Effects of urban green spaces and related urban morphology parameters on urban sound environment

by

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ABSTRACT

Urban morphology in combination with soundscape planning and design are important parameters towards the development of sustainable cities. Towards this direction this study primarily investigates the effect of urban morphology and green-space related parameters on traffic noise in different analysis levels. Secondly, it complements this first objective approach with a subjective one, investigating peoples' perceptual attributes using auditory and visual stimuli. Both approaches aim at merging the gap between acoustics and planning on the grounds of the new holistic approach of urban sound planning.

At first, a triple level analysis was conducted including case study cities across Europe with a view to understand to what extent greener cities can also be quieter. The analysis was conducted using GIS tools and noise data from European databases combined with land cover parameters. Results were scale-dependent with lower noise levels to be achieved in cities with a higher extent of porosity and green space coverage. A further cluster analysis combined with land cover data revealed that lower noise levels were detected in the cluster with the highest green space coverage. At last, a new index of ranking cities from the noisiest to the quietest was proposed.

Using the findings concerning green spaces and traffic noise from the previous study, a second analysis was conducted focused on eight UK cities. The green space variables were adjusted to incorporate also parameters related to spatial pattern and smaller ontologies, such as vegetated backyards or front yards. Parameters related to urban morphology, such as buildings and roads were also investigated. The analysis was conducted in a macro, meso and micro scale using regression models and GIS tools. Cities were divided in two types of settlement forms (linear, radial) and results showed that the latter were associated with a higher green space ratio. Green space and morphological parameters managed to predict the L_{den} levels in two cities with an explained variance up to 85%. Results suggested that urban green space variables combined with other features of urban morphology conduct a significant role in traffic noise mitigation and can be used as a priori tool in urban sound planning.

The third part of the study focused particularly on the effects of vegetation and traffic-related parameters on the sound environment of urban parks. The sound environment was evaluated using both simulated traffic data and in situ

measurements from mobile devices inside the parks. Results showed that simulated noise distribution in the park scale varied between 43 and 78 dB(A) with a maximum range of 9 dB(A) per park and higher noise variability for L_{A10}. Two groups of parks were identified according to the distance from the international ring road. For measurement data, L_{A90} *and* L_{A10} were higher outside the parks with differences up to 6 dB(A) for L_{A90} and up to 14.3 dB(A) for L_{A10}. Additional correlations were also detected between noise levels and morphological attributes, while slightly higher noise levels were detected in areas covered with grass compared with tree areas.

The previous objective findings were combined with a perceptual study on the transition from prediction to soundscape and design implementation. In this study the relationship between land use and sound sources was explored. The stimulus material was based on binaural recordings and 360°-videos. Participants were required to assess the dominance of sound sources and the appropriateness of land use and socio-recreational activities. Results showed that the activity-based environment can be explained by two main Components. The green space coverage and the proximity to roads were the most significant parameters in the prediction of these two components. In the final stage, a multivariate analysis (MANOVA) was used in order to identify significant variations for the land use activity variables in the three urban activity profiles. The whole process emphasized on the importance of linking urban planning and design with soundscape from the land use activity viewpoint.

In the final stage, two of the previous UK case study cities were selected in order to develop a mapping model to aid soundscape planning with parallel implementation and assessment of its effectiveness. Ordinary Kriging interpolation was used in both cases to simulate the predictive values in unknown locations. In Sheffield, the soundscape model was based on the prediction and profiling of sound sources, while in Brighton in the prediction and profiling of perceptual attributes. The cross-validation process in both cases presented small errors with slightly underestimated prediction values. The outcomes from both case studies can be applied in environmental noise management and soundscape planning in different urban scales.

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List of Acronyms

dB	Decibel (unweighted)
dB(A)	Decibel (A-weighted)
Agglomeration	An area having a population in excess of 100,000 persons and a population density equal to or greater than 500 people per km^2 and which is considered to be urbanised.
ASE	Average Standard Error
CRTN	Calculation of Road Traffic Noise in UK
DEFRA	Department for Environment Food & Rural Affairs
EC	European Commission
EEA	European Environmental Agency
EIONET	European Environment Information and Observation Network
END	Environmental Noise Directive
EPA	Environmental Protection Agency
GIS	Geographical Information System
GLM	General Linear Model
GPG	Good Practise Guide
GWR	Geographically Weighted Regression
IDW	Inverse Distance Weighted
ISO	International Standards Organization
L_{Aeq}	Equivalent Continuous Sound Pressure Level using A-weighting
L_{day}	The L_{Aeq} over the period 07:00 – 19:00, local time (for strategic noise mapping this is an annual average)
L_{den}	The L_{Aeq} over the period 00:00 – 24:00, (for strategic noise mapping this is an annual average)
$L_{evening}$	The L_{Aeq} over the period 19:00 – 23:00, local time (for strategic noise mapping this is an annual average)
L_{night}	The L_{Aeq} over the period 23:00 – 07:00, local time (for strategic noise mapping this is an annual average)
LUR	Land Use Regression
MANOVA	Multivariate Analysis of Variance

Acronyms

MPE	Mean Prediction Error
MSE	Mean Standardised Error
MLU	Multifunctional Land Use
NDVI	Normalised Difference Vegetation Index: *Simple indicator that can be used to analyse remote sensing measurements, typically for green space coverage. It is calculated by the visible and near-infrared light reflected by vegetation.*
NPSE	Noise Policy Statement for England
PCA	Principal Component Analysis
RGB	Red-Green-Blue colour bands
RMSPE	Root Mean Square Prediction Error
RMSSE	Root Mean Square Standardized Error
SPL	Sound Pressure Level
UDP	Unitary Development Plan
WG-AEN	Working Group - Assessment of Exposure to Noise
WHO	World Health Organization

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Chapter 1: Introduction

1.1. Research background

Traffic noise through the EU Directive 2002/46/EC has mainly been investigated in terms of people's exposure to high noise bands within various agglomerations. Living in an urban environment where over 44% of the EU population, are regularly exposed to noise levels over 55 dB(A) (WHO,2011), parameters related to urban morphology in connection with green space attributes can moderate the adverse effects of traffic noise from a planning viewpoint.

According to Kropf (2005), urban morphology refers to a hierarchy of different characteristics at different interdependent scales involving a) building elements, b) road infrastructure and c) land use components. In the policy level urban form indicators have been applied to describe the extent of urban sprawl and assess developing scenarios (Allen, 2001; Galster et al., 2001; Knaap et al., 2005; Song & Knaap, 2004). However, since there is a direct relationship between urban morphology and traffic noise though mobility patterns (Burton et al., 2000), some of these indicators have also been used to describe the relationship with traffic noise at different scales.

Comparisons start at the building façade level or small neighbourhoods within the same city (Hao et al., 2015a; Guedes et al., 2011; Lam et al., 2013; Silva et al., 2014; Tang & Wang 2007) and can also be extended to more than one cities of different urban densities and building form (Salomons & Pont, 2012; Wang & Kang, 2011). Although, the above-mentioned studies provide useful evidence on the building or neighbourhood level; from a planning viewpoint a broader scale analysis covering the entire city is needed. So far, only one study at that level is known to the author by Ryu et al., (2017).

In this network of different morphological elements green spaces have a direct and dynamic relationship with the urban structure (Ståhle, 2010). According to Schipperijn et al., (2010) they refer to all publicly owned and publicly accessible open spaces with a high degree of cover by vegetation. So far commonly applied solutions of active noise control include the use of vegetation for traffic noise screening (Huddart, 1990), vegetated noise walls (Van Renderhem et al., 2015) or tree belts (Attenborough & Taherzadeh, 2016; Fang et al.,2003; Kang 2007a; Kragh, 1981) and different planting schemes (Papafotiou et al., 2004; Van Renterghem et al., 2012).

In the park scale, many studies have dealt with the investigation of perceptual characteristics based on the users' experience (Brambilla et al., 2013; Jabben et al., 2015; Jeon & Hong, 2015), however, a few of them (González-Oreja et al., 2010; Kothencz & Blaschke, 2017) have used objective parameters, such as park size, tree density and tree canopy to investigate the extent of quietness inside parks. Another issue with this type of quiet or shielded green space areas is that traditional noise mapping techniques cannot capture the short-term temporal noise variability (Wei et al., 2016). For this reason, dynamic noise mapping techniques gradually become more popular either using fixed sensors (Sevillano et al., 2016) and smartphone applications (Bilandzic et al., 2008; D'Hondt et al., 2013) or a combination of fixed and mobile stations (De Coensel et al., 2015).

Finally, green spaces as a land use type has been used in regression models with other morphological parameters to predict traffic noise levels (Aguilera et al., 2015; Goudreau et al., 2014; Xie et al., 2011). Despite the high accuracy of these models their generalisation and application in other cities is difficult due to their complexity and the large number of predictors. As a result, a simple prediction model where green space variables would be the only predictors can be more advantageous.

On the other hand, the investigation of purely objective noise parameters without involving human perception is inadequate in a holistic planning perspective (Alves et al., 2014). This is why soundscape as a complementary approach comes into action. According to Brown (2014) sound in soundscape is used as a resource and not as a waste as in noise control. So far, sounds in the urban environment have mainly been approached either in terms of classified sources (Brown et al., 2011) and relative sound maps (Hong & Jeon, 2015). The distribution of sound sources within the city is affected by urban planning since the latter influences the various travel patterns (Burton et al., 2000). Moreover, urban planning in terms of the exhibited urban activities and land use may conduct a crucial role in soundscape studies when considering the effect of sound sources. The only issue is that up to now there has been little effort to integrate soundscape principles into the current urban planning and environmental framework (Smith & Pijanowski, 2014; Weber, 2013). Probably the main difficulty is to find a good balance where the two approaches act in a complementary way (Brown, 2014; Genuit, 2013).

Apart from sound sources and urban activity profiles, another crucial issue is the visual representation of perceptual attributes using soundscape mapping tools. The ultimate aim of this process that is currently on-going is a gradual incorporation of the soundscape design in the planning process. Adams et al., (2009) have described the stages in the UK urban planning system, where soundscape can be incorporated in. So far, soundscape mapping in different scales has been perceived as a process of visualizing three main parameters: a) sound sources (Aiello et al., 2016), b) psychoacoustic parameters (Hong & Jeon, 2017; Lavandier et al., 2016) and c) perceptual attributes relevant to soundscape quality (Aletta & Kang, 2015).

Nevertheless, most of these studies are focused on a simple description of the soundscape environment without a more elaborate analysis on profiling areas based on different soundscape criteria. Therefore, urban morphology, land use and soundscape parameters are the three pillars of urban sound planning that are necessary nowadays for sustainable and healthy cities.

1.2 Aims and objectives

Research aim

The aim of this research is to explore how elements of urban morphology and particularly green spaces can affect traffic noise distribution in urban areas. This research question can further be analysed in multiple objectives as presented below:

Research objectives

➢ *Objective 1*

The first aim was to provide through the analysis of noise mapping and land cover data, an evidence of whether greener cities can also be quieter. This aim was investigated on three geographical scales (administrative, urban, kernel) in the agglomeration level using a top-down perspective. The effect of scale transition was also investigated on the final results. The correspondent objectives (*Chapter 4*) were:

- to explore the effect of forest, urban green and agricultural areas on noise distribution in the administrative level
- to explore the effect of green space indicators on noise indices in the urban level and to explore the effect of green space indicators on noise indices in the kernel level of the investigated cities.

➢ *Objective 2*

The aim here is to analyse the effect of urban morphology and green spaces on traffic noise.

A triple level analysis was conducted on the macro, meso and micro-scale. The macro-scale refers to the analysis examining the study areas as entities where three objectives were identified (*Chapter 5*):

- the relationship between urban morphology and traffic noise

- the relationship between green space ratio, green space pattern and traffic noise with the settlement forms
- the effect of street typology on traffic noise distribution.

In the meso and micro-scale the aim was to identify and assess the effectiveness of indicators related to urban morphology in traffic noise distribution. The meso scale refers to the analysis conducted in the 30 individual tiles of the study areas and the micro-scale in the analysis conducted only in the eight tiles of the city centres, one tile per city.

➢ *Objective 3*

The aim was to investigate the influence of vegetation and traffic-related parameters on the sound environment in urban parks based on physical data. This aim was achieved through the following objectives (*Chapter 6*):

- investigation of noise level distribution in the park scale caused exclusively by the surrounding traffic.
- investigation of noise level distribution in point scale according to the recorded noise levels inside the parks.
- identification of possible clusters in the noise measurements based on the inside-outside relationship.
- identification of possible correlations between the green space attributes of the parks and other morphological parameters and
- presentation of noise level differences between areas covered by trees and grass in the parks.

➢ *Objective 4*

The aim was to investigate the relationship between sound sources and land use in the urban environment. For this reason the following objectives were drawn (Chapter 7):

- identify the appropriateness of a list of human activities in different urban environments by conducting a Principal Components Analysis (PCA).
- identifying variables of urban morphology, to be used as predictors of the PCA components.

- identifying sound sources profiles.
- identifying human activity profiles.
- identify the relationship between sound sources and activity profiles and finally
- identify which human activities can be best distinguished among groups of urban activity profiles.

➢ *Objective 5*

Multiple aims were recognized for this case including the development of a mapping tool to aid soundscape planning, assess its effectiveness and identify particular profiles with common characteristics. The objectives connected to the above aims were (Chapter 8):

- the definition of individual steps that should be followed in order to reach at the final stage of a complete soundscape map.
- assessing the effectiveness of the interpolation algorithm applied in the maps using the cross-validation process and finally
- the clustering of sub-regions in each case study area into groups according to specific query filters.

1.3Thesis structure

In summary this thesis consists of two main parts or original research work. The first part includes chapters 4,5 and 6 and can be summarized under the general title of "*prediction and calculation*" of road traffic noise based on green space and other morphological parameters. The connective bond in these chapters is that similar research questions are investigated in different scales starting from entire agglomerations and moving down to sample areas within cities and finally urban parks.

The second part is complementary to the first one and covers the theme of "*perception and design implementation*" in soundscape, since human perception is a vital attribute in this process. Chapters 7 and 8 in this part explain the connection between land use, urban activities and sound sources as well as the utility of soundscape mapping as a tool in the planning process. The structure of each chapter is analysed below:

Chapter 1 - *"Introduction"* generally introduces the research background on traffic noise distribution, noise mapping and green spaces. It also provides the potential to study the effects of green spaces and urban morphology on traffic noise distribution in urban areas. The chapter ends with a detailed reference to research questions aims and objectives for the current study.

Chapter 2 - "*Literature review*" initially reviews previous studies related to the effect of urban morphology and green spaces on traffic noise. It refers to to the most extensively used urban form indicators and moves on to the effect of vegetation from the tree level up to the scale of green spaces as a land use element. Then, the review covers the topic of green space simulation in noise mapping, noise analysis using GIS tools and ends with a review on noise mapping practices such as participatory and soundscape mapping.

Chapter 3 - "*Methods*" explains the reasons of inaccuracies in noise mapping, the ground effect according to ISO 9613-2 and the parameter studies of ground effect under different configurations.

Chapter 4 - "*Relationship between green space-related morphology and noise pollution"* refers to the agglomeration level analysis. This chapter investigates the effects of green space-related parameters - from a land cover viewpoint - on traffic noise pollution in order to understand to what extent greener cities can also be quieter. The study initially includes 25 agglomerations six of which were further analysed in depth and ranked from the quietest to the noisiest. Seven different formulas to measure the extent of quietness were calculated until to find the one, which was correlated with green space parameters as well. Results were found to be affected by the scale of analysis; however, the initial hypothesis was confirmed under certain conditions.

Chapter 5 - "*Relationship between urban green spaces and other features of urban morphology with traffic noise distribution*" refer to the city level analysis. This chapter investigates the relationship between features of urban morphology related to green spaces, roads or buildings and traffic noise distribution in urban areas. The analysis was applied in sample areas of eight UK cities with different historical and architectural background, following two different settlement forms: radial and linear. An extended analysis was performed for two of the cities following different settlement patterns. Finally, in the last stage the analysis was focused only on the eight city centres. Quantitative methods combined with GIS tools were used for the results. In total 18 variables were constructed and tested for possible relationships with noise levels (L_{den}). Results revealed the relationship between morphological attributes and noise levels with a possible implementation of these indices as an "a priori" tool for urban sound planning.

Chapter 6 - "*The influence of vegetation and traffic-related parameters on the sound environment in urban parks*" refers to the park level. This chapter deals with the effects of vegetation and traffic-related parameters on the sound environment in urban parks. Eight parks of different sizes and varying proximity to the city's ring road were selected in Antwerp, Belgium. The noise environment was evaluated with a dual scale approach (park, point-based) using simulated traffic data from the surrounding roads in the first case and measurement data from mobile devices in the second. Percentile weighted sound levels were calculated considering various indicators (L_{A10}, L_{A50}, L_{A90}, L_{Aeq}). Special emphasis was put on background noise (L_{A90}) and peak values (L_{A10}). The effect of traffic was also validated using a cluster analysis tool that revealed different patterns of noise levels concentration among the parks.

Chapter 7 - "*Relationship between land use and sound sources in urban environments*" explores the relationship between sound sources and land use in the urban environment. The main material was based on binaural recordings conducted in the city centre of a medium sized city like Sheffield and 360-video stimuli. Both data types were used for a listening experiment, where participants were required to assess the dominance of sound sources and the appropriateness of land use activities for each place. In total 16 variables of social and recreation activities were used, six variables of land use and another set of five morphological variables. The dimension reduction process using the Principal Component Analysis (PCA) showed that the activity-based environment can be explained by two main Components (C1, C2). The green space coverage and the proximity to roads were the most significant parameters in the prediction of these two Components. In the final stage, a multivariate analysis (MANOVA) was used in order to identify significant variations for the land use activity variables in the three urban activity profiles. The whole process emphasized on the importance of linking urban planning and design with soundscape from the land use activity viewpoint.

Chapter 8 – "*Positioning soundscape mapping in environmental noise management and urban planning*" provides an overall framework of five steps for the development of a mapping model to aid soundscape planning. Then, it tests its implementation and effectiveness in two UK cities with similar land use characteristics. This chapter is using the same study area in Sheffield as in Chapter 7, but the analysis is focused on the number of different sound sources recorded by a single observer. Sound source variability is then accompanied by the variability of perceptual attributes in Brighton through a group soundwalk. In both cases the final results are tested using the cross-validation process in order to test the model effectiveness. Finally, an attempt is made to create specific soundscape profiles based on border values for Sheffield and combined queries for Brighton.

Chapter 9 - **"**Conclusions and future work" gives an overall picture of the main findings from this original research and suggests ways of improving and completing the research gap in the future.

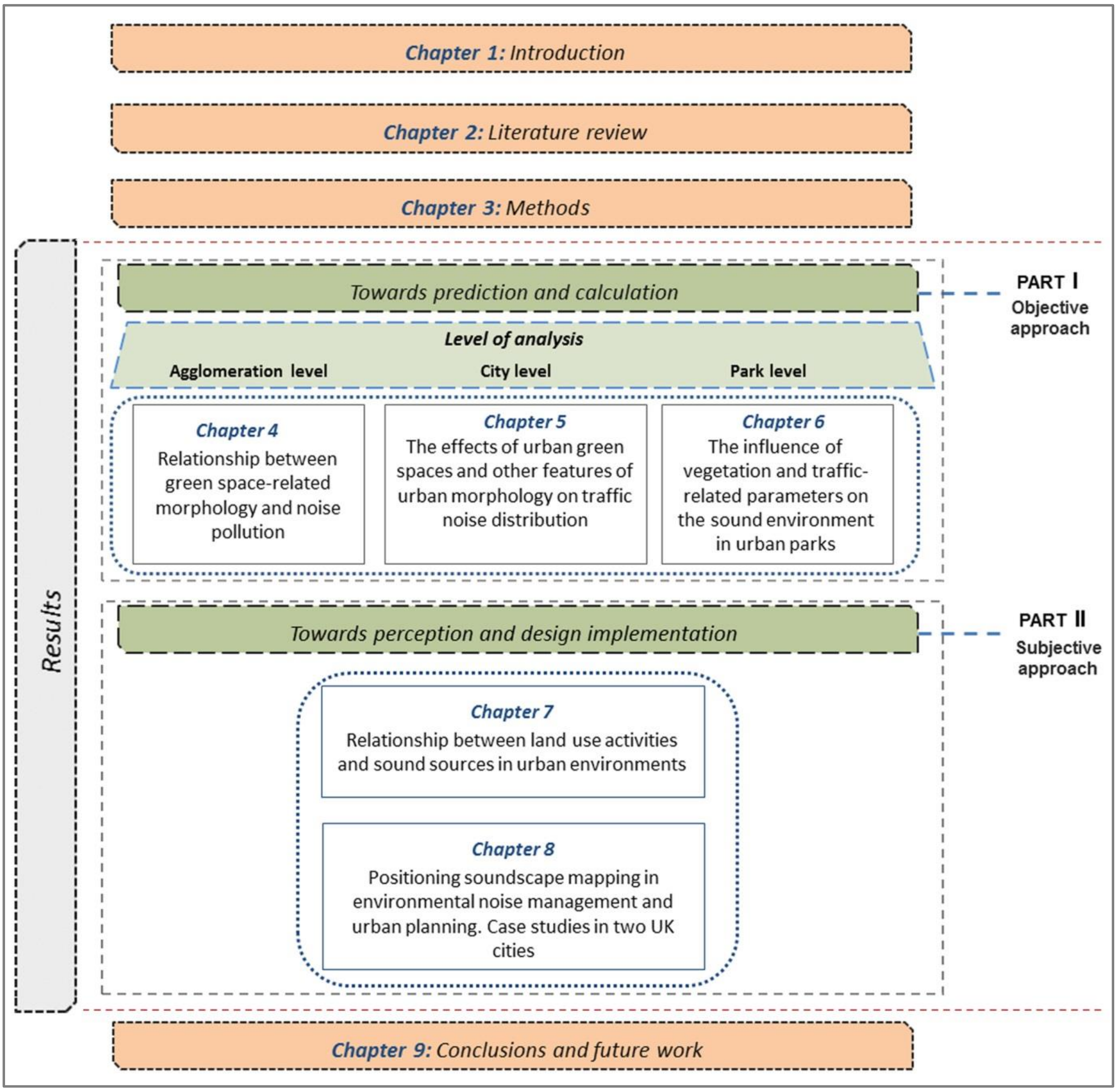

Fig.1.1. Overall thesis structure

Chapter 2

Literature review

To explore the impact of green spaces in traffic noise mitigation within dense urban environments, this Chapter extensively reviews the current literature on urban morphology and different green space categories. At first, Section 2.1 covers the current studies within the last two decades concerning the most widely used urban form indicators. Then it refers exclusively to studies that investigated the connection between urban morphology and traffic noise in different scales. Section 2.2 makes a short introduction with measures of accessibility related to green spaces, analyses the physics of sound propagation from the ground perspective and finally reviews previous studies referring to the effect of vegetation and land use in noise mitigation through regression models. Lastly, Section 2.3 refers to the contribution of GIS in the strategic noise mapping framework, the simulation of green spaces in noise mapping and the different noise mapping categories depending on the input data.

2.1. Urban morphology

The urban morphology or urban form in other terms has been the main topic of investigation during the last 20 years as part of an on-going research on the way that cities tend to expand and evolve. According to Anderson et al., (1996) as presented in Tsai (2005), urban form can be defined as the spatial pattern of human activities in a certain point in time. Batty (1994), as cited in Chakraborty (2009) goes a bit deeper and argues that it represents: "*the spatial pattern of elements composing the city in terms of its networks, land use, building spaces, defined through its geometry mainly, but not exclusively, in two rather than three dimensions*". A similar definition by Kropf, (2005), recognises the main elements of urban form as a hierarchy of different characteristics at different interdependent scales involving a) building elements, b) road infrastructure and c) land use components.

From a functional viewpoint, Tsai, (2005) recognized the categories of density, diversity and spatial structure pattern and suggested the Moran's I index to measure the extent of clustering. Density refers to the degree of activity or intensity, while diversity to the extent of interaction among different land uses. On the other hand, spatial structure pattern may characterize various land use phenomena, such as monocentric versus polycentric forms, centralized versus decentralized patterns and continuous versus discontinuous developments

It is worth emphasizing more on the spatial pattern structure and the extent of diversity in the cities as this has been an issue since the beginning of the 20th century with modernist planners, such as Le Corbusier, who tried to oversimplify the built environment with utopian cities. As Boeing, (2017) mentions, later studies have shown that over-simplicity and top down approaches that decompose the living structure of urban systems kill vital social processes. This is also the reason why Batty, (2008) emphasizes that urban morphologies although complex and messy, they have a bottom up development that helps them to grow organically and be ordered. As a result, planned cities are considered an exception rather than the paradigm. The following section is going to present the most popular urban form indicators that have been used either as urban policy tools or in conjunction with noise.

2.1.1. Urban form indicators

In the policy level urban form indicators have been used mainly to quantify urban form in terms of city expansion and urban sprawl. This is because the control of land use segregation, automobile dependency or residential density is a vital factor for sustainable and effective urban policies (Royal and Town Planning Insititute, 2015). Consequently, the description of urban form indicators is more useful if they can be used as a tool to assess developing scenarios, formulating plans and monitoring their effectiveness (Knaap et al., 2005).

Previous attempts to quantify patterns of urban form have mainly been focused the growth of suburban areas in comparison with the core part of the cities (Chinitz, 1965), as cited by Knaap et al., (2005). From the variables that have already been used as a measure of quantifying urban form and urban sprawl, Galster et al., (2001) use eight indices (density, continuity, concentration, clustering, nuclearity, centrality and proximity) tested for 13 study areas and calculate the respective sprawl rankings. However, these indices are more descriptive and less connected to public-policy according to Knaap et al. (2005). On the contrary Song & Knaap, (2004), use multiple indicators, which are easier to be calculated and were applied in order to conduct a comparative analysis in urban form of two neighbourhoods in Portland. Finally, these indicators comprise an evolution of the policy-based indicators developed by Allen (2001) as part of a GIS-based support system for community planning.

Based on studies relevant to urban form, Table 2.1 summarises the most common indicators from the literature presented in this Chapter. Nevertheless, when it comes to noise-related aspects it is essential to move from the "compactness-sprawl" perspective to the individual entities that form the dynamic environment of cities, such as buildings, street-blocks, plots and street patterns (Larkham & Pendlebury, 2008). These parameters are investigated in the following section.

Table 2.1. Review of the most common urban form indicators

Parameter	Authors
Street design and circulation systems	
Internal connectivity	Knaap et. al (2005)
External connectivity	Knaap et. al (2005)
Street intersections	Knaap et. al (2005)
Number of blocks	Knaap et. al (2005)
Length of blocks	Knaap et. al (2005)
Number of Cul de Sacs	Knaap et. al (2005)
Distance of first row Buildings to Road (DFBR): Mean of horizontal distances from the frontal facades of the first-row buildings (low positive relationship)	Hao and Kang (2013, 2014)
Road Area Fraction (RAF): Proportion of roads in total area	Hao and Kang (2013, 2014)
Road coverage ratio: RCOR Proportion of roads in the total area	Hao and Kang (2013, 2014)
Buildings	
a. Floor area ratio	Knaap et. al (2005)
b. Lot size	Knaap et. al (2005)
Building Plan Area Fraction (BPAF): Ratio of the plan area of buildings to the total surface area	Hao and Kang (2013, 2014)
Building Surface Area to Plan Area Ratio (BSAPAR): The sum of building surface area divided by the total surface area of the study region	Hao and Kang (2013, 2014)
Building coverage ratio (BCOR): Proportion of buildings in the total area	Hao and Kang (2013, 2014)
Population density	Galster et al., 2001; Song & Knaap, 2004
Land use	
a Land use diversity index	Galster et al., 2001; Knaap et a., 2005)
b. Land use proximity	Galster et al., 2001; Song & Knaap, 2004
Pattern	
Concentration, clustering, centrality	Galster et al., 2001; Huang et al., 2007; Song & Knaap, 2004
Accessibility	
a. Distance to a public park	Allen, 2001; Knaap et. al (2005)
b. Commercial distance: median distance to the nearest commercial use	Allen, 2001; Knaap et. al (2005)
c. Bus distance: Median distance to the nearest bus stop	Allen, 2001; Knaap et. al (2005)
Green spaces	
Porosity index (ROS): Proportion of open space to the total urban area	Ariza-Villaverde et al., 2014; Chakraborty, 2009; Huang, Lu, & Sellers, 2007; Silva et al., 2014
Acres of park per 1,000 residents	Allen, 2001
Accessible space coverage (ASPC): The coverage of all open spaces excluding the buildings and roads	Wang and Kang (2011)

2.1.2. Urban form and traffic noise

The individual components that refer to the internal form of cities (e.g accessibility, land use, compactness) as mentioned in Chakraborty, (2009) are directly connected with urban planning and management. Apart from that urban planning influences the urban form and mobility patterns (Burton et al., 2000) and consequently the distribution of sound sources within the city.

As a result, there is a direct correlation between urban morphology/form and traffic noise distribution. This relationship has been investigated in the past by various researchers at different scales from building façades and small neighbourhoods and expanding to entire cities.

Building façades and small neighbourhoods in a single city

Lam et al., (2013) investigatd the relationship between traffic noise and urban form in a Hong Kong city using a sample of 212 residential complexes from eleven urban form configurations. It was found that the building desing and arrangement are crucial parameters in noise distribution. In particular, the lowest noise levels were identified in areas with a buidling envelop format (self-screening) combined with low levels in building and road coverage. In terms of building heights, the mixed configuration was proved the quitest thanks to the multiple screening effects.

The historical evolution of a city is another significant factor that can affect the urban form and traffic noise levels. In such a study Tang & Wang (2007) investigated four urban forms developed in different chronological periods since 1794. The study showed that the lowest noise levels were found in historical areas with narrower roads, complex road networks and a higher density of intersections. Surprisingly these areas had the highest building lot space and the lowest green space coverage.

Similar to Lam et al., (2013), Silva et al., (2014) compared the theoretical and measured noise levels in the building façades of ten urban forms extended between two and four building blocks. The correlation of typology variables with noise levels showed that “Compactness” and “Porosity” indices increase proportionally to noise levels, while “Complexity Perimeter Index” has an inverse relationship. As in Lam et al., (2013), it was found that forms with a higher percentage of shielded or shadow areas correspond to lower noise levels, while the opposite happens with unobstracted forms of no obstacles between buildings and roads. Finally, the study verified that it is possible to minimize in advance the effects of noise in façades, by adjusting the layout and configuration of the building form.

