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Interactive Soundscapes: 360°-Video Based Immersive Virtual Reality in a Tool for the Participatory Acoustic Environment Evaluation of Urban Areas, Virginia Puyana-Romero, Lilian Solange Lopez-Segura, Luigi Maffei, Ricardo Hernández-Molina and Massimiliano Masullo, Acta Acustica **vol. 103** (Number 4), 2017, pp. 574-588

DOI
https://doi.org/10.3813/AAA.919086

Acta Acustica united with Acustica
Vol. 103 (2017) 574 – 588

DOI 10.3813/AAA.919086

Interactive Soundscapes: 360°-Video Based Immersive Virtual Reality in a Tool for the Participatory Acoustic Environment Evaluation of Urban Areas

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Summary

The development of the Information and Communication Technologies (ICT) allows advanced interactive participation of citizens in the decision making processes. These participatory processes can be conducted through an innovative technology such as the Immersive Virtual Reality (IVR), as long as this technology is accessible and affordable for citizens. This paper explains the development of an online interactive tool that combines the use of IVR with maps. The tool can be used for the evaluation and monitoring of the spatial changes in the environmental noise appraisals of different areas of the city for future design processes, and will allow to involve a higher number of participants in comparison with laboratory experiments. It is aimed at becoming a collective participatory tool that uses spatial audio and virtual scenarios for a smart soundscape study, with the unique condition that the users have a smartphone and an IVR phone based headset, or the head mounted display Oculus Rift. A preliminary implementation of this tool has been tested in the Naples, using 360°-video based Immersive Reality and in situ sound registrations with the Ambisonic technique. The outcomes on the citizens' participation are shown through coloured maps. Laboratory test in the anechoic chamber and on-site interviews have been conducted to compare the results with the ones of the home test and evaluate the validity of the tool. The data analysis show no statistically significant differences between the outcomes of the three modalities of multisensorial experience evaluated for the variables under study.

PACS no. 43.50.Qp, 43.50.Rq, 43.66.-x

1. Introduction

The smart city is a conceptualization of an urban model based in sustainable solutions that apply Information and Communications Technology (ICT) through the participation of the society, institutions and firms, to improve the quality of life of the population. The channels of citizens' participation evolve in parallel to the improvement of the ICT, and nowadays citizens would be able to take part of several decision making processes related with environmental issues only with a tablet, smartphone or PC and internet connection. The high use of the internet has contributed to the development and adaptation of new technologies to be used online. This is the case of the Immersive Virtual Reality (IVR), which has already penetrated in the market of videogames and online applications with great success. The potential and attractiveness of this tool can be used to involve citizens in active processes of participation, as it allows having an immersive experience of real or simulated scenarios.

In this paper we are going to explain the development and testing of an online participatory tool that uses interactive maps and IVR for the multisensory evaluation or urban soundscapes and for indirectly raise awareness about the acoustic environment conditions.

1.1. Citizen participation and the ITC in the management of the acoustic environment

Citizen participation is considered a necessary stage in the process of development and implementation of environmental policies and management practices. The principles of public participation and transparency are inherent to environmental legislation such as the Air Quality Directive 2008/50/EC that consider the citizen's participation as an important part of the decision making process. Likewise Environmental Noise Directive 2002/49/EC (END) [1] "provides that noise maps and action plans are made pub-

Received 20 August 2016,
accepted 8 June 2017.

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licly available and that the public concerned may participate in the elaboration of noise reduction action plans" [2].

Citizen's participation and commitment in the management of the acoustic environment are essential for a sustainable development. However the involvement of citizens in the decision making processes should go beyond the regulatory constraints. Most regulatory constraints focus only on the negative effects on sounds, without taking into account that non acoustic factor can influence the sound perception. Therefore, it is necessary to count with the citizen's participation to evaluate the perception of the acoustic environment of existent or future scenarios. Citizen's participation brings different benefits to the sound urban planning e.g. public support for the planning decision, transparency of the process, avoidance of conflicts and costly delays, and spirit of goodwill, cooperation and trust between citizens and decisions makers [3]. In addition to the planning benefits, we may highlight the positive effects of awareness on changing behaviours in order to improve the citizen's quality of life.

The terms active and passive participation have been used in different fields in relation to the social performance [4,5,6], behaviour at work [7] or interaction with new technologies [8]. We will use both terms to refer to the kinds of participation promoted by administrations or research programs related with the management and improvement of the acoustic environment (see Figure 1). The passive participation is about informing citizens of the acoustic environment conditions and making them aware of the negative effects of the exposition to high noise levels. It is intended mainly to change individual's behaviour, but without any feedback of the receivers of the information (e.g. awareness campaigns, noise maps or educational programs which just inform citizens). The active participation consists in the development of mechanisms that allow to take into account citizens' opinion and get them involved in the decision making process (e.g. through ideas competition, surveys or public consultations). It is intended to change regulations or to improve and preserve the acoustic quality of an area.

The evolution of the ITC and the increase dependence of the population on the internet of things allow new participation channels, less tedious and more attractive for the users than the traditional ones. The consultation of awareness campaigns such as the one promoted by the World Health Organizations [9,10,11,12] or the European Environmental Agency [13,14] and the access to applications that inform in real time of the noise levels measured through fixed sensors [15,16,17] are examples of passive participation based on the ITC. The widespread of the ITC enables the implementation of different channels that promote simultaneously active and passive participation in a very efficient way. Web pages such [18,19,20] provide information about the acoustic conditions of a place through audio-visual material (passive participation), and simultaneously ask people their appraisals of the acoustic environment (active participation). Other approaches, in addition to request a subjective evaluation of the acoustic environment, use people and their mobile phones as moving sensors to measure noise levels through community-based monitoring initiatives and represent the results in web maps (e.g. [21]–[30]). Although it might seem that the named web pages had been promoted by decision makers for their usefulness to the improvement of the urban acoustic environment it was not so. Instead, they were promoted by research programs, universities, private entities or associations.

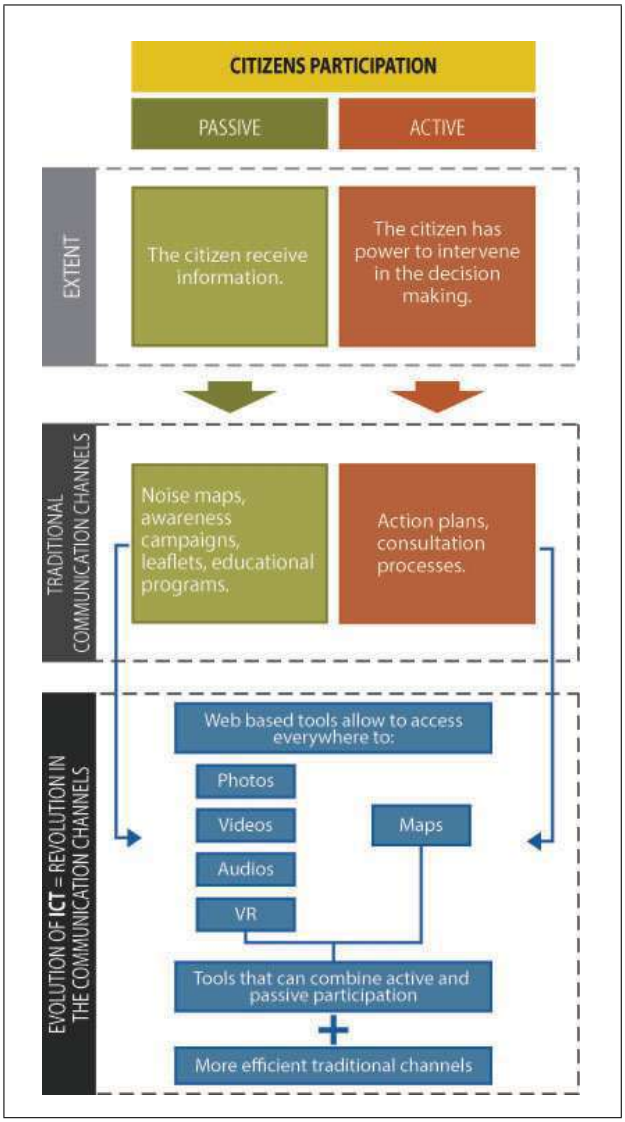


Figure 1. Current situation and evolution trend in the forms of citizens' participation in noise problems and urban sound planning.

A study recently conducted [31] reviewed 41 websites of local administrations that had a specific section about "environmental noise". That study and a subsequent review revealed that the 73% of websites enabled only passive participation, and that only 24% promoted the active participation through noise control plans [31,32] (although that active participation was carried out through traditional channels). Among the web sites examined in that study, not any of them included maps with soundscape appraisals or multisensory information.

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The low dissemination power of the traditional resources strongly affects the processes of citizen participation. New active participation channels based on the ICT that include innovative and attractive technology as the IVR may fill in the gap between administrations and citizens in relation to the improvement of the acoustic environment and the soundscape design.

1.2. Maps and immersive virtual environments and their applications in the soundscape evaluation

The IVR enable the evaluation of the acoustic environment for its capability to immerse the users in a virtual urban scenario. Some research studies have realized of the wide range of advantages that involve the use of the IVR and have integrated it as a work instrument (e.g. [33,34,35,36]). However, the IVR techniques are hardly used neither considered by the stakeholders in the decision making processes despite their high potential to obtain a community feedback of existent and future acoustic environments.

The sound system used in the IVR techniques has been object of different research studies, especially for the creation of new acoustic environments with high degree of realism: an example can be found in the auralisation of sounds (e.g. [36,37,38]). In the investigation of existing soundscapes and specifically with the development of virtual reality techniques, the Ambisonic system has become more popular due to the reduced number of channels that it uses in order to codify complete sound information with simple mathematical solutions [38]–[42]. Many studies intended to evaluate the multisensory nature of perception have been based on this registration and sound reproduction system (e.g. [33], [43]–[47]). For the generation of the virtual scenarios, these studies have used 3D computer generated modelling, which realism level has been improving over the years with the development of new gaming engine software.

The Desktop Virtual Reality (DVR) and the IVR have been recently used to involve the population in online participative initiatives to change the living environment. They allow considering the opinion not only of policymakers or urban planners, but also of the citizens to achieve a consensus on the best urban planning solution [48]–[51]. Although the use of DVR and IVR normally involve only the design of the visual environments, nowadays there are some research works that take advantage of the development of the ITC for the creation of virtual audio-visual environment to evaluate existing areas with DVR techniques [52].

Furthermore, in the field study of soundscape, there has been a progressive implementation of the use of maps to show different aspects of the subjective evaluation of the acoustic environment (e.g. [18, 22, 53, 54]). These maps may be used in urban sound planning to elaborate hypothesis and later conclusions intended to improve the acoustic environment. The elaboration of multilayer maps, based on the users appraisals, may add information about the social sphere, behaviours and predominant sensorial modalities and are innovative procedures that can boost the architecture, planning and soundscape design [55,56,57]. The existent soundscape maps, implemented in web pages, are normally supplemented with multimedia information such as images, videos and geolocated audio [18,58]. This reproduction types do not lead to a realistic correspondence between the visual and acoustic stimulus, because of the flat, and in most cases, static visual display of the environment [59].



Figure 2. Stretch of the Naples waterfront with the locations of the virtual scenarios.

1.3. Aim of this study

The aim of this paper is the development of an online participatory tool for the audio-visual evaluation of existent urban environments. This tool is intended to be used by municipalities and stakeholders in order to evaluate the appraisals of the citizens on the quality of the acoustic environments and involve them in the decision making process.

The tool integrates the use of IVR, DVR and multilayer maps in a web environment. For this it was created a web platform that allows having a VR experience with three hardware reproduction systems of virtual scenarios: Oculus Rift DK2 (IVR), mobile based head mounted display (IVR) and a laptop or desktop (DVR). The virtual scenarios are created by a spherical composition of videos recorded in each area under study. The Ambisonic technique is used for the playback of spatial audio registered on-site.

In order to check the validity of the first two reproduction systems, subjective tests were conducted and the results compared with the ones of an on-site survey campaign.

2. Materials and methods

2.1. Locations under study

The audio-visual data used in this research was collected along Naples waterfront (see Figure 2). Representative sites were chosen with the aim of reproducing through IVR the main characteristics of the soundscape and its

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physical context. The sites were selected attending to heterogeneity criterion, in relation with aspects such as historical values, traffic types or performed activities. Although the website developed allows to have a VR experience of ten locations, for the purposes of this research work only three were considered. These three areas were selected according to diversity criterion regarding not only the kinds of traffic, but also the kind of sound sources that may be heard. In site 1 the traffic noise is predominant and the natural sources are seldom perceived. In site 2 the sound of the sea waves can be daily appreciated, and the traffic can only be perceived as background noise. In site 3, although it is a pedestrian area located at the entrance of the beach, the background noise is quite high and the sound of the waves can hardly be perceived.

2.2. Stimuli registration and data processing

The construction of the immersive virtual scenarios was carried out with 360 degree videos and spatial audio samples, recorded in the sites under study (see Figure 3).

It is first useful to outline what is meant in the present methodology section when using the terms Virtual Reality (VR), Desktop Virtual Reality (DVR), IVR and 360°-video based IVR. VR is a general term used to define "the technology that provides almost real and/or believable experiences in a synthetic or virtual way" [60]. Desktop VR is a particular VR technology that "uses a computer monitor as display to provide graphical interface for users. Although they lack the immersion quality, they consist of computer-generated environments which exist in three dimensions (even if they are shown on a 2-D display)" [60]. The Immersive VR is another VR technique that "completely immerse the user inside the computer generated world, giving the impression to the user that he/she has "stepped inside" the synthetic world. This can be achieved by using either the technologies of Head-Mounted Display (HMD) or multiple projections" [61]. 360°-video based VR (Desktop or Immersive VR) is a technology in which the displayed images "are video recordings where a view in every direction is recorded at the same time shot using an omnidirectional camera or a collection of cameras" [62,63,64]. In the 360°-videos there is less interaction as the user cannot make displacements through the environment. There are two possible types of 360°-videos, the ones created from a 3D computer-generated scenario, and the ones composed by videos recorded in a real place, with video-cameras located in fixed or moving positions. The use of 360°-videos recorded in real places enable a spherical visualization of the surrounding context and the display of the moving sources simultaneously to the spatial reproduction of the surrounding sound.

The video cameras used for this study were GoPro Hero4, and were placed in a tripod at a height of 160 cm. For the development of the participatory tool, one 360°-spherical video in a fixed position was created per each location. The videos were saved in mp4 format, with the following settings: frames rate 24 fps, video bitrate of 24000kbps, video compression standard H.264 and a 4K

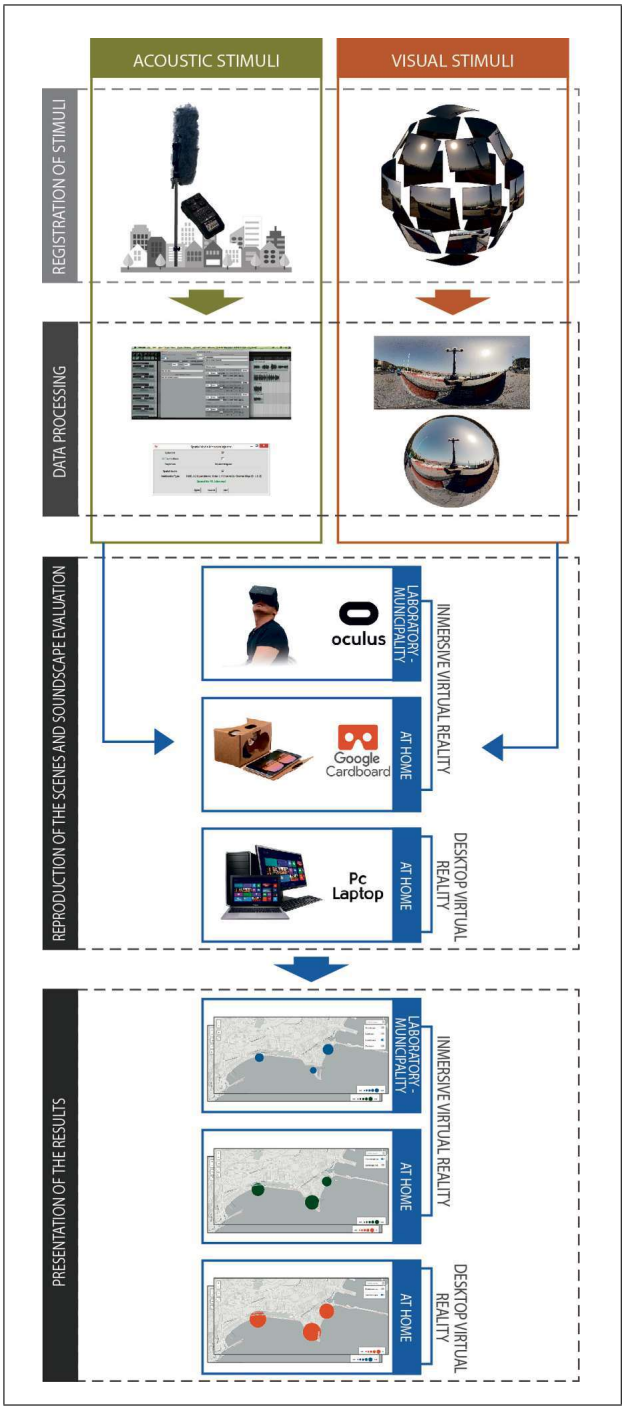


Figure 3. Work flow followed for the construction of the virtual scenarios and the web page.

output. The 360°-videos, elaborated from the recordings made in situ, had duration of 90 seconds.

The Ambisonic technique was used to register the sound stimuli. This technique allows registering audio signals containing complete spatial information. The Ambisonic recording and reproduction system provides a good sense of immersion and envelopment in comparison with other techniques as stereophony and transaural techniques [65]. It has been used for the registration and playback of the audio stimuli in many acoustic research works based on the VR e.g. [33], [43]–[47].

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Audio recordings were made by an Ambisonic microphone (Soundfield SPS 200) and a portable recorder (Zoom H6) while registering the videos. At the same time, the sound pressure levels were measured by means of a sound level meter (SOLO 01dB) with the microphone close to the Soundfield one. In this way the soundscapes were documented to be later reproduced, so the user of the tool may perceive the acoustic environment through DVR or IVR in a similar way as in the moment of its registration. The digital recordings were saved at a sampling rate of 48 kHz. The Ambisonic microphone used is fitted with four capsules matched in a tetrahedral arrangement. The four capsules deliver a 4-channel A-format that was converted to B-format through the Surround Zone VST Plugin [66]. The microphone was placed near the videocameras so as to avoid possible interference, at the height of 160 cm.

2.3. Website developed and VR reproduction systems used

This tool has been implemented in a web environment that allows three ways of experiencing the audio-visual scenarios due to three possible hardware-software reproduction system that the users may select according to their available devices. The video and audio scenes were the same for the three reproduction systems. The difference among the reproduction systems resides in the hardware-software that the user has to use to have an audio-visual experience of the virtual scenarios.

After the selection of the reproduction system, the users were instructed to perform the tests. In order to access to the scenarios interactively, the sites were integrated in a web map (see Figure 4). The map with the locations under study allowed the users to click on the sites in order to have the virtual experience and answer the questionnaire about them. One scenario was shown per site. Once the user answers the test, the responses were included in a database to generate multilayers maps that could be visualized later on by users.

The first reproduction system allows the user experiencing the 360°-video based IVR scenarios through the Oculus Rift DK2 head mounted display (see Figure 3). For that, the user should download a standalone application developed for this tool to visualize the 360°-videos with the spatial audio. The user would experience this reproduction system with headphones or 5.1 speaker's configuration (according with the two application settings available). A different speaker's configuration has not been implemented, but can be used although its immersive quality is not warrantied. The first reproduction system has been thought to be a relatively precise way to evaluate people's perception of the soundscape quality by municipalities or soundscape designers. It uses an affordable hardware reproduction system to get a realistic immersive experience: Oculus Rift head mounted display, a desktop or laptop and headphones or a 5.1 speakers' configuration, with the requirement of a proper calibration of the playback system. Municipalities can locate the system for example in a room

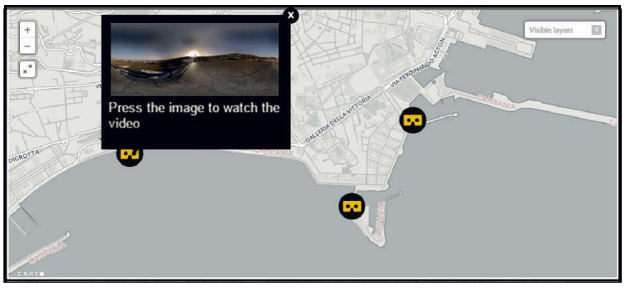


Figure 4. Webpage display after the selection of the second reproduction system. Map that integrates the locations from which the user can start the IVR experience. Symbols represent the reproduction system selected.

near a waiting area, or in places specially equipped for such purpose. Although it was thought to be used by municipalities, it can be also used by anyone who has Oculus Rift at home.

The second reproduction system is based on the use of a smartphone and a IVR phone based headset. The smartphone should be equipped with gyroscope sensor, and work with Android Operating System (minimum version Android 4.1). The user can experience IVR scenarios through the display of 360-degree YouTube videos with spatial audio [67]. Likewise, the gathered information may be visualized and reproduced at home using available and affordable technology such as a smartphone and a phone based head mounted display (such Google Cardboard). That tool enables an IVR experience with spatialized audio, but with less quality of movement and less immersive sensation than the previous one.

The third reproduction system allows the user to enjoy DVR scenarios through the screen of the PC (desktop or laptop) (see Figure 3). In comparison to the other modes of reproduction, the immersive capacity of the third reproduction system is the lowest one, as the videos are shown on a 2D display) [60].

One weakness of the tool resides in the lack of control in the audio playback system when the subject uses it at home, due to the high variety of loudspeakers or headphones available, if we consider the first or third mode of experiencing the scenarios, or if we consider the second one, the wide range of mobile phones models that can be found in the market (with different operating systems, different speakers, different manufacturers...). As the audio characteristics are constrained by the reproduction system, the user has the option of calibrating the audio playback system, or just experiencing the tool, without any kind of "calibration". Instructions are given to the users in case they want to conduct the calibration of the audio playback system (section 2.3.2).

After the selection of the reproduction system, the users had to answer a group of closed questions, formulated to assess the validity of the responses. In particular they were asked whether the sound level of the reproduction system was "calibrated" or not, and if it was, the measured background noise, the measured reference level (see section 2.3.2) and the type of audio playback system used.

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Table I. Web questionnaire included in the three available ways of reproduction of the scenarios. The questions are followed by the corresponding scales.

1. General appraisals on the perceived stimuli:
   How would you rate the following aspects in this scenario?
   Soundscape: 1 = Very bad, 7 = Excellent
   Landscape: 1 = Very bad, 7 = Excellent
2. Semantic differential analysis:
   How would you say this soundscape is regarding the following adjectives?
   1 = Unpleasant, 7 = Pleasant
   1 = Uneventful, 7 = Eventful
   1 = Monotonous, 7 = Exciting
   1 = Chaotic, 7 = Calm
3. Sound sources:
   How do the following sound sources contribute to the quality of the sonic environment? Give an appraisal only on the sound sources that you can hear in this video. (Cars, motorbikes, voices...)
   1 = Negatively, 7 = Positively
4. Expectations:
   How much does this place match with your expectations?
   1 = Does not match at all, 4 = Completely matches

With regards to the three reproduction systems, the acceptance criterions for the inclusion of the responses of a certain subject in the map representation were the use of a "calibrated" audio playback system and a measured background noise level below or equal to 35 dBA (the mentioned level was chosen according to the maximum background noise level recommended by [68] for rooms with specific intelligibility speech features needed). In addition, only the answers of the subjects that used the following audio playback systems were consider in the representation of the maps: 5.1 speakers setup in the first reproduction system, smartphone's speakers in the second one, and 5.1 speakers setup in the third one.

Subsequently, for the selected reproduction system the subjects were asked to fill in a survey per site with four groups of questions (Table I): 1. General appraisal on the perceived stimuli, 2. Semantic differential analysis, 3. Sound sources and 4. Expectations. The responses to the first three groups of questions were given in a 7 points Likert scale, and the ones to the last group in a 4 points Likert scale.

The answers of the tests were post-processed, and the results showed in web maps available for all the users. Different layers can be individually or simultaneously displayed in order to compare the mean scores of the variables in each site. For each reproduction system, two maps were created (see Figure 3, bottom). The first map on the results of the general appraisals about the perceived stimuli allowed the visualization of the layers of the soundscape and landscape quality. The second map on the results of the semantic differential analyses allowed the visualization of four layers namely pleasantness, eventfulness, calmness and excitement.



Figure 5. Results layer of the soundscape quality (SQ) of the tests conducted with the second reproduction system. The circles represent the mean scores per site of the appraisals on the SQ given by all the participants that have used the second reproduction system and had reported a background noise level =35 dBA (Mean SQ Site 1=3.62, Mean SQ Site 2=5.38).

Figure 5 shows an example of map of the general appraisals on the perceived stimuli, corresponding to the second reproduction system. It displays the layer of the soundscape quality. The sizes of the circles are proportional to the mean scores of the appraisals on the soundscape quality, allowing at a glance to have an idea of the differences between zones regarding the variable shown. When the user clicks on a specific site the numerical value of the mean score is also displayed.

It would be desirable to find an easy and affordable way of "calibrating" the levels of the audio playback system, matching the emission levels of the playback system with a reference noise registration (a calibration in frequencies was discarded, because its complexity would discourage participants in the use of the tool). The widespread use of the smartphones makes them the perfect device to perform that operation. If they were accurate enough, the mobile phone would substitute the sound level meter to conduct that "calibration". Among the wide range of smartphone brands available, the ones working with Android operating system are the most popular ones.

In the next section, the accuracy of Android mobile phone applications without a previous "calibration" for measuring sound levels is analysed.

2.3.1. Evaluation of Android mobile phone applications without a previous "calibration" for measuring the sound levels of the audio playback system at home

An evaluation of mobile phone applications was recently performed by the National Institute for Occupational Safety and Health of Columbia on Android and iOs apps [69]. The study concluded that some iOs applications may be considered accurate and reliable to assess occupational noise exposures. Unfortunately, due to the wide variance shown between the same app measurements on Android devices, only the results of the iOs apps were shown in that study. A similar study was recently conducted to evaluate the performance of different iOs and Android app in the measurement of the environmental noise [70]. They led

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to the conclusion that although some Android apps performed better than those for the iOS in relation with the reference values, the high degree of measurements variability associated with the brand discourage the use of Android mobiles without a previous calibration. However they only tested three Android App.

We performed a similar test to [69] on 7 medium-range mobile phone models equipped with Android operating system in order to verify the validity of the measures conducted with different smartphones and Android App for our purposes. 7 Android applications were tested. These applications measured unweighted and A-weighted sound levels. The sets app-smartphone were not calibrated for the test. All the mobile phones and the apps kept the factory setting. The procedure and kind of statistical analyses conducted was similar to the one described in [69]. The results obtained in the evaluation of the use of Android app for measuring the emission sound level of the mobile devices or speakers setup used for the home performed test discourage the use of Android mobile phones without a previous calibration of the app-smartphone. The previous conclusion supports the outcomes on the Android app reached in [69], in which the Android apps are considered not to fulfil the needed requirements to be used for the occupational noise assessments. The reason argued for these results is the lack of standardization of the microphones and other audio devices among the different manufacturers.

A recent study that evaluated the performance of smartphone-based sound level meter apps (with devices equipped with Android or iOs operating system) concluded that "... calibrated, quality smartphone device with an app tailored to that specific hardware can be a useful tool to a qualified professional" [71].

We support that conclusion, and therefore, the mobile phones have to be "calibrated" to be used as sound level meter for the purposes of the present study. In the case that municipalities would want to perform this kind of test, the calibration of the mobile phones would be conducted with the help of a sound level meter, a device that is normally in possession of the municipalities.

2.3.2. "Calibration" of the audio playback system

Instructions were given in the webpage in case that the users had the possibility to conduct the calibration of the audio playback system. Users were asked to sit down in the place in which they were going to have the virtual experience (in the middle of the room if they use the first or second reproduction system and in front of the computer if they use the third one). The microphone of the sound level meter (or a calibrated smartphone) should be at the level of the ears. Furthermore, with the second reproduction mode, the mobile phone should be at an approximate distance of 20 cm from the microphone of the sound level meter. The sound level meter used for the calibration had to be at least class 2. The user had to reproduce through the speakers a pure tone available at the web page and increase or decrease the volume till the sound level meter (or the calibrated phone) measures 75 dB. Subsequently, with the volume previously fixed, the user had to reproduce a pink noise (with limited broadband 500 Hz–2 kHz) available in the webpage and verify that the sound level is approximately 65 dBA, with a tolerance of ±1.5 dB. If not, the responses of the subjects would not be considered when representing the maps. The described method had the intention of getting acceptable precision (±1.5 dB) in the playback levels of the audio samples used in the home conducted tests (in comparison with the sound levels measured on-site) through a simple procedure that could be performed by everybody without a specific training.

Before developing the above method, an evaluation of the "calibrated" sets app-Android smartphones for measuring the sound levels of the playback system was conducted. We assumed that a municipality that could promote this kind of citizens' participation and undertake the mobile phones "calibration" do not have available any room with special acoustic features to perform it. That is why the "calibrations" tests were conducted in a room of a size of 4.5m x 6.0m, that could be in any administrative building.

Positions of the smartphone and the microphone of the sound level meter were the ones described above (particularly two tripods were used, at a height of 1.2m each). The noise levels measured by means of the smartphone were compared with the ones of a sound level meter Brüel & Kjær 2210. The background noise levels, below 30 dB, were measured before and after the calibrations to ensure that the room acoustics remained consistent. The calibration mode of the best performed app was used to conduct the tests.

Following the method described above, reference emission levels of 1kHz tone were tested in steps of 5 dB from 50 to 85 dB. Once the volume was adjusted, the three samples (corresponding to the three evaluated scenarios) were reproduced and measured with the mobile phones used in the present research work. The multi-window option was activated in the mobile phones in order to allow two applications operate simultaneously. The reference level of an emitted 1kHz tone at 75 dB was the one that led to the most accurate calibrations, tested in the three audio samples registered in the three locations of the present study. For that samples, the maximum difference of levels measured by the app and the sound pressure level meter was of −1.10 dB and +0.89 dBA.

2.4. Comparison of three test methodologies for the multisensory evaluation of urban scenarios: On site surveys, laboratory tests and home compiled tests

Laboratory tests are characterized by guaranteeing total control and repeatability of testing. On the contrary, home performed tests involve the inclusion of certain variables under control that may affect the validity of the results. The aim of this part of the study is to verify the validity of the results of the tests performed with the 360°-videos in laboratory and at home in comparison with the on-site

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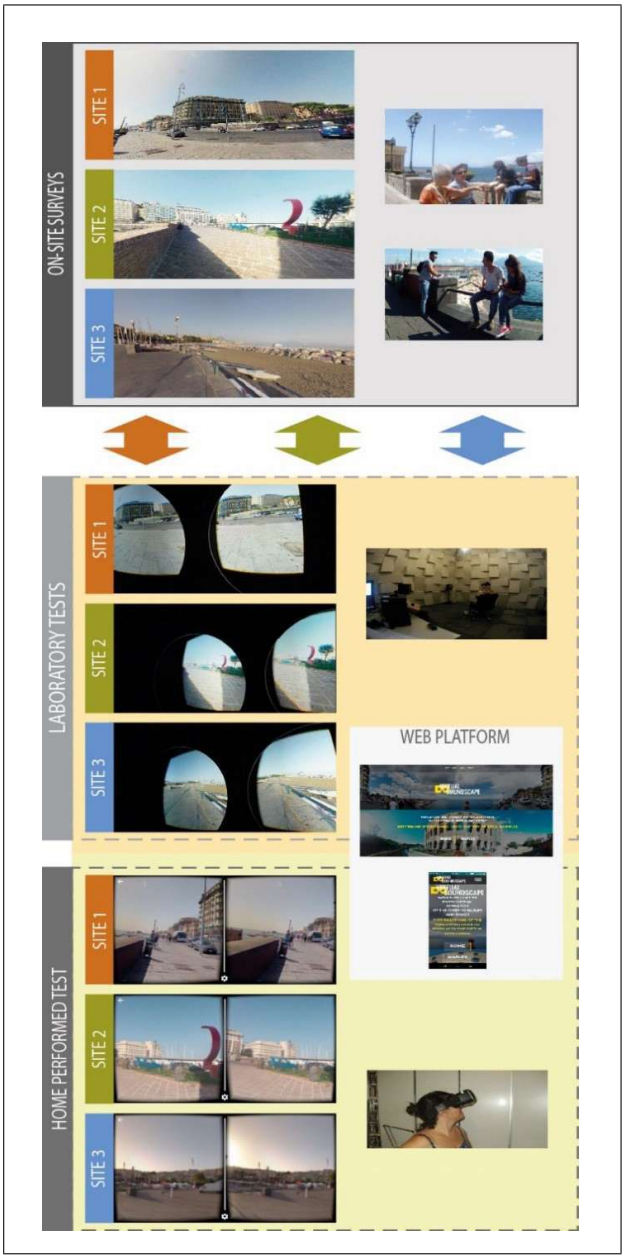


Figure 6. Comparison of three modalities of multisensory test: on-site interviews, laboratory test and home conducted test.

ones. To this end, a comparison of three modalities of citizen's participation was conducted in order to evaluate the quality of immersive experience performed with the IVR reproduction systems of the developed tool: on-site interviews, laboratory test (IVR-Oculus) and home-compiled test (IVR-mobile phone based head mounted display) (see Figure 6). To that end, three sites were considered for the comparison.

Different studies have compared the development of a certain activity in a traditional and in a VR environment in order to evaluate the ecological validity of the VR for that purpose [72]–[76]. The performance of tasks such as the human navigation ability [72], the executive function in adolescence [75] or the attention performance in class [74] were evaluated in a single scenario. In the present research three scenarios were tested.

A comparison between the results of a laboratory test based on IVR (with a 3D computer generated scenario) and a survey conducted outdoor was recently performed by this team in a previous research study with very positive outputs [43]. Oculus headset was used to display the 3D scenario. The results of that test revealed that there were no statistical differences among the questions considered [35,43]. The test conducted in the current section presents several differences with regard the one previously mentioned. On the one hand, in the present study three 360°-video based images are displayed while in the previous one 3D scenarios complete generated with a computer were used. On the other hand, in the present study are compared the results of tests performed with two kinds of headset and contour conditions, Oculus in the laboratory tests and a mobile phone based head mounted display in the home-conducted tests, while in the previous research performed in laboratory only Oculus headset was used for the comparison.

An open to road traffic area (site 1) and two pedestrian areas (site 2 and site 3) of the Naples waterfront were chosen to perform this comparison (see Section 2.1).

The three samples constituted by the three groups of subjects that participated in the present study were completely independent. Each subject participated only in one test modality. A total of 158 subject participated in the test for the comparison of the three test modalities.

2.4.1. On-site interviews

Three groups of subjects were recruited randomly in the three real outdoor sites considered for the comparison. Each participant answered the questionnaire in only one location. The total number of interviews was 30 in site 1, 32 in site 2 and 34 in site 3. A questionnaire composed by closed questions was supplied to the interviewees. Before starting the questionnaire, subjects were warned that the questions referred only to the site in which they were located. Subjects were requested to answer the questions regarding the stimuli perceived during the interview. Also, they were asked not to influence their responses by previous experiences or preconceived ideas. The interviews were made between 10.00 and 17.00 o'clock in weekdays, to make the conditions match with the ones in which the video and sound were registered.

2.4.2. Laboratory test

A total of 26 subjects underwent the laboratory test. They were staff and student volunteers of the University of Campania. Each subject had to answer the questions regarding the three sites under study. The tests were performed in an anechoic chamber. The playback equipment consisted of 5 loudspeakers (Dynaudio BM5A MKII) and a woofer (Dynaudio BM9S) arranged in a 5.1 system. The computer was connected to the speakers via a Motu 828 MKII external soundcard. The 4 B-format recordings were converted by means of the Surrounding Zone plug-in of Soundfield to be reproduced in a 5.1 loudspeaker configuration. The emission levels of the audio playback system were calibrated in order to measure in the position of the subject

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(at the centre of the anechoic chamber) the same sound equivalent levels than the ones registered during the video recording (with a tolerance of ±1 dB). The LAeq of the registrations were 64.2 dBA in site 1 and 54.2 dBA in site 2 and 55.6 dBA in site 3.

An Oculus Rift DK2 head mounted display was used to conduct the laboratory experiment (see Figure 3). The test session consisted of the reproduction 360°-video through the Oculus Rift head mounted display while the questions were made. Before the reproduction of the videos, subjects were asked to pay attention to what they were hearing and listening during the session, avoiding to take into account previous experiences of the sites that they could have. An explorative visualization of each scenario was conducted at the beginning of the test in order to avoid distractions due to experiencing the technology (that could cause lack of attention to the test itself).

This test can be equivalent to the ones suggested to be performed in the waiting areas of the municipalities with the whole playback sound system calibrated.

2.4.3. Home conducted test

35 participants underwent the home conducted test. They were staff and student volunteers of the University. Each one had to answer the questions regarding all the sites under study.

First Order Ambisonic audio channel layouts were used for the creation of the 360°-degree YouTube videos. Mp4 360-degree video files with the spatial audio metadata were created and uploaded to the YouTube web [67].

Home tests were made in the subjects' house with their own smartphones, if they met the requirements to display the 360°-videos (gyroscope sensor and Android 4.1 or higher), or a smartphone lent by the laboratory for this purpose.

The calibration of the mobile phone for the comparison test was conducted before lending the participants the equipment following the procedure explained in section 2.3.2.

The mobile-based head mounted display was supplied by the laboratory to the subjects in order to conduct the experiments. Two participants, which had a smartphone that met the necessary requirements, used their own mobile phones after being calibrated. Participants were asked not to change the configuration setting of the smartphone. Before the delivery of the equipment, subjects were requested to read carefully the instructions of the web page, to enter in the section corresponding to the reproduction of the videos through the mobile-based head mounted display, and to answer the questions corresponding to all the areas under study. The instructions of the webpage consisted on a brief description of the test and the type of questions. It also included a test to verify that there had been no changes in the smartphones settings that consisted on the playback of a pink noise sound that should measure approximately 65 dBA. The subjects were advised to perform the test in a room with low background noise.

The first questions of the test were related with the validity of the calibration of the mobile phone and the level of the background noise. Only the answers of the participants with background noise levels below or equal to 35 dBA were considered in the comparison test. The answers of two participants were rejected for that reason. Subjects were also asked to write the number of dBA measured by the app during the playback of the reference pink noise. A tolerance of ±1.5 dB was considered for not rejecting the answers. According to this criterion, the answers of no participant were rejected.

Two mobile phone based head mounted display were used in the experiment: Google Cardboard and Laserbeak 360 VR Glasses.

2.4.4. Data analysis and results

Two groups of questions were analysed. The questions were formulated in the same way in the three tests under study. The first group corresponds to the 'general questions about the sense stimuli' (see Table I). In particular, subjects were asked to give their ratings to the soundscape quality (SQ) and to the landscape quality (VQ). The responses were given in a seven points Likert scale from 'very bad' to 'excellent'. The second group corresponds to a 'semantic differential analysis' about the soundscape rated in four bipolar scales (unpleasant/pleasant (SQ_PL), uneventful/eventful (SQ_EV), chaotic/calm (SQ_CA), monotonous/exciting (SQ_EX) based on the circumplex model proposed in [77]. Semantic differential questions were rated in a seven points Likert scale (See Table I).

Kruskal-Wallis test was applied to the data under study. It is a non-parametric test used to determine if there are statistically significant differences between groups of the dependent variables and it can be applied when the independent variables are ordinal. Kruskal-Wallis test performs better than the Anova test for non-symmetrical data [78] such as the one of the present study. Like most non-parametric tests, it is calculated on ranked data, so a previous conversion of the measurement observation to their ranks in the overall data was needed.

In the selection of the samples used for conducting Kruskal-Wallis test, the total number of interviews conducted outdoor in each site (30 in site 1, 32 in site 2 and 34 in site 3), and the number of laboratory (26 subjects) and home compiled test (35 subjects) was reduced to 24 in site 1 and site 2, and to 21 in site 3 in order to have samples of similar characteristics. The responses of 50 subjects were rejected. The reason of the rejection of two of them was to exceed the maximum background noise level allowed in the home conducted test. The other 48 were rejected randomly regarding age criterion to homogenize the samples of each group. The distribution of the sample of the three groups under study regarding age and gender is shown in Table II.

2.4.5. Evaluation of the appraisals on the perceived stimuli

Figure 7 plots the Kruskal-Wallis mean ranks of the appraisals on the perceived stimuli. In site 1, the Kruskal-Wallis test shows that there is no statistically significant

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Table II. Sample distribution of the three kind of test performed: On-site interviews, laboratory tests and home compiled tests.

Age	Gender	On-site interviews Site 1	Site 2	Site 3	Lab. test (Oculus) Sites 1, 2	Site 3	Home test (Cardboard) Sites 1, 2	Site 3
18-29	W	9	11	8	11	9	9	9
	M	9	9	9	10	9	12	9
30-39	W	1	1	1	1	1	0	1
	M	1	1	0	0	0	1	0
40-49	W	1	1	1	0	1	2	1
	M	2	1	1	2	1	0	1
50-59	W	1	0	1	0	0	0	0
	M	0	0	0	0	0	0	0
Total		24	24	21	24	21	24	21

difference in the soundscape appraisal's score between the different groups considered (on-site test, laboratory test and home compiled test), $\chi^2(2) = 4.419$, $p = 0.11$ with a mean rank "on-site" score of 47.92, 35.08 for "laboratory" tests and 39.52 for "home" tests (Table III).

Likewise, no statistically significant difference was found in the appraisals on the soundscape quality in site 2, $\chi^2(2) = 0.003$, $p = 0.998$, neither in site 3, $\chi^2(2) = 2.275$, $p = 0.321$. Similar results were found for the evaluations of the landscape quality in the three sites selected. The differences among the three kinds of test on the appraisals of the soundscape quality of site 1, located in a pedestrian area, is very low with a p-value much higher than the reference level $p = 0.05$, what indicates a high similarity in the appraisals on the soundscape quality among the three kinds of test.

2.4.6. Evaluation of the semantic differential analysis

Figure 8 plots the Kruskal-Wallis mean ranks of the semantic differential analysis of the soundscape. The results of the Kurskal Wallis test for the pair of adjectives unpleasant/pleasant for both sites show that the statistical significance is higher than the critical value p=0.05, and therefore, the null hypothesis cannot be rejected (Site 1: $\chi^2(2) = 0.716$, $p = 0.398$ with a mean rank "on-site" tests' score of 45.44, 45.69 for "laboratory" tests and 40.72 for "home" tests. Site 2: $\chi^2(2) = 1219$, $p = 0.544$ with a mean rank "on-site" score of 45.63, 40.66 for "laboratory" tests and 38.73 for "home" tests. Site 3: $\chi^2(2) = 4228$, $p = 0.121$ with a mean rank "on-site" score of 38.1, 32.81 for "laboratory" tests and 31.15 for "home" tests) (see Figure 8). Consequently no differences between groups emerged from the results of the test in the semantic differential variables under study.

A tendency can be observed in more positive ratings of the pleasantness, calmness and eventfulness of the soundscape in the three areas under study in the on-site interviews with respect to the laboratory and home compiled test. This may be due to multiple factors, such as motivation of being in the place, or the incomplete multisensory experience of the laboratory and home compiled test.

The output of the test reveals no statistical differences between the results of the three test regarding the two groups of variables analysed, the ones related with the sense stimuli and the semantic differential variables.

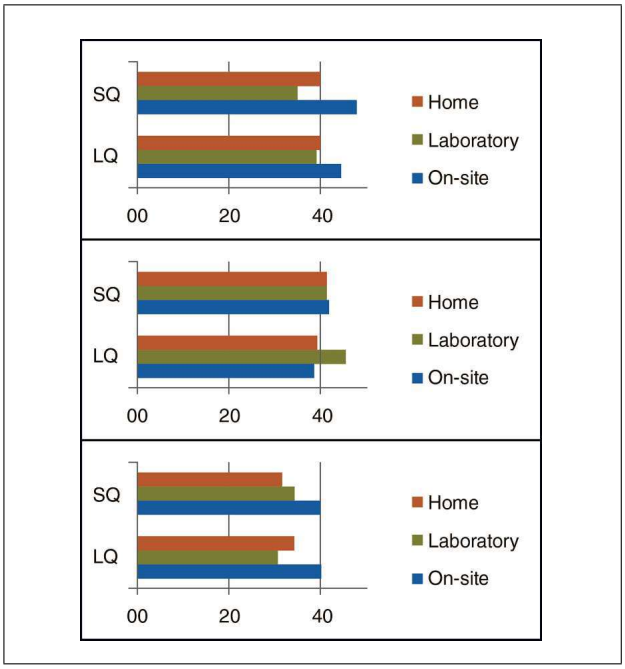


Figure 7. Kruskal-Wallis mean ranks of the appraisals on the soundscape quality (SQ) and the landscape quality (LQ). Top graphic: site 1. Middle graphic: site 2. Bottom graphic: site 3.

Table III. Chi-Square and statistical significance of the evaluation on the general appraisals of the perceived stimuli.

		LQ	SQ
Site 1	Chi-Square	0.950	4419
	p-value	0.622	0.11
Site 2	Chi-Square	1680	0.003
	p-value	0.432	0.998
Site 3	Chi-Square	2.634	2.275
	p-value	0.268	0.321

2.4.7. Discussion

The results encourage the use of the tool under the constraints stablished along this research ("calibration" of the

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Table IV. Chi-Square and statistical significance of sematic differential analysis of four bipolar scales: unpleasant/pleasant (SQ_PL), uneventful/eventful (SQ_EV), chaotic/calm (SQ_CA), monotonous/exciting (SQ_EX).

		SQ_PL	SQ_CA	SQ_EV	SQ_EX
Site 1	χ^2	0.716	4307	0.317	0.626
	p	0.398	0.116	0.854	0.731
Site 2	χ^2	1219	2605	1195	0.716
	p	0.544	0.272	0.550	0.398
Site 3	χ^2	4.228	4.560	0.119	1.563
	p	0.121	0.102	0.942	0.458

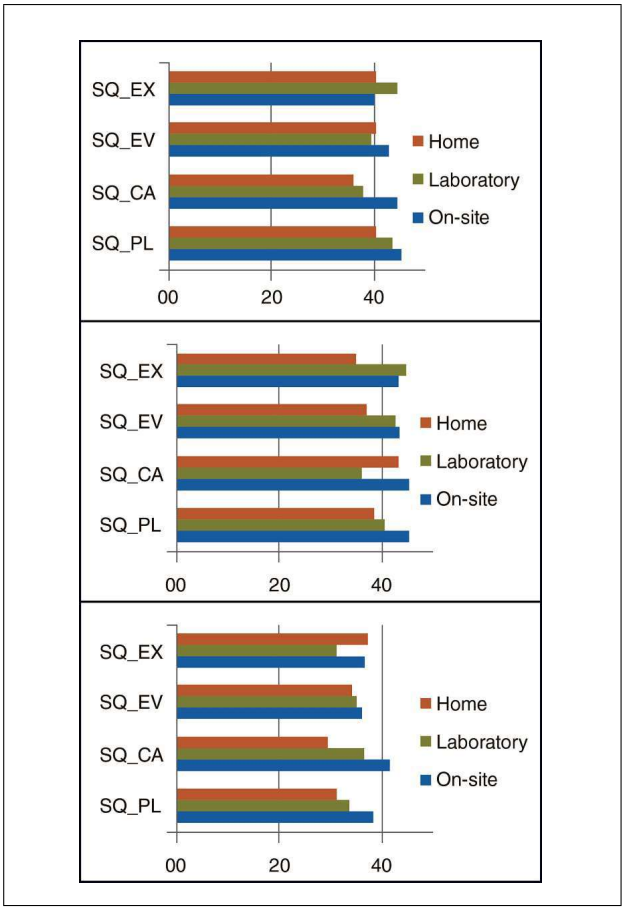


Figure 8. Kruskal-Wallis mean ranks of the sematic differential analysis of the soundscape of four bipolar scales: unpleasant/pleasant (SQ_PL), uneventful/eventful (SQ_EV), chaotic/calm (SQ_CA) and monotonous/exciting (SQ_EX). Top graphic: site 1. Middle graphic: site 2. Bottom graphic: site 3.

audio playback system and background noise in the room of experiment below or equal 35 dBA). However, although users were not able to "calibrate" the audio playback system, they can have an immersive virtual experience of the places under study and answer the questionnaire. Those answers may be taking into account just as participatory effects, but not in the maps representation. Nevertheless, the active listening and experiencing of the immersive virtual scenarios and to answer the questionnaire may aware users with no "calibrated" playback system of the acoustic conditions of a specific place regarding, for example, the kind of the predominant source or the degree of match between the sources heard and the desirables ones in relation to the nature of the place.

The "calibration" conducted for the comparison and the relatively good precision of the verification measures (with a difference with the reference level within ±1.5 dBA) favoured the good performance of the test carried out at home with the smartphone and the head mounted display. So much so, that no difference were found in comparison to the tests conducted with a device specifically design to generate immersive virtual reality experiences as Oculus Rift.

Through the last decades, there had been many soundscape studies that evaluate the quality of the acoustic environment using different audio (recorded samples, auralized sounds, headphones, 5.1 speakers setup…) and visual reproduction media (photographs, videos, VR). Although many of them arrived to the same conclusions, just a few examples which compare audio-visual reproduction techniques were found [65,79,80]. That studies compared the techniques in relation with parameters such as the localization of sounds [63,78,79], immersion and evolvement of the sound [65,79] or fidelity, sense of space and quality of the reproduced sounds [79]. None of them asked questions regarding the audio visual scene that was being reproduced, because they focused on features with regard to the own audio playback technique. In [81] is studied the ecological validity of two audio playback techniques (stereophonic and Ambisonic) without any visual reproduction in relation with questions about the soundscape. The research work concluded that the spatial immersion of the Ambisonic technique contributes to the cognitive representation of urban background noise". However, no images were shown.

In our case, the two compared techniques used spatial audio, although the audio-visual reproduction systems were different. Users were not asked about the sense of presence or the immersive capabilities of both techniques (Oculus Rift/5.1 speakers setup and smartphone head mounted display set), neither about the provenance of the sound sources or the interaction capabilities of the systems. Probably the results of the test regarding that questions would have shown differences among the reproduction techniques.

Although the output of the test comparing three test modalities are promising, it would be wrong to extent the results to areas with different features to the ones considered in this study or to different questions to the ones analysed without further investigation. The areas under study have certain common characteristics such as the vision of the water that has been demonstrated to affect positively to the evaluation of the assessment of the soundscape quality e.g. [82,83]. The low variability of the answers shown with very positive answers given may have contributed positively to the success of the outcomes of the comparison test. As it has been outlined before, questions related for

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example with the sense of presence or the immersion capability of the reproduction modalities would have led to find differences among the techniques.

The calibration of the smartphones conducted for the comparison test could be carried out by any municipality, as most of them own a sound level meter. Only an advertisement campaign should be necessary to convince citizens to calibrate their phones, which would be a positive circumstance not only for undergoing the test, but also to know the sound levels they are exposed to in their daily lives.

As the tool is accessible to architects, designers and urban planners may foster the inclusion of the soundscape approach in the design process from the initial stage. The tool can be easily adapted to meet the objectives of different researches or planning projects. It is also understandable by citizens and other stakeholders, making it a very accommodative benchmark for the urban sound planning [84].

3. Conclusion

This research work integrates the use of IVR and multilayer maps in a web environment. Three different hardware reproduction systems have been implemented in the web site in order to make a multisensory IVR affordable for all publics through Oculus Rift DK2 (IVR), through mobile based head mounted display (IVR) and through a laptop or desktop (VR).

The integration of the IVR and web maps was undertaking in order to generate a new alternative tool easy to implement for expert and amateurs in their multisensory evaluation projects. The use of 360° videos allows a spherical visualization of the surrounding context matching with the spatial audio. It has also an accessible and comprehensible interface for the users, and it allows experiencing and enjoying the IVR for participatory purposes. The tool can be easily shared through a web environment and the devices used for the reproduction of the immersive virtual scenarios are available and affordable for the general public. With this tool, citizens have the possibility to participate in the decision making process of urban sound planning through the evaluation of existing scenarios of a city. It can be consider a way to generate direct and effective connections between the citizens, which can evaluate urban environments from home, and the public administrations. The tool offers the possibility to the decision makers of taking into account the appraisals of the participants in order to undertake urban renewal projects intended, for example, to improve the acoustic environment of a certain area with negative ratings, or to try to reproduce the acoustic features of a place positively rated.

The display of the results in multilayer maps allow at a glance to have an idea of the differences between the locations in relation to the variables under study. The layers can be consulted isolated or overlapped, enabling the comparison of ratings with regard to the same location of different variables. This kind of graphic information displayed in maps can be easily interpreted and implemented in innovative architecture and planning processes.

So far a weak point of the tool is the lack of homogeneity in the audio playback system of the users at home. In order to get certain degree of homogeneity and make the home conducted test valid, the users should calibrate the emission of their audio systems with a sound level meter, or a calibrated app-smartphone.

A comparison has been conducted among the two possible modalities of using the tool (for an immersive experience) and the interviews conducted in the real sites. The first one, using Oculus Rift DK2 would be similar to a laboratory test, and can be conducted in municipality rooms fitted for this purpose, calibrating the whole audio emission system. The second one, using a mobile phone based head mounted display and a smartphone, can be used from home and allows also an immersive multisensory experience, but with lower quality of audio and video reproduction. The results have shown the validity of both laboratory test and home compiled test to evaluate visual and acoustic stimuli. Similar results were obtained in [35] and [43] with laboratory test and 3D-constructed scenarios displayed through Oculus with a 5.1 audio playback system. In our tests, results have been extended to the lower level of quality of the immersive experience obtained through mobile phone based head mounted display. Consequently there are no difference between the use of the Oculus Rift DK2 and the IVR -mobile phone based head mounted display with regard to the appraisals on the pleasantness, calmness, eventfulness and excitement of the acoustic environment, neither with the soundscape and the landscape quality in the sites under study.

Therefore, the outcomes of the comparison encourage the use of the innovative IVR tools offered in the website in order reach a high number of individuals than traditional channel and enhance the participatory urban planning. The goodness of the results also allows considering these tools as an alternative to traditional on-site interviews campaigns.

Acknowledgement

The research was funded by the People Programme (Marie Curie Actions) of the European Union's 7th Framework Programme FP7/2007-2013 under REA grant agreement no. 290110, SONORUS "Urban Sound Planner".

References

[1] T. H. E. E. Parliament, T. H. E. Council, O. F. The, E. Union: Directive 2002/49/EC of the European Parliament and of the Council relating to the assessment and management of environmental noise. Off. J. Eur. Communities (2002) 12–25.

[2] Air Quality and Noise Legislation - Environment - European Commission. http://ec.europa.eu/environment/legal/law/5/e_learning/module_4_9.htm.

[3] A. Cogan, S. Sumner, J. Hertberg: Citizen Participation. The Practice of State and Regional Planning. 1986.

Document downloaded by @DAEL, 2026-11-20 03:57:28 - personal use only

[4] S.-M. Horng: A Study of Active and Passive User Participation in Virtual Communities. J. Electron. Commer. Res. **17** (2016) 289–311.

[5] M. Y. Abdullah, N. R. A. Bakar, M. H. Mahbob: Student's Participation in Classroom: What Motivates them to Speak up? Procedia - Soc. Behav. Sci. **51** (2012) 516–522.

[6] M. Reason: Participations on Participation: Researching the 'active' theatre audience. Particip. - J. Audience Recept. Stud. **12** no. 1 (2015) 271–280.

[7] A. Persson, B. Wanek, A. Johansson: Passive versus active operator work in automated process control-a job design case study in a control centre. Appl. Ergon. **32** no. 5 (2001) 441–451.

[8] E. Montague, J. Xu: Understanding active and passive users: The effects of an active user using normal, hard and unreliable technologies on user assessment of trust in technology and co-user. Applied Ergonomics **43** no. 4. (2012) 702–712.

[9] G. Belojevic, R. Kim, S. Kephalopoulos: Assessment of needs for capacity-building for health risk assessment of environmental noise: case studies. Eur. Comm. Jt. Res. Cent. (2012) 1–50.

[10] M. Braubach, D. E. Jacobs, D. Ormandy: Environmental burden of disease associated with inadequate housing: Summary report. World Heal. Organ. Eur. (2011) 1–13.

[11] T. Hellmuth, T. Classen, R. Kim, S. Kephalopoulos: Methodological guidance for estimating the burden of disease from environmental noise. (2012) 69.

[12] W. S. Joseph: Night noise guidelines for Europe. J. Am. Podiatr. Med. Assoc. **100** no. 5 (2009) 1–162.

[13] EEA: Good practice guide on quiet areas, no. 4. (2014) 1–58.

[14] European Environmental Agency: Noise in Europe 2014, no. 10, 2014.

[15] P. Bellucci, L. Peruzzi, G. Zambon: LIFE DYNAMAP project: The case study of Rome. Appl. Acoust. **117** (2017) 193–206.

[16] W. Wei, D. Botteldooren, T. Van Renterghem: Monitoring sound exposure by real time measurement and dynamic noise map. Forum Acusticum 1, 2014.

[17] N. B. Roozen and M. Rychtáriková: Laser scanning vibrometry measurements on a light weight building element. pp. 1–5.

[18] Barceloneta Sonora. https://barcelonetasonora.wordpress.com/.

[19] Lisbon soundmap. http://www.lisbonsoundmap.org/.

[20] Archivio Italiano Paesaggi Sonori. www.archivioitalianopaesaggisonori.it/.

[21] I. Schweizer, R. Bärtl, A. Schulz, F. Probst, M. Mühlhäuser: NoiseMap - Real-time participatory noise maps. World (2011) to appear.

[22] J. Cordeiro, N. Makelberge: HURLY-BURLY: An experimental framework for sound based social networking. in The 16th International Conference on Auditory Display, 2010, no. mainly CMC, 109–113.

[23] http://cs.everyaware.eu/event/widenoise.

[24] http://www.noisetube.net/#&panel1-1.

[25] N. Maisonneuve, M. Stevens, M. E. Niessen, L. Steels: NoiseTube: Measuring and mapping noise pollution with mobile phones. Environ. Sci. Eng. (Subseries Environ. Sci. (2009) 215–228.

[26] E. Kanjo: NoiseSPY: A real-time mobile phone platform for urban noise monitoring and mapping. Mobile Networks and Applications **15** no. 4. (2010) 562–574.

[27] R. Rana: Ear-Phone? A context-aware End-to-End Participatory Urban Noise Mapping System. June, 2010.

[28] N. Maisonneuve, M. Stevens, B. Ochab: Participatory noise pollution monitoring using mobile phones. Inf. Polity **15** no. 1–2 (2010) 51–71.

[29] Sound Around You. http://www.soundaroundyou.com/.

[30] C. Mydlarz, I. Drumm, T. Cox: Application of novel techniques for the investigation of human relationships with soundscapes. Inter-noise 2011, 1–7.

[31] S. U. degli S. di Napoli: Research Study 06-005-APAT: New methodologies for the evaluation and control of environmental noise in urban sites with the involvement of the population. Final Report.

[32] G. Licitra: Which information for the European and local policy makers? Noise mapping in the EU - models and procedures 2013, p. 1 online resource (xii, 412, [15] of plates).

[33] B. N. J. Postma, D. Poirier-Quinot, J. Meyer, B. F. Katz: Virtual Reality Performance Auralization in a Calibrated Model of Notre-Dame Cathedral. EuroRegio2016, June 2016, 1–10.

[34] A. Cirafici, A. Natalia, V. P. Senese: Acoustic comfort aboard transportation systems. Multisensory evaluation by means of virtual reality and subjective testing. Interaction of colour scheme and noise in the metro interior. Color Color. Multidiscip. Contrib. **VIII** (2012) 119–127.

[35] L. Maffei, M. Masullo, A. Pascale, G. Ruggiero, V. Puyana Romero: Immersive Virtual Reality in community planning: Acoustic and visual congruence of simulated vs real world. Sustain. Cities Soc. (2016).

[36] M. Vorländer, D. Schröder, S. Pelzer, F. Wefers: Virtual reality for architectural acoustics. J. Build. Perform. Simul. **8** no. 1 (2015) 15–25.

[37] M. Vorländer, D. Schröder, F. Wefers, S. Pelzer, D. Rausch, T. Kuhlen: Virtual reality system at RWTH Aachen University. International Symposium on Room Acoustics, ISRA 2010, August 2010, p. 9.

[38] M. Vorländer, F. Wefers, J. Stienen, S. Pelzer: Interactive acoustic virtual environments using distributed room acoustic simulations. EAA Joint Symposium on Auralization and Ambisonics, 2014, 48–55.

[39] D. G. Malham, A. Myatt: 3-D Sound Spatialization using Ambisonic Techniques. Comput. Music J. **19** no. 4 (1995) 58–70.

[40] J. Pablo, E. Hurtado, J. Polack, O. Warusfel: Objective comparison between Ambisonics basic decoding and a SIRR-based parametric decoding in the context of concert hall auralization. no. 3 (2014) 1–10.

[41] G. Kearney, M. Gorzel, F. Boland, H. Rice: Depth Perception in Interactive Virtual Acoustic Environments using Higher Order Ambisonic Soundfields. Proc. 2nd Int. Symp. Ambisonics Spherical Acoust., 2010.

[42] M. Vorländer: Virtual Acoustics: Opportunities and limits of spatial sound reproduction for audiology. Hausdeshoerens-Oldenburg.de **422** (2008) 413–422.

[43] L. Maffei, M. Masullo, A. Pascale, G. Ruggiero, V. Puyana Romero: On the Validity of Immersive Virtual Reality as tool for multisensory evaluation of urban spaces ScienceDirect On the Validity of Immersive Virtual Reality as tool for multisensory evaluation of urban spaces. in Energy Procedia. 6th International Building Physics Conference, IBPC 2015, June 2015, 0–6.

Document downloaded by @DAEL, 2026-11-20 03:57:28 - personal use only

[44] M. Cooper, M. Taylor: Ambisonic sound in virtual environments and applications for the blind people. Eur. Conf. Disabil. Virtual, 1998 113–118.

[45] P. Lindborg: Correlations Between Acoustic Features, Personality Traits and Perception of Soundscapes. Proceedings ofthe International Conference on Music Perception and Cognition, 2012.

[46] L. Maffei, M. Masullo, S. Basturk: New Tools for the Noise Annoyance Assessment of Projects. 2nd Int. Congr. Acoust., September 2010, 2–7.

[47] L. Maffei, D. Fernández, A. Pascale, M. Masullo, V. Puyana Romero: A multisensory tool to evaluate the perception due to the transformation of naples' waterfront. in 45o Congreso Español De Acústica. 8o Congreso Ibérico De Acústica. European Symposium on Smart Cities and Environmental Acoustics, 2014.

[48] S. Axford, G. Keltie, C. Wallis: Virtual Reality in Urban Planning and Design. in Multimedia Cartography, 2001, 283–294.

[49] J. Engel and J. Döllner: Immersive Visualization of Virtual 3D City Models and its Applications in E-Planning. International Journal of E-Planning Research **1** no. 4 (2012) 17–34.

[50] P. A. Winkes, J. C. Aurich: Method for an enhanced assembly planning process with systematic virtual reality inclusion. Procedia CIRP **37** (2015) 152–157.

[51] K. Okulicz: Virtual reality-based approach to manufacturing process planning. Int. J. Prod. Res. **42** no. 17 (2004) 3493–3504.

[52] L. Jiang, L. Maffei, M. Masullo: Developing an online Virtual Reality application for e-participation in urban sound planning. in EuroRegio 2016, June 2016, 13–15.

[53] F. Aletta, E. Margaritis, K. Filipan, V. Puyana Romero, O. Axelsson, J. Kang: Characterization of the soundscape in Valley Gardens, Brighton, by a soundwalk prior to an urban design intervention. Euronoise, 2015, 1547–1552.

[54] F. Aletta, J. Kang: Soundscape approach integrating noise mapping techniques: a case study in Brighton, UK. Noise Mapp. **2** no. 1 (2015).

[55] P. Lercher, B. Schulte-Fortkamp: The relevance of soundscape research to the assessment of noise annoyance at the community level. ICBEN 2003, 2003, 225–231.

[56] A. Ståhle: Sociotope mapping - exploring public open space and its scape planning practice. Nord. J. Archit. Res. **19** no. 4 (2006) 59–71.

[57] L. Lavia *et al.*: Sounding Brighton?: practical approaches towards better soundscapes. Inter-noise 2012, 2012, p. 12.

[58] A. Radicchi: Emotional geography & soundscape studies? Beyond the cognitive approach in (sound) mapping urban spaces. EAEA-11, Track 2, 2013, 267–272.

[59] V. Signorelli: Unfolding the Soundmaps. Suggestions for Representing and Sharing the Sensory Form of Urban Spaces Through Virtual Environments and Web-Mapping Technologies. Proc. Invis. Places / Sound. Cities. Sound Urban. Sense Place, 2014, 153–167.

[60] B. Furht (Ed.): Desktop Virtual Reality. Encyclopedia of Multimedia. Springer US, 2008, 150–151.

[61] B. Furht (Ed.): Immersive VR. Encyclopedia of Multimedia. Springer US, 2008, 345–346.

[62] E. Fassbender, W. Heiden: Atmosphaeres – 360°-Video Environments for Stress and Pain Management. Springer International Publishing, (2014) 48–58.

[63] C. Weissig, O. Schreer, P. Eisert, P. Kauff: The Ultimate Immersive Experience?: Panoramic 3D Video Acquisition. in Advances in Multimedia Modeling, February 2010, 2012.

[64] 360-degree video - Wikipedia. 2017. https://en.wikipedia.org/wiki/360-degree_video.

[65] C. Guastavino, V. Larcher, G. Catusseau, P. Boussard: Spatial audio quality evaluation?: Comparing transaural, ambisonic and Stereo. Proc. 13th Int. Conf. Audit. Disp., 2007.

[66] A. Farina, L. Tronchin: Measurements and reproduction of spatial sound characteristics of auditoria. Acoust. Sci. Technol. **26** no. 2 (2005) 193–199.

[67] D. Cower: Spatial Audio RFC. 2016. https://github.com/google/spatial-media/blob/master/docs/spatial-audio-rfc.md.

[68] Swedish Council for Building Reserach: Acoustic Guide: selection of acoustic quality in buildings, 1996.

[69] C. A. Kardous, P. B. Shaw: Evaluation of smartphone sound measurement applications. J. Acoust. Soc. Am. **135** no. 4 (2014) EL186-EL192.

[70] E. Murphy, E. A. King: Testing the accuracy of smartphones and sound level meter applications for measuring environmental noise. Appl. Acoust. **106** (2016) 16–22.

[71] D. P. Robinson, J. Tingay: Comparative study of the performance of smartphone-based sound level meter apps , with and without the application of a ¡ IEC-61094-4 working standard microphone , to IEC-61672 standard metering equipment in the detection of various problematic workplace. 2014, 1–10.

[72] I. J. M. van der Ham, A. M. E. Faber, M. Venselaar, M. J. van Kreveld, M. Löffler: Ecological validity of virtual environments to assess human navigation ability. Front. Psychol. **6** (2015) 637.

[73] Z. Campbell, K. K. Zakzanis, D. Jovanoski, S. Joordens, R. Mraz, S. J. Graham: Utilizing Virtual Reality to Improve the Ecological Validity of Clinical Neuropsychology: An fMRI Case Study Elucidating the Neural Basis of Planning by Comparing the Tower of London with a Three-Dimensional Navigation Task Technology. Appl. Neuropsichology **16** no. 4 (2009) 295–306.

[74] T. D. Parsons, T. Bowerly, J. G. Buckwalter, A. A. Rizzo: A Controlled Clinical Comparison of Attention Performance in Children with ADHD in a Virtual Reality Classroom Compared to Standard Neuropsychological Methods. Child Neuropsychol. **13** no. 4 (2007) 363–381.

[75] G. Lalonde, M. Henry, A. Drouin-Germain, P. Nolin, M. H. Beauchamp: Assessment of executive function in adolescence: A comparison of traditional and virtual reality tools. J. Neurosci. Methods **219** no. 1 (2013) 76–82

[76] H. Kamide, Y. Mae, T. Takubo, K. Ohara, T. Arai: Direct comparison of psychological evaluation between virtual and real humanoids: Personal space and subjective impressions. Int. J. Hum. Comput. Stud. **72** no. 5 (2014) 451–459.

[77] Ö. Axelsson, M. E. Nilsson, B. Berglund: A principal components model of soundscape perception.. J. Acoust. Soc. Am. **128** no. 5 (2010) 2836–2846.

[78] T. Van Hecke: Power study of Anova versus Kruskal-Wallis test. J. Stat. Manag. Syst. **15** no. 2–3 (2012) 241–247.

[79] J. Cordeiro, Á. Barbosa, A. Santos: A Soundscape Assessment Tool Based on a Massive Multichannel Loudspeaker

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Setup. in Proceeding of Echopolis-Days of Sound 2013: Sounds, noise and music for re-thinking sustainable city and econeighborhood. 2013.

[80] E. Armelloni, P. Martignon, A. Farina: Comparison between different surround reproduction systems. 118th Convention Audio Engineering Society, 2005.

[81] C. Guastavino: Ecological Validity of soundscape reproduction Ecological Validity of Soundscape Reproduction. Vol. 91, November 2004, 0–19.

[82] J. Y. Jeon, P. J. Lee, J. You, J. Kang: Perceptual assessment of quality of urban soundscapes with combined noise sources and water sounds. J. Acoust. Soc. Am. **127** no. 3 (2010) 1357–1366.

[83] L. Galbrun, F. M. a Calarco: Audio-visual interaction and perceptual assessment of water features used over road traffic noise. J. Acoust. Soc. Am. **136** no. 5 (2014) 2609.

[84] M. Raimbault, D. Dubois: Urban soundscapes: Experiences and knowledge. Cities **22** no. 5 (2005) 339–350.

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