Research Article

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LIFE+2010 QUADMAP Project: results obtained from the analysis of data collected during the application of the new methodology to the pilot quiet areas

Abstract: Since the 90s, quiet areas have commonly been considered as places to be acoustically preserved or where acoustic interventions should be implemented to reduce noise levels. With the enforcement of the Environmental Noise Directive in 2002, a formal definition of a '*quiet area in agglomeration*' and a '*quiet area in open country*' was established. However, many Member States complained about the absence of guidelines regarding the identification and management of quiet areas. The LIFE QUiet Areas Definition and Management in Action Plans (QUADMAP) project started in 2011 to contribute to the Directive's incomplete requirements for quiet areas. The project's main result has been the introduction of a flexible methodology for the selection, analysis and management of quiet areas in agglomeration in which both acoustic and nonacoustic parameters are evaluated. The current paper illustrates the analyses carried out on the data collected during the application of the selection, analysis and management phases of the developed methodology in the different pilot cases selected during the Project. Mentioned analysis are aimed at verifying the benefits of the proposed complementary selection criteria ('relative quiet urban areas' identification criteria and 'homogeneous urban areas' subdivision criteria), at defining the measurement periods most representative of the areas and the acoustic and nonacoustic parameters to be considered as the most significant.

1 Introduction

1.1 Environmental noise problem

Noise is a major environmental issue, especially in urban areas, as it affects large numbers of people. The main consequences of the exposure to environmental noise are the annoyance to humans and the disturbance to various human activities; however, it also has serious health outcomes in terms of cardiovascular disease, cognitive impairment, sleep disturbance, tinnitus and annoyance [1, 2]. Specifically, one in three individuals is annoyed during the daytime and one in five suffer from disturbed sleep at night, mainly due to road traffic noise which is ranked second amongst the principal environmental stressors. In fact, according to the Environmental Noise Guidelines published in October 2018 by the World Health Organization [45], at least 100 million people in the EU are affected by road traffic noise and in western Europe alone at least 1.6 million healthy years of life are lost as a result of road traffic noise. The possible effects of noise exposure are further substantiated by a report from the European Environment Agency [12] which states that the exposure to excessive noise results in 8 million EU citizens suffering from sleep disturbance, 125 million people affected by noise levels greater than 55 dB(A), over 900,000 cases of hypertension and at least 43,000 hospitalisations per year. Moreover, the EU Environment Action Programme to 2020 en-

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titled '*Living well, within the limits of our planet*', committed to significantly decrease noise pollution in the EU and move closer to levels recommended by the World Health Organization (WHO) by 2020. Another aspect to be considered is the potential for noise to influence a wide range of socially–relevant behaviours, such as a decrease of tolerance in noisy environments or the occurrence of anxiety in social contexts.

1.2 EU policy on noise and quiet areas

Concerning the implementation of EU policy related to noise, emissions at source have been regulated in the EU for many years. For example, maximum noise limits for motor vehicles, household appliances and outdoor equipment were established in the 1970s. More recently, measures to control noise from operations and airports and the regulation of noise levels from industrial facilities have broadened the control of environmental noise. Concerning quiet areas, the Green paper on Future Noise Policy [3] represents the foundation for preserving them, stating that instruments such as noise maps help to identify quiet areas, especially where interventions to reduce noise levels are needed and where levels of noise exposure should not increase.

The assessment of environmental noise was regulated at an EU level in 2002 when the EU enacted the Environmental Noise Directive (END) [4] to deal with the assessment and management of environmental noise. The END defines environmental noise as '*being unwanted or harmful outdoor sound created by human activities, including noise emitted by means of transport, road, rail and air traffic and from industrial activities*'. The END aims to provide indications and recommendations about specific acoustic items such as noise mapping, action planning, the relevance of communication and dissemination towards citizens and quiet areas. The main necessities highlighted by the END are to '*define a common approach intended to avoid, prevent or reduce on a prioritized basis the harmful effects, including annoyance, due to the exposure to environmental noise and to preserve the environmental noise quality where it is good*'.

Quiet areas are distinguished between quiet areas in agglomerations and quiet areas in open country. They are defined in Article 3 of the END as '*quiet area in agglomeration shall mean an area, delimited by the competent authority, for instance which is not exposed to a value of Lden or of another appropriate noise indicator greater than a certain value set by the Member State, from any noise source*' and '*quiet area in open country shall mean an area, delimited by the competent authority, that is undisturbed by noise from traffic, industry or recreational activities*'. Article 8 and Annex V refer to actions plans and state that such plans should also aim to protect quiet areas against possible noise increases.

Except for the formal definitions provided above, the END does not provide a detailed methodology of how to deal with quiet areas. In fact, after the first review phase of the END implementation [5], many Member States complained the absence of any guidelines about quiet areas. Five years later during the second implementation review of the END [6], it emerged that the majority of EU Member States had still not designated any quiet areas. The number of existing quiet areas had increased by 50% in the second END revision; however, this increase was accounted for by just five Member States [Austria, Hungary, Ireland, Lithuania and the UK (considering only Wales and Scotland)]. Moreover, the Countries or cities that had introduced criteria to deal with quiet areas had adopted very different approaches as stressed at European level [7, 8]. In addition, although the large–scale application of a procedure for quiet areas in open country was firstly tested in Greece [9] and recently repeated in several other European Countries [10], the need for specific requirements for the protection of these areas still has to be addressed.

In summary, the two main issues concerning quiet areas are: (1) the need to introduce a clearer and more applicable definition of both quiet area in agglomerations and quiet area in open country and (2) the need for quiet area designation guidelines which should be sufficiently specific but also leave Member States a certain degree of freedom according to their local needs. The present article, in the wake of the previously published one concerning the description of the methodology applied to quiet areas in agglomerations [44] focuses on the ways in which the different types of analyses on the data collected during the experimentation phase have been carried out and on the obtained results.