Another study by Guedes et al., (2011) also confirmed the above findings especially as regards areas with high building density. In those cases, the least exposed building façades on highways were recognised as more noise priviledged. The authors studied the influence of urban shapes on environmental noise using 19 data collection points around the city of Aracaju in Brazil. Different acoustic scenarios were considered, where the beneficial role of façades was highlighted on the formation of acoustic shadow zones.

In the same scale, Hao et al., (2015a) used 20 sample sites in the city of Assen, in Netherlands, in order to assess how seven morphological parameters can attenuate traffic noise both on façades and in open areas. It was shown that areas with higher building coverage (BPAF) can potentially have noisier indoor environments, while the street pattern in terms of the “Building Height to Road Width Ratio” did not provide any significant noise level attenuation. However, another study from Ariza-Villaverde, et al., (2014) found that there is a positive correlation between the “street width to building height ratio” with ambient noise levels, using the theory of fractal analysis.

The crucial parameters of building attributes highlighted by Hao et al., (2015a) was also acknowledged by De Souza & Giunta, (2011) in a Brazilian city. The authors used GIS and Artificial Newral Network (ANN) models to study the realtionship between urban indices and noise levels in a small residential neighbourhood. Results were obtained from 40 reference locations and showed that apart from traffic volume, high noise levels were recorded in areas with high "Floor Space Index" (FSI).

Comparison between different cities

An important study, although not directly related to noise, but exclusively to the comparison of urban form among different cities around the World was conducted by Huang et al., (2007). The study used spatial metrics to cluster and measure the differences in similar morphological indices as the ones referred by Galster et al., (2001).

Concernign noixe and expandig the comparisons in more than one cities, Wang & Kang, (2011) studied the effect of morphological parameters on traffic noise distribution in Greater Manchester (UK) and Wuhan (China). These two cities are of significantly different urban densities, building form and traffic pattern. It was found that indices such as Road and "Building Coverage" as well as "Accessible Space Coverage" had significant effects on noise levels, taking into consideration the relevant land use attributes in the area.

Another two cities (Amsterdam, Rotterdam) were compared - in terms of noise pollution - using numerical calculations by Salomons & Pont, (2012).The authors used indicators related to traffic elasticity and dealt with urban density and urban form for various idealized urban fabrics. The derived results showed that sound levels were inversely proportional to population density, "Floor Area Ratio" (FAR) and "Ground Space Index" (building coverage). On the contrary, the shape of the building blocks (closed block, double strip and single strip) was proportional to road network density and building block shape. Finally, the effect of noise was greater at the least exposed façades (quiet façade) than on the most-exposed ones.

The above studies provide very useful evidence on the effects of urban morphology on traffic noise and the appropriate design of the buildings' layout form from the planning stage. However, the comparisons - either in the same city or in different cities - remain on the scale of façades or small neighbourhoods with no evidence for possible results on the city level. This is the knowledge gap that this study is going to investigate.

On the top of that, one of the most distinguishable morphological parameters, as presented in the previous studies, is related to green or open spaces (Table 2.1). Since this element comprises the main focus of the current research more details on it are provided in the following section.

2.2. Urban green spaces

The term "green space" appeared in the literature of city-planning less than half a century ago (Rezaee et al., 2012). According to Schipperijn et al. (2010), urban green spaces refer to "*all publicly owned and publicly accessible open spaces with a high degree of cover by vegetation, e.g. parks, woodlands, nature areas and other green spaces, which have a designed or planned character as well as a more natural character*".

Open green spaces enhance the sense of recreation and social well-being, while they are also related to health benefits cutting down work-related stress (Gobster & Westphal, 2004). In many cases, they are the most crucial factor as regards environmental pollution burden, absorbing rainwater and pollutants (De Ridder et al., 2004) and reducing the effects of urban heat islands (Rizwan et al., 2008).

In the planning and policy field, green spaces are usually quantified either in terms of "*area-based measures*" or "*accessibility-based measures*". Indicators from the first category such as green space area per person and green space ratio have already been mentioned in the previous section (Table 2.1). These measures were proved influential for modernist urban planners at the beginning of the 20^{th} century, however "accessibility" nowadays is easier to be measured and provide complementary information for citizens' preferences.

In particular for UK there is a very comprehensive guide named "*Natural England's Accessible Natural Greenspace Guidance*" by Natural England (2010). The revised guide of 2010 provides detailed recommendations for equal green space accessibility to all residents by improving access, biodiversity and connectivity. The report uses area based-measures and three characteristic types of natural green spaces namely: National Nature Reserves, Country Parks and Local Nature Reserves. Wolch et al., (2014) found that green space accessibility can also be affected by the ethnic background and the level of affluence in some areas. Such differences were highlighted by the authors between Chinese and US cities revealing the disproportional benefits for rich white people.

A study from Ståhle (2010) on how urban design can affect green space accessibility found out that some densely populated districts in Stockholm experience higher green space accessibility compared to low density suburbs. To interpret this paradox, the author reconsidered the concepts of attraction and accessibility through the use of axial line distances. Evidence-based findings confirmed the important role of parks' spatial integration in the city in correlation to their attractiveness.

The improved accessibility of green spaces does not only contribute to a more sustainable urban environment, but also to the reduction of urban noise (De Ridder et al., 2004). The physical characteristics of sound that cause this attenuation, as well as previous studies referring to this topic at different scales are discussed in the following section.

2.2.1. The physics of sound propagation

The previous section highlighted the importance of green spaces in different aspects and the relevant indicators in the planning stage. In an attempt to go deeper and look for the reasons that green spaces can effectively reduce noise pollution it is essential to make a brief introduction in the physics of sound propagation as follows.

In real conditions, the sound propagation is affected by a number of factors such as: a) absorption of sound in the air, b) meteorological conditions (turbulence, refraction) and c) interaction with solid obstacles (barriers, buildings) or porous ground. The sound pressure level ($\boldsymbol{Lp}$) taking into account the previous parameters is calculated according to *Eq. 2.1* as:

$$Lp = Lw - 20\log(r) - 11 + DI - A_{abs} - A_E \qquad \textbf{\textit{(Eq. 2.1)}}$$

$Lw = sound\ power\ level$

$r = distance\ from\ source\ to\ receiver\ (meters)$

$DI = Directivity\ Index$

$A_{abs} = atmospheric\ absorption\ (dB)$

$A_E = excess\ attenuation\ (dB)$

The total excess attenuation A_E (dB) is a combination of multiple effects as shown in *Eq. 2.2*.

$$A_E = A_{weather} + \boldsymbol{A_{ground}} + A_{turbulence} + A_{barrier} + A_{vegetation} + A_{other} \qquad \textbf{\textit{(Eq. 2.2)}}$$

The focus of this study is particularly on the ground attenuation (A_{ground}) and not on similar parameters such as vegetation ($A_{vegetation}$), which refers to the effect of tree foliage.

A better explanation of this term is given by Attenborough (2002), who mentions that sound propagation close to the ground is sensitive to the acoustical properties of the ground. Porous surfaces allow sound to penetrate, which leads to further absorption or delay of the sound wave due to thermal exchanges or friction. Since the interaction of sound with outdoor ground involves interference, there can be either enhancement associated with constructive interference or attenuation resulting from destructive interference as shown in Fig.2.1.

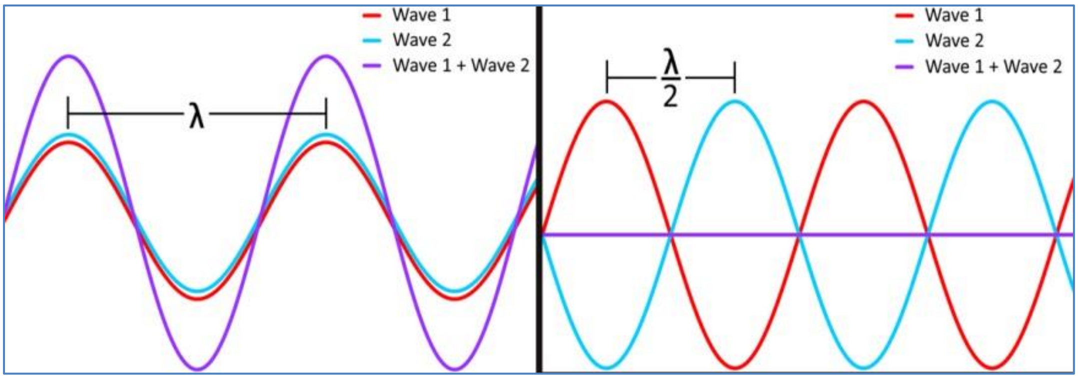

Fig.2.1. Example of positive interference (left) and negative (right) with the subsequent changes in the wave length. Source: http://angstromengineering.com/thin-film-u/introduction-optical-coatings/

This sound interference for porous surfaces is known as "ground effect" or "ground attenuation" ($\boldsymbol{A_{ground}}$) and leads to the outdoor noise level reduction that is mentioned in many prediction schemes (Timothy Van Renterghem et al., 2015). Accurate prediction of ground effects requires a good knowledge of the absorptive and reflective properties of the surface (Hannah, 2006). More details with respect to ground effect uncertainties and simulations are provided in Chapter 3.

Another index of measuring the acoustic impedance of ground surfaces is flow resistivity, which measures the ease with which air can move in and out of the ground. It represents the ratio of the applied pressure gradient to the induced volume flow rate per unit thickness of material and has units of Pas m^{-2}. High flow resistivity is related to higher difficulty of the air to flow through the surface. Flow resistivity is inversely proportional to porosity, meaning that high flow resistivity is related to low porosity. For example, wet compacted silt may have a high flow resistivity of 4,000,000 $Pasm^{-2}$ and porosity as low as 0.1. Other models for the acoustic properties of the ground include the tortuosity (or twistiness) and air permeability (Rossing, 2007). Having these parameters in mind, it is easier to refer to the green space effects on traffic noise control as discussed in the following section.

2.2.2. Green spaces in noise control

The key point when referring to previous studies in this field is to understand that the effect of green spaces in noise attenuation can be analysed in various scales starting from a single tree up to the effect of green spaces as land use attribute. An example is presented in Fig.2.2. According to Cohen et al., (2014) noise attenuation due to green spaces range between 6 and 27 dB(A) depending on the distance between source and receiver as well as planting parameters.

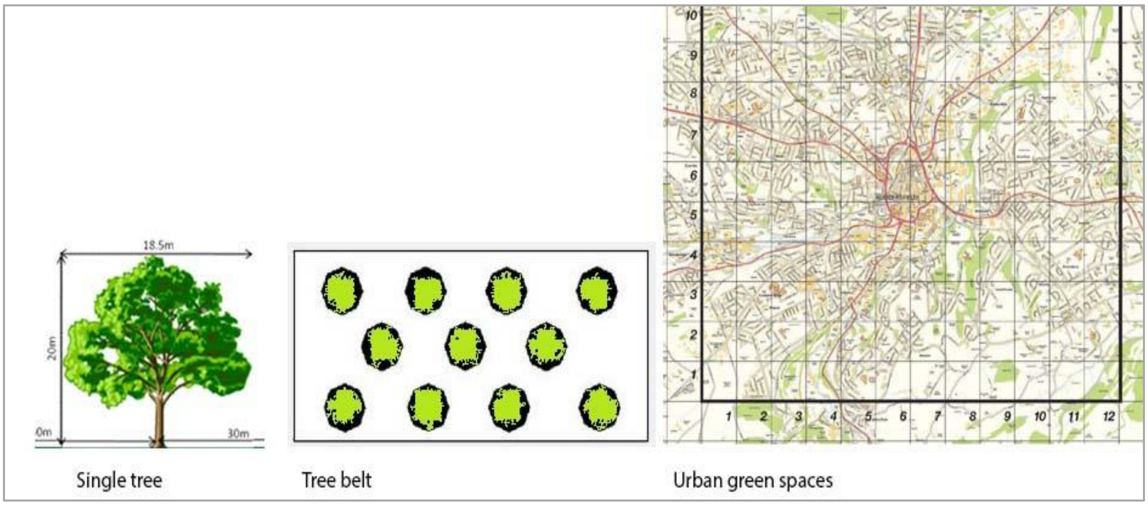

Fig.2.2. Representation of the scales of application with respect to the various effects of vegetation in noise mitigation.

Single plants

The sound attenuation for single plants is caused by the mechanisms of sound absorption, sound diffusion - which occurs when the sound wave bumps on the vegetation and is reflected back - and sound level reduction, which is caused by the transmission of the acoustic wave through vegetation (Kang, 2007a). In the lower scale of a single tree it has been found that the size and type of trees, the source distance from the stem axis and the amount of leaves can affect the reverberation time. In particular, a study by Yang et al., (2011) showed that even a single tree can increase reverberation time, especially at high frequencies. Another study by Smyrnova et al., (2010) compared five different plant types typical for European streets. The study showed that all of them were effective for sound attenuation as street furnitures with sound absorption over 0.5 in high frequencies. Significant attenuation up to 10 dB(A) was found in cases of vertical greenery by Wong et al., (2010). The noise reduction in these cases was higher in the middle and low frequencies and lower in the high frequency spectrum due to scattering from greenery. Pathak, et al., (2011) moved on to recommendations of specific plant types suitable for green belt development that are tolerant to air pollution.

Tree belts and shrubs

Apart from single plant or trees, tree belts and shrubs have also been used in the urban environment. As mentioned in Attenborough & Taherzadeh, (2016) detailed recommendations and examples for the design of noise buffers using plant belts have already been provided by the early 1970s. In particular, the US Department of Agriculture and National Agroforestry (Agroforestry Net, 1998) has published guidelines based on the studies of Cook & Van Haverbeke, (1974). According to Kragh, (1981) a relative attenuation of 3 dB(A) in L_{eq} was found for tree belts of 15-41 meters wide. Another study from UK by Huddart, (1990) signified a maximum attenuation of 6 dB(A) in L_{10} due to traffic, through 30 meters of dense spruce, compared with the same depth of grassland. Noise attenuation in this study was found to be proportional to the distance between vegetation and roads. The final outcome of the study was that noise attenuation can be maximised by the combined presence of tree belts and shrubs.

Previous experiments in tree belts by Fang et al.,(2003); Fang & Ling, (2005) found that the belt width is more important as a parameter of noise reduction than the tree height or the receiver and source height. It was also shown that large shrubs and dense tree belts can provide up to 6 dB(A) of noise attenuation, which is double the effectiveness of medium-sized shrubs and sparse tree belts. As regards the planting orientation, Papafotiou et al., (2004) found that lanes vertical to the source are less effective than the parallel ones.

In another study, which tested the effectiveness of different planting scheme configurations (simple cubic, rectangular, triangular and face-centred cubic) (Van Renterghem et al., 2012), shrubs provided a maximum of 2 dB(A) attenuation considering passing-by light vehicles at 70 km/h. The study provided also minimum values for tree spacing (3m) and stem diameter (11cm) in order to start having positive values of attenuation. Another important finding has to do with the type of soil. For example, forest floor soil was found to give 3dB(A) of noise reduction more compared to grassland. Finally, Kang (2007a) mentions that wide belts of tall dense trees with a depth between 15-40 meters have an extra attenuation of 6-8 dB(A) at low (250 Hz) and high (>1kHz) frequencies.

Parks

One of the most common green space elements in the urban environments are parks. Although not clearly stated at the END, these areas have the highest probability to be designated as “quiet” or “calm” areas (European Environment Agency, 2014) within agglomerations. Consequently, it is important to investigate their inner and surrounding environment. As a result, many studies have investigated the environmental effect of urban parks on noise and air pollution. However, some of them focused on either describing their ambient noise environment compared to nearby squares and streets (Cohen et al., 2014), or rating their urban value based on people’s perception (Brambilla et al., 2013; Jabben et al., 2015; Jeon & Hong, 2015; Nilsson & Berglund, 2006; Tse et al., 2012). The above studies are very useful when the main focus in placed on perceptual characteristics, however from the design viewpoint it is necessary to have quantified indicators able to represent the parks' performance and rating.

Few studies have used a quantitative methodological approach. For example, González-Oreja et al., (2010), used objective parameters, such as park size, tree density and tree canopy coverage to investigate the correlation with the equivalent noise level (L_{EQ}). Using a sample size of 21 spots of urban green spaces in a Mexican city they found significant negative correlations between the tree features and noise levels.

Finally, Kothencz & Blaschke, (2017) used GIS to quantify spatial green space indicators and correlate them with human perception. The objective parameters included data related to area size, vegetated surfaces, water surfaces and building-related indicators. A moderate correlation between the percentage of vegetated surfaces and the "impression of the environment" confirmed the hypothesis that "greener" parks are more appealing to visitors. The visitors' perception was shown to be affected also by the built-up areas within a buffer zone of 50 meters around the parks. Nevertheless, the study did not use traffic noise indices, but instead asked participants to describe noise disturbance in their own words.

The quantitative assessment of parks, as regards their environmental quality, can also be used in a higher policy level, where land use parameters are taken into consideration within a sustainable planning management context. In this context it is important to know which land use parameters can be used as predictors for noise levels and what is their effectiveness. The next section is dedicated to this topic.

2.2.3. Land use in noise control

2.2.3.1. Ground and land use regression models

Land use or land cover refers to the different types of ground that affect sound propagation due to their physical properties as discussed in § 2.2.1. Even the same land cover class such as "grassland" involves a wide range of ground effects as mentioned by Van Renterghem et al., (2015). A more detailed evidence on this topic is also presented in the Work Package 4 of HOSANNA project referring to the acoustical effects of porous surfaces (Attenborough et al., 2012), where 47 types of land were tested in terms of flow resistivity. This part of the project investigated the acoustical effects of replacing acoustically hard ground with acoustically soft ground alongside an urban road. Results showed that in terms of grass types, pasture and sport field grass provide the highest dB reduction compared with smooth hard ground.

In the urban scale the ground effect is better represented in terms of land use parameters seeking to predict noise levels through the so called "Land Use Regression" (LUR) models. Although this technique is very popular for the prediction of air pollution levels (Kanaroglou et al., 2005), there a few recent studies that replicated and adjusted this method on noise levels.

The first study using LUR models by Xie et al., (2011) focused exclusively on six land use types as predictors. Industrial, residential and green space areas at different buffer distances were used in the regression. The model was tested in three spatial scales from downtown to regional areas with an R^2 value between 75% and 83.2% and better result obtained for the regional areas (83.2%).

Goudreau et al., (2014) used 149 sampling locations measuring noise levels for different period over two consecutive years. In their analysis they make seasonal distinctions between winter and summer periods. The LUR model for L_{Aeq} was shown to perform better for summer periods with 64% of the spatial variability to be explained. The best predictors out of 69 tested variables were the Normalized Difference Vegetation Index (NDVI), the length of main arteries, highways and bus lines, as well as the proximity to the airport. Finally, the root mean square error was slightly higher during winter (4.5 dBA) compared to summer (3.3 dBA).

Aguilera et al., (2015) made a distinction between the possible predictor variables (46) collected from GIS data and the variables collected when visiting the measurement sites (17), although there were overlapping indices. The study found significant correlations between the long-term noise estimates from traffic noise models and the noise estimates developed by the two LUR models. The latter, concerning the GIS-variables were proved slightly more effective than the one with on-site and GIS variables together, with a total variance explanation between 0.60 and 0.89 in both models. Surprisingly this study used only road and building attributes with no reference to green space parameters.

Gozalo et al., (2016) used a sample of 154 points and examined 135 variables as possible predictor. They finally used eight of them to develop a regression model for traffic noise levels with high accuracy (R^2 = 0.63). The model was validated and tested in 30 new sample locations with the prediction error to be lower than 2 dB(A). The highest correlated variables with noise levels in this study refer to the presence of commercial areas, the road width and length, the number of traffic lights and attributes related to street lanes. Although the final prediction error was low, the generalisation of this model can possibly face problems in the data availability in other cities, since some of these attributes are very detailed and place-oriented.

Ragetti et al., (2016) considered various noise sources (traffic, rail, air) in their LUR model and apart from L_{Aeq} they used also L_{den} and L_{night} as predictors. The sample size was relatively higher, compared to Gozalo et al., (2016) and Goudreau et al., (2014) with 204 sites to be included in the analysis. Out of 34 possible predictors, seven were proved significant, with the most important to include NDVI like Goudreau et al., (2014). Land use variables such as the ratio of low density residential areas and office zones were also included in the model. The final model managed to explain between 59% and 69% of the total variance for all the three noise indicators.

Lastly, the study from Ryu et al., (2017) is the only one compared to the previous that is based on façade noise levels extracted from the official noise map and not from in situ measurements. The authors used a raster approach to calculate both the morphological variables and the average noise levels in cells of 250x 250 meters. Eight out of the initial 12 independent variables were used in the LUR model for the entire city with the final variables to refer to: traffic characteristics (traffic volume, traffic speed), road geometrical attributes and land use parameters including green spaces. Table 2.2 below presents an overall summary of the previous references with details for the correlated variables, the representation of green spaces and the achieved R^2 value of the models.

Table 2.2. Review table of the most recent references dealing with LUR noise models.

Authors	**Sample size**	**Total variables**	**Correlated variables**	**Green spaces**	**Index**	R^2
Xie et al., 2011	101	6	3	land use	L_{eq}	0.75-0.83
Goudreau et al., 2014	149	69	4	NDVI	L_{Aeq}	0.64 (summer) 0.40 (winter)
Aguilera et al., 2015	39-60	(46-GIS) (17-onsite)	2-4	-	L_{Aeq}	0.66-0.87:GIS vars 0.61-0.89:All vars
Ragettli et al., 2016	204	34	7	NDVI	L_{Aeq}	0.68
Gozalo et al., 2016	154	135	8	relaxation & walking areas	L_{eq}	0.63
Ryu et al., 2017	1201 (cells)	12	8	land use	$L_{Aeq\text{-}night}$	direct & indirect impacts

Although the above models achieve a high accuracy level for short or long-term noise levels, they are quite difficult to handle and generalise in other cities. The main reasons why this happens are: a) the complexity of some indicators, which are difficult to be calculated in other cities in case some data are missing, b) the arbitrary selection of parameters, c) the variables' significance within various buffers distances does not guarantee that the same variables will be significant in the same buffer ring of another city, d) careful selection of measurement points is required.

On the contrary the inclusion of a few parameters related to green spaces can simplify the model, generalise and test its effectiveness in different cities and compare sites even between different countries. This is the aim of the current research - especially in Chapters 4 and 5 - where other morphological parameters are not excluded, but have a complementary role in the model.

GIS is the main tool that was used in LUR studies for data analysis related to the calculation of the morphological variables. However, as a tool it is an integral part of the the strategic noise mapping process as well. Consequently, it is important to analyse the software's possibilites in noise mapping compared to the traditional noise mapping softwares and investigate their complementarities and limitations. These issues are explained in detail in the next section.

2.3. Noise mapping

2.3.1. GIS in the noise mapping framework

The noise mapping process is based on the interoperability of noise modelling and data analysis software, where the use of Geographical Information Systems (GIS) is mandatory. The individual steps of using GIS in the strategic noise mapping process are described in detail in WG-AEN v.1 (2003, p.53). These include the following:

1) ***Data acquisition:*** all datasets concerning road network, building and height data, topographic maps with elevation details, population data and other site maps are collected for quality assurance and imported in the GIS management system.

2) ***Scheme preparation:*** the data that are necessary for the noise mapping process are organised in categories such as sources, obstacles, population and simplified to the minimum level of accuracy. For example, as King (2013) mentions, one reflection is enough to guarantee sufficient noise mapping accuracy in the strategic level. It is also more appropriate to use a 10x10 meter grid in urban areas, as the 5x5 meter can cause a delay up to 125% of the initial calculation time.

3) ***Bi-directional data exchange between GIS and the noise mapping software***: all geometrical and source data are imported in the noise mapping software, where the calculation model is selected coupled with the calculation parameters and settings that will define the final level of accuracy in the noise map. The calculated numeric noise levels are exported back to GIS in order to be processed.

4) ***Noise data analysis in GIS***: areas where the noise limit values are exceeded are geo-referenced with the correspondent land use. Noise levels are also calculated for the georeferenced population data (number of people under certain noise bands). In the final stage smaller noise maps are collated together to form the final large noise map.

5) ***Data presentation to the European Council (EC) and the to the public***: the noise mapping results are presented in overlapping layers with aerial photos and inform the public either through web pages or reports. The EC receivers the results and prepares separate reports for all member states. An overview of the whole process is presented in Fig.2.3.

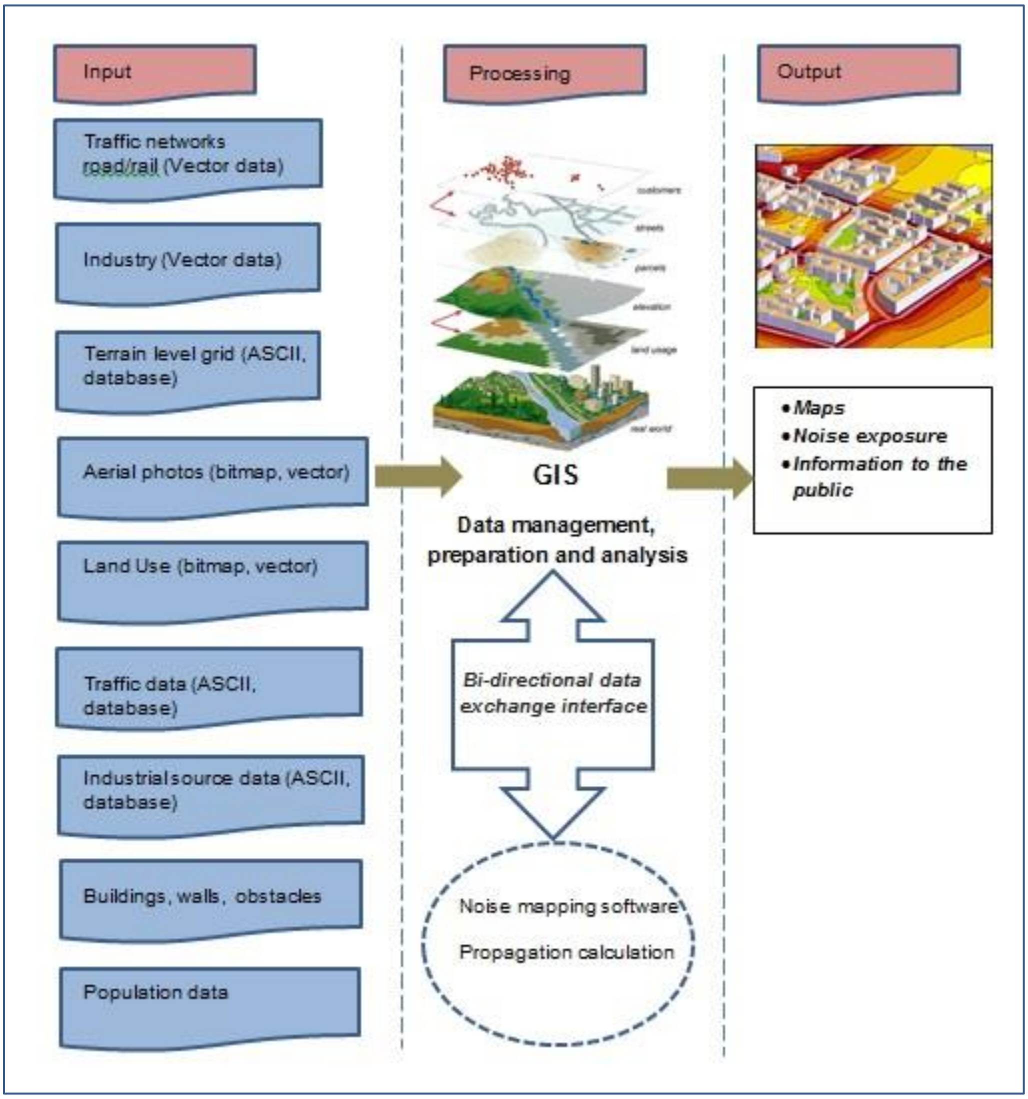

Fig.2.3. Overview of the noise mapping process (WG_AEN, 2003, p53) with emphasis on the bi-directional data exchange during the processing stage.

Multiple advantages occur from the use of GIS in all steps of the noise mapping process as explained in the same Guide (p.57). The most important from all of them that are highlighted in the Guide is the integration of the multiple acoustically relevant data from different authorities into a single geodatabase. Secondly, the interoperability of the System with noise mapping softwares allows fast and accurate data exchange, which is crucial for noise-triggered decision making. This property provides enhanced control and better understanding of the data accuracy and completeness. Apart from that, the centralised maintenance enhances the functionality of data management and allows the system to be well-organised.

Finally, in the presentation stage, web-GIS tools facilitate the availability of information to the public by creating an interactive and easily accessible environment. The next section refers to the input data stage (Fig.2.3) and in particular to the green space dataset and the way this information is simulated in the noise mapping softwares.

Although GIS has been used extensively in noise mapping, the main aim of the software so far has been to allocate the population in specific noise bands and to enhance the visualisation of the final mapping results. In the best case, it has been used as an alternative stand-alone noise mapping suite. However, GIS softwares have increased capabilities in noise mapping analysis and prediction using raster, interpolation and clustering functions. These capabilities are worth to be further explored.

2.3.2. The simulation of green spaces in noise mapping

As described in § 2.2.1 one of the basic input data for noise mapping refers to terrain and land use related to ground cover. There are three main sources so far according to the Guidance Note for Strategic Noise Mapping (Environmental Protection Agency, 2011, p.63, 64): The OSi Largescale, the OS Mastermap and the CORINE land cover dataset. According to the same source, the experience with the first two datasets has raised particular issues concerning the complexity of the raw dataset in the context of noise propagation modelling. This is because detailed ground datasets can delay the calculation process when a whole agglomeration is considered, depending also on the complexity of the model.

As regards CORINE dataset, it is available in a scale of 1:50,000 for UK compared to 1:100,000 for most of the European countries. Results have shown that the simplified version can be used within agglomerations with very little change in the calculated noise level. The final raster dataset has a minimum map unit of 25 hectares, which in the 1:100,000 scale is represented by a 5x5 mm square (European Environmental Agency, 1999). In total there are four main nomenclatures (artificial surfaces, agricultural areas, forests - semi natural areas and wetlands).

For noise calculation in smaller areas compared to entire agglomerations the OS Mastermap Topography layer can also be used. It is more detailed and built in a bigger scale (1:1,250). As depicted in Fig.2.4 it is more precise than CORINE 2000, since it entails detailed information relevant to smaller vegetation polygons. It is also characterised by information relevant to the vegetation type: for example, coniferous and non-coniferous trees.

