol* 1991; 11(3): 201–230.
108. Kaplan S. The restorative benefits of nature: toward an integrative framework. *J Environ Psychol* 1995; 15(3): 169–182.
109. De Groot JI. *Environmental psychology: an introduction*. Hoboken, NJ: John Wiley & Sons, 2018.
110. Payne SR. Are perceived soundscapes within urban parks restorative. *J Acoust Soc Am* 2008; 123(5): 3809–3809.
111. Van Kamp I, Klaeboe R, Kruize H, et al. Soundscapes, human restoration and quality of life. In: *INTER-NOISE and NOISE-CON congress and conference proceedings*, vol. 253, 2016, pp. 1205–1215.
112. Kudryavtsev A, Stedman RC and Krasny ME. Sense of place in environmental education. *Environ Educat Res* 2012; 18(2): 229–250.
113. Kudryavtsev A. Urban environmental education and sense of place, 2013. https://ecommons.cornell.edu/handle/1813/34149
114. Adams J, Greenwood DA, Thomashow M, et al. Sense of place. In: Russ A and Krasny ME (eds) *Urban environmental education review*. Ithaca, NY: Cornell University Press, pp. 12–25, 2017.
115. Bruce NS and Davies WJ. The effects of expectation on the perception of soundscapes. *Applied Acoustics* 2014; 85: 1–11.
116. Yilmazer S and Acun V. A grounded theory approach to assess indoor soundscape in historic religious spaces of Anatolian culture: a case study on Hacı Bayram mosque. *Build Acoust* 2018; 25(2): 137–150.
117. Aletta F, Kang J and Axelsson O. Soundscape descriptors and a conceptual framework for developing predictive soundscape models. *Landscap Urban Plan* 2016; 149: 65–74.
118. Bruce NS, Davies WJ, Adams MD, et al. Development of a soundscape simulator tool, 2009. http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.376.2433
119. Sudarsono AS, Lam YW and Davies WJ. The validation of acoustic environment simulator to determine the relationship between sound objects and soundscape. *Acta Acust United Acust* 2017; 103(4): 657–667.
120. Rossignol M, Lafay G, Lagrange M, et al. Simscene: a web-based acoustic scenes simulator, 2015. https://hal.archives-ouvertes.fr/hal-01078098v2/document
121. Dokmeci PN and Kang J. Classification of architectural spaces from the viewpoint of acoustic comfort. In: *INTER-NOISE and NOISE-CON congress and conference proceedings*, 2010, pp. 3839–3857. https://www.ingentaconnect.com/content/ince/incecp/2010/00002010/00000006
122. Yorukoglu PND and Kang J. Analysing sound environment and architectural characteristics of libraries through indoor soundscape framework. *Arch Acoust* 2016; 41(2): 203–212.
123. Yilmazer S and Acun V. A qualitative approach to investigate indoor soundscape of the built environment. In: *INTER-NOISE and NOISE-CON congress and conference proceedings*, vol. 258, 2018, pp. 680–691.
124. Acun V and Yilmazer S. A grounded theory approach to investigate the perceived soundscape of open-plan offices. *Appl Acoust* 2018; 131: 28–37.
125. Kang J, Aletta F, Gjestland TT, et al. Ten questions on the soundscapes of the built environment. *Build Environ* 2016; 108: 284–294.
126. Engel MS, Fiebig A, Pfaffenbach C, et al. A review of socio-acoustic surveys for soundscape studies. *Curr Pollut Rep* 2018; 4(3): 220–239.
127. Kang J and Schulte-Fortkamp B. *Soundscape and the built environment*. London: CRC Press, 2016.
128. Reis HT. Reinvigorating the concept of situation in social psychology. *Person Soc Psychol Rev* 2008; 12(4): 311–329.
129. Lewin K. Behavior and development as a function of the total situation. In: Carmichael L (ed) *Manual of child psychology*. Hoboken, NJ: John Wiley & Sons, 1946, pp. 791-844.
130. Simonsen J, Svabo C, Strandvad SM, et al. *Situated design methods*. Cambridge, MA: The MIT Press, 2014.
131. Schön DA. *The reflective practitioner: how professionals think in action*. New York: Routledge, 1983.

132. Haraway D. Situated knowledges: the science question in feminism and the privilege of partial perspective. *Femini Stud* 1988; 14(3): 575–599.