1.3 Benefits of quiet areas

Despite the lack of designated quiet areas described in Section 1.2, the damaging effects of noise and the benefits that quiet areas can bring to the population are now known. In fact, people living in quiet areas suffer fewer of the negative health effects commonly seen in those exposed to sound levels experienced in an average urban environment [11]. Quiet areas are beneficial for the health and well–being not only of residents but also of regular visitors [12, 13]. Direct comparative studies between quiet

and noisy urban and rural areas showed that quality of life increases as noise levels decrease and that health–related quality of life is highest in quiet rural locations [14]. In addition, easily accessible quiet areas near to noisy places are supposed to reduce the perception of annoyance [15, 16], together with the perception of sounds which are considered not congruent with the environment [17]. The restorative benefits of quietness were also observed. People suffering from illness recover faster in natural surroundings and this effect was also applicable to the presence of quietness and natural sounds [18–20]. Finally, people become sensitive to the sounds that most disturb them thus heightening their annoyance; pleasant sounds promote health and annoying sounds impede it [21].

2 The LIFE QUADMAP project and the developed methodology

In the current Section some information about the QUADMAP Project are reported, together with a brief description of the implemented methodology in order to introduce the analysis described in the following sections. The final version of the methodology has been deeply described by the authors in a previous published conference paper [27] and in a Journal article [44]. The QUiet Areas Definition and Management in Action Plans (QUADMAP) project, which started in September 2011 and completed in June 2015, was co–financed into the LIFE+2010 Environmental Programme to contribute to the open research topics summarised at the end of Section 1.2. The main objective of the QUADMAP project was to develop a harmonised methodology to provide practical indications to select, analyse and manage quiet urban areas (QUAs) assuming that noise is only one of the several pollution sources causing discomfort and not only noise limits (to which reference is made in the END) have to be evaluated and established in order to satisfy the citizens expectations.

The project has a very demonstrative and participative character, as the proposed methodology has been tested in a consistent number of pilot areas in Italy (Florence), Spain (Bilbao) and the Netherlands (Rotterdam) and citizens have been actively involved in the interventions' definition.

At the beginning of the project, a depth analysis of the state of the art about existing strategies to deal with quiet areas was made. Moreover, a questionnaire has been submitted to almost 40 stakeholders (e.g. competent authorities) from The Netherlands, Belgium, Norway, UK, Italy,

Germany, Spain, Portugal and France concerning already implemented procedures about QUAs and answers were evaluated (Figures 1–2).
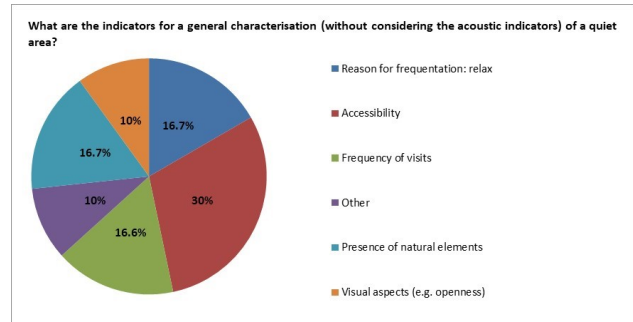

Figure 1: Answers to the stakeholders' question about general (not acoustic) indicators for quiet areas.
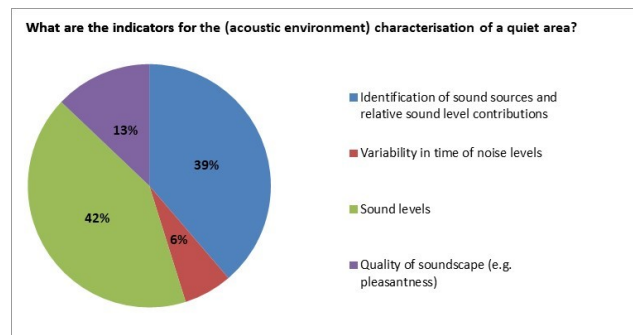

Figure 2: Answers to the stakeholders' question about acoustic indicators for quiet areas.

Concerning the acoustic and the nonacoustic indicators mentioned by stakeholders, they were all considered (in different phases) as input for the QUADMAP methodology in accordance with the 'soundscape' concept [22], its applicative methods [23–25] and the 'holistic' approach for the designing of integrated, sustainable and environmental friendly solutions [26]. In particular, the accessibility, the presence of natural elements and the visual aspects (e.g. the landscape) were all specifically included in the expert analysis and in the end–user questionnaire, while the frequency of visits was introduced in the end–user questionnaires. Similarly, acoustic indicators were evaluated in both long– and short–term acoustic measurement surveys.

According to the carried–out studies, a draft version of the methodology for the selection, analysis and management of QUAs was defined, together with a proposal for an alternative definition of QUAs to be integrated as far as

possible with the official existent one. The proposed definition is indeed '*a QUA is an urban area whose current or future use and function require a specific acoustic environment, which contributes to the well–being of the population*'. Then, the final version of the method was obtained after its implementation in the pilot cases.

Concerning the selection phase, partners have agreed since the beginning of the Project that an area can be preselected as a potential QUA not necessarily because the noise levels measured inside the area are lower than an established threshold, but also according to the category of land use currently indicated for the specific area in the general urban planning (e.g. residential, park, garden, school area, etc.) or to the area's current function (e.g. social relationships, conversation, resting, reading, playground, sport activities, leisure activities etc.).

Referring to the first variable, noise levels can be evaluated from noise maps delivered by each Member State for all agglomerations with over 100.000 inhabitants as required by the END [4]. These noise levels are compared to a threshold set by each Member State to establish if the area is currently quiet or not when considering only the acoustic climate. In the QUADMAP methodology, a threshold of 55 dB(A) is suggested based on state–of–the–art analysis and it is associated to the Lden parameter which was chosen based on the analysis of the state of the art (as also reported in [29]), probably also resulting from the possibility of a direct comparison with the data available from the noise mapping that is provided based on the Lden and Lnight parameters.

