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Analysis of Field Data to Describe the Effect of Context (Acoustic and Non-Acoustic Factors) on Urban Soundscapes

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Abstract: The need to improve acoustic environments in our cities has led to increased interest in correcting or minimising noise pollution in urban environments, something that has been associated with the resurgence of the soundscape approach. This line of research highlights the importance of context in the perception of acoustic environments. Despite this, few studies consider together a wide number of variables relating to the context, and analyse the relative importance of each. The purpose of this paper is therefore to identify the acoustic and non-acoustic characteristics of a place (context) that influence an individual's perception of the sound environment and the relative importance of these factors in soundscape. The aim is to continue advancing in the definition of an acoustic comfort indicator for urban places. The data used here were collected in various soundscape campaigns carried out by Tecnalia in Bilbao (Spain) between 2011 and 2014. These studies involved 534 evaluations of 10 different places. The results indicate that many diverse contextual factors determine soundscape, the most important being the congruence between soundscape and landscape. The limitations of the findings and suggestions for further research are also discussed.

Keywords: soundscape; acoustic comfort; acoustic environment; acoustic and non-acoustic predictors; environmental experience; questionnaires

1. Introduction

The key principles of soundscape [1–5] have been developed within the ISO 12913 standard, with regard to its definition and conceptual framework [1], as well as data collection [6]. According to this standard, soundscape is "the acoustic environment as perceived or experienced and/or understood by a person or people in context". In other words, soundscape is defined as the way people perceive, experience, or understand the acoustic environment in a physical setting. Therefore, acoustic environment refers to physical phenomena, while soundscape is a perceptual construct [7].

Within this conceptual framework, soundscape is understood as highly dependent on the context [7]. Context is meant as the physical place where the acoustic environment exists and, according to the ISO definition, this "includes the interrelationships between a person, activity and place, in space and time [. . .] and may influence soundscape through (1) the auditory sensation; (2) the interpretation of the auditory sensation; and (3) responses to the acoustic environment." [1].

As Brown and his colleagues stated in the first chapter of *Soundscape and the Built Environment* [3], context is a generic term that includes the non-acoustic components of a place (even a person's previous experience and memories) and plays a major role in the perceptual construction of an acoustic environment. However, as Brown stated, this diagram is "short on detail as to what those contextual components might be". Herranz-Pascual et al. [8] addressed this drawback and situated the environmental experience of sounds in public places firmly within an environmental people-activity-place framework [6]. This Environmental Experience Model has guided the methodological design and research presented in this paper. In accordance with this model, the perception of the acoustic environment in a specific place (soundscape) is defined not only by considering acoustic features, but also the physical context (characteristics of the place), and the interactions of people and the community with the place itself [8].

In recent years, the importance of context factors has been one of the most widely-discussed issues in the soundscape approach [1,7–15]. Many studies conclude that elements related to the visual dimension, safety or cleanness, among others, are more relevant in the overall environmental experience of a place than acoustic parameters, particularly when considering soundscape and quietness. There are many references that highlight the relevance of context factors (e.g., landscape [9–11,14,15], geography and thermal conditions [16], maintenance, and cleanness [12]), and person- or community-related features such as culture and personal characteristics) in the soundscape approach, since these items have a remarkable influence on the perception process [1,17,18]. In addition, there is increasing evidence that the congruence between the different elements of a place is important in human preference [19], as well as how they influence the expectation of a place [20].

However, few studies have analysed the combined influence of these factors on soundscape [13,21,22]. Therefore, the challenge is to identify the relative importance of each one of them (when taken together) in order to find out the most influential and important variables when describing the experience that locals and visitors have in their interaction with a space and its sound.

In a similar vein, a recent publication [23] explores the significance of a wide range of acoustic and non-acoustic factors in the soundscape of several public urban spaces in the city of Vitoria-Gasteiz (Spain). This work shows that the variable which best explains soundscape is the congruence between soundscape and landscape as perceived by the user of the place. Other relevant variables relate to the physical characteristics of a place, such as a person's perception of water or traffic, as well as an acoustic index associated with the acoustic climate (LA10–LA90). The key finding of the work involves the need for holistic soundscape studies that integrate acoustic and non-acoustic variables and their relationships, combining subjective and objective perceptions of a place.

Likewise, this paper analyses the contribution of a similar set of acoustic and non-acoustic factors to predict the soundscape in other public urban places in the city of Bilbao (Spain). It aims to identify the variables (and their relative importance) that best predict soundscape pleasantness, considered here to be a global indicator of acoustic comfort, one dimension of urban comfort understood as the ability of an urban space to create a pleasant environmental experience for the people who use it, contributing to the population's health. This indicator may be used to support decision-making related with the soundscape in urban places when it is not possible to obtain the opinion of the users of these places directly.

The ultimate goal of this research is to contribute to the understanding of how an urban soundscape can create a pleasant environmental experience (acoustic and urban comfort) for the people who use it, contributing to population's overall well-being and health.

2. Methods

The case studies, tools and methods used to develop the project are presented below. This section includes an analysis of the data collected in the ten places analysed, using methods that describe both acoustic and non-acoustic factors, and the subjective perception of the users of these spaces.

2.1. Case Studies

The case studies correspond to five soundscape campaigns carried out by Tecnalia from 2011 to 2014, with 534 evaluations by individuals, in 10 places considered analysis units. Each analysis unit corresponds to a homogenous urban area (HUA) with similar acoustic characteristics, functionality and use.

These places are part of 5 urban environments (spaces) located in Bilbao (Basque Country, Spain). The studies were carried out as part of several projects that applied the concept of "islas sonoras", or sound islands (led by Bilbao City Council) [24,25], and the QUADMAP LIFE project [26].

The urban spaces and places are (Figure 1):

1. Paseo del Arenal (2011): Pedestrian urban square located in Bilbao's historical district, considered the best way of entering the city's old quarter. This space was subdivided into 3 places, differentiated by their functionality and use, but which have similar acoustic characteristics:

    a. Playground zone (1.1): An area containing playground equipment for children, where the main sound sources are the voices of children and their carers.
    b. Trees (1.2): The place closest to the estuary. It contains dense vegetation, as well as small pools and water fountains along the 3 walkways comprising it. The predominant sound sources are voices, footsteps and running water.
    c. Walkway (1.3): Place connecting the square with the old quarter of Bilbao, where the main sound sources are traffic and human voices.

2. Plaza Nueva (2011): Pedestrianised urban square located in Bilbao's historical quarter surrounded by arcaded buildings. This space was subdivided into 3 places with common acoustic characteristics, but differentiated by their functionality and use:

    a. Arcades (2.1): Covered, arcaded walkway, close to nearby bars (human sound sources) where people get together to socialise.
    b. Centre (2.2): Open area in the centre of the square that is used mainly by children playing. The main sound sources are children's voices.
    c. Terraces (2.3): Open zone close to the arcades, for use by clients of the nearby bars (bar terraces), where the main sound sources are human voices.

3. Plaza Levante (2012): A small square situated in the San Ignacio neighbourhood, close to the underground entrance. This place is used for spending time in as well as being a pedestrian thoroughfare (3.1). The predominant sound sources are road traffic (buses) and people (voices and footsteps).
4. Plaza San Pedro Deusto (2012): Space located in the Deusto neighbourhood, near the church of San Pedro de Deusto and the main urban traffic thoroughfare in the area. The place selected corresponds to the area containing large plane trees, mainly used for spending time in, as well as being a pedestrian thoroughfare (4.1). The main acoustic sources are traffic, human voices and footsteps.
5. Plaza General Latorre (GLT): Urban square located in the Basurto neighbourhood. It was renovated to make it the city's first sound island, according to soundscape criteria, as part of the LIFE QUADMAP European project [26]. The place was evaluated prior to its renovation in 2012 (5.1) and afterwards (2014) (5.2). Initially, it was a noisy square (road traffic), with poor access and primarily used by elderly people. The refurbishment led to an enormous improvement in this public space and its acoustic comfort, as traffic sources now coexist with the noise of humans and water fountains.

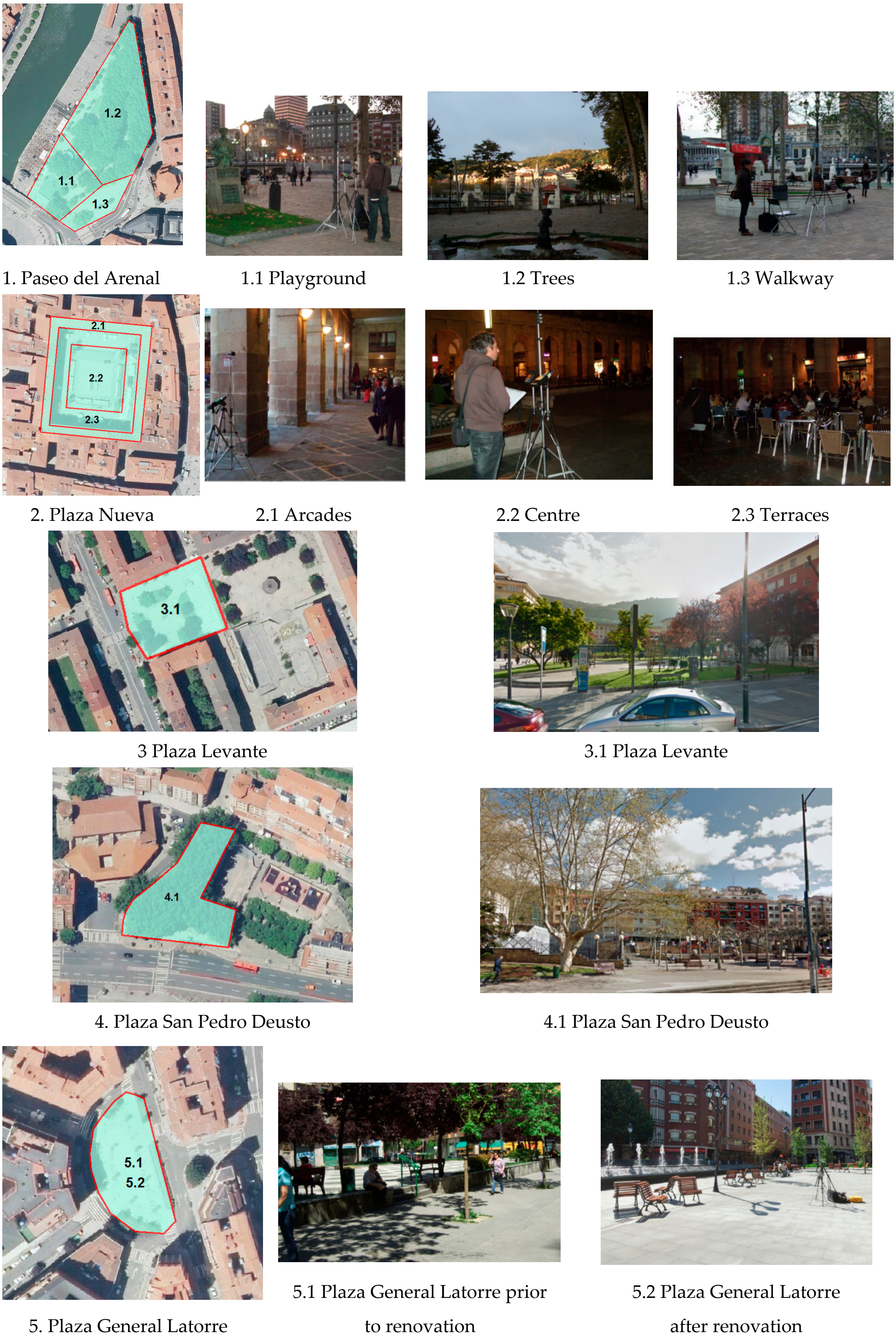

Figure 1. Images of the five public spaces and specific analysed units.

This study includes people's different uses of each of these places. At the different locations analysed, the predominant use is as a place to pass time (except in the centre of Plaza Nueva) and as thoroughfares (except for the playground area in Paseo Arenal and the terraces of Plaza Nueva). Recreational use is fundamentally limited to the zones where children play (the playground in Paseo del Arenal, the central area of Plaza Nueva, and Plaza General Latorre after renovation) although Plaza Nueva and Plaza GLT have no specific facilities for this purpose.

2.2. Method for Assessing the Physical Context

A method is proposed for describing each area, in which a set of objective variables related to the quality of services and the diversity of the place is estimated. The procedure used to measure the physical environment is an initial proposal based on simplified estimates, with one single value for each physical characteristic in each of the analysis units. The presence of vegetation (GREEN) and/or water (BLUE) elements, and the level of artificiality (GREY) are quantified by estimating the mean percentage of each of these elements on a (2D) map. In some cases, the total percentage of green, blue and grey elements is greater than 100% because trees or water may project over artificial surfaces. The estimates of the different characteristics of the location were performed by the person responsible for the psychosocial studies (Herranz-Pascual), based on her knowledge of the different sites analysed during the campaigns in the field.

More specifically, the value of %SKY is estimated by the technician as an approximation of the mean percentage of the sky that could be observed by a person using the analysis unit from any point. Similar methods have been used in other research based on panoramic photographs of places [13], though the visibility of the sky is too uncertain and dependent upon other factors, such as orientation, gaze direction, field of view, etc. [10,11]. The intention in performing this estimate was to get an indicator of the openness of analysed places, for which purpose it seemed to be of interest to use a measurement of the mean percentage of the sky that could be viewed by a user in the analysed location, even if this was just an approximate estimate.

Other characteristics such as the level of maintenance, safety, the presence of businesses (shops), traffic and facilities were also assessed. Each of these characteristics was evaluated by a working group that assigned them one out of four possible values: 1 for low presence; 2 for medium; 3 for high; and 0 meaning not applicable. For instance, the existence of one or two shops or other services such as banks in each analysis unit is considered a low presence, if there are three to five it is considered medium, while if it is over five it is classified as high. Maintenance is regarded as high when the soil in the area is clean, there is no graffiti on the walls, and the urban furniture is not in bad condition; it is medium when one of these criteria is not met; and low when two or more are not.

In addition, the presence of urban elements, i.e., landmarks and cultural heritage, was assessed using three scores: 0, not present; 1, visible from the study area; and 2, part of the study area. Table 1 shows a description of the physical characteristics and landscape features in the ten places analysed.

This method, conceived to characterise the places, is based on a tool developed in the QUADMAP project [27].

Social interaction was also assessed by a working group who assigned the following range of values: 1 for low interaction in a specific place, i.e., 2 or 3 people talking or interacting; 2 for a medium level, i.e., 2 or 3 groups of people interacting; and 3, for high interaction, i.e., more than 3 groups. A score of 0 means that no interaction between people is observed.

The ten places are strongly homogeneous in terms of maintenance and safety, which are generally high, as well as for the presence of landmarks and heritage. There is very little water present in the various places analysed.

In contrast, they differ widely in terms of existence of facilities, traffic, economic activity, and green areas. These differences are also reflected in the characterisation of the settings in terms of greenness (%GREEN), and artificiality (%GREY), as well as the openness of the place (%SKY).

Table 1. Description of the ten analysis units addressed.

Areas	Paseo del Arenal			Plaza Nueva			Pl. Levante	Pl. San Pedro	Pl. GLT	
Spaces	**Playground (1.1)**	**Trees (1.2)**	**Walkway (1.3)**	**Arcades (2.1)**	**Centre (2.2)**	**Terraces (2.3)**	**Square (3.1)**	**Plane Trees (4.1)**	**Before REN (5.1)**	**After REN (5.2)**
					Evaluation (1)					
Maintenance	3	3	3	1	3	3	3	3	3	3
Security	3	3	3	3	3	3	3	3	3	3
Shops	0	0	0	3	0	1	2	1	2	3
Traffic	1	1	1	0	0	0	1	2	3	2
Facilities	3	1	1	0	1	0	2	2	2	3
Social	3	1	2	3	2	2	1	2	3	3
					Presence (2)					
Landmark	1	1	1	1	1	1	0	1	0	0
Heritage	1	1	1	1	1	1	1	1	0	1
					Percentage					
%GREEN	10	70	20	0	10	5	40	60	20	35
%BLUE	0	5	0	0	0	0	10	5	5	25
%GREY	90	30	80	100	90	95	60	40	80	65
%SKY	60	30	85	0	40	40	60	30	65	65
					Other features					
area (m^2)	972	4000	1800	960	484	1400	5300	4500	975	975
Distance to buildings (m)	80	35	45	1	16	4	25	30	11	11

(1) Evaluation: 1 low; 2 medium; 3 high; 0 not applicable; (2) Presence: 0 not present; 1 visible from the study area.

These are urban environments with a very different amount of vegetation, ranging from 0% to 10% in Plaza Nueva to 60%–70% in the tree-lined areas of Arenal and San Pedro-Deusto. The openness of these environments (%SKY) is very diverse. In our studies, there is a location with 0%SKY (analysis unit 2.1. Arcade in the Plaza Nueva), because it is a covered site (under the covered walkway along the edge of the square). The remaining estimated values range from 30% (analysis unit 1.2 Trees, in which the sky is covered up by large trees) to 85% (analysis unit 1.3. Walkway, because it is a large area not bordered by buildings), both on Paseo del Arenal.

The level of social interaction in the playground areas and GLT square, both before and after the renovation, is high. In contrast, there is little interaction between people in the tree-lined area of Paseo del Arenal, where it is more common to find people on their own, lost in contemplation. The same can be said of Plaza Levante, although this may be due to the season, when the low temperatures do not invite people to hang around, and may change in warmer weather, for example.

With regard to surface area, there are two clear categories: one of around 1000 m^2 and the other of 4000–5000 m^2, coinciding with the greener areas. The distance to the buildings varies greatly.

As shown in this section, the analysis areas include squares, recreational areas and urban parks. None of the places evaluated is natural. Although there are trees and green areas, these zones predominantly contain constructed elements, i.e., they are basically urban.

2.3. Method for Assessing the Acoustic Environment and Soundscape

The main challenge when assessing a soundscape is that it is a multifaceted phenomenon and hence cannot be measured using a few simple numbers. In general, soundscape must be measured and evaluated through human perception of the corresponding acoustic environment [1,22]. Therefore, all measurement procedures, whether collecting physical or perceptual data, have to be strongly related to the way humans perceive the acoustic surrounding.

Below we present the materials and methods used to collect the acoustic and perception information from the users of these places. They are in line with the general criteria described in ISO 12913:2 [6]. In our case, the acoustic parameters were recorded at the same time as the questionnaires were completed by the users of the places. The acoustic measurement results corresponding to each questionnaire were assigned a time slot. Acoustic measurement periods were considered to last 10 min, as this was the average duration of the interview.

The following sections contain a description of the procedures used to collect information on each aspect of the soundscape. The measuring procedures, both acoustic and perceptive, were the same in all the different studies included in this work.

2.3.1. Acoustic Parameters

In each of the ten places, one or two acoustic measurement points were established, in accordance with the size of the area and the spatial variation of the sound levels in the analysis units.

The acoustic environment was then assessed through noise measurements. The overall measuring time in the places considered was 1 h and 30 min for different assessment periods (day or evening), at 2 m from the ground.

The following indicators were recorded using Brüel & Kjær Type 2260 Class 1 integrating sound level meters: $LA_{eq,1s}$, LA_{max}, LA_{min}, and the percentiles LA10, LA50, and LA90. Additionally, the technician taking the measurements identified any sound events and noted its source.

From the measurements taken in each place, during post-processing, acoustic data were extracted every 10 min [28], with the following indicators being obtained: $LA_{eq,10min}$, $LA_{min,1s}$, $LA_{max,1s}$, LA10, LA50, LA90, and total events.

To identify events in post-processing a method based on the principle of dynamic thresholds was applied. This method compares the instantaneous level $LA_{eq,1s}$ with the energy averages of the $LA_{eq,5s,downstream}$ (5 s earlier) and $LA_{eq,5s,upstream}$ (5 s later). This way, a sound event is detected when noise level variation implies a difference with both downstream and upstream averages that exceed the threshold. For a sound event to be perceived, it should theoretically be greater than 10 dB of continuous noise and, in fact, there are procedures that use this threshold. The method used in our studies was designed to detect events caused by activities and sound sources characteristic of urban environments during the period of use by the public, i.e., the daytime. To this end, the initial studies analysed various options to define the dynamic threshold to be applied during post-processing of the time span of the sound levels recorded. Considering the acoustic levels and their variation in these particular acoustic environments, it was concluded that a dynamic threshold of 6.5 dB allows the detection of a number of events similar to the perception of the sound environment by the technician who was taking the measurement.

In addition, according to the sound source that originated the events, the expert technicians classified them as positive, negative or neutral [28]. In this way, sources considered natural and those involving social interaction were ranked as positive, while mechanical and industrial noise (e.g., traffic) were set as negative. Finally, those which were perceived differently depending on the listener were considered neutral. From the positive and negative events identified in the timeframe of the questionnaire, the balance of events was calculated as the difference between the number of positives and negatives. Thus, a positive balance means a higher ratio of positive events and vice versa.

The number of sources perceived is a variable that is used to describe the acoustic environment. Therefore, the participants were also asked to identify all the sound sources perceived and classify them as pleasant or unpleasant. Next, the source balance was calculated as the difference between the amount of pleasant and unpleasant sources; a positive balance indicates that there are more pleasant sources than unpleasant ones.

2.3.2. Soundscape Assessment

As the soundscape concept deals with the perception of acoustic environments by communities, this feature is usually evaluated by distributing questionnaires to help understand how individuals perceive urban spaces. These forms include semantic scales with descriptions of the soundscapes [3]. It is, therefore, imperative that the public must participate in the soundscape evaluation process [29].

These studies apply a method referred to as "soundwalk" in the ISO 12913:2 standard [6]. It is the most frequently used method for data collection and to explore areas where local experts open a data field for triangulation, allowing the identification of a soundscape and its components. The protocols can vary in several aspects, including the way acoustic measurements are taken, how participants are asked, the sampling of participants, sample size, soundwalk duration, education level and the collection of visual information [4].

In order to assess a users' perception of the places evaluated and their soundscapes, a questionnaire was handed out following the ISO guidelines on soundscape [1] and the Environmental Experience Model [8], which included the developments made by various researchers. This questionnaire gathers data on around 60 variables structured into two parts:

1. General questions to be answered at the start of the evaluation of an urban place. This section includes the following items:
    a. Personal factors (24 variables): Sociodemographic variables, residential factors, perception of self-health and emotions, and psychosocial issues. These variables provide a full characterisation of the respondent.
    b. Previous experiences (2 variables): The participants are asked to report on how they generally used the place prior to the analysis, including frequency and reason for use.
2. Current experiences in the place (30 variables): Questions to be answered on site at the same time as the acoustic variables are measured. The questionnaire includes the following aspects:
    a. Landscape (6 variables): General perception of the place is assessed by applying a semantic differential (SD) that contains items such as: pleasantness, tranquillity and beauty

(5-point scale). The SD is defined according to general criteria [20]. The participants are also asked about what they like most and least about the place and if they would use the place for relaxing in.

b. Soundscape (10 variables): Participants are asked about their perception of the acoustic environment and the global acoustic atmosphere, as well as their evaluation of the congruence of the sounds with the urban place. The soundscape is evaluated using a SD that contains descriptors such as: pleasantness, tranquillity, relaxing, natural, vibrant, informative, and congruent (5-point scale) [30].

Our case studies are aimed at explaining the soundscape experienced in the place (dependent variable), for which the soundscape pleasantness was used as a general indicator. This variable is proposed through a 5-point SD scale, where 1 indicates completely unpleasant and 5 means completely pleasant.

2.4. Participation Campaign

The participants in the study were people staying in the 10 analysis units in Bilbao when the soundscape study was conducted. Data collection was carried out during the periods when the public space is most typically used by the general public. This is either in the evening (Plaza Nueva and Paseo del Arenal), in the morning between 11:00 and 13:30, or in the afternoon between 17:00 and 19:30. The observations were made in autumn (October to December), with the exception of the studies in Plaza General Latorre, which took place in spring (May). In each place, there were one or two interviewers who contacted the users and asked them to participate.

The participants are users of the urban spaces analysed who agreed to take part in our research projects voluntarily by responding to the questionnaire after having been informed in accordance with the procedures established by the current laws in Spain and the Basque Country on personal information protection and statistical confidentiality. The participants were informed during the stage of information collection by the person who administered the questionnaire and in informational notes within the questionnaire itself. Consent is regarded as being implicit as soon as the interviewee agrees to take part by responding to the questionnaire.

In total, 534 evaluations were made by the users of the places addressed. To facilitate the data processing and analysis, each participant was assigned the acoustic measurement that corresponded to the 10-min period that most closely matched the time when they were filling out their questionnaire. This resulted in 406 valid cases containing perception and acoustic data. In each place between 30 and 60 evaluations were completed (Table 2).

Table 2. Characteristics of the participants in the ten places studied in Bilbao (in terms of percentage).

Areas	Paseo Arenal			Plaza Nueva			Pl. L	Pl. SPD	Pl. GLT			Differences
Space	(1.1)	(1.2)	(1.3)	(2.1)	(2.2)	(2.3)	(3.1)	(4.1)	(5.1)	(5.2)	Total	
No. of samples	37	34	44	32	31	42	54	31	44	57	406	
Female	75.7	44.1	61.4	68.8	74.2	59.5	63.0	35.5	50.0	64.9	75.7	$p < 0.05$
Living in Bilbao	78.4	85.3	77.3	71.9	74.2	83.3	88.9	93.5	100.0	91.1	78.4	$p < 0.01$
Secondary studies	29.7	44.1	38.6	40.6	38.7	40.5	44.4	29.0	38.6	35.1	29.7	Not significant
University studies	54.1	35.3	45.5	56.3	45.2	57.1	24.1	45.2	40.9	33.3	54.1	$p < 0.05$
Employed	75.7	41.2	56.8	65.6	54.8	64.3	50.0	61.3	45.5	33.3	75.7	$p > 0.001$
Unemployed	13.5	8.8	9.1	6.3	19.4	9.5	11.1	12.9	25.0	14.0	13.5	Not significant

Paseo del Arenal: (1.1) Playground; (1.2) Trees; (1.3) Walkway. Plaza Nueva: (2.1) Arcades; (2.2) Centre; (2.3) Terraces. Plaza Levante: (3.1) Square. Plaza San Pedro Deusto: (4.1) Plane trees. Plaza General Latorre: (5.1) before renovation, in 2012; (5.2) after renovation, in 2014.

Social and demographic differences were observed between the people considering each of the ten spaces. There were significant differences with regard to sex ($\chi^2 = 21.406$; $df = 9$; $p < 0.05$) educational level ($\chi^2 = 58.804$; $df = 36$; $p < 0.05$), and working situation ($\chi^2 = 93.407$; $df = 45$; $p < 0.001$), as shown in Table 2.

3. Results

The results presented in this chapter are structured into 3 parts. The first details the descriptive results of the acoustic and non-acoustic variables. Comparisons between the ten places are facilitated by several one-way Welch's ANOVAs for acoustic parameters and Chi-square tests for subjective variables. The second part involves a correlational analysis using subjective and objective factors in order to examine the degree of association between the different variables. Finally, a regression analysis was conducted in order to understand which acoustic and non-acoustic variables could best predict soundscape in urban places [31], as well as their relative importance.

3.1. Descriptive Results

3.1.1. Acoustic Description

Table 3 shows the mean values of the acoustic parameters measured and calculated both for the global sample and for each place. The values of the indicators are the arithmetic mean for each 10-min measurement period. In the case of $LA_{eq,t}$, these are the arithmetic means of the energy averages calculated.

Table 3. Compared arithmetic means of acoustic variables according to the areas analysed (ANOVA analysis: * significant differences $p < 0.05$).

Areas	**Paseo Arenal**			**Plaza Nueva**			**Pl. L**	**Pl. SPD**	**Pl. GLT**		**GLOBAL**		
Spaces	**(1.1)**	**(1.2)**	**(1.3)**	**(2.1)**	**(2.2)**	**(2.3)**	**(3.1)**	**(4.1)**	**(5.1)**	**(5.2)**	**MEAN**	**MIN**	**MAX**
$LA_{eq,10min}$ *	63.0	59.9	64.2	69.2	64.8	66.7	58.7	65.6	62.4	64.9	63.7	57.0	72.0
$LA_{max,1s}$ *	73.5	69.8	75.6	78.2	76.1	77.8	70.3	75.0	75.4	74.2	74.4	64.0	91.2
$LA_{min,1s}$ *	56.9	54.2	58.1	64.1	59.5	60.4	51.3	54.4	54.8	59.1	57.1	47.1	66.8
LA10 *	64.9	60.8	65.5	70.7	66.4	68.4	60.0	66.5	63.6	66.1	65.1	57.3	73.9
LA50 *	62.5	59.8	64.0	69.0	64.4	66.3	58.4	65.4	62.2	64.6	63.4	56.4	71.9
LA90 *	61.0	59.2	63.0	67.6	63.1	64.8	57.4	64.7	61.2	63.7	62.3	55.8	70.4
LA10–LA90 *	3.9	1.7	2.5	3.1	3.3	3.6	2.5	1.7	2.3	2.4	2.7	1.0	12.2
No. total events *	3.5	1.0	1.3	1.3	2.2	1.8	1.6	1.0	1.3	1.6	1.7	0.0	10.0
No. positive events *	0.3	0.0	0.3	0.2	0.2	0.0	0.6	0.6	1.1	0.6	0.4	0.0	4.0
No. negative events *	0.6	0.5	0.8	0.3	1.0	0.1	1.3	0.2	0.0	0.5	0.6	0.0	5.0
No. neutral events *	2.6	0.5	0.2	0.9	1.0	1.7	0.1	0.2	0.2	0.4	0.7	0.0	9.0
Event balance *	0.3	0.5	0.5	0.2	0.9	0.1	0.7	−0.5	−1.1	−0.1	0.1	−4.0	5.0
No. total source	2.2	2.0	2.1	2.0	1.4	1.8	5.3	4.7	2.1	2.5	1	2.7	7
No. pleasant sound source *	1.3	1.3	0.9	1.2	1.0	1.2	1.0	1.4	0.6	1.4	1.1	0.0	7.0
No. unpleasant sound source *	0.9	0.7	1.2	0.8	0.4	0.5	1.3	1.5	0.9	0.5	0.86	0.0	6.0
Sound source balance *	0.4	0.6	−0.3	0.4	0.7	0.7	−0.3	−0.1	−0.3	0.9	0.3	−6.0	7.0

Paseo del Arenal: (1.1) Playground; (1.2) Trees; (1.3) Walkway. Plaza Nueva: (2.1) Arcades; (2.2) Centre; (2.3) Terraces. Plaza Levante: (3.1) Square. Plaza San Pedro Deusto: (4.1) Plane trees. Plaza General Latorre: (5.1) before renovation, in 2012; (5.2) after renovation, in 2014. For all of the parameters significant differences were detected (* $p < 0.05$) between the places (one-way ANOVAs).

It can be said that the average number of sound events per unit of time was low, between 1 and 2 events every 10 min. Only in the areas with children playing, i.e., the playground zone of Paseo del Arenal (1.1) and the centre of Plaza Nueva (2.2), this mean value was higher (3.5 and 2.2 events, respectively), being categorised as neutral. There were only two zones with a negative average balance of events: Plaza San Pedro (4.1) and GLT before renovation (5.1). In the centre of Plaza Nueva (2.2) and in Plaza Levante (3.1), the average balance of events was the most positive.

Regarding the sources characterising the environment, it may be concluded that, generally, there were more pleasant sources than unpleasant ones. For that reason, the balance was positive except in Plaza Levante (3.1), the walkway of Paseo del Arenal (1.3), and GLT before renovation (5.1).

The equivalent sound levels measured on Paseo del Arenal were in the range of 58.9 and 69.2 dBA, with the highest level recorded in the playground area (1.1). In contrast, the lowest level was recorded in the tree zone (1.2).

Plaza Nueva (2.1–2.3) was considered the most artificial space of those studied. It was divided into three places: the arcade where there is a high number of bars; the terrace area which is often occupied by tables from the bars and musicians; and the central area, where children play. The noisiest zone was the arcade, where values in the range of 61.6–72.1 dBA were recorded, probably due to the reverberating effect.

The lowest sound levels were registered in Plaza Levante (3.1), ranging between 56.6 and 62.7 dBA.

The $LA_{eq,10min}$ levels registered in Plaza San Pedro Deusto (4.1) varied from 64.2 dBA to 66.9 dBA.

In Plaza General Latorre (5.1 and 5.2) noise measurements were taken both before and after its renovation. Although the average $LA_{eq,10min}$ levels increased due to the incorporation of water noise in the square, the highest $LA_{eq,10min}$ levels recorded were lowered to 3.5 dBA due to the reduction of traffic noise.

In conclusion, it can be said that the places with the highest sound levels are pedestrian thoroughfares and places where children play. Considerable noise was recorded in areas with high background level, i.e., those normally used for recreational purposes (bars and play areas for children). In contrast the lowest level recorded was in zone 1.2, i.e., the tree zone in Paseo del Arenal.

3.1.2. Soundscape and Landscape Description

To compare the results of the subjective indicators for the ten places, since they were measured using ordinal scales, the chi-square test statistic was used.

There are differences between the landscape (LSC) and soundscape (SSC) variables in the ten places (Table 4). The most positive perception in landscape, soundscape and congruence was found in GLT after renovation (5.2), and in the most natural space, the tree-lined area of Paseo del Arenal (1.2), followed by the centre (2.2) and terraces (2.3) on Plaza Nueva. In contrast, Plaza GLT before renovation (5.1) and Plaza San Pedro de Deusto (4.1) were perceived the most negatively.

Table 4. Percentage of positive perception (scores 4 and 5 of the ordinal 5-point scale) of landscape (LSC) and soundscape (SSC) in the ten analysis areas (* $p < 0.001$ associated to χ^2).

Areas	Paseo del Arenal			Plaza Nueva			Pl. L	Pl. SPD	Pl. GLT		Total
Spaces	**(1.1)**	**(1.2)**	**(1.3)**	**(2.1)**	**(2.2)**	**(2.3)**	**(3.1)**	**(4.1)**	**(5.1)**	**(5.2)**	
SSC Pleasant *	59.5	79.4	45.5	62.5	67.7	73.8	37.0	3.2	34.1	96.5	57.2
SSC Quiet *	24.3	64.7	9.1	25.0	45.2	57.1	40.7	19.4	34.1	94.7	43.9
SSC Relaxing *	32.4	61.8	22.7	21.9	54.8	64.3	29.6	9.7	43.2	94.7	45.8
SSC Vibrant *	40.5	14.7	38.6	37.5	35.5	38.1	14.8	12.9	61.4	93.0	41.4
SSC Natural *	64.9	70.6	34.1	50.0	74.2	76.2	36.5	6.7	50.0	85.5	55.8
SSC Informative *	19.4	35.3	25.0	34.5	35.5	26.2	17.6	20.0	56.8	87.3	37.9
SSC Fun *	59.5	50.0	38.6	43.8	61.3	57.1	18.5	0.0	51.2	98.1	49.5
SSC Familiar	81.1	87.9	77.3	83.9	77.4	81.0	63.0	66.7	84.1	98.2	80.4
SSC Speech transmission *	35.1	82.4	31.8	43.3	71.0	73.8	24.1	6.7	43.2	82.5	50.1
SSC/LSC Congruence *	37.8	79.4	30.2	58.1	41.4	69.2	69.8	22.6	47.7	80.7	55.8
LSC Pleasant *	75.7	85.3	61.4	68.8	45.2	83.3	50.0	45.2	40.9	100	66.7
LSC Quiet *	10.8	11.8	11.4	6.3	29.0	9.5	51.9	32.3	2.3	98.2	30.3
LSC Beautiful *	27.0	38.2	25.0	21.9	25.8	31.0	63.0	35.5	6.8	100	41.3

Paseo del Arenal: (1.1) Playground; (1.2) Trees; (1.3) Walkway. Plaza Nueva: (2.1) Arcades; (2.2) Centre; (2.3) Terraces. Plaza Levante: (3.1) Square. Plaza San Pedro Deusto: (4.1) Plane trees. Plaza General Latorre: (5.1) before renovation, in 2012; (5.2) after renovation, in 2014.

Other places with low tranquillity-related scores were the arcades in Plaza Nueva (2.2), where sound reverberates, and the Paseo del Arenal walkway (1.3).

Soundscape familiarity and landscape pleasantness were high for most of the places analysed.

In general, almost two thirds of the participants (61%) would use the place they assessed for relaxing in. However, this percentage was higher in very natural places, like (1.3) the area with trees in Paseo del Arenal (79%) and (3.1) Plaza Levante (78%), and those with significant water elements, such as (5.2) Plaza GLT after the renovation (74%). This was also true for Old Town spaces, including the improvised children's play area (76%). The places least frequently chosen to relax in were the thoroughfare zones (1.3) and children's play areas (1.1) in Paseo del Arenal (34% and 41%, respectively), in addition to the Plaza Nueva arcades (2.1), with their high degree of reverberation, and (5.1) Plaza GLT before the renovation (50%). These results are congruent with those described before with regard to the soundscape, the landscape and their congruence.

3.2. Acoustic and Non-Acoustic Correlations

Correlations show the degree of association between the variables addressed in this study. When they are very high, they provide information on the level of redundancy between variables, which can thus be reduced. The Pearson correlation between acoustic variables is shown in Table 5. The $LA_{eq,10min}$ and percentile (LA10, LA50 and LA90) parameters correlate well (r = 0.99). There is also a high degree of correlation between $LA_{eq,10min}$ and $LA_{min,1sec}$ parameters (r = 0.82), and between the acoustic index and the percentiles. This indicates a high level of redundancy between these variables in the acoustic environments analysed.

Table 5. Pearson correlations [(1)] between acoustic variables (n = 406).

Acoustic Variables	$LA_{eq,10min}$	$L_{Amin,1s}$	$LA_{max,1s}$	LA10	LA50	LA90	LA10–LA90	No. Total Events	No. Positive Events	No. Negative Events	No. Neutral Events
$LA_{eq,10min}$	1										
$LA_{min,1s}$	0.82	1									
$LA_{max,1s}$	0.68	0.42	1								
LA10	0.99	0.80	0.73	1							
LA50	0.99	0.83	0.65	0.98	1						
LA90	0.98	0.82	0.58	0.94	0.99	1					
LA10–LA90	0.45	0.29	0.67	0.57	0.40	0.26	1				
No. total events	0.18	-	0.46	0.26	0.15	-	0.61	1			
No. positive events	−0.11	−0.20	0.10	−0.12	−0.1	−0.11	-	0.31	1		
No. negative events	-	-	-	-	-	−0.15	0.40	0.49	-	1	
No. neutral events	0.25	0.23	0.33	0.30	0.23	0.17	0.45	0.71	−0.11	−0.12	1
Event balance	-	-	-	-	-	-	−0.35	−0.22	0.57	−0.81	-

[(1)] $r > 0.10$ ($p < 0.05$); $r > 0.17$ ($p < 0.01$).

The relationship between acoustic indicators and acoustic events is low. It should be considered that the average number of sound events detected per unit of time was low. The closest relationships are observed between the total number of events (N total events), LA_{max} and LA10–LA90. This latter variable is also strongly associated with negative and neutral events, and has an inverse relationship with the balance of events. The total number of events mainly depends on neutral events, the most frequent ones, whereas its balance depends inversely on the negative events and directly, but to a lesser extent, on the positive ones.

When the relationship between acoustic indicators and pleasantness indices is analysed (Table 6), it can be concluded that in most cases there is very little, generally non-significant correlation between them. Few (in the order of 0.10) but positive correlations of acoustic parameters with landscape pleasantness (LSC_Pleasant) are found, indicating that pleasantness increases along with noise levels.

Moreover, the closest correlations are found between acoustic parameters and the total number of sound sources identified (No. total sources). These correlations are negative, meaning that the higher the noise level, the lower the sound diversity of the places analysed.

In contrast, there are almost no significant relationships between the different indices of events and the subjective pleasantness indicators. Neither are there any statistically significant correlations between acoustic parameters and the number of positive sound sources (No. pleasant source).

Soundscape pleasantness (SSC_Pleasant) is only associated to $LA_{min,1s}$ and events balance; and this is a positive but weak relationship. It implies that the greater the number of positive events (an increase in the balance), the greater the pleasantness. There are also low and significant positive correlations between $LA_{eq,10min}$ and LA50, and use of the place to relax in.

Table 6. Pearson significant correlation ($p < 0.05$) between acoustic parameters and pleasantness of sources, landscape and soundscape.

Parameters	$LA_{eq,10min}$	$LA_{min,1s}$	$LA_{max,1s}$	LA10–LA90	LA10	LA50	LA90	No. Total Events	No. Positive Events	No. Negative Events	No. Neutral Events	Event Balance
No. total sources	−0.27	−0.39	−0.19	−0.16	−0.27	−0.27	−0.26		0.12	0.12	−0.14	
No. pleasant sound source	-	-	-	-	-	-	-	-	-	-	-	-
No. unpleasant sound source	−0.11	−0.16	-	-	−0.11	−0.10	-	-	-	-	-	-
Sound source balance	0.12	0.15	-	-	0.12	0.12	0.12	-	-	-	-	-
SSC_Pleasant		0.16	-	-	-	-	-	-	-	-	-	0.11
LSC_Pleasant	0.12	0.15	0.12	0.11	0.13	0.11	0.10	-	-	-	-	-
Relaxing use	0.10	-	-	-	-	0.10	-	-	-	-	-	-

3.3. Regression Analysis: Acoustic and Non-Acoustic Factors

To identify the acoustic and non-acoustic variables that best explain the soundscape pleasantness (SSC-pleasant) and their relative relevance [31], step-by-step regression analysis is used. SSC-pleasant is introduced as the dependent variable.

Separately, the variables that best explain soundscape pleasantness are:

(a) For acoustic parameters: $LA_{min,1s}$ and $LA_{eq,10min}$, which account for 7.4% of the variance of soundscape pleasantness.

(b) For acoustic event assessment: The balance of acoustic events (positive versus negative), which accounts for just 1%.

(c) For sound source assessment: The balance of pleasantness (3.8% of variance explained).

(d) For physical characteristics of the surroundings: The percentage of surface covered by water (%BLUE), the presence of traffic and social interactions, and the surface area of the place, which explain 14.1% of the variance.

(e) The variable that represents whether or not people would use the place to relax in accounts for 4.7% of the variance in soundscape pleasantness of a place.

Considering all of the variables related with the acoustic environment (points a, b and c), it can be said that the acoustic factors that account for a significant percentage of variance in soundscape pleasantness are, firstly, the balance of pleasantness of the main sound sources (R^2 adjusted = 0.038); secondly, $LA_{min,1s}$ (R^2 adjusted = 0.055); thirdly $LA_{eq,10min}$ (R^2 adjusted = 0.109); and lastly the number of negative events (R^2 adjusted = 0.120). These variables account for 12.0% of the soundscape variance, which means a 62% increase compared with the variance explained by acoustic indicators (7.4%).

By including non-acoustic variables (point d) in the analysis as well, the percentage of variance explained in soundscape pleasantness rises even more: (1) by the presence of water (%BLUE); (2) be the presence of traffic (R^2 adjusted = 0.121); (4) by the balance of pleasantness among the main sound sources (R^2 adjusted = 0.139) and surface area sources (R^2 adjusted = 0.149); $LA_{eq,10min}$ (R^2 adjusted = 0.164) and $LA_{min,1s}$ (R^2 adjusted = 0.171); and (5) by $LA_{max,1s}$ (R^2 adjusted = 0.177). The objective and objectifiable variables, both acoustic and non-acoustic, account for 17.7% of soundscape pleasantness variance, 48% in the variance explained by acoustic variables (12%) and 239% in that explained by acoustic indices (7.4%).

If the variable most closely related with soundscape pleasantness, the congruence between soundscape and landscape, is also included in the analysis, the percentage of explained variance is 31.9%. This variable, though subjective, could be made "objectifiable", which is one of the challenges we face into the future. By including it in this analysis, we achieve an increase of 62% in the variance explained by objective and "objectifiable" variables, thereby increasing the variance explained by acoustic indices four-fold, making it the most relevant variable in the analysis (R^2 adjusted = 0.243); following the variables related to the physical characteristics of the place, such as the presence of traffic and water (R^2 adjusted = 0.283), the surface area (R^2 adjusted = 0.296), $LA_{eq,10min}$ (R^2 adjusted = 0.305) and the balance of pleasantness of the acoustic sources (R^2 adjusted = 0.314), as well as the total number of identified sources (R^2 adjusted = 0.319).

Table 7 shows the results of the of the step-by-step regression analysis with all acoustic and non-acoustic factors as independent variables without (a) or including (b) SSC/LSC congruence.

Table 7. Linear regression analysis (step-by-step method): percentage of variance (%var) of soundscape pleasantness (SSC-Pleasant) explained by acoustic and contextual variables (a) without SSC/LSC congruence ($F(6.395) = 14.378$; $p < 0.001$) or (b) including SSC/LSC congruence ($F(7.386) = 27.266$; $p < 0.001$).

SSC-Pleasant	Included Variables	R^2 Adjusted (without SSC/LSC Congruence (a)	R^2 Adjusted (with SSC/LSC Congruence (b)
All acoustic and non-acoustic variables	SSC/LSC Congruence	-	0.243 (1st)
	%BLUE	0.040 (1st)	0.283 (3rd)
	Traffic	0.121 (2nd)	0.263 (2nd)
	Sound source balance	0.139 (3rd)	0.314 (6th)
	Surface area (m^2)	0.149 (4th)	0.296 (4th)
	$LA_{eq,10min}$	0.164 (5th)	0.305 (5th)
	$LA_{min,1s}$	0.171 (6th)	-
	$LA_{max,1s}$	0.177 (7th)	-
	No. total sources	-	0.319 (7th)
	% var	17.7%	31.9%

4. Discussion and Conclusions

The main conclusion from the results is that the objective and "objectifiable" variables (acoustic and non-acoustic) explain a relatively low percentage of variance (less than 20%) in soundscape pleasantness. This means that the best way to perform an accurate evaluation of pleasantness in the acoustic environment of an existing place is to ask the users of that place about the pleasantness which they feel in the existing soundscape.

This paper is based on the goal of creating methods to predict soundscape pleasantness in such a way that they can be used as a tool to support decision-making in the management of public spaces, when direct user perception cannot be ascertained. Though the percentage of variance explained by the objective and objectifiable variables is not high, the inclusion of uncommon acoustic parameters in the regression model, such as the sound source balance, and non-acoustic parameters for the characteristics of the physical environment, leads to increases in the explained variance of 62% and 48%, respectively. Moreover, including a variable which we believe to be objectifiable in the future, such as soundscape-landscape congruence, will also produce a significant increase in the explained variance in soundscape pleasantness. Therefore, one conclusion is that a wide variety of parameters contribute to explaining pleasantness in the soundscape.

The need to take into account a wide range of factors in order to predict soundscape pleasantness reinforces the idea that soundscape studies should always be holistic and integrated, and based on contributions from different disciplines, among which human and social sciences play a key role as soundscape is a construct of human perception. To explain the soundscape, it is necessary to focus on both the acoustic and non-acoustic variables of the place (context, as defined in the ISO standard), integrating objective (acoustic and non-acoustic) and subjective variables [1,3,4,13,22]. The proof of this complexity is the fact that the congruence between the soundscape and the landscape as perceived by the user of the place is the best predictor of soundscape pleasantness. The relevance of congruence or coherence between soundscape and landscape has also been highlighted by other researchers [19,32,33].

Other major elements when explaining soundscape pleasantness include physical context factors. This is in line with recent literature and the developments of two ISO standards focusing on soundscape. In this study, the two main physical context variables in the analysis areas were the presence of water, quantified as the surface area covered by water, and traffic. The relevance of water on acoustic, visual and space indicators was also underlined by recent work describing the soundscape of the waterfront areas in Naples [13]. In that research, in which the percentage of sea in areas where the road traffic was limited or opened, the perception of the acoustic environment was positively affected.

It is therefore important to outline a consistent, consensually determined method for defining these physical context factors. This paper and other previous work [13,27] propose a method that identifies the elements relating to the quality of the spaces (maintenance and safety) and the presence of nature, both green and blue components. Similar indices have been widely used in urban planning and, more recently, in acoustics, to evaluate the soundscape of urban and rural areas [10,11,13]. In this study the physical context variables, despite their simplicity; have contributed to explaining the soundscape pleasantness felt by people in urban places. Therefore, it is considered necessary to agree on common indicators representing them.

Another important finding is that acoustic parameters are relevant when predicting soundscape pleasantness, though their contribution is low. The poor positive relationships between acoustic and subjective indicators may indicate that in some of the places studied there are activities involving high sound levels, such as children playing or social interaction on the terraces of bars, but which are considered pleasant because they are associated with relaxing activities. However, this may also occur due to the generally weak relationship between objective parameters and their perception, a finding also reached in other fields of research: Some are closely related to the soundscape, such as being disturbed by noise, while others are less related, such as perception of health. In general, the percentage variance explained for disturbance by sound on the basis of acoustic indicators is equal to 9%–15%, even higher than those we found (7%). When the assessments are about positive aspects such as pleasantness, beauty, etc., their relationship with objective parameters appears to be somewhat weaker due to the greater level of subjectivity involved.

Another remarkable result related with acoustic factors is the low contribution of sound events to the soundscape pleasantness in a place, which is surprising considering the vast literature supporting this relationship. Only weak relationships were detected between the balance of events, soundscape pleasantness and quietness and beauty of the landscape, in such a way that the more positive the balance of events, the higher the level of soundscape pleasantness, and the higher the calm and beauty of landscape. This result may, of course, be influenced by the event detection method applied in the study and the characteristics of the acoustic environment analysed.

However, the contribution of the number of sound sources identified by participants and related pleasantness is remarkable. The results seem to indicate that the most important variable for soundscape is the overall acoustic characterisation of the place (sound sources) rather than specific sound events. The total number of sources could reflect the sound diversity in the environments analysed, and the balance of sources reveals the need for a predominance of pleasant sources in order for the soundscape to be considered pleasant.

The results presented in this paper are similar to those found in the previous study conducted in Vitoria-Gasteiz [23], with the percentage of explained variance also being similar (32% and 36%, respectively). In both studies, it was concluded that the most significant aspect in soundscape pleasantness is the congruence between soundscape and landscape. The consistency of the results seems to indicate that these studies have a higher reproducibility than that typical of psychological correlations and experiments. The final report of an ambitious project that replicated a hundred psychological experiments published in three of the most prestigious journals in its field in recent years reported that more than 60% of the experiments "failed", meaning that they could not reproduce the results of the original experiment [34].

This research constitutes a step forward in defining an indicator of acoustic comfort for a place to be applied in outdoor soundscape studies and in the analysis of urban places. In order to predict soundscape pleasantness in future scenarios, this indicator should be based on easily-accessible variables (objective and objectifiable criteria). In this respect, we propose explaining soundscape pleasantness by using the following four factors: (1) congruence between soundscape and landscape (objectifiable); (2) physical characteristics of the space (presence of specific elements and evaluation of the degree of naturalness concerning water (%BLUE), vegetation (%GREEN), and openness of the space; (3) certain acoustic variables (LAeq/LA50 and LA10–LA90 or another form representing the presence of events); and (4) balance between the identification of sound sources and their perception.

We believe that this indicator can be useful in estimating the pleasantness of a soundscape when no user evaluations can be obtained. This occurs mainly in new situations and at non-existent sites (when designing new spaces or redesigning those currently in existence, for instance), or when asking users is not advisable, because it might create false expectations or for some other reason. In these situations, the results presented in this paper can help politicians and city technicians get an approximate idea of the soundscape pleasantness existing at the location of interest. This will allow them to reach decisions with better outcomes.

The results suggest some possible lines for future research. On the one hand, it is necessary to investigate the objectification of congruence between soundscape and landscape, the most relevant variable in soundscape pleasantness. On the other, it seems essential to continue researching the effect of sound events, comparing different procedures for their detection as well as the results of studies performed in different acoustic environments, and in the development of a rigorous, consensually determined procedure for measuring the physical characteristics of an environment.

Acoustic comfort is one dimension of urban comfort, understood as the ability of an urban space to create a pleasant environmental experience for the people who use it, contributing to the population's general health. Nevertheless, to understand the contribution of urban soundscape pleasantness to the welfare and health of people and communities it is necessary to further explore the effects of acoustic comfort.

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