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Modeling Knowledge in Environmental Analysis: A New Approach to Soundscape Ecology

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Abstract: Planning activities are inherently technical, political and organizational exercises, being both constructions of action optimization over time and "social" organizations promoting action. Thus, they require organization and consensus. In this context, the concept of processes that develop based on diffused interactions between different agents appears useful and rather effective. Cognitive agents and reactive agents coexist in a system of relations and interactions. This allows the context in which environmental management and/or planning processes take place to be modeled in its essential parts. Scholars and researchers have often wondered if behavioral proxies of the environment-agent can be singled out for possible inclusion in a multi-agent system (MAS) layout. This challenge is of particular interest today, considering the potential offered by the spread of intelligent sensor networks, able to represent and model various "behaviors" of the environment-agent. Today's growing interest in research in the field of planning is enhanced by an awareness of the complexity issue embedded in planning. In this framework, this paper is realized as a pilot study on the knowledge of sound and soundscapes as elements characterizing the environment-agent in the context of environmental planning processes. The study reflects a contextual difficulty of collecting extensive data in uneasy conditions: nevertheless it reports results and suggestions useful in an innovative MAS-oriented perspective.

Keywords: multiagent-system; soundscape ecology; modeling knowledge; environmental planning

1. Introduction

The recognized complexity of planning knowledge today implies the need for new planning methodologies. The development of multi-agent cognitive processes, in particular when agents are different and dynamically associated to their interaction arenas, can have various implications. In particular, interesting aspects include scaling problems in distributed interaction, continuous feedback on problem structuring (formal, informal, hybrid, etc.) language and representation, the differences between agents [1].

Regarding scaling problems, today there is a growing number of studies on multi-agent interactions within spatial and environmental planning processes. However, the emergence and presence of human agents, who increasingly act jointly with artificial agents in a social and physical environment (for example, with sensors or data mining routines), often suggest the use of hybrid multiagent system (MAS) approaches [2,3].

The controversial yet growing orientation of spatial planning toward so-called "environmental sustainability" has introduced new agents to the development process of plans. Environmental laws and norms, increasingly diffused in many countries, today legitimize wide social participation in planning debates. For example, the diffusion of impact assessment and strategic assessment norms in Europe, from the 1990s onward, has generated a wide discussion arena and also an important opportunity for the development of new technologies.

A variety of social groups—often on opposing sides of the environment context—have access to both technical and political debates. They contribute to the structuring of territorial plans and projects, being able to delay or accelerate them, in an attempt to defend interests often erroneously considered absolute principles [4].

In confrontations and conflicts, a mediation space often emerges, over seen by mediators or negotiators. They play a role similar to the so-called "intermediate agent" figure, well known in logic and computer science literature, which is essential in the coordination of organizations for the development of complex tasks [5].

Currently, neither theory nor practice regarding such planning "multi-agencies" can clarify certain theoretical and practical problems that appear nevertheless significant. Firstly, the democratic, oligarchic, or even aristocratic basis of multi-agencies (expert vs. non-experienced agents, for example [6]) does not have a clear construction and legitimization process, and is open to many theorems or cases of impossibility [7,8]. Secondly, the approach of cooperative compromise to solutions appears "logically" unfit to phenomena that are external to the interactive activities of agents. Thirdly, the principle of emergent properties and the "super-sum of parts", coming from the theory of systems, does not seem always clearly claimable in cognitive domains [9]. These are just some examples of the problems that multi-agencies need to address.

However, plans represent intrinsically technical, political and organizational processes. In fact, they aim to build up evolving lines of action optimization in short to medium and long term; additionally, they involve, shape and even nurture social organizations oriented to action, hence looking at organization and consensus as significant framing characters [10].

In this context, the concept of processes that develop based on diffused interactions between different agents appears useful and rather effective. In particular, the inherent flexibility of the entity-agent concerning its essence (biotic vs. abiotic, physical vs. virtual), type (cognitive vs. reactive), behavior (intentional vs. reflex) allows different agents to be considered different in an integrated hybrid layout managed with an ontological approach. Cognitive agents and reactive agents coexist in a system of relations and interactions that allows the essential parts of the context in which the environmental management and/or planning processes take place to be modeled. It is obvious that modeling an ecosystem to which planning activity is addressed may result in an unmanageable complexity, requiring degrees of simplification and approximation that are incompatible with the objectives of planning itself. However, scholars and researchers have often wondered if behavioral proxies of such environment-agent can be singled out, for possible inclusion in a MAS layout—at least limited to some specific aspects of direct interest of the study or activity at hand [11]. In the case of planning for the management of common resources, this approach is becoming more and more interesting and shared. For example, in the context of water policies the characters shaping the environment-agent pertain to the water resource, whose behaviors and measurement possibilities are well known and have long been shared [12,13]. In recent times, the investigation has been extended to less sectorized domains with noteworthy developments [14–16]. The challenge is also stimulating when considering the increasing potential offered by software engineering and computer science. In particular, today, the spread of intelligent sensor research allows the construction of sensor networks able to represent and model various "behaviors" of the environment-agent, to detect and measure its elements, whether biotic or abiotic, to detect, measure, and sometimes even to identify/discover relationships that are ontologically and/or mathematically formalized [17,18]. Today's growing interest in research in the field of planning is enhanced by an awareness of the complexity issue embedded in planning.

The knowledge-to-action process "theorized" by Friedmann [19] implies that the consequences of actions undertaken without a thorough knowledge mirroring the complexity of the environment would be uncertain, or could even be dangerous in the long run. Scenarios built with the aim of planning the development of a community based on a sustainable use of resources would be found to be ineffective, on that basis. Particularly, when dealing with the ecological footprint of human settlements, the behavior of the environment-agent is essential to simulate and implement planning processes.

In this framework, this paper focuses on the knowledge of sound and soundscapes as elements characterizing the environment-agent in the context of environmental planning processes.

Traditionally, at the design and planning levels, the role of sound is largely subject to a concept of sound as *a sensation from which to defend oneself.* The legislation is largely consistent with that interpretation, too: the "noise plans" and the European legislation on environmental acoustics, in fact, confirm that restricted view.

However, this simplification appears out dated today. Nowadays, the quality of urban life depends little on the intensity of auditory sensations, and the pursuit of silence does not automatically imply an improvement in acoustic comfort. A place completely free of acoustic sensations, for example, could generate feelings of discomfort at a physical and mental level, maybe because of its unnaturalness.

The study of sound in a closed environment is normally based on a fundamental concept: how can the sound produced by various sources be used to determine the dynamics between the anthropic and natural worlds? Under a MAS perspective, as mentioned above, this question becomes significant and structural in processes of spatial organization and management of complex environments such as urban settlements.

An analysis was therefore carried out in order to evaluate the dynamics of competition or cooperation that are established between the above environments, analyzing natural sound, as an indirect indicator of the present biodiversity character [20]. Despite the contextual difficulty of collecting extensive data in non-ideal conditions, the results of this study could provide useful pointers for planners working in an innovative MAS-oriented perspective. The selected case study is the Regional Natural Park of Lama Balice, in the metropolitan area of Bari. The following section of this paper analyzes the theoretical and methodological background of sound perception and soundscape ecology studies. Then Section 3 describes the above-mentioned case study, with methodology issues and the discussion of results. The paper ends in Section 4 with some concluding remarks and research perspectives.