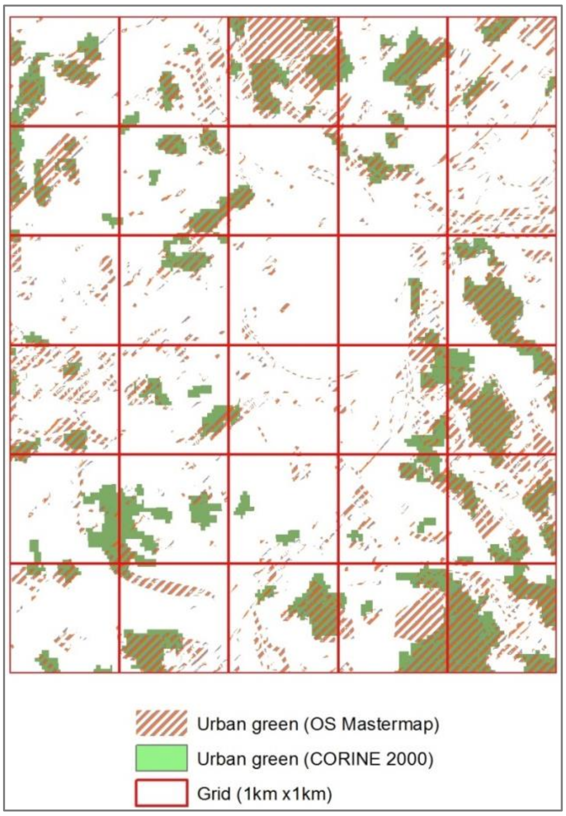

Fig.2.4. Differences in green space patches between CORINE 2000 and OS Mastermap.

Issues raised as regards the effect of green space complexity in noise level accuracy led to validation calculations, which proved that noise level differences are very small between the previous two datasets as mentioned by EPA (Environmental Protection Agency, 2011). Table 2.3 presents the default ground factor ("G") assigned to each land use class as suggested by the Toolkit 13.2 (European Commission, 2007). The range of "G" varies between "0"and "1" with the first option to characterise acoustically reflective (rigid) surfaces and the second to be used for absorptive surfaces. Details about the input data and how they can affect the accuracy of noise mapping are mentioned in detail in § 3.1.

Table 2.3. Default ground absorption for land use classes according to Toolkit 13.2.

Land use	Ground factor
Forest	1
Agriculture	1
Park	1

Heath land	1
Paving	0
Urban	0
Industrial	0
Water	0
Residential	0

Overall, looking at the general picture of GIS contribution in noise mapping, apart from the input and processing part with green space simulation, there is a broad range of studies. These studies cover not only the typical population allocation in different noise bands, but extend to dynamic and participatory noise mapping, where citizens have a more active role in the entire process. Apart from that, the complementary field of soundscape mapping gradually gains more attention. These topics are presented in more details in the following section.

2.3.3. Noise mapping practices

2.3.3.1. Noise mapping and urban planning using GIS technologies

The combined use of GIS and noise mapping in environmental assessment and urban planning has made significant progress during the last ten years. At first, Lee et al., (2008) used noise mapping for an environmental impact assessment project considering multi-reflections, refractions and absorption criteria. The authors considered three scenarios for present and planned situations considering the effect of a noise barrier.

The importance of GIS in noise mapping has also been highlighted by efforts to create a unified GIS platform incorporating sound mapping tools, such as the recent work by Keyel et al., (2017). The authors managed to develop an open-source toolbox adaptable to users' needs able to incorporate three sound propagation models taking into account all noise attenuation factors as traditional models do (ISO 9613-2). The tool can be applied in environmental, population and planning studies, since it can incorporate road traffic and individual sound sources. Another open-source system combining GIS and noise mapping tools is OrbisGIS developed by Fortin et al., (2012). The authors developed a partitioning system that divides the study area in optimal subdomains and allows parallel computing, which optimises resources and is efficient for large scale noise mapping.

An innovative approach to improve noise mapping techniques and apply them in urban planning was performed by Deng et al., (2016). The authors combined building information modelling (BIM) and 3D GIS in order to evaluate traffic noise levels in indoor and outdoor environments based on a single platform. Both Deng et al., (2016) and Fortin et al., (2012) took into consideration the first reflections in order to yield more accurate results. The main issue with strategic noise mapping is that the outputs are based on simulations of traffic flows and not on actual noise measurements. Towards this direction researchers have tried to introduce the concept of dynamic noise mapping as presented below.

2.3.3.2. Dynamic noise mapping

In particular, Sevillano et al., (2016) worked on the development of the DYNAMAP project, dealing with the design and implementation of real time noise mapping using low cost sensors spread in large areas or cities. The fast and real-time response system using web-GIS can help in strategic noise mapping updates with minimum resources. This is the main comparative advantage of this project, since previous efforts of real-time (dynamic) noise mapping were restricted in small areas, due to the high cost of software and equipment.

The last ten years crowdsource noise level applications have been developed for mobile phones giving another perspective in the noise mapping process. An example of this technology was “NoiseTube” mentioned by Maisonneuve et al., (2009). In this case localised noise data are collected using a smartphone application combined with a web server for data processing and presentation in Google Earth. Lavandier (2013) were based also in “NoiseTube” application in order to collect objective noise data from mobile phones and at the same time store perceptual data from questions to the mobile owners.

Although the main issue in smartphone noise mapping - presented also by other researchers (Bilandzic et al., 2008; D'Hondt et al., 2013) - is data credibility due to the large amount of input resources needed, Murphy & King (2016) presented promising results as regards their accuracy. Specifically, they found that a particular noise application had an accuracy with ±2 dB across all reference conditions

2.3.3.3. Soundscape mapping

Noise mapping coupled with the corresponding Noise Action Plans aim at noise level reduction and the adoption of measures for a sustainable future. However, the techniques presented in the previous section for strategic and dynamic noise mapping can only partially reflect the real level of annoyance and other perceptual parameters related to citizens. For this reason, this section refers to the presence of the human factor through the field of soundscape mapping.

It is crucial to start from the official definition of "soundscape" according to IS0 12913-1, (2014) as: "*an acoustic environment as perceived or experienced and/or understood by a person or people, in context*". Soundscape mapping refers to the visual representation of perceived sound sources, perceptual attributes and less often psychoacoustic parameters.

Starting from the first category, Rodríguez-Manzo et al., (2015) used the general sound source classification system of Brown et al., (2011) adjusted to the character of the sound environment of a local pedestrian street in Mexico. Although, the area is restricted it is a good example of soundscape mapping for sound sources using recorded data.

In a more comprehensive study for sound sources Ailelo et al., (2016) were based on tagged information of georeferenced pictures for the cities of London and

Barcelona in order to investigate for the first time the relationship between emotional aspects and sound sources. Their study used seven sound source categories in order to classify sound words, however all of them can be decomposed to the basic three sound source categories (anthropic, natural, technological) as defined by Brown et al., (2011). The study initially associated different street types with sound profiles resulting in expected and rational outcomes. For example, primary roads were associated with transport sounds, while pedestrian streets with human, indoor and music sounds. Secondly, they investigated people's perception on the identification of chaotic, monotonous, calm and exciting areas.

In a different classification system for sound sources compared to Brown et al. (2011), Papadimitriou et al., (2009), examined the cartographic representation of soundscape's morphology in rural areas based on the origin of the sound sources (anthropophony, biophony, geophony), their time variability and the perceived intensity of each sound source category. Although the paper refers to areas which are not affected by human activities it has a structured methodological approach that makes it applicable to urban areas.

In the same wavelength as Papadimitriou et al., (2009), Liu el et., (2013) used GIS techniques to visualise the soundscape variability of three sound sources namely: anthropophony, biophony and geophony in a multi-land use urban area. The demonstrated model is indeed very accurate with a wide temporal variability and presents the capabilities of GIS tools in combined visualization patterns. However, there are still issues related to accuracy of the model due to the small number (2) of simultaneous observes.

Apart from sound sources, perceptual or psychoacoustic parameters are necessary to be represented in a complete soundscape mapping framework. In this direction, Lavandier et al., (2016) measured and visualised the perceived pleasantness in various Parisian public places based on predictors related to the perceived loudness, voices, birds and traffic. The prediction model was compared with a correspondent one, which used georeferenced data related to morphological features, such as traffic, gardens and voices in commercial or recreational areas. The research found correlations between loudness and the perceived level of traffic and discusses the different criteria of sound assessment between local residents and passers-by.

Hong & Jeon (2017) and Aletta & Kang (2015) also included the soundscape representation of perceptual variables. Especially Hong & Jeon (2017) incorporated psychoacoustic parameters for the study area including spatial variations of the perceived soundscape quality. On the other hand, Aletta & Kang (2015) tried to adjust their mapping representations based on different planning scenarios, which shows an effort to integrate soundscape mapping in the planning process.

The above studies have dealt with the issue of soundscape mapping isolated from the planning process or by leaving this gap to be explored in a future research. Only Aletta & Kang (2015) have made a step forward towards this direction as part of the wider aim within the EU SONORUS project to merge the gap between acoustics and urban planning. More details on this topic are provided in Chapter 8.

2.4. Conclusions

The evidence of effectiveness from urban morphological parameters on traffic noise distribution and the effectiveness of green spaces on the same issue show that these two factors can be used in the early design or planning stage prior to any noise reduction measure. This review highlighted the lack of analysing green spaces as a land use parameter and the need to simplify the complex regression models.

We also highlighted the lack of further analysis in noise mapping data using GIS tools that can provide essential information for profiling and clustering areas in combination with land use data.

Another issue is that traditional noise maps are insufficient to provide evidence for perceptual attributes related to citizens. For this reason, it is important to investigate perceptual parameters, but not in a fragmented way. For example, a relationship between sound sources and land use in the urban environment can potentially provide important results useful in the planning stage. Apart from that, using perceptual attributes for mapping purposes is gaining ground nowadays as shown in the current review. However, the use of soundscape mapping in combination with area profiling and land use attributes still needs further investigation.

The next chapter refers to the effectiveness of noise mapping and particularly all the accuracy issues that have been detected so far since the date that the END was put into action.

Chapter 3

Methods

3. Methods

This chapter overall examines the topic of uncertainty in strategic noise mapping with special emphasis on sound attenuation due to the ground effect as initially described in Chapter 2. It starts by analysing the reasons of inaccuracy (Section 3.1) and moves on to the simulation of the ground effect under various calculation models (Section 3.2). Special emphasis is placed on the ground attenuation according to ISO 9613-2 (Section 3.3) with parameter studies for frequency-based and A-weighted sound pressure levels (Section 3.4). The chapter ends with the comparison of different urban configurations using the ISO 9613-2 and marginal ground effect values for rigid and porous ground (Section 3.5).

3.1. Reasons of inaccuracy in strategic noise mapping

The aim of this section is to analyse the reasons of inaccuracy in noise mapping with a particular focus on uncertainties around ground effect. A coherent review was performed and is presented here as regards the way that the ground effect is simulated under the different calculation protocols with a particular emphasis on ISO 9613-2. Specific parameter studies are also shown and compared using this calculation method.

3.1.1. General uncertainty parameters in strategic noise mapping

Since the release of the END in 2002, numerous studies have been performed on the investigation of strategic noise mapping uncertainties and possible ways to reduce them. These studies have been released either in the form of Good Practise Guides (GPGs) or by single researchers. In the second case, Hepworth, (2007) confirms that accuracy issues in noise mapping are caused by the following four parameters:

a) input data

b) software issues related to propagation

c) calculation models

d) result interpretation.

Popp, (2009) accepts this classification, but replaces the software-related issues with the category of human mistakes. In all cases, a detailed analysis of the factors and the research conducted in each one of these categories is presented below.

a) Input data

Errors in input data can be caused due to the different level of detail and accuracy due to multiple sources, the lack or assumptions in geometrical data such as building height and the compromises in traffic volume data (Popp, 2009). On the top of that, the fleet structure in terms of heavy and light vehicles is rarely available not to mention their distribution in day, evening and night values. Additional errors can be added due to lack in georeferenced or population data and shortage of metada, such as the absolute or relative height of buildings.

A previous study by Ausejo et al., (2011) assessed the uncertainty of the road traffic source emission first by using default traffic data and then by the use of improved measured data. In some cases, the differences between the two methods reached up to 8.7 dB(A). They also suggested the Monte Carlo method as an optimal solution to quantify uncertainty of input data.

b) Propagation uncertainty in combination with input uncertainty (software-related)

Hepworth, (2007) and the companies involved dealt with propagation uncertainty in an attempt to improve the first version of GPG. The emphasis was placed at non-geometric factors such as speed, traffic volume, flow composition and road surface type coupled with geometric parameters related to height, location and ground surface type. The highest decibel error was caused by traffic flow, vehicle speed and road gradient. Overall, it was shown that the total uncertainty increases when the accuracy of multiple input data entry is low. Another factor that can increase the errors is the extent of complexity of the acoustic environment, as mentioned in the report of the Dynamap project (Cerniglia et al., 2015, p.18). However, the authors suggest an increase in the number of measurement positions to counteract this effect.

c) Calculation models

Calculation models include simplifications in order to reduce the calculation time, however most of the times there is a lack of transparency as regards the exact details in this issue. Moreover, some of them are still old from the period that computer calculations did not even exist (Popp, 2009). An additional limitation mentioned by the same author is the defined search radius out of which no reflections or obstacles are taken into account. For example, the results using the French calculation method XP S 31-133 are significant only within a distance of 800 meters from the road under consideration.

Hepworth et al., (2006) presented the effect of efficiency techniques in five noise mapping softwares assessing the final error using the CRTN methodology. The study compared benchmark calculation times with no efficiency settings with the individual tests of each one of the investigated settings. Results showed that some of the settings that presented a poor performance up to 4.56 dB(A) included the maximum height difference of the ground (contours), the source search radius and the reflection radius. On the contrary, settings with an error between 0.03 and 1.49 dB(A) included the minimum section length of roads, the projection of line sources and the increment angle between the receiver and the sources. The study finally showed that it is not directly assumed that a reduction in calculation time will infer a smaller error.

Similarly, Probst (2013) also put emphasis on the requirements that must be fulfilled by software products and calculation methods in order to increase the transparency in calculations independent of the applied software. Like Hepworth et al., (2006) he suggests the existence of a standardized reference setting as a way of comparison with the applied acceleration techniques. The other suggestion has to do with the visual representation of all ray paths taken into account with emphasis on the ones that are more critical according to the respective calculation method.

In terms of ground simulation in the different models, Probst (2010) mentions that the old engineering models such as ISO 9613-2, RVS 4.0 and RLS-90 take into account the height of the sound ray and produce and empirically-based level attenuation with absorbing ground. These methods, despite their little shortcomings, seem to be preferred by acoustic consultants with special emphasis to ISO 9613-2 (Probst & Huber, 2010). On the contrary, the new models such as Harmonoise or Nord 2000 include a phase-related approach based on different ray lengths and the ground impedance. However, the produced outcome in this case needs much more time to be calculated; makes sense only for narrow frequency bands and can produce unexpected patterns (Probst & Huber, 2010).

d) Result interpretation – data evaluation

Due to the aforementioned parameters it is not easy to identify incorrect noise mapping results. Apart from this there are also representation issues with colour variations from one noise band to the other to be sometimes indiscernible. At a European level, there seems to be no coordination as regards the choice of colours used for the various noise bands under consideration (Alberts & Alférez Rudio, 2012).

Looking at the broader picture of those disparities - with 15 years of experience under the EU Directive – it has been shown that it is still difficult to present comparable and consistent results on the percentage of people being exposed to excessive noise levels across the EU Member States. This is why the CNOSSOS-

EU assessment method is nowadays the only way to provide a unified umbrella for strategic noise mapping and eliminate these discrepancies.

Finally, integrating a noise calculation standard into a noise mapping software is a complex task involving a team of experts. In this process, emphasis should be put on the definition of the extent and quality of standard itself. The next section refers in particular to the contribution of the GPGs in the elimination of noise mapping errors.

3.1.2. Ground effect uncertainties according to the GPGs

All series of GPGs aim at providing a series of toolkits in order to assist the Member States to fulfil their END requirements. Practical guidance was necessary when some key data were missing or they did not exist in the appropriate scale and detail (Shilton et al., 2005). The WG-AEN (2007, p.53) recognises the main factors that affect the technical accuracy of 2 dB(A) within the actual values and at the same time it provides evidence of the errors that can be caused due to the ground effect.

To be more specific, the European Comission Working Group (WG-AEN, 2007, p.112) states clearly that using a non-absorptive ground surface type as the default type of ground can lead to local extreme inaccuracies of 10 dB(A). Land use classification can minimize these errors by distinguishing between urban, suburban and rural areas. Overall, the guide provides error levels up to 1.5 dB(A) in 95% of the cases. The small error uncertainties in ground surface type are also confirmed by the studies that DEFRA conducted for the second version of GPG (Hepworth, 2007).

Although ground absorption has been included in the noise mapping process in terms of land cover, there are still two main issues which remain unsolved. Firstly, there is a high degree of simplification, while coping with partial or no data for ground type. Secondly, there is no consensus as regards the minimum area size that should be taken into account when it combines different ground surface types.

In order to solve the above problems the Good Practise Guide for Noise Mapping (WG-AEN, 2007, p.35) made the following suggestions: a) when insufficient data exists, it is recommended to use default values for hard ground in urban areas and soft ground in countryside areas, b) areas with a minimum size of 250 m^2 are recommended to be included ignoring narrow stripes of land such as roadside verges with less than three meters of width in agglomerations. The last suggestion can reduce the accuracy of the land cover dataset and reduce the calculation time in the noise mapping process. However, from the perceptual viewpoint long green stripes should not be neglected, since usually they provide a visual shield from passing-by cars (Scottish Natural Heritage, 2013, p.56).

3.2. Simulation of the ground effect attenuation under different calculation models

The third factor of uncertainty as mentioned in Section 3.1.1 refers to the differences in calculation models. This chapter is going to focus in particular on the different ways that groud is simulated in those models and differences among them. Environmental noise modelling refers to the process of theoretically-achieved noise levels within the area on interest under a specific set of conditions (National Physical Laboratory, 2014). The different methods vary in complexity and the scope of applications. Three categories can be distinguished: a) engineering methods, b) semi-analytical methods and c) numerical methods.

Concerning engineering methods, they are simple and are based on the calculation of rays or particle tracks representing the sound propagation from sources to the receiver. These models - although less accurate for multiple reflections or shielded areas (Hornikx, 2016) - are very transparent and precice (Probst, 2008). A dual classification is presented in Table 3.1 dividing them in “*energy-related”* and “*phase-related”* according to the determination of the ray path or path to particles path. Energy-based models such as ISO 9613-2, CRTN and NMPB 2008 apply an energetic superposition of incoherent sounds, which simplifies the calculations, but may casue frequency deviations between measured and calculated noise levels. On the contray, in phase-relarted models like CNOSSOS, Harmonoise and Nord 2000 the ground reflections and direct sounds are superposed considering their relative phase (Probst, 2008).

Table.3.1. Ground effect simulation in engineering models classified in energy and phase-based according to Probst, (2008).

Energy - related models		
ISO 9613-2	**CRTN**	**NMPB-2008**
Ground factor (G) for frequency-based attenuation and A-weighted sound pressure level based on the mean height of the propagation path above the ground	Application of correction factor (I) of ground absorption when the ground surface between the edge of the road and the receiver is totally or partially absorptive. Four classes of absorbent ground cover correspond to four classes of "I" between 0 and 1.	The model breaks down the source lines into elementary point sources. For such elementary paths the ground attenuation is described by the ground factor G (0≤G≤1), which is frequency independent (Sétra, 2009). The model introduces a corrected G value named G_{target}, which is defined as the fraction of the individual G values in each ground surface along the propagation path. a) For homogenous conditions: If $G_{target} \neq 0$ then ground attenuation ($A_{sol,H}$) takes into account the third octave band (Hz). If $G_{target}=0$ then (Asol,H)= -3 dB b) For downward-refraction conditions: Different source and receiver heights are used to convey for the effect of the bending sound ray taking into account the effect of turbulence as well.
Phase - related models		
CNOSSOS-EU	**Harmonoise**	**Nord 2000**
Corrected (G) under favourable and homogenous conditions based on the presence (or none) of diffraction. Eight classes of G. G_{path} is the fraction of absorbent ground over the entire propagation path.	Ground attenuation (ΔL_{Gc}): expressed as a weighted average of two different ground attenuations. a) $\Delta LG_{,flat}$: for almost flat ground, b) $\Delta LG_{,valley}$: for valley-shaped terrain. Both equations are based on modified Fresnel weights, while $\Delta LG_{,valley}$ needs also the calculation of a spherical-wave reflection coefficient (Salomons et al., 2011)	Ground type: 8 impedance classes of flow resistivity. Ground roughness: 4 classes with values between 0 and 1.

Since phase-related models are more complex to be applied for strategic noise mapping, this research is going to emphasize on energy-related models and in particular ISO 9613-2. This model is simple and over the years it has been proved representative of the actual noise levels (Tang & Wang, 2007). Moreover, it is available to be tested. More details are provided in the following Section.

3.3. Ground attenuation according to ISO 9613-2

According to ISO 9613-2 ground attenuation (A_{gr}) is the result of sound reflected by the ground surface interfering with the sound propagating directly from source to receiver as shown in Fig.3.1.

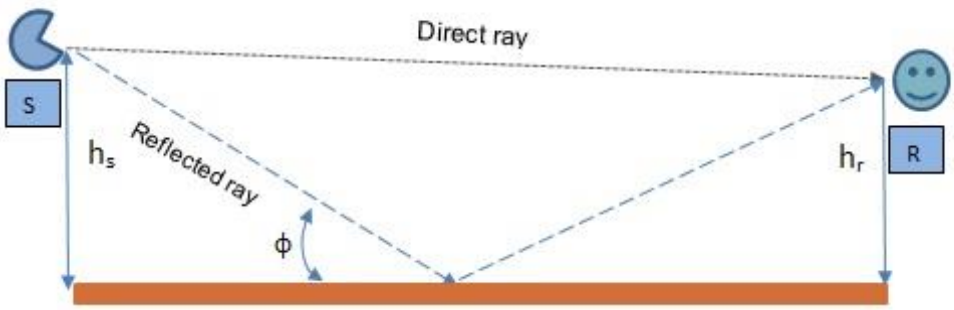

Fig.3.1. Reflected and direct ray in outdoor sound propagation between source **(S)** and receiver **(R)**

The extent of absorption is relevant to the frequency of the sound wave and the ground porosity quantified by the ground factor (G). Smooth and hard surfaces will produce little absorption; whereas thick grass may result in sound levels being reduced by up to about 10 dB per 100 meters at 2,000 Hz (Truax, 1999). High frequencies are generally attenuated more than low frequencies.

As shown in Fig.3.2 the ground attenuation is determined primarily by the ground surfaces near the source (**s**) and near the receiver (**r**). For simplification reasons the method assumes either a flat ground or one with constant slope identifying three distinct regions for ground attenuation: the source region, the middle region and the receiver's region. Based on this methodology the ground attenuation depends mostly on the properties of the source and the receiver's region and not on the size of the middle one (ISO 9613-2, part 7.3). Mathematically, this can be expressed according to the following equations and Table 3.2.:

$$A_{gr} = A_s + A_r + A_m \quad \textbf{(Eq. 3.1)}$$

- A_{gr}: *Ground attenuation*

- A_s: *Attenuation in the source region*
- A_r: *Attenuation in the receiver's region*
- A_m: *Attenuation in the middle region*
- $h_{r,s}$: *Height of source - receiver*
- d_p: *Distance between source and receiver projected onto the ground planes*

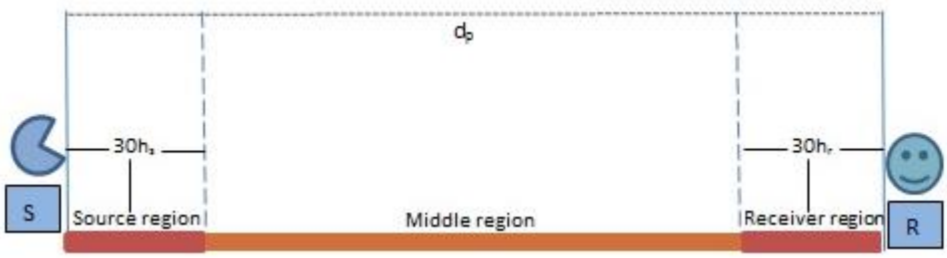

Fig.3.2. Example of source (s) and receiver (r) region in ground attenuation according to ISO 9613-2.

Table.3.2. Expressions of ground attenuation calculation per octave band according to ISO 9613-2.

Nominal frequency	A_s or A_r (dB)	A_m (dB)
63	-1.5	$-3*q^2$
125	-1.5+ G x a' (h)	
250	-1.5+ G x b' (h)	
500	-1.5+ G x c' (h)	
1000	-1.5+ G x d' (h)	$-3q*(1-G_m)$
2000		
4000		
8000	-1.5 x (1-G)	

$$a'(h) = 1{,}5 + 3 \times e^{-0.12(h-5)^{.2}} \times \left(1 - e^{-\frac{dp}{50}}\right) + 5.7 \times e^{-0.09h^{.2}} \times (1 - e^{-2.8} \times 10^{-6 \times dp^2})$$

(*Eq. 3.2*)

$$b'(h) = 1.5 + 8.6 \times e^{-0.09 \times h^2} \times (1 - e^{-dp/50}) \quad \textbf{(Eq. 3.3)}$$

$$c'(h) = 1.5 + 14 \times e^{-0.46 \times h^2} \times \left(1 - e^{-\frac{dp}{50}}\right) \quad \textbf{(Eq. 3.4)}$$

$$d'(h) = 1.5 + 5{,}0 \times e^{-0.9 \times h^2} \times (1 - e^{-\frac{dp}{50}}) \quad \textbf{(Eq. 3.5)}$$

$q = 0 \; when \; dp \leq 30(h_{s+}h_r)$

$q = 1 - \frac{30(h_s+h_r)}{d_p}$ $when\ d_p > 30(h_s + h_r)$ **(*Eq.3.6*)**

G_m= *ground attenuation in the middle region*

3.4. Parameter studies in ground effect attenuation using ISO 9613-2

This section is going to present parameter studies under different calculation scenarios for frequency-based attenuation and A-weighted sound pressure levels at the receiver's position. In the first case the mathematical formulas of Table 3.2 are going to be used for the calculation of ground attenuation contributions as described in Equation 3.1.

3.4.1. Frequency-based attenuation

The following scenarios in Figs.3.3, 3.4 present different combinations for source and receiver heights in 1.5 and 10 meters above the ground. The d_p was investigated in a range between 90 and 2,000 meters with the marginal values of "0" and "1" for the ground absorption (G). In both Figures, the red lines represent cases where $d_p = 30(h_s + h_r)$. Considering a minimum source-receiver height of $h_{s,r(min)} = 1.5m$ in the first case and *10m* in the second case, the minimum source-receiver region is $d_{p1} = 90m$ and $d_{p2} = 600m$ respectively.

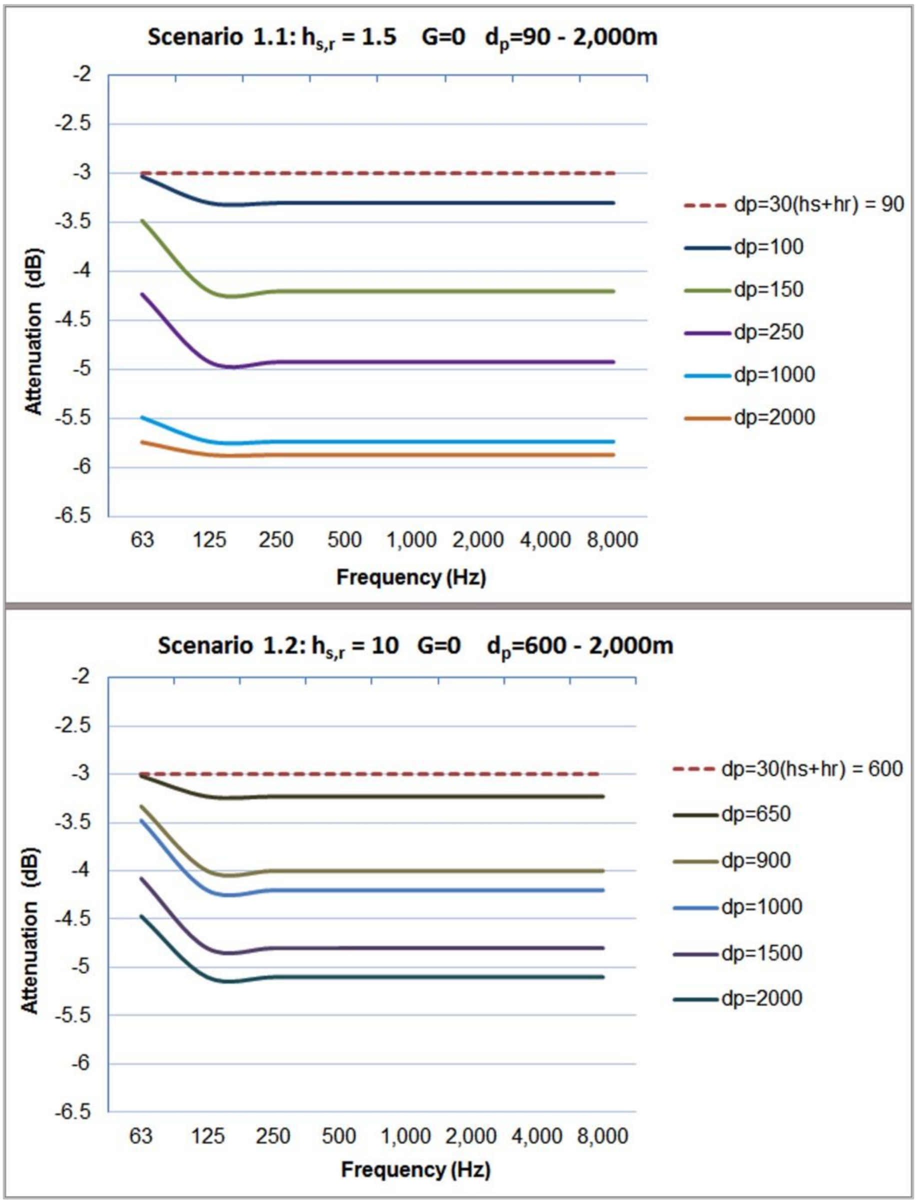

Fig.3.3. Scenario 1: Ground attenuation per octave band for G=0, d_p=1.5-2,000m and (a) $h_{s,r}$=1.5m, (b) $h_{s,r}$=10m

The ground attenuation (A_{gr}) in Fig.3.3 is present even when all the three individual surfaces (source, middle, receiver) are hard (G=0). In these cases, the ground attenuation is higher in the lower frequencies up to 250 Hz and then remains constant only depending on the distance (d_p) between the source and the receiver. The total attenuation for this scenario is between -6 and -3 dB for a source-receiver height between 1.5 and 10 meters. Finally, it can be seen that the attenuation is inversely proportional to the d_p. This is particularly obvious in the high d_p values of

1,000 or 2,000 meters (Fig.3.3), where the attenuation difference can reach up to 1.7 dB under different $h_{s,r}$.