133. Brown JS, Collins A and Duguid P. Situated cognition and the culture of learning. *Educat Res* 1989; 18(1): 32–42.
134. Lave J and Wenger E. *Situated learning: legitimate peripheral participation*. Cambridge: Cambridge university press, 1991.
135. Clancey WJ. A tutorial on situated learning. In: Self J (ed.) *Proceedings of the international conference on computer and education*. Charlottesville, VA: AACE, 1995, pp. 49–70.
136. Gero JS. *Towards a model of designing which includes its situatedness*. Aachen: Universal Design Theory, Shaker Verlag, 1998.
137. Meadowcroft J. Who is in charge here? Governance for sustainable development in a complex world. *J Environ Policy Plan* 2007; 9(3–4): 299–314.
138. Shove E and Walker G. Caution! Transitions ahead: politics, practice, and sustainable transition management. *Environ Plan A* 2007; 39(4): 763–770.
139. Kowaltowski DC, Bianchi G and De Paiva VT. Methods that may stimulate creativity and their use in architectural design education. *Int J Technol Des Educat* 2010; 20(4): 453–476.
140. Lawson BR. Cognitive strategies in architectural design. *Ergonomics* 1979; 22(1): 59–68.
141. Welling H. Four mental operations in creative cognition: the importance of abstraction. *Creat Res J* 2007; 19(2–3): 163–177.
142. Yazgan EÖ and Akalın A. Metaphorical reasoning and the design behavior of ‘pre-architects’. *Int J Technol Des Educat* 2018; 29: 1193–1206.
143. Templeton D and Saunders D. *Acoustic design*. Amsterdam: Elsevier, 2014.
144. Mehta M, Johnson J and Rocafort J. *Architectural acoustics: principles and design*. Upper Saddle River: Prentice Hall, 1999.
145. Lord P. *Detailing for acoustics*. Milton Park: Taylor & Francis, 1996.
146. Long M. *Architectural acoustics*. Amsterdam: Elsevier, 2005.
147. Egan MD. *Architectural acoustics (J. Ross Publishing Classics)*, vol. 4. Plantation, FL: J. Ross Publishing, 2007.
148. Maekawa Z, Lord P and Rindel JH. *Environmental and architectural acoustics*. London: Spon Press, 2011.
149. Ermann MA. *Architectural acoustics illustrated*. Hoboken, NJ: John Wiley & Sons, 2014.
150. Beranek L. *Concert halls and opera houses: music, acoustics, and architecture*. New York: Springer Science, 2012.
151. Cox TJ and D’antonio P. *Acoustic absorbers and diffusers: theory, design and application*. London: CRC Press, 2009.
152. Kuttruff H. *Room acoustics*. London: CRC Press, 2014.
153. Berardi U. Teaching acoustics in architectural programs in Canada. *Can Acoust* 2017; 45(3): 98–99.
154. Satoh F, Sakagami K and Omoto A. Application of a smartphone for introductory teaching of sound environment: validation of the precision of the devices and examples of students’ work. *Acoust Sci Technol* 2016; 37(4): 165–172.
155. Sakagami K, Satoh F and Omoto A. Revisiting acoustics education using mobile devices to learn urban acoustic environments: recent issues on current devices and applications. *Urban Science* 2019; 3(3): 73.
156. Elejalde-Garíca MJ and Macho-Stadler E. Using a smartphone to investigate classroom acoustics. *J Phys* 2019; 1287. https://iopscience.iop.org/article/10.1088/1742-6596/1287/1/012023
157. Llorca J, Redondo E, Alba J, et al. Generation of architectural designs using soundscapes: first findings. *DAGA* 2018; 8: 1046–1048.
158. Llorca J, Redondo E and Vorländer M. Learning room acoustics by design: a project-based experience. *Int J Eng Educat* 2019; 35(1): 417–423.
159. Llorca J, Zapata H, Redondo E, et al. Bipolar laddering assessments applied to urban acoustics education. In: *World conference on information systems and technologies*, Berlin, 24 March 2018, pp. 287–297. New York: Springer.