2. Theoretical and Methodological Background

The sounds of nature, which are inextricably linked to environmental quality, are dramatically influenced by a variety of human activities. Technological improvements, including automated recording devices, very high capacity low-cost storage, developments in the processing of acoustic data and the emergence of new theories related to landscape ecology, have given a significant drive to research in this field. The natural environment analysis methodology is based on the principles of Soundscape ecology, and conducted by means of specific interfaces known as sonometers which allow a qualitative analysis of photometric and spectrographic recordings made in situ.

In [21] (p. 205), Schafer acknowledges that "sounds are characteristic features of the landscape, able to reflect the natural processes that govern them", allowing the assignment of a soundscape to a specific geographical context, the identification of its anthropogenic and biological processes and the study of the spectral and temporal patterns which emerge.

The perception of contemporary urban landscape is a complex phenomenon: the resulting image, by which we identify a city today, is the result of a combination of different synesthetic sensations.

Landscape is dynamic and ever changing, determined not only by natural processes, but also to a great extent by human-controlled processes, which are, unfortunately, governed by economic and cultural factors [22].

Sound landscape in particular is subject to constant change, a tendency which is amplified in large urban areas, especially in cities. The soundscape has thus become a cultural invisible and intangible property, which changes in response to factors as diverse as the level of human activity and the succession of natural phenomena.

Michael Southworth writes, in a famous seminal precursor work on soundscapes: "In this historic period, in which technological progress is transforming the sounds of the city into one confused noise it is not enough to design environments that only meet the visual perception" [23] (p. 49).

In the same article, he describes studies on a heterogeneous group of people's auditory perception of Boston, in order to explore the consequences of auditory stimuli on the quality of urban life. The subjects (blind, visually impaired, deaf and hearing people) were pushed around the city on a wheel chair by a guide. Southworth's goal was to identify the changes in the soundscape of the city in function of the time of day and the changing weather conditions. The conclusion of this study was, as might be expected, that the temporal and meteorological factors clearly influenced the perception of the urban soundscape.

Furthermore, Southworth deduced from the results that "the visual experience of the city is closely related to the sounds that accompany it" [23] (p. 65). In his studies, the route taken was described as a "journey" in the city, but the primary goal of Southworth was to determine what it was possible to understand about the city by simply listening, in order to determine what were the favorite and most-hated sounds and noises of city users, and in what way the sound and visual environments are interrelated. This way of walking through the city, paying attention to all the visual and acoustic stimuli, is thus defined as a "soundwalk".

More recently, soundscape ecology has been described by including different sounds, namely biophony, geophony and anthrophony, emanating from a given landscape to create unique acoustical patterns across a variety of spatial and temporal scales. Attempts have been carried out to build indices such as NDSI as means to differentiate between, e.g., anthrophony and biophony [24].

One of the first known attempts to quantify the different biological varieties which characterize the soundscape was analyzed by Krause et al. [25]. Conducted at the "Sequoia National Park", California in 2002, the study was the first attempt at examining different sources of sound in different ecosystems.

It employs several techniques of listening, scoring and then analyzing the spatial-temporal patterns of sounds. Conducted with support from the U.S. National Park Service, the study included sounds from animals, the wind, rain and streams, along with sounds from humans (mostly from aircraft).

Animal behavior is related to cognitive and ecological landscapes in the paper by Farina et al. [26]. Francis et al. [27] describe a study that examines occupancy and nesting success of noisy and quiet landscapes. They found that occupancy of two species of birds, the gray flycatcher (*Empidonax wrightii*) and the western scrub jay (*Aphelocoma californica*), was lower near the location of chronic gas well compressors. Nesting success of the western scrub jay was higher in noisy environments, possibly as a result of reduced predation on adults or nestlings. They also compared noise levels in areas where sound barrier walls were erected and concluded that these substantially reduced the "footprint" of gas well compressor noise.

The sounds that are emitted from the landscape vary in function of time and space. Forests, grasslands and many other natural environments support a wide range of sounds, which differ for every kind of creature living there: mammals, birds, amphibians and insects [28]. The most dramatic changes are due to the evanescent and unstable nature of the acoustic space, as it depends on the weather.

To try to understand thoroughly a soundscape complex, it is necessary first to identify its component aspects, and then to determine the number of different noises and their relative volumes, the various scales of the process (location, landscape, countrywide) and its socio-ecological value.

3. The Study Case

3.1. General Framework

Natural areas close to cities are traditionally considered as endangered environments. In fact, relationships with the urban area are set up and often develop in dangerous terms for plant and animal species. Garbage and sewage dumping, and erosion are some wide spread damaging features. However, it is typically a two-way relationship, and the positive "green lung" effect toward cities is notoriously decreasing as cities' ecological footprints increase. Different agent profiles are active in carrying out such relationships, both in the urban and in the natural environments, so that a MAS-based approach can plausibly investigate on their aspects, causes and possible dimensions. From the urban settlement side, agents play manifold roles and activities, depending on the size and quality of impacts received and delivered from/to the near natural environment. For possible profiles and hierarchies of agents to be explored in this sense, reference can be made to the (scant) field literature [29]. On the other hand, modeling a natural environment from a MAS-approach point of view is a very hard task, as commonly known and reported in literature [30]. However, recent experiences have based modeling attempts on selected environment's "behaviors", i.e., features that can be monitored and represented through dynamic indicators and that can be seen as proxies for the "environment agent" in the specific relational model to be built [31].

The context selected for the present study is particularly interesting in this sense, being rich in biological and ecological complexity, in terms of both specific natural features and signs of anthropic impacts. When such features can be valued and represented either qualitatively or quantitatively during their dynamic evolution, they can be structured in a frame of linkages with urban agents in terms of mutual relations and activity exchanges. This situational condition allowed the setting up of a MAS-based framework to explore the urban-environmental system of Lama Balice. In particular, the soundscape "behavior" of the environment area was measured and analyzed, in order to infer impacts and possible scenarios on this complex rural-urban nexus.

3.2. The Soundscape of the Regional Park "Lama Balice"

Given the complexity of the Apulian territory, characterized by a series of shallow karst valleys known as "lame" which run down to the Adriatic, the Lama Balice Regional Natural Park was chosen as the focus of this study.

The Regional Natural Park is a protected area of 495 hectares located in the province of Bari.

Lama Balice is a geographic natural and historical entity. Over the centuries it has periodically been used by the nearby city as an open urban waste dump, ignoring its real beauty and environmental value. The Lama is one of the most significant karst phenomena of central Apulia.

The park takes its name from Lama Balice which, with its 37 km length is one of the longest shallow karst valley sin the province (Figure 1).

It originates in the Bitonto municipal area, and even in this initial section it has all the characteristics of a typical Apulian "lama". It is oriented in a SW-NE direction, sloping down towards the sea and has two morphological configurations: one is shallower and more sinuous, while the other, in which the incision increases appreciably, is characterized by steep cliffs where the stratified limestone can be observed. Here, there are natural occurring caves, which still retain traces of ancient prehistoric settlements, to which numerous manmade excavated or expanded caves have been added. Similar phenomena can be observed in the remaining 40% of the lama, which is in the territory of Bari, the regional capital, including the Chianchiarello caves, which are an important testimony of Paleolithic settlements in the metropolitan area. The karst nature of the whole area is evident from the presence of these numerous natural and manmade caves. Moreover, there is also abundant evidence of habitation of the territory in historic times, as the entire Lama Balice basin is characterized by medieval houses, churches and farms.