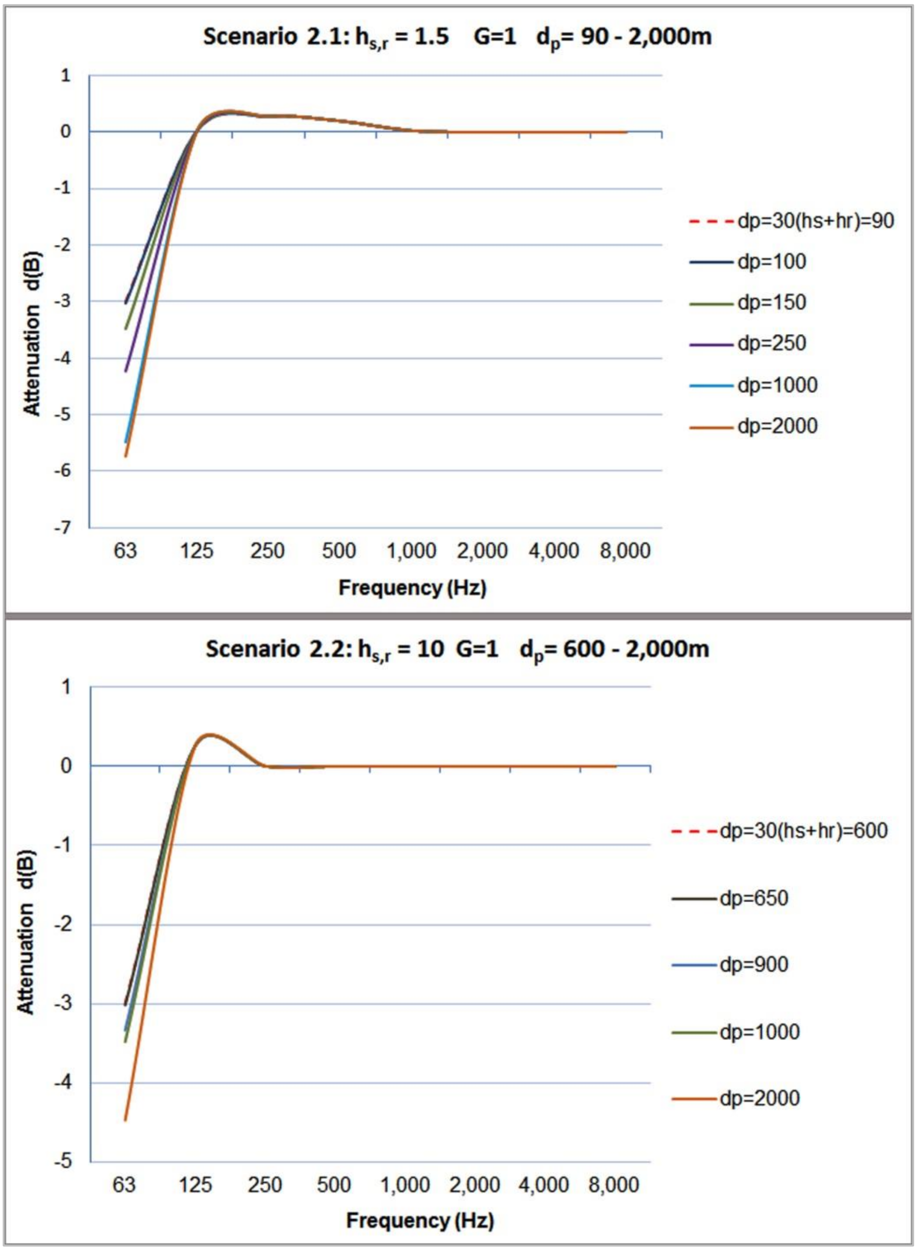

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Fig.3.4. Scenario 2: Ground attenuation per octave band for G=1, dp=1.5-2,000m and (a) hs,r =1.5m, (b) hs,r =10m

In the second scenario presented in Fig.3.4 the same parameters were tested with G=1. In this case the attenuation is almost similar (-5dB to -3dB) in 63 Hz and then gradually zeroes. The threshold value of zeroing is different based on the $h_{s,r}$

value. For example, for $h_{s,r}$=1.5 meters there in no attenuation after 1,000 Hz, while for $h_{s,r}$=10 meters the critical elimination value is 250 Hz.

3.4.2. Attenuation for A-weighted sound pressure levels

For large distances and under the following conditions:

- interested in the A-weighted sound pressure level at the receiver's position
- the sound propagation occurs over a porous or mixed-porous ground
- the sound is not a pure tone

the ground attenuation is calculated according to Equation 3.7. Negative values of ground attenuation in this case shall be replaced with zero.

$$A = 4.8 - (2h_m/d) * [17 + (300/d)] \geq 0 \quad \textbf{\textit{(Eq.3.7)}}$$

h_m: *mean height of the propagation path above the ground*

d: *distance from source to receiver*

The results presented in Fig.3.5 show that the attenuation is higher with a lower mean height of the receiver's position. However, there seems to be a convergence at the attenuation level - around 5 dB(A) - after 500 meters no matter the h_m value. These results were also consistent with the findings in the frequency-based attenuation as regards the effect of the source-receiver height.

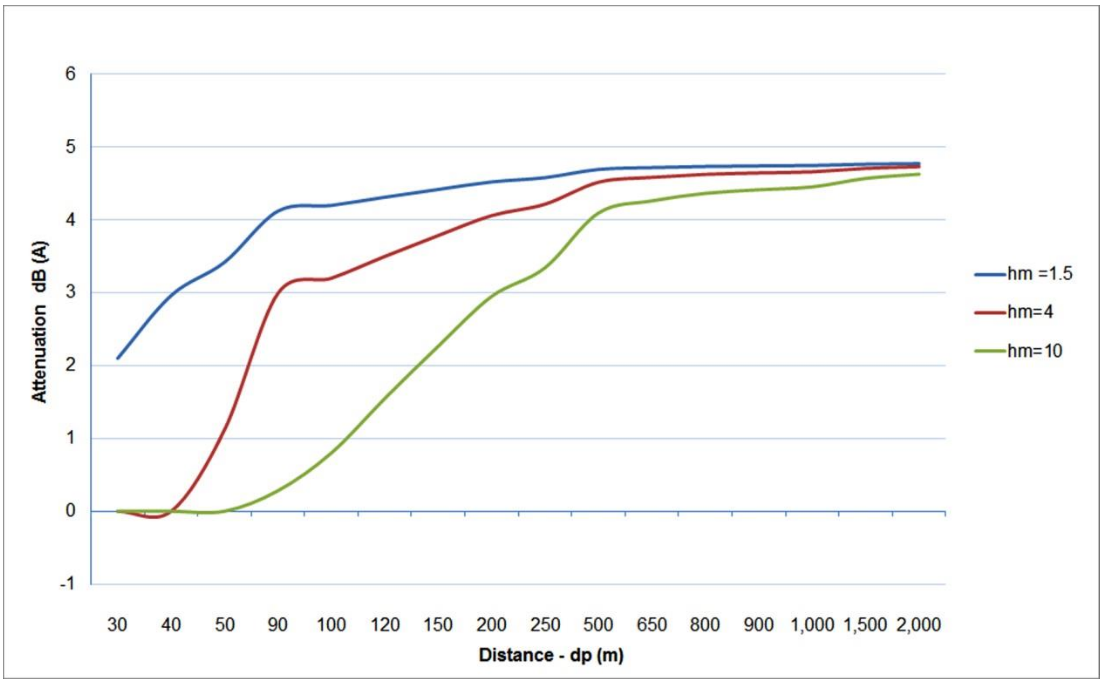

Fig.3.5. Attenuation in receiver's position with different height (h_m) scenarios.

3.5. Parameter studies in ground effect under different configurations

In this example two different configurations under the ISO 9613-2 model were examined: a "square" and a "rectangular" one as these are the most common configurations that can be found in realistic urban conditions. The aim is to compare the same configuration under absorptive and reflective conditions for the ground. For this reason, two different scenarios were considered, one with a totally reflective ground (G=0) and a second one with a totally porous ground (G=1) within the area surrounded by the external roads.

In each scenario two cases were taken into account for the green space configuration. In the first one, the green space polygons were placed in a vertical arrangement towards the inner roads and in the second one in a parallel arrangement with respect to the roads, as shown in Figs.3.6, 3.7. The configurations were designed is such as way so as to fit the same number of buildings in their inner area, however the current comparisons dealt only with the ground factor effect in the absence of additional obstacles such as buildings.

For the analysis we used CadnaA simulation software (v.4.6.153) using a grid of 10 meters and receivers placed at four meters above the ground. A maximum number of two reflections was considered in all cases. In both configurations, the external roads belong in the “federal” class with 20,000 Veh/18h and the inner roads in the “local” class with 4,000 Veh/18h. The corresponding traffic speed was 100 and 80 km/h respectively. Finally, the comparison among the different cases as regards the noise levels was performed by counting the pixels in each noise band using the “*histogram tool*” in Photoshop CS5.

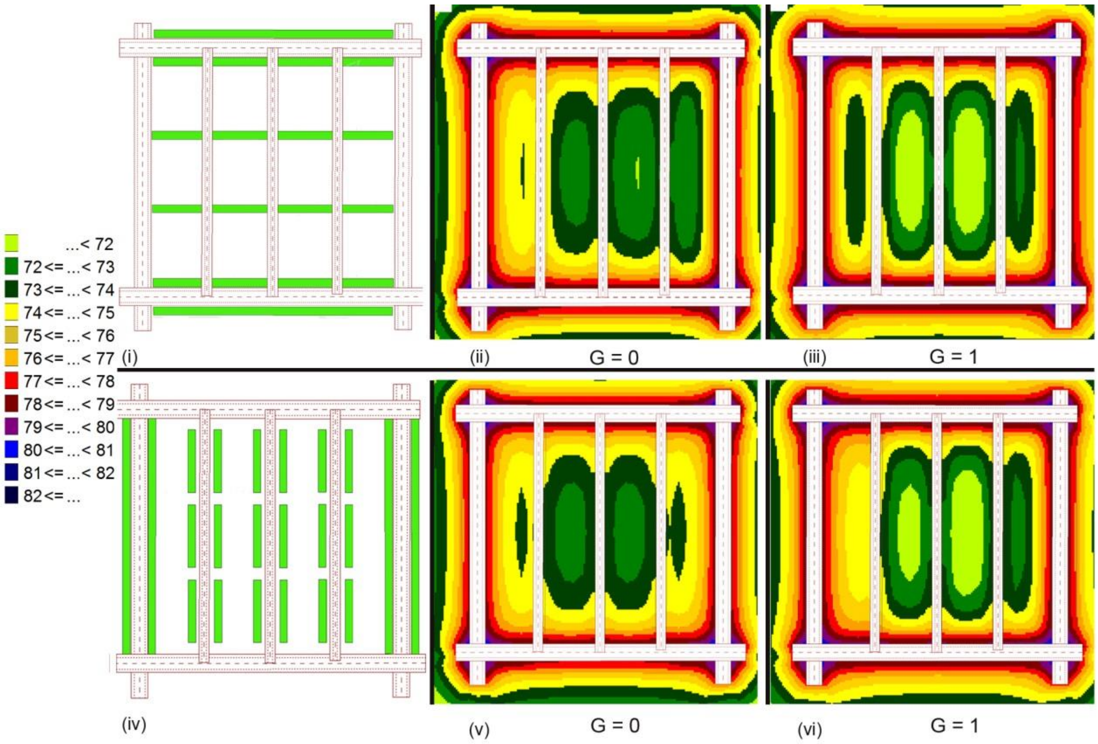

Fig.3.6. Noise propagation in a square form tested with different ground factors and green lanes placed in a vertical (ii,iii) and parallel arrangement (v, vi) to the inner roads.

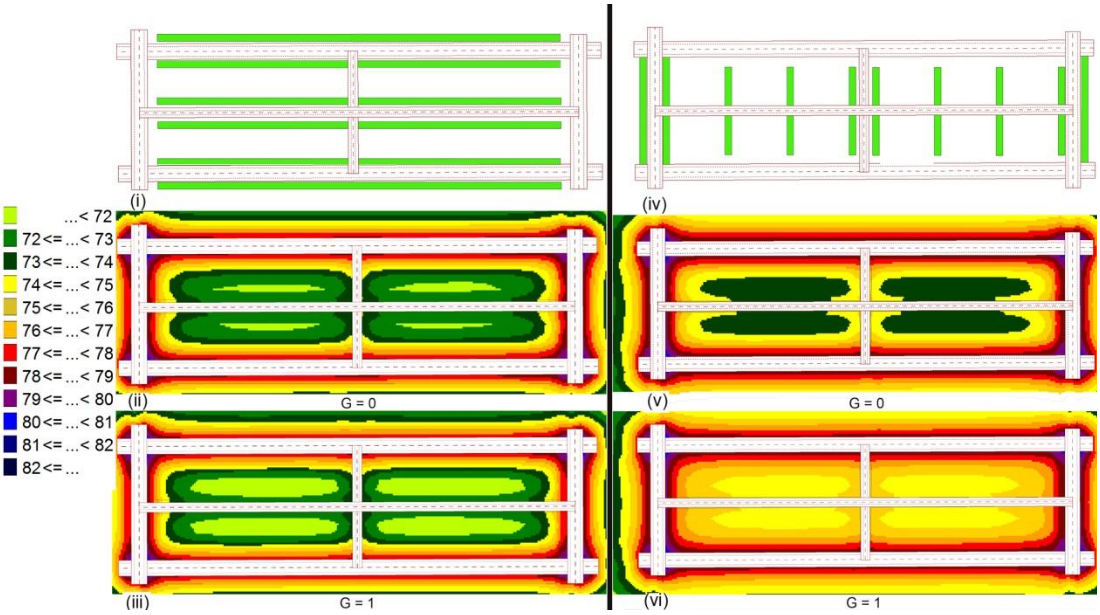

Fig.3.7. Noise propagation in a rectangular form tested with different ground factors and green lanes placed in a vertical (ii,iii) and parallel (v,vi) arrangement to the inner road.

3.5.1. Comparison between square and rectangular configurations under two different green space patterns and ground factor values.

The square and the rectangular configurations were compared individually under the dual marginal conditions of the ground factor (G=0 or G=1). The total number of pixel count in the porous condition was subtracted from the respective noise bands in the rigid ground condition. Positive results as presented in Fig.3.8 denote that with porous ground there was an increase in the number of pixels and the corresponding area compared to rigid ground. On the contrary, negative values denote that even if the ground is transformed from rigid to porous, the first ground condition prevails with more pixels.

What is clear in Fig.3.8 is that the parallel arrangement of green spaces is probably more effective than the vertical one, since the number of pixels in the lowest noise band (71dB) is maximized. For the rest of the noise bands between 72 and 74 dB the condition is more unstable, which does not lead to a clear conclusion, while for the rest of them minor changes can be detected.

Concerning the rectangular configuration presented in Fig.3.9 both the vertical and the parallel green space pattern increased the porous area at 74 dB. However, the highest impact was found for the vertical configuration with almost four times more pixels than the horizontal one. In the rest of the noise classes between 75 and 82 dB, the ground effect had either a negligible or no effect.

The general outcome from both Figures (3.8, 3.9) is that for square configurations green space patches seem to be more effective when placed parallel to the inner roads. On the contrary, for the rectangular configurations green space patterns can possibly maximize the quiet areas when placed vertically to the inner road and parallel to the peripheral main roads.

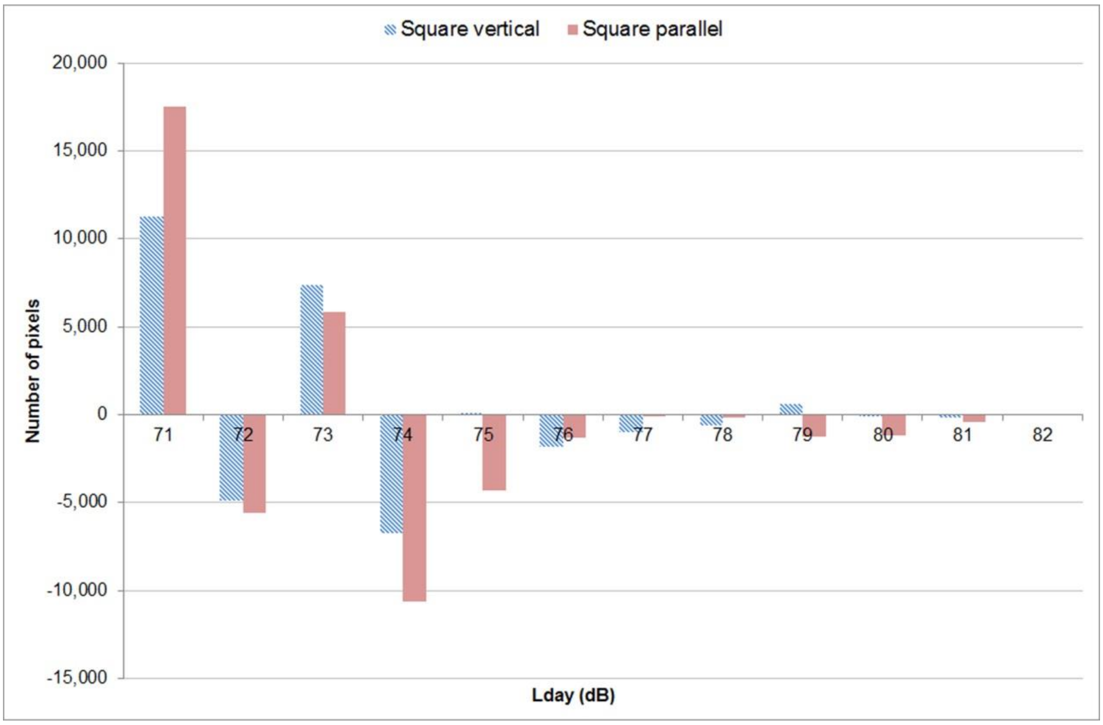

Fig.3.8. Comparison between the vertical and parallel to the inner roads green space arrangement for the square configuration as shown in Fig.3.6. The total number of pixels per noise band on the y axis is calculated by subtracting the ones in the rigid condition (G=1) from the ones in the porous condition (G=0).

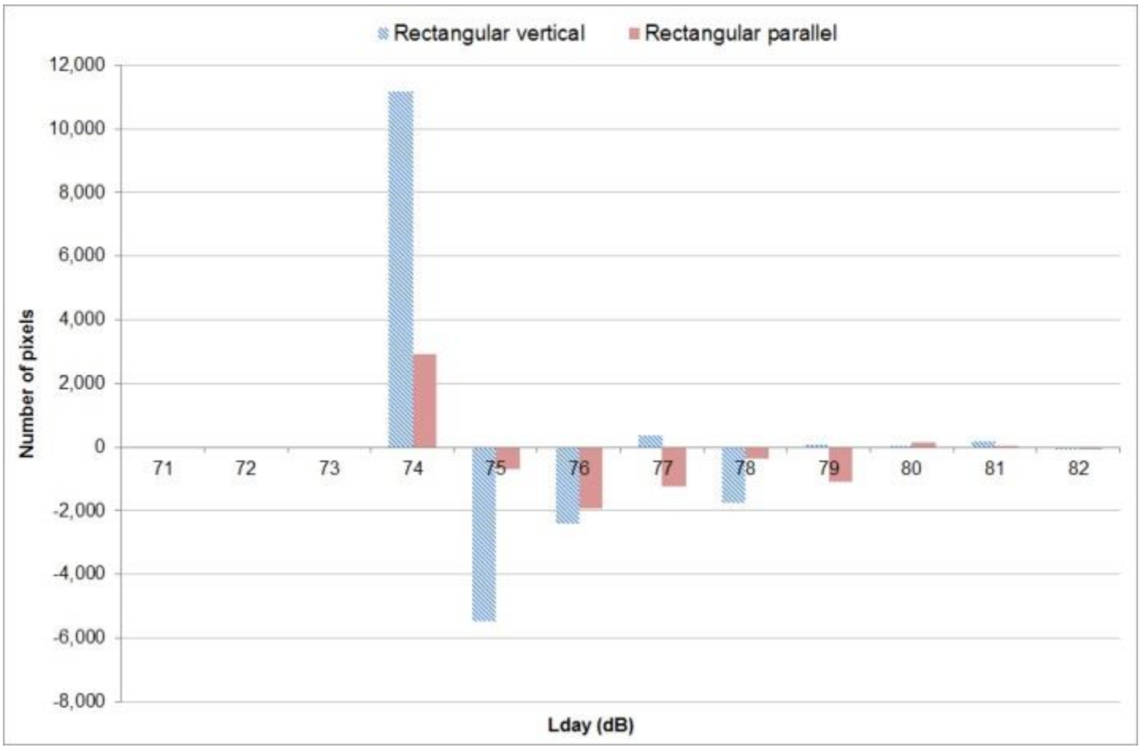

Fig.3.9. Comparison between the vertical and parallel to the inner road green space arrangement for the rectangular configuration as shown in Fig.3.7. The total number of pixels per noise band on the y axis is calculated by subtracting the ones in the rigid condition (G=1) from the ones in the porous condition (G=0).

3.6. Summary

This chapter initially reviewed and analysed the four commonly recognised reasons of inaccuracy in strategic noise mapping, namely: input data, software parameters, calculation models and result interpretation. With respect to input traffic and default traffic data, an error up to 8.7 dB(A) can occur. In the sound propagation uncertainty, the highest decibel error was shown to be caused by traffic flow, vehicle speed and road gradient. In the calculation models, simplifications related to the search radius, the contour lines density, the minimum section length of roads or the increment angle can yield an error between 0.03 and 4.56 dB(A) within the 95% confidence interval. It was also shown that in terms of ground simulation the old engineering models such as ISO 9613-2, RVS 4.0 and RLS-90 are preferred for their simplicity, despite the high accuracy provided by phase-related models such as Harmonoise and Nord 2000.

Additional errors can take place also in the ground effect calculation. Parameters related to input data and the wrong land use classification can lead to inaccuracies within $\pm$1.5 dB(A) in 95 % of the cases. In cases of missing data, the WG-AEN recommends to use default values for hard ground and in any case to include green space areas over 250m^2 excluding roadside verges.

The frequency-based attenuation of sound absorption based on ISO 9613-2 was also tested under two different scenarios within a distance (d_p) of 90 and 2,000 meters between the source and the receiver. For hard grounds (G=0) the attenuation was higher in the lower frequencies up to 250 Hz and then remained constant only depending on the d_p. The total attenuation for this scenario was between -6 and -3 dB and inversely proportional to d_p. In the scenario with absorptive ground (G=1) the attenuation ranged between -3 and -5 dB and had its peak between 63 and 125 Hz with zero values after 250-500 Hz. For large distances between the source and receiver over a porous or mixed-porous ground the attenuation was higher with a lower mean height (h_m) of the receiver's position. However, there seems to be a convergence at the attenuation level after 500 meters no matter the h_m value.

In the last Section (3.5) two different configurations representing a "square" and a "rectangular" form were tested under ISO 9613-2 using two green space patterns. In the first case, the parallel arrangement of green spaces to the inner roads is probably more effective than the vertical one with a bigger area to be allocated to the lowest noise band. Finally, in the rectangular configurations green space patterns can possibly maximize the quiet areas when placed vertically to the inner road and parallel to the main peripheral roads.

PART I:
TOWARDS PREDICTION AND CALCULATION

Chapter 4
Agglomeration level

The content of this chapter has been published in a peer-reviewed journal under the title:

Margaritis, E., & Kang, J. (2017). Relationship between green space-related morphology and noise pollution. *Ecological Indicators*, 72, 921–933

4. Relationship between green space-related morphology and noise pollution

Despite the different calculation models described in Chapter 3 there are reasons to support the comparison among different strategic noise maps constructed under the framework of the END. Two of them are: the technical accuracy of 2 dB(A) according to the WG-AEN (2007) and the small errors due to incorrect ground type, which are within 1.5 dB(A) in 95% of all cases. As a result, this chapter assesses the extent of quietness in different EU cities (agglomerations). Firstly, a review is presented on previous studies concerning the criteria used for European cities' classification, the relationship between green spaces and traffic noise in different scales and the most widely used green space indicators to characterize entire cities (Section 4.1). In the next stage (Section 4.2), a detailed description of the research methods is presented. Results are analysed in three scales (administrative, urban, kernel) with cities' ranking and the most appropriate indicators described in Section 4.3 with the final conclusions to be included in Section 4.4.

4.1. Previous studies and research questions

The problem of exposure to traffic noise is rapidly increasing and is closely related with the rapid urbanization process taking place around the world. Nowadays, 54 per cent of the world's population lives in urban areas, a proportion that is expected to rise to 66 per cent by the year 2050 (United Nations, 2012). As a consequence of this process, noise annoyance problems are caused, leading one out of five Europeans to be regularly exposed to sound levels during the night that can trigger serious damage to health (WHO, 2009). This is the reason why the European Community adopted measures for the noise reduction through the Environmental Noise Directive (2002/49/EC), hereinafter called the "END".

Other benchmarking reports on a European scale classified cities according to various urban forms (Schwarz, 2010) or sustainability indices (The Economist, 2009). However, the last report refers to transport variables, which cannot provide a direct assessment of the noise pollution in these cities. From the viewpoint of soundscape, studies on a European context are rare and there is the need to establish a common protocol for soundscape exposure assessment (Lercher & Schulte-fortkamp, 2015). Lastly, in the European Green Capital Award (European Commission, 2014), the quality of the acoustic environment was taken into consideration using the exposure of people above or below certain noise bands whenever these results were available.

Green spaces have been used as an inherent element of urban form, referring to the interaction between outdoor space - including road infrastructure - and buildings (Valente-Pereira, 2014). All these three factors can affect traffic noise distribution in various levels. Previous studies have examined their effect either on the building level (Oliveira & Silva, 2010; Salomons & Berghauser Pont, 2012; Silva et al., 2014) or in large neighbourhoods (Hao et al., 2015a; Tang & Wang, 2007). At the city level, traffic noise has been measured either through the use of landscape metrics (Oliveira & Silva, 2010; Mõisja et al., 2016; Weber et al., 2014) or with the help of indicators related to road and building characteristics (Aguilera et al., 2015; Hao et al., 2015b). Finally, on regional level, an attempt to approach noise issues by emphasizing on the identification and designation of “quiet areas” according to land use criteria was performed by Votsi et al., (2012).

The relationship between traffic noise and green spaces has been investigated in multiple scales. The majority of these studies focuses on the small-scale, where the absorption or scattering effects of branches and leaves are investigated (Attenborough, 2002; Aylor, 1972; HOSANNA, 2014; Huddart, 1990; Van Renterghem et al., 2014). This kind of researches cover a wide range from the single tree (Yang et al., 2011) to different plant types (Horoshenkov et al., 2013) or various tree belts (Van Renterghem et al., 2012). Interesting quantitative approaches on the park scale have also been developed by Pheasant et al. (2010) with the Tranquillity Rating Prediction (TRAP) tool and by Brambilla & Gallo (2016) with the QUIETE index. At the city scale, previous works have selectively emphasized the quantitative assessment of parks concerning traffic noise reduction (Cohen et al., 2014; González-Oreja et al., 2010). Other studies investigating also the users' perception of the acoustic quality in the parks have been performed by Brambilla et al., 2013; Brambilla & Maffei, 2006; Weber, 2012.

However, there is little evidence on the effect of green spaces as a land use parameter on traffic noise. The most frequent use is through land use regression (LUR) models (Goudreau et al., 2014; Ragettli et al., 2016), or in a local scale through the TRAP tool by Pheasant et al. (2010), which can be very useful in the absence of noise maps, but still of limited range and dependent on on-site noise measurements.

Widely used indicators for green spaces usually refer to green space coverage (Fuller and Gaston, 2009; Zhao et al., 2013) or green space per inhabitant (ISO 37120; WHO, 2010). Others include also the proximity to green areas (Herzele and Wiedemann, 2003; Hillsdon et al., 2006; Kabisch et al., 2016; Morar et al., 2014; Natural England, 2010; Ståhle, 2010) or more complex indicators referring to the balance between green and built up areas (De la Barrera et al., 2016). Furthermore, there are shape-oriented indices which measure the distribution of green spaces (Margaritis & Kang, 2016; McGarical & Marks, 1994; Verani et al., 2015).

Therefore, this chapter is going to provide an evidence-based approach of whether greener cities (agglomerations) can also be quieter. This research question is investigated on three geographical scales: administrative, urban and kernel in order to investigate also the scale effect on the results. The correspondent aims are:

a) the effect of forest, urban green and agricultural areas on noise distribution in the administrative level, b) the effect of green space indicators on noise indices in the urban level and c) the effect of green space indicators on noise indices in the kernel level of the investigated cities.

4.2. Methods

The methodology used investigates the relationship between green space and noise indicators in three different levels starting from a general to a more focused scale. For comparison purposes, the six cities namely: Antwerp, Helsinki, Brussels, Prague, Amsterdam and Rotterdam mentioned in levels two and three also exist in level one. The first part of the analysis refers to the administrative or agglomeration level as defined in the END, since the city borders in both cases are mostly the same. The second one refers to the urban level, which usually covers an area smaller than the administrative borders of the cities. Finally, the third level refers to small kernel areas of 500x500 meters each, covering the six cities. It should also be made clear that the level of accuracy in these noise maps is acceptable for this kind of strategic analysis, in spite of the differences in the production software or input data, since all the results have to comply with the END requirements.

4.2.1. Administrative level

4.2.1.1. Case studies selection

Out of the available 216 agglomerations in the European Environment Information and Observation Network (EIONET) database, 25 were selected (12%) covering 11 out of 20 European countries. This was the maximum available sample size, since the selection process was based on the availability of both noise mapping and land cover data for the same agglomerations. The aim was to cover mostly medium-sized cities between 100,000 and 500,000 inhabitants, with bigger ones to serve as a means of comparison. The population density of the sample as shown in Fig.4.1 has a broad range between 842 and 6,249 people / km^2, while the population size of the agglomerations varies between 117,073 and 1,543,781 inhabitants. The agglomeration area ranges between 110 and 496 km^2 as presented in Table 4.1, while the green area coverage ranges between 35 and 405 km^2. Finally, the agglomeration borders were provided by the EIONET Agency as generalised polygon shapefiles.

