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Five questions on the indoor soundscape approach for regenerative buildings

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ABSTRACT

Regenerative building design represents a paradigm shift from current sustainability practices towards a new design approach, as it focuses not only on limiting negative impacts but also on promoting a positive contribution to social and ecological systems. Regenerative design and indoor soundscape research share a multidisciplinary approach and the common aim of improving people´s health and well-being. Indeed, soundscape science, originally developed in the context of urban planning, has been recently applied to the indoor built environment as a research framework that integrates noise control engineering methods with physical, social, and psychological approaches in order to foster the design of indoor spaces positively perceived by building users. The five questions presented in this paper investigate several aspects related to this emerging field of research: 1) the contribution of acoustic design to regenerative buildings; 2) differences and similarities between indoor and outdoor soundscape approaches; 3) methodologies for "measuring" indoor soundscapes; 4) the potential of sound management for biophilic design, and 5) the relationship between "wanted" sounds and health outcomes. This study relied on structured interviews with a panel of experts conducted as part of the COST Action RESTORE. Together with interviewees, an agenda for future advances in indoor soundscaping is proposed.

1. INTRODUCTION

Restorative and regenerative design are approaches that aim at restoring and reinforcing the state of health of social and ecological systems through appropriate community planning and building design (e.g. for residential, school, office, healthcare buildings) [1–3]. Compared to traditional sustainability design, the target is not only reducing the negative impact of the construction industry but also providing positive impacts on the environment, on health and quality of life of its inhabitants through the design action. The present study seeks to contribute to the ongoing discussion on restorative and regenerative design concepts and their application, by addressing the role of acoustics in such a paradigm shift towards "doing more good" for our society and environment [2]. Interestingly, a similar paradigm shift is taking place in acoustic design. Indeed, traditional noise control approaches made great efforts to minimize noise annoyance (i.e. "less bad") by reducing sound levels. Sound has been typically considered as unwanted (i.e. "noise"), regardless of its spectral and temporal composition and meaning, and as such it has been treated as a "waste" to be reduced. Moreover, reducing dB levels did not always result in less annoying or more positive acoustic environments. Differently, the soundscape research has evolved as a framework that integrates psychological, (psycho)acoustical, physiological, and social factors to investigate how people experience the acoustic environment, in context [4,5]. By embracing a perceptual perspective, sound is differentiated according to people´s preference and exploited as a design "resource" for shaping healthy and supportive acoustic environments, positively perceived by their users. Regenerative design and soundscape principles hence share a multidisciplinary approach and the common aim of designing better-than-neutral built environments. Primarily applied in the context of urban planning

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[6], the soundscape approach has been increasingly applied indoor to address the perceived acoustic quality of indoor built environments, thus referring to "indoor soundscapes" [7–10]. Despite the huge impact potential in terms of improving health, well-being and quality of life in building occupants [9], indoor soundscape research and practice are still at an embryonic stage and as such need the underpinning science and practical guidance to be provided. The present work seeks to contribute to this emerging field of research by providing an initial discussion over some of the questions that are open. The five questions are based on the qualitative analysis of structured interviews with a panel of experts. Lastly, crucial gaps in indoor soundscape research are discussed and an agenda for future advancements in the field is proposed.

2. METHODS

Four experts were identified, having different backgrounds as researchers or practitioners in the field of urban soundscape, indoor soundscape, acoustic design, public health and well-being. They were Jack Harvie-Clark, Jian Kang, Lisa Lavia and Antonella Radicchi. Given the preliminary and explorative nature of the study, the selected interviewees were not intended to comprehensively cover the many possible viewpoints that can be present in the scientific community but to provide some expert opinions for establishing an initial discussion in the field of indoor soundscape research.

Interviews were conducted remotely between April and May 2019 through online meetings. Interviewees were provided in advance with the information sheet and consent form, containing a list of eight open-ended questions employed for the data collection. Conversations were recorded, transcribed and analysed by thematic coding. The analysis reported here was not carried out by the interviewed authors. According to a theoretical approach [11], data have been coded around the five specific research questions guiding the present study. The analytic process started by organizing data according to patterns in semantic content (i.e. semantic approach), and then summarising and interpreting data in "an attempt to theorise the significance of the patterns and their broader meanings and implications" [11]. An example of the coding process and theme formation is reported in Table 1, with reference to Question 1. Final themes resulting from the analytic process are presented in Table 2. In the discussion section, all the authors provide suggestions to set a future Research Agenda.

