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CITI-SENSE: methods and tools for empowering citizens to observe acoustic comfort in outdoor public spaces

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Abstract: The purpose of this research was to design and deploy tools that apply the concept of citizen observatories and empowering citizens in the assessment of acoustic comfort in public places. The research applies an iterative cycle of design and this article presents the results of a demonstrative experiment carried out in situ using the first products developed. This work was undertaken as part of the CITI-SENSE project. A viable technical and procedural solution was designed and tested in a field demonstration, where 53 people were engaged to provide 137 observations in the city of Vitoria-Gasteiz, using environmental sensors connected to a smartphone. The results have been analyzed and discussed in terms of the product's attractiveness for engaging citizens in the evaluation of acoustic comfort in urban places, the accuracy of the noise levels measured by the acoustic app service integrated into the smartphone, and its ability to obtain simultaneous acoustic and perception data. The results presented in this article are considered a step forward in the research into developing solutions for assessing acoustic comfort. Limitations of the proposed solution are discussed, as are suggestions for further research.

Keywords: acoustic comfort; empowerment; soundscape; citizen observatories

1 Introduction

Acoustic comfort is a key part of the general public's environmental experience of urban places and, for this reason; it affects their enjoyment and use of these spaces [1]. The user's perception of an area's soundscape determines their acoustic comfort in that place. Although methods have been proposed for assessing soundscape, involving complex analyses of objective data representing the public's perception of the acoustic environment, the importance of context (previous experiences and relationships with the places, as well as the physical characteristics of the space) makes it essential to gather users' real, in situ perceptions of the spaces in order to assess the soundscape.

It is therefore interesting to investigate how the concept of the Citizens' Environmental Observatory[1] can be applied in the study of the acoustic comfort of urban spaces. This research faces three main challenges:

1. Engaging people in the evaluation of acoustic parameters: What this means in terms of tools, building an attractive design, constructing a user friendly solution, and giving feedback to the citizens in diverse ways. For example, quick and simple feedback on site, while they are making their observations of the places, as well as more in-depth feedback during follow-up. Contribution from the social sciences is also needed in terms of empowerment and expectation management, although these aspects are not addressed in this paper.
2. Obtaining simultaneous objective and subjective data on site. The most valuable information obtained when applying the citizen observatories concept is a person's contribution to the assessment. The combination of physical acoustic measurements and the perception of the soundscape enrich the assessment, and the solution shall find pairs of objective and subjective data that increase the understanding of how places are perceived by users.
3. Giving technical credibility to the objective data measured. The solution will not be as accurate as

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1 Communities of users that share technological solutions, information products and services, and community participatory methods, using appropriate communication solutions, thus complementing established environmental data and information systems and improving local environmental decision making.

the acoustic reference equipment used for acoustic inspection, but the accuracy of the objective data should be known and validated for decision-making purposes.

The overall objective of this research was to design and deploy tools that apply the concept of citizen observatories and empower citizens in the assessment of acoustic comfort in public places. These tools should meet the challenges defined above and provide relevant solutions. The research applied an iterative cycle of design, by combining the development of solutions with demonstration in real situations. This research was undertaken as part of the CITI-SENSE project.

This article presents results of the demonstrative experiment carried out using the first products developed. The results should be understood in terms of the steps taken towards responding to the three key aspects mentioned above.

2 State of the art

Addressing acoustic comfort requires the adoption of a soundscape approach [2]. The soundscape concept deals with the perception of acoustic environments by communities [3]. Perception is usually evaluated by distributing questionnaires that use tools to understand how citizens perceive urban spaces, such as semantic scales with descriptions of the acoustic environments [4], and questions about the pleasantness of sound sources [5]. There are many references that highlight the relevance of context in the soundscape approach to a place (*e.g.*, landscape [6, 7], thermal conditions, maintenance, and cleanness), as well as the characteristics of the person or community (*e.g.*, culture, personal characteristics), since these aspects have a remarkable influence on the perception process [8**?** , 9].

From an acoustician's point of view, many studies have focused on identifying the most relevant acoustic indicators to describe soundscape. L_{50} and L_{10}–L_{90} parameters, psychoacoustic indices, and other aspects have been analyzed. Combinations of these indicators and perception information have also been used to represent or evaluate soundscape (*e.g.*, matrix chart, L_{Aeq} with visual dimension, scope) [11]. Currently, there is no scientific consensus on a common method for evaluating soundscape using acoustic parameters even though the concept is already defined [4] and there is greater scientific accord from the perception approach.

On the other hand, the objective of the research includes engaging people in assessing environmental variables. Therefore, the public must participate in the soundscape evaluation process [12]. Traditionally, citizens have participated in the assessment of the acoustic environments through questionnaires or personal interviews and, in some cases, using binaural equipment combined with questionnaires to obtain a holistic approach [13]. In published studies, the information had to be post-processed for interpretation into useful information for decision-making purposes. As a result, citizens took part in such studies had no real-time feedback on the results of their evaluations.

Citizen observatories for empowering people in the assessment of soundscapes should accurately evaluate acoustic comfort and provide real-time feedback on the evaluation as measured by people [14]. Solutions that use TIC technologies should be considered. The ITC solutions for assessing soundscape must be portable, user friendly, capable of post-processing, sufficiently accurate in evaluation, and able to provide real-time results that can be understood by the public without technical backgrounds in acoustics.