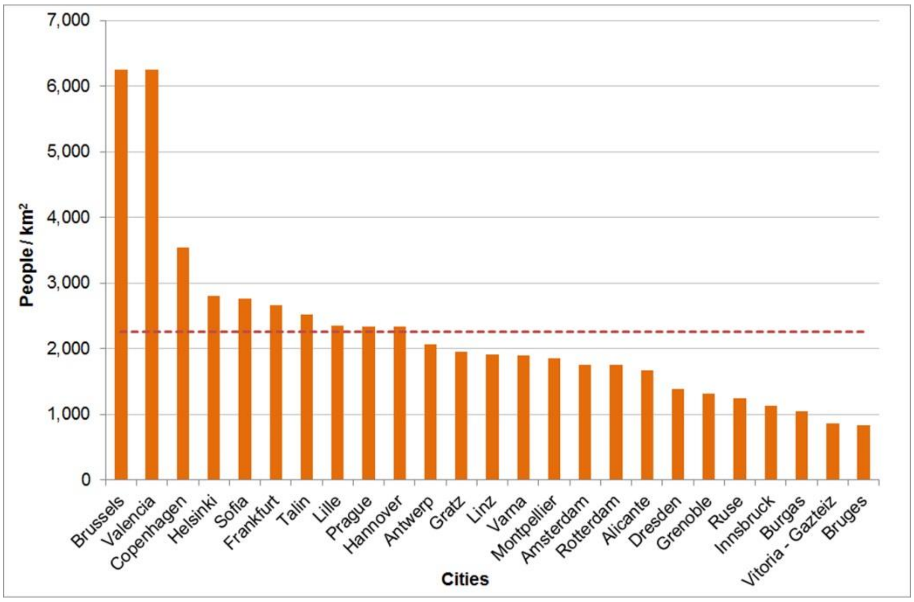

Fig.4.1. Population density and average value (dotted line) in the administrative level for all agglomerations (Source: EIONET).

Table 4.1. General characteristics of the 25 agglomerations sorted in a descending form for the population density field.

City	Area (km^2)	Pop. Density (people/km^2)	Total Green (km^2)	Total Green (m^2/person)
Brussels	160	6,249	38	38
Valencia	130	6,249	94	115
Copenhagen	302	3,546	104	97
Helsinki	200	2,805	69	123
Sofia	492	2,760	116	85
Frankfurt	250	2,660	107	160
Tallin	159	2,527	100	250
Lille	426	2,348	196	196
Prague	496	2,340	282	243
Hannover	238	2,333	96	174
Antwerp	205	2,062	35	83
Gratz	128	1,960	56	223
Linz	111	1,911	48	225

Varna	169	1,892	95	297
Montpellier	155	1,855	70	242
Amsterdam	152	1,752	46	173
Rotterdam	150	1,752	38	146
Alicante	200	1,674	136	406
Dresden	329	1,387	187	410
Grenoble	327	1,315	405	942
Ruse	127	1,240	80	508
Innsbruck	110	1,133	84	672
Burgas	219	1,050	204	884
Vitoria - Gazteiz	276	857	230	972
Bruges	139	842	71	602

4.2.1.2. Noise data and indicators

As Europe moves forward towards a common noise policy with harmonised noise indicators; population exposure assessments can become a valuable tool of evaluating the current and future noise conditions. The current data are sent to EIONET from the member states through reports submitted during 2007 and updated until August 2013. Population exposure is measured by the percentage of people affected per noise band using the L_{den} index as mentioned in Table 4.2. This index was used in the current study in the absence of original noise mapping data at the agglomeration level.

Table 4.2. Definition of variables related to noise (source: EIONET) and green spaces (source: Urban Atlas) in the agglomeration level.

Variables		
Noise indices *(% of people affected per noise band)*	***Green space indices***	
L_{den}(55-59)		
L_{den}(60-64)	Agricultural areas (%)	Agricultural areas (m^2/person)
L_{den}(65-69)	Forest areas (%)	Forest areas (m^2/person)
L_{den}(>70)	Urban green areas (%)	Urban green areas (m^2/person)

4.2.1.3. Green space data and indicators

Green spaces at this level are divided in three categories, namely: a) Agricultural areas, b) Forest areas, and c) Urban green areas. These categories have already been defined in the Urban Atlas land use dataset (EEA, 2010), where green space data was downloaded from. Accordingly, the correspondent indices are expressed as the coverage ratio per category and as the percentage per person (Table 4.2). From the noise perspective, these areas represent the porous surfaces with higher sound absorption than rigid surfaces.

The Urban Atlas land cover dataset is available for Large Urban Zones with more than 100,000 residents. The final data are provided in a scale of 1:10,000, while the original data come from satellite images of 2.5-meter resolution, which is very precise for the analysis on a city scale. However, it can also be used complementarily to other datasets such as CORINE land cover, which makes the analysis easier and more comprehensive.

4.2.2. Urban level

4.2.2.1. Case studies

From the 25 agglomerations, six cities were selected as presented in Fig.4.2 in order to perform a more detailed analysis on the urban level. The difference between the agglomeration and the urban level is the existence of original noise mapping data for the latter. On the top of that, the noise mapping area in these cases is equal to or smaller than the agglomeration area, firstly because the main emphasis is in the core city parts and secondly because agglomerations are abide by specific population criteria (2002/49/EC).

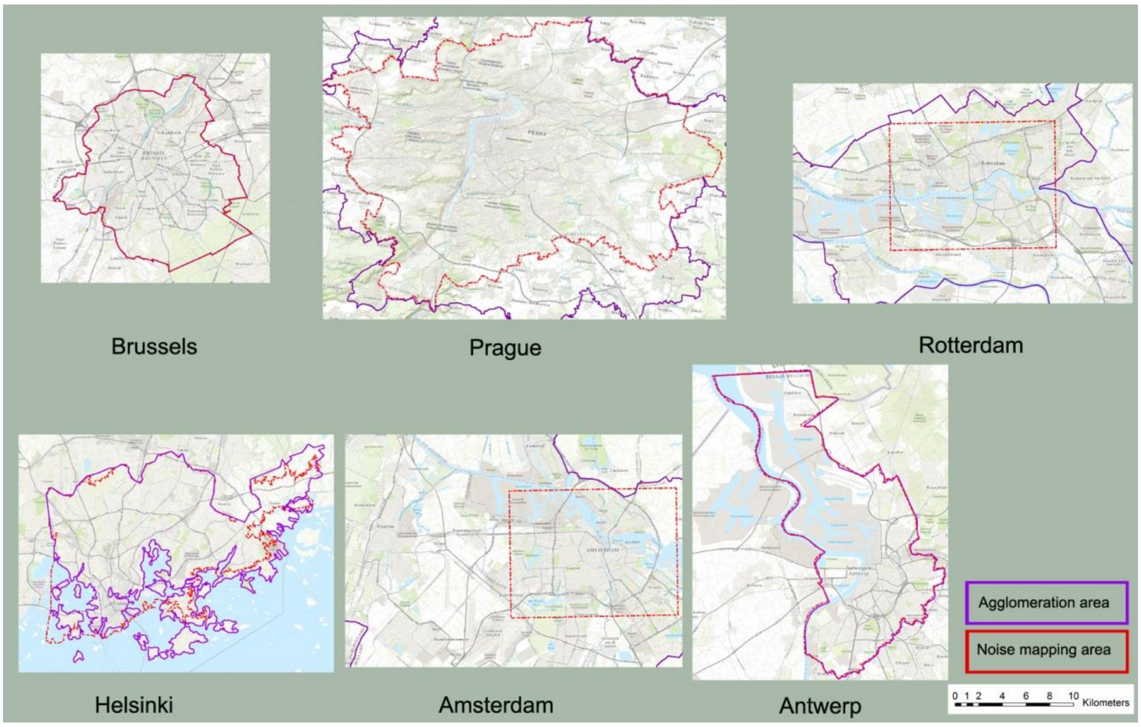

Fig.4.2. Degree of differentiation between the agglomeration and the noise mapping area in the six cities. (Source: Brussels Institute for Environmental management, Czech Republic: Ministry of Health, Netherlands: Calculation of road traffic noise, Helsinki City Council, Antwerp City Council, Topographic Basemap: ESRI)

There were two criteria for the selection process: a) the city should have an available online noise map, b) the noise map should be continuous and cover the entire region, not only the major roads. According to Table 4.3, the population size of the selected cities ranges between 464,009 and 1,160,641 inhabitants. Apart from Prague and Brussels the rest of the cities are in the upper population limit of mid-sized cities ($M_{population}$=520,651) based on the classification criteria by Bolton & Hildreth (2013). Additionally, population density in five out of six cases range between 2,340 and 3,715 people ($M_{denisty}$=3,425) per km^2 (Table 4.3).

Table 4.3. General characteristics of the cities in terms of size and population density.

Agglomeration name	**Agglomeration area (km²)**	**Noise mapping area (km²)**	**Population (noise mapping area)**	**Density (people/km²)**
Brussels	160	162	999,899	6,172
Amsterdam	219	152	564,664	3,715
Rotterdam	326	149	464,009	3,114
Helsinki	186	200	570,578	2,853
Antwerp	205	205	483,353	2,358
Prague	496	496	1,160,641	2,340

4.2.2.2. Noise data and indicators

In every noise map it was necessary to calculate the percentage of pixels belonging to the different noise bands. For similarity purposes and in order to have comparable results among all the cities five noise bands were defined as presented in Fig.4.3.

All maps were imported in ArcGIS and converted to a raster file of 10-meter grid resolution through a supervised classification. The same grid size has been used for the noise maps produced by the Department of Environment, Food and Rural Affairs (DEFRA). An identical process was followed for the green space data. Then with the help of "Zonal Statistics" tool it was rendered feasible to have the exact number of noise and green space pixels per band.

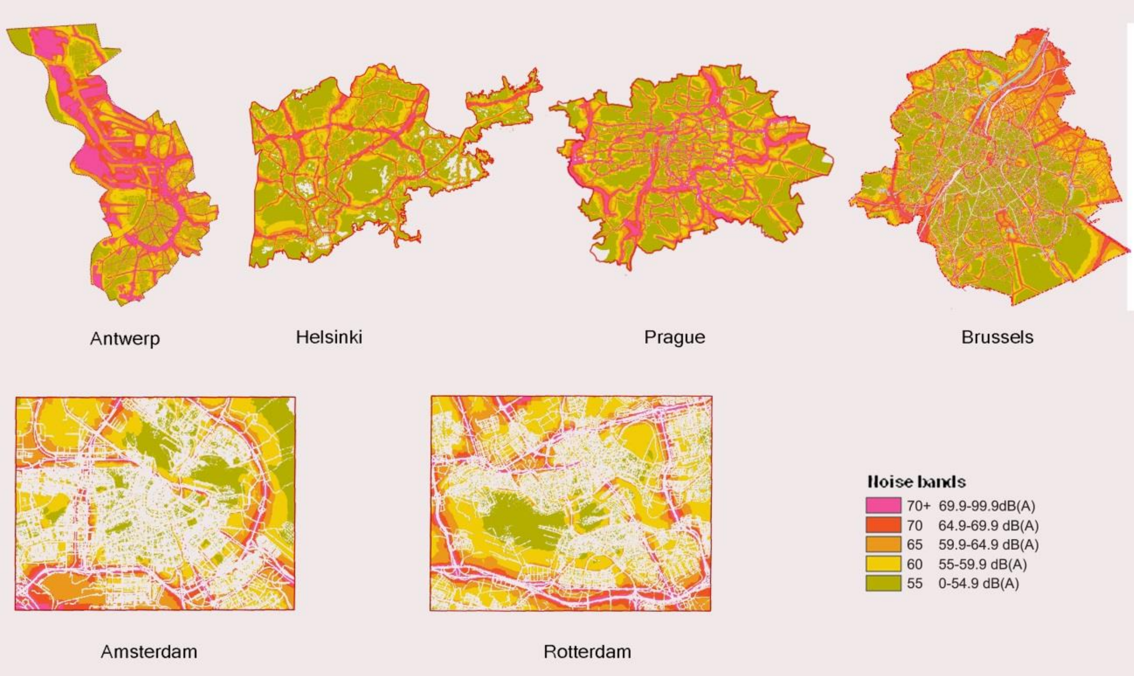

Fig.4.3. Representation of the noise maps for the six cities using a common noise band scale.

In this level seven different noise indices - as presented in Table 4.4 - were formulated and tested in order to check which one can better describe the extent of noise pollution in the cities. Overall, three main approaches were adopted. In the first one the main idea was to compare the number of pixels in the marginal bands of 55 dB(A) and over 70 dB(A) in each city. This was sorted out with different combinations as described in Δnoise 1-3. Another group of indicators (Δnoise 4, Δnoise 6) involved also the intermediate noise bands between 60 and 70 dB(A). Finally, the last index includes all the noise bands in a weighted sum. This index attributes inverse weights from 1 to 5 by enhancing the lower noise bands and diminishing the importance of the higher ones. The identification of the most suitable noise index is based on the highest correlation between noise and green space indices.

Apart from the above indicators, other parameters were also tested for possible correlations with green space variables and proved unsuccessful. More specifically, these include the Building and Road Coverage, as well as five classes of the road network hierarchy (Motorway, Residential, Primary, Secondary and Tertiary) defined as ratios of the total road length.

Table 4.4. Noise and green variables tested in the agglomeration level.

Variables	Definition / Notes	Formula
Ratio per noise band		
p55	% of noise pixels - 0 - 54.9 dB(A)	p55 = 55(i) / sum (noise pixels)
p60	% of noise pixels - 55 - 59.9 dB(A)	p60 = 60(i) / sum (noise pixels)
p65	% of noise pixels - 60 - 64.9 dB(A)	p65 = 65(i) / sum (noise pixels)
p70	% of noise pixels - 65 - 69.9 dB(A)	p70 = 70(i) / sum (noise pixels)
p70p	% of noise pixels - 70 - 99 dB(A)	p70p = 70p(i) / sum (noise pixels)
p(x)(i), x=55,..70p	number of pixels per noise band	
Noise indices		
Δnoise 1	Index proportional to noise (↑↑)	Δnoise1 = p70p/p55
Δnoise 2	Index proportional to noise (↑↑)	Δnoise2 = p70p / p55 + 70p
Δnoise 3	Index inversely proportional to noise (↑↓)	Δnoise3 = sum (p55-p70) / p70p
Δnoise 4	Index inversely proportional to noise (↑↓)	Δnoise4 = p55 / [average (p60 - p70p]
Δnoise 5	Index proportional to noise (↑↑)	Δnoise5 = p70p / [(average (p55-p70p)]
Δnoise 6	Index inversely proportional to noise (↑↓)	Δnoise6 = [(p55 / p70p) * (1 / sum (p60-p70)]
Δnoise 7	Index inversely proportional to noise (↑↓)	Δnoise7 = [5*p55+4*p60+3*p65+2*p70+p70p]
Green space indices		
Green Space Ratio (Δgsr)	% total green spaces	Δgsr = Green space surface / Sum area
Extent of porosity (Δporous)	% porous to non-porous surfaces	Δporous = Δgsr / (BCOV** + RCOV**)
Forest ratio (Δtrees)	% green space classified as "trees"	Δtrees = Area of trees / Sum area
Free field ratio (Δfree field)	% green space classified as "free field"	Δfree field = Area of free field / Sum Area
BCOV	Buildings ratio	BCOV = Area of buildings / Sum area
RCOV	Road Coverage ratio	RCOV = Road area / Sum area

4.2.2.3. Green space data and indicators

There are various classification typologies for green spaces, which vary between eight and nine categories depending on the classification criteria (Bell et al., 2007; Panduro & Veie, 2013). In this research, a first set of indicators was established referring to the green space coverage in the cities; firstly as a ratio compared to the whole area (Δgsr) and secondly as a percentage between porous and rigid areas

(Δporous) as presented in Table 4.4. Green space data were extracted by Mapzen (Mapzen, 2016), which uses the latest Openstreetmap dataset under an open license.

A second set on indicators was formulated from the sound propagation perspective, where noise attenuation is higher with the presence of trees and lower with grass or any other low vegetation (ISO 9613-2). Subsequently, the indicators established were named as "Δtrees" and "Δfree field". The first one refers to areas with a predominant presence of trees such as forests, nature reserves and orchards, while the second one involves lower vegetation with grass, scrubs, allotments or parks. Finally, Openstreetmap was selected as a more favourable dataset compared to Urban Atlas, since in the second case data were not available for all cities.

4.2.3. Kernel level

In the last level of analysis, a more focused approach was followed compared to the urban level using the previous six cities so as to test the same correlations between noise and green. Specifically for this analysis a Geographically Weighted Regression (GWR) approach was applied, which can better describe the geographical variations between the variables instead of assuming that a single linear model can be fitted to the entire study area (Bristol University, 2009). The parameters used in the GWR tool in ArcGIS (ESRI, 2016a) included a fixed kernel type combined with the AICc bandwidth method, which can identify the optimal adaptive number of neighbours for each case study area. The produced output refers to a multipart area composed of various 500x500 meter-pixel blocks. This grid size is suitable for the urban scale and complies with the level of analysis that most urban design or neighbourhood plans are produced.

In order to bring the noise and green space data in an applicable format for the GWR, some steps had to be followed in advance. First of all, by using the Block

Statistics tool in ArcGIS (ESRI, 2016b), green space data were aggregated using the rectangular neighbourhood option. The aggregation field distinguishes forest areas from free field areas (grass) by applying a weight of "2" in the first case and a weight of "1" in the second case. For the noise data the same tool was used calculating the average values of the cells. The final output files ranged between 1 to 5,000 for the green areas and 55 to 80 dB(A) for noise levels. However, the final resolution in both datasets was adjusted to 500x500m as depicted in Fig.4.4 so as to keep a balance between precision and calculation time.

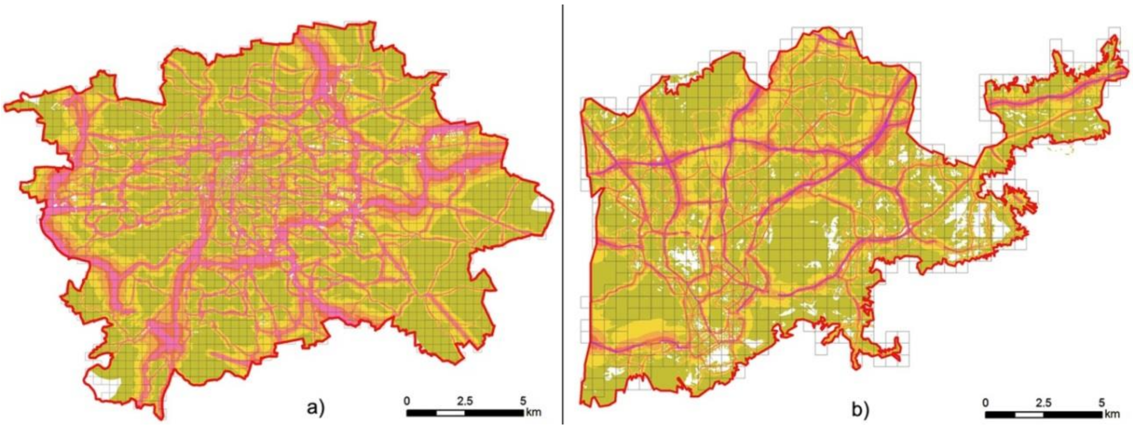

Fig.4.4. Example of the applied kernel (500x500m) in Prague (a) and Helsinki (b).

In the final step, a cluster analysis was applied in order to identify the character of each cluster in terms of land cover characteristics. The Grouping Analysis tool (ESRI, 2016c) was used for this purpose with no spatial constraints, which allows features to be grouped only based on their spatial proximity. Practically this process works in the same way as the k-means partitioning method. At last, the produced clusters were intersected with CORINE land cover data (European Environment Agency, 2006) of the finest resolution (100mx100m) in order to get a more precise idea concerning the spatial distribution of the clusters.

4.3. Results

4.3.1. Effect of green spaces on noise at the administrative level

The question investigated at this level is whether the different green space categories such as forests, urban green and agricultural areas can have an effect on noise. For this reason, a first cluster analysis was performed in order to divide the agglomerations in groups of “high” and “low” green space areas per person. The particular cluster analysis can make the identification of correlations between noise and green easier, since direct linear relationships between the two variables were not found.

For the identification of possible clusters within the agglomerations a hierarchical analysis with the three green space categories - where the percentage of population is involved - was applied using the Ward’s method in SPSS. The analysis of coefficients and the “elbow rule” showed that the optimal number of clusters is two. According to this result, the 25 agglomerations were classified in two groups of high and low green, as depicted in Fig.4.5a.

The first cluster contains six agglomerations (Alicante, Bruges, Burgas, Innsbruck, Ruse, Vitoria-Gazteiz) with high percentage of agricultural and forest areas, while the urban green is low. On the contrary, the second cluster with 19 agglomerations is more balanced among the three categories with a slightly higher percentage of urban green, but lower average green space per person in the other two categories compared to the first cluster.

The first independent samples T-test was applied solely for the green space categories. It was found that there was a significant difference in the mean values of agricultural ($t(23)=6.7$, $p=.002$) and urban green ($t(23)=-4.6$, $p=.002$) between the two groups of cities. On the contrary, there was no difference in the mean values of the forest areas ($t(23)=-2.5$, $p=.80$). The second T-test was then applied in order to test the hypothesis that the percentage of people exposed to the lowest noise band

(55-59) and the cluster of agglomerations with the higher percentage of green ("cluster 1") are positively correlated.

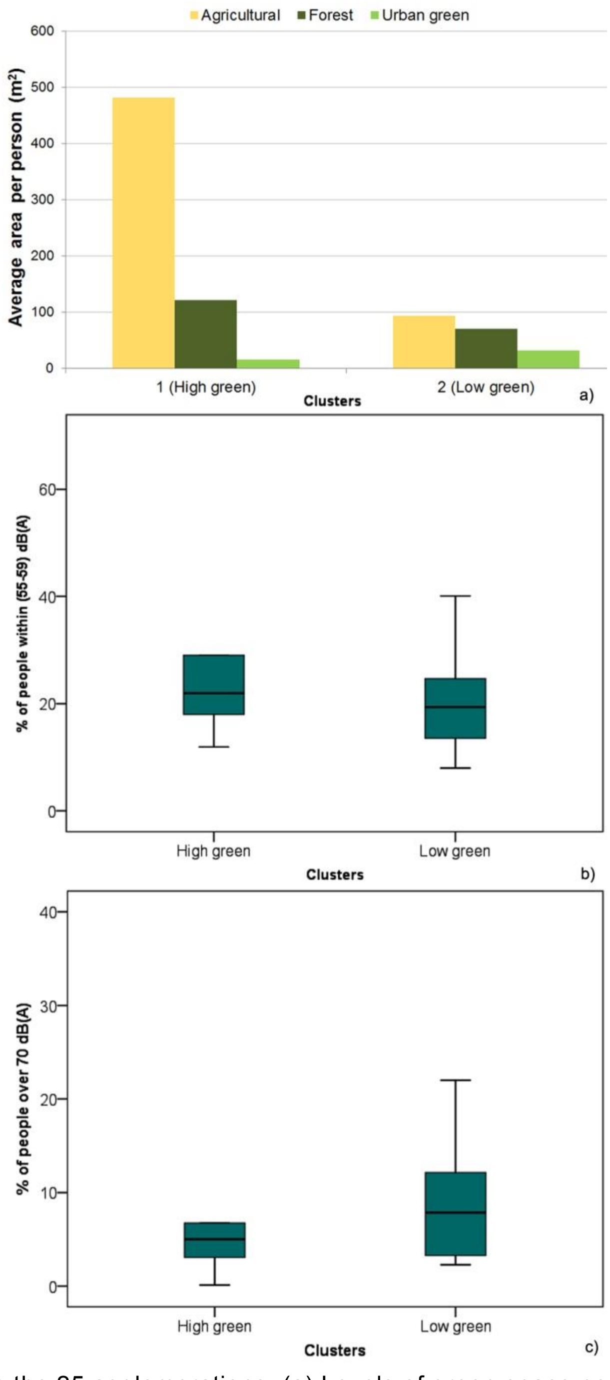

Fig.4.5: Analysis in the 25 agglomerations: (a) Levels of green space per person in the two clusters, (b) percentage of people within the 55-59 dB(A) noise band, (c) percentage of people over 70 dB(A) according to the hierarchical analysis.

The same process was followed in order to check whether there is a negative correlation between the percentage of people exposed to the highest noise band (>70) and "cluster 1".

Results from both tests proved that the variances between the two clusters were different from each other ($t(23)_{55\text{-}59}$=1.21, p=.23 and t(23)>70=-1, p=.32.), however these differences were not statistically significant as it can be seen also in the box-plots of Figs.4.5b,4.5c. In spite of this fact and taking into account the scale of analysis, there is a tendency, showing that more people are inclined to live in "cluster 1" (Fig.4.5b). Similarly, in Fig. 4.5c it can be seen that the majority of people living in areas of more than 70 dB(A) belongs within cluster 2, where all green space indices are lower.

In an attempt to identify similarities in the characteristics of the agglomerations within each cluster it was shown that cities in the first group have a population density lower than the average. From a land use perspective, according to the Urban Atlas classes, these agglomerations are mostly covered by "discontinuous low density urban fabric" mixed with industrial activities around the core urban area. Moreover, these places are characterised by a clear segregation between urban and green classes, with a low percentage of mixture.

On the contrary, the second cluster involves agglomerations with 43% higher population density on average than "cluster 1". A higher coverage in the "continuous" and "discontinuous" dense urban fabric was also observed, which is expected due to the population density increase. Finally, there is a higher percentage of mixture between green and urban classes in contrast with the segregated landscape of "cluster 1".

4.3.2. Effect of green space indicators on noise in the urban level

4.3.2.1. Trends between noise and green

Before the statistical analysis a graphic representation of the variations between noise and green (Δtrees+Δfield) was produced so as to identify possible common trends among the six cities. According to Fig.4.6 three different trends in terms of noise and green can be recognised.

The first one refers to cities like Helsinki and Prague where there is a parallel decreasing tendency both in the number of noise pixels and green for each noise band. Moreover, both cities represent cases with a very high proportion of quiet areas, which belong in the 55 dB(A) band and the highest proportion of green in the same frequency. A variation of this trend can also be identified in the cities of Amsterdam and Rotterdam, where the decreasing tendency in noise and green starts from 60 dB(A) instead of 55 dB(A).

The second trend refers to cities like Brussels, where noise has a more normal distribution among noise bands compared to the first trend. Moreover, green and noise follow opposite tendencies in the middle noise bands demonstrating that the relationship between these two indices is not always proportional.

Finally, the last trend refers exclusively to the city of Antwerp, since it presents a pattern, which is opposed to the expected one as observed in the first trend. Cities in this category have relatively high percentage of green spaces and high noise levels with small variations in all bands. It is also interesting that in Antwerp noise and green present an increase also in the highest frequency. One of the possible reasons for this profile is the fact that Antwerp is also a Trans - European Transport Networks corridor with many highways and constant traffic.

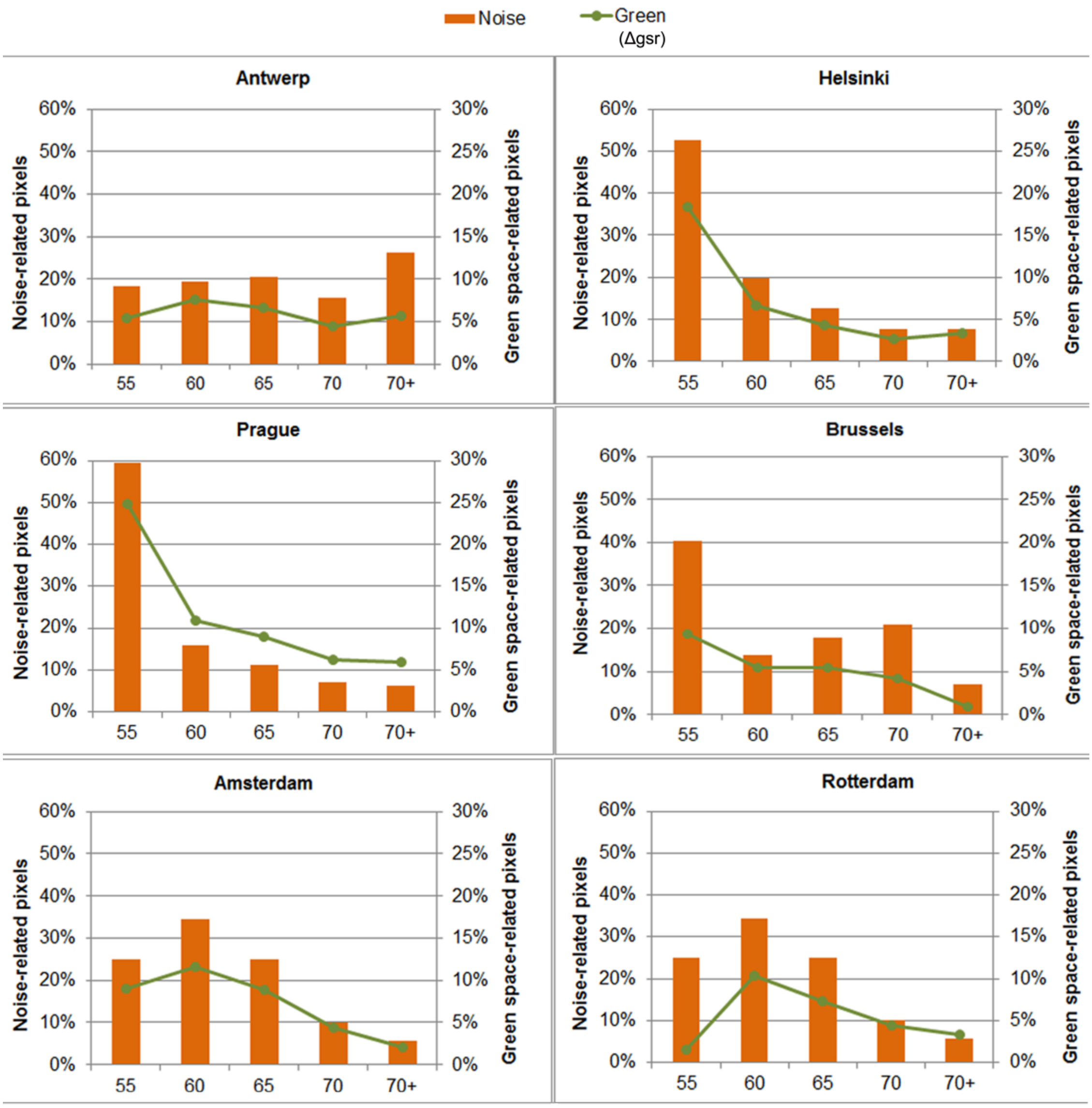

Fig.4.6. Comparison of the percentage related to noise pixels and pixels related to Green Space Coverage (Δgsr) for the six cities.