160. Hong JY and Jeon JY. Exploring spatial relationships among soundscape variables in urban areas: a spatial statistical modelling approach. *Landscap Urban Plan* 2017; 157: 352–364.
161. Fowler MD. Soundscape as a design strategy for landscape architectural praxis. *Des Stud* 2013; 34(1): 111–128.
162. Yang S, Xie H, Mao H, et al. A summary of the spatial construction of soundscape in Chinese gardens, 2016. http://www.ica2016.org.ar/ica2016proceedings/ica2016/ICA2016-0678.pdf
163. Blesser B and Salter LR. *Spaces speak, are you listening? Experiencing aural architecture*. Cambridge, MA: The MIT press, 2009.
164. Lines R. *Applied science in design practice: a study of the use of acoustic knowledge during architectural design practice*. Masters Thesis. Melbourne: Royal Melbourne Institute of Technology, 1997.
165. Lacey J. Site-specific soundscape design for the creation of sonic architectures and the emergent voices of buildings. *Buildings* 2014; 4(1): 1–24.
166. Lacey J. Silencing urban exhalations: a case study of student-led soundscape design interventions. *J Sonic Stud* 2017; 14: 1–15.
167. Hellström B. Acoustic design artifacts and methods for urban soundscapes: a case study on the qualitative dimensions of sounds. http://www.diva-portal.org/smash/record.jsf?pid=diva2%3A793358&dswid=1351
168. Hellström B. *Noise design: architectural modelling and the aesthetics of urban acoustic space*. PhD Thesis, Institutionen för arkitektur, Lund, 2003.
169. Forssén J, Hornikx M, Van der Aa B, et al. Toolbox from the EC FP7 hosanna project for the reduction of road and rail traffic noise in the outdoor environment, 2014. http://publications.lib.chalmers.se/records/fulltext/207780/local_207780.pdf
170. Schulte-Fortkamp B and Kang J. Soundscape research in networking across countries: cost action TD0804. *J Acoust Soc Am* 2010; 127(3): 1801–1801.
171. Dökmeci P, Aletta F, Frost M, et al. Cost short term scientific mission: training course on soundscape analysis: soundwalk, recordings, analysis and listening tests. https://hal.archives-ouvertes.fr/hal-00810840/document
172. Alves S, Estévez-Mauriz L, Aletta F, et al. Towards the integration of urban sound planning in urban development processes: the study of four test sites within the SONORUS project. *Noise Map* 2015; 2(1). DOI: 10.1515/noise-2015-0005.
173. Alves S, Scheuren J, Kropp W, et al. Urban sound planning – the SONORUS project, 2016. http://publications.lib.chalmers.se/records/fulltext/242257/local_242257.pdf.
174. HOSANNA. Novel solutions for quieter and greener cities, 2013. http://www.hosanna.bartvanderaa.com/includes/upload/DELIVERABLES/HSNNA_SUMMARY_BROCHURE_JANUARY_2013.pdf (accessed 28 September 2019).
175. Kropp W, Forssén J and Estévez Mauriz L. Urban sound planning – the sonorus project, 2016, https://research.chalmers.se/en/publication/242257 (accessed 28 September 2019).
176. Alves S, Scheuren J and Altreuther B. Review of recent EU funded research projects from the perspective of urban sound planning: do the results cope with the needs of Europe's noise policy? *Noise Map* 2016; 3(1). https://www.degruyter.com/downloadpdf/j/noise.2016.3.issue-1/noise-2016-0007/noise-2016-0007.pdf
177. Yang W and Kang J. Soundscape and sound preferences in urban squares: a case study in Sheffield. *J Urban Des* 2005; 10(1): 61–80.
178. Chen B and Kang J. Acoustic comfort in shopping mall atrium spaces – a case study in Sheffield Meadowhall. *Arch Sci Rev* 2004; 47(2): 107–114.
179. Kang J. On the diversity of urban waterscape, 2012. https://hal.archives-ouvertes.fr/hal-00811058/document
180. Aletta F and Xiao J. What are the current priorities and challenges for (urban) soundscape research? *Challenges* 2018; 9(1): 16.