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Research Article

The SENSEable Pisa Project: Citizen-Participation in Monitoring Acoustic Climate of Mediterranean City Centers

The concept of urban sustainability and liveability closely depends on multi-level approaches to environmental issues. The ultimate goal in the field of noise management is to involve citizens and facilitate their participation in urban environmental decisions. The SENSEable Pisa project, based on the concept of Real-Time City and Smart City, presents an acoustic urban monitoring system based on a low-cost data acquisition method for a pervasive outdoor noise measurement. The system is based on the use of noise sensors located on private houses in the center of Pisa, which provide a good model for the current acoustic climate of Mediterranean city centers. In this study, SENSEable acquisitions show a strong anthropogenic component not revealed by public strategic maps. The anthropogenic component, commonly known as *movida*, becomes increasingly critical in Mediterranean cities, therefore, it is necessary to explore methods highlighting this new source and to adopt strategies for the creation of reliable noise pollution maps.

Keywords: Acoustic pollution; Anthropogenic noise; Citizen participation; Smart City; Urban monitoring

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1 Introduction

Considerable progress has been made in Europe in noise emission regulation and reduction. The 2002/49/EC (END) Directive (http://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX:32002L0049) of the European Parliament and of the Council of June 25, 2002 relating to the assessment and management of environmental noise, provides active public involvement, offering citizens the opportunity to participate in drawing up plans of action. The importance of involving citizens in environmental policies is stated by the Århus convention (30/10/2001) (www.unece.org/fileadmin/DAM/env/pp/documents/cep43e.pdf), signed by the United Nations Economic Commission for Europe in 1998 and finally included in the EU legislation with the European Decision 2005/370/EC (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2005:124:0001:0003:EN:PDF). In 2009, the US Government, through the "Open Government Directive (OGD)," stated that "Government should be transparent, participatory and collaborative, using technology to share and cooperate with other agencies, businesses, and non-profits, and the public at large," available from: www.whitehouse.gov/open/documents/open-government-directive.
The Italian Constitution 5th Title reform establishes, within Article nr.118: "The State, regions, metropolitan cities, provinces, and municipalities shall promote the autonomous initiatives of citizens, both as individuals and as members of associations, relating to activities of general interest, on the basis of the principle of subsidiarity."

Innovative technologies, nowadays increasingly employed by public administrations, offer new possibilities in creating means for citizen-participation [1]: development of e-democracy [2], ICT technologies, e-government, and e-participation. Such innovations facilitate the relationship between citizens and administrations/institutions, aiming to increase the inclusion of citizens within political and local governance. A wide range of mobile and social networking with Web 2.0 technologies and methods [3] including Skype, YouTube, blogs, and social networks such as Facebook and Twitter, can promote effective e-participation in healthy city studies (e-participation "is the sum of both the government programs to encourage participation from the citizen and the willingness of the citizen to actively take part in social life," UN Public Administration Country Studies, available from: http://groups.itu.int/LinkClick.aspx?fileticket=8WX-1d29UnY%3D&tabid=1862).

However, citizens are currently far from any real participation in decisions on the management of the city they live in.

The SENSEable Pisa Project is based on the concept of Real-Time City [4] and Smart City [5], aiming at developing a smart and low-cost system for the acquisition of noise data, as well as at collecting and analyzing large amounts of data related to the urban landscape for further use in urban planning and optimization. A pervasive outdoor noise measurement infrastructure has been developed, using low-cost sound sensors, placed on

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Abbreviations: L_{day}, day equivalent level; L_{den}, day-evening-night equivalent level; $L_{evening}$, evening equivalent level; L_{night}, night equivalent level.

facades of citizen's houses, and connected to their own Wi-Fi access points.

According to a study on the quality of life in 2013, Pisa (Italy) was classified in the 30th position among Italian administrative centers, while the Urban Ecosystem Report 2012 (Il Sole 24 Ore – Life Quality in Italian Cities, available from: www.ilsole24ore.com/speciali/qvita_2013/home.html) placed it at the 13th position. Pisa has recently worked hard to improve the quality of life and the liveability in the city. Despite the efforts to improve its performance as an "intelligent city," Pisa fell from the 10th to the 20th position in the dedicated Italian ranking (Italian intelligent cities classification – Italy [October 16, 2013], available from: www.icitylab.it/icity-rate-2013-la-nuova-classifica-italiana-delle-citta-intelligenti). In this context, we believe it is necessary to provide tools for a more precise noise levels monitoring and simultaneously involve citizens in the process of spreading awareness of the problem.