4.3.2.2. Correlations between noise and green space indicators

The effect of green space indicators on noise indices was investigated in the urban level by using all the related variables (Table 4.4). A Pearson product-moment correlation coefficient was computed to assess the relationship between the seven noise indices and the four green space dependent variables. Results proved that there was a positive correlation for two of them. In particular Δnoise4 was positively correlated with Δporous ($r=.76$, $n=6$, $p=.045$) and Δgsr ($r=.82$, $n=6$, $p=.023$). Similarly, Δnoise6 had a positive correlation with Δporous ($r=.79$, $n=6$, $p=.035$) and

Δgsr (r=.85, n=6, p=.016). The scatterplot presented in Fig.4.7 summarizes these results. As Fig.4.7a shows lower noise levels - expressed with high values of Δnoise4 (R^2=.72) and Δnoise6 (R^2=.80) - can be achieved with higher levels of porous surfaces. Similar results can be achieved with an increase in the green space coverage (Δgsr) as shown in Fig.4.7b reaching a high correlation coefficient (R^2 >.90).

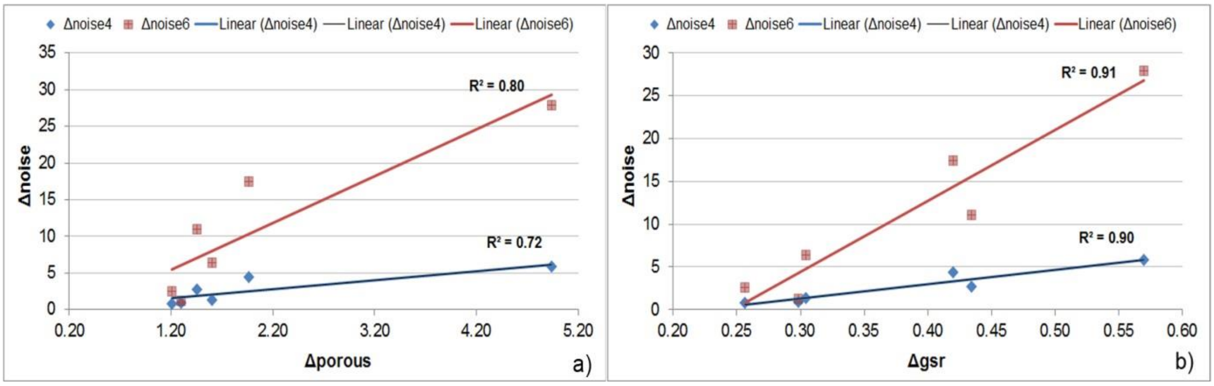

Fig.4.7. Coefficient of determination (R^2) between Δnoise4, Δnoise6 and (a) Δporous, (b) Δgsr

A simple linear regression model was then calculated to predict noise levels (Δnoise6) based on Δporous and Δgsr. The formulated regression equation provided statistically significant results ($F(2,4)=25.1$, $p<.05$) with an R^2 of .92. The variable of Δporous had the highest contribution in the model (R^2=.62) and Δgsr contributes with an additional value of R^2=.30. Practically this means that the balance of porous surfaces in a city can possibly contribute to the reduction of traffic noise through proper land use planning.

4.3.2.3. Ranking of cities based on the selected noise index

The selection of Δnoise6 as the most suitable noise index at the urban level provides the opportunity to rank the case study cities from the “quietest” to the “noisiest”. The ranking process among the cities as presented in Fig.4.8 showed that the less noise-polluted city at this level is Prague, with Helsinki, Brussels, Amsterdam, Rotterdam and Antwerp to follow. The results reveal that the sequence of cities according to the noise index is not always the same with the order of cities based on the porosity index or the green space coverage. Practically this means that quieter cities can potentially be greener, however this does not always work vice versa. For example, Amsterdam appears quieter than Brussels; however, Brussels has a higher ratio of green space coverage (Fig.4.8).

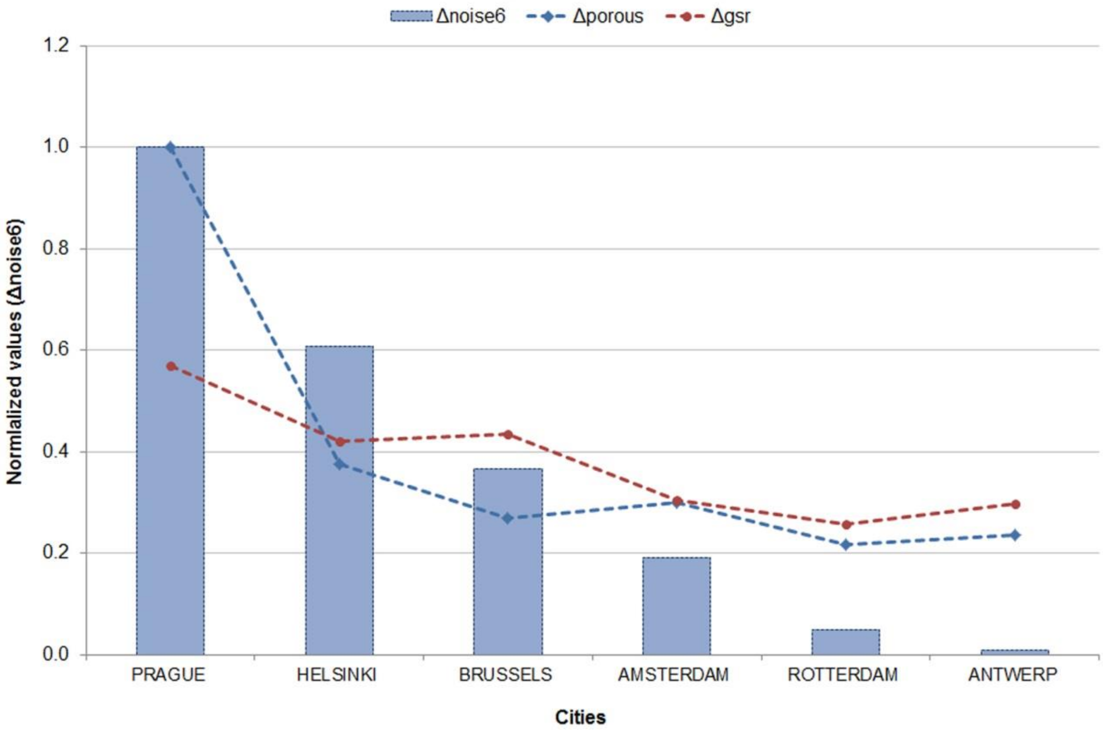

Fig.4.8. Ranking of cities from the quietest to the noisiest and interaction with Δporous and Δgsr.

4.3.3. Effect of green space indicators on noise in the kernel level

At this level correlations between green and noise were tested for each city via a GWR approach by applying a moving search window in kernels of 500x500 meters. The sample of 14,932 observations (kernels) was big enough to facilitate this process. Then results were grouped into clusters in order to identify patterns between the green and noise variables. In the final stage, the groups were intersected with land cover data for a more comprehensive identification of the cluster characteristics.

At first, the corresponding results of the GWR presented in Fig.4.9 gave significant correlations between noise and green with an R^2 range between .60 and .79. Such high correlations indicate that the relationship between the two variables varies locally and is more meaningful when analysed using a moving window approach with a fixed kernel. Prior attempts to interpret the same relationships using an Ordinary Least Squares (OLS) linear regression model provided insignificant results. Finally, as regards the cities, the highest correlation was calculated for Rotterdam (R^2=.79), while the lowest for Brussels (R^2=.60). Areas that present no results within the borders of each city represent kernels with no intersection between noise and green space data.

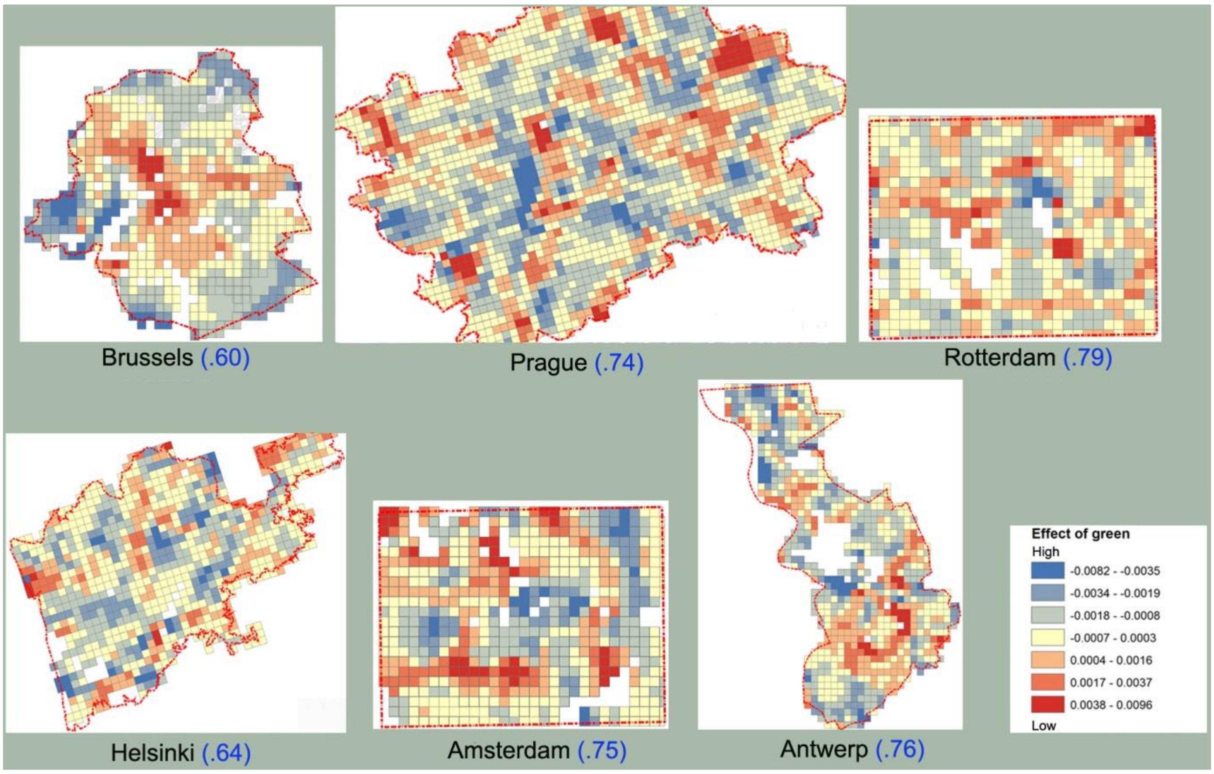

Fig.4.9. The effect of green (Δgsr) on noise according to the results of the GWR model and the associated correlation coefficient (R^2) for each city.

Overall, the transition from one level to the other showed that the relationship between noise and green can vary. However, some core relationships especially in the urban and kernel level remained unchanged. In particular, the negative correlations in the urban level suggest that planners should emphasize more on the balance between green space surfaces and built-up surfaces, since it seems to be more meaningful as an indicator compared to the green space coverage itself.

Also, issues related to the already known *Scale Modifiable Area Unit Problem* (MAUP) where: "*the imposition of artificial units of spatial reporting on continuous geographical phenomena can generate artificial pattern*s" (Heywood, 2006) were minimized thanks to the small kernel size (500x500m) in the GWR and the application of a moving window with a fixed kernel.

4.3.3.1. Ranking of cities

In order to test the consistency of the noise index (Δnoise6), which was selected for the analysis on the urban level, a similar approach was followed also for the kernel level. The index was recalculated for each area of 500x 500m and the final results were averaged for the entire cities. Results shown in Fig.4.10 present similarities and differences compared to the corresponding ones for the urban level (Fig.4.8). Specifically, three cities, namely Brussels, Rotterdam and Antwerp retained their ranking positions (3rd, 5th, 6th). On the contrary Prague was moved from the first position to the fourth, while small changes were evident for Helsinki, which was moved from the second to the first position. Finally, Amsterdam was ranked second instead of the fourth position in the urban level. Overall, it seems that the transition from one scale to the other had an impact on the noise assessment of the cities, although robust results in half of the case studies prove that the index has the potential to be consistent. Other parameters that were expected to have an effect on the final ranking comparison include the transformation of noise levels from discrete to continuous values and the selected size of the kernel (500x500). In all cases, these results can only provide a general initial insight for each city, which can further be elaborated during the planning process.

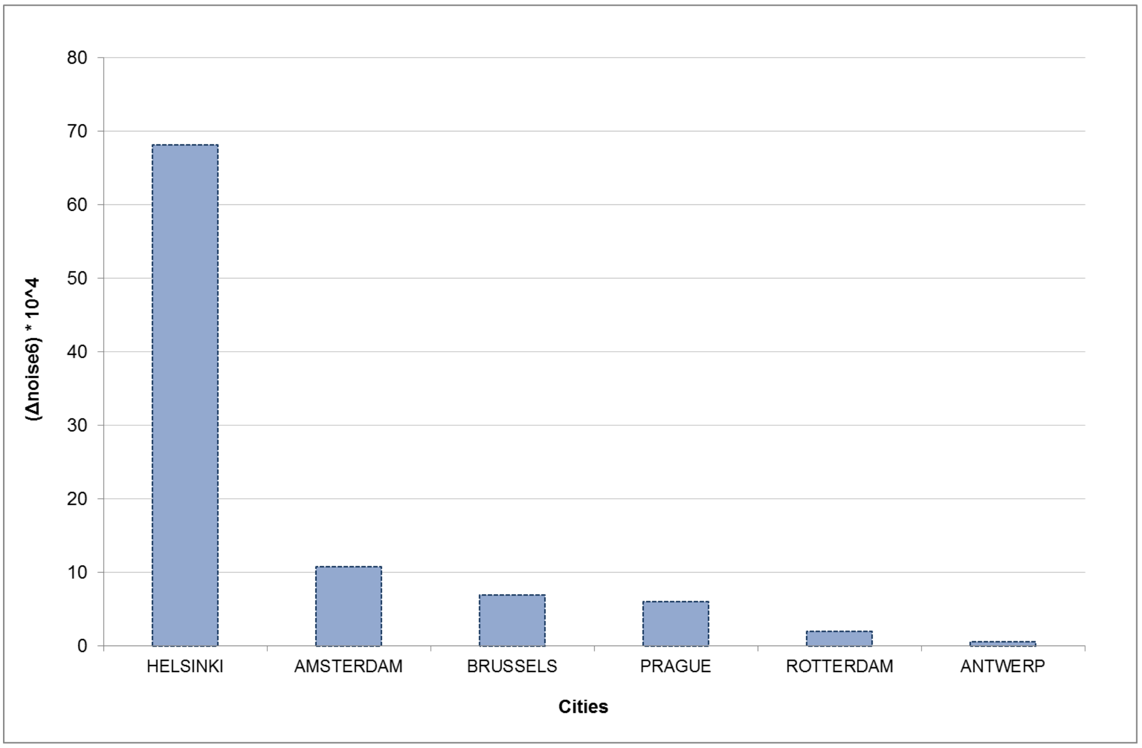

Fig.4.10. Ranking of the cities according to Δnoise6 calculated in the kernel level.

4.3.3.2. Cluster analysis in the kernel level

A cluster analysis was applied after the GWR results were obtained. This process can lead to a better understanding of the kernel areas according to the correlations between noise and green space indices. The optimal number of groups as presented in Fig.4.11a was equal to 3 according to the results from the total "within sum of squares" plot with the number of clusters. The graph in Fig.4.11b describes the balance of the two variables among each cluster. What can be concluded is that "cluster 1" is typical of high green space coverage and low noise levels, while opposite characteristics are present for cluster 3. Lastly, cluster 2 presents a balanced amount of green and noise in lower proportions compared to the other two clusters.

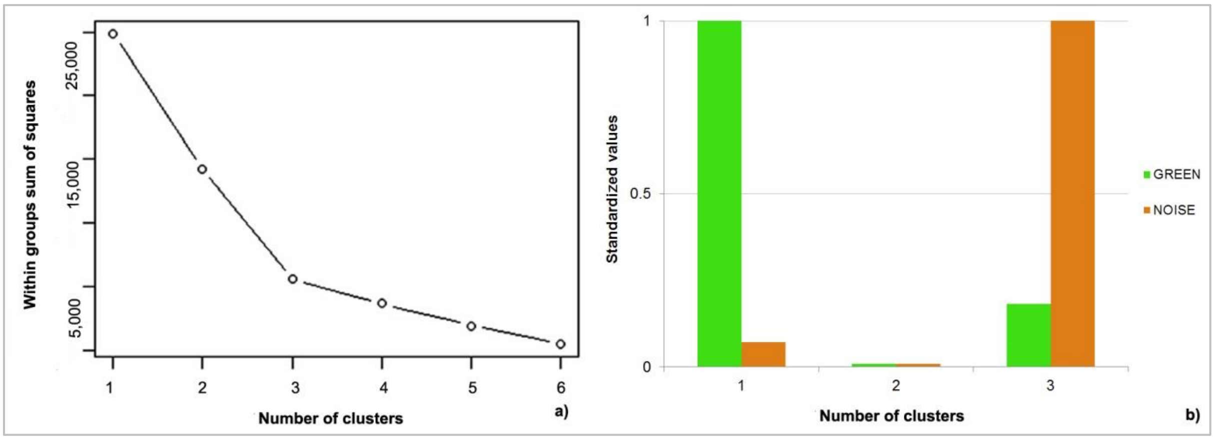

Fig.4.11. (a) Number of clusters and variance explained (within groups sum of squares). The optimal number of clusters is determined according to the "elbow rule". (b) Cluster variations based on the balance between green and noise using normalised values.

The grouping analysis as shown in Fig.4.12 presents the spatial distribution of the three clusters in the case study cities. Areas representing "group 1" are typical of high green space coverage and low noise levels. Such areas are more representative in Prague (46%), Brussels (17%), Antwerp (16%) and Helsinki (15%), with fewer samples in the other cities. Areas of "group 2" represent kernels with low green space coverage and also low noise levels. This kind of places can be found in the majority of the territory in Helsinki (68%), Amsterdam (60%), Rotterdam (59%) and Brussels (58%). Finally, areas of "group 3" with low green space coverage and high noise levels were evident in all cities, however higher proportions were identified in Antwerp (51%), Rotterdam (35%), Amsterdam (31%) and Prague (30%).

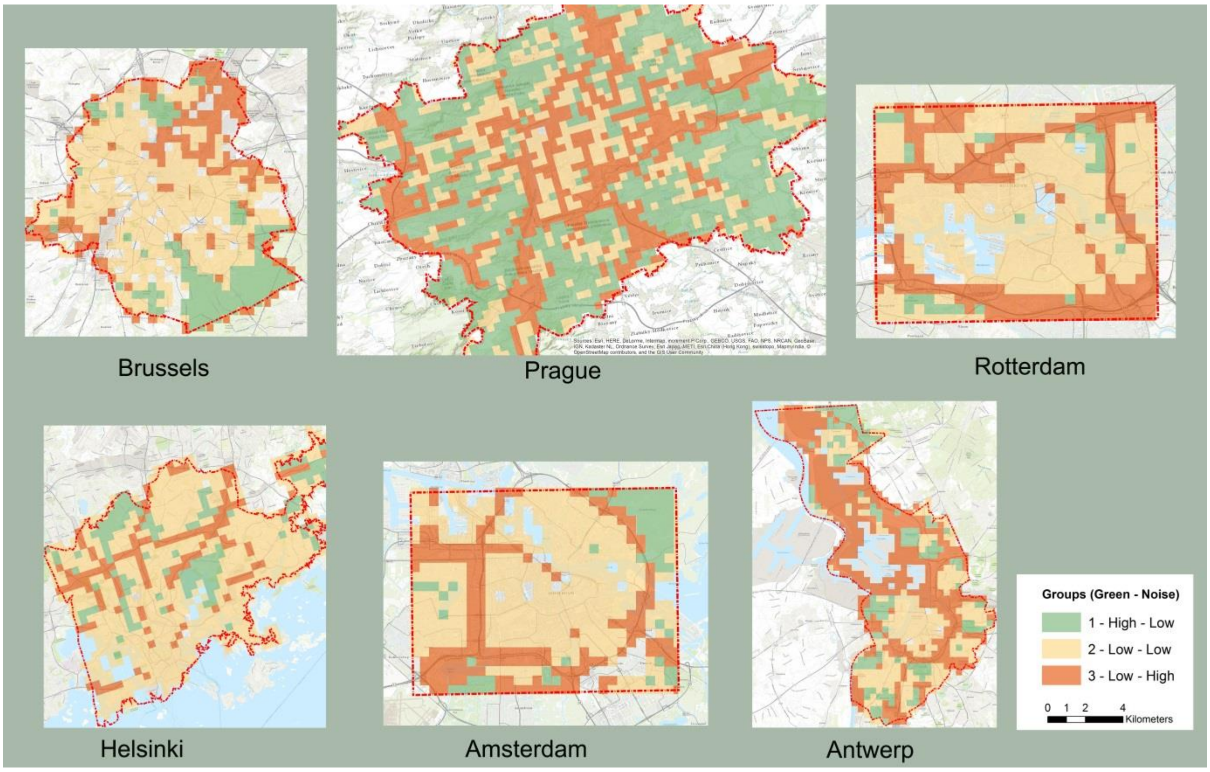

Fig.4.12. Spatial distribution of the three clusters representing the relationship between noise and green. Results are based on the k-means algorithm and the grouping analysis tool in ArcGIS. Basemap source: ESRI 2016d.

More comprehensive conclusions can be drawn when combining the results of the cluster analysis with CORINE land cover data. The analysis as presented in Fig.4.13 revealed that over 30% of the agricultural and forest areas belong to "cluster 1" and a small amount of the total urban areas (5%). Very low percentages were present in this group as regards the industry, infrastructure, the rest of the vegetation and the water bodies.

Cluster 2, which has low levels of noise and green was found to include the highest percentage of total urban areas (21%) and very low proportions in all the other classes. The relationship between noise and green was not so evident in this group or at least results were poorly correlated even with a GWR approach. The highest amount of green spaces in this group was found in the forest class (14%).

Lastly, cluster 3 has the highest percentage in industry and infrastructure and also the lowest in forest areas. Urban areas constitute the class with the highest proportion in the group (10%) as in the other two clusters and agricultural areas depicted a higher percentage than cluster 2.

In general, cluster 3 appeared to have a reduced amount of green spaces compared to “cluster 1”. In particular, there was a reduction of 17% in forest and agricultural areas and 1% in the rest of the vegetation. Overall it was shown that at least in the marginal clusters (1,3) noise and green had an inversely proportional relationship.

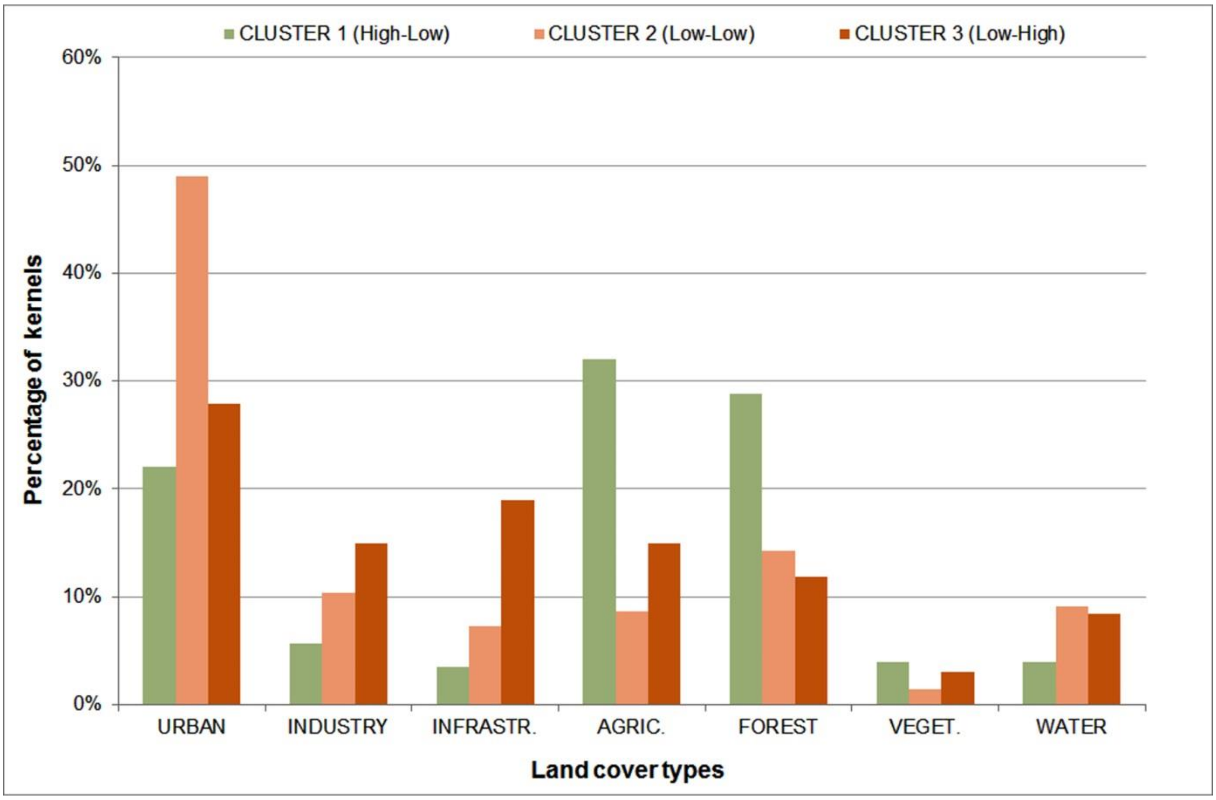

Fig.4.13. Land cover types (CORINE) distributed over the three clusters of the kernel-level analysis. The combination of “high” and “low” refer to the relationship between “green” and “noise”.

4.4. Conclusions

The purpose of this study was to investigate whether greener cities around Europe can also be quieter and less noise polluted. For this reason, an analysis was conducted investigating possible correlations between green space-related indicators and traffic noise indices. The analysis was applied in three levels (administrative, urban, kernel) from a broader to a smaller scale. Conclusions can be summarized as follows:

- *Administrative level*

In the administrative level it was found that there was not a direct correlation between green space indices and the population exposed in low (55-59 dB(A)) or high (over 70 dB(A)) noise bands. As a result, the hypothesis that the percentage of people, exposed in the 55-59 noise band, would be higher in the cluster with the higher green space index was not confirmed. The same happened with the hypothesis that the percentage of people exposed in more than 70 dB(A) would be higher in the cluster with the lower green space index.

Concerning the land use attributes in the two clusters, it was found that “cluster 1” was related to urban and industrial areas with low population density and high segregation between the green and urban classes. On the contrary “cluster 2” was associated with high urban land cover and high population density, but lower segregation between green and urban areas.

- *Urban level*

In the urban level it was proved that quieter cities can potentially be greener, however this does not always work vice versa. On the top of that the analysis showed that lower noise levels can possibly be achieved in cities with a higher extent of porosity and green space coverage.

- *Kernel level*

In the kernel level, significant correlations between noise levels and the green space coverage per grid were identified using the GWR approach.

Two types of correlations were formed: one between green and noise forming different clusters and another one using the previous clusters combined with land cover data. In the first case, kernels were classified in three groups depending on the balance between green space coverage and noise levels. In the second case, three groups were formed with land cover data showing that noise levels were minimized in the group that had the highest percentage of forest and agricultural areas in combination with the minimum coverage of infrastructure areas. On the contrary, the cluster with the highest noise levels was combined with the maximum coverage in infrastructure and industrial land cover.

A further research on the clusters' urban part can reveal more in-depth correlations between noise and green space features for the core parts of the cities. Specifically, a combination of noise mapping data and application of a land use regression model can also be effective in noise pollution prediction in the urban and sub-urban areas at an early planning stage.

Chapter 5

City level

The content of this chapter has been published in a peer-reviewed journal under the title:

Margaritis, E., & Kang, J. (2016). “Relationship between urban green spaces and other features of urban morphology with traffic noise distribution”. *Urban Forestry & Urban Greening*, *15*, 174-185.

5. The effects of urban green spaces and other features of urban morphology on traffic noise distribution

This Chapter is the second one using prediction and calculation methods after Chapter 4. The comparison among EU cities in the previous Chapter is now completed by the inclusion of UK cities using similar green space indicators and enriched with additional morphological indices. The analysis is focused on sample areas within cities instead of entire agglomerations in an attempt to apply a top-down analysis approach. Section 5.1 refers to the previous studies as regards the relationship between urban form and traffic noise in the dwelling scale up to the description of street pattern typologies in the urban scale. Green space indicators are also mentioned from the pattern viewpoint. The study sites and all the necessary indicators are described in Section 5.2, while results on macro, meso and micro scale are examined in Section 5.3. A discussion on the planning implications at different scales is included in Section 5.4 with the final conclusions to be made in Section 5.5.

5.1. Previous studies and research questions

Traffic noise is an increasing problem in the contemporary society and the prevalent noise source in the urban environment (Quis, 1999). About 210 million people, over 44% of the EU population, are regularly exposed to levels over 55 dB(A), a limit which has been recognised by the World Health Organisation (WHO, 2011) to pose a serious risk to health. The Environmental Noise Directive (END) (2002/49/EC) and the supplementary noise action plans set the base for developing community measures for noise reduction emitted by major sources.

The generic structure of urban morphology, according to Kropf (2005), is a hierarchy of different characteristics at different interdependent scales involving a) building elements, b) road infrastructure and c) land use components. In this network green spaces have a direct and dynamic relationship with the urban structure (Ståhle, 2010). Previous studies have put emphasis on diverse building arrangements or formations and the effect of noise on façades (Oliveira & Silva, 2011; Guedes et al., 2011; Salomons & Berghauser Pont, 2012; Silva et al., 2014). Others focused more on the dwelling scale within the same or different cities (Wang & Kang, 2011; Hao & Kang, 2013; Lam et al., 2013). However, in the urban scale, morphological parameters have been investigated to a lesser extent in connection with traffic noise (Tang & Wang, 2007; Salomons & Berghauser Pont, 2012) and more as part of the urban sprawl process (Galster et al., 2001; Knaap et al., 2005; Tsai, 2005) or land use attributes (Chakraborty, 2009; Kashem et al., 2009).

