29th International Congress on Sound and Vibration
The annual congress of the International Institute of Acoustics and Vibration (IIAV)
9–13 July 2023
ICSV29

ON THE DEVELOPMENT OF SOUNDSCAPE INDICES (SSID)

Jian Kang, Francesco Aletta, Tin Oberman, Andrew Mitchell, Mercede Erfanian
UCL Institute for Environmental Design and Engineering, The Bartlett
University College London, United Kingdom
email: j.kang@ucl.ac.uk

The growing field of soundscape studies considers sound environments as perceived, in context, with an interdisciplinary approach. In this paper, based on an ongoing European Research Council (ERC) Advanced Grant project, the current developments on establishing "soundscape indices" (SSID) are outlined, including: the SSID framework; the SSID protocol for field soundscape survey, and the SSID protocol for laboratory soundscape listening tests; establishment of the open SSID soundscape database; analysis of relationships among psychological, (psycho)acoustical, neural and physiological, and contextual factors, as well as their effects on soundscape descriptors; soundscape evaluation in different languages and cultures; an integrated soundscape prediction model; `soundscapy`, a soundscape analysis tool for soundscape designers; and work towards a single soundscape index. It is expected that SSID will adequately reflect levels of human comfort to integrate (and eventually replace) decibel-based metrics commonly used in existing (international) regulations, shifting the focus from noise control to a more holistic approach, and contributing to smart cities/buildings and digital engineering.

Keywords: soundscape, soundscape indices, soundscape prediction, soundscape model

1. Introduction

The growing field of soundscape studies considers sound environments as perceived, in context, with an interdisciplinary approach [1]. This is fundamentally different from the conventional decibel-based approaches, which form the basis of most regulations on sound environment worldwide [2]. Therefore, it is essential to develop new measures to overcome the problems of decibel-based measures, to better reflect people's perception, in context [3-5].

In this paper, based on an ongoing European Research Council (ERC) Advanced Grant project [6], the current developments on establishing soundscape indices (SSID) are outlined, including: the SSID framework; the SSID protocol for field soundscape survey, and the SSID protocol for laboratory soundscape listening tests; establishment of the open SSID soundscape database; analysis of relationships among psychological, (psycho)acoustical, neural and physiological, and contextual factors, as well as their effects on soundscape descriptors; soundscape evaluation in different languages and cultures; an integrated soundscape prediction model; `soundscapy`, a soundscape analysis tool for soundscape designers; and work towards a single soundscape index.

2. SSID framework

Aletta et al. [7] proposed a definition of soundscape descriptors and indicators, where the former are "measures of how people perceive the acoustic environment", whilst the latter are "measures used to predict the value of a soundscape descriptor". Taking a further step, soundscape indices can then be defined as single-value scales derived from either indicators or descriptors that allow for comparisons across soundscapes. This process is schematically described in Figure 1 [6], where the framework for developing soundscape indices could be organised into main steps including collecting soundscape data and characterising the (acoustic) environment, analysing the relationships among psychological, (psycho)acoustical, neural and physiological, and contextual factors and their effects of on soundscape descriptors, and integrated soundscape prediction modelling on the relationships between descriptors and indicators. This will, in turn, pave the way for the definition of the soundscape indices that will be used as single-value representations of the soundscape quality of a place.