In addition, a set of complementary variables and approaches for the preselection phase were introduced (e.g. the rQUA criterion, Section 3.1) and their use was suggested according to the specific policies of the competent body. As an example, the decision to pre–select a QUA could be opened to a public participation process, according to the 'participative' character of the project.

Concerning the analysis phase, a preliminary study is carried out by technicians in each municipality to understand whether the potential quiet area should be divided into HUAs, which are smaller areas evaluated uniformly according to parameters related to landscape, use and distance from noise sources.

In each HUA, the detailed analysis starts with a nonacoustic analysis performed by experts. Experts are requested to evaluate some nonacoustic factors grouped in three main categories: principal nonacoustic criteria (e.g. landscape, natural elements, cleanliness, maintenance and safety), general criteria (e.g. urban environment, proximity to residential areas, accessibility, proximity to noise sources, presence of a multisource scenario and measures

to reduce noise) and behavioural criteria (e.g. number of users, distribution of users and performed activities). The analysis phase proceeds with the implementation of long–term measurements in each HUA. These measurements define the homogeneous periods in which to perform subsequent analyses. The minimum requirements to carry out long–term measurements are defined in the Project guidelines [29]. Once long–term measurements are performed in each HUA, end–user questionnaires are submitted and short–noise measurements are concurrently performed. The questionnaire is submitted to users in the area at the same time as the short–term measurements to collect information about people's acoustic perception. The questionnaire has been designed by project's partners in accordance with previously carried out experiences in similar acoustic fields, with the scientific contribution of psychologists and in accordance with the American Psychological Association's guidelines on the ethical treatment of human subjects. The structure of the questionnaires is fully available in the Project guidelines [29] at www.quadmap.eu.

The final evaluation of all analyses carried out on the pilot areas is made in order to understand if an area can be considered as already quiet, according to the following criteria:

- – If the criteria evaluated in each analysis (i.e. expert analysis, end–user questionnaires and noise measurements) do not have a negative rating, the area can be defined as quiet.
- – If a criterion is present in only one analysis (e.g. in the expert analysis) and has a negative rating (red colour), the area is defined as potentially quiet.
- – If a criterion is present in more than one analysis (e.g. in both the expert analysis and the end–user questionnaire) and has a negative rating (red colour) in the expert analysis, the corresponding score assigned by end users should be checked. If the evaluation given by end users is also negative the area is defined as only potentially quiet.

If according to the Analysis phase an area is defined as already quiet, a plan to preserve or increase its quality and promote its use should be prepared; however, if an area is assessed as potentially quiet, a plan to improve its quality using appropriate measures should be implemented. In the latter, the general suggestion is to implement any intervention to solve critical aspects emerging from the analysis phase and to be inspired by the suggestions of experts or end users for the intervention definition. Following the design and implementation of the interventions, four criteria can be verified to prove their effectiveness:

Table 1: Synthesis of analyses on achieved data.

Analysis name	QUADMAP methodology phase	Analysis aim	Adopted method	Work environment
Verification of the rQUA method	Selection phase	Demonstrating the use of the rQUA criterion as a complementary method	Application of the rQUA criterion in nine pilot areas	Geographical Information System environment (ArcGIS)
Verification of the HUAs subdivision method	Analysis phase	Demonstrating the use of the HUA subdivision method	Application of nonparametric models to answers given by end users about variables (e.g. landscape, area use and distance from noise sources) also adopted by experts in the HUA subdivision	Statistical environment (SPSS)
Introduction of a method to select the best time periods for further analysis	Analysis phase	Identifying time periods to be considered homogeneous for further analysis	A search for time periods in which a few selected acoustical parameters assume values close to the weekly average values	Statistical environment (Excel)
Definition of the most significant acoustic parameters in relation to the qualitative parameters	Analysis phase	Identifying the acoustic parameters that have a strong correlation with qualitative parameters	Application of ordinal regression models to establish the relationship between acoustic and nonacoustic parameters	Statistical environment (SPSS)

- A reduction of noise levels compared to a threshold level (e.g. 55 dB Lden).
- A reduction of noise levels compared to the noise levels before the intervention.
- A reduction of unpleasant noise events or an increase in pleasant events.
- An improved end–user perception with respect to the ante–operam scenario.

3 Research goals and methods

The aim of the current article is to explain the analyses carried out on data collected during the methodology implementation in the pilot areas. Specifically, the following analyses were performed:

- Verification of the benefits of the complementary 'relative QUA (rQUA)' selection method

- Verification of the Homogeneous Urban Areas (HUAs) subdivision method
- Introduction of a method to define the best measurement periods
- Definition of the most significant acoustic parameters in relation to the qualitative parameters.

Table 1 provides further indications about the aim of each analysis together with the applied methods were performed. Analysis are illustrated in detail in Sections 3.1 – 3.4.

The above listed analysis have been made on data almost concurrently collected in 10 pilot cases in Florence, Bilbao and Rotterdam. Synthetic information about the case studies is shown in Table 2.
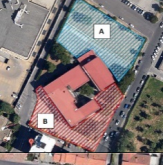
The selected areas have been six school–yards in Florence, two parks in Rotterdam and a square and a green corridor in Bilbao and the most common affecting noise source is road noise. Several quantitative (noise maps, short and long–term measurements, wave recordings) and

Table 2: Essential information about pilot cases.

City	Area name	Area image	Type	Main noise source
Florence	P. Uccello		School	Aircraft and road noise
Florence	E. De Filippo		School	Road noise
Florence	A. Manzoni		School	Road noise
Florence	F. Dionisi		School	Road noise
Florence	M. Vamba		School	Road noise
Florence	P. Fedi		School	Road noise
Rotterdam	Southern		Park	Road noise
Rotterdam	Spinoza		Park	Road noise
Bilbao	General La Torre		Square	Road noise
Bilbao	S. Marina		Green corridor	No specific noise source but a need to redevelop the area

qualitative (answers to end–user's questionnaires, general and non–acoustic information about the perception of the area) data have been collected and analysed. The aims of the data analysis were both to update the methodology (with particular regard to the selection and the analysis phases) and to obtain opinions and suggestions also for the interventions' designing from the interviewed citizens. Once interventions were designed and implemented, post–intervention data have been collected, in order to definitely optimize the methodology [27, 28], with specific regard to the management phase, to produce appropriate guidelines and to verify that the interventions really corresponded to the needs expressed by users.