It can immediately be observed in Figure 2 that the context in which this natural park lies is almost entirely shaped by human activity, between the airport site to the northwest and the city, which has sprawled right up to the boundaries of the lama.

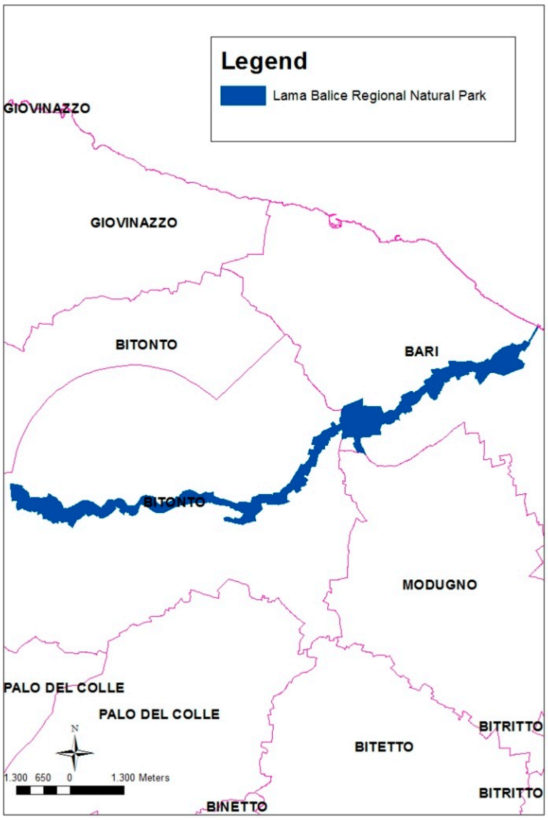

Figure 1. Extension of Lama Balice regional natural park area.

Figure 2. Orthophotos of Lama Balice boundaries and neighborhoods.

Indeed, the natural path of the lama has in fact been changed as a result of the development of the metropolitan city of Bari and its numerous and ever more imposing road and rail infrastructure. All this significantly impairs the water drainage role that the lama naturally plays.

As stated above, some sections of the lama are low and sinuous, while others are steep and have a remarkable rocky stratification providing a variety of habitats. The lama, which serves as a rest area for migrating birds, is cultivated in some sections, while others maintain the original Mediterranean maquis (Kermes oaks, holm oaks, Macedonian oaks, and various shrubs), making the lama one of the most interesting naturalistic areas in Apulia, and whose biodiversity is a treasure to be jealously guarded. The lama is rich in plant species which have disappeared elsewhere, and have survived here as a result of the inaccessibility of certain parts of the lama and the natural conditions which prevail therein.

3.3. Materials and Methods

Starting from the above research framework, an exploration and possible evaluation of the complex natural/urban environment of the area of Lama Balice through the study of its soundscape becomes significant. Therefore, a careful analysis was carried out to choose the most representative locations to be considered.

Nine points of the Lama Balice area were selected, evenly distributed from its mouth to the central section, taking into consideration its natural-artificial lay-out and analyzing only the areas closest to the metropolitan area of Bari. In particular, the natural environment of the lama was divided into three sections, and a point was selected to represent each section, the first labeled "Foce Lama Balice", the second "central Lama Balice" and the third "Lama Balice". For each section, a further two points were then chosen, as representative of the surrounding artificial environment, one on each side of the lama, in correspondence with the selected point in the lama itself (Figure 3).

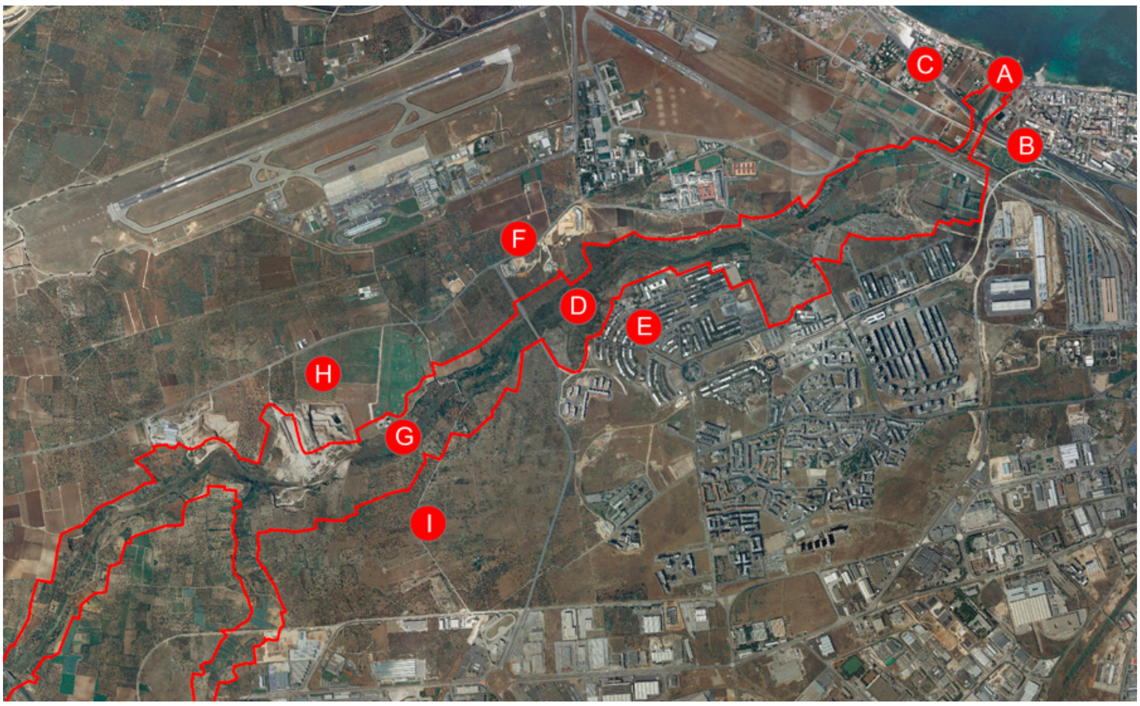

Figure 3. Locations of the selected monitoring points.

The exact geographic coordinates of each point were obtained by means of GPS SAT and are shown in Table 1.

Table 1. Description of monitoring points with reference to N, E coordinates and height.

Point	North Coordinate	East Coordinate	Height (m)
A—Mouth Lama Balice	41°08′25″	16°48′28.4″	8
B—Built-up urban area	41°08′13.5″	16°48′49.7″	−6
C—Holiday Homes	41°08′46.1″	16°47′41.8″	0
D—Central Lama Balice	41°07′57.7″	16°47′32″	16
E—Built-up school	41°07′44″	16°46′57.7″	40
F—"Parco dei Principi" Hotel	41°07′55″	16°46′27.2″	6
G—Lama Balice	41°07′21″	16°45′59″	41
H—Agricultural area	41°07′21.7″	16°46′10.7″	57
I—Suburban area	41°07′33.6″	16°45′26.4″	65

The measurements were performed for a given reference time (T_R), defined in accordance with Annex A (Ministerial Decree, 16 March 1998) as part of the day in which measurements are taken. The duration of the day was divided into two reference times: day time between 06:00 and 22:00 and nighttime between 22:00 and 06:00. The observation time (T_O) was also defined, i.e., the time period in which the noise conditions to be evaluated occur during the T_R. Finally, T_M is defined as the measurement time of duration equal to or less than the time of observation, as a function of the variability in the noise characteristics, in such a way that the measurement is representative of the phenomenon.