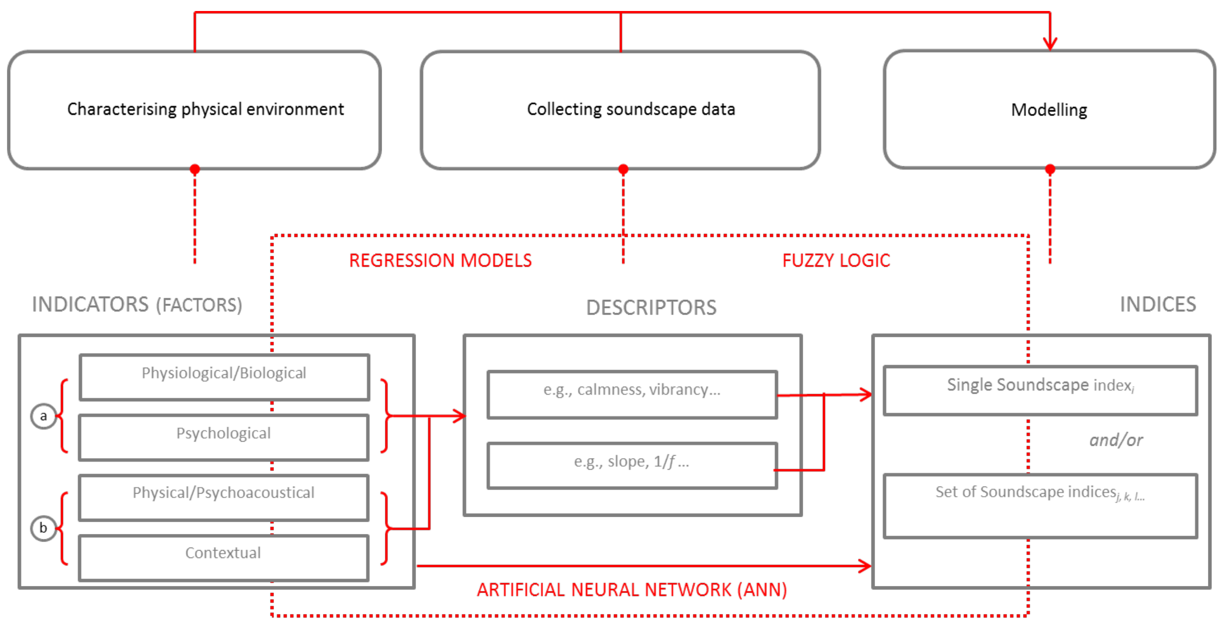

Figure 1: Framework for developing soundscape indices [6].

3. SSID protocol for field and laboratory studies

A SSID protocol for characterising urban soundscapes for use in the development of SSID and general urban research has been developed, which consists of two stages: a Recording Stage to collect audio-visual recordings for further analysis and for use in laboratory experiments, and a Questionnaire Stage to collect in situ soundscape assessments via a questionnaire method paired with acoustic data collection [8]. In the Recording stage the First-Order (or higher) Ambisonics recordings are made simultaneously with 360◦ video which can be reproduced in a virtual reality environment. In the Questionnaire Stage in situ questionnaires are conducted using a slightly altered version of Method A (questionnaire) from Annex C of the ISO/TS 12913-2:2018 technical specification [9-11] collected either via handheld tablets or paper copies of the questionnaire. Typically, a minimum of 100 responses are collected at each location during multiple 2–5-h sessions over several days. During the survey sessions, acoustic data are collected via a stationary Sound Level Meter running throughout the survey period and through binaural recordings taken next to each respondent. These acoustic and response data are linked through an indexing system so that features of the acoustic environment can be correlated with individual responses or with the overall assessment of the soundscape. Key adjustments and improvements to previous methodologies for soundscape characterization have been made to enable the collation of data gathered from research groups around the world.

A SSID protocol for laboratory soundscape listening tests has also been developed [12], building on the Recording stage of the SSID on-site protocol and based on experience from several laboratory experiments and reviews [13-15]. SSID laboratory experiments rely on auditory stimuli delivered via an Ambisonics speaker array and visual stimuli delivered via an immersive virtual reality (IVR) head-mounted display in three degrees of freedom, while the questionnaire responses are collected inside the IVR simulation. The protocol takes into account characterisation of the listening room, playback system, calibration of playback levels, assembling a virtual experimental environment, questionnaire deployment, control measures keeping track of participants behaviour, data quality control measures, and outlines the reporting structure expanding on the one recommended in the ISO/TS 12913-2 [9].

4. SSID soundscape databases

Based on the data collected under the protocol, a large-scale, International Soundscape Database has been established [16], which is available online. Currently the core of this database are individual soundscape questionnaires collected for 1,500+ participants completed in situ in multiple urban public spaces across several cities in Europe, and the psychoacoustic analysis of 30s binaural recordings which can be matched up to each questionnaire. These urban spaces include places like parks, urban squares, green spaces, and market streets. Therefore, the data is organised by LocationID, then SessionID, then GroupID. The excel file organises the data according to the labels given above. In addition, a table with photos and descriptions of each of the locations is provided.

It is the intention that this dataset be added to and augmented with new locations, cities, and contexts in the future. This will be done both by the SSID team at University College London, but we also strongly welcome contributions from other researchers and practitioners. If a soundscape assessment is collected according to the SSID Protocol, it can be integrated with the rest of the database to form a large, cohesive, and ever-growing database of soundscape assessments.

5. Relationships among various factors

Understanding the relationships among psychological, (psycho)acoustical, neural and physiological, and contextual factors, as well as their effects on soundscape descriptors, is vital for the SSID development. While considerable works have been carried out in this aspect [17-18], considering land use factors [19-22] and general contextual factors [23-24], social factors [25-26], physiological factors [27-28], and other physical factors such as smell and thermal conditions [29-30], for developing SSID models, a series of analysis has been carried out based on the large-scale SSID database [31-32], and an additional database, Deep Learning Techniques for noise Annoyance detection, DeLTA [33].