3.1 Results of the application of the rQUA criterion

Concerning the selection phase, a possible complementary criterion named 'rQUA criterion', which was developed by the city of Paris and the QUADMAP partner Bruitparif [27], was also introduced based on acoustic criteria. This criterion relies on the concept of 'relative noise', which is also called 'noise gradient' or 'sound contrast', and is articulated by the:

- creation of a spatial grid spaced 10×10 m on a city or area noise map,
- assignment of the energetic combination of road and rail noise expressed with the day–evening–night level (Lden) parameter to each vertex of the spatial grid
- creation of a 250 m radius buffer centred on each vertex
- evaluation of the Lden average value to be referred to the buffer
- evaluation of the difference (Δ) between the Lden average value and the Lden absolute value

The advantage of this method is that it allows the quietness of a site to be evaluated not only according to its absolute noise level (Lden above or below 55 dB(A)) but also according to the difference between noise levels in a specific zone (referred to the single vertex) and their neighbourhood. The classification of areas according to the rQUA method is shown in Table 3. The areas assigned as green or yellow categories are considered as quiet, while areas assigned as orange and white categories cannot be considered quiet according to their rank (Table 3). In the QUADMAP project, the rQUA criterion was tested on nine pilot areas to determine if it could effectively give useful information according to the exclusively acoustical criterion.

Table 3: Classification of areas according to the rQUA method.

Colour	Lden$_{absolute}$ dB(A)	Δ=Lden$_{average}$ −Lden$_{absolute}$	Classification of the area
Green	≤ 55	> 10	Quiet
Yellow	≤ 55	≤ 10	Quiet
Orange	> 55	> 10	Potentially quiet
White	> 55	≤ 10	Potentially quiet

1=A. Manzoni (5400 m²)
2=P. Fedi (3140 m²)
3=G. La Torre (1280 m²)
4=F. Dionisi (3500 m²)
5=P. Uccello (7280 m²)
6= M. Vamba (4486 m²)
7= Spinoza (700000 m²)
8= E. De Filippo (7470 m²)
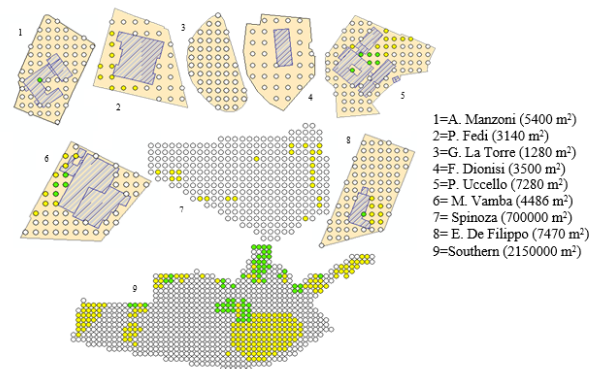9=Southern (2150000 m²)

Figure 3: Results of the application of the rQUA method in the Manzoni school in Florence (the darker grey colour is representative of the "white" category and the lighter grey of the "green" category).

Figure 3 shows the results of the rQUA method application in the Manzoni school in Florence.

The results from the rQUA method application show that the number of green and yellow vertices is significantly lower (e.g 20 %) than the white vertices in all pilot cases, while the orange points are totally absent. This means that in correspondence with the single vertices ideally located inside the pilot areas, which are noisier than the surrounding ones, Lden is > 55 dB(A). Consequently, pilot areas cannot be considered to be quiet according to the rQUA method based solely on acoustic criteria; however, the rQUA method based on the Lden noise map provides additional acoustic information about the area under test, with variable two (noise levels) of the preselection phase only consisting of a comparison of noise levels with a 55 dB(A) threshold (see Section 2). Finally, once the rQUA criterion was tested in the pilot areas, it was proven to only be usable as an acoustic complementary tool for the preselection phase. Moreover, the results obtained following application of the rQUA method suggest that this method may be useful in the definition of noise reduction interventions. It was consequently proposed as a possible tool in the management phase as described in the following. The original

Table 4: Possible categories of QUAs established using the modified rQUA method.

Colour	$Lden_{absolute}$ dB(A)	$\Delta = Lden_{average} - Lden_{absolute}$
Blue	> 55	> −5(*) and ≤ 10
Red	> 55	≤ −5(*)

(*)=The 5 dB threshold associated with the red and blue categories was suggested as a benchmark after the application of this tool to the pilot case of schoolyards in Florence.
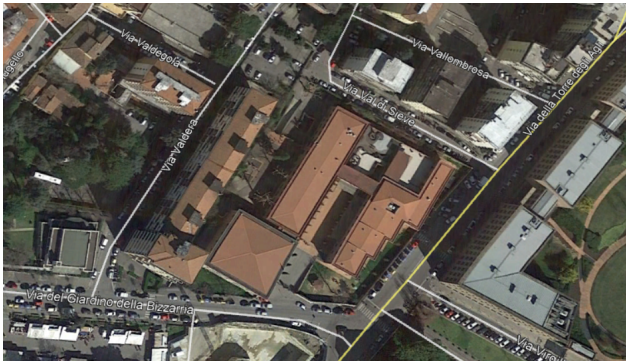

Figure 4: Vamba school. Green highlights the first HUA and pink highlights the second HUA.

classification of areas provided by the rQUA method (Table 4) did not identify which kind of intervention, if any, could improve the acoustic environment in the 'white' category. Therefore the 'white' class (Lden > 55 dB(A) and Δ dB(A) ≤ 10) was further split into two categories and new identifying colours attributed (Table 4).

