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A comprehensive methodology for the multidimensional and synchronic data collecting in soundscape

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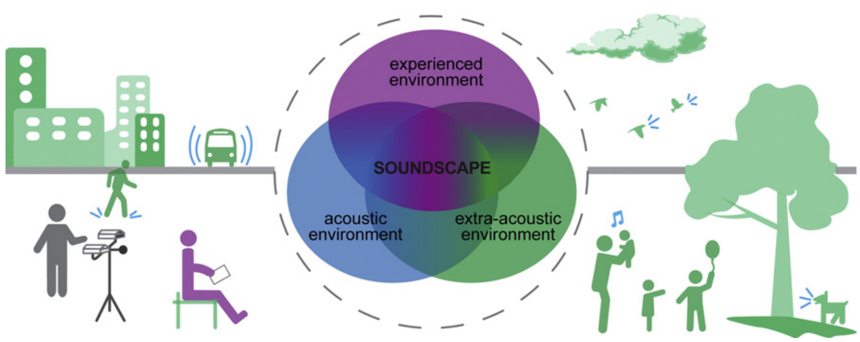
HIGHLIGHTS

- Multiple soundscape variables are divided into 13 components contained in three main entities.
- Enables complex soundscape data to be incorporated in environmental studies
- Provides a framework and preliminary protocol towards standardized methods in soundscape
- Results based on the experience of testing in a variety of urban environments of different cultures

GRAPHICAL ABSTRACT



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ABSTRACT

The soundscape paradigm is comprised of complex living systems where individuals interact moment-by-moment among one another and with the physical environment. The real environments provide promising conditions to reveal deep soundscape behavior, including the multiple components involved and their interrelations as a whole. However, measuring and analyzing the numerous simultaneous variables of soundscape represents a challenge that is not completely understood. This work proposes and applies a comprehensive methodology for multidimensional and synchronic data collection in soundscape. The soundscape variables were organized into three main *entities*: experienced environment, acoustic environment, and extra-acoustic environment, containing, in turn, subgroups of variables called *components*. The variables contained in these components were acquired through synchronic field techniques that include surveys, acoustic measurements, audio recordings, photography, and video. The proposed methodology was tested, optimized, and applied in diverse open environments, including squares, parks, fountains, university campuses, streets, and pedestrian areas. The systematization of this comprehensive methodology provides a framework for soundscape research, a support for urban and environment management, and a preliminary procedure for standardization in soundscape data collecting.

1. Introduction

The soundscape paradigm considers the individuals integrated with their environment and making up part of it. A lively environment is both

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dynamic and interactive, which means that individuals do not exclusively perceive the environment but also react to it. These reactions may involve different ways of emitting sounds, which, in turn, feed back into the acoustic environment. Thus, the soundscape paradigm does not consider the individuals as passive receivers of sound but recognizes them as an active and constituent part of the environment. According to this approach, soundscapes represent complex and dynamic living systems where individuals and their environments are mutually fed (Nielbo, 2015).

Focusing on human individuals, the standard ISO 12913-1 defines soundscape as "the acoustic environment as perceived or experienced and/or understood by people, in context" (ISO 12913-1, 2014). This definition reflects a holistic human-centered approach, which means that it is necessary to consider the multiple factors involved. Besides, the soundscape paradigm considers sound as a resource that is liable to be planned and managed in space and time. A core reason for the soundscape paradigm was the virtual failure of high-cost noise abatement policies, which considered the sound in cities to be a residue intended to be reduced as much as possible (Brown, 2011; Raimbault and Dubois, 2005). Alternatively, the soundscape paradigm recognizes the environmental, social, and cultural significances and importance for a given community in respect to particular acoustic environments and sounds (Kang, 2015). The importance of studying the soundscape resides in the potential it gives for designing new acoustic environments, as well as remediating and managing existing ones, pursuing the population welfare. Nevertheless, the complexity of soundscapes requires interdisciplinary and multicultural efforts to achieve these goals (Davies et al., 2013).

In this work, the individuals that compose the soundscape are called *soundscape interactors*, abbreviated as *interactors*. Interactors are all beings who are potentially capable of acoustically interacting with the environment, i.e., able to emit sounds (either vocally or not) as a reaction to what they perceive. According to this conception, animals and several insects can be considered interactors as well (Wiseman, 2015). However, in this work, interactors are only those humans capable of consenting to participate in the investigation. It is noted that the interactors that make up part of the soundscape are not necessarily constrained to its physical boundaries, since sound is able to cross them. The sounds present in an environment interact with humans in a way that is much more complex than acoustic and psychoacoustic parameters can report. The incidence of environmental sound perceived by a person does not solely depend on the physical properties of the acoustic waves, but also on many other factors. These factors make up part of the soundscape experience and are referred to as the *context* (ISO, 2014). Articulating previous concepts, it can be said that interactors and the environment are in constant interaction with each other, representing an indivisible couple (Beer, 2000).

Reality represents the most complete source for understanding the meaning of soundscapes, embracing the multiplicity of concurrent dimensions in its context. Moreover, real soundscapes allow for the establishment of communication mechanisms between local experts and researchers, favoring the convergence of research and reality through participation. In spite of the profuse research on soundscape conducted so far in past years, most contributions have been made by means of laboratory work, while just a small proportion have been provided by means of field methodologies.

The main soundscape research methodologies described in the literature are *soundwalks* (SWs) and *fixed locations* (FLs). The SW strategy is applied to *exogenous* interactors of the environment. On the other hand, the FL strategy may be applied either with either *endogenous* or exogenous interactors of the environment. An endogenous interactor is a being that is spontaneously found in the environment, while an exogenous interactor has been introduced for research purposes.

Originally, Schafer included the soundwalk as a method to perceive soundscapes (Schafer, 1969). A soundwalk consists essentially of a path followed by one or many participants (*soundwalkers*) that listen attentively to the surrounding sounds. Often, the listening process is complemented by recordings (e.g., questionnaires, audio recordings). In this millennium, many variants of soundwalks have been applied to listen, understand, or analyze urban soundscapes (Adams et al., 2008; Semidor, 2006; Turra et al., 2016; Bahali and Tamer Bayazit, 2014; Jeon et al., 2010; Bruce and Davies, 2014; Nilsson and Berglund, 2006; Nilsson et al., 2012; Jeon et al., 2011a; Hong et al., 2011).

On the other hand, some investigations have been conducted by applying the FL sampling strategy. From among these investigations, it is important to mention the one conducted by Ge et al. (2009), who developed a procedure for data collecting and analysis called *soundscapegraphy*. They collected objective and subjective soundscape data within an urban area divided into two size-meshes, one size for acoustic measurements and other for providing questionnaires to an exogenous group of people, focusing the survey on sound preference and congruity. Kim et al. (2015) also applied a mesh-based data collection method through a survey of exogenous individuals, complemented with binaural audio recordings.

However, just a few studies have been carried out applying the FL sampling strategy with endogenous interactors. Nilsson and Berglund (2006) evaluated the soundscape quality in the parks of Stockholm by mean of questionnaires and measurements of sound pressure levels. Szeremeta and Zannin (2009) studied four parks in Curitiba by means of applying questionnaires simultaneously with five-minute acoustic measurements in accordance with the ISO 1996 procedure (ISO 1996-1, 2003). Jeon and his collaborators measured a three-minute A-weighted equivalent sound pressure level (L_{eqA}) while individuals were silently responding to a questionnaire (Jeon et al., 2011b). Tse et al. (2012) investigated the soundscape at urban parks in Hong Kong by means of questionnaires at the same time that they measured L_{eqA} and percentile levels and recorded audio. Brambilla et al. (2013) applied face-to-face interviews in parks while conducting acoustic measurements.

One main difficulty for establishing field research methodologies is the previously mentioned complexity of soundscape systems, which is reflected in the large number of involved variables, their different natures, their complex interactions, the unsteady and unrepeatable conditions distinctive of these types of systems, and the cultural differences. A core reason due to which soundscapes change continuously and never return to an identical state is that they are composed by beings interacting with one another and with the medium. The interactors never repeat exactly the same way that they interact, and each stimulus may lead to new and different responses moment by moment.

The unsteady nature of real soundscapes has not yet been properly described though integral methodologies, although Schulte-Fortkamp stated in 2002 that "subject-centered methodological procedures should be used to develop a suitable measurement procedure" (Schulte-Fortkamp, 2002). In spite of the fact that the practice of repeating data collection at different moments may provide information on the long-term dynamics of particular variables in a certain location, it does not report transversely about the interactions taking place at a specific moment as a whole. In order to take into account the moment-by-moment complexity of a soundscape, it is required to collect the multiple dimensions simultaneously, which enables the study of the complex interactions within the interactors-environment couple. According to the soundscape paradigm, data collection of physical variables should be useful and conditioned to the presence of and the activity conducted by the interactors in the environment (ISO, 2014; Kang, 2007; Kogan, 2012; Schulte-Fortkamp, 2002; Truax, 1999).

Nevertheless, collecting a multiplicity of simultaneous soundscape variables requires lengthy, detailed, and careful fieldwork, which has high costs if the process needs to be repeated in several environments. It is reasonable to think that these high costs have represented an obstacle for the development and implementation of exhaustive field methodologies. The absence of methodological systematizations for data collection has caused soundscape research to be based on different, isolated, and inhomogeneous field methods. The lack of a soundscape data collection protocol does not impede the achievement of the specific goals of each work, although this fact has made comparative analyses difficult (e.g., transversal, longitudinal, spatial, and transcultural analyses). In 2011, Axelsson stated that "progress in soundscape research requires a common agenda" (Axelsson, 2011), which, certainly, should be based on comparable methodologies.

In spite of the mentioned difficulties regarding field research, the current methodological approaches point towards this goal, founded on the premise that integral methodologies are needed for achieving deep comprehension of real soundscapes. This approach conceives a soundscape as a whole complex system, whose elements and interactions cannot be isolated from one other. Accordingly, the observation unit is the environment-interactor couple.

The present work develops, tests, and applies a comprehensive methodology for the multidimensional and synchronic data collection in soundscapes. This method can be applied in any kind of environment where there is at least one person willing to respond (either urban or not). The application of this comprehensive methodology provides field data for the integral analysis of soundscapes.

The multiple considered variables were organized into three wide groups called *entities*, containing 13 sub-groups of variables called *components*. For collecting field data to feed the variables, a procedure articulating synchronic techniques for data collection was developed, including surveys answered by the interactors, acoustic measurements, audio recordings, photography, and video. This paper includes the description of each technique and a detailed guide for implementing the techniques through a field procedure.

This comprehensive methodology was originally tested in 86 cases in Córdoba city in Argentina (Kogan et al., 2013). During this preliminary process, the proposed methodology was adjusted and optimized. The preliminary exploration of the environments included the communication with the interactors spontaneously found in the environments, providing a local-expertise point of view about soundscapes. This included daily, weekly, and seasonal dynamics, soundmarks, and the specific meaning of the soundscapes. This previous study set the methodological base and contributed to appropriate decisions regarding spatial and temporal collection priorities.

Subsequently, the methodology was positively applied to 580 cases in 123 locations corresponding to 30 open public environments of four cities: Córdoba and Rosario (Argentina), Lund (Sweden), and Valdivia (Chile). The environments studied included squares, parks, fountains, pedestrian areas, university campuses, streets, and other environments in commercial, residential, recreational, and cultural areas (Kogan et al., 2016). These environments produced enough data to perform multidimensional analyses respecting the complex and holistic nature of soundscape and its inherent interactions. The methodological approach provided frequent interaction with the community, which gave feedback about technical procedures and the environments from the user's point of view.

On one hand, the application of this methodological tool contributes to interdisciplinary practices, enabling the spatial soundscape data to help in areas such as environmental impact, mitigation, air quality, public health, social wellness, urban planning, design and management of landscape and green areas, road traffic policies, and legislation, among others (Adams et al., 2006; Andringa et al., 2013; Brown, 2011, 2014; Jabben et al., 2015; Kang & Schulte-Fortkamp, 2016; Raimbault and Dubois, 2005; Vogiatzis and Remy, 2014). On the other hand, this work represents a preliminary protocol for data collection on soundscape. The further systematization of these kinds of methodologies may lead to new standards for soundscape studies, allowing the comparison of different field studies (Axelsson, 2012; Brown et al., 2011; Genuit and Fiebig, 2014; Schulte-Fortkamp and Brooks, 2015).

Although previous research in soundscape has applied field methodologies with particular aims, there is a lack of systematized methods for the synchronic multidimensional data collection of real soundscapes. Thus, the main contribution of this article is the proposition of a preliminary protocol for the soundscape measurement. This may serve as a base for standardization and provides a supportive instrument for research and management towards making the soundscape paradigm operational. In summary, the novel aspects of this work are as follows: 1) the organization of the multiple soundscape variables into 13 components contained in three main entities, 2) the development and systematization of a comprehensive methodology for the synchronic multidimensional data collection in soundscapes (enabling the multi-criteria analysis and the management of complex soundscape data to be incorporated in the environmental studies), and 3) the elaboration of a practical guide for implementing this comprehensive methodology based on the experience of testing this methodology in a variety of urban environments of different cultures.

2. The entities of a soundscape

A soundscape can be characterized by means of three entities: experienced environment (Entity 1), acoustic environment (Entity 2), and extra-acoustic environment (Entity 3). Soundscape takes place in the junction of these three entities. This is represented by the conceptual scheme of Fig. 1.

This scheme represents a taxonomical approach to the multidimensionality of soundscape. Therefore, soundscape variables were arranged according to these three entities. Each entity is integrated by different *components*, 13 in total (C1 to C13), representing groups of variables that are classified according to their thematic nature. This classification for soundscape dimensions has been inspired by previous research (Brown et al., 2011; ISO, 2014; Jeon et al., 2011a, 2011b; Herranz-Pascual et al., 2010; Yu and Kang, 2010; Zhang and Kang, 2007).

2.1. Entity 1: experienced environment

This entity represents the soundscape experience of the interactors in the environment. This experience includes sound perception, sound interpretation, responses, sound sources perceived and their meaningfulness, expectation, judgments, and assessments about the acoustic environment, activities conducted, and appropriateness of the soundscape in regards to the surrounding environment and the activities conducted on this, extra-auditory perceptions and their coherence with soundscape, familiarity with the environment, habits of visits, and perceived social cohesion. This entity also includes an auditory profile, sound preferences, psychological factors, socio-demographic variables, and

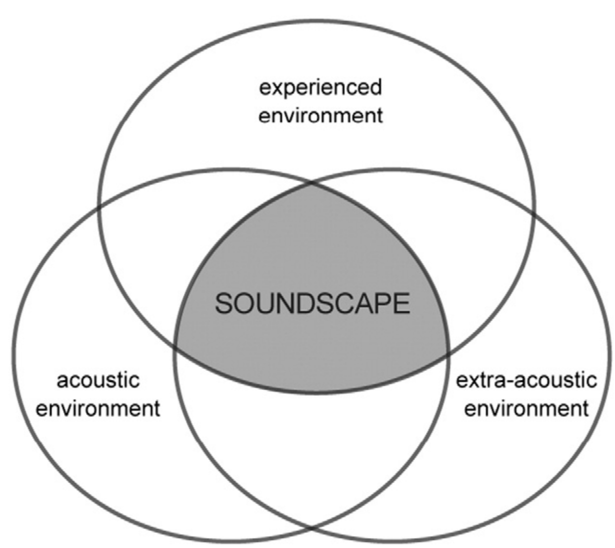

Fig. 1. A simplified conceptual scheme of the three entities of variables essential to a soundscape.

cultural background, since these factors potentially influence soundscape experience. The multidimensionality of this entity is organized into eight components:

C1) Socio-demographic data: Includes the social, cultural, and demographic variables of the interactors that may potentially influence their valuation or expectations of the environment.
C2) Integral auditory profile: Includes the variables representing the auditory inherent aspects of the interactors, sound preferences, sensitivity to music and noise, and other key aspects of their life history related to sound perception and its meanings (Yu and Kang, 2010).
C3) Familiarity: Represents the previous experiences of the interactor in the environment. It includes the visiting habits, frequency of attendance, activities conducted, and motivations to go (Nielbo et al., 2013, Szeremeta and Zannin, 2009).
C4) Mental and physical state: Corresponds to the present state of the interactor. This includes emotional state, mood, thoughts, mental representations, propositional attitudes, and physical sensations (Andringa and Lanser, 2013; Goldstein, 2000).
C5) Listening to sound sources: Refers to the type of sounds in the environment that interactors are currently listening to, classified according to the nature of their sources. It is considered the grade of dominance of every type of source and the self-evaluation of its effect on the perceived soundscape (Axelsson et al., 2009; Axelsson et al., 2010; Brown et al., 2011; Niessen et al., 2010; Steele et al., 2016).
C6) Soundscape assessment: Component with the purpose of assessing, classifying, and rating the current soundscape. It contains the necessary variables to feed a perceptual model, as well as overall evaluations of the acoustic environment (Axelsson et al., 2012a; Axelsson et al., 2009; Axelsson et al., 2010).
C7) Extra-auditory perception: Represents overall and specific perceptions and sensations regarding the environment, including visual and olfactory evaluations of aesthetics, air purity, visualization of sound sources, and social cohesion (Jeon et al., 2011a; Jeon et al., 2011b; Liu et al., 2013; Preis et al., 2015; van Kamp et al., 2016).
C8) Expectations and coherence: Represent the expectations of the acoustic environment, the appropriateness of the soundscape in regards to the environment and coherence of heard sounds, according to the environment functions and to the intended conducted activities, as well as perceived affordance (Andringa and Lanser, 2013; Axelsson, 2015; Nielbo et al., 2013).

2.2. Entity 2: acoustic environment

This entity represents the characterization of the objective acoustic environment. This characterization includes both the sound sources composing the environment and the parameters derived from acoustic measurements and audio recording. Their components are as follows:

C9) Composition of the acoustic environment: Refers to the inventory of the characteristic of sources at the environment, its characteristics, locations, movement, and temporal behaviors (Bunting and Chesmore, 2013; López-Pacheco et al., 2014; Torija et al., 2014; Yang and Kang, 2014).
C10) Acoustic parameters: Component containing acoustic parameters reporting about the environment, including its acoustic energy, dynamics, dispersion, and spectral content.
C11) Soundscape parameters: Component that includes non-conventional objective parameters related to soundscape. These parameters derive from psychoacoustics, signal temporal structure, auto- and cross-correlation functions, musical likeness, and spectro-temporal modulations (Chen and Zhao, 2016; Chen and Zhao, 2013; De Coensel and Botteldooren, 2007; Filipan et al., 2016; Rychtáriková and Vermeir, 2013).

2.3. Entity 3: extra-acoustic environment

This entity represents those aspects of the physical environment beyond sound, including its stable characteristics as well as the transient state at the moment of the multidimensional data collection. Its components are as follows:

C12) Characteristics of the environment: Characteristics and distinctive features of the environment. These features that describe the environment remain mostly steady over time (or either do not change significantly or do it cyclically). These features include geographic delimitation, morphology, vegetation (presence, distribution, and type), spaciousness, urbanism, architecture, artistic installations, projected and real uses of the environment, permissible land use, surroundings, and cyclical patterns of use (daily, weekly, and seasonal) (Jabben et al., 2015; Kang & Schulte-Fortkamp, 2016; van Kempen et al., 2014).
C13) Current state of the environment: It includes the state of the environment during multidimensional data collection. These transient circumstances include weather, air quality and pollution, cleanliness, affluence, type of activities conducted in the environment, events and presence of animals (Brambilla et al., 2013; Jeon et al., 2011b).

3. Techniques for field data collection

The multiple soundscape dimensions contained in the defined entities and components were arranged through complementary and synchronic techniques for data collection by means of two different sampling strategies. These synchronic techniques include acoustic measurements, audio recordings, questionnaires, photography, and video. Environment characteristics and state were also obtained, and direct communication mechanisms with interactors were applied.

3.1. Sampling strategies

As mentioned in the introductory section, two different sampling strategies may be applied for field data collection in soundscapes: SW and FL. From a topological point of view, the SW strategy is represented by lines in the land. Statistically, this strategy implicates a non-probabilistic incidental sampling, where the interactors are previously selected. This implies that the variations of the control variables associated with the participants are minimized. Nevertheless, a soundwalk implies intentionally introducing interactors (soundwalkers) to an environment who are not spontaneously found in that environment (exogenous).

In contrast, FL strategy represents points in the land. This strategy can be applied either with endogenous or exogenous interactors in the environment. Due to the possibility of applying this strategy with endogenous interactors, it was chosen as the preferred one in this work (and is consequently more described in this article). However, for certain conditions, it is convenient to apply the SW strategy, and it was indeed applied in several environments.

Fig. 2 schematizes the general sequence for the synchronic data collections by applying the FL sampling strategy to endogenous interactors of the environment.

As represented in Fig. 2, a research team member (RTM) identifies an interactor or small group of interactors in the environment of interest and approaches them. If the interactor(s) consents to respond to the questionnaire, directions are given to them while the instruments are arranged in their proximity. When the interactor(s) begins to answer Part II of the questionnaire, the instruments start to synchronously record. If the interactor(s) declines to participate, then a RTM looks for other interactor(s) and repeat the procedure. In the following subsections, each type of collecting technique is described, and in the next section, a detailed guide for the implementation of the field methodology is given.

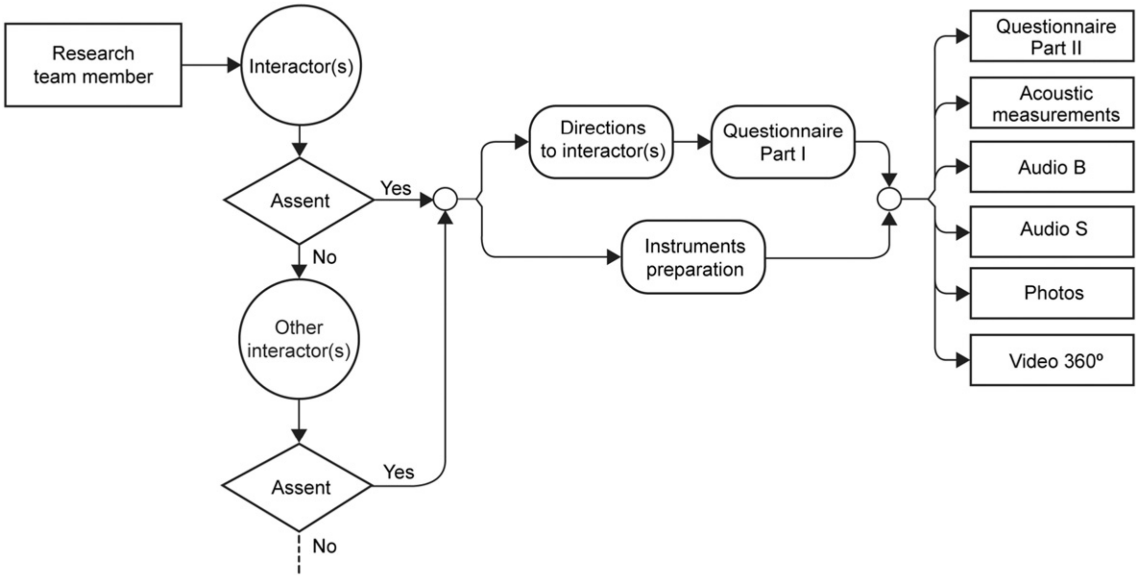

Fig. 2. Conceptual scheme of the in situ procedure according to the fixed-locations sampling strategy in soundscape data collection.

3.2. The questionnaire

For the subjective evaluation, interactors are asked to concentrate on the environmental sound and respond to the questionnaire individually and, preferably, quietly. The subjective instrument is anonymous and includes two parts (I and II). Part I of the questionnaire includes general questions regarding the interactor and his or her previous experience in the environment. This part includes questions about the socio-demographic data of the interactor, an integral auditory profile, sound preferences, and familiarity with the environment. Part II represents the dimensions directly related with the soundscape experience running at that moment. Thus, other techniques and instruments for data collection should be synchronized with this part of the questionnaire. The classification of the sound sources was inspired based on the criterion of Axelsson and his collaborators (Axelsson et al., 2012a; Axelsson et al., 2009; Axelsson et al., 2010). For the soundscape assessment, an already validated perceptual model known as the Swedish Soundscape Quality Protocol was applied (Axelsson et al., 2009, 2012a, 2012b).

Likert-type scales were applied for all ordinal categorized variables. Some subjective variables were treated in binary, non-ordinal categories or an alphanumeric base. The questionnaire was designed to be clear and self-explanatory in order to avoid (or minimize) doubts from the interactors during the subjective evaluation. The questionnaire included open fields for collecting typed data from respondents in order to promote communication with the interactors, encouraging them to express their perceptions and opinions. The content of the questionnaire is shown in Table 1.

For the codification of each survey applied, a five-character alphanumeric code was used. The first two characters identify the city of the evaluated environment, followed by three numeric characters for an ordinal (chronological) classification of the surveys applied in each city. In the case that the questionnaire was responded to as a result of a soundwalk, the letter "W" is included in the first character. Each question of the questionnaire was codified taking into account the entity and the component that it represents, besides an identification number. The categorized answers were labeled with their corresponding numeric values (in order to reduce mistakes in the transcription process).

3.3. Acoustic measurements

The following acoustic descriptors were obtained by means of sound level meters (SLMs): a) unweighted 1/3-octave-band spectrum, b) equivalent sound pressure level ($L_{AS,eq}$), c) maximum sound pressure levels ($L_{AS,max}$ and $L_{AF,max}$), d) minimum sound pressure level ($L_{AS,min}$), d) 10-percentile-exceeded sound level ($L_{AS,10}$), and e) 90-percentile-exceeded sound level ($L_{AS,90}$). The measurements were conducted using the A-weighting network, except for the 1/3-octave-band spectrum that was not frequency weighted. Slow time response was employed in all measurements. Additionally, the fast time response was employed for the maximum sound pressure level, since this response represents a better approach for quantifying the acoustic energy reached by a receiver from impulsive noise sources in cities (e.g. fireworks, tire explosions), which may impact noticeably in the experienced acoustic environment. The integration period for each measurement was normalized to five minutes (Szeremeta and Zannin, 2009), since this is a reasonable period for the interactors to answer the Part II of the questionnaire. The acoustic measurements were taken at approximately the height of each interactor's ears.

3.4. Audio recordings

Two audio recording techniques were applied, named Audio B and Audio S. Audio B is a calibrated binaural recording using in-ear electret microphones (integrated with earphones), and Audio S is a monaural recording at measurement quality (omnidirectional and flat-response condenser microphone built in with the SLM). The audio files were obtained in ".wav" format with a 24-bit resolution and a sample rate of 48 kHz. The duration of the audio recording was five minutes, coinciding with acoustic measurements. Audio recordings were taken approximately at the same height and orientation of each interactor's ears. Audio recordings allow the calculation of acoustic and soundscape parameters (in addition to those likely to be obtained by acoustic measurements).

3.5. Photos

Photographs were taken in every measurement location, providing complementary information. The photos show the position of the interactors in the environment from different points of view, as well as the environment conditions and surroundings. Photography also reveals the placement of the instruments in respect to the environment and the interactors while they were responding the survey.

Table 1
Structure of the soundscape questionnaire.

Part I			
Age	Gender		Occupation
Place where grew up		Kind of current home	
Rating of environmental noise at home	Normality of audition		Sensibility to noise
Sensibility to music	Favorite sounds		Preferred soundscapes
Frequency of visit to the environment		Activities conducted	
Part II (synchronized with other data-collecting techniques)			
Current emotional and physical state			
Extent of the current presence of 6 types of sound sources:			
Sound from human beings	Natural sounds	Music	
Traffic noise	Fan noise	Other noises	
Extent of agreement with the following soundscape attributes:			
Pleasant	Chaotic	Exciting	Eventful
Calm	Annoying	Uneventful	Monotonous
Overall acoustic evaluation and reasons	Overall visual evaluation	Visualization of sound sources	Olfactory assessment
Appropriateness of soundscape to the environment and reasons		Unexpected sounds	

3.6. Video

A 360° video was taken for each set of measurements at every evaluated location of the environment. The duration of each video was one minute, synchronized with the acoustic measurements, the audio recordings, and Part II of the questionnaire.

3.7. Environment information

Environment information was acquired from different sources, including urban management sources, cartography, online services, measurements, in situ observation, surveys, communication with interactors, and audiovisual registrations. Weather data considered included cloud cover, temperature, relative humidity, atmospheric pressure, and wind speed and direction. The weather information corresponding to the place evaluated was obtained for each data collection time period. A one-sheet form for assisting the field work was generated, named Field Form. This form is filled in situ with the data of the daily field work (e.g., calibration data, codes, locations) and the state of the environment.

3.8. Communication

Different communications mechanisms with interactors were implemented. Open questions in the survey were included, allowing the interactors to freely express their perceptions and opinions or clarify aspects about the soundscape experience. After the interactor(s) completed the questionnaire, oral feedback was favored, both regarding the soundscape experience and the suitability of the subjective instrument just applied. This occasion provided the interactors with the possibility of contributing to the research through their comments and suggestions. Open debates were carried out at the ends of the soundwalks, which enabled an affable and interactive mechanism of participation. Additionally, since this was a pilot experience, interactors participating in the soundwalks were invited to make graphic representations about their soundscape experience in a certain environment.

4. Practical guide for the field procedure

Based on the above-described experience, the following sequence for the implementation of the field methodology is recommended:

1. Selection of environment and time for data collection: Several complementary criteria can be applied for supporting the decisions in order to select the environment for data collection and choose the proper time to do it. It is recommended to have some previous knowledge about the long-term dynamics of the environment to evaluate: daily, weekly, and seasonal (Kogan et al., 2013). It is also convenient to consider soundmarks (Schafer, 1993). Direct communication and open interviews with interactors are recommended in the preliminary stage.
2. Prior preparation: Set up the instruments, questionnaires, forms, maps, and accessories (windscreens, batteries, memories, tripods, boards for responding questionnaires, pens, etc.).
3. Arrival to the environment: At least two RTMs are required for the synchronic data collection. The first RTM operates the SLM and audio recorders, while the second RTM communicates with the interactors and operates the cameras (see Fig. 3). If possible, photography and video recording should be performed by a third RTM. Check details by visual observation of the surroundings (sound sources, interactors, weather, and safety) and readiness of the instruments, calibration, and filling out the field form.
4. Approaching the interactors: Identify interactor(s) in the locations of interest (individual or small groups). Approach them, explain briefly the scope of the project and the implications for them (respond to an anonymous questionnaire and appear in pictures and videos just for research purposes). Ask their consent to participate in the investigation.
5. Directions to interactors: If the interactors consent to participate, some basic instructions are given for responding to the questionnaire: a) Concentrate in the acoustic environment, b) Use the hands and not the voice to call to the second RTM if necessary, and c) Respond to the questionnaire individually. While the second RTM gives these directions, the first RTM arranges the instruments near the interactors.
6. Photos: As soon as the interactors begin answering the questionnaire, either the second or third RTM begins to take photographs. Getting images from different viewpoints is convenient. In particular, it is important to register the position of the interactors within the environment and with respect to the sound sources as well as the location and orientation of the instruments with respect to the interactors. It is also desirable to register the visual perspective of the interactors. It is very important to take photos with discretion, so do not distract or disturb the interactors.
7. Recording and measurements: When at least one of the simultaneous interactors surveyed arrives at Part II of the questionnaire, the first RTM starts the audio recording and SLM for five minutes (preset).
8. Locating the instruments: Preferably, a location behind the interactor(s) visual field should be selected for setting up the tripod with the instruments. This location is important for not distracting the interactors and for the first RTM to be able to watch what part of the questionnaire is being answered. This location should be close enough to measure similar acoustic data to what the interactor(s) receive, but not so near to cause discomfort to them. A very close position may produce useless recording and measuring of sounds

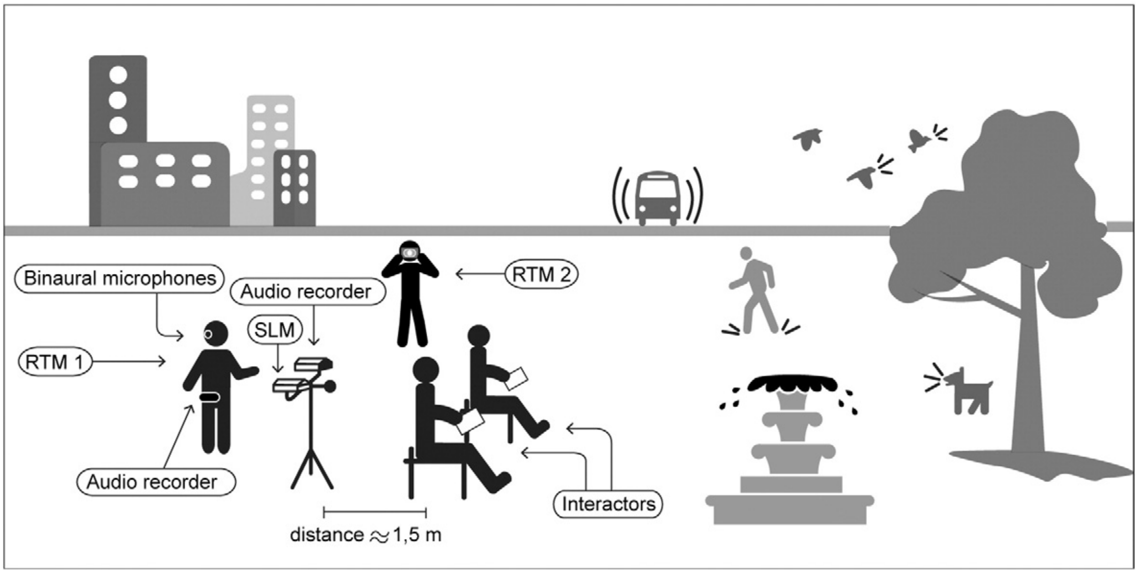

Fig. 3. Layout of the data collection scene in the environment, including the suggested position and orientation of the research team members (RTMs) and the instruments.

intrinsic to the application of the questionnaire (e.g., doubts of the interactors, movement of the folders or pens). In accordance with the empirical experience, commonly, a distance around 1.5 m would be appropriate, but depending on factors like the environment's characteristics, the number of concurrent interactors participating, and their positions, the optimal distance may range between 1 m and 3 m. The first RTM should preferably face the same orientation as the interactors (see Fig. 3), since this RTM holds the binaural microphones.

9. Video 360°: Synchronized with the beginning of the audio recordings and acoustic measurements (and following a gesture from the first RTM), the second RTM initiates a 360° video. The position of the camera should be chosen in order to capture the main features of the environment and the location of the interactors and to maintain discretion during filming.
10. Stopping the instruments: When the five minutes of acoustic measurements and audio recording are completed, the first RTM fills in the field form with the information related to the set of measurements conducted (codes of interactors, locations, and files; time; gains of audio recordings; main acoustical parameters; and comments).
11. End of completing questionnaires: When the last participating interactor finishes filling out the questionnaire, all sheets are picked up. It is recommended to check if all parts of each questionnaire have been properly answered. Oral feedback regarding the soundscape experience is requested from the interactors. This communication moment also focuses on the correct understanding of all written questions and other comments that the interactors might have. Subsequently, each filled questionnaire is coded with the location and the ordinal code of the interactor.
12. End of data collection in the environment: Verify instrument calibration, check the completeness of all codes of locations and questionnaires, and verify that the digital archives have been correctly saved and that the field form has been properly filled in.

In addition to the steps described above, the following complementary advice is given for the implementation of the field methodology:

- The minimum suggested number of RTMs is two, but the optimal number is three.
- It is convenient for the efficiency of the procedure that the RTM in charge of communications with interactors (second RTM) has good oral skills and social empathy.
- Every time it is possible, apply the questionnaire to a small group of interactors at the same time (it provides a more solid subjective simultaneous evaluation). In order to sample a location with multiple concurrent interactors, they should be close each other and initiate the survey together.
- Use cameras with discretion, avoid large devices, and avoid using the cameras too close to the interactors (especially facing them).
- Give a small gift to the interactors to show appreciation for their participation.
- It is convenient to use a unique tripod with a T-accessory for the instruments, since employing two tripods is unpractical.
- Use a single-page dual-sided questionnaire, and provide to the interactors a rigid, thin board to support it and a pen.

5. Application cases

The comprehensive methodology was applied in 30 environments corresponding to four cities: Córdoba, Rosario (Argentina), Valdivia (Chile), and Lund (Sweden) (Kogan et al., 2016). Every environment was evaluated in a definite number of locations, totaling 123. Most environments were evaluated though the FL sampling strategy, while others were evaluated by means of soundwalks, two conducted in Cordoba and one in Rosario (Turra et al., 2016). The total number of application cases is 580. Out of the cases, 76 were acquired by means of the SW sampling strategy. Data collection took place from June to December (2013–2016) on different days of the week between 11:00 a.m. and 8:00 p.m., depending both on the dynamics of the environment and on practical concerns (Kogan et al., 2013). Various evaluated environments contain fountains (Kogan et al., 2014). Table 2 shows the evaluated environments and the sampling strategies applied. Partial results have been presented (Kogan et al., 2016), and further specific results will be opportunely reported.

The following equipment and software were employed for the multidimensional data collection and data processing:

- Sound pressure level meters and hand-held sound analyzers: Brüel & Kjær 2270 Class 1 (Córdoba and Lund); Brüel & Kjær 2250 Class 1 (Córdoba and Rosario); Norsonic Nor140 Class 1 (Lund); Rion NL 31 (Córdoba); Svantek 943 B Class 2 (Valdivia).
- Microphones: Measuring microphones Brüel & Kjær Types 4189, 4231, and 4964 (infrasound) and Svantek SV-MI17; binaural microphones Roland CS-10EM.
- Calibrators: Brüel & Kjær Type 4231, Quest QC-10.
- Solid state stereo audio recorders: Tascam DR-100MK II; Stereo digital audio recorder Zoom H4N; Zoom H1.

Table 2
Environments where the comprehensive methodology was applied. It includes the two-character code of the environments, the code of the city (Córdoba [CO], Lund [LU], Rosario [RO], and Valdivia [VA]), and the sampling strategy (fixed location [FL], soundwalk [SW], or both).

Code	Name of the environment	Type of environment	City	Sampling strategy
AT	Park around Teatrino	Campus park	CO	FL
BE	Bar of Economics	Square in Campus	CO	SW
BO	Bosquecillo	Campus park	CO	Both
BP	Buen Pastor	Fountain in town	CO	Both
BR	Brujas	Campus park	CO	Both
CA	Cathedral Square	Square	LU	FL
OT	Obispo Trejo	Pedestrian street	CO	FL
EC	Portal of Economics	Campus main street	CO	SW
FE	Lund Station Square	Square with fountain	LU	FL
FL	City park fountain 2	Fountain in city park	LU	FL
FP	City park fountain 1	Main fountain in city park	LU	FL
FT	Grand Hotel Square	Square	LU	FL
FU	Lundagard square	Campus square with fountain	LU	FL
IT	Ituzaingo street	Street in commercial-residential area	CO	SW
JB	Jardin Botánico	Botanic garden	VA	FL
LI	Lilla Fiskaregatan	Pedestrian street	LU	FL
PA	Pabellón Argentina	Campus square-fountain	CO	FL
PI	Plaza Italia	Square in downtown-fountains	CO	FL
PO	Patio Olmos	Fountain at main crossroad	CO	Both
PS	Plaza Seca	Square at Campus	CO	FL
PT	Laguna de los Patos	Small lake at Campus	CO	Both
PU	Patio UTN	University square surrounded by buildings	CO	SW
RC	Portal of Fontanarosa Cultural Centre	Crossroad of an important street with a pedestrian in downtown	RO	SW
RF	Plaza Barranca de las Ceibas	Square with a large fountain	RO	SW
RP	San Martin and Córdoba	Crossroad of 2 main pedestrian streets	RO	SW
RR	Parque Nacional a la Bandera	Urban park facing the Paraná river	RO	SW
SO	Paseo de Sobremonte	Square with a central fountain in downtown	CO	FL
ST	Lund Central Station	In front to Station (across Bangatan avenue)	LU	FL
TE	Parque Las Tejas Este	Small urban park	CO	FL
TO	Parque Las Tejas Oeste	Small urban park	CO	SW

- Cameras: Nikon Coolpix S5200; Camcorder JVC; Camcorder Mini DV MD80; Samsung S3.
- Accessories: Dome protection for infrasonic measurements Brüel & Kjær Type UA-2133
- Software: InfoStat 2015 (Di Rienzo et al., 2015), Quantum GIS 2.14, Excel 2013, Octave 2.0.0., Audacity 2.1.2.

6. Outcomes

The application cases of the described comprehensive methodology allowed for the achievement of fruitful outcomes, showing the feasibility for managing large and complex data in a convenient way. This work is part of a project concerning soundscape methodologies and analysis, whose specific results exceed the scope of this article. The main outcomes that are possible when applying this comprehensive methodology are as follows:

- Understanding the relationships among variables from different surroundings through multivariate analysis and complementary techniques, bringing a base for building up soundscape indexes.
- Mapping the distribution of soundscape results in the territory by creating supplementary maps by joining previous ones through different GIS layers. These maps include soundscape assessment by population; expectations and coherence of soundscapes with the different environments according with their functions and uses; audibility of sound sources and degree of presence of each type of source; acoustic parameters; non-conventional soundscape parameters; relationships among objective and subjective evaluations; conflicts among population expectancy and measured variables; relations of the extra-acoustic environment with the perception of the acoustic environment; and maps linking demographic factors with the soundscape, among others.

In sum, the application of the proposed comprehensive methodology enables us to know the population perception and expectations in respect to soundscapes, which can be properly shown and interpreted by mean of GIS techniques. Thus, an integral GIS of soundscape represents a useful tool for soundscape management, design, urban planning, interdisciplinary management, and remediation of the environment (Brown, 2014). This GIS is liable to be obtained as a result of the multidimensional data collection proposed in this work. This tool may lead to administrative practices that are more sustained than those based only on conventional noise maps, since the former are centered directly in population perception and preferences. Moreover, in this respect, a soundscape GIS allows for incorporation of conventional noise maps as complementary layers and comparison of them with the results of the soundscape maps.

The soundscape management throughout GIS allows the identification of sound sources that should be mitigated, protected, encouraged, and reorganized in the territory or over time, promoting public health and social welfare in public environments.

A potential outcome of the proposed methodology is the cross-cultural analysis of soundscapes, since this methodology represents a data collection protocol that sets a common framework, offering at the same time enough versatility and opening to be adapted to different conditions. These cultural adaptations can be achieved mainly by means of the surveys and the oral communication mechanisms.

These kinds of outcomes provide potential guidance tools for many professionals and specialists, such as soundscape researchers, acousticians, planners, policymakers, politicians, environmentalists, urban consultants, social scientists, traffic planners and engineers, designers, thematic mapmakers, architects, and artists, among others.

6.1. Limitations

The main limitation for applying the comprehensive methodology through the FL strategy is the lack of spontaneous interactors willing to respond to the questionnaire in certain environments. It is difficult to apply this procedure in urban environments where people only pass through. This situation is aggravated if there are no facilities to sit down in for answering the questionnaire. These conditions are commonly found in central streets and avenues. Nevertheless, even in these types of environments, it is often possible to find willing interactors (e.g., street sellers or employees taking a break) and also improvised structures for sitting (e.g., stairs or porticos). The unavailability of endogenous interactors willing to participate can be a difficulty that does not solely depend upon the type of environment, but also on the culture and on the communication skills of the RTMs. The SW sampling strategy may be a more favorable alternative for these environments and cultures.

Another limitation is the time-consuming cost that repeating this multidimensional methodology for data collecting in different environments, locations, and moments may have.

6.2. Suggestions for optimization and expansion

An enhancement for the forthcoming applications of the comprehensive methodology would be to measure atmospheric and air quality variables at each location in a synchronic mode with the rest of the data collection techniques. In accordance with the conceptualizations of the entities and components defined, there are additional subjective aspects that would be convenient to incorporate in the questionnaires for the next field research. A way to reduce the extensive time that is needed for transcribing data from the filled surveys would be to apply digital questionnaires through tablets. However, in the case of many interactors (or soundwalkers), the costs would be considerably increased.

7. Conclusions

A comprehensive field methodology for soundscape research was developed and applied as the result of a long-term work. This methodology is founded in the multidimensional and synchronic data collection of environments with the presence of human interactors. This work emerges from the necessity to make operational the complex soundscape paradigm through concrete and applicable field methods. In this sense, three entities were defined, which are integrated, in turn, by different thematic groups of variables called components. These entities and their components represent the different dimensions of soundscapes, comprising the soundscape experience of the interactor, the acoustic environment, and the extra-acoustic environment. The measurement of variables corresponding to the entities and their components is performed by means of synchronic data acquisition techniques, including surveys, acoustic measurements, audio recordings, video, and photos, as well as complementary mechanisms both for communication with the interactors and for getting environment information.

Subsequent to the test of the field procedure and its optimization, the comprehensive methodology was applied in 30 diverse environments of four cities. A large number of interactors participated in the multidimensional data collection. These studies have shown the application feasibility of the proposed methodology. The comprehensive methodology was systematized, and a detailed implementation procedure was formulated. The application of the comprehensive methodology produces fruitful outcomes, including multiple, versatile, and interrelated soundscape GIS maps, which represent a key instrument for policymakers and planners dealing with the acoustic environment. This work provides a framework for research and represents a preliminary protocol towards standardized methods in soundscape.

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