Table 1: Extract of the coding process for Question 1

Question 1: ***How can Acoustic Design contribute to shaping Regenerative Buildings?***		
Codes	**Example of excerpt**	**Theme**
Multisensory research	*"There is a need to cover a much more accurate picture of the foundational importance of acoustics to the interaction of all of the other senses."*	Dealing with complexity in user-building and building-city interaction
Integrated design	*"To me the best way to address a good acoustic quality is to implement integrated urban design and planning approaches"*	
…	…	

Table 2: Core themes resulting from the thematic analysis

Question	Themes
Q1: ***How can Acoustic Design contribute to shaping Regenerative Buildings?***	Dealing with complexity in user-building and building-city interaction
Q2: ***What Differences and Similarities exist between Outdoor and Indoor Soundscape Approaches?***	Differences in context - expectations
	Differences in the acoustic environment
	Differences in soundscape strategies
Q3*: How can we "measure" Indoor Soundscapes?*	Methods for the acoustic environment
	Methods for the subjective response
	Methods for soundscape prediction
Q4: ***What is the Potential of Sound Management for Biophilic Design?***	Reproduction of natural sounds indoor
Q5: ***How are "wanted" sounds related to health outcomes?***	Need to review current noise limits from a soundscape perspective

3. RESULTS

Themes emerging from the thematic analysis are summarized in Table 3. For each research question, the main themes are labelled in the first column and shortly described in the second column.

Table 3: Summary of themes emerged from the thematic analysis for the five questions

Q1: ***How can Acoustic Design contribute to shaping Regenerative Buildings?***	
Dealing with complexity in user-building and building-city interaction	There is a need to understand the (positive and negative) impact of acoustic quality on people´s productivity, health, well-being and quality of life. This scientific evidence can reinforce the role of acoustics in a design process that is at the moment visually oriented, thus making it recognizable by policy makers. The impact of acoustics should be assessed from a perceptual point of view and through a multisensory approach, integrating disciplines related to acoustics, sociology, psychology and physiology. This aligns with the soundscape framework. The awareness of sound and noise potentials can change current design practices, providing designers with a larger variety of technologies to be applied to the source-receiver path. Participatory processes should be applied to engage users, public authorities and all the relevant stakeholders in the building design process. This is central to the soundscape approach in order to ensure that the design meets people´s preference. Integrated design practices should be implemented both at urban and building levels in order to address the complexity of user-building and building-city interactions.
Q2: ***What Differences and Similarities exist between Outdoor and Indoor Soundscape Approaches?***	
Differences in context - expectations	In outdoor urban spaces people typically spend a limited amount of time, usually while relaxing or moving across the city, and are often provided with the opportunity to choose their preferred place to walk and relax. In contrast, people tend to spend much more time indoors, performing a great variety of tasks, often without being able to move to better places or to choose where to stay.
Differences in the acoustic environment	Enclosed spaces can be affected by a combination of outdoor-generated and indoor-generated sounds and are characterized by a reverberant sound field that can amplify both sounds and noises.
Differences in soundscape strategies	In indoor spaces, masking strategies should be based on the appropriate combination of indoor and outdoor sounds according to people´s perception (i.e. wanted vs. unwanted sounds). Masking opportunities can be provided by outdoor natural and urban sounds, music (often played through headphones), masking systems and indoor natural features (e.g. fountains).