The equivalent continuous level of weighted sound pressure "A" relative to long-term time (L_{Aeq}, TL) can be reported:

(a) to the mean value over the whole period, with reference to the equivalent continuous level of weighted sound pressure "A" relative to all the time TL, expressed by the equation:

$$L_{Aeq},\ TL\ = 10log\log\left[\frac{1}{N}\sum_{i=1}^{N}10^{0,1\ (L_{Aeq},\ T_R)i}\right]\text{Db} \tag{1}$$

where N are considered reference times; and

(b) to the single time interval in T_R. In this case a 1-h T_M is located within the T_O, in which the phenomenon in question takes place. ($L_{Ae}q$, TL) is the equivalent continuous level of weighted sound pressure "A" resulting from the sum of the M measurement times T_M expressed by the following equation:

$$L_{Aeq},\ TL\ = 10log\log\left[\frac{1}{M}\sum_{i=1}^{N}10^{0,1\ (L_{Aeq},\ T_R)i}\right] \tag{2}$$

where i is the single 1-h interval in the ith TR.

According to this legislation, the measurement of the continuous equivalent level A-weighted sound pressure "A" in the reporting period ($LAeq$, T_R) is given by:

$$T_R = \sum_{i=1}^{n}(T_o)_i \tag{3}$$

This can be performed either: (a) by means of continuous integration where the L_{Aeq}, T_R is obtained by measuring the ambient noise during the entire reference period, with the exclusion of any interventions in which abnormal conditions occur, which are not representative of the study area; or (b) with the sampling technique, where the L_{Aeq}, T_R is calculated as the average of the values of the equivalent continuous level of weighted sound pressure "A" relative to the intervals of the observation time (T_O) i. The L_{Aeq}, T_R is given by:

$$L_{Aeq},\ T_R = 10\ \log\left[\frac{1}{T_R}\sum_{i=1}^{n}(T_o)_i 10^{0.1 L_{Aeq,\ (T_o)_i}}\right]\text{dBA} \tag{4}$$

According to the legislation itself, the measuring method detects values (L_{Aeq} and T_R) representative of ambient noise in the reference period, the area in question, the type of the source and of its noise emission propagation. The measurement must be rounded up to 0.5 dB.

The tool used was a "Solo" type sound level meter, a unidirectional receiver which records sounds generated by a source placed in front of it, with a frequency range from 100 Hz to 5 kHz.

Having chosen recording points which move from less natural to more natural areas, it was expected that the analysis of the results would show to a continuous lowering of the maximum sound level in terms of decibels (dB). This analysis was carried out through the study of spectrograms, processed with the software associated with the sound level meter, dB Trait, which allows the recognition of TC (tonal components) and IC (impulsive components) in accordance with MD16/03/98.

In particular, the following sections outline the data that were taken into account.

3.3.1. Time-History

This is a sound level lot measured in dB (calculated according to a time base defined by the user) as a function of time. This plot not only gives an overview of a sound climate for a certain environment, but also provides an in-depth description of specific noise events (Figure 4).

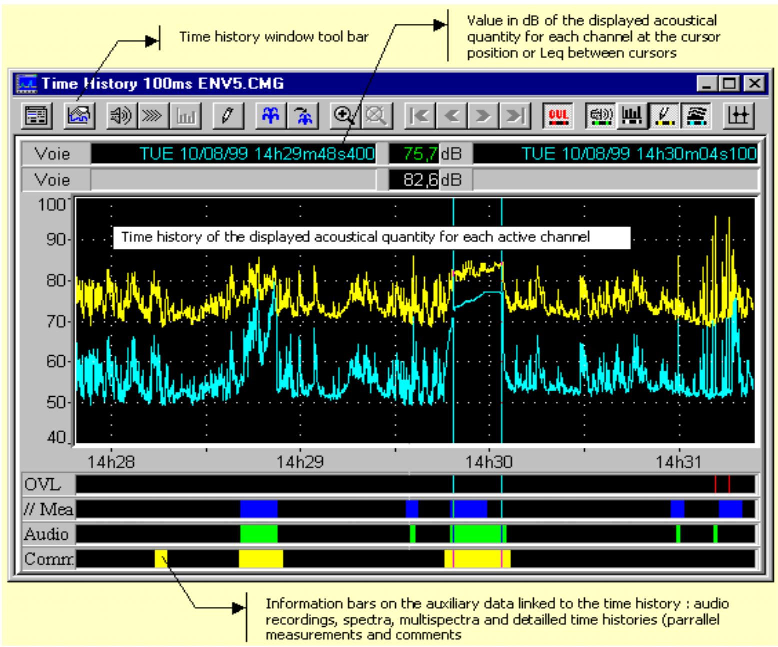

Figure 4. Time-history example.

3.3.2. Sound-Spectrum

This is a sound level lot measured in dB according to frequency band (calculated according to a time base defined by the user) as a function of time. These sound levels are given for each octave or third octave, frequency bands of the acquired spectrum, allowing a chronological history to then be established for each frequency band. This plot offers an overview of a sound climate for a given environment, with the frequency domain information. The spectra relative to the average sound, maximum and minimum sound level can also be determined (Figure 5).

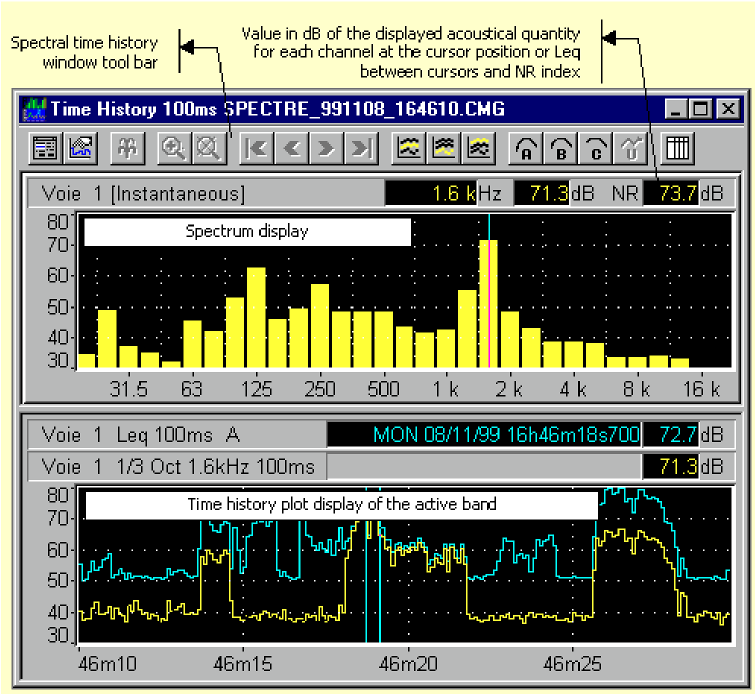

Figure 5. Sound-spectrum example.

3.3.3. Leq and Ln

These determine the sound level equivalent and statistical indices referring to certain fractiles, in particular L95, L90, L50, L20, L10, L5 and L1 were analyzed. By the term fractile, the value of the random variable corresponding to the percent chance of being exceeded is mceant, i.e., the value above which the percent of random values falls. The sound level recorded at L95 can be regarded as the "background sound" to any given environment, as opposed to its L1, which is understood as "disturbing noise", and thus does not belong to the standard of the same environment.

3.4. Results

The data collected for each of the nine recording location points are presented below, together with a brief description of the habitat located at the data collection point. The results are then analyzed and discussed in the following section.

Nine monitoring points were chosen, as it was considered interesting to move first within the Lama environment. Initially, the three most "natural" points were chosen ("Mouth Lama Balice", "Central Lama Balice" and "Lama Balice") and the soundscape for each of them was recorded, whenever it underwent changes with respect to the previous point. Changes relate in particular to the natural landscape, in terms of biodiversity. Subsequently, for each of the three points the two most "artificial" points were chosen, respectively right and left of the "natural" point.

We are dealing here with an innovative pilot study and therefore, considering the amount of data used, a proper statistical analysis could not be regarded as significant. The analysis was developed using an empirical and qualitative approach.

3.4.1. Mouth Lama Balice

The mouth of Lama Balice is the final part of the Regional Park, it consists of a highly disturbed artificial tract. It has a forest coverage rate of 50%, with plant species such as *Typha*, *Phragmites austrialis*, mixed algae, and a few tufts of beached *Posidonia oceanica*. There are also several animal species such as the ringed plover (*Charadrius hiaticula*) and various gull species.

The sound measurements began at 16:01 and terminated at 16:06, providing the following time history (see Figure 6), from which it can be seen that a maximum noise level of 70.6 dB and a minimum sound level of 46.3 dB were recorded. The background sound is identified by use of the average spectrum, which identifies a sound level whose L95 is 49.7 dB.

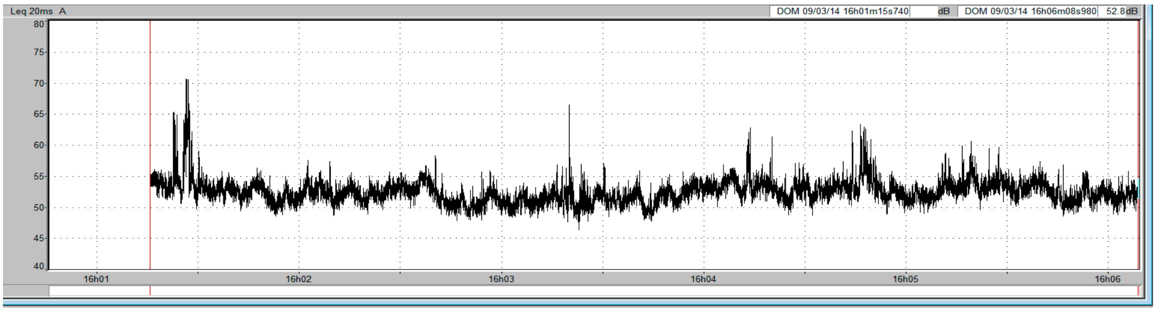

Figure 6. Time history "Mouth Lama Balice".

3.4.2. Built-up Urban Area

The built-up urban area is a populated area, strongly characterized by "noise" and by the presence of buildings of considerable height. It has a near-zero forest cover, in the order of 2%, with a limited flora and fauna, including various palm spp and numerous starlings (*Sturnus vulgaris*).

The measurements started at 16:21 and terminated at 16:27, with the following time history (see Figure 7). A maximum noise level of 82.8 dB was recorded with a spectrum defined as having a minimum sound level of 39.5 dB. The background sound is identified by use of the average spectrum showing a sound level identified with an L95 of 42.9 dB.

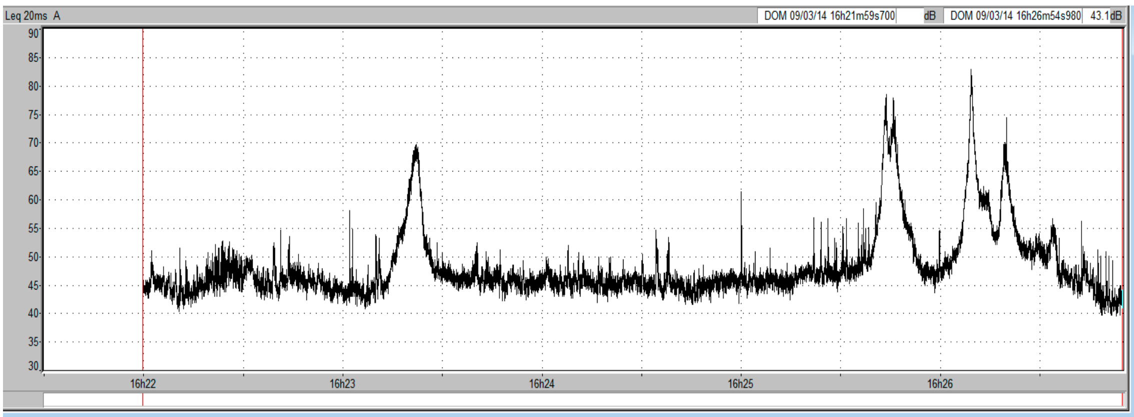

Figure 7. Time history "Built-up urban area".

3.4.3. Holiday Homes

The point "holiday homes" is a populated area, lying between the coast and State Route 16, which has been subjected to illegal construction phenomena. It lacks forest cover, while animal species present include turtledoves (*Streptopelia turtur*) and Italian sparrows (*Passer italiae*). Measurements started at 16:47 and terminated at 16:53, with the following time history (see Figure 8). A maximum noise level of 63.6 dB was recorded, with a minimum sound level of 48.4 dB. The background sound, detected through the use of the average spectrum shows a sound level identifiable with an L95 of 51.7 dB.

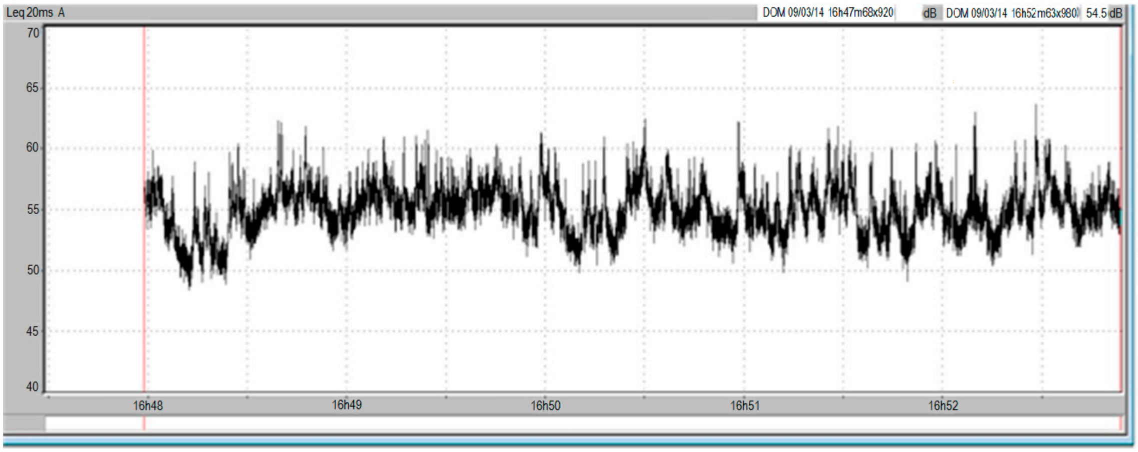

Figure 8. Time history "Holiday Homes".

3.4.4. Central Lama Balice

Central Lama Balice is predominantly a natural area, with a forestation rate of 70%, in particular consisting of olive trees (*Olea europaea*), downy oak (*Quercus pubescens*), and holm oak (*Quercus ilex*). Measurements started at 17:38 and terminated at 17:43, providing the following time history (Figure 9).

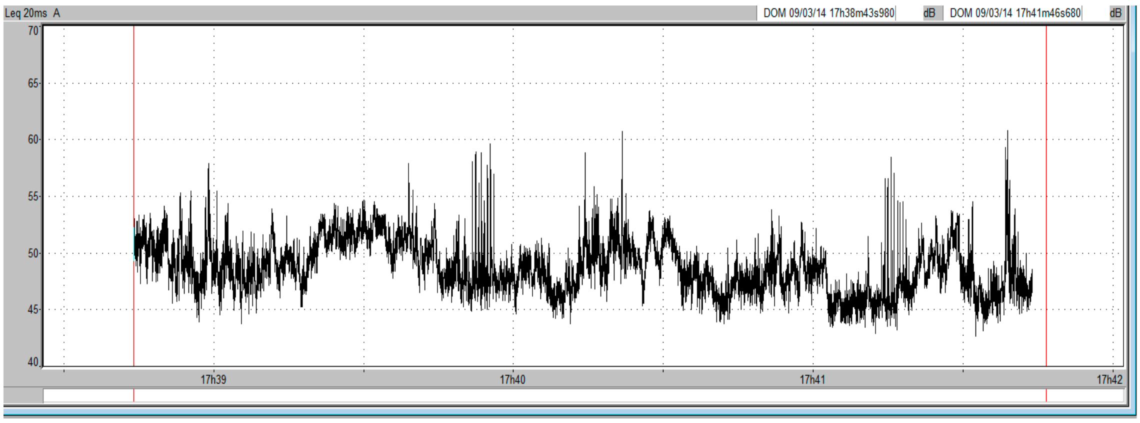

Figure 9. Time history "Central Lama Balice".

A maximum noise level of 60.8 dB was recorded, with a minimum sound level of 42.6 dB with its spectrum. The background sound is identified by means of the average spectrum that shows a sound level identified with an L95 equal to 45.2 dB.

3.4.5. Built-Up School

The point identified as "built-up school" is located near a school, with a low forest coverage of 10%. Measurements began at 09:45 and terminated at 10:00 with the following results summarized in the following time history (Figure 10). A maximum noise level equal to 70.4 dB was recorded, whose spectrum shows a minimum sound level of 37.8 dB. The background sound is 40.7 dB.

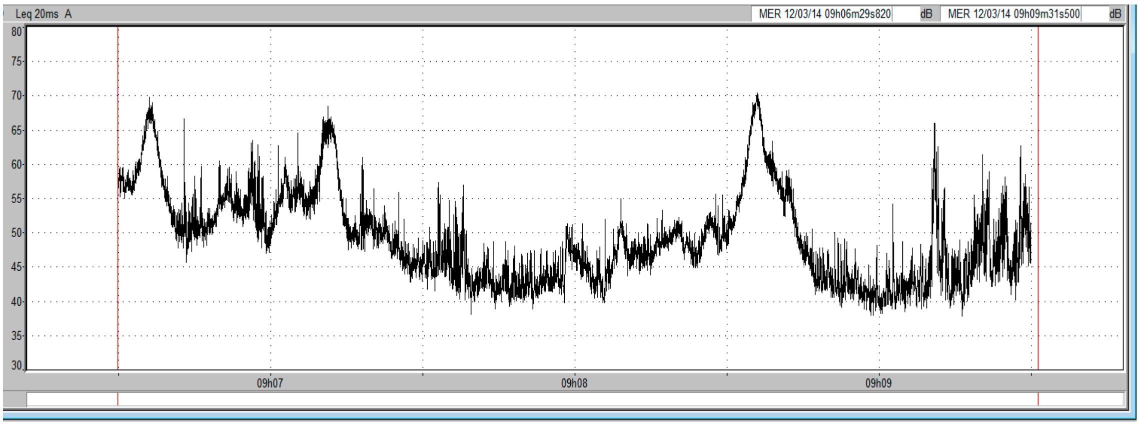

Figure 10. Time history "Built-up school".

3.4.6. "Parco dei Principi" Hotel

The "Parco dei Principi" Hotel is an imposing building structure overlooking the Lama Balice. The local context is represented by arable land lying fallow with a total coverage of 30%, and is devoid of animal species. The recording started at 17:48 and terminated at 17:53. Its spectrum is shown in Figure 11. The maximum sound level recorded was 76.5 dB, while the minimum level was 47.4 dB. The background sound has an L95 of 52.3 dB, identified by the average spectrum.

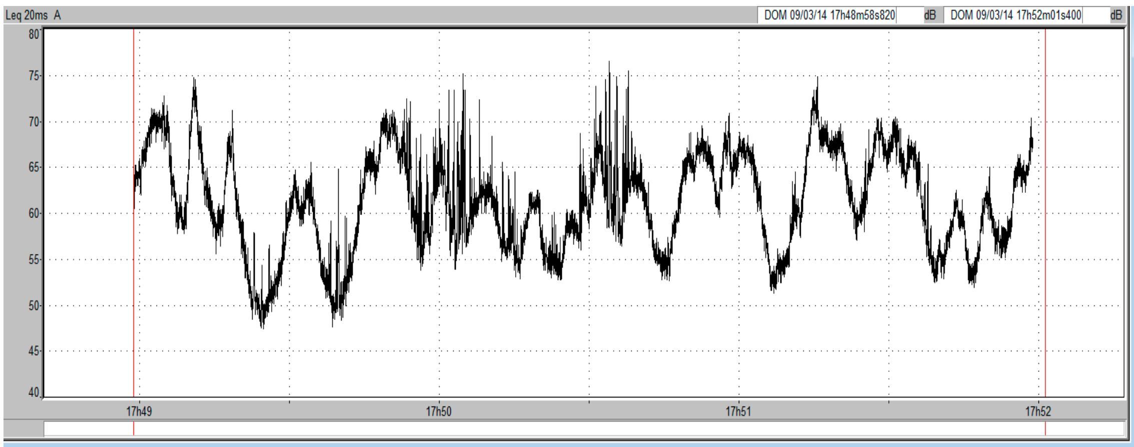

Figure 11. Time history "Parco dei Principi" Hotel.

3.4.7. Lama Balice

The center of the Natural Regional Park is characterized by the highest percentage of vegetation, rich in olive trees (*Olea europaea*), downy oak (*Quercus pubescens*) and holm oak (*Quercus ilex*). Among the animal species Cetti's warbler (Cettiacettia) has been identified. It is situated near the airport, a source of very loud noise. The recording started at 18:01 and terminated at 18:04 (Figure 12). The peak which very easily noted, is 59.1 dB, while the minimum level is 35.5 dB. In this case the natural sound will not vary much with the upper limit, the L95 fractile, for which a value of 35.2 dB was found.

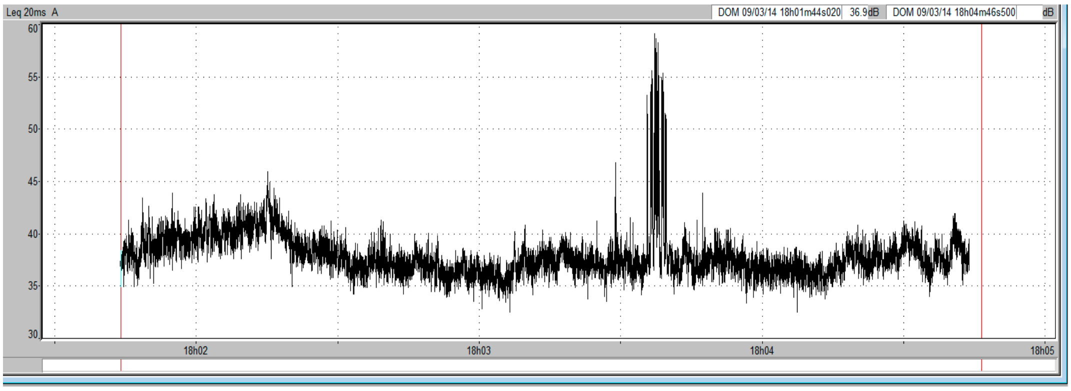

Figure 12. Time history "Lama Balice".

3.4.8. Agricultural Area

The point monitored identified as "industrial area" is not far from the city center. It is, in fact, characterized by mainly agricultural land, being the least built up section of the industrial zone of the city. It is also characterized by a constant stream of vehicles, given the importance of the road that passes through it, which links the cities of Bari and Bitonto.

Measurements began at 09:45 and terminated at 09:48. The time history shows the following results (Figure 13), the maximum sound level recorded was 78.7 dB, while the minimum was 39.3 dB, with an average spectrum sound level at L95 of 43.5 dB.

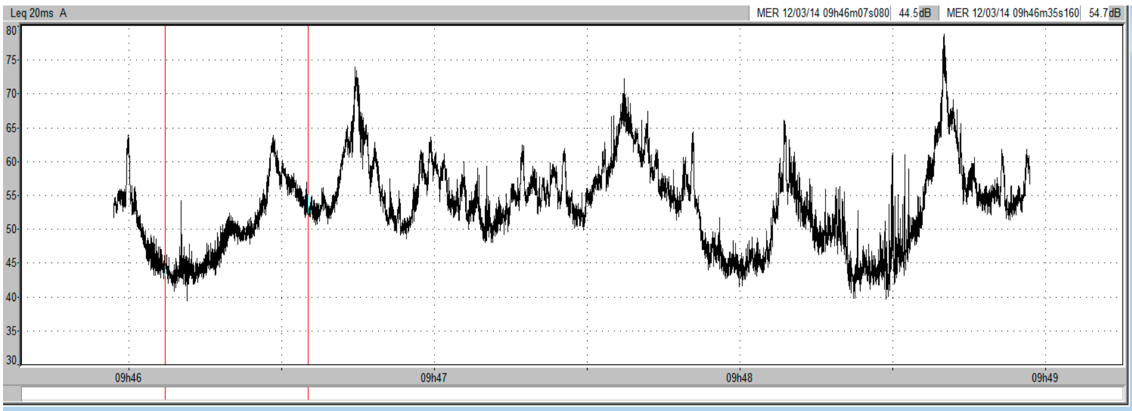

Figure 13. Time history "Agricultural area".

3.4.9. Suburban Area

The point defined as "peri-urban area" is in an area outside the current urban sprawl, characterized by a high index of vegetation. The recording started at 10:12 and finished at 10:15. The time history (Figure 14) below shows a peak noise level of 67.6 dB, while the minimum level was 36.2 dB. The measurements show that the average spectrum is characterized by a sound level at L95 of 38.5 dB.

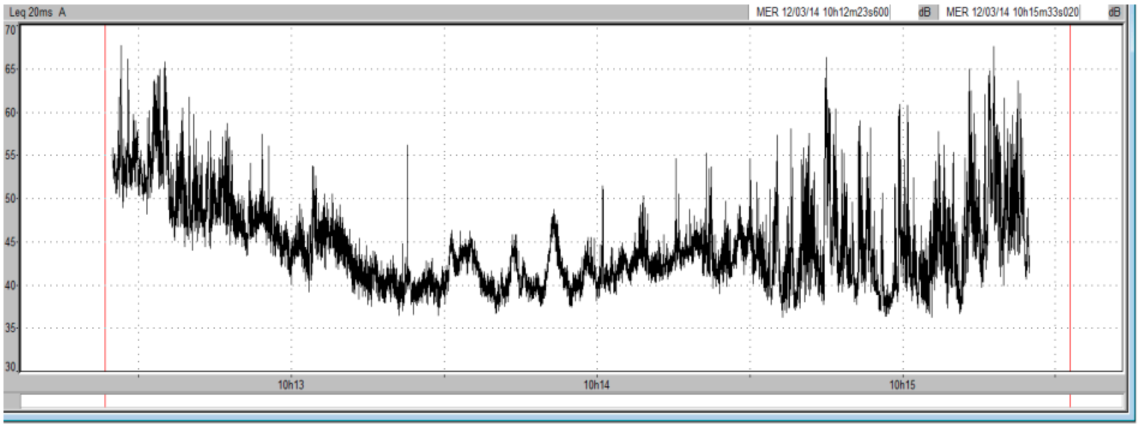

Figure 14. Time history "suburban zone".

3.5. Discussion

The data processed previously were studied applying the regulations issued by noise pollution legislation 447/95. A brief summary of these regulations follows.

Ambient noise is described by equivalent continuous level of weighted sound pressure "A" relative to the L_{Aeq} and T_M measurement time; environmental noise and residual noise must have the same reference and acquisition characteristics.

Levels measured on the L_A ambient noise apply the correction factors for the presence of tonal components, low frequency components, an impulsive character and the presence of noise with reduced duration

$$L_C = L_A + K_I + K_T + dB \quad (5)$$

In this study, we determined absolute limit values of input L_{eq} in dB_A (Art. 3 DPCM 14/11/97) by applying this correction factor.

The absolute limit input values, referring of course to the characteristics of a given area, must be respected at every point of the territory, unless restrictions or exceptions have explicitly been granted by the competent authority. Thus, if the absolute limit input values compared with the environmental noise level L_{Aeq}, T_R (encompassing the level of all the events which occurred, without exception, as a reference contained in paragraph 11, Annex A, DM 16.03.98) are respected, the survey and testing can be stopped regardless of whether it is "in correspondence with the spaces used by people and communities".

The absolute limit values of emission L_{eq} in dB_A (Article 2 DPCM 14/11/97) are also prescribed.

The emission limit value is the maximum value of noise that may be emitted from a single sound source, measured in the vicinity of the source, as defined in Article 2 paragraph 1 letter e) of the Law 26/10/1995 n. 447.

The measurements and checks are to be carried out at the "spaces used by people and communities".

Having summarized the legislative framework, it is now possible to correlate the results obtained with the input and output limits, depending on whether the data refer to a natural area or in a predominantly man-made area.