The solution proposed by Tecnalia involves the use of a smartphone [15] (with an internal service that allows it to act as a sonometer), as well as an external microphone, since the internal one has certain restrictions for performing acoustic measurements. This solution includes a mobile application (hereafter referred to as app) running on the smartphone that guides the participant to make an "observation", by following an experimental protocol. The observation combines an evaluation of acoustic indicators and a perceptual analysis of the acoustic environment. Post-processing of data is carried out to provide the result of the evaluation in the app as soon as it has been completed, so the observers receive easily interpretable feedback on their evaluation. This post-process applies a combined indicator of acoustic comfort developed by Tecnalia: the ESEI (Environmental Sound Experience Indicator) index. This indicator is currently being evaluated and considers not only noise levels, but also the identification of noise events (based on a dynamic threshold principle), and the composition and perceived pleasantness of the sound sources in the area.

Considering this state-of-the-art approach, Tecnalia has designed a tool to assess acoustic comfort that is based on the measurement of $L_{Aeq,1sec}$ global levels in combination with L_{Amax} and L_{Amin} levels. $L_{Aeq,1sec}$ levels allow several acoustic indicators to be constructed [16]. Psychoacoustic index assessment is not integrated into the tool due to the limited calculation capabilities of the smartphone, since it must run several routines at the same time. Although it is known that psychoacoustic indexes are useful for describing soundscapes, certain decisions had to be made to simplify the solution and some published works highlight that those indicators are not as crucial [17].

Therefore, the solution proposed by Tecnalia measures sound levels, evaluates perception (using an embedded questionnaire that is filled in simultaneous with the measurement), and provides easily interpretable data by combining the results of the two approaches (objective and subjective measurements).

3 Methodology

To test whether the solution proposed by Tecnalia met the three requirements or challenges set out in the aim of this research, an iterative process of design, implementation, and demonstration was followed.

To begin with, a viable technical solution was designed. This solution allows citizens to collect objective data and input subjective data relating to their observation of urban places that they visit, and includes a protocol that defines how the participant must make the observation.

The technical and procedural operation of this solution was tested in a real field demonstration, as part of the CITI-SENSE project. CITI-SENSE facilitated this first phase of the research and, in turn, defined certain conditions that were considered in the context of the experiment.

3.1 Context of the research: the CITI-SENSE project and citizen observatories

The global intention of the CITI-SENSE EU project [2] is to develop "citizens' observatories" (CO) designed to empower citizens to contribute to and participate in environmental governance and enable them to support and influence community and societal priorities and associated decision making [18]. The CITI-SENSE project is based on three fundamental concepts: technological platforms for distributed monitoring, information and communication technologies (ICT), and societal involvement.

In the broadest sense, a CO for supporting community-based environmental governance may be defined as the citizens' own observation and understanding of environment-related problems and, particularly, their reporting and commenting on these issues. In this way, the CO is intended to promote the citizens' contributions as active participation in environmental governance [19, 20].

3.2 Empowerment initiative in public spaces

The research presented in this article is part of the work completed to implement one of the empowerment initiatives of the project. The specific objective of the project activity is to empower citizens in the design of public places from an environmental point of view, including comfort criteria. The final intention of the project in this field includes the following:

- Allow citizens to collect and share quantitative and qualitative information relating to the environment of existing public places, as well as their well-being in those places;
- Allow the city authorities to collect novel information about the ecosystem services provided in public places; and, in return,
- Support a dialogue between citizens and the authorities in order to adapt their planning process to improve or preserve the environmental conditions in public spaces.

The analysis carried out in the pilot case focuses on environmental comfort and includes acoustic comfort, thermal comfort, and the visual experience, by obtaining user observations that integrate physical parameters and perceptions [21]. Therefore, the data gathered goes beyond the assessment of soundscape, with sufficient information collected in the context.

Empowerment experiences should include decision-making participatory processes. Therefore, citizens must participate not only in the evaluation process [13], but also in the decision-making process related to the management of the situations assessed.

3.3 Methodological proposal for citizen empowerment in public spaces

Therefore, in the framework of the CITI-SENSE project and considering the current state-of-the-art, a first version of the solution was defined. This solution combines hardware and software tools that measure the objective and

2 CITI-SENSE is a FP VII EU co-funded project. CITI-SENSE started in October 2012 and lasts for a period of four years. The consortium is led by NILU (Norwegian Institute for Air Research) and comprises 27 partners from 11 European countries (Norway, Netherlands, Czech Republic, Spain, UK, Austria, Italy, Belgium, Serbia, Belgium, Slovenia) and 4 non-European partners. The consortium combines the expertise of research centers and companies that develop sensors and sensor devices.

subjective parameters of the environmental conditions in urban spaces and a protocol for using the tools in an appropriate way, considering the goals of the project.

The solution comprises

- a smartphone, that allows post-processing of acoustic signals,
- an external microphone for measuring noise levels,
- a smartphone app that allows citizens to provide evaluation in a user-friendly way and which provides data on their perception of the area,
- procedures for measuring acoustic and perception elements to evaluate acoustic comfort, based on the state-of-the-art regarding soundscape, and
- a protocol for making the observations that includes clear instructions for the participants.