The accepted definition of urban green spaces by scientists of different backgrounds refers to public and private open spaces in urban areas covered by vegetation directly or indirectly available for the users (Haq, 2011). This broad category includes mainly parks, forests, public squares, recreational grounds and private front or backyard garden land. On-going interdisciplinary research is being carried out; either emphasizing the effect of vegetation on traffic noise in terms of trees, plants and hedges (Kragh, 1981; Huddart, 1990; Van Renterghem & Botteldooren, 2002; Fang & Ling, 2005; Kang, 2007a; Wong et al., 2010; Pathak et al., 2011; Yang et al., 2011; Horoshenkov et al., 2013; Van Renterghem et al., 2014) or studying the acoustic properties of the ground in terms of porosity and other similar parameters (Attenborough, 2002; Gołębiewski, 2007; Attenborough et al. 2012; Bashir et al. 2015).

Previous work has put emphasis on individually assessing the effectiveness of parks on traffic noise reduction (González-Oreja et al., 2010; Cohen et al., 2014). However, in these cases the weight was put more on the contribution of greenery in soundscape perception (Nilsson & Berglund, 2006) and not in the distinction between rigid and porous ground. Similarly on the urban scale, green space patterns have previously been investigated using various spatial metrics (McGarical & Marks, 1994). Nevertheless, these indexes do not provide any statistical significance for the degree of clustering or dispersion of the pattern. The latter can be measured by two metrics: a) the centroid-based Average Nearest Neighbour index (ANN) and the edge-based Connectivity index calculated by the Conefor software (Saura & Torné, 2009).

The street pattern, as a component of the urban morphology, gives a specific identity to each city. In particular, "settlement form" can be used as a term to describe the network structure of distinct units such as cities and towns (Marshall & Gong, 2009). For planning purposes at a city-scale level, Lynch and Hack (1962) proposed three simple systematic patterns/forms: radial, linear and grid. In radial patterns, a main ring road acts as the area constraint around built-up areas, while linear patterns refer to developments, laid out along a transportation 'spine' (Marshall & Gong, 2009). In the same level, Marshall (2005) recognized over 100 descriptors related to street patterns. Nevertheless, all the derivative patterns fall back into the neat sets of rudimentary typologies (radial, grid, linear).

Therefore, the aim of this Chapter is to quantitatively investigate the relationship between features of urban morphology and traffic noise distribution with special emphasis on urban green spaces. The historical and architectural background of the cities was also investigated as a complementary element. A triple level analysis was conducted on a macro, meso and micro-scale. For the macro-scale, three aims can be identified: a) the relationship between urban morphology and traffic noise, b) the relationship between green space ratio, green space pattern and traffic noise with the settlement forms and c) the effect of street typology on traffic noise distribution. In the meso and micro-scale the aim is to identify and assess the effectiveness of indicators related to urban morphology in traffic noise distribution.

As regards the scales of interest, the macro-scale refers to the consideration of the sample areas as entities represented by a single value per variable. In the meso-scale, each variable is calculated separately for each one of the tiles. Finally, in the micro-scale, the analysis is conducted particularly within a single tile from each city.

5.2. Materials and Methods

5.2.1. Study sites

In the first part, a macro-scale analysis was conducted among eight cities of different settlement form according to the classification proposed by Marshall (2005). As shown in Fig.5.1 the first four cities, grouped as "radial", (Coventry, Leicester, Nottingham, Sheffield) contain a main urban core surrounded by a circumferential road system. The remaining four (Bournemouth, Blackpool, Southend, Brighton) were grouped as "linear", since their structure is based on a few main vertical or horizontal arteries. The analysis was restricted within the boundaries of the first agglomeration level, which is equal to, or smaller than, the official administrative ones.

In the second part, a deeper meso-scale analysis was conducted between a radial and a linear city; Sheffield and Brighton. Sheffield, apart from being one of the greenest cities in UK (Sheffield City Council, 2010), has many similarities with Brighton in terms of land use. Specifically, the two sample areas have almost the same percentage of Building Coverage, Road Coverage and porous surfaces including yards and parks. Finally, in the micro-scale level a detailed comparison is performed using the same methodology and variables trying to classify the city centres according to their morphological characteristics.

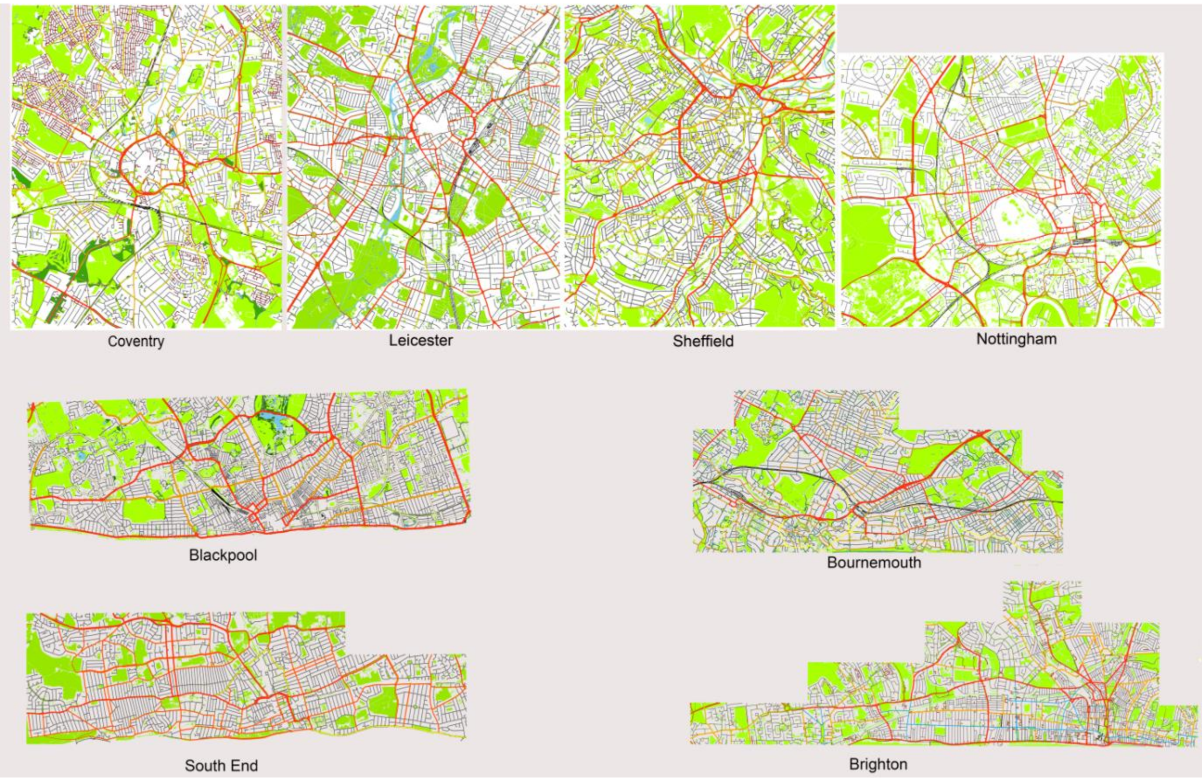

Fig.5.1. Green space distribution in radial and linear settlement forms.

Historically, most of the cities such as Coventry, Nottingham, Brighton, Southend and Leicester date back to the 5th-7th AD or earlier as Anglo-Saxon or Celtic settlements. On the contrary, Sheffield and Bournemouth have a more recent history since they were founded in early 12th and 19th century respectively (Local Histories, 2015). In the old times, all of the radial cities had a fortified settlement surrounding for defensive purposes. This is a possible reason for the ring road structure, which was developed in the later years. Great changes took place after World War II in the urban structure of every city leading to the regeneration of many areas and Council House development between 1920 and 1960. At the same period public green spaces become officially protected as a response against industrialization and town expansion.

In terms of population dynamics it can be seen in Fig.5.2a. that all radial cities outgrow the linear ones with an average size of 380,000 inhabitants compared to 190,000 inhabitants (Office for National Statistics, 2011). Historically, Nottingham and Sheffield reached the threshold of 150,000 residents in the beginning of 19th century, while the majority of cities were in the same position between 1930s-1960s apart from Bournemouth (Fig.5.2a). However, a comparison among them is feasible since they are mostly average-sized cities with similar population size within the sample areas (M=160,000, S.D=28,000) as shown in Fig.5.2b.

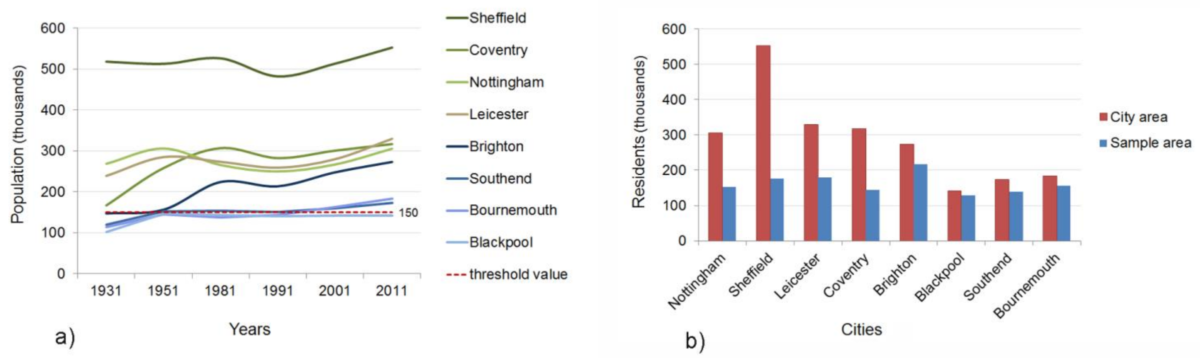

Fig.5.2. a) Population evolution since 1930, b) Population comparison between cities in the Local Authority level and sample areas (2011).

5.2.2. Sample and grid size selection

The sample area in each city at both scales (macro, meso) was defined by a grid, placed so as to include the broad city centre and the nearby areas. Another criterion was to place the grid in such a way so as to cover as many “solid” areas as possible, since many parts close to the agglomeration borders appeared vacant with no noise data. Only tiles of less than 10% of missing data were considered valid. Finally, in the micro-scale approach, central areas that accumulate a great variety of services and are usually considered as the “heart” of the city were chosen for the analysis.

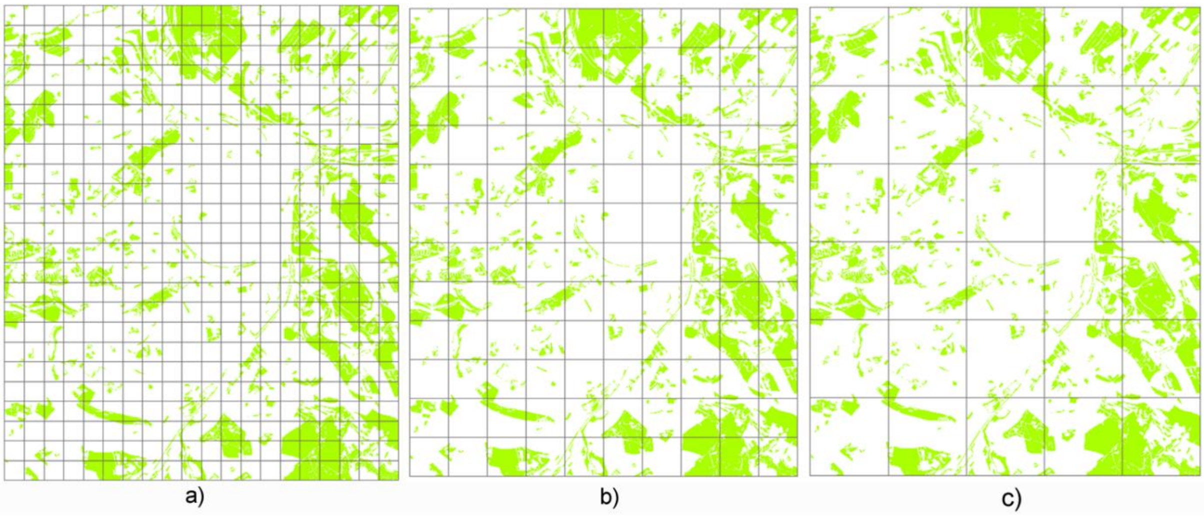

Fig.5.3. Possible grid sizes and respective coefficients of determination (R^2) between green space ratio and noise levels (L_{den}) tested in Sheffield: a) 250x250m - R^2=.07, b) 500x500m - R^2=.037, c) 1,000x1,000m - R^2=.285.

The grid resolution was calculated in advance through, three different linear regression tests considering tiles of 250 meters, 500 meters and 1,000 meters as presented in Fig.5.3. Results proved that the highest coefficient of determination (R^2), between the ratio of all green spaces and noise levels per tile, occurred with the 1,000-meter tile (R^2=.29, $p<.05$). As a result, the selected tile size was 1km x 1km. The sample size was then calculated using a G-Power test for a multiple regression fixed model. The appropriate sample size aiming at a variance of over 70% within a confidence level of 95% and three final predictors was 27 observations. Ultimately, the selected sample of 30 observations (30km^2) satisfied the above criterion. With the current resolution, the sample area can cover 38% - 88% of the total noise mapping area depending on the city.

5.2.3. Noise level data

The data source for noise levels lies on the online noise maps for the first round agglomerations produced by the English Department for Environment Food and Rural Affairs (DEFRA, 2007). The current noise levels correspond to an average day over the whole year. For the current research this was 2006, since it is the year with the latest available public data. Additional data for land cover, ground elevation, meteorology and building heights are included in the official noise mapping process, but no in situ noise measurements. The final product is a 10-meter grid raster dataset. As shown in Fig.5.4, there are six noise classes of 5dB each; ranging from 0 to 75+ dB(A) using the L_{den} and L_{night} indices (END, p.7). The maps have been produced for areas, which include a population of more than 250,000 residents and a density of more than 500 persons/km^2. Since original data were not available for this research, each noise map was reconstructed from the beginning as a new raster dataset in the finest available resolution. The number of noise classes and the colour palette in the new file comply with DEFRA's legend (Fig.5.4).

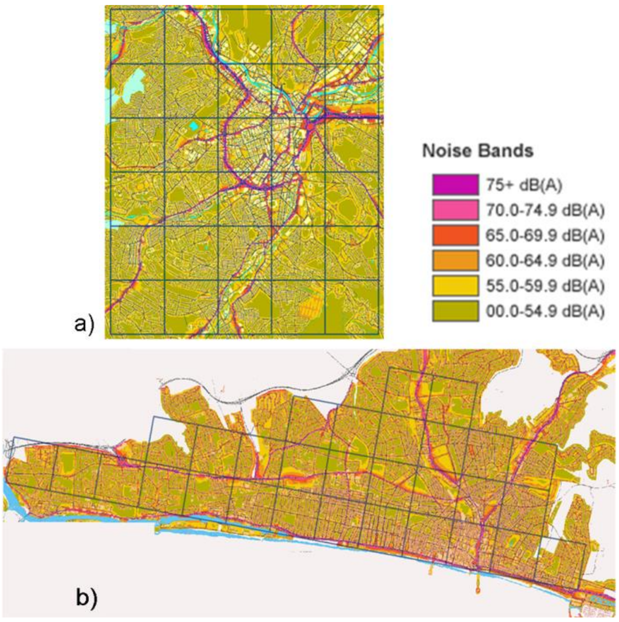

Fig.5.4. Examples of noise maps with the applied grid of 1km for: a) Sheffield and b) Brighton.

5.2.4. Urban morphological data

The vector 2D datasets related with the morphological parameters were extracted using the OS Mastermap Topography collection (Ordnance Survey, 2007) (1:1,250). The same variables were calculated for all scales; nevertheless four variables were not available in the macro-scale and two in the meso and micro-scale. As reported on Table 5.1 three morphological categories can be distinguished according to their semantic content ("Green Space Ratio", "Green Space Pattern", "Buildings and Streets") and one called "Geodemographic".

Green spaces in this study are divided in two classes. The first class is called "Natural Urban Green" and refers to the ratio of parks, urban forests, public squares and recreational grounds in the sample area. The second class is classified as "Gardens" representing the areas of private front yards and backyards covered by grass and some small green areas between houses which do not belong to the first category. Finally, the two buffer-related variables comprise green areas from the first class within a buffer zone of 100 meters around the two road categories. The aggregation of Natural Urban Green and Gardens represent the porous surfaces in the city. Respectively, the total amount of roads, buildings and other manmade structures account for the rigid surfaces.

The second category refers to the spatial pattern of Natural Urban Green. Shapes over 0.1 ha were used in order to remove the biased effect of small polygons. The Average Nearest Neighbour (ANN) index is expressed as the ratio of the observed distance (Do) among the centroids of the green patches divided by the expected distance (Dε) in a hypothetical random distribution. A distance threshold value among the patches is not necessary to be defined by the user as in other pattern analysis tools. If the index is less than 1 the pattern exhibits clustering, while in the opposite case the trend is towards dispersion. Only statistically significant results were used within a significant level of $p<.01$. Finally, the Conefor Connectivity index calculates the total distance of all possible combinations among the patches divided by the number of combinations. Higher values of the index signify a tendency to dispersed patterns.

Table 5.1. Explanation of variables per category and scale: data available at this scale (/), data not available at this scale (O).

Parameter	Explanation	Scale Macro	Scale Meso	Scale Micro
Green Space Ratio				
Natural Urban Green ratio	Ratio of green spaces that belong to the Natural Urban Green class	/	/	/
Gardens ratio	Ratio of green spaces that belong to the Gardens class	O	/	/
Primary Buffer Zone	Area of Natural Urban Green within 100m from Primary Roads	O	/	/
Local Buffer Zone	Area of Natural Urban Green within 100m from Local Roads	O	/	/
Green Space Pattern				
Average Nearest Neighbour (ANN) index	Centroid-based index measuring the extent of clustering or dispersion of green space patches	/	/	/
Conefor Connectivity index	Edge-based index measuring the extent of connectivity among green space patches	/	/	/
Buildings and Streets				
Building Coverage ratio	Ratio of built surface compared to the total surface	/	/	/
Building Perimeter	Total perimeter of all buildings	/	/	/
Number of Buildings	Total number of buildings	/	/	/
Road Coverage ratio	Ratio of road surface compared to the total surface	/	/	/
Primary Road Intersections	Number of street intersections in the Primary Roads	O	/	/
Local Road Intersections	Number of street intersections in the Local Roads	/	/	/
Primary Roads Length ratio	Ratio of Primary Roads Length to the total road network	/	/	/
Secondary Roads Length ratio	Ratio of Secondary Roads Length to the total road network	/	O	O
Minor Roads Length ratio	Ratio of Minor Roads Length to the total road network	/	/	/
Local Roads Length ratio	Ratio of Local Roads Length to the total road network	/	/	/
Geodemographic				
Population	Number of residents, 2011 Census (Output Areas)	/	/	/
Car Availability ratio	Number of cars per resident, 2011 Census (Output Areas)	/	/	/

The third category consists of variables related to road categories (Ordnance Survey, 2014) and building attributes calculated on average values per tile. Height values have not yet been available from Ordnance Survey. Finally, the last category refers to geodemographic variables such as population and Car Availability ratio in the Output Areas (OA) according to the 2011 Census.

5.2.5. Calculation of noise levels

In the meso-scale each map was clipped in 30 smaller raster files in accordance with the borders of the tiles, while a single raster file was considered in the macro-scale. All noise indices (L_n) were then calculated using a Matlab code, which converts the colour values per pixel (RGB) in noise levels as presented in Fig.5.5. Buildings, roads and inland water were attributed with a zero dB(A) value. A distinction should be made between the current noise levels, which are spatial (Ls_n) and the traditional time-based percentile sound levels (L_n). Ls_n corresponds to the percentage of the pixel values. Consequently Ls_{10} represents the 10% of all values, while Ls_{90} represents the background noise or the 90% of the total data when these are sorted in a descending form. In the meso-scale, for each one of the 30 tiles all Ls_n noise indicators (Ls_{10}, Ls_{90}, Ls_{min}, Ls_{max}, $Ls_{den_{avg}}$) were calculated in both cities. On the macro-scale, there was one value per index calculated using the entire sample area (30 km^2) without further tiling. The same process was repeated for the morphological variables.

0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	60	60
0	0	0	0	0	60	60
0	0	0	0	0	60	60
0	0	0	0	0	60	60
0	0	0	0	0	60	60
0	0	60	60	60	60	60
0	0	60	60	60	60	60
60	60	60	60	60	60	60
60	60	60	60	60	60	60
60	60	60	60	60	60	60
60	60	60	60	60	0	0
60	60	60	60	60	0	0
60	60	60	60	60	0	0
60	60	60	60	0	0	0

Fig.5.5. Matlab code results presenting the transformation from RGB pixel values in dB(A) levels.

5.2.6. Calculation of morphological variables

The calculation of this process was accomplished using ArcGIS (v.10.1) and the British National Grid coordinate system. In total sixteen morphological variables were tested in all levels and two extra geodemographic variables (Table 5.1). Indices related to Green Space Ratio were calculated using the Analysis toolbox, while street-related variables with the Network Analyst toolbox. Ultimately the Green Space Pattern was explored through the ANN and the Conefor Connectivity index.

5.3. Results

5.3.1. Macro-scale

5.3.1.1. Correlations between urban morphology and traffic noise

A Pearson product-moment correlation coefficient was used to assess the relationship between the group of morphological variables and traffic noise levels for the eight cities. Results proved that two variables were found to be statistically significant in this level with the green space variables to be excluded. Firstly, there was a negative correlation between the ANN index and traffic noise r(8)=-.71, p<.05.

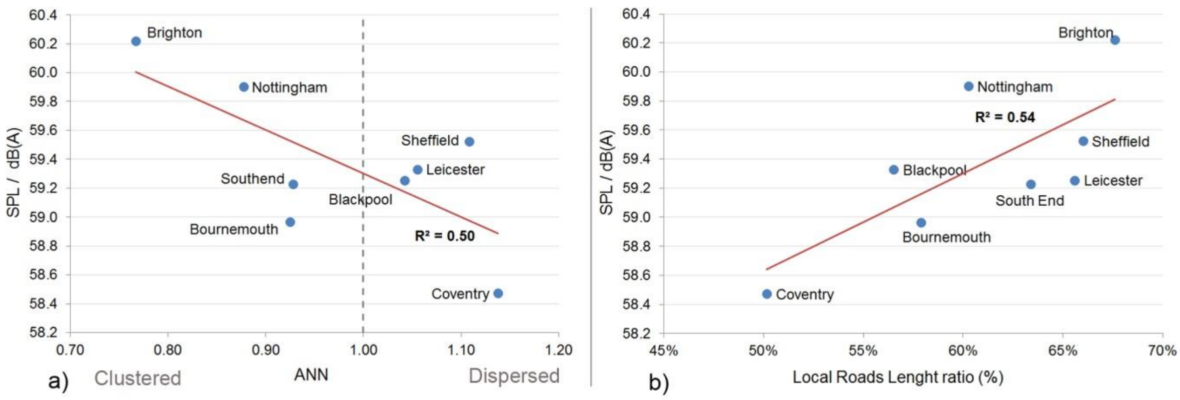

Fig.5.6. Statistically significant variables interacting with noise levels in the macro-scale: (a) Negative effect of the ANN (R^2= .50), (b) Positive effect of the Local Roads Length ratio (R^2 = .54).

The scatter plot in Fig.5.6a summarizes the results suggesting that an increase in the distance between neighbouring green patches can possibly be correlated with a decrease in traffic noise. Among the eight cities described in Table 5.2, Brighton presented the lowest value of the index (ANN=.77) and Coventry the highest (ANN=1.14). Secondly, there was a positive correlation between the Local Roads Length ratio and noise levels r(8)=.73, p<.05 presented in Fig.5.6b. Brighton and Coventry represent once more the marginal cases with 67.6% and 50.2% respectively. This correlation is practically related to higher internal network connectivity. More local roads increase the number of street connections with the Primary and Secondary Network allowing for more cars and higher traffic flows.

Table 5.2. Cities of linear and radial typology with noise and green space attributes

Cities	Settlement form	Noise levels dB(A)	Natural Urban Green ratio (%)	ANN	z-score	*p*	Pattern
Coventry	radial	58.47	25	1.14	8.05	< 0.001	Dispersed
Leicester	radial	59.25	22	1.04	2.68	< 0.001	Dispersed
Nottingham	radial	59.9	24	0.88	-11.7	< 0.001	Clustered
Sheffield	radial	59.52	26	1.11	7.78	< 0.001	Dispersed
Bournemouth	linear	58.97	21	0.93	-4.29	< 0.001	Clustered
Blackpool	linear	59.33	23	1.06	3.2	< 0.001	Dispersed
Southend	linear	59.23	18	0.93	-3.36	< 0.001	Clustered
Brighton	linear	60.22	21	0.77	-13.41	< 0.001	Clustered

5.3.1.2. The effect of Green Space Ratio, Green Space Pattern and traffic noise in cities of different settlement form.

The assessment of the relationship between Natural Urban Green ratio and the two settlement forms was performed via an independent sample t-test. The assumptions of normality and homogeneity were tested and satisfied. According to the scatter plot in Fig.5.7a, it was proved that there was a significant difference in the average values of Natural Urban Green for radial (M=.24, SD=.017) and linear cities (M=.20, SD=.021); conditions, t=2.61, p=.040. Therefore, it is reasonable to deduce that radial cities are associated with a higher Natural Urban Green ratio compared to linear cities and generalize this conclusion also in other urban areas with similar settlement form in UK. A possible explanation is that linear cities are usually built close to the coastline and tend to develop a denser urban structure with less green areas than mainland cities.

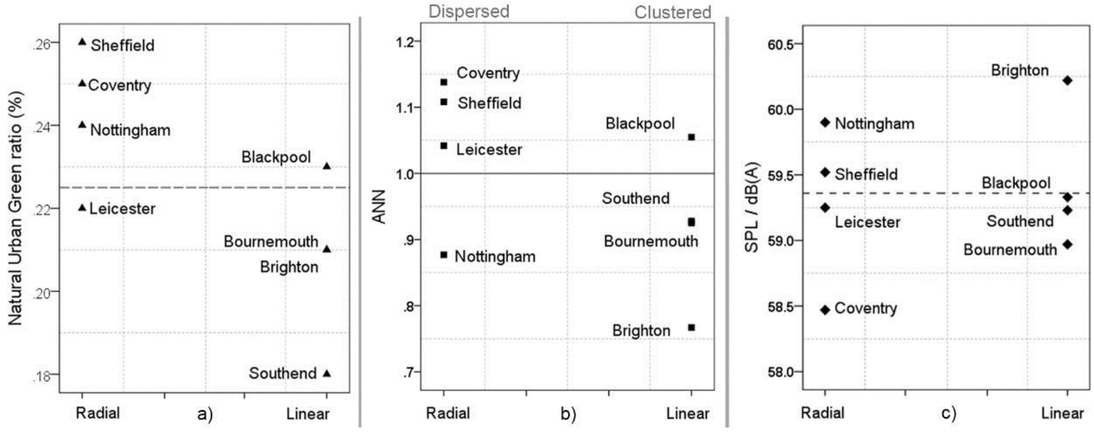

Fig.5.7. Dot plots describing the relationship of the two settlement forms with: (a) Natural Urban Green ratio, (b) ANN and (c) Noise levels.

As a result, radial cities are more likely to have a lower average L_{den} than linear cities under the same traffic conditions. The comparison of Green Space Pattern in radial and linear cities was tested using the Conefor index and the ANN index, however only the second one provided statistically significant results. Fig.5.7b demonstrated that three out of four radial cities tend to follow a dispersed pattern (ANN>1). With the same proportion, linear cities present a trend towards following a clustered pattern (ANN<1). These tendencies were proved strong, but not statistically significant in the correspondent ANN scores of the t-test (t=-1.47, p=.19). The reason of those tendencies can be attributed mainly to the local topography since linear cities are usually restricted by physical obstacles (e.g. sea), while radial cities are more flexible in expanding. Overall, these trends can be generalised in other cities of similar settlements, after validating this hypothesis within a bigger sample. According to Fig.5.7c, noise levels for radial and linear cities are almost evenly distributed ranging from 58.5 dB(A) to 60.2 dB(A) with no significant difference between them. The 5 dB(A) difference between noise classes reduces the accuracy of the final L_{den}. Nevertheless, these levels should be considered more as an indicative tendency of the whole city, rather than precise values.

Car Availability ratio can also provide useful evidence about the expected noise levels. Results presented in Fig.5.8 confirm that three out of four linear cities are above the average value (M=0.41). The overall results from Figs.5.7, 5.8 increase the probabilities for radial cities to be accredited as “less noisy” than linear cities, in a macroscopic approach.

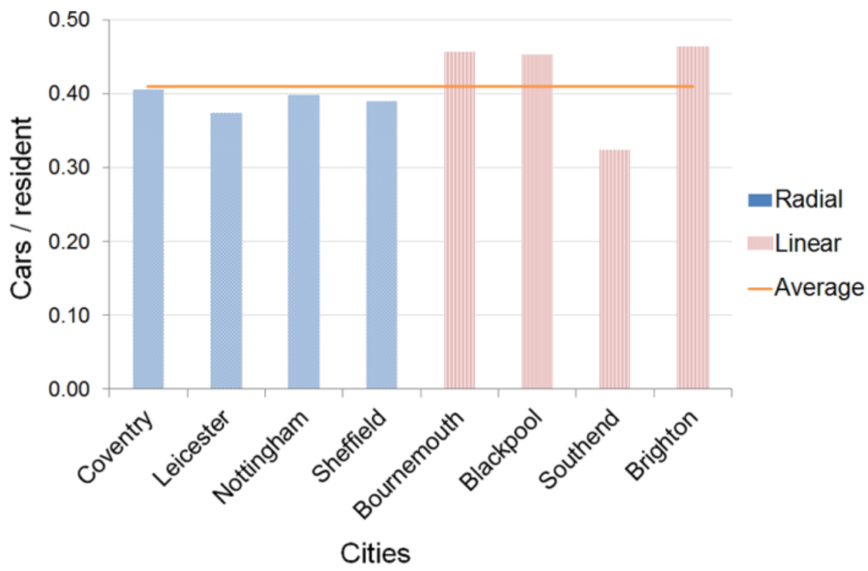

Fig.5.8. Car Availability ratio in linear and radial cities.