	Natural features and active systems playing sounds do not replace a proper acoustic design. Added sounds must fit for the usage of the space, creating supportive environments depending on the tasks to be performed and meeting the personal preference, ideally after being negotiated with final users.
Q3*: How can we "measure" Indoor Soundscapes?*	
Methods for the subjective response	Survey methods currently used in post-occupancy evaluations should integrate soundscape methodologies (cf. ISO/TS 12913-2 [12]) able to better describe the human perceptual response to the acoustic environment. These include rating scales, questionnaires and interviews. Soundwalks might be directly applied indoor or adapted and modified to address the peculiarities of indoor contexts (e.g. sedentary activities), under the framework described by the ISO 12913 series [12–14]. Mobile applications can be used as data collection tools to gather feedback from building users on the perceived acoustic environment when they want to and independently from the researcher. In self-report methods responses may be biased due to the attentive listening mode participants assume when they are asked to perform a soundscape evaluation. This risk can be overcome through non-participatory methods [15].
Methods for the acoustic environment	Traditional methods from noise control engineering, room and building acoustics should be combined with psychoacoustic methodologies, able to determine the basic auditory sensations elicited by sounds. Binaural recordings would allow aurally accurate analyses and reproductions of the acoustic environments. Combination of different soundscape methods related to the human perception, the acoustic environment and the context is encouraged, as it allows data validation through triangulation.
Methods for soundscape prediction	The use of virtual reality technologies (auralization and visualization) allow soundscape assessments to be performed on artificial virtual environments before the building realization. There is a need to develop new soundscape indices by coupling physical and perceptual data. Indoor soundscape indices would be able to predict the way building users perceive the acoustic environment during the design stage.
Q4: *What is the Potential of Sound Management for Biophilic Design?*	
Reproduction of natural sounds indoor	Some of the interviewees declared themselves skeptical of solutions based on natural sounds playback, as they would be perceived as "fake". In playing natural sounds indoor, it is important to provide a coherent combination of visual and audio stimuli related to natural elements. Visual scenes may be provided through pictures or window views. Added sounds should be in any case "wanted" by building users, suitable for the tasks to be performed, designed and evaluated according to soundscape methods and following participatory processes. Artificial biophilic sounds might contribute in enhancing indoor soundscape quality by providing a contact with nature. However, the acoustic quality of a space cannot entirely rely on them. As building users or individual preference might change over time, the space should be acoustically suitable even without the presence of those added sounds.
Q5: *How are "wanted" sounds related to health outcomes?*	
Need to review current noise limits from a soundscape perspective	The WHO organization has provided outdoor noise limits based on established exposure–response relationships between the environmental noise generated by transportation, wind turbines and leisure events and the proportion of people with a health outcome [16]. Limits provided by the Environmental Noise Guidelines for the European Region are bounded by the emergence of annoyance rather than of other physical or mental diseases (e.g. increased risk of ischemic heart disease, hypertension, mental health). Noise limits might be relaxed in case of low annoying or pleasant sounds, at least within levels that impede the emergence of annoyance or different health outcomes. A threshold level can thus be identified, below which the soundscape quality is determined by sound type (wanted vs. unwanted) rather than by sound level. The overall level should not exceed such threshold to avoid the emergence of health risks caused by noise and sound exposure. The threshold level might depend on several factors, among which the availability of control over the environment, the performed task and the length of the exposure (Figure 1).

4. DISCUSSION: CHALLENGES OF INDOOR SOUNDSCAPE RESEARCH

The five questions provided an overall picture of the emerging indoor soundscape research field and pointed out many knowledge gaps that need to be addressed in the future by researchers and practitioners:

- Perceptual dimensions underlying the affective response to the indoor acoustic environment should be identified, accounting for the peculiarities of indoor soundscapes compared to outdoor ones (Question 2) and of different building typologies (e.g. residential, school, office, healthcare buildings). Along with such perceptual constructs people's perception can be assessed and the effectiveness of design actions evaluated [17,18];
- People´s response to combined environmental stimuli in the presence of different personal and contextual factors should be investigated through multi-domain research approaches [19,20] (e.g. sound and high temperature while mitigating overheating conditions, or sound and different visual stimuli);
- Soundscape data collection methods need to be tailored to indoor soundscape features (Question 3), following the general framework described by ISO 12913 series [12–14]. If integrated into current post-occupancy survey procedures [21], indoor soundscape data collection methods can help gathering a more general view of what people expect and needs from their environment from a functional, emotional and social point of view;
- Soundscape data collection methods can inform perception-driven indoor soundscape design practices based on enhancing wanted sounds and masking/reducing unwanted ones according to people´s perception. This can lead to the development of new technologies (e.g. passive or active systems) or to rethinking existing ones according to a new perception-based knowledge (e.g. building automation systems, active noise control, ventilation systems [10]), in keeping with an occupant-centric design and operation of buildings [22];
- Further research and field studies should focus on the potential benefit provided by natural sounds for biophilic purposes (Question 4) but also by commonly available urban sounds in providing a contact with the outdoor and a sense of place, depending on the specific building typology and urban context;

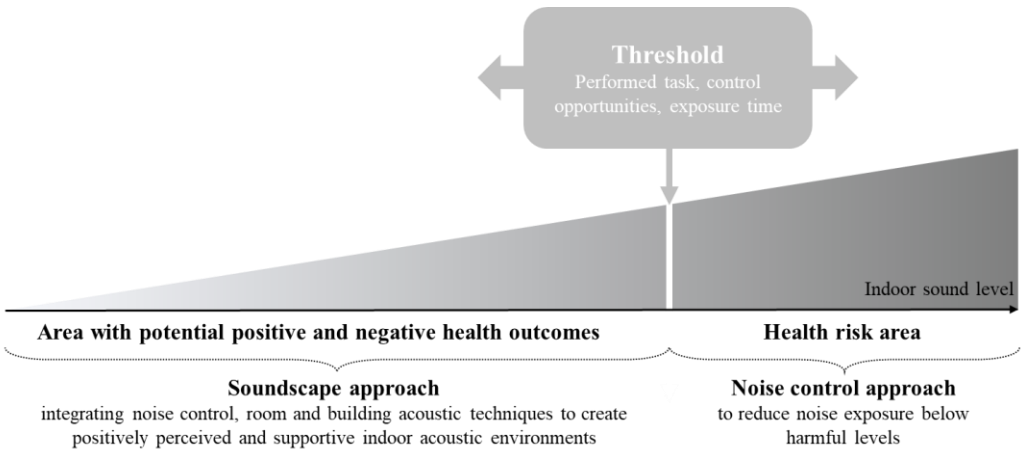

Figure 1: Soundscape and noise control approaches in relation to health outcomes. The horizontal axis conceptually depicts increasing indoor sound levels. A threshold level distinguishes an upper area in which a noise control approach must be applied to lower sound and noise exposure below harmful levels (i.e. health risk area). Below the threshold level, a soundscape approach should be applied in order to enhance wanted sounds over unwanted ones, reducing the negative health outcomes and fostering the positive ones. Threshold levels depend on the space use, control opportunities and exposure time.

- New scientific evidence can inform on positive and negative outcomes of sounds on people´s health and well-being. Going beyond mere cause-effect relationships between decibel noise exposure and resulting annoyance, new exposure thresholds can be identified below which apply soundscape methodologies for regenerative design purposes (cf. Question 5 and Figure 1), according to a salutogenic approach of the built environment;
- In the case of places of work and study, for example, a better understanding should be gained on the relationship between tasks building users are called to execute and the cognitive and emotional states they must achieve to perform at best, and specifically on how wanted sounds and intelligibility conditions can impair or support such relationship;
- As regards soundscape predictability, by triangulating physical and perceptual data, research efforts need to focus on the development of indoor soundscape indices, integrating existing knowledge from noise control, psychoacoustic, building and room acoustics, able to predict during the design stage how the design choices will result in specific perceptual outcomes.

5. CONCLUSIONS

The present study presented emerging themes on the application of the indoor soundscape approach for regenerative building design (e.g. in residential, school, office, healthcare buildings). The discussion pointed out the importance of perceptual and multisensory research from the one side and integrated participatory design practices from the other to enable a holistic overview of the complex building-user interrelations, thus reducing the risk of mismatches between expected and real (i.e. in-situ) building experience by space users. Soundscape methodologies adapted to address the peculiarities of indoor soundscapes can help to measure and predict human perceptual responses to the acoustic stimuli, in context. This perceptual perspective could capture a wider picture of the negative and positive impacts of the acoustic environment on human health, well-being and quality of life. These insights further strengthen the role of acoustics in indoor building design initial stages and challenge many current design practices based primarily on a noise control approach.

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