The following sections present a description of the tool developed and the protocol used in the solution, followed by the process used for testing the solution in the demonstration exercise, including the selection of both participants and places for observation.

3.3.1A) Description of the solution: the tool

Responding to the above principle and requirements, the final ITC solution developed to empower citizens in the evaluation process is composed of the following elements:

- Element 1: The CITI-SENSE app: a mobile app is seen as the best way to facilitate citizens' observations of public spaces.
  This app controls the sensors used to evaluate the most important environmental parameters in terms of acoustic comfort (thermal comfort is also assessed by using external equipment connected via Bluetooth to the smartphone).
  The app measures global $L_{Aeq,1sec}$ levels, as several acoustic indicators can be constructed from those levels. As part of the measurement, the time history is registered and shown, as are the global $LA_{eq,T}$, LA_{max} and LA_{min} levels during the measurement period. The app detects noise events by using a dynamic threshold principle, and when an event is detected it asks the participant to provide evaluations accordingly (*e.g.*, pleasantness and type of noise source). Finally, it calculates the Environmental Sound Experience Indicator (ESEI) index developed by Tecnalia, which is being validated, taking into account the information provided on the questionnaire.

The questionnaire comprises two parts:

- General questions to be answered before any observations are made in the urban places proposed. Each participant responds to this section once, which includes the following items:
  - ◇ *Personal factors*: sociodemographic variables, residential factors, perception of self health and emotions, life style factors, and psychosocial factors. These variables allow the characteristics of the sample to be described when the measured data are analyzed.
  - ◇ *Assessment of four urban places and information on how participants use these spaces (previous experiences):* before making any observations in the urban places proposed, they are asked to report on how they habitually use the areas.
- Questions to be answered in situ (actual experiences) in each of the places and at the same time as the objective variables are measured. The questionnaire includes the following aspects:
  - ◇ *Global experience and perception of the place*: General perception of the place is measured by applying a semantic differential (SD) that contains items such as: pleasant, secure, well-maintenance, natural, tranquil and warm. SD is defined according to general criteria [22]. The participant is also asked what they like most and least about the place, allowing them to link to a photograph of these elements. Finally, there are questions about global acoustic and thermal comfort at the time of the observation, emotions, and perceived level of stress at the beginning and the end of the experience.
  - ◇ *Sound environment perception or soundscape*: Participants are asked about their perception and evaluation of environmental sounds and the global acoustical atmosphere, as well as their evaluation of the congruence of any sounds in the context of the urban place. The soundscape is evaluated us-

ing a SD (22) that contains items such as: pleasant, calm, relaxing, natural, vibrant, informative, and clear.

- Element 2: A smartphone (Nexus 5) provides the platform for this app. A smartphone was selected as it is currently the most common portable device available to citizens. Android is the most suitable platform in this study given its open platform characteristics and relatively low cost.
- Element 3: An external microphone with a wind screen: During some preliminary tests in environmental conditions, it was identified that the smartphone's built-in microphone is highly sensitive to wind, which affects any measurement made outdoors. Therefore, an external microphone with a standard protective windscreen was added to the measurement chain. This solution also provides greater accuracy for certain sound frequencies than the internal microphone. After analysis, and a search for a low-cost microphone, the Edutige EIM-003 was chosen as part of the acoustic sensor for its sensitivity.

The assessment of the whole measurement chain's performance is presented in the results section.

The architecture of the system that allows data collected in the observations to be uploaded to a server as part of the database with all the data gathered in the CITI-SENSE project is not described in this article [23].

3.3.1B) Description of the solution: observation protocol

The observation procedure used drastically influences the results obtained. So a protocol was established to define how participants should make their acoustic observations of the urban places. It details the tasks they must carry out during the observation. The timing of each task is estimated and the entire observation takes approximately 20 minutes, including an at least 15-minute noise level measurement.

Each person participating in the data collection received the following equipment:

A smartphone, with the app installed for use, with an external microphone placed at the top including a wind screen.

Figure 2 illustrates the protocol for making the acoustic observations. First, the participant was asked to spend five minutes observing the place to gain experiences of the space, as they are expected to make conscious observations and assessments.

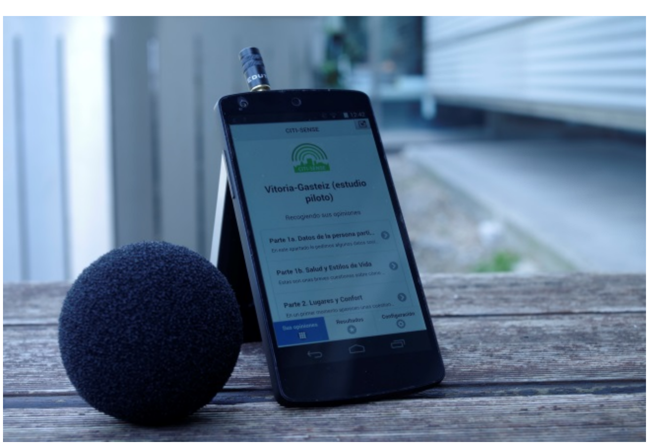

Figure 1: The CITI SENSE kit for the observations.

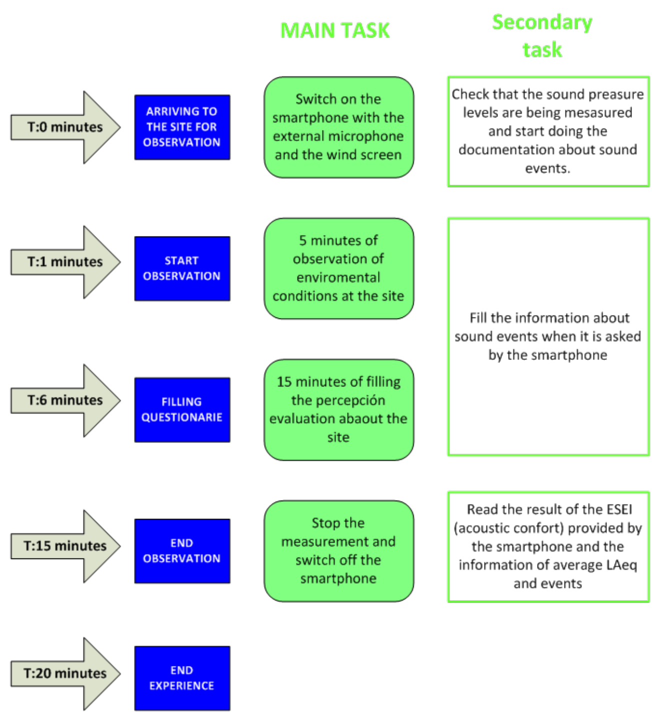

Figure 2: Protocol for making acoustic observations.

During the observation, the time-history of the $L_{Aeq,1sec}$ values of the ongoing measurement is shown on the smartphone screen. Sound events can appear at any moment during the observation on a pop-up message displayed on the screen each time a sound event is detected. When this occurs, the user is asked to identify their perception (*i.e.*, pleasant or unpleasant) and the type of sound source in the event.

Figure 3 shows the result provided by the app at the end of the observation.

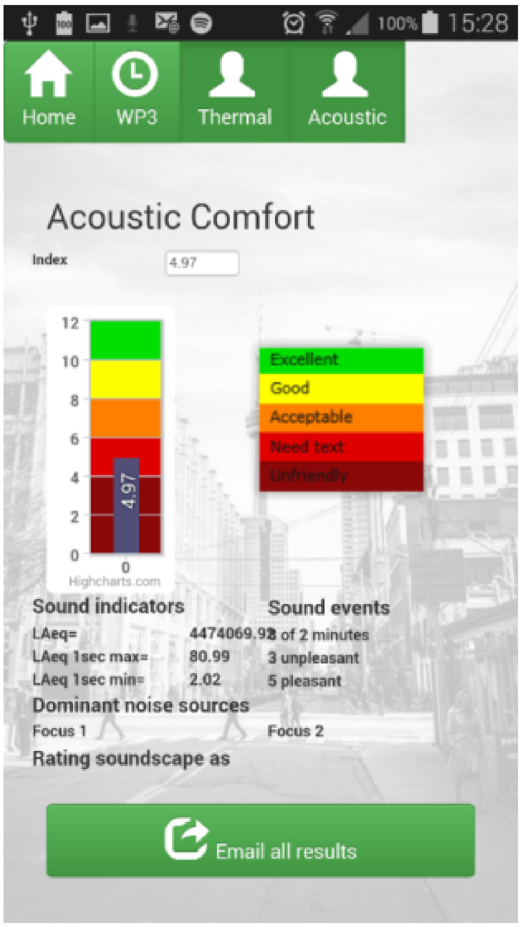

Figure 3: Acoustic app.

The assessment of acoustic comfort is presented in terms of ESEI indicator values. A scale is provided to gauge participants' understanding of the sound environment's comfort level that the value represents.

Other variables are also displayed, such as $LA_{eq,T}$, LA_{max} and LA_{min} global levels, number of noise events and perceptual rating by the participant, as well as the dominant sound sources identified.

To obtain this information the app combines the physical results measured by the sensors with the results of the participant's perception from the questionnaire.

Citizens who participate in the demonstrative exercise can access all the results once the observation is finished. All the results of the observations are uploaded and visualized on the web site of the public spaces empowerment initiative in the CITI-SENSE project: http://vitoria.citi-sense.eu/en-gb/citisense.aspx. On this webpage, citizens can see the results of their personal observations and compare them with the average values of all the observations.

3.3.2 Process of testing the solution

To test how the solution proposed responses to the requirements established in the objectives of this research, two types of activities are developed. On one hand, the technical performance of the entire acoustic measurement chain in terms of global noise levels (dBA) is tested in an anechoic chamber and compared to a reference Type 1 sonometer (Brüel & Kjaer 2238). The details of the testing and results,are presented below.

On the other hand, a demonstrative exercise is carried out in Vitoria-Gasteiz (Spain), consisting of inviting citizens to conduct observations on the quality of public spaces using the solution proposed for collecting environmental data and also recording their perceptions of the places. Analyzing the results of this experience, some conclusions can be drawn about the ability of the solution to engage people in the evaluation of acoustic parameters and simultaneously obtain objective and subjective on-site data.

Since the observational procedure is both crucial and complex, in order to assure that it is applied correctly during the demonstrative exercise, the participants are accompanied by experts as they made their observations.

This limitation means that the participants do not have full autonomy to go to any place at any time. They are asked to do at least one observation at two of the selected locations. For this reason, a schedule is proposed for organizing the demonstrative exercise. The process for recruiting participants and a description of the sample group are described below.

Data is collected from 53 people who made a total of 137 observations in the field, at four urban places in Vitoria-Gasteiz.

The recruitment process for the demonstrative exercise

In the CITI-SENSE project, one objective of the demonstration exercise is to assess the quality of the four urban areas in order to give feedback to participants. However, in this paper such analysis is not presented, since it is not directly linked to the aim of the research.

An initial recruitment objective is established regarding the number of participants, places and observation points. This objective involves engaging at least 50 partici-

Table 1: Characteristics of the sample group of participants in the demonstrative exercise in Vitoria-Gasteiz and in each place.

N of the sample	33	42	34	30	139		
	Armesto Square	Los Herran	Salinillas Park	Olarizu	% TOTAL	freq	Differences
Women	51.6%	52.4%	61.8%	50.0%	54.0%	74	ns
Living in Vitoria - Gasteiz	80.7%	92.9%	94.1%	100.0%	92.0%	126	*
University studies	45.2%	43.9%	50.0%	46.7%	46.3%	63	ns
Secondary studies	32.3%	46.3%	35.3%	40.0%	39.0%	53	ns
Employed	45.2%	36.6%	41.2%	40.0%	40.4%	55	ns
Unemployed	6.5%	14.6%	20.6%	26.7%	16.9%	23	ns

pants and obtaining 15 observations per point, where nine points were allocated at four observation locations, making a total of 15X9 = 135 observations. Each participant had to make an average of three observations in more than one place.

The participants are volunteers recruited from the general public in the city of Vitoria-Gasteiz, either through their participation in civic associations or direct contact. The criteria for selecting participants were fixed by the team of Iritziak Batuz[3]. The whole process is described in deliverable D3.3 of the CITI-SENSE project [24].

The selection of civic associations to be contacted used the following criteria:

1. Diversity of volunteers: Variability of demographic profiles is considered the most important criterion in terms of the results regarding perception and assessment of the attractiveness and user-friendliness of the solution.
2. Participants' interest in the aim of the study: Certain civic associations are pre-selected due to the scope of their social interests. Schools that teach subjects related to environmental issues in the city are also selected.
3. Geographic diversity: It is considered appropriate to use participants from different parts of the city in order to uncover potential differences in perception relating to the neighborhoods that they live in.

The local civic associations are invited to a specific workshop where the objectives of the exercise are explained and the solution (*i.e.*, tool and protocol) is presented. In this workshop, attendee expectations are noted relating to both the observations of urban places and the whole initiative. A total of 53 people are engaged.

As seen in Table 1, there are no relevant social or demographic differences between the people engaged in each of the places.

Most of the differences between the people making the observations in each place are considered non-significant. There is only a significant difference between places when considering residential area ($\chi^2 = 28.263$; df = 15; $P < 0.05$). This is considered a good sample for validating the solution to assess comfort levels in those places.

Before the launch of the demonstration exercise, participants engaged to make the observations attend a specific training workshop on how to use the CITI-SENSE kit that includes the tool and protocol for making observations.

Legal aspects referring to the protection of private data were addressed in the CITI-SENSE project and the participants signed two legal documents informing them of their rights and duties with regard to the data collected from them in the observations.

The observations of four places are made from 13 to 24 April, 2015 and a schedule is drawn up according to the participants' availability.

After the observations were made, the participants are invited to a feedback workshop so that they cansee the results achieved in terms of the evaluations collected at each observed urban place. In this workshop, an experimental empowerment exercise is conducted where they were asked to identify the most valuable elements of the places and provide suggestions on how the places could be improved. Attendees assess the global experiences and the solutions for evaluating environmental quality in urban places by means of a questionnaire.

3 Iritziak Batuz is Spanish consulting company on public participation, governance and social innovation, participating in the consortia of CITI-SENSE and in the development of the Empowerment Initiative at Vitoria-Gasteiz.

4 Results

The results of how the solution proposed responses to the requirements established in the objectives of this research are presented in the following paragraphs, including: 1) the technical credibility of the acoustic performance of the solution; 2) the ability of the solution to simultaneously collect objective and subjective data on site; and 3) the attractiveness of the solution for engaging people in acoustic parameter evaluation.

4.1 Technical credibility of the acoustic data

As previously mentioned, in this framework, it is necessary to offer user-friendly products for acoustic evaluation to facilitate use and improve citizen engagement. Another important criterion in the selection of the measurement system is to keep it as affordable and accessible as possible to promote usage by citizens. Nevertheless, data obtained must be sufficiently accurate and representative of the acoustic comfort in the evaluation area.

The accuracy of the noise level measurements made by the solution's acoustic measurement chain was analyzed and the results have already been published [25]. First, the effect of wind on the measurements was checked. The noise level of a continuous noise source was measured with the smartphone in the presence of wind (from 1.5–2 m/s up to 3–4 m/s), as well as with a Type 1 sonometer. The reference equipment includes a wind screen and the smartphone was tested both with and without. The results obtained were compared in order to observe the effect of the presence of wind on the values measured. Table 2 shows the biasing effect of wind on the measurements, even at low wind speeds. This demonstrates the need to add a wind screen. Finally, the efficacy of the screen in removing the effect of wind was also tested.

Table 2: Results of the quality of acoustic measurements in the presence of wind.

Wind (ranges)	Noise Level (A) Sonometer with wind screen	Difference in Noise Level Smartphone **without** wind screen – (A)	Difference in Noise Level Smartphone **with** wind screen – (A)
1.5–2 m/s	55 dBA	6.8 dB	−1.2 dB
2–2.5 m/s	55 dBA	14.2 dB	0.6 dB
2.5–3 m/s	56 dBA	17.9 dB	−0.5 dB
3–4 m/s	58 dBA	18.6 dB	−0.2 dB
4–5 m/s	60 dBA	21.3 dB	0.1 dB

The acoustic performance of the solution was tested. The measurement chain comprises the acoustic app service running on the smartphone, the EDUTIGE EIM-003 microphone and the Brüel & Kjaer wind screen WQ-1099. The testing was developed in a semi-anechoic chamber with a background level of 25 dBA. The acoustic source was omnidirectional (Brüel & Kjaer 4296). The parameter applied was $L_{Aeq,T}$. The testing was carried out by measuring broad noise (pink and white) at three noise levels of 55, 65, and 75 dBA. The noise levels measured using the measurement chain were compared to the levels measured simultaneously by a Type 1 sonometer as reference equipment (Brüel & Kjaer 2238). The system had a constant deviation from the reference equipment, so it was calibrated in global noise levels (dBA).

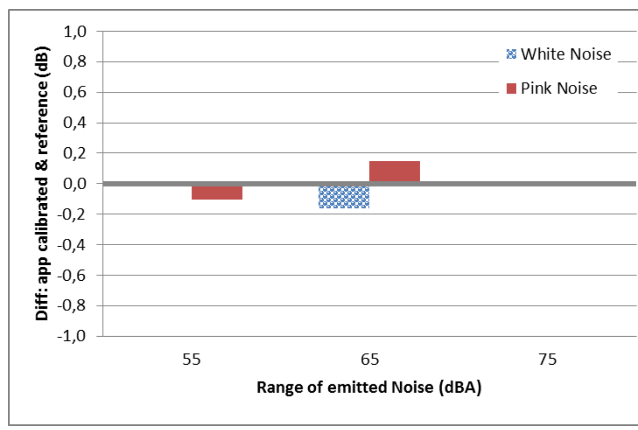

Figure 4: Difference: app calibrated and reference.

Figure 5 shows the accuracy of the system designed by Tecnalia, expressed in terms of deviation from the reference equipment.

To analyze the acoustic comfort of public places, the ESEI indicator developed by Tecnalia was used [26]. This indicator considers not only the traditional environmental acoustic indices (*e.g.*, LA_{eq}), but also the composition of the sonic environment and the way it is perceived by users of the area. These acoustic items are considered essential in the current state-of-the-art soundscape approaches. The ESEI is used to summarize information and provide citizens an intuitive overall view of the acoustic comfort by using a quality scale running from 0 to 12.

As mentioned above, Tecnalia is developing a validation process for this indicator, which is not within the scope of this research. Since soundscape is understood as part of a holistic environmental experience of being in an urban space, the validation needs data from real observations made by citizens, linked with other variables that describe the spaces assessed. The data collected in this demonstrative exercise and in earlier soundscape studies will be analyzed to test how the indicator reflects users' perception of acoustic environment.

4.2 Simultaneous objective and subjective data

One of the aims of the solution that being tested is the simultaneous collection of objective and subjective data on site.

The results of both subjective and objective observations were analyzed, in order to create a database of 137 observations including all data collected by each participant as a set of variables describing the participant's demographics, assessment of the place, and the environmental and acoustic conditions in that location.

Therefore, the database contains 137 observations with 170 variables for each observation mainly obtained from the questions to be answered in situ, as previously presented in this paper. Other variables are added to complete the data base:

1. 29 variables describe the psychosocial and health factors of the person, such as perceived health, sound and thermal sensitivity, emotions and perceived stress.
2. 41 variables describe the participant's previous experience of the place being observed, including frequency and time of use (day, week, season), and so on.
3. 30 variables reflect how the person perceived the conditions in the urban place at the moment of the observation, including:
   - A holistic perception of the place, expressed using a SD applying 11 bipolar adjectives.
   - How they consider their general comfort level with focus on three specific variables: acoustic comfort, thermal comfort, and comfort linked to the quality of the light.
   - Some specific variables to understand what type of activities they would carry out in the area in the present conditions, for instance if they would use the place for relaxing in.
4. 20 variables describing the soundscape, expressed using a SD applying 12 bipolar adjectives.
5. Six indices to identify the observation (*e.g.*, place, point, and nexus ID).
6. Six acoustic parameters measured by the equipment (LAeq,T, LAeqmax, LAeqmin, and number of events, assessed as positive or negative by the person).

In addition to this information, the time history of the $L_{Aeq,1sec}$ global noise levels is recorded in order to calculate other acoustic parameters.

Figures 6 to 10 show examples of the analysis of objective and subjective variables collected, regarding acoustic conditions and soundscape. In this case, the distribution of values collected for an urban area (Los Herran: bus station area) are presented: $L_{Aeq,T}$, and the number of positive and negative events. Also shown below are the results of the SD on soundscape and the identification of the dominant sound sources.

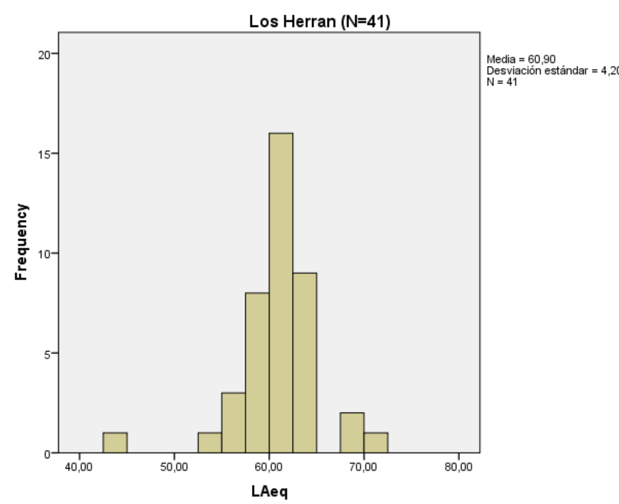

Figure 5: Noise levels measured in all the observation made in one place. A total of 41 observations were developed.

5 Engaging people

Finally, 53 people were engaged to make observations in the field at the four urban places selected and are considered as participants. They made a total of 153 observations and each participant evaluated at least two sites. During the observations, 52 photos were taken and 215 comments about their preferences (*i.e.*, 139 positive "most liked elements" and 76 negative "most disliked elements") were obtained as feedback of the involvement of participants with the initiative. Regarding the workshops of the project, 20

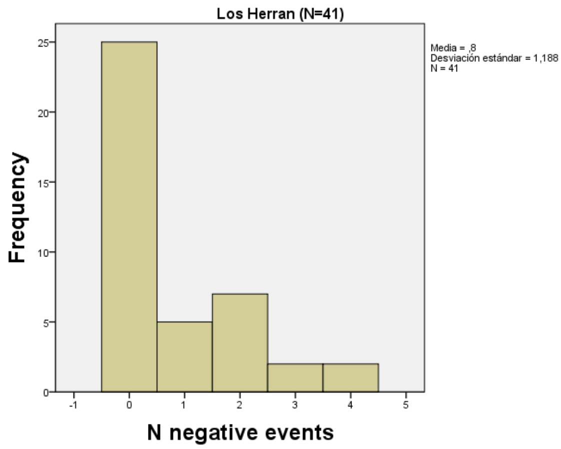

Figure 6: Number of noise events identified by the system during the observation at one place and evaluated as negative by participants. A total of 41 observations were developed.

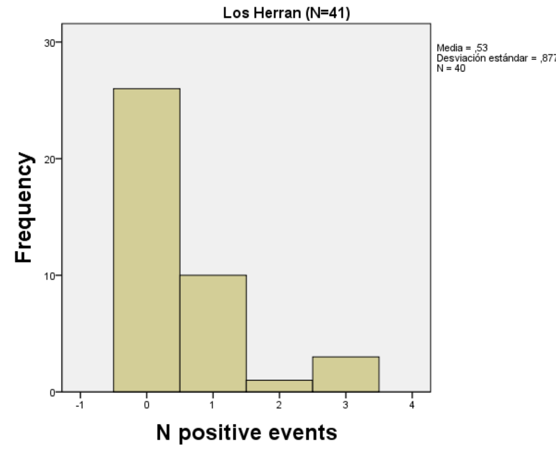

Figure 7: Number of noise events identified by the system during the observation at one place and evaluated as positive by participants. A total of 41 observations were developed.

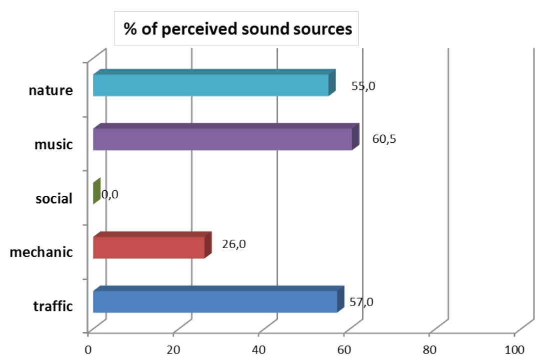

Figure 8: Type of noise sources annotated by participants as dominating during the observation at one location. % of times that the sound source is detected in the different observations in the evaluation point. A total of 41 observations were developed.

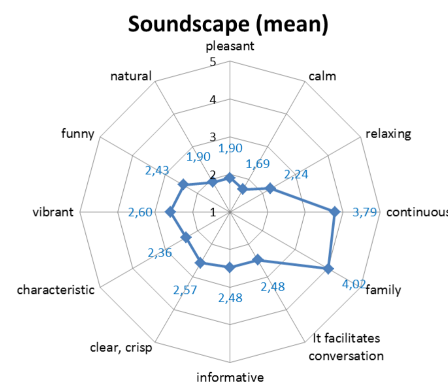

Figure 9: Mean result of the description of soundscape during the observation assessed by participants at one location (being 5 totally agree and 1 totally disagree). A total of 41 observations were developed.

participants attended the initial one, where they received information on the project and the specific tasks they were asked to carry out and 24 participants attended the final workshop.

In the initial workshop the participants were questioned regarding their expectations of the observations of urban places and the initiative as a whole. Twenty-six feedback questionnaires were collected, since some additional answers were sent by mail. With regard to expectations about the usefulness of the observation results, the most repeated aspects included the possibility of using the project and its results to educate and raise awareness of these issues, and the need to improve comfort in public spaces with up to nine mentions out of twenty-six.

On the other hand, some aspects of the project were mentioned as potentially critical: Doubts about the need to obtain data to improve the comfort of urban areas, and an emphasis on the difficulties of generalizing the use of these devices, since they are not available to a significant number of people.

In the final workshop after observations, participants evaluated both their overall experience and the solution for assessing environmental quality in urban places. The results of the questionnaire filled in by the participants are shown in Figure 10.

The technical solution was also evaluated, in which opinions depended strongly on the age of participants. While older participants thought that the solution was complex and not very intuitive, younger people considered it practical, user-friendly, manageable and intuitive.

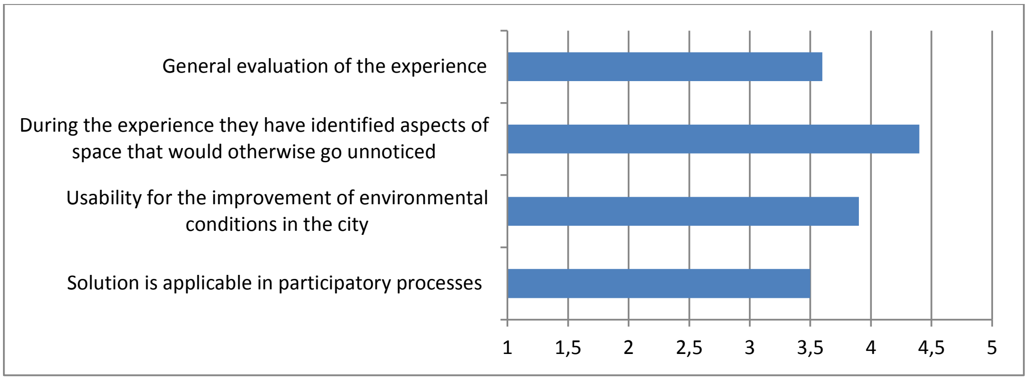

Figure 10: Participants' evaluation of the experience and solution scored from 0 to 5. Mean of the evaluations (being 5 fully agree and 1 totally disagree).

6 Discussion

The described solution can be applied for engaging citizens in the evaluation of the acoustic environment and acoustic comfort in urban places, integrating perception data with acoustic measurements that are made simultaneously.

The presented solution includes 1) a set of devices and software that allow the accurate evaluations to be considered in the decision-making process and 2) a protocol for carrying out the observation. A training process is required to assure that the observations are developed in an appropriate way.

Currently, this solution is limited to be compatible with the specific smartphone model discussed in this paper. To assure the technical quality and robustness of the measured acoustic data, it was decided to calibrate the acoustic app to a specific smartphone model, meaning its use cannot be generalized, but it must be used as part of a process that includes providing the kit to participants.

Other solutions of acoustic apps exist that are more universal but with poorer technical quality, some of which offer users the option to calibrate the app. This latter option could increase the complexity of the solution and, as a consequence, reduce the possibility of it being used in a more general way and engaging people. Besides these issues, the need to protect the microphone to avoid the effect of wind outdoors has not been addressed in any of these solutions.

Although future work may improve the solution presented in this article, it can already be applied to develop different empowerment initiatives in noise and quietness management, including 1)Evaluating quiet areas and collecting ideas for their improvement, 2)Identifying priorities for Noise Action Plans including citizen perception, 3)Participatory co-design of action within the Noise Action Plan framework.

More in-depth research will now be carried out on the database created in the demonstration exercise. To do this, Tecnalia will work on validating the ESEI by analyzing this new database as well as data from previous soundscape studies. The general principle of the indicator, combining objective and subjective data, in accordance with the current state-of-the-art in the field of soundscape is confirmed in this research and provides evidence that this can be implemented using a smartphone mobile app to measure the acoustics and provide rapid feedback to citizens assessing the soundscape.

7 Conclusions

The results presented in this paper constitute a relevant step forward in the iterative cycle of research and design for developing tools to apply the concept of citizen observatories and to empower citizens in the assessment of acoustic comfort in public places.

The initial objectives of the research have mostly been met, although a more in-depth analysis of the collected data is needed for complementary purposes. Limitations of the proposed solutions have been found, as have suggestions for its improvement. Therefore, the direction of future research in this area has already been established.

The solution presented here contributes to improving citizen participation in the urban design of their cities, providing collaborative frameworks for specific decisions to improve, preserve or create urban places.

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