5.3.1.3. Validation of the ANN index

A simulation using CadnaA software was applied in order to validate the results of the ANN index in the macro-scale approach. Five different scenarios of porous ground arrangements and a reference case with totally rigid ground were tested as presented in Fig.5.9. ISO 9613-2 and CRTN were used as the main protocols in the model.

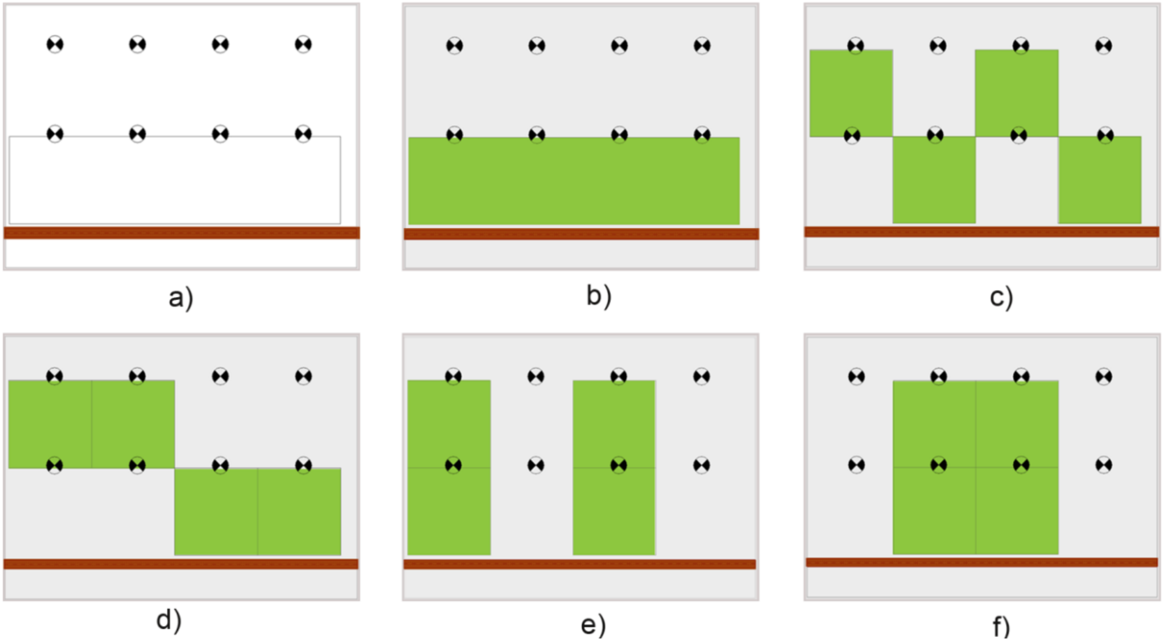

Fig.5.9. Reference case (a) and five different configuration scenarios of porous patches (b-f).

Six receivers were added in stable positions with a distance of 100 meters between them. Finally, a federal road of 50,000 Veh/18h was used as the unique traffic source. Results in Fig.5.10 proved that the highest attenuation in average values among the eight receivers was achieved when the green patches were more dispersed (cases c-e) and not clustered (cases b,f). These results confirm in a restricted scale the findings of Fig.5.6a, where dispersed patterns are related to lower noise levels.

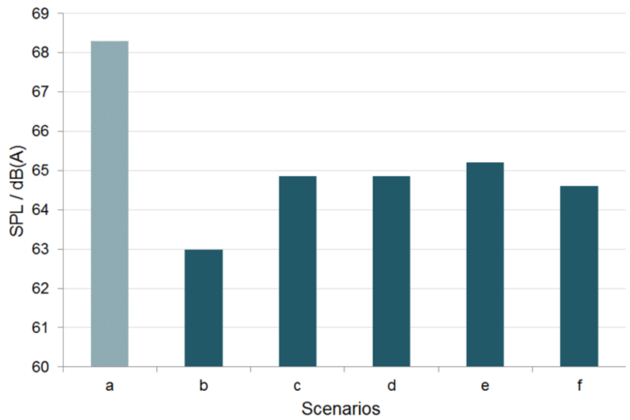

Fig.5.10. Average noise levels for the six receivers calculated for every scenario of porous configuration

5.3.2. Meso-scale

5.3.2.1. Identification and effectiveness of morphological indicators related to traffic noise.

The meso-scale analysis presented in Table 5.3 demonstrated that 6 out of the eighteen variables tested (See Table 5.1), were proved correlated for both cities within the confidence interval of 99%. As far as Sheffield is concerned, positive correlations with noise levels were indicated for the Building Perimeter r(30)=.67 and the Local Road Intersections r(30)=.66. The proportion of Gardens ratio and Natural Urban Green ratio had a negative correlation with L_{den}, r(30)=-.62 and r(30)=-.54 respectively. In Brighton positive correlations were reported for the Local Road Intersections, r(30)=.67 and Car Availability r(30)=.54, while a negative effect was observed for Gardens ratio, r(30)=-.61. Finally both cities had high positive correlations in Primary Roads Length with r(30)=.82 and r(30)=.70. The positive correlation of Building Perimeter only for Sheffield can be explained by the combination of larger buildings and higher noise levels in the city centre. On the contrary, more distant and less noisy areas tend to present larger building blocks but lower Building Perimeter since houses are smaller.

Table.5.3. Pearson correlation (r) and summary results for the regression analysis in Sheffield and Brighton (** p<.01)

	Variables	Pearson (r)		Model	β	t	Sig.	VIF
Sheffield	Primary Roads Length	.82**	Sheffield	(Constant)	57.26	88.23	< 0.01	
	Building Perimeter	.67**						
	Local Road Intersections	.66**		Gardens ratio	-.24	-2.58	0.02	1.54
	Gardens ratio	-.62**		Local Road Intersections	.42	5.17	< 0.01	1.18
	Natural Urban Green ratio	-.54**		Primary Roads Length	.52	5.27	< 0.01	1.76
Brighton	Primary Roads Length	.70**	Brighton	(Constant)	57.92	133.3	< 0.01	
	Local Road Intersections	.67**		Car Availability ratio	.20	1.41	0.17	1.45
	Car Availability ratio	.54**		Local Road Intersections	.25	1.81	0.08	1.70
	Gardens ratio	-.61**		Primary Roads Length	.48	4.11	< 0.01	1.22

A linear regression analysis was conducted in order to test the effectiveness of the variables in Table 5.3 as inputs in a noise prediction model for L_{den}. The multicollinearity diagnostics and the data cleaning process eliminated predictors with Variance Inflation Factor (VIF) higher than 10 (Table 5.3), a commonly used cut-off value suggested by Myers (1990). It was found that the model in Sheffield explained 85.5% of the variance (R^2=.85, F(3,26)=51.2, p<.05) using three variables. Among them the Primary Roads Length (β=.52) was proved to have the highest impact on noise levels as expected, followed by Gardens ratio (β=-.24) and Local Road Intersections (β=.42). Accordingly, the regression model in Brighton accounted for 72% of the total variance (R^2=.72, F(3,29)=21.4, p<.05). Car Availability ratio (β=.20) was used instead of Gardens ratio since it had a stronger effect, proving that particular geodemographic metrics can also explain part of the variance. Local Road Intersections (β=.25) and Primary Roads Length (β=.48) were the other two variables contributing in the prediction models.

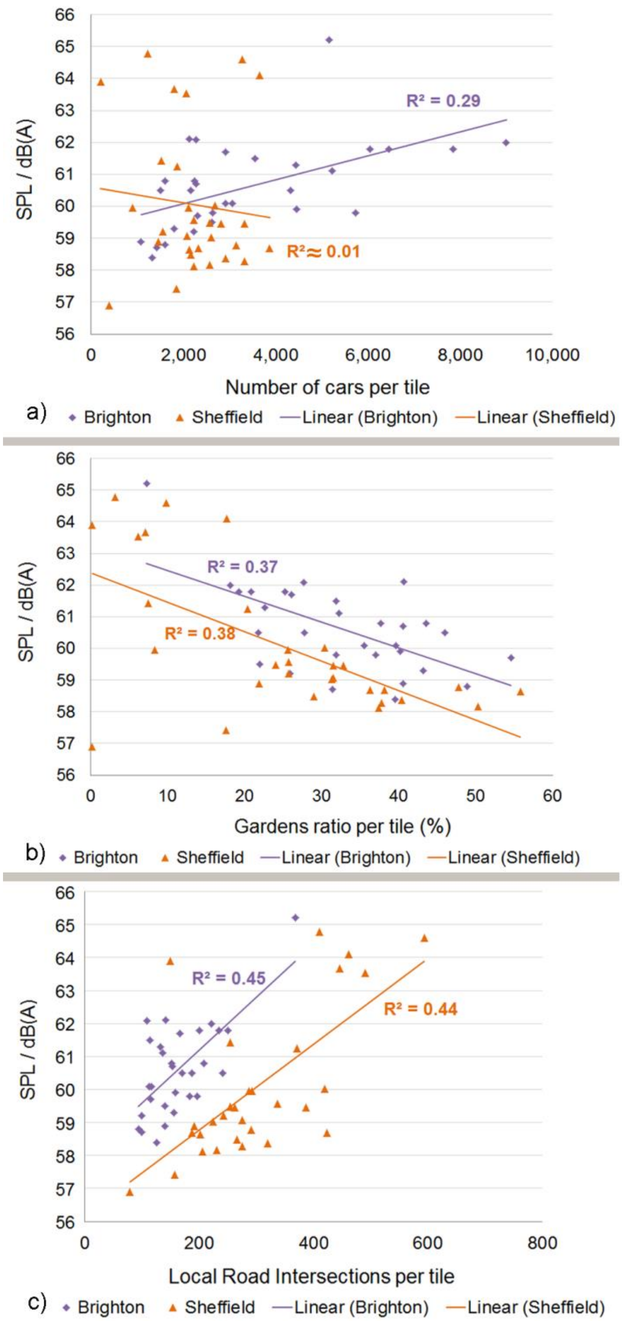

Fig.5.11. Linear trend of variables significant in the regression models for Sheffield and Brighton: a) Car Availability, b) Gardens ratio, c) Local Road intersections.

Fig.5.11 presents an individual assessment of the variables included in the regression models apart from the expected effect of Primary Roads Length. This variable reflects the main traffic volume in all cities and as a result it has the primary weight in noise levels. As it can be seen in Fig.5.11a Car Availability had an effect on noise levels only for Brighton (R^2=.29) denoting that it can be used as a prediction variable only in certain cases. According to Fig.5.11b the coefficient of determination for Gardens ratio was higher in Brighton (R^2=.37) than in Sheffield (R^2=.28). This trend can be partly explained by the local urban design, since Brighton has a higher amount of garden terraced houses. Consequently, areas with these housing characteristics are more probable to present lower noise levels in both settlement forms.

Despite the similar Road Coverage ratio in the class of local roads for both cities (74.4% and 77.6%); an increase in Local Road Intersections is very likely to lead to higher noise levels according to Fig.5.11c. However the settlement pattern of the city should also be considered. It is characteristic that the city of Sheffield - following a radial settlement - has on average lower noise levels with 8,832 intersections, while Brighton as a linear city has higher noise levels with 4,928 intersections in the same area. In terms of urban structure this fact denotes that the city of Brighton has also larger building blocks and reduced connectivity between the roads.

5.3.3. Micro-scale

5.3.3.1. Comparison among the city centres

The final level of analysis included eight city centres as presented in Fig.5.12. A Pearson correlation among the 18 variables (See Table 5.1) revealed that there was a significant positive correlation only with the Number of Buildings (r=.84, p<.01) as it is presented in Fig 5.13a. Consequently city centres with more buildings experience higher noise levels.

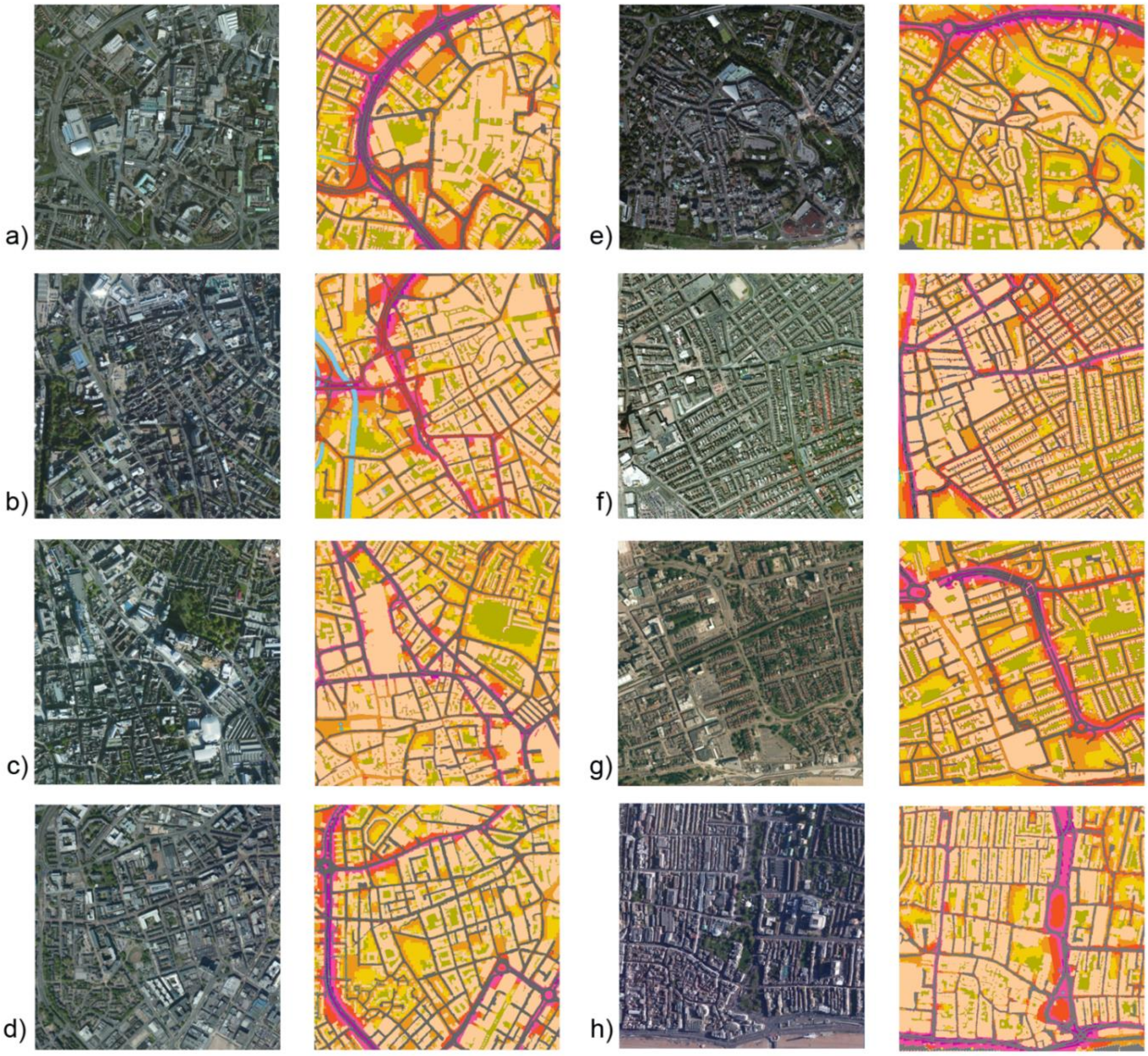

Fig.5.12. Radial city centres: a) Coventry, b) Leicester, c) Nottingham, d) Sheffield / Linear city centres: e) Bournemouth, f) Blackpool, g) Southend, h) Brighton.

The building coverage was also investigated as a complementary factor related to the Number of Buildings. However, Fig.5.13b proves that Building Coverage ratio itself is not enough in order to end up with a solid conclusion, since areas with similar index values can experience different noise levels.

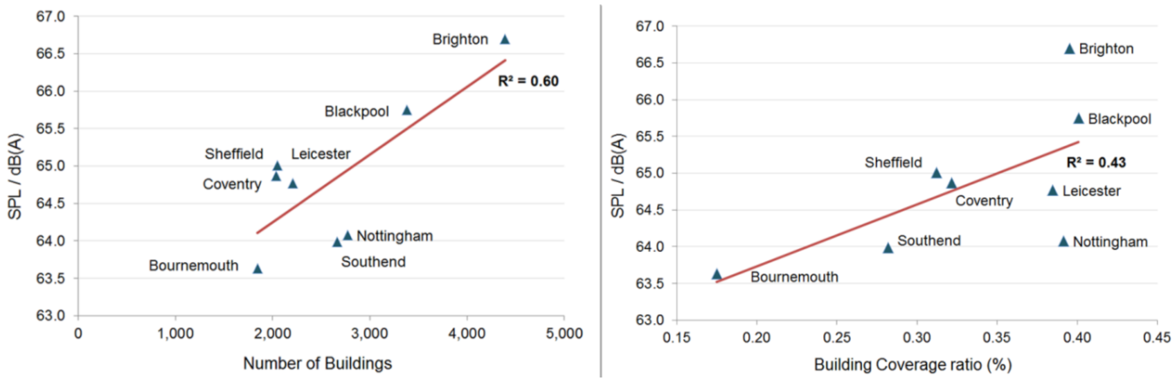

Fig.5.13. Linear association between noise levels and: a) Number of Buildings (R^2=.60, b) Building Coverage ratio (R^2=.43).

A k-means algorithm was then applied in order to identify pairs of cities with similar attributes based on the Number of Buildings, the Building Coverage ratio and the noise levels. Results according to the cluster membership in Table 5.4 proved that the first group includes the centres of Brighton, Blackpool, Leicester and Nottingham. These places appear to have similar values of Building Coverage ratio, but different noise levels (Fig.5.13b). Apparently, Brighton and Blackpool have the highest ranking both in Building Coverage ratio and in the Number of Buildings. From an architectural viewpoint, the Regency type in Brighton and the heavy Victorian influence in Blackpool have both affected to some extent these tendencies with the long building blocks and the dense terraced houses. Leicester and Nottingham have similar Building Coverage ratio thanks to the greater and more ponderous buildings. These centres are highly affected by the Baroque and Renaissance style with some Victorian influences as well.

Table 5.4. Cluster membership of the city centres according to the k-means algorithm.

Cities	Cluster	Distance
Brighton	1	2,514
Blackpool	1	7,872
Leicester	1	8,583
Nottingham	1	1,605
Southend	2	23,197
Sheffield	2	6,726
Coventry	2	16,471
Bournemouth	3	0

In the second group, city centres such as Southend, Sheffield and Coventry were clustered together. These city centres have significantly lower Building Coverage ratio and Number of Buildings while varying in population dynamic. All of them are influenced by the Victorian architecture and their centres especially in Sheffield and Coventry consist mainly of traditional semi-detached or terraced houses combined with post-war high-rise flats. Finally, the city centre of Bournemouth presented the lowest levels in all the previous indexes, forming a cluster itself. Due to the late rise in its population and enhanced by the fact that it has the greatest percentage of green space coverage among the other centres, it is currently the place with the lowest noise levels. Overall, it was clear that noise levels in the city centres do not seem to correspond to the population evolution or the car availability of these cities. On the contrary, they were more related to building attributes and the relevant architectural influences, which affected their current style.

5.4. Discussion: planning implications at different scales

Measurable metrics and quantitative statistical analysis were used to assess the relationship between green spaces in urban areas and other features of urban morphology with traffic noise distribution. For this purpose cities of different settlement forms were analysed in a triple-scale approach with different implications at each scale.

5.4.1. Implications in the macro-scale

In a macro-scale level, urban sound planning policies can be more targeted when considering the settlement profile of the city. The first evidence for both settlement forms is that scattered green spaces can possibly enhance noise attenuation not only due to their physical characteristics, but also due to the fact that they restrict high population densities and car usage (Moudon, 2009). However, the fact that linear cities have more probabilities to be "noisier" suggests that in such places noise mitigation measures may require a higher budget or more traffic calming interventions. By all means, the Green Space Pattern needs further validation in more cities of similar settlement form. The effort to classify various cities according to their settlement form does not set a rigid rule for the expected noise levels. In the current analysis evidence towards characterizing linear cities as "noisier" was given by their higher ratio of Road Coverage and Primary Roads Length. The average L_{den} levels and the Car Availability ratio also appear to be higher in this settlement type, despite the similar population in all cities.

5.4.2. Implications in the meso and micro-scale

Previous studies which investigated the connection between urban morphology and traffic noise have shown that a high number of street intersections is combined with fewer vehicle miles travelled (Knaap et al., 2005) and lower noise levels (Tang & Wang, 2007; Ariza-Villaverde et al., 2014). Results in Sheffield and Brighton give rise to opposite conclusions probably because of the different scale of analysis and the methodology for noise level calculation. The fact that Natural Urban Green ratio was not statistically significant in Brighton as in Sheffield does not underestimate the importance of this variable in urban sound planning (De Ridder et al., 2004), but is rather related to the methodology and the input data used. Possible solutions for active noise control should involve land use and transportation planning in parallel with traffic calming measures. So far noise abatement techniques involve the application of buffer zones and land use compatibility plans especially close to highways. This last measure is already a reality in many cities and these policies can save millions per year from noise barriers construction (Pinckney, 2005). Effective tools for urban planning strategies with simultaneous increase of green spaces were developed in the BUGS project (BUGS, 2001). Examples of effective land use control with simultaneous traffic calming effects can also be found in the "garden city movement" (Howard, 1902). UK cities such as Milton Keynes, Glenrothes and Telford following this pattern combine a single-use zoning plan emphasizing on green space distribution and sinuous roads configuration.

The relationship between the ANN index and green patches suggests that green spaces are likely to become more accessible in a dispersed pattern. However, this configuration does not always end up in lower noise levels (Ståhle, 2010). On the other hand every revitalization plan should also focus on its gentrification effects when property values rise to such an extent that local residents are led to displacement (Wolch et al., 2014). Low levels of traffic noise were also observed in areas with terraced houses of small perimeter accompanied by a backyard or front yard. Consequently this housing pattern presents high noise effectiveness in residential areas.

In the micro-scale level, results proved that the same building density achieved with different number of buildings can infer diverse traffic noise effects. Specifically, more buildings are related to higher noise levels, in spite of the fact that there is evidence for the opposite in particular cities (Salomons & Berghauser Pont, 2012). Planning strategies in the city centres should be more oriented towards traffic and soundscape interventions, since the built environment is highly unchangeable. In this process the applied trends in domestic architecture for noise mitigation should also be considered.

5.4.3. Implications in all scales

The common variables identified in these scales can be summarized in street characteristics (connectivity, hierarchy), land use and geodemographic attributes. There is also an indication that the Green Space Pattern can possibly affect noise levels in conjunction with the above parameters. The absence of correlation in Natural Urban Green ratio or Gardens ratio on the macro-scale suggests that some variables might be scale or grid-dependent, consequently their significance has to be cross-validated in different scales. Overall, since traffic noise attenuation is a multi-disciplinary issue, morphological and geodemographic parameters should be considered in accordance with traffic calming measures. Complementary actions involving masking of the traffic with natural sounds such as bird songs (Strohbach et al., 2009; Hao et al., 2015b) are also useful.

5.4.4. Restrictions and future investigation

In the overall process, restrictions such as the aggregation effect caused by the grid size should be taken into account in future investigation. In spite of the 5 dB(A) range in each noise band, the accuracy is not critically affected within an urban scale analysis. A possible decrease of this error can be tested by applying a raster-based approach in GIS or by decreasing the grid size. A further validation of the current results in other cities of similar settlement type can make the findings more coherent and drive to a paradigm shift as regards the optimization of noise levels according to different criteria.

5.5. Conclusions

The purpose of this study was to investigate the relationship between traffic noise distribution and urban morphology in eight UK cities of different settlement forms. Land use parameters emphasizing on green spaces - combined with buildings, roads and demographic attributes - were quantified using GIS and statistical analysis tools in a triple level approach. In a first macro-scale level, four cities of radial settlement form were compared with four cities of linear form. In the second meso-scale level, a more thorough investigation of the same parameters was conducted between two cities from the above categories. In the final micro-scale level the analysis was focused only on the eight city centres. The historical and architectural background of the cities was also taken into consideration. Conclusions can be summarized as follows:

- The *macro-scale analysis* shows that radial and linear cities are usually liable to a different Green Space Pattern. The distribution of Natural Urban Green spaces can be a possible reason affecting noise levels throughout the cities. In particular, a dispersed Green Space Pattern combined with the proper road and building attributes - under similar traffic conditions - is positive evidence for lower noise levels, in contrast with a clustered one. Secondly, higher internal network connectivity caused by an increase in the Local Roads Length ratio, is also connected to higher traffic noise levels, since more connections are created along the network. The range of these variables is different when comparing cities of different settlement form.

The radial cities in this investigation were associated with a significantly higher Natural Urban Green Ratio than linear cities, allowing for a generalization of this conclusion also to other urban areas with similar settlement forms in UK. Moreover, the majority of radial cities follows a dispersed green pattern, while the majority of linear cities follows a clustered one. The previous two conclusions and the fact that dispersed patterns were related to lower noise levels in these settlements leads to the indirect inference that radial cities are more likely to be "quieter" than linear cities under similar traffic and demographic conditions.

• In the *meso-scale analysis* it was shown that in Sheffield an increase in Building Perimeter, the Local Road Intersections or the Primary Roads Length can infer a rise in traffic noise levels. On the contrary, land use variables such as Gardens ratio or Natural Urban Green ratio were proved to be negatively related to traffic noise. From the above parameters Local Road Intersections and Primary Roads Length were proved significant also in Brighton followed by Car Availability ratio. Ultimately, the prediction models for traffic noise managed to explain successfully more than 70% of the variance in both cities proving that traffic noise prediction for urban areas can be based to a great extent on common morphological variables.

• In the *micro-scale level*, only the Number of Buildings was proved correlated to noise levels. The Building Coverage ratio was investigated as a complementary variable. Three classification groups were formed according to the historical and architectural background of each city centre. Places in the first group (Brighton, Blackpool, Leicester Nottingham) were typical of similar Building Coverage either affected by Regency and heavy Victorian influences or by Baroque and Renaissance style. The three places in the second group (Southend, Sheffield, Coventry) were typical of lower Building Coverage and noise levels characterized by post war and modern architecture. Finally, the city centre of Bournemouth with the most recent history and the lowest noise levels was classified alone with a significant distance from the other groups.

Generally, it was revealed that in order to reduce traffic noise levels, based on the case studies in typical UK cities it is essential to take into consideration different parameters of urban morphology. Demographic variables can also provide evidence of the expected noise levels; however they are not always reliable. Finally, the stability of the prediction models can be tested among different UK cities using the same input parameters.

Chapter 6

Park level

The content of this chapter has been accepted for publication in a peer-reviewed journal as:

Margaritis E., Kang J., Filipan K., Botteldooren D. *"The influence of vegetation and traffic-related parameters on the sound environment in urban parks".* Landscape and Urban Planning

6. The influence of vegetation and traffic-related parameters on the sound environment in urban parks

Following the analysis from the city level as discussed in Chapter 5, this Chapter moves on to a smaller scale, in an attempt to investigate the sound environment within the most common green space features that dominate in the urban environment, parks. In this case, vegetation within them is quantified in relation to the existence of areas covered with trees or grass. A review is presented in Section 6.1 concerning the development of dynamic noise mapping, the importance of vegetation in noise mitigation and the environmental quality of urban parks. Section 6.2 describes the general characteristics of the investigated parks coupled with the green space and noise data derivation. Section 6.3 includes the results in park and point scale, the cluster analysis in the parks and the comparison between tree and grass areas. The discussion part has been incorporated in this section as well. Final conclusions are presented in Section 6.4.

6.1. Previous studies and research questions

Traffic noise has been closely related to health issues (Bodin et al., 2009; Fyhri & Klæboe, 2009; Pirrera et al., 2010; Selander et al., 2009). In particular, according to the review report from the Environmental Burden of Disease (EBD) (Hänninen et al., 2014) noise was ranked second among the selected environmental stressors evaluated in terms of their public health impact in six European countries.

The Environmental Noise Directive (END) (2002/49/EC) - through the Noise Action Plans - has made an attempt to quantify the percentage of people living within critical areas of high noise levels. However, the noise levels reported in the END are based on the results of traditional noise mapping methods based on simulations of annual average traffic data and refer to a strategic level. Moreover, in practice, measurement campaigns found significant deviations between measured and calculated acoustical indicators (De Coensel et al., 2015), especially in shielded zones or quiet areas (Wei et al., 2016).

At the same time the technological boost in acoustic measurement devices has made the acquisition of real-time noise data much easier either through mobile phones (D'Hondt et al., 2013; Guillaume et al., 2016; Maisonneuve et al., 2009; Murphy & King, 2016; Rana et al., 2015) or through the use of portable devices (Can & Gauvreau, 2015; Filipan et al., 2014). These methods can be used in the production of the so-called "dynamic noise maps" with various models being proposed (Can et al., 2010; Cho et al., 2007; De Coensel et al., 2005; Gereb, 2013; Ma & Cai, 2013; Szczodrak et al., 2013; Wei et al., 2016;). The increased accuracy of dynamic noise mapping in shielded or quiet areas makes this method more appropriate in noise level calculation within green areas and parks, the importance of which has also been highlighted in the "*Good Practise Guide on Quiet Areas*" (EEA Techical Report, 2014) and other studies (De Ridder et al., 2004; Gidlöf-Gunnarsson & Öhrström, 2007).

From the noise perspective, previous studies pointed out the importance of vegetation on traffic noise mitigation through the use of trees, tree belts, plants or hedges (Aylor, 1972; Fang & Ling, 2005; Fricke, 1984; Huddart, 1990; Jang et al., 2015; Kragh, 1981; Onder & Kocbeker, 2012; Van Renterghem et al.,2012; Van Renterghem et al., 2015; Yang et al., 2011). The above references provide general guidelines or refer to the specific experimental conditions.

On a broader scale, the latest studies assessing noise level distribution have applied regression models using morphological and land use parameters (Aguilera et al., 2015; Margaritis & Kang, 2017; Ryu et al., 2017). The same regression-based approach has also been applied in soundscape mapping with physical, acoustic and perceptual data using different interpolation techniques (Hong & Jeon, 2017). Complementary to these tools, clustering techniques are also important in the identification of "cold" and "hot" spots in large noise datasets. Such tools are provided in ArcGIS (v.10.3.1) and belong in the category of local spatial pattern analysis tools (Hot Spot Analysis-Getis-Ord Gi*, Local Moran's I). In this study we used the Hot Spot Analysis tool, since we were not interested in the identification of statistically significant spