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# Mobile App for Soundscape evaluation for the Spanish speaking community validated through principal component analysis

## Aplicación móvil de evaluación del paisaje sonoro para la comunidad hispanohablante validada mediante el análisis de componentes principales

**Jorge Eduardo Useche[1] | Belman Jahir Rodríguez[1] | Andrés Felipe Guevara[1] | Jhoan Sebastián Romero[1] | Marcelo Herrera Martínez [1] | Luis Fernando Hermida[1]**

[1]Programa de ingeniería de Sonido, Universidad San Buenaventura, Bogotá, Colombia.

**Correspondence**
Marcelo Herrera
Email: mherrera@usbbog.edu.co



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**Abstract.**Soundscapes represents the way in which people perceive and experiment the sounds of a particular acoustic environment. In this paper we explain the procedure carried up to develop a Mobile App for the evaluation of soundscapes in the case of Spanish speakers and its validation through principal component analysis. The application (called "SSEBOG") was implemented for android devices, and it is based on the ISO 12913-2 standard. The application allows geolocation, audio recording, image capture, feedback to users and data processing. A pilot test over a group of 56 persons evaluating the same acoustic environment was carried up with the App. The results of the principal component analysis indicate that the translations propose are consistent with the circular pattern model for the classification of the soundscapes frequently used for English speakers, however, the results suggest that the meaning of the diagonals in the circular pattern model does not correspond to a simple translation to Spanish.

**Keywords:** : Mobile application, Soundscape, Principal component analysis, Perceptual attribute.

## Resumen

Los paisajes sonoros representan la forma en que las personas perciben y experimentan los sonidos de un determinado entorno acústico. En este artículo explicamos el procedimiento llevado a cabo para desarrollar una aplicación móvil para la evaluación de paisajes sonoros en el caso de personas hispanohablantes, y su validación a través del método de componentes principales. La aplicación (llamada "SSEBOG") fue implementada para dispositivos Android y está basada en la norma ISO 12913-2. La aplicación permite geolocalización, grabación de audio, captura de imagen, retroalimentación a los usuarios y procesamiento de datos. Con esta

aplicación se desarrolló una prueba piloto en un grupo de 56 personas que evaluaron el mismo entorno acústico. Los resultados del análisis de componentes principales muestran que las traducciones propuestas son consistentes con el modelo de patrón circular para la clasificación de paisajes sonoros frecuentemente usado para angloparlantes, sin embargo, los resultados sugieren que el significado de las diagonales en el modelo de patrón circular no se corresponde a una simple traducción al español.

**Palabras clave:** Aplicación móvil, paisaje sonoro, análisis de componentes principales, atributo perceptivo.

## 1 | INTRODUCTION

In 1969, the first scientific article containing the word "soundscape" was published. The term born in a multidisciplinary context associated with fields as urban planning, noise and health, and music [1]. To understand the term "soundscape", first is necessary to understand the term "acoustic environment", which is defined as "sound at the receiver from all sound sources as modified by the environment" [2]. On the other hand, a soundscape is defined as an "acoustic environment as perceived or experienced and/or understood by a person or people, in a context" [2]. Different models have been proposed to evaluate subjective qualities of acoustic environments [3, 4, 5, 6]. In this process many subjective attributes have been considered, however several studies have changed the set of original variables (used for the description of a soundscape) for another set with a smaller number of them, using methods as the Principal Component Analysis (PCA) [3]. The reduction of the number of variables allows two features: identify the main concepts needed to the subjective description of the soundscapes, and the classification of them for practical purposes as for example urban planning [7, 8, 9, 10, 11, 12].

The evaluation of subjective attributes has been done using two main methods: questionnaires with open and closed questions, and with acoustic descriptors as for example the equivalent sound pressure level A-weighted (LAeq), the percentiles LA10-LA90, the Zwicker loudness in sones (N10-N90) [3], [13, 14, 15], the acoustic complexity index (to quantify the complexity of the soundscape) [11], the normalized difference soundscape index (to quantify the relation between biophonic and anthrophonic sounds) [16], and many other coming from the processing of acoustic data with different programs [17, 18, 19].

Some relations appear between the objective acoustic descriptors and subjective attributes, for example, negative correlations have been found between LAeq and some perceptual attributes associated with the dimensions of pleasantness and comfort, indicating that high values of noise are undesirable [3], [20]. Other subjective attributes, as for example the related with the dimensions of activity, vibrancy, eventfulness, and temporal variation, do not present simple correlations with the acoustic descriptors and a more complex description is necessary [6], [20].

Many mobile applications, as *Hush city*, have been developed for the evaluation of crowdsourced noise and sound maps [21],[22]. Different methods have been developed to calibrate the smartphones to take significant values of Sound Pressure Level (SPL), allowing the elaboration of noise maps [22]. The subjective experience associated to the perception of an acoustic environment is also related to the visual properties of the place in which the sound is produce[12],[23], [24], so, additionally to the questionnaire, the measurement of acoustic quantities and the relationship results of those subjective attributes, some of the apps include a tool to take pictures of the place in with the acoustic environment is located.

Many studies about subjective qualities of acoustic environments have been carried out in English, with questionaries and subjective attributes designed to be applied in this language. In comparison, relative few works have treated the correct translation of subjective attributes to other languages [25, 26, 27, 28, 29, 30]. As the meaning and weight of some words change depending on the language [13], then there are necessary future efforts defining criteria to a proper translation between different languages, and the validity of previous works if there are applied in languages different to English. In this direction, in 2019, the Soundscape Attributes Translation Project (SATP) was created with the purpose of study the correct translation of terms in 15 different languages [30].

In this work we present a procedure to construct a mobile application for the evaluation of soundscapes for

the Spanish speaking community, and the analysis of the data collected to investigate the meaning in Spanish of the axes of the circular pattern model first proposed by Axelsson, Nilsson and Berglund (2010). The PCA method was used to analyze the gathered information, showing that the translations to Spanish proposed in this work allow the use of the model proposed by Axelsson, Nilsson and Berglund in the two main orthogonal axes: *pleasant* and *unpleasant*, *eventful* and *uneventful*, and in the diagonal with the attributes *exciting* and *monotonous*. However, our results suggest that the diagonal with the attributes *chaotic* and *calm* must be taken carefully in the translation to Spanish because these attributes do not present a suitable correlation with the two main orthogonal axes. Besides, the APP save the information using adjacent matrices, allowing future research relating to graph theory and perceptual attributes of soundscapes. This paper is organized as follows: the methodology section presents the procedures followed in the construction of the App and the methods proposed to analyze the data. Results and discussion section shows the main interfaces of the APP, the results obtained in the campus of the San Buenaventura University (Bogotá, Colombia), and the corresponding analysis with PCA. Finally, the last section presents the conclusions and the future perspectives.

## 2 | MATERIAL AND METHODS

This section contains the procedure followed to design the interface of the APP, the questionnaire applied to the user, the criterion proposed to select the number of people that would prove the app to obtain significant statistical results with the PCA method, and the way in which the PCA method can be used to analyze the information collected by the APP.

### 2.1 | Language and main features of the App

The Mobile App “SSE-BOG” is developed for Android devices and users register with their personal email accounts (e-mail, Facebook or Google). It uses the Geocoder library from Google to obtain the exact current location of the acoustic environment in which the user is doing the evaluation, and then it allows to carry out an evaluation of it through a questionnaire.

The evaluation is developed through a series of questions, defined according to perceptual attributes. The App applies a questionnaire based in the method A of the ISO/TS 12913-2:2018, in which some questions are design to be compatible with a numerical evaluation through a five points Lickert scale. Additionally, the application allows the user to take a picture and record a sound fragment of the corresponding acoustic environment. This data is sent to a database created on firebase platform (an extension of Android Studio used to create a database, measure the performance of the App and other features) and then the data is download from firebase using a MATLAB program in which the data is organized.

### 2.2 | Questionnaire

The questionnaire is designed to collect subjective data on how people perceive an acoustic environment. Method A of the ISO/TS 12913–2:2018 considers three different categories to be evaluated: sound sources, perceived affective quality and overall quality[13, 14].Since the app is applied for users with Spanish as native language, the questions used in the Method A was translated to Spanish according with the following criteria:

- Words and sentences are translated from English with the closest words in Spanish unless the word or sentence will be confused for the user. In that case a closest synonym will be used.
- In the translation of the possible answers for some questions, the words used in Spanish must be in agree with an interval Likert scale.

The following Table 1 presents the questionnaire as presented in the ISO/TS 12913–2:2018, and the corresponding translation made in Spanish:

**TABLE 1** Questions from the questionnaire in English and their corresponding translation to Spanish.

| Category | Questions | Preguntas |
|---|---|---|
| Sound Sources (Fuentes Sonoras) | To what extent do you presently hear the four following types of sounds? | En este momento, ¿hasta qué punto escucha los siguientes cuatro tipos de sonidos? |
| Perceived Affective Quality (Calidad Percibida) | For each of the 8 scales below, to what extent do you agree or disagree that the present surrounding sound environment is? | Para cada uno de los siguientes atributos, ¿qué tan de acuerdo o en desacuerdo está usted con que el atributo describe el entorno escuchado? |
| Overall Quality (Ambiente en general) | Overall, how would you describe the present surrounding sound environment? | En general, ¿cómo describiría el sonido presente en el ambiente? |
| | Overall, to what extent is the present surrounding sound environment appropriate to the present place? | En general, ¿hasta qué punto el sonido presente es apropiado para el lugar? |

The attribute "Vibrant" was the unique attribute of the Perceived Affective Quality category that was not used. This is because this term is common in English; however, its Spanish translation is not common at all, and it could be confusing among Spanish speakers. For the attributes "Eventful" and "Uneventful" an additional explanation was included for a better understanding of the Spanish speaker's community (see Table 3).

**TABLE 2** Response types from the questionnaire in English and their corresponding translation to Spanish.

| Category | Response types | Tipos de respuesta |
|---|---|---|
| Sound Sources (Fuentes Sonoras) | Not at all; A little; Moderately; A lot; Dominates completely. | No del todo; Un poco; Moderadamente; Bastante; Domina Completamente. |
| Perceived Affective Quality (Calidad percibida) | Strongly agree; Agree; Neither agree, nor disagree; Disagree; Strongly disagree. | Completamente de acuerdo; En acuerdo; Ni en acuerdo, ni en desacuerdo; En desacuerdo; Completamente en desacuerdo. |
| Overall Quality (Ambiente en general) | Very good; Good; Neither good, nor bad; Bad; Very bad. | Bastante bueno; Bueno; Ni bueno, ni malo; Malo; Bastante malo. |
| | Not at all; Slightly; Moderately; Very; Perfectly. | Totalmente inapropiado; inapropiado; Ni apropiado, ni inapropiado; Apropiado; Totalmente apropiado. |

An additional list of attributes was included in the Perceived Affective Quality category. These terms were selected from the 116 attributes considered by Axelsson et al. (2010) in order to complement the original ones considered in the Method A of the ISO/TS 12913–2:2018. The attributes *natural*, *artificial*, *interesting*, and *silent* were included because the nature of these attributes is not considered in the eight attributes of the Method A. The attribute **exciting** was included because the translation in Spanish of this attribute could replace the meaning of *vibrant*. The attribute *boring* was included to complement the attribute *monotonous* and to observe if in Spanish these attributes are equivalent. Finally, the attribute *unpleasant* was included instead of annoying (in many cases this terms have been used as synonyms [14]), which was replaced by the term *"ruidoso"* in order to explore the differences between these concepts in Spanish. With these elections, a total of 14 different attributes in Spanish were considered.

**TABLE 3** Attributes from the questionnaire in English and their corresponding translation to Spanish. *The word *"Ruidoso"* was included instead of *annoying* because this term has been used with the same meaning of *unpleasant* [14]

| Category | Attribute | Attribute in Spanish |
|---|---|---|
| Perceived Affective Quality (the Method A of the ISO/TS 12913–2:2018). | Pleasant | Agradable |
| | Chaotic | Caótico |
| | Vibrant | ——- |
| | Uneventful | Sin eventualidad (pocos eventos ocurriendo en el lugar) |
| | Calm | Pacífico |
| | Annoying | Ruidoso* |
| | Eventful | Eventualidad (muchos eventos ocurriendo en el lugar) |
| | Monotonous | Monótono |
| Additional attributes proposed by the authors of this paper. The attributes were selected from [3]. | Natural | Natural |
| | Artificial | Artificial |
| | Exciting | Emocionante |
| | Boring | Aburrido |
| | Interesting | Interesante |
| | Silent | Silencioso |
| | Unpleasant | Desagradable |

### 2.3 | Sample size determination

The number of people to obtain significant statistical results depends on the population considered. As the population target of the App is anyone with normal hearing, in general this number is great and unknown. However, in many cases only a specific number of people frequent an acoustic environment most of the time, so the population of the study can be determined or assumed.

A common formula to determine the number of people that must participate in the evaluation is given by [31]:

$$n = \frac{k^2 N p q}{e^2(N+1) + k^2 p q} \tag{1}$$

where n is the sample size, "N" is the population size, "k" determines the confidence level, *"e"* corresponds to the desired margin of error, and *"p"* and *"q"* are the proportion of individuals possessing and not possessing (respectively) the specific characteristic measured, that in the case of the soundscape evaluation corresponds to the normal hearing condition. In the present study, the campus of the San Buenaventura University in Bogotá, Colombia was selected to carry out several tests with the APP to obtain significant statistical information of the perception of its acoustic environment, specifically by the students of the Sound Engineering program. The population size was approximated to 500 students, "k" was taken as 1.96 (95% of confidence), "e" was taken as 0.075, and "p" and "q" were taken as 0.9 and 0.1 respectively, estimating that at least the 90% of the evaluated subjects (young people with less than 30 years old) possess a normal hearing condition [32, 33] . With these parameters, the samples size is approximately of 55 students.

### 2.4 | Likert scale and adjacency matrix

In the questionnaire, the answers for the questions of the perceived affective quality category were prepared in such a way that it can be represented using an interval Likert scale of 5 points. For the analysis, the following numbers were associated to each answer:

**TABLE 4** Values associated to each answer in the perceived affective quality category of the questionnaire

| English | Spanish | Punctuation |
|---|---|---|
| Strongly agree | Completamente de acuerdo | 2 |
| Agree | De acuerdo | 1 |
| Neither agree, nor disagree | Ni en acuerdo ni en desacuerdo | 0 |
| Disagree | Desacuerdo | -1 |
| Strongly disagree | Completamente en desacuerdo | -2 |

With the punctuation of Table 4 for different locations, the App organizes the information in an adjacent matrix representing the value of the perceived attributes for each soundscape. Table 5 shows the general form of the adjacent matrix of size *mxn*. The matrix shows the information of *m* soundscapes, each one evaluated over *n* perceptual attributes. For the case in which the same soundscape is evaluated more than one time, as in the case of this study, the matrix entries correspond to the average punctuation of all subjects. For future purposes, this way of organizing data allows the visualization of information using graphs [34], a mathematical formalism that recently have been used to explore the relation between subjective attributes and soundscapes. New tools for the visualization and analysis of quantitative information associated to soundscapes is a relevant research issue nowadays [35].

**TABLE 5** General form of the adjacent matrix. This matrix contains information about *"m"* soundscapes, each one evaluated over *"n"* perceptual attributes.

| | Attribute 1 | Attribute 2 | . . . | Attribute *n* |
|---|---|---|---|---|
| **Soundscape 1** | 2 | 0 | | |
| **Soundscape 2** | -1 | 1 | | |
| .<br>.<br>. | .<br>.<br>. | .<br>.<br>. | | |
| **Soundscape *m*** | | | | |

## 3 | RESULTS AND DISCUSSION

This section shows the main interfaces of the APP SSE-BOG, the results obtained with the App in the San Buenaventura University, and the corresponding analysis of the data using PCA.

### 3.1 | Main interfaces of the APP and PCA analysis

Fig. 1 shows two of the main interfaces of the App SSE-BOG: welcome interface (Fig. 1, left) and the initial part of questionnaire (Fig. 1, right).

Using the data collected in the San Buenaventura University for the 14 attributes evaluated in the perceived affective quality, the variance of the PCs was obtained. Table 6 shows the variance obtained (decreasing order) for each one of the fourteen PCs and the eigenvalues of each perceptual attributes in the two most

important PCs using MATLAB and Python libraries (assuming that the first two PC contain enough information to represent the main properties of the fourteen perceptual attributes of the soundscape).

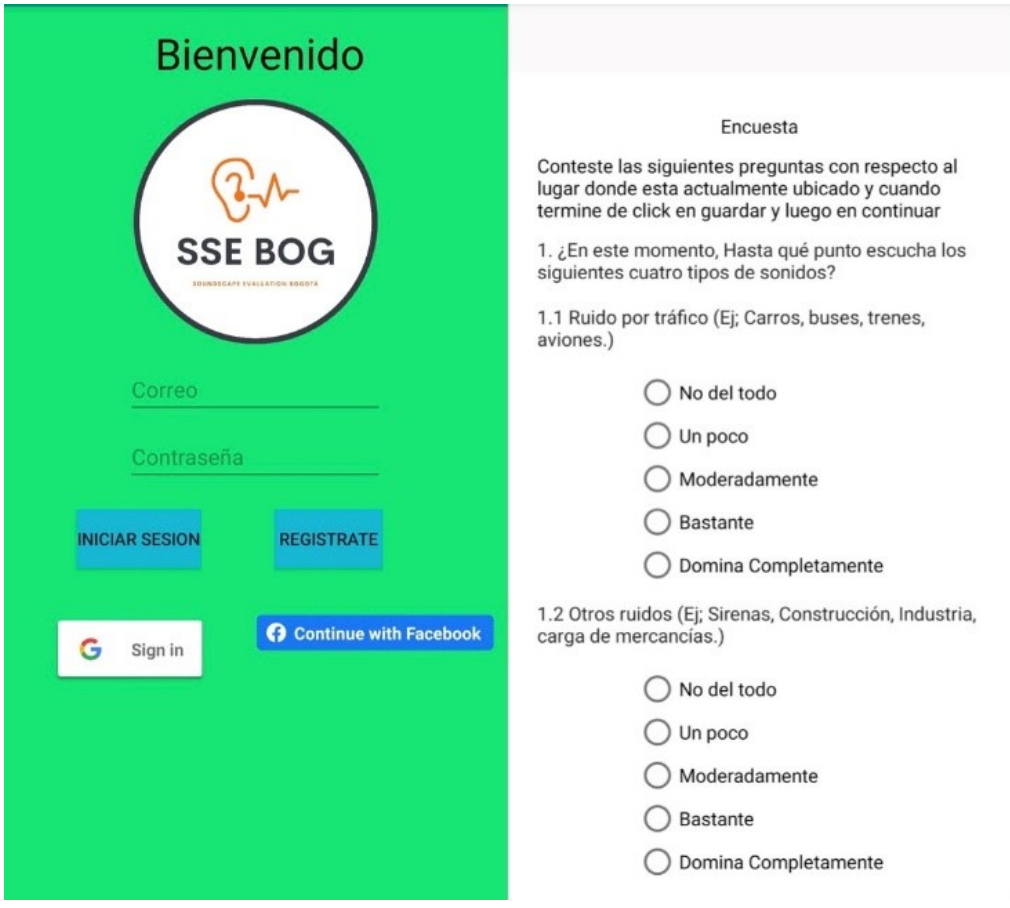


**FIG. 1** Welcome interface and initial part of the questionnaire.

For the two libraries, the first component is positive correlated with the attributes *"Pleasant"*, *"Natural"*, and *"Calm"* (for these attributes the first component has large magnitudes in the eigenvalues while the second component has low magnitudes in the eigenvalues), and negatively correlated with the attributes *"Unpleasant"*, *"Artificial"*, *"Chaotic"*, and *"Annoying"* for similar reasons. On the other hand, the second component have a positive correlation with the attribute *"Eventful"* and a negative one with the attribute *"Uneventful"* (although it must be considered that in the latter case the first component has a considerable value). Additionally, no significant differences were found between the terms *"ruidoso"* (used instead *annoying*) and *"desagradable"* (*"unpleasant"*).

Considering that the attributes *pleasant* - *unpleasant* and *eventful* - *uneventful* correspond to the two main orthogonal axes in the circular pattern model proposed by Axelsson, Nilsson and Berglund (2010) (see Fig. 2), the results obtained are consistent with this classification, however some differences appear. The attribute *interesting* presents significant positive correlations with the two main PCs, and the attribute *boring* presents significative negative correlations with the two main PCs. In the circular pattern model of Axelsson et al. (2010) (Fig. 2), these types of correlations correspond to the attributes *exciting* and *monotonous* respectively, which are located at $\theta = 45$ and $225$ in the circular pattern model, so, the results suggest that a suitable translation in Spanish for these attributes is *interesting* and *boring*. The attributes located at $\theta = 135$ and $\theta = 315$ in the circular pattern model of Axelsson et al. (2010) correspond to *chaotic* and *calm* (see Fig. 2), however the results obtained in our study are not consistent with this classification because these attributes present high correlations with only one of the PCs.

Taking into account the previous results, for the case of the San Buenaventura University (Bogotá Campus), attributes as “Pleasant”, “Natural”, and “Calm” (with their opposite terms or antonyms), as well as “Eventful” and “Uneventful” are central to describe the most important subjective properties of the soundscape.

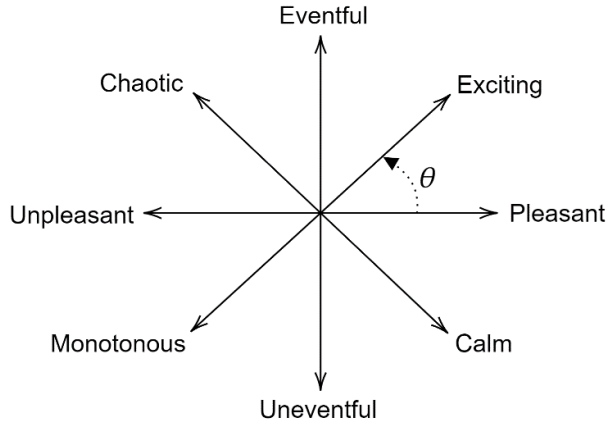


**FIG. 2** Circular pattern model proposed by Axelsson, Nilsson and Berglund (2010) for the subjective analysis of soundscapes.

Additionally to questionnaire, the mobile application allows to capture a sound fragment from the acoustic environment, and a photography of the evaluation place. Fig. 3 shows the remaining interfaces of the APP: the photography interface (Fig. 3, left), and the audio recording interface (Fig. 3, right).

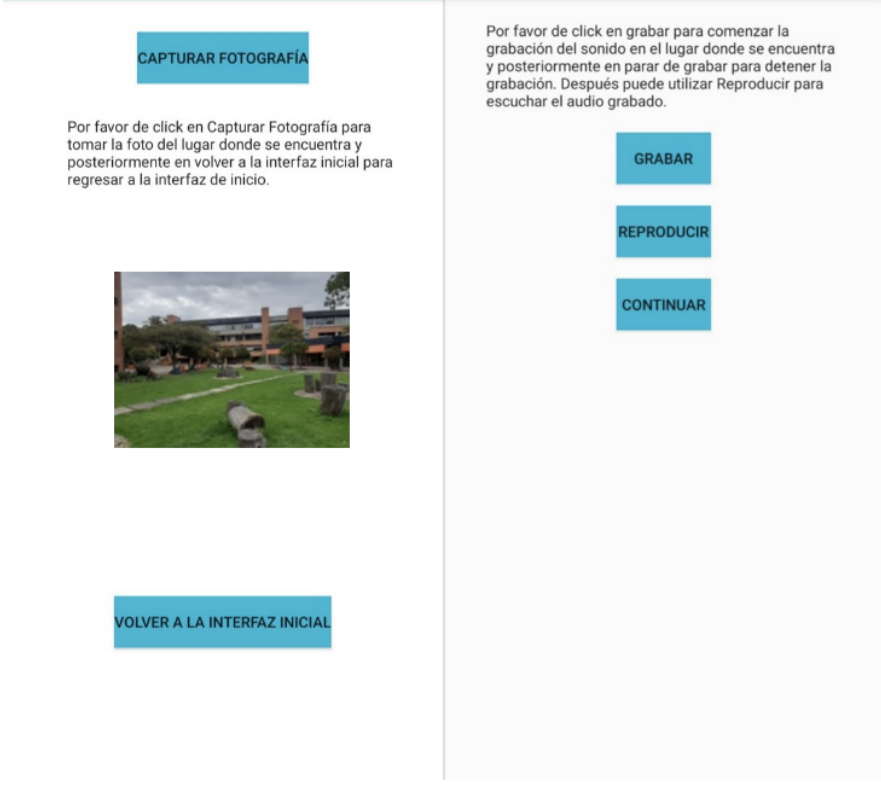


**FIG. 3** Audio recording and photography interfaces.

Table 7 shows the mean results for the questions in the categories of sound sources and overall quality in the case of the San Buenaventura University. In the sound sources category, the most important contributions come from natural and human beings sounds. Additionally, from the overall quality category, these sounds are perceived as enough good, however, the participants do not consider that these sounds are enough appropriated for the acoustic environment of the University. From the PCA analysis, the principal component $C_1$ can describe the natural sounds present in the environment and the pleasant sensation of these sounds.

**TABLE 6** Variance value in every Principal Component (PC) and eigenvalues of each subjective attribute in the PC number 1 and 2 (denoted as C1 and C2) using Python and MATLAB libraries.

| | | | Python library | | MATLAB library | |
|---|---|---|---|---|---|---|
| **PC** | **Variance** | **Attribute** | **C1** | **C2** | **C1** | **C2** |
| 1 | 28,49 | Eventful | -0,79 | 6,06 | -1,55 | 6,09 |
| 2 | 11,11 | Exciting | -0,40 | 2,49 | -1,13 | 2,51 |
| 3 | 7,83 | Interesting | 4,45 | 3,43 | 3,69 | 3,46 |
| 4 | 6,78 | Pleasant | 10,51 | 0,39 | 9,77 | 0,41 |
| 5 | 5,79 | Natural | 11,26 | 1,15 | 10,51 | 1,17 |
| 6 | 5,53 | Calm | 10,93 | -0,54 | 10,19 | -0,52 |
| 7 | 4,99 | Uneventful | 3,97 | -5,66 | 3,23 | -5,64 |
| 8 | 4,70 | Monotonous | -0,07 | -2,74 | -0,84 | -2,72 |
| 9 | 4,26 | Boring | -5,74 | -4,13 | -6,50 | -4,11 |
| 10 | 3,75 | Unpleasant | -10,25 | -0,13 | -10,98 | -0,12 |
| 11 | 3,43 | Artificial | -9,53 | -1,13 | -10,27 | -1,11 |
| 12 | 3,28 | Chaotic | -9,66 | 0,96 | -10,41 | 0,98 |
| 13 | 2,94 | Annoying | -8,58 | 1,94 | -9,30 | 1,95 |
| 14 | 2,52 | Silent | 3,91 | -2,09 | 3,15 | -2,06 |

**TABLE 7** Average answer in each question of the questionnaire categories

| Category | Question | Answer options | Item(s) | Mean answer |
|---|---|---|---|---|
| Sound Sources | To what extent do you presently hear the four following types of sounds? | Not at all (1); A little (2); Moderately (3) A lot (4); Dominates completely (5) | Traffic noise (e.g., cars, buses, trains, airplanes) | A little (Un poco) |
| | | | Other noise (e.g., sirens, construction, industry, loading of goods) | A little (Un poco) |
| | | | Sounds from human beings (e.g., conversation, laughter, children at play, footsteps) | Moderately (Moderadamente) |
| | | | Natural sounds (e.g., singing birds, flowing water, wind in vegetation) | Moderately (Moderadamente) |
| Overall Quality | Overall, how would you describe the present surrounding sound environment? | Very good (1); Good (2); Neither good, nor bad (3); Bad (4); Very bad (5) | | Good (Bueno) |
| | Overall, to what extent is the present surrounding sound environment appropriate to the present place? | Not at all (1); Slightly (2); Moderately (3); Very (4); Perfectly (5) | | Moderately (Ni apropiado, ni inapropiado) |

On the other hand, the principal component $C_2$ can describe the effect of the anthrophony sounds in the sense that these sounds produce some "events" in the soundscape, however the nature of the sounds, and the suitable of these sounds for the acoustic environment, is impossible to determine only with the PCA results, for this reason the analysis of the questions in the sound sources and overall quality categories is complementary to the PCA. It is important to remark that $C_1$ and $C_2$ have the possibility of describing the most important properties of the soundscape, however, these PCs cannot determine if exists a positive or negative correlation of each one of these PCs with the features of the soundscape. For this purpose, the specific punctuations collected in the adjacent matrix are necessary.

## 4 | CONCLUSIONS

In the context of soundscape assessment in different languages there is not a clear methodology to extrapolate the results obtained in one language to another one. In this paper, the PCA has been used to validate the translation to Spanish of the main subjective attributes associated to soundscapes. Using the PCA method over the data collected, the two most important principal components were identified: one of them can be interpreted as a mixture of the attributes pleasant, natural and calm (and its corresponding opposite terms), and the other one is associated with the attribute "Eventful" (and "Uneventful"). These results are consistent with the corresponding ones obtained by Axelsson, Nilsson and Berglund (2010) analyzing subjective attributes in English language, who found that the attributes *pleasant - unpleasant* and *unpleasant - uneventful* correspond to the two main orthogonal axes in a circular pattern model, however, some differences appear with our study. First, the diagonal axes at $\theta = 45$ and $\theta = 225$ in the Axelsson et al. model (2010) (Fig. 2) are characterized by the attributes *exciting* and *monotonous* respectively, but our study suggests that these angles are better characterized by the translations in Spanish of the attributes *interesting* (*interesante*) and *boring* (*aburrido*) for $\theta = 45$ and $\theta = 225$ respectively. Second, the diagonal axes at $\theta = 135$ and $\theta = 315$ in the Axelsson et al. model (2010) are characterized by the attributes *chaotic* and *calm*respectively, however, our study suggests that the translation to Spanish of these attributes must be taken carefully because these attributes present high correlations with only one of the PCs, and the expected behavior must show high correlation with both PCs.

### Declaration of Interest

The authors declare that there is no conflict of interest.

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