The time history allowed us to understand if there were sound variations within a given time, chosen subjectively. In most cases, this time was recorded for 5–6 min, except for three points belonging to the same "band", i.e., "Lama Balice" (the natural area), "Agricultural area" and "Suburban area" (the populated areas), because no significant changes were detected beyond 3 min.

What emerges is that Lama Balice, although defined as a protected area, is in fact subject to numerous stresses (see Table 2). One such stress condition can be easily connected to the maximum sound value of 59.1 dB recorded in the Park in a supposedly totally natural atmosphere, with peaks of 70.1 dB and 60.8 dB, respectively, at the lama mouth and near central Lama Balice, respectively. These are non-protected environments, subject to noise pollution as it is easy to verify with the limits on those. The peaks that characterize the corresponding time histories are not natural and therefore reasonably attributable to anthropogenic action. In particular at the mouth of the *lama*, there are significant disturbances caused by the continuous automotive passage resulting from the presence of State Route 16, but also due to the state of degradation of the environment. This part has been completely abandoned to itself, and it is for this reason that it has become effectively an illegal tipping area (Figure 15).

Table 2. A synthesis of case-study findings.

Point	Maximum Noise Level
A—Mouth Lama Balice	70.1 dB
B—Built-up urban area	82.8 dB
C—Holiday Homes	63.6 dB
D—Central Lama Balice	60.8 dB
E—Built-up school	70.4 dB
F—"Parco dei Principi" Hotel	76.5 dB
G—Lama Balice	59.1 dB
H—Agricultural area	78.7 dB
I—Suburban area	67.6 dB

Figure 15. Pollution of Lama Balice mouth.

As for the more natural part of the Lama Balice, the highest level recorded is attributable to the International Karol Wojtyla Airport as well as to the profound change that the land has had to suffer to make room for Bari Palese Golf course, which faces the Regional Natural Park. While representing the most natural environment analyzed, quite high spikes were detected within the time history associated with this section of the park (Figure 16).

Figure 16. Lama Balice Regional Natural Park.

The same trend is observed in the peripheral areas of the lama where the disturbance is almost totally caused by the presence of the Airport. These areas are subject to various forms of pollution attributable to the carelessness with which the town safeguards its own natural resources.

The data regarding the perimeter areas are not better: indeed, they are characterized by many more defined peaks, with a background noise level that is only to a very small extent attributable to natural sound. This indicates that the natural environment has been exploited and deleted to give space to infrastructure for various purposes.

The famous "Parco dei Principi" Hotel is a typical example; it looms over the lama with its total grandeur. The maximum peak recorded in that area is 76.5 dB, exceeding the legal limit.

Along the same lines are the results obtained for points immersed in urban areas, "built-up school" and "built-up urban area." These have a low rate of vegetation cover, high automotive passage, with relative increase in degradation. Here, relatively "modest" spikes were recorded, of no less than 72 dB for the former and 80 dB for the latter recording points (Figure 17).

Figure 17. Above "built-up school" and under "built-up urban area".

4. Conclusions

This research has been carried out within the context of the growing awareness of the complexity issue in planning. In general, many aspects of complexity are both the object and the result of planning knowledge and practice. This fact implies the need for innovation in planning process methods and content. The development of multi-agent cognitive processes how several implications and reasons of interest, especially when the agents are different and dynamically associated with their arenas of interaction [32].

In these concerns, a growing interest has developed toward multi-agent approaches in planning. However, they have been carried out only qualitatively, not using explicit, formalized and/or predefined MAS-based framework structures, as in the Ferber's or Wooldridge's studies [5,33]. In short, the need to involve a number of different agents in the planning process in turn raises a number of issues. These include raising awareness and exchanging complex knowledge, the representation of structured concepts, the support of different formal or informal languages, the structuring of complex problems through the use of forms of synchronous or a-synchronous communication [34]. Consequently, the need for a MAS-type approach and support has emerged almost naturally, in a bottom-up process, stimulated by the prerogatives of the activities being carried out. As mentioned earlier, these processes assume the use of hybrid human/artificial environments, today timidly appearing as operational support to planning. Delay occurs both because research documented in the literature is confined to a few case studies strictly financed by target-oriented projects, and because of the objective difficulty of managing mostly qualitative data, being informal, discrete and hardly compatible with the continuing needs of environmental governance systems [35,36].

This research reveals interesting points of reflection, aimed at relating natural and artificial territorial sectors, as in the case of the Regional Natural Park of Lama Balice. The approach used for the analysis, namely soundscape ecology, highlighted the importance of enhancing environmental structures such as canyons, which are incredible corridors of biodiversity, though frequently heavily modified by human activity. These are complex territories, whose land use has been subjected to processes of fragmentation and heterogeneity causing massive environmental damage.

Therefore, a need to build inter-institutional networks now emerges, aimed at safeguarding the functionality and potential of the Regional Natural Park and the canyon system in general. In fact, despite showing high noise levels, even in its most natural areas, the resilience of the system still remains remarkable. Indeed, the last monitoring survey carried out by the network of environmental activists "Argonauts" and "Pro Lama Balice") reports the presence of as many as about 200 bird species in 2015.

Sound represents one of the indicators of biodiversity of an area, and in this case it shows very marked features, becoming "noise" and emphasizing the process of interaction between the natural and the anthropic worlds. The analysis of soundscape can be an additional tool for environmental monitoring, which should be implemented and intensified in order to regenerate, enhance and control the growth trend of species found in natural landscape. The case-study of Lama Balice, even in its preliminary configuration, suggests that the degree of formalization allowed by soundscape analysis is particularly useful in a context of MAS-based systems. In fact, multi-agent architectures are built on models heavily dependent on the formalization degree of relationships established between agents involved. In the original computer-science context of multi-agent models, software of (intelligent) robots rely on highly formalized functions, routines to interact and exchange data. Instead, hybrid (human/natural/artificial) multi-agent contexts, as in this case-study of Lama Balice, rely heavily on informal and/or qualitative data that involve hardly-manageable models. This problem is particularly harsh when trying to elicit knowledge and/or behavioral data from non-cognitive agents-whose functioning is nonetheless of critical importance as in the case of natural environments. The possibility of inferring and formalizing environment behavior, even limited to a number of features as in the present soundscape-oriented case study, allows its inclusion in a multi-agent model and enhances the actual feasibility of a proper MAS architecture.

This is very important in the field of urban/environmental management and planning, as a multi-agent system can allow a more coherent building up of visions, scenarios and ultimately planning policies. In fact, a proper decision-support system (DSS) emerges as a feasible perspective in this case, which is particularly helpful in that it can support decisions in a very complex system such as the environmental one—and, in the case of Lama Balice, being also at the forefront of an urban complex system.

Finally, a need to find strategies emerges, in order to create models to implement the scientific results. In turn, these would be an important investigate tool, which could also raise the awareness of both citizens and institutions, in order to provide a better understanding of the level of perception of the natural-artificial space, for example through the use of questionnaires. Envisioned future scenarios will depend on an enhanced environmental awareness, in order to protect the few urban natural resources still available. This be could carried out by designing cities with areal involvement of citizens and institutions, aimed at obtaining long-term results in terms of environmental protection.

From the point of view of multi-agent modeling, the inclusion of the "sound behaviors" of the environment to support the enhancement of differentiated soundscapes is a critical element in planning issues. It is a further step towards building support systems for environmental decisions that can structurally mirror the complexity at hand and, therefore, would be intrinsically sustainable.

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