Towards sustainable urban sound environment: several case studies in Greece.

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Summary
In the frame on the European directive 2002/49 for the study of the environmental noise, Greece, between 2012 and 2016, had the opportunity to develop a specific methodology in order to analyse the sound environments of several neighborhoods in large and medium size cities of the country : Volos, Larissa, Heraklion, Chania, Agrinio, Corfou and Thessaloniki. This paper presents the multidisciplinary approach used and shows how noise data are cross analysed with urban and architectural data and perception descriptors by inhabitants. It shows how theses results has been implemented in the several noise actions plans proposed to the authorities. Finally, the paper discusses the necessary evolution of this approach, not only to reduce noise exposure problems, but above all, in order to make the city evolve towards the production of sustainable sound environments.

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1. Introduction

The first scientific works on the sound environment can be traced back to the essays of the Canadian composer R. Murray Schafer in his book "The tuning of the world" [1] who was the first to discuss the neologism of soundscape in order to describe "an environment of sound (or sonic environment) with emphasis on the way it's perceived and understood by the individual, or by a society". Since this first definition, the notion of sound environment had the objective of characterizing the perception by a group of individuals that necessarily also depends on a spatial context and a particular culture. This notion has made it possible to propose a qualitative approach to sounds, to insist on the natural dimensions of these landscapes, and above all to propose a way of classifying landscapes in order to preserve them. Within the context of the explosion of the production and operation of means of transport (cars, busses, railways , aircrafts) in Europe and in all the industrialized countries, and the first crises in the energy field, has awakened different social groups and research teams an environmental conscience which marked the beginnings of environmental noise research.
At the same time, in France, in Grenoble, Jean-François Augoyard, in the research center CRESSON, with his young team of acousticians and architects explored, in a similar logic, the notion of sound effect, proposing for the first time a repertoire of sound effects [2] in order to describe the interactions of the sound environment with the actions and the perception of the inhabitants [3]. Based on their work, this group has been able to propose a formalization of the concept of sound environment, including not only the ecological approach of Murray Schafer but also the works in acoustic engineering [4, 5]. Actually, this research aims to define the environment in the way we're interacting with it and it's the reason why it develops this idea of three different dimensions of the sound environment.

- Environmental dimension level describing all physical, emission and propagation characteristics for all types of environmental sound sources including e.g. noise barriers and various propagation obstacles, road surface characteristics,

urban soil media, shape and use of buildings, etc. (see figure 1 as an example). This dimension is quite predictable and permits to evaluate with high accuracy for example the quantity aspect in noise reduction resulting from those mitigation choices. Figure 1 illustrates visually the analysis of the environmental dimension contains e.g. street morphology, building's high, type of soils, width of the urban road, traffic synthesis, human activities etc.

Figure 1: A typical urban road section at Alikarnassos district, Herakleio, island of Krete: the sound environment is mainly determined by road traffic, street morphology, materials and human activities linked to shops and services

- Milieu dimension level (social practices) which aims to describe all the uses that the area already offers and additionally all other that may be offered as well, consisting in acting on a master land use plan level, that welcomes or discourages some distinct uses, such us public open or "intra muros" spaces, restaurants, cafés, bars, public gathering places, schools, playgrounds, markets, allowing multiple events, etc. This dimension level is not fully predictable, but the possibility of choosing to implement or to avoid and even exclude, certain activities, may affect the global acoustic environment.
- Soundscape dimension level, characterizing the most aesthetic and symbolic links that residents establish with the particular sounds of their neighborhood, highly valued by their aesthetic characteristics, such as some natural sounds, city sounds e.g. church bells, markets, schoolyards, etc. This dimension is also quite difficult to predict but it consists an important factor for the success of a broader noise action plan. Figure 3 illustrates visually a location in Chania urban agglomeration (old city port) where both inhabitants and tourists can rest and enjoy the spatial landscape and the soundscape. This view presents the dimensions of the sound environment to focus on. The sources and their relative impact in people's perception are therefore described, in order to understand, in each location, where people may enjoy the full length of the soundscape and eventually the minimal conditions of their existences.

We therefore consider that the notion of sound environment refers to all the sources and sound productions of a place, whether or not covered by the above mentioned European Directive on environmental noise: It includes noises from transports and industrial sites but also human activities linked with the places and sounds of nature. It's for this reason that in this approach a comprehensive method is proposed in order to complete the Strategic Noise Maps (SNM) introducing a series of layers focusing on the qualitative dimensions of the sound environment. The cross analysis of these documents allows to update a noise action plan enriched by for the goal of rehabilitating the sound environment. In this sense a way to create the sound environment of tomorrow and thus propose, beyond the regulations, a design for a sustainable sound environment is assessed.

2. Noise, Environment, Soundscape

Thus for more than 20 years, a double movement in studies on the sound environment is presented. First of all, acoustic engineering is becoming more and more open to other disciplines such as geography, urban planning, statistics and sociology in order to better understand all the dimensions of the problem. In this sense, all the works on geographic information systems (GIS) to represent and manage sound environment are for us an interesting evolution. From the simple geo-localization and the representation of noise measurements on a map [6] to experimental works in order to propose expertized and simplified tools to manage sound environment by authorities [7], most of the research works in this branch are using cartography tools in

order to summarize several analysis and discuss results in between disciplines: acoustics, transports analysis, topography, geography, town planning and architecture. In this logic, Greece developed such methodology since its first SNM in Volos and Larissa (central Greece) [8].

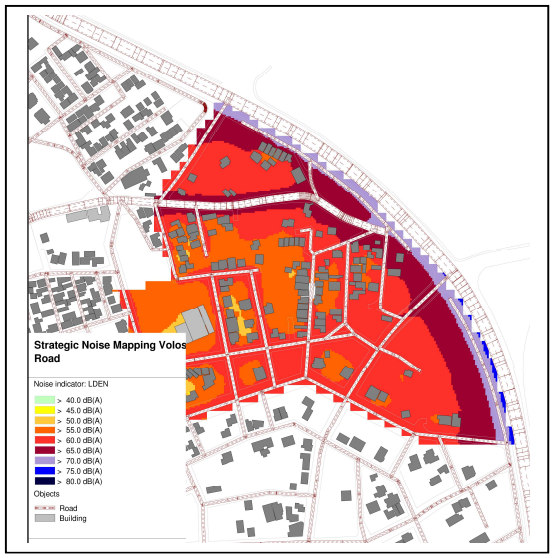

Figure 2. SNM: Lden index simulation in Karagats urban area, Volos, Greece.

At the same time, acousticians and soundscapers are also trying to define criteria in order to assess soundscapes and generalize their studies in multiple and diverse contexts. Many works follow principles tested by room acoustics studies and psychoacoustics [9, 10, 11, 12] and try to find new criteria that can articulate simulation or measured values with perception qualities assessments. For example recent works, as Rychtáriko and Gerrit, [13] try to automatically classify soundscapes through a set of acoustic criteria as "the related to the sound intensity (defined through sound pressure level), temporal changes of the sound, evaluated through roughness and fluctuation strength, frequency spectrum (via the sharpness parameter), and spaciousness via the so-called urban inter-aural level difference". Although significant progress has been made since early work, an in situ approach involves taking into account other variable dimensions such as multisensory perception and user actions [14].

Thus the question put to developers and acousticians should not be limited to the quantitative and qualitative assessment of the environment or of the soundscape. Indeed, it's more a question of giving proposals for spatial planning on issues specific to the sound environment. The European directive has made it possible to set the common bases to try to deal with cases where the sound environment is synonymous with noise (of transport and industrial). How can this directive be supplemented to address qualitative dimensions (not necessarily noisy) of all sound sources in the environment [15].

In this general context, in a significant number of cities and urban agglomeration in Greece proposed between 2012 and 2016 a different approach that is presented hereafter. This approach aims to overcome the inevitable measures of noise control of any NAP in order to also provide a Sound Environment Action Plan (SEAP). In other words, this new form of noise action plan is not only dedicated at reducing by abatement measures the Lden levels in the most "noisy" areas, but it proposes a comprehensive acoustic and non-acoustic actions on selected urban neighborhoods in order to preserve, transform or re-create a sustainable sound environment for the inhabitants.

This paper offers a summary description of the method illustrated by the studies that have been carried out in Volos, Larissa, Heraklion, Chania, Agrinio, Corfu and Thessaloniki [16, 17, 18, 19, 20, 21,22,23] in the frame of the application of the directive 2002/49.

3. Pluridisciplinary methodology and results

In the period 2012 to 2016, in the urban agglomerations of Volos, Larissa, Chania, Heraklion, Corfu, Agrinio and Thessaloniki, such methodology has been applied and implemented in especially selected urban areas due to their special sound identities. In many cases, these urban areas have been chosen because of their proximity to a main axe of transportation (peripheral road and train stations as in Volos, or train lines as in Larissa, or international airport proximity such as Heraklion and Corfu). Some of the UAs have been selected also due to the fact that are expected to experiment a major modification of the existing local network of mass transportation (relocation of the international airport of Heraklion, the opening of the new metro line in Thessaloniki). Some urban agglomerations also were interested to test possible modification and re-organization of their traffic plans (Volos city center, Larissa, Agrinio, Thessaloniki) including also the impact of

mitigation noise measures e.g. noise barriers, introduction of urban roundabouts (Volos) as also street pedestrianization projects (Volos, Thessaloniki). Whatever the particular case studied, in these urban neighborhoods the in depth evaluation of their environmental qualities and relevant noise problems was introduced. The objective of the analysis was, obviously, to evaluate the environmental noise and proposing mitigation measures. But beyond that, these cases studies aimed at the qualitative dimensions of the environment and by setting up a cartography, we propose tools to analyze the existing environment and to propose positive evolutions of the sound environment.

Figure 3: Urban typology map (Yellow: U-form street section, Blue: L-form street section, Brown: for open spaces).

By reducing the scale of the analysis (from the urban agglomeration scale to the neighborhood scale), it was possible to analyze the given district "IN a street by street level", or even "islet by islet and building by building" and therefore access the relation between the existing urban form and the sound propagation. In addition to the SNM approach (figure 2), several type of maps are introduced in order to better understand, the appearance and the propagation conditions of the main sound sources in the selected urban areas.

3.1. Urban typology map

U-shaped or L-shaped section and open road are usually the 3 categories represented in this map and it's aim is to simply represent the third dimension on a 2D map i-e to draw a layer that interests acoustic propagation conditions of sounds (see figure below). This map, to be presented, preferably, on a satellite view background (roster), gives a rapid idea where reflection effect of building's facades can create or not a more or less reverberated urban sound environment. It's a first approach in determining whether the acoustic space of the public spaces, in a given urban area, is rather "closed", "half-closed" or "open".

Figure 4: SNM: Lden simulation (Larissa SNM- Greece - UA of Echekratida): visualization of silence islet in between buildings blocks

3.2 Spatio-acoustic typology map

This map shows how the urban forms can potentially create several acoustic effects (acoustic filters, mask, cutting effect, reserves of silence, urban acoustic room, sound rhythms, etc.). This map is based on a series of *in situ* observations that include acoustic measurements, sound recordings and attentive listening of the site at different times of the day and week.

This map, (see figure 04) for example in the UA of Echekratida in the urban agglomeration of Larissa, private and semi-public space in between the building blocks creates some kind of silence islets

actually because of the mass and the height of the existing buildings. It was important to show that in situ analysis campaigns were executed (sound recordings, observations and interviews), and their results combined with the SNM simulation were able to show that the topography of the district, and the given forms of the existing buildings are able to create easily identifiable sound effects when someone walks through the district. In a global analysis of the soundscape qualities, it's important to show clearly in an appropriate map such potentials of the existing urban form.

3.3 Map of predominant uses

This type of map shows the most prevalent uses of public spaces and buildings: pedestrian streets and alleys, street for both pedestrians and cars circulation in reduced speed, low traffic road, heavy traffic road, shops, offices, cultural, educational, health or religious buildings, etc.

Such map (figure 7) shows how the existing dwellings, crafts, shops, churches, schools, industrial buildings are mixed in an urban area and how they're characteristics of its urban identity. It also gives an idea of the localization of the sound sources that can be heard in the area, e.g. linked with the road traffic noise or industrial equipment operation and also indicating the use of the existing public spaces. For example, the sector shown on the above map (Karagats UA) is actually neutral because it presents the same activities (almost) in the whole area (residential and sports infrastructures).

3.4 Sound signals map and sound marks map

This part of the analysis regarding the sonic qualities assessment by residents and mapping is very important in order to understand how the area's population is living in the existing acoustic environment and how they produce, use and finally receive and evaluate the sounds during their everyday life. This assessment approach uses interviews executed within the local residential population on the basis of a semi-directive questionnaire as proposed in previous publications [19, 20, 22]. For each urban area, individual interviews was conducted based on the same questionnaire, recorded on digital recorder. These interviews were translated in text that has been analysed trough recurrence of meaning principle. Each time, interviewers try to select inhabitants depending where they were living in the neighborhood. Many interviews were conducted. They were analysed systematically and the investigators decided to stop the interviews as soon as the spectrum of possible answers became stable.

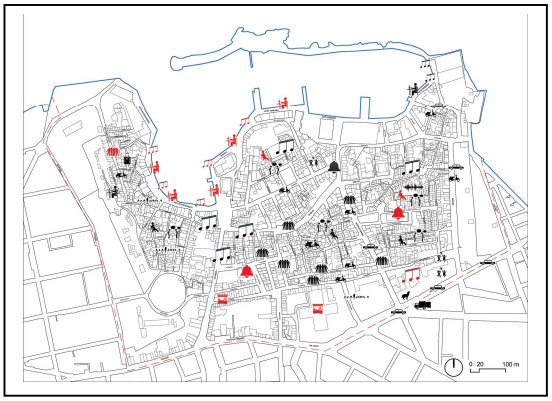

Figure 5 : Sound signals and sound marks Map. Chania.Crete.

Such interviews give us the capacity to develop properly the relevant sound signals and then to constitute a sound marks map that can summarize all transmitted information by the interviewed population. Obviously such a map is not able to represent all possible audible sound sources in an UA. On the other hand it presents the signals and/or sound events identified by the inhabitants, related to the UA activities, even if produced outside its boundaries but clearly perceived in the research area.

All these sounds are audible indications of the sound identity of the given urban area, even if sometimes, some of them can only be heard within its relevant boundaries. They're typical of the area so when these sounds are perceived, some people will realize that they're actually "at home". In this case, we have a "sound mark". It's important to underline that this specific type of map does not actually show any sound sources in order for the map not to become unreadable, due to the fact that its goal is to describe accordingly all that the local people hear. Within all the sounds that one can hear in a day, in a week, or even within a year, some are the most memorable, marking, therefore, the ordinary perception of the district's people. They're either pleasant or unpleasant; but they mark people's minds, being therefore the signs and markers of the sound identity of this particular district Simple icons are used in order to represent

on a map the sounds as they can be heard and produced in the area we study (see fig. 5).

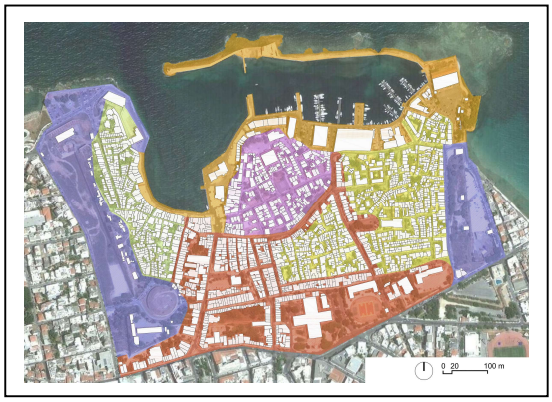

Figure 6 : Sound identity Map. Chania, Crete.

The compilation of all the available interviews can bring out specific inner areas of the district, rather homogeneous, in terms of how sounds are produced and heard within the district. These are the identities that help to describe - on an average level - how, in a specific area, people perceive and produce sounds. For each of them, we try to give a name or a description of the urban area that may characterize its sound environment. This type of map actually aims to summarize in a simplified way all that the interviews have emerged (see fig. 6).

This map is the final one to describe the sound environment and it forces the researcher to synthesize information from previous maps. Indeed, it's difficult to compile on a map the dynamic behavior of the sound environment. However, even if it's constantly evolving, this sound environment differentiates in the ears of the inhabitants. Some recurring points are observable, the conditions of production and propagation of sounds (but also noises from transportation) are also repetitive. It's then possible to determine in a neighborhood one or several sub-areas that characterize, on average, what people can hear and live in these spaces (see fig. 12). In this sense, this map synthesizes the four first and thus gives in a simple form the keys to design an action plan for the sound environment.

By following the previous methodology, for a selected area, it's possible to cross-analyze at a minimum of six distinct overlapping layers of noise maps, including (a) the SNM (b) the Urban Typology Map (c) the Spatio-Acoustic Typology Map, (d) the map of predominant uses (e) the Sound Signal and Sound Markers Map and also (f) the Sound Identity Map. The SNM gives a precise idea of the industrial and traffic noise that characterize each district. The urban typology map completes the previous SNM by introducing an evaluation of the propagation space qualities. Then the Spatial-Acoustic Typology map describes the built environment that might influence the sound propagation creating locally specific sound effects. The Map of predominant uses also add the information on activities spotted within the built environment and the public spaces. This first 5 layers-maps can be cross-analyzed in order to explain how the given built space, sound sources and the activities co-exist in the same urban environment. The two last maps e.g. the Sound Signal & Sound Markers Map and the Sound Identity Map were built by using the contents of the interviews. The creation of these "overlapping mapping" databases in correlation with the quantitative noise measurements, allows an in-depth analysis of the acoustic qualities and the possibly negative sound aspects of the district, clarifying – as well - the reasons for various problems regarding mainly acoustic diminished qualities. They also facilitate the decision making procedure on a local level as well as on the Urban Agglomeration planning level (noise sources, propagation conditions, urban built forms, ground coverings, social dynamics and organization of the district, etc ...). Therefore for each distinct district, an action plan is proposed based on sound analysis identities and SNM. This work is illustrated on an area of the city of Volos that has never been the subject of previous publications and is decomposed according to the three dimensions of the sound environment that we have described in the introduction that is to say regarding to the dimension of the environment, the milieu and the soundsdscape.

4. Conclusions

Such studies are possible to supplement the European Directive 2002/49/EC on environmental noise through a series of approaches, observations and analyses regarding the sound environment. The main aspects of sound quality e.g. stimulus-response compatibility, pleasantness of sounds, and the identifiability of sounds or sound sources are important to addressed within the proposed noise

action plans. The proposed approach complements both the quantitative approach of the EU Directive and the qualitative approach of the urban acoustic environment. It's based on the research of various teams who consider, that the only sources of environmental noise (transport and industry) are not the only ones responsible for the sound quality of the urban environment..

This approach proposes, therefore, further the creation of a series of maps that complete the engineering approach of SNM and NAPs by means related to sound perception, geography, and sociology. To be more efficient, this approach requires, however, additional data to be collected, with emphasis to inhabitants' perception in connection with a series of observations and in situ recordings. It implies that the analysis must be carried out on a neighborhood scale, and for this reason, it may be assumed that a survey done for one neighborhood is not, necessarily, immediately replicable as identic for other neighborhoods. Nevertheless, a comprehensive study of several different neighborhoods may introduce indicators for each district separately but also for the entire urban agglomeration.

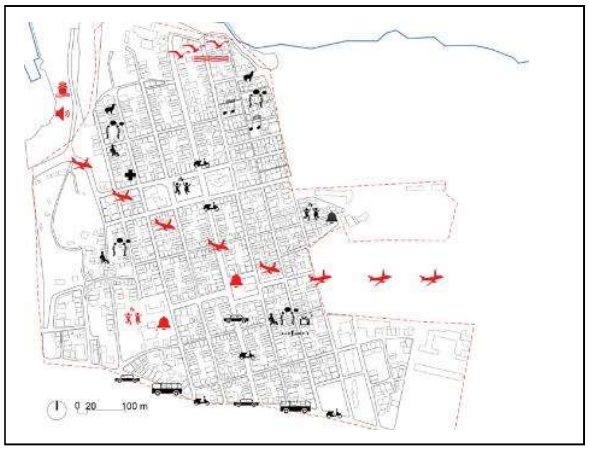

Figure 7 : Sound identity Map. Thessaloniki, city centre.

It's therefore relatively important to properly select the UAs to be further studied "under the microscope". Indeed, it needs to represent both the peculiarities of the urban agglomeration, and the UA, and also to focus on a significant number of development issues. For example, in Volos urban agglomeration, the study focused on a number of districts with variable densities at the edge of an urban ring road which over the years has seen its traffic to be considerable increased. In the same way, in the UA of the Old city, in Volos, presenting actually the main entrance of the city, is directly connected to the city's train station focus was given to the implementation of three major roundabouts in order to further facilitate fluidity of the road traffic. As a result, the proposed solutions can also be generalized to other similar neighborhoods or simply have to engage the authorities in thinking about issues that involve the whole territory: access to public transport, development of several soft transport modes, relocation of transport infrastructures, creation of both recreation and sport facilities, distribution of commercial activities and housing, preservation of parks and gardens, etc. To illustrate this, it can be said that often, in the case of the Greek urban agglomerations, mentioned above, relevant environmental studies proposed the introduction of bicycle networks in order to minimize the use of the private cars and promoting more ecological modes transportation.

Therefore the proposed solutions within the context of the management and rehabilitation of the sound environment are not necessarily from acoustic solutions and mitigation measures. The sound environment requires that we take care of all sound sources and their spaces of propagation and reception by inhabitants. As a result, this approach, must also be open to the expertise of all stakeholders in urban space planning such as architects, urban planners, transportation engineers and politicians.

One can criticize this approach by saying it doesn't not provide an exhaustive and scientific evaluation of the soundscapes of a city. The methodology is generalizable, a part of the resolutions also, but it's important to say that this method does not allow to suggest "miracles" for any type of urban areas and in any context. The method is contextual quantitative and qualitative approach, therefore is strongly dependent on the location trying to articulate acoustic measurements to the live experience of the inhabitants. The purpose of such approaches is to evaluate the minimum conditions for the existence and protection of these sound qualities (acoustic, spatial or social) within the relevant NAP in order to protect them, and further promote them and also proposing new ones. It's actually a quite innovative perspective, aiming to analyses the existing situation and to identify the main features and the design of its development.

In this sense, this methodology allows to reveal what makes a neighborhood specific from the sound point of view avoiding, therefore, actions that could make it neutral, without quality and by producing an indifferent sound environment without interest or curiosity for the inhabitants. We believe that, in this sense, this approach makes it possible to produce sustainable sound environments insofar as they're identified by their inhabitants in which the modifications that we propose are shared by the residents and therefore ready to evolve with them. In this sense, a sustainable sound environment would be an environment with the qualities identified by the inhabitants whose evolution would be sustainable for them.

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