2 Materials and methods

2.1 Mediterranean city center acoustic climate: Pisa as a case study

Pisa is an Italian town of about 85 000 inhabitants, the sixth most populated municipality in the Region of Tuscany. Ancient walls surround the historic center of Pisa and the access of vehicles is controlled by a Telepass system (called ZTL, limited traffic zone). The historical area of the Lungarni (the two parallel roads following the banks of the Arno River) and the areas nearby represent the real city center, a meeting place for residents, students, and tourists. Every night this area comes to life thanks to cafes, restaurants, pubs, and clubs. During the day, the Lungarni are open to vehicular traffic and represent the main transit point for both pedestrians and vehicles. More or less a hundred pubs and restaurants, open during the evening and through part of the night, are located in the city center. It is possible to identify an ideal quadrilateral area, with high commercial density, defined as active due to its number of shops, shoppers, tourists and social exchanges (Fig. 1).

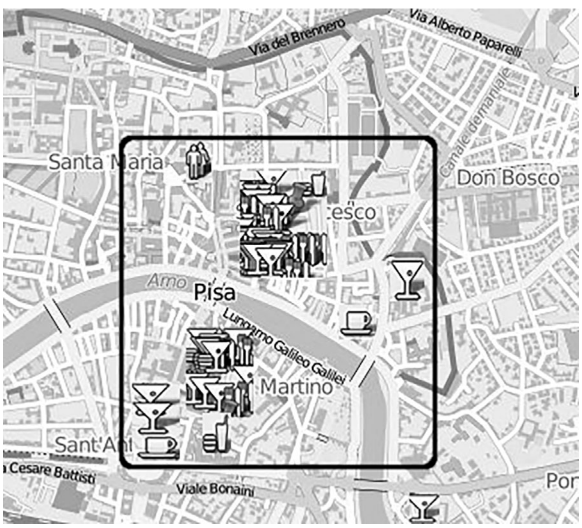

Figure 1. Main entertainment locations in Pisa center (this figure was created using a cartographic map of OpenStreetMap®, www.openstreetmap.org).

The center of Pisa has the typical architectural shape of Mediterranean towns, with many claustrophobic winding lanes [6, 7], narrow alleys lined with tall buildings on both sides, sometimes intercepting other streets, allowing some openings in the walls of the canyon. Frequently small squares (about 200–400 m^2) join canyon streets. The favorable climatic conditions allow the phenomenon of collective enjoyment of public places in the evening and night hours. In Pisa, as in many other Mediterranean cities, noise pollution is increasingly becoming a critical issue for citizens, in particular during the night hours. The 2002/49/CE EU directive (http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32002L0049) imposes to big agglomerations to provide strategic noise maps, to be updated every 5 years, in order to have an indicator of people exposure to transportation infrastructure noise. The Pisa urban administration adopted an Urban Traffic Plan, a Structure Plan, a Municipal Noise Classification Plan, and noise mapping. Nowadays, noise maps of Pisa are available on the SIRA database (Sistema Informativo Regionale dell'Ambiente, http://sira.arpat.toscana.it/sira).

2.2 Citizens participation

The dissemination of the project was realized by implementing several steps. First, an engaging website (www.senseable-pisa.it/it, no more active) has been created, able to raise the curiosity of citizens by employing e-marketing, community management criteria, digital marketing strategies, social media, and online strategies [8]. The site provided information about the project, the impact of noise on human health and clues on the future graphic method of noise data representation on a city-map. The website was indexed in the main search engines linked to popular keywords such as "noise" or "health." Besides, a lot of information was spread by classical methods as local newspapers, local radios, social, and scientific meetings and events (*e.g.* Pisa Internet Festival, www.internetfestival.it) and words of mouth. A cultural Association was also created to manage crowd-founding and public relations with citizens interested in SENSEable Pisa project and results (Cultural association DUSTLab – Italy (updated 2014), available from: www.dustlab.org).

The SENSEable Pisa web site was connected to the main social networks (Facebook, Twitter) to allow dissemination, collaboration, and to inform participants and followers about the progress of the project. On the web site, on the menu item "Map," a city map was provided (SENSEable Pisa – Italy, updated 2014 October, available from: www.senseable-pisa.it/it), similarly to what happens in the EU-LIFE HARMONICA Project (www.harmonica-project.eu). Interacting with the map, it was possible to get information about the sound level values through flags varying their color according to the different value ranges (Fig. 2a). By simply clicking on flags, it was possible to follow the time graph of the noise, checking the daily, weekly, and monthly time history, continuously updated (Fig. 2b). The platform, linked to social networks such as Facebook and Twitter, allowed citizens to be informed about noise levels in real time and eventually to express their opinions.

2.3 Data acquisition with a low-cost platform

SENSEable Pisa Project adopts a specific methodological approach intended to achieve high levels of citizen involvement. Low-cost noise sensors have been placed directly on the terraces and

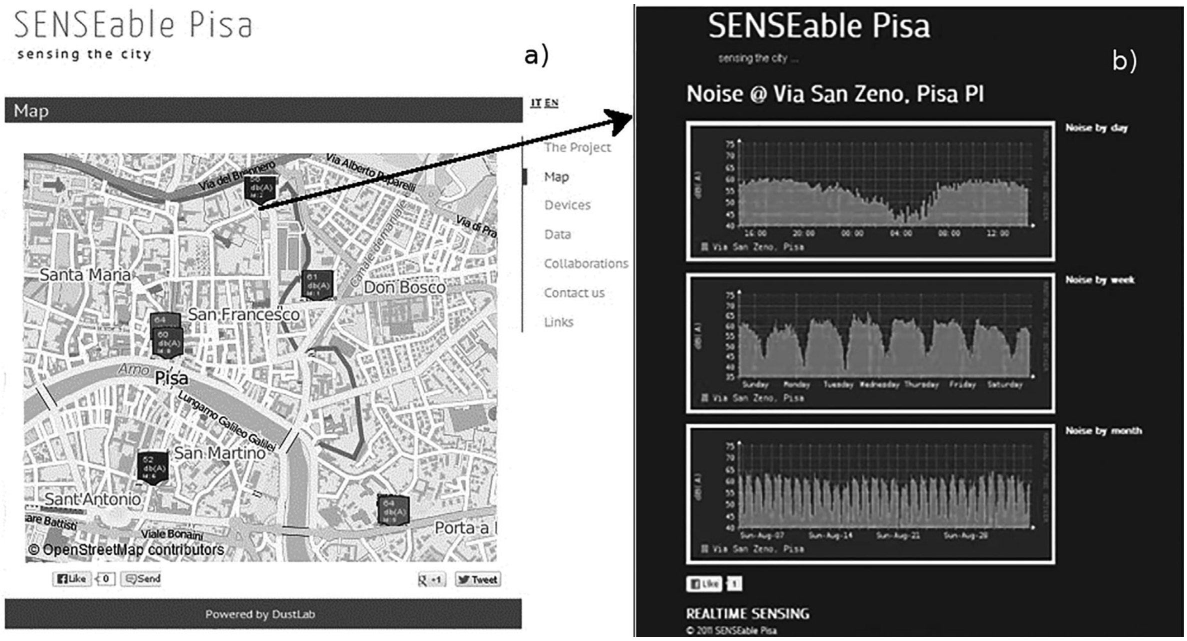

Figure 2. (a) Graphical representation of the website homepage showing the flags as noise value ranges indicators (this figure was created using a cartographic map of OpenStreetMap®, www.openstreetmap.org) and (b) Time history of noise levels for via San Zeno, Pisa.

windowsills of citizens to monitor noise in different areas of the city center. According to privacy policy, "Every citizen, owner of the sensor outside location, gave written permission to conduct the outdoor noise monitoring study from that site."

The microphones have been placed adjacent to the facade, about 50 cm below of the windows (as shown in Fig. 3b). In this configuration, the noise component coming from inside the apartment is lower than the external component of about 10–20 dB (A) and then negligible.

The sensors are based on a micro-controller technology or embedded PC. The data gathered by the monitoring devices were sent to a remote server and collected in a time series database, TSDB. The microcontroller elements are usually supplied with a wireless data transmission system, with the possibility to be powered also by solar panels (Fig. 3a), while the embedded PC is powered by AC connection.

These sensors used the wireless connection of the houses they are located in, and continuously acquired data in real-time, day, and night. Such sensors have been tested in the laboratory by a qualified acoustic engineer. The sound level meter connected to the transmitting stations uses low-cost microphones composed by a ¼-inch condenser, protected by a waterproof cover (Fig. 3c and d) and connected to a circuit for pre-amplification with analogic filter bank. This is a very low-cost solution, able to detect sound pressure levels in a range 35–110 dB (A).

In order to test the system's reliability, several tests were carried out to verify microphone directionality, long-time system accuracy, and comparison with class I measurement instruments. In Fig 4b and c, the frequency response compared to that of a class I instrument is shown, along with a directivity plot of a microphone for octave bands.

Figure 4a shows the error distribution between a SENSEable system sensor and a class I sound sensor. The sensors, in the frequency and amplitude range of interest for this application, between 16 and 20 kHz and between 35 and 95 dB (A), show a maximum gap of 0.3 dB (A).

The system acquires noise levels in dB (A) every second. A qualified acoustic engineer obtained useful data manually removing spurious

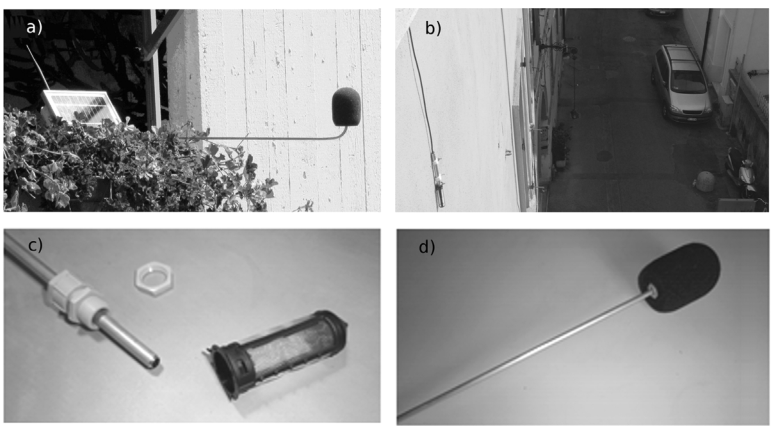

Figure 3. (a) Microphone powered by solar panel, (b) the microphone placed adjacent to the facade, about 50 cm below of the windows, (c) and (d) microphone and waterproof covering.

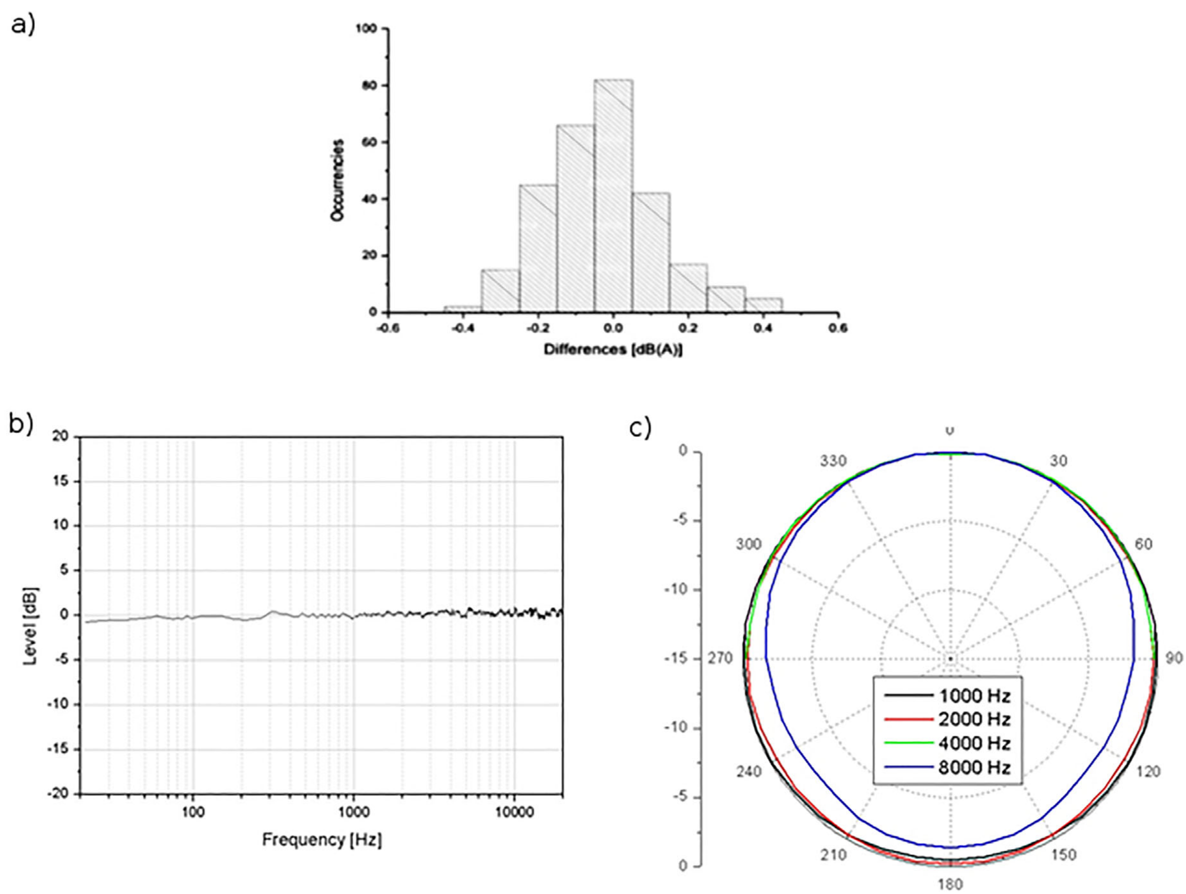

Figure 4. (a) Distribution of differences between the sensors employed within SENSEable project and gold standard class I sensors, in the frequency range 16–20 kHz, between 35 and 95 dB (A), (b) frequency response in diffuse field, and (c) frequency response in polar plot.

events. Meteorological events such as rain and wind were instead automatically deleted through information achieved from a weather station with measurements every 5 min (Meteo Pisa – Pisa, Italy, available from: www.meteopisa.it).

3 Results and discussion

3.1 Citizens involvement

Thanks to the use of smart technologies and citizen participation means, already demonstrated to be well accepted in this particular kind of environmental monitoring [1, 9, 10], the population of Pisa expressed great interest and actively participated at various levels in the implementation of the project. Specifically, people participated to the project by funding it financially through donations, enabling wide-range timely acquisition, providing wireless networks and the location for sensor equipment, and spreading content.

In less than a month, the interest of many citizens has been obtained: They have followed assiduously monitoring on social networks and participated to Dustlab information meetings (see Tab. 1). Among citizens who have expressed interest in the project, ten of them, residing in the central area of Pisa, offered to place low cost sensors on their own facades, providing the connection to the sensor network. Sensors have been placed out of their windows, or balconies; their collaboration has been essential for the project implementation.

3.2 Noise data results

In this study, two types of noise levels were analyzed: Levels measured by SENSEable sensors in specific locations of the center of Pisa, and levels estimated by the public strategic map provided by SIRA. Acoustic maps shown in SIRA use a time-limited sampling method, usually restricted to a week for road noise mapping. These levels are then used to calibrate a physical model of sound propagation based on the geometry of the buildings, on their shape and on the sound absorption coefficients of urban surfaces (streets, facades, etc.) [11]. Thanks to the physical model, it is possible to obtain the sound levels in wider areas, in order to create noise maps. The biggest limitation of such planning tools is their static nature: Updates are made every 5 years, likely giving obsolete representations of situations that are not ongoing [12]. Moreover, these maps do not take into account the possible temporary alterations of urban acoustic environments, such as the modification of the urban road network, the presence of a construction site, and recreational and social activities. Currently, public data about the acoustic environment are generally difficult to obtain and interpret without the assistance of expert personnel.

On the other hand, SENSEable adopted a sampling method given by a continuous acquisition focused on some strategic sites, found to be effective according to literature [13]. Therefore, data provided by SENSEable are continuous and displayable in real-time online maps (Fig. 5).

Table 1. Level of citizen engagement in SENSEable Pisa project

Level of citizen's engagement	Number of citizens engaged
Total amount of social and non-social feedbacks	1121 (100%)
Non-social feedbacks: Letters, email, and interventions at Dustlab meetings	14%
Feedbacks on social networks (Twitter, Facebook, and Google API)	86%
Comments and contents sharing on social networks	10%
Active participation: Citizens who have financially supported or have offered to place low cost sensors on their own facades	1%

During this case study, ten sites in the center of Pisa have been chosen. Data were acquired for more than 2 years starting with the first acquisition in June 2012 (1-s sampling). After the data acquisition and analysis, five sensors have been chosen, those with more complete and representative dataset (Fig. 6a): sensors with too many missing data have been excluded as well as sensors providing redundant information. The five chosen sensor locations can be divided into two main groups, according to their levels of anthropogenic noise: The first one (sensors no. 1, 2, and 3) with low levels of anthropogenic noise and high levels of vehicular noise and the second one (sensors no. 4 and 5) with high levels of anthropic noise and low levels of vehicular noise.

Noise indicators used in this study are day equivalent level (L_{day}), evening equivalent level ($L_{evening}$), night equivalent level (L_{night}), day-evening-night equivalent level (L_{den}).

The Italian Law no.194 (August 19, 2005, www.acustica.it/docpdf/dlgs194_190805.pdf) provides the following definition:

$$L_{den} = 10\log\left[\frac{14\times 10^{\frac{L_{day}}{10}} + 2\times 10^{\frac{L_{evening}+5}{10}} + 8\times 10^{\frac{L_{night}+10}{10}}}{24}\right] \qquad (1)$$

where L_{day}, $L_{evening}$, L_{night} are determined by continuous long-term measurements of equivalent weighted (A) levels, averaged on a day, evening, and night period basis. ISO 1996-2: 1987 (www.iso.org/iso/home/store/catalogue_ics/catalogue_detail_ics.htm?csnumbee=41860) defines:

(1) The overall d–e–n (day–evening–night) is the period starting at 6 am until 6 am of the following day.
(2) The day period is the period starting at 6 am until 8 pm.
(3) The evening period is the period starting at 8 pm until 10 pm.
(4) The night period is the period starting at 10 pm until 6 am of the following day.

For strategic noise maps L_{day}, $L_{evening}$, L_{night} are evaluated over a period basis of at least 1 year.

3.3 Short-term acquisitions during Giugno Pisano

The first experiment focused on data acquired in June 2013, being June in Pisa the month of the movida (Giugno Pisano), with very high levels of night activity.

Figure 6b shows an interesting overview of average hour-by-hour noise levels acquired by SENSEable sensors during June 2013. In locations no. 1, 2, and 3 (Via Matteucci, Via De Amicis, Via San Zeno) vehicular traffic represents the main noise source, with lower levels at around 4 am and higher levels between 6 am and 7 pm, due to intervals of greater or lesser use of vehicles. This result agrees with some literature dealing with other Mediterranean cities [14]. Instead, locations no. 4 and 5 (Piazza delle Vettovaglie, Piazza Garibaldi), are characterized by loud anthropic noise, as happens in other Italian city centers [15]. In addition, in June people tend to spend more free time outdoors, due to the pleasant climate, meeting in central streets and squares banned to vehicular traffic. Thus, in location no. 4, inserted into a pedestrian area, the highest sound levels appear between 7 pm and 2 am, while in location no. 5, where vehicular traffic is suspended during the night, the highest noise

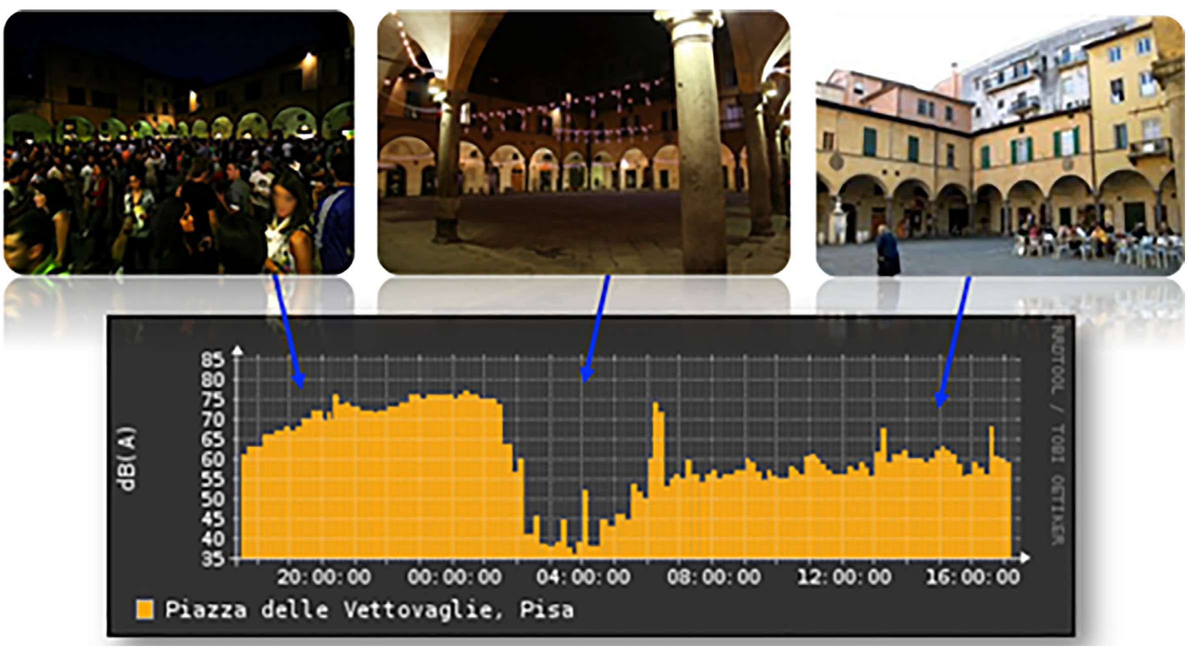

Figure 5. Noise profile and daily activities in Piazza delle Vettovaglie, Pisa.

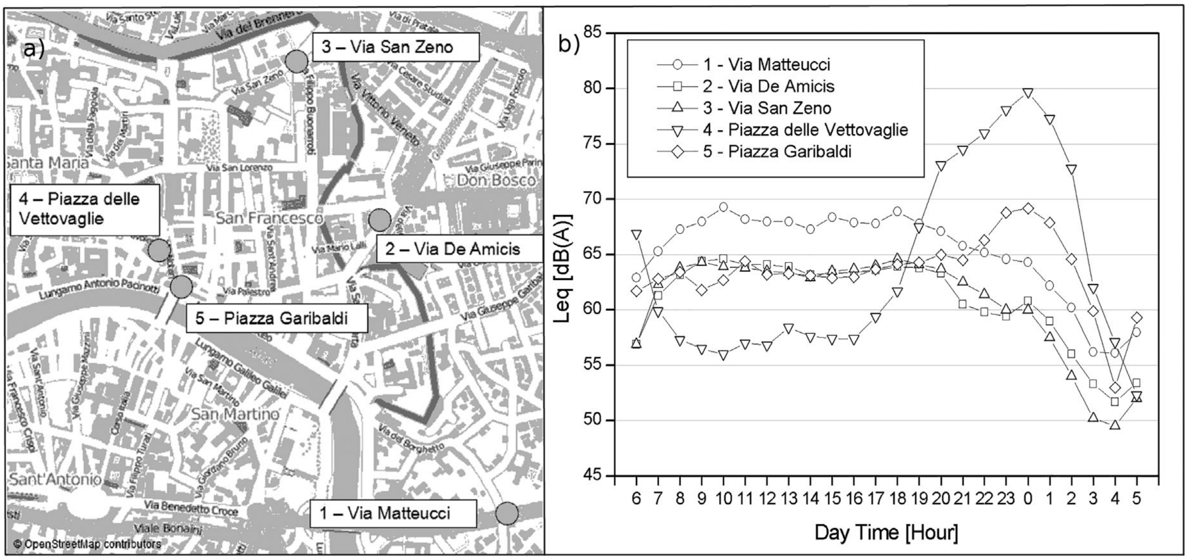

Figure 6. (a) Map of sensor locations (this figure was created using a cartographic map of OpenStreetMap®, www.openstreetmap.org) and (b) average hourly sound levels calculated by the SENSEable sensors in June 2013.

level is reached between 10 pm and 2 am. Moreover, location no. 4 reaches higher noise values than 5, because of the different architecture of the square and the presence of a larger number of pubs and bars.

In this experiment L_{day}, $L_{evening}$, L_{night} have been calculated over a period of 1 month (June 2013), and then compared with SIRA's L_{day}, $L_{evening}$, L_{night} estimated over a period 1 year (2013).

Table 2 shows that in locations no. 1, 2, and 3 (Via Matteucci, Via De Amicis, Via San Zeno) L_{night} and L_{den} values estimated by SIRA and SENSEable are very similar, while in locations no. 4 and 5 (Piazza delle Vettovaglie, Piazza Garibaldi), the discrepancy is greater.

This kind of comparison is only useful to point out that in places with low anthropic noise levels, the indicators of static strategic maps agree with indicators of SENSEable dynamic maps, while in places with high anthropic noise levels, strategic maps fail to detect such component [12, 13].

3.4 Long-term acquisitions from January 1, 2013 to December 31, 2013

Figure 7 shows noise levels for SENSEable and SIRA at two different sites of Pisa center, during 2013. As we can see in the figure, the two systems detect different types of noise pollution, which could be interesting to represent together, as they provide different information.

The sites taken into account are Via San Zeno (sensor no. 3, low levels of anthropic noise), and Piazza Garibaldi (sensor no. 5, high levels of anthropic noise).

For SIRA, L_{night} levels were estimated over the year 2013.

For SENSEable, L_{night} levels were weekly mediated over continuously acquired 42-wk monitoring starting January 1, 2013. In both locations, we notice a decrease of 5 dB (A) in summer, due to vacations from work and a consequent reduction in vehicular traffic. Otherwise, while the values obtained by sensor no. 3 are nearly constant during the year and very similar to SIRA L_{night} levels, the sensor no. 5 has a less predictable trend, strongly characterized by anthropic noise. Omitting the 4 wk of August, the average value over the whole SENSEable acquisition period for sensor no. 3 is 55.6 dB (A), with a variation from SIRA L_{night} of 0.7 dB (A), while for sensor no. 5 is 71.6 dB (A), with a variation from SIRA L_{night} of 15.3 dB (A).

4 Discussion

These results show the influence of anthropogenic activity on acoustic pollution and highlight the great underestimation of anthropic noise impact on acoustic climate, not easily predictable and not considered in strategic maps based on physical models (such as SIRA). In this regard, SENSEable method can be seen as a complement and an integration of strategic maps, in order to give a more comprehensive picture of the acoustic climate of the city, also taking into account the anthropic noise, and completing the overview of infrastructural noise

Table 2. Day–evening–night equivalent level (L_{den}) in dB (A) and night equivalent level (L_{night}) in dB (A) calculated by SENSEable system over a period basis of 1 month (June 2013) and by SIRA system over a period basis of one year (2013), for five different sensor locations

Sensor location	L_{den} SENSE	L_{den} SIRA	ΔL_{den}	L_{night} SENSE	L_{night} SIRA	ΔL_{night}
1 Via Matteucci	70.2	70.1	0.1	62.2	61.3	0.9
2 Via De Amicis	64.8	66.1	1.3	56.6	56.1	0.5
3 Via San Zeno	65.6	65.9	0.3	57.7	56.1	1.6
4 Piazza delle Vettovaglie	79.7	60.5	19.2	74.1	51.0	23.1
5 Piazza Garibaldi	71.8	65.0	6.8	65.9	56.2	9.7

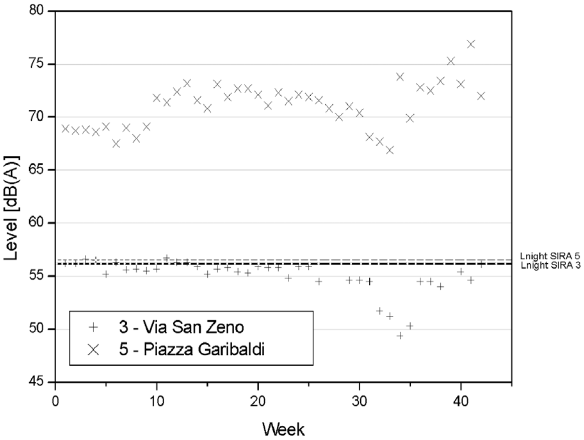

Figure 7. Mean-weekly noise levels calculated by SENSEable sensors with 42-wk continuous measurements from January 1, 2013 to December 31, 2013 for Piazza Garibaldi (anthropic and traffic noise) and Via San Zeno SENSEable sensor (only traffic noise). In the graphic are also represented SIRA levels of L_{night} (2013) for the same sensor locations.

captured by classical acquisition techniques. SeNSEable method does not use high-cost sensors, as many noise monitoring methods do [1, 16], but reaches an excellent value for money. The aim of our project is to improve the data reliability thanks to the sampling size, through a high user involvement, such as, for example, NoiseTube (www.noisetube.net), which provides users with a low-cost noise exposure dosimeter integrated in the smartphone. The dosimeter informs users of their daily amount of noise pollution. In addition, NoiseTube can record and collect both perceptive and acoustic data since the volunteer can also respond to a perceptive questionnaire [17].

Simultaneously, the Project sought to involve citizens in the process of monitoring, control, data dissemination, and awareness-raising. For this purpose, acoustic data have been presented in a simplified form, suitable to be shared on social networks, as in the WideNoiseProject (www.widetag.com/widenoise) [18].

5 Concluding remarks

SENSEable project shows an important influence of anthropic noise in a Mediterranean city center. Anthropic noise levels recorded by sensors highlight critical features of daily sound emission, as also demonstrated elsewhere [14, 19–21]. These are potentially dangerous for citizens' health, in the long run, being sometimes beyond the limits allowed by the current law. We believe that traditional platforms of noise data acquisition (like SIRA) provide a global overview of the acoustic climate of a city, however, owning a static nature and using interpolation techniques, thus, not being able to provide a punctual description of noise pollution. Moreover, traditional approaches, based on top–down strategies, involve an excessively long period between data acquisition and action planning. The process of public information and dissemination often takes a long time, while citizens could benefit from a more pervasive and tangible source of information. A significant example of e-participation and crowdsourcing related to noise problems is the Sound Around You project (www.soundaroundyou.com). Other projects take into account environmental sensing using smartphones and sharing results via an app that uses the devices' microphones such as NoiseTube (www.noisetube.net), WideNoise (www.widetag.com/widenoise), and Da-Sense (www.da-sense.de). Basing on these examples and on the concepts of Real-Time City [4] and Smart City [5], the SENSEable Pisa Project implemented a real-time acquisition and information sharing method, with a bottom–up involvement policy, based on active citizen participation [1, 9, 10], with a low-cost acquisition system. The case study of Pisa achieved high involvement and awareness of the citizens, as expected, thanks to the existing literature on the argument [9, 10], and good performance and reliability in acquisitions, with respect to gold standard measurements, as demonstrated above. This outcome could open several opportunities in the near future, among which the possibility to compare the data achieved with the SENSEable Pisa Project platform with the real-time results from a dynamic map that considers only the transport infrastructure [22, 23].

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