According to this new subclassification, the 'red' category refers to cases where there is an acoustic contrast between the specific point and its neighbourhood, while the 'blue' category refers to areas where there is no acoustic contrast. The characterisation of the associated noise sources and the possible noise reduction measures in the two groups are:

– Blue category: there is no main noise source and only strategic measures should be adopted at a district level (e.g. reduced speed or vehicle–free zones etc.).
– Red category: the most relevant noise source is well–identified and limited measures performed at the edge of the areas (e.g. noise screens, low–noise road surfaces etc.) can be implemented.

## 3.2 Results of the evaluation of HUA subdivision from end−user questionnaires

Concerning the analysis phase, once an area is preselected (according to the procedure recalled in Section 2), the methodology requires the subdivision of each QUA into HUAs (previously performed by municipality technicians) to be assessed. To verify the usefulness of the HUA definition procedure and the effectiveness of its application, responses to the end−user questionnaires submitted in the pilot areas concerning the evaluation of parameters related to landscape, area use and distance from noise sources were analysed. Among the pilot areas, the procedure for defining HUAs led to an actual subdivision in only four schoolyards in Florence. Therefore, the analysis was performed with reference to these case studies. Questionnaires were used to check whether answers to specific questions could be considered unequally distributed in each HUA (Table 5) according to a nonparametric model [30]. Although nonparametric models require the sample to be random, they do not consider the statistical distribution parameters (not known in the current study) and adapt to few samples. The evaluation was performed using the statistical software programme SPSS (version 22) using a one−way ANalisys Of VAriance (ANOVA) and the Jonckheere−Terpstra test.

The output of the model is returned in terms of values such as 0, where the specific variable is equally distributed in the sub−areas, and 1 when the specific variable is not equally distributed in the sub-areas (Table 5). The results from the nonparametric analysis suggest that only division of the M. Vamba schoolyard into HUAs could be avoided, since all variables can be considered equally distributed in the sub−areas, while this was originally considered appropriate because of two different noise sources affecting different zones (Figure 4).

This can be explained by the observation that although there are two influencing noise sources (via del Giardino della Bizzarria and via della Torre degli Agli), there is a main source (via della Torre degli Agli) that is the same distance from both HUAs that determines the acoustic climate in both areas. This was further confirmed by evaluating the LAeq parameter; however, also in the case study of M. Vamba, the result was considered acceptable and conservative as it produced more sub−areas than strictly necessary. For the remaining areas, nonparametric statistical tests confirmed at all the use of the subdivision in HUAs (Table 5).

Table 5: Results obtained after the use of nonparametric tests (0 = equally–distributed parameter; 1 = unequally–distributed parameter).

Variables	E. De Filippo	P. Uccello	A. Manzoni	M. Vamba
Traffic source perception	0	1	0	0
Other mechanical sounds perception	0	0	0	0
Human sound perception	1	0	0	0
Natural sound perception	0	0	0	0
Perception of the sound environment as unpleasant–pleasant	1	1	1	0
Perception of the sound environment as noisy–calm	0	1	0	0
I perceive the current soundscape as good	1	1	1	0
I consider current sounds very congruent with this place	1	0	0	0
I perceive as pleasant: AIR QUALITY	1	1	1	0
I perceive as pleasant: SAFETY	1	1	1	0
I perceive as pleasant: WELL–MAINTENANCE	1	0	1	0
I perceive as pleasant: SERVICES AND EQUIPMENT	0	1	0	0
I perceive as pleasant: ACCESSIBILTY	0	0	0	0
I perceive as pleasant: ACOUSTIC ENVIRONMENT	0	1	1	0
I perceive as pleasant: NATURAL ELEMENTS	1	0	1	0
I perceive as pleasant: CLIMATE	0	0	1	0
I perceive as pleasant: VISUAL ASPECTS	1	0	1	0
I perceive as pleasant: SMELLS	0	0	1	0
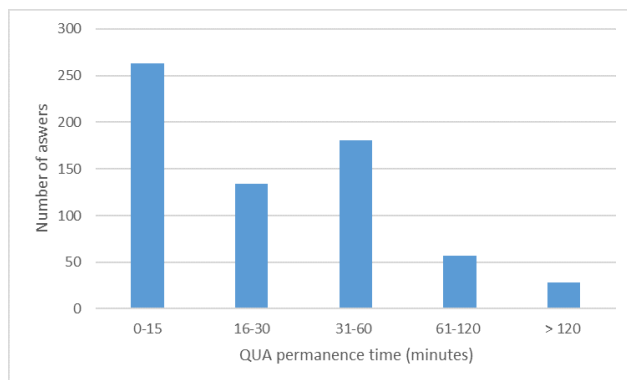
Figure 5: Evaluation of the permanence time in selected pilot areas from end–user questionnaires.

3.3 Results of the evaluation of time variability from long–term measurements

The long–term acoustic data were investigated to define the time variability of the acoustic climate in the pilot areas (Section 2) and, consequently, the best time periods to carry out in–depth analysis (end–user questionnaire submission and short–term measurements). A time interval of 1 hour was considered for the analysis of long–term measurements, as the results from end–user questionnaires

(Figure 5) showed that the average permanence in the pilot areas was mostly up to 1 hour.

Furthermore, the literature [31, 32] suggests that the recommended acoustic parameters for establishing time periods in which the acoustic environment can be considered homogeneous are:

- LA50 or LAeq: to represent the average noise levels.
- LA10–LA90: to represent the acoustic climate and the presence of noise peaks.

The conditions required to define the homogeneous time periods are that noise levels (expressed by indicators such as LA50 or LAeq and L10–L90 computed on an hourly basis) are close (±3 dB) to the average levels obtained in the time period T corresponding to 1 week. The relationships to be verified were:

$$LA50(T) - 3 < LA50(hour) < LA50(T) + 3 \quad (1)$$

or

$$LAeq(T) - 3 < LAeq(hour) < LAeq(T) + 3 \quad (2)$$

and

$$[LA10 - LA90](T) - 3 < [LA10 - LA90](hour) \quad (3)$$
$$< [LA10 - LA90](T) + 3.$$

As an example, in the case of the Dionisi school, long–term data analysis (Figure 6 and Table 6) showed that
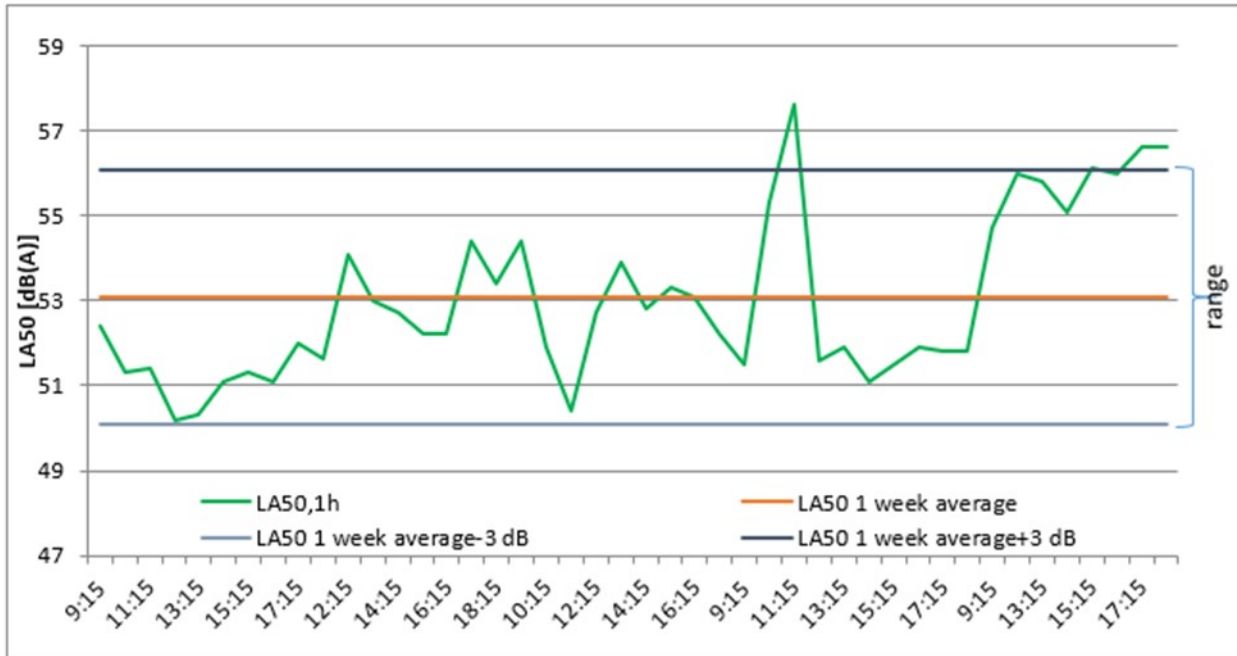
Figure 6: Long–term measurements collected in the Dionisi schoolyard during its opening times.

Table 6: Time periods in which the LA50 falls in the defined range and average values of L50 and L10–L90 (T = 1 week) at the Dionisi school.

|	LA50	LA10–LA90		LA50	LA10–LA90		LA50	LA10–LA90
	MONDAY			TUESDAY			WEDNESDAY	
9:00	in range	in range	12:00	in range	in range	9:00	in range	in range
10:00	in range	in range	13:00	in range	in range	10:00	in range	in range
11:00	in range	in range	14:00	in range	in range	11:00	in range	in range
12:00	in range	in range	15:00	in range	in range	12:00	in range	in range
13:00	in range	in range	16:00	in range	in range	13:00	in range	in range
14:00	in range	in range	17:00	in range	in range	14:00	in range	in range
15:00	in range	in range	18:00	in range	in range	15:00	in range	in range
16:00	in range	in range				16:00	in range	in range
17:00	in range	in range				17:00	in range	in range
18:00	in range	in range						
	THURSDAY			FRIDAY				
9:00	in range	in range	9:00	in range	in range			
10:00	in range	> range	10:00	in range	in range			
11:00	> range	> range	11:00	in range	in range			
12:00	in range	in range	12:00	in range	in range			
13:00	in range	in range	13:00	in range	in range		L50	LA10–LA90
14:00	in range	in range	14:00	in range	in range	Average	53.1	6.6
15:00	in range	in range	15:00	> range	< range			
16:00	in range	in range	16:00	in range	< range			
17:00	in range	in range	17:00	> range	< range			
18:00	in range	in range	18:00	> range	in range			
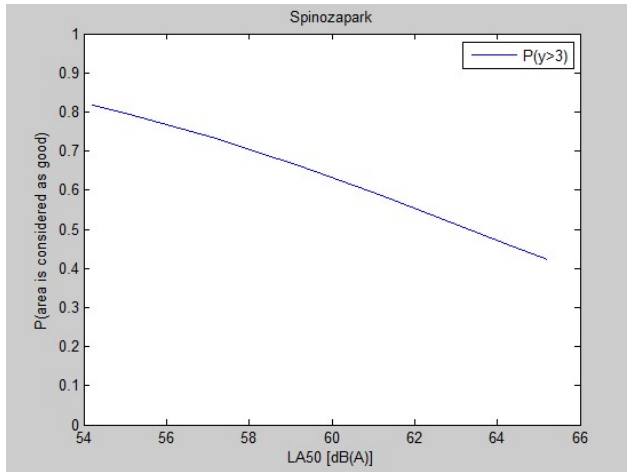
Figure 7: Probability that the end users consider an area as good (score of at least 3 out of 5) as the noise levels (expressed in terms of LA50 parameter) change in Florence pilot areas.

Figure 8: Probability that end users consider an area as good (score of at least 3 out of 5) as the evaluation of the well-maintainance (score from 1 to 5) changes in Spinoza park.

many time slots can be considered homogeneous for further analysis. This result, together with the validation of the effectiveness of the method, was confirmed from the comparison with the outputs of the end-users questionnaires and of the expert analysis.

3.4 Results of the evaluation of the statistical relationship between short–term measurements and answers from end–user questionnaires

Once data from measurements surveys and submitted end–users questionnaires have been collected, the idea was to look for a statistical relationship between objective and subjective data also considering other works available in literature such as the work of Garcia–Perez [34] in which an indicator combining the intensity of sounds, the presence of noise events, the users' perception has been proposed and the study of Watts [35] in which levels of rated tranquillity are reliably predicted in quiet places by using the TRAPT (Tranquillity Rating Prediction Tool) model which expresses the tranquillity rating as a function of the percentage of natural and contextual features of an area and of the Lday parameter.

During the QUADMAP project statistical analysis were performed on collected short–term measurements (objective data) and answers to selected questions from end–user questionnaires (subjective data) to identify the significant acoustic parameters that could represent end–user perceptions. The final aim was to understand whether the users' general perception (not only acoustic) of a QUA
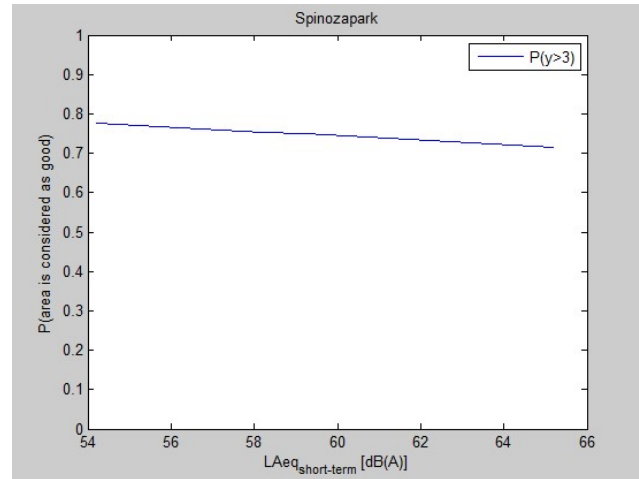
could be related to objective acoustical information and to other qualitative aspects of the area [36]. The answers to the end–user questionnaires were collected as a score from 1 to 5, therefore an ordinal regression model was used for the analysis as it is considered the most appropriate for predominantly ordinary variables [33, 37]. Ordinal regression models determine the probability of obtaining a value for the dependent variable (y) lower than a certain score (k) and express this as an exponential function of the independent variable (x) according to the following equation:

$$P(y \le k) = \frac{e^{\alpha_k - \beta_i x_i}}{1 + e^{\alpha_k - \beta_i x_i}} \quad (4)$$

where k ranges from 1 to the number of categories–1, and i ranges from 1 to the total number of independent variables. The dependent variables (selected questions from the end–user questionnaire) were:

– 'Do you agree or disagree with the following statement: I value this area in general as good?'
– 'How would you describe the sound environment in this area during your visit, being it noisy–calm?'
– 'Referring to this area, I perceive the acoustic environment as pleasant'.

The independent variables were:

– Quantitative: LAeq short term, LA50 and LA10–LA90.
– Qualitative: 'Referring to this area, I perceive each of the following items as pleasant: natural elements, air quality, safety, well–maintenance, etc.'.

The principal results (Figures 7–8) showed that the LA50 was the most appropriate quantitative variable to de-

Table 7: Pilot areas, acoustic and nonacoustic characteristics and design interventions.

Pilot area	Acoustic characteristic	Acoustic design interventions	Nonacoustic characteristic	Nonacoustic design interventions
Vamba/Montessori schoolyard (Florence)	Noise from a nearby road infrastructure	Noise barrier	Need for an external teaching space	Part of the barrier is green type. A wooden platform in the garden area protected by the barrier was designed
Dionisi schoolyard (Florence)	Noise from a nearby road infrastructure	Noise barrier	Need to discourage people from outside the area approaching and calling the children	Blackboards integrated into the internal side of the barrier
Manzoni schoolyard (Florence)	Noise from a nearby road infrastructure	Noise barrier	Need for shaded areas with benches and games	Five trees and 30 concrete cube seats
De Filippo schoolyard (Florence)	Noise from a nearby road infrastructure	Noise barrier	Need for shaded areas with benches and games	Four trees and 20 concrete cube seats; 2 sound games
P. Fedi schoolyard (Florence)	Noise from a nearby road infrastructure	Additional road signs containing the prescribed speed limit of 30 km/h (minor intervention)	–	–
P. Uccello schoolyard (Florence)	Noise from a nearby road infrastructure	Noise barrier	The schoolyard is a bit used and there is a lack of equipment (i.e. elements for a seat)	Seats made up of concrete cubes (45 x 45 x 45 cm) with antigraffiti treatment
S. Marina green corridor (Bilbao)	None (background noise of traffic < Lden 55)	–	None	Selective tree thinning of nonautochthonous plants (Pinus Pinaste)
G. La Torre square (Bilbao)	Noise from traffic	Urban barrier for traffic noise combined with a fountain (that creates background water sound and water sound events related with jets), improved traffic flow to give priority to pedestrians and increased greenery (developing small hills)	Need to modify dominant sound sources and increase positive events to improve safety, accessibility, cleanliness and maintenance	Increasing the pedestrian accessibility, creating visual permeability, improving the construction quality through materials and services (putting 43 trees in the area and increasing the presence of benches), increasing the resting areas in the square and the greenery area, increasing the acoustic comfort in the area (pleasant sounds coming from urban furniture with vertical water dispensers)
Southern park (Rotterdam)	Noise from traffic	Low–noise paving	–	–
Spinoza park (Rotterdam)	Noise from traffic	Low–noise paving	–	–

Figure 9: Example of interventions performed in Vamba and Dionisi schools (a green and glass barrier, respectively) and in Spinoza and Southern parks (low noise paving).

Figure 10: Examples of interventions performed in La Torre square (a noise barrier and fountain to create masking sounds).

scribe the users' perception in accordance with their general perception of the area and that the general perception of the area was strongly related to qualitative factors (i.e. the good maintenance status of the area). In fact, if compared to other tested and generally used acoustic indicators (e.g. LAeq) it turned out that the LA50 can be more representative of the average perception because not affected by extraneous temporary noise events.

4 Discussion

Each section of the methodology proposed by the QUADMAP project and related tools were applied in the selected pilot cases. The results obtained, combining end–user questionnaires, acoustical measurements and expert analysis, allowed the detection of the main acoustic and nonacoustic criticalities. Starting from these outcomes, it was possible to obtain useful indications for the definition of solutions to be implemented. Table 7 reports

characteristics defined in the pilot areas and the designed interventions, while Figures 9–10 provide examples of some implemented interventions.

During the QUADMAP project, tools introduced for the analysis phase were applied during both the pre– and post–intervention phases in all pilot areas, and the results were finally compared. For the pilot cases selected in Florence, the questionnaire results during the post–intervention phase were generally positive.

According to the expert analysis, highlighted criticalities were also dealt with.

The General LaTorre square was a practical example of a successful application of the holistic approach adopted by the project (see Section 2). In fact, the post–intervention questionnaires collected in this area showed that there was a remarkable change in the perception of the sound atmosphere, with 73.4% of users considering it calm (an increase of 40.5%) and 78.8% considering it pleasant (an increase of 41.2%). The perception of general conditions in the area also improved, and it is currently perceived as safer, cleaner, more accessible, more aesthetically pleasing and better maintained. Moreover, the perception of the sound atmosphere changed dramatically, with the dominant sources changing from traffic to water and from birds to children's voices. In this pilot case, the post–intervention results in terms of the analysed end–users questionnaires suggested that the proposed procedures for intervention design were appreciated. Referring to the short–term measurements associated with the questionnaires, noise levels were slightly increased (2–3 dB) after the realisation of interventions. However, the composition of the sonic atmosphere was very different and there was a noticeable reduction of traffic–associated negative events. This result also reflects the effectiveness of the interventions according to criteria reported in Section 2, since a reduction of unpleasant noise events and an increase in pleasant events occurred. The improved perception of quality in some areas interested by QUADMAP

project can be linked to the sound identity of places, as it has been identified via Soundscapes Analysis actions combined with the evaluation of aesthetic, holistic and serendipity parameters characterizing areas and proposed interventions in a more general frame of variables related to global comfort [38]. Moving from the considerable scientific relevance acquired in recent years by soundscape–based methods (from only 5 works published in international journals in 2000 to more than 100 publications in 2016 [39]), QUADMAP developers have taken in account sound masking and sound enrichment solution as possible improvements of the sound quality and globally perceived comfort of quiet areas. ISO 12913-1: 2014 standard has been considered, as it provides a definition and a conceptual picture of the soundscape, explaining the relevant factors for the measurement and reporting of studies and research concerning the soundscape, as well as for the planning, design and management of urban soundscapes. Also the definition of noise as 'sound out of place' given by W. Clarkson Kaye [40] has been considered: corrective soundscape elements have been designed, including active sound solutions, for improving perceived quality in function of cultural factors and experiences. As a result of the ante–post surveys, it has been clear that in urban planning and quiet areas design, the 'immersive' perception of the landscape cannot be ignored: in this transition from object of contemplation to a living space, perception of landscape is multisensory and the sound component becomes an important element in definition and use of the landscape. Under this approach, further developments of methods for the definition of quiet areas can be defined, considering the diverse contribution of acoustics to global perceived comfort, as annoyance interferes with verbal communication, causes behavioural and relational discomforts and from the other side, the sense of pleasantness related to a place is significantly enhanced by a comfortable sound environment. In some papers that have anticipated the publication of the new edition of WHO Guidelines for the European region [45] we can see how quality of life and quality of places systematically deal with the problems deriving from the poor or good acoustic quality (and consequent levels of exposure to noise) of the places where people spend most of their time. These evidences can be very useful in considering the factors that can make a Quiet Area acoustically comfortable [41, 42].

5 Conclusions

Although the importance of QUAs is widely recognised at a European level for their acoustical and general health benefits, only a small number of Countries have managed to introduce these areas in their respective cities. This is mainly because no specific guidelines for this topic were introduced until 2015.

In 2015, the LIFE QUADMAP project succeeded in defining a complete but flexible method to select, analyse and manage QUAs. In this method, both the main variables and complementary tools were introduced. The effectiveness of the method was demonstrated when it was tested in 10 pilot areas in Italy (Florence), Spain (Bilbao) and the Netherlands (Rotterdam).

An additional challenge of the QUADMAP project was to propose a method that was able to evaluate both acoustic and nonacoustic aspects of QUAs and to include a participative approach. Questionnaires were submitted to end users and experts in each municipality, both before and after the realisation of dedicated acoustic (e.g. noise barriers) and nonacoustic (e.g. new seats for external school lessons) interventions. The collected opinions revealed a clear improvement in the perception of these areas.

An added value of the research carried out in the frame of the project is that the specific analysis on acoustical and nonacoustic data has been made. In this perspective, the focus of the present article is to show the results obtained from the analysis of data collected during the project from the experts of the municipalities, end–users questionnaires and measurements surveys and described in Sections 3.1 – 3.4. The obtained results confirm the validity of the rQUA criterion as a complementary selection method and of variables introduced for evaluating the necessity of QUAs subdivision in HUAs. Moreover, a method to identify the most homogeneous time intervals in terms of noise levels was introduced following the evaluation of long–term measurements. Finally, the existence of a robust relationship between the LA50 parameter and the end user's general perception of QUAs and between the general area perception and evaluation of the qualitative aspects (i.e. maintenance of the area) was confirmed using ordinal regression models.

Finally, interest in the use and diffusion of the QUADMAP guidelines is increasing in EU countries. For example, some aspects of the QUADMAP guidelines have been adopted by the city of Mitylene (Greece) where the participatory approach and selection criteria were successfully used in the identification of QUAs [43]. Moreover, in Norway, the definition of new national guidelines on quiet

areas is in progress and the possibility of including some aspects of the QUADMAP guidelines is under evaluation.

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