An analysis to assess the influence of psychological well-being and demographic factors including age, gender, occupation status, ethnic backgrounds and education levels as top-down factors on the dimensions of the soundscape circumplex, i.e., Pleasantness and Eventfulness, was carried out [31]. Linear mixed-effects modelling applying backwards-step feature selection was used to model the interactions between internal factors including psychological well-being, age, gender, occupation status, ethnic backgrounds, education levels and the soundscape pleasantness and eventfulness, while accounting for the random effects of the survey location, namely, the context. It was shown that internal factors account for approximately 1.4% of the variance for pleasantness and 3.9% for eventfulness, while the influence of the locations accounted for approximately 34% and 14%, respectively. Psychological well-being is positively associated with perceived pleasantness, while there is a negative association with eventfulness only for males. Occupation status, in particular retirement as a proxy of age and gender, was identified as a significant factor for both dimensions. Since the influence of the locations, with their distinct acoustic profiles, could explain the model better, we delve deeper into the effects of psychoacoustic factors that compose these profiles (loudness, spectral content and temporal structure of sounds) on pleasantness, eventfulness and the underlying physiological representations. While physiological responses (indicative of sympathetic nervous system activation) are linearly associated with loudness rather the sound type, pleasantness and eventfulness are primarily modulated by the sound type (natural and mechanical), and to a lesser degree by loudness. This suggests that pleasantness and eventfulness do not always fully align with physiological responses. In addition, the eventfulness of natural and mechanical sounds is predominantly modulated by the spectral content, when the spectral content of sounds is attenuated, the eventfulness difference between natural and mechanical sounds diminishes and people tend to judge the sounds based on their temporal structure. Although the spectral content of sounds seems to influence soundscape, it does not reflect on the physiological responses. Altogether, it appears that loudness and spectrotemporal characteristics of sounds affect soundscape and the underlying physiological responses at varying degrees and these characteristics give rise to soundscape discrepancies between natural and mechanical sounds.

Also relevant is the analysis of such relationships in other kinds of places such as mountain landscape [34], temples [35], and indoor spaces [36], also considering a range of users such as blind [37] and older people [38-39]. It is also important to consider the effects of time domain, such as sequential spaces, both outdoor [40] and indoor [41-42].

6. Soundscape evaluation in different languages and cultures

Cross-cultural differences have been shown in soundscape evaluation [43]. On the other hand, while the use of questionnaires for soundscape evaluation is a key aspect of soundscape research, as standards and protocols mainly exist in English, using an appropriate translation and cross-cultural adaptation (CCA) methodology is essential to maintain content equivalence between source and target language [44]. To address this gap, an international collaboration was initiated with soundscape researchers from all over the world. Translation into 19 different languages, obtained through focus groups and panels of experts in soundscape studies, was carried out, and then, using the same set of soundscape stimuli, comparisons were made based on laboratory listening test across different countries [45]. It was observed that in some cases, a multi-stage process was developed, and the proposed instrument was piloted with follow-up primary data collection, such as a small-scale listening experiment or soundwalk. This approach was more often used in cases where previous references in the literature were not available, making a scoping task more desirable. More importantly, it was noted that the main challenge was the possibility of translating each of the eight attributes of the ISO document with a single word in a different language. The outcomes of the study show that almost every group opted to avoid a one-word translation of the English attributes and aimed for 2-3 terms that would together convey more clearly the meaning of the perceptual construct of interest. This was particularly difficult when considering the transition from alphabetic to logographic systems, which often required more terms to retain the meaning.

7. An integrated soundscape prediction model

The prediction of soundscape descriptors using soundscape indicators have been explored [46], along with comparison among different soundscape modelling methods [47], which suggests that the compared performance between linear and non-linear methods does not show remarkable differences, although non-linear methods might represent a more suitable choice in models where complex structures of indicators are used.

The unprecedented lockdowns resulting from COVID-19 triggered changes in human activities in public spaces. Building on the SSID database with pre-COVID data, a predictive modelling approach was developed to characterize the changes in the perception of the sound environment when people could not be surveyed but sound recordings could be made [48]. Using these 30-s-long recordings, linear multilevel models were developed to predict the soundscape pleasantness (R2 =0.85) and eventfulness

(R2=0.715) during the lockdown and compare the changes for each location. The performance was above average for comparable models. This study demonstrates the usefulness of predictive modelling and the importance of considering contextual information when discussing the impact of sound level reductions on the soundscape.

The model presented in [48] represents an advance for current soundscape methods and provided insight into the likely soundscape during the COVID-19 lockdown. However, it does not yet represent a generalisable soundscape model which can be applied widely as a design and assessment tool. Current prediction model development is therefore investigating several avenues for generalising the model, in particular by incorporating additional contextual information. Preliminary work has demonstrated that visual information, drawn from automated semantic segmentation of videos using deep neural networks [49], has the potential to be incorporated into a soundscape model. In addition, the DeLTA project has provided new insights into how automated sound source recognition models can be integrated to provide meaningful semantic information.

8. A soundscape analysis tool for soundscape designers

Soundscape pleasantness and eventfulness, as specified in ISO [9, 50], are key descriptors the soundscape prediction models. In order to characterise the soundscape of a particular space or time, perceptual responses from multiple people must be collected and subsequently summarised or aggregated to describe the general soundscape of the location. The ISO recommended measure of central tendency is the median, while the recommended measure of dispersion is the range [50]. Given this single point on the circumplex cannot be considered to be a realistic representation of the average perception of the acoustic environment, and there is no representation of dispersion, a method for presenting the results of standardised assessments as a distribution of soundscape perception within the circumplex space has been proposed [51]. An example is given in Figure 2. Such a tool simplifies the analysis process for soundscape researchers and can be used by soundscape designers to compare different designs.

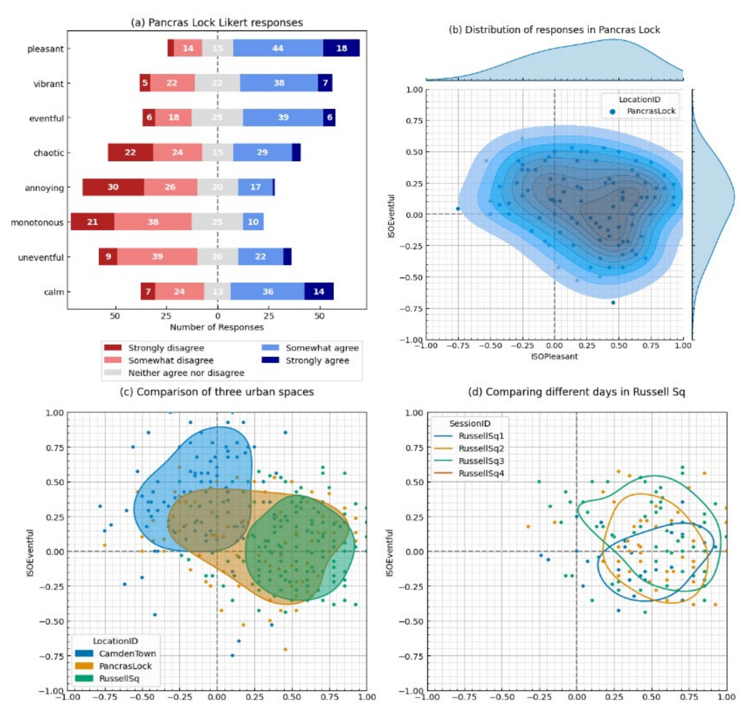

Figure 2. A demonstration of `soundscapy`, a soundscape analysis tool for representing soundscape perception as probabilistic distributions.

9. Work towards a single soundscape index

While soundscape descriptors including pleasantness and eventfulness can be predicted using the soundscape prediction models, which are useful at the design stage to adjust different design treatments, it is often desirable to rank different designs to make final decision [52]. Therefore, a single soundscape index is required. A ranking method is being developed, taking into account the evaluation of the overall quality, with a range of soundscape situations, with cases collected in the SSID database as a basis. The single soundscape index can also be used along with other considerations such as soundscape valuation [53] including preservation values [54]. By taking into account these additional factors, the soundscape approach provides a comprehensive and holistic evaluation of the soundscape, enabling designers and planners to create soundscapes that are not only functional and aesthetically pleasing, but also have positive impacts on human well-being, the environment, and cultural heritage.

Overall, the single soundscape index, combined with other considerations such as soundscape valuation and preservation values, provides a valuable tool for designers, planners, and decision makers, helping them to create better soundscapes for everyone.

10. Conclusions

It is expected that SSID will adequately reflect levels of human comfort to integrate (and eventually replace) decibel-based metrics commonly used in existing (international) regulations, shifting the focus from noise control to a more holistic approach, and contributing to smart cities/buildings and digital engineering.

Acknowledgements

This research was funded through the European Research Council (ERC) Advanced Grant (no. 740696) on "Soundscape Indices" (SSID). We want to thank Magdalena Kachlicka and Matteo Lionello for their support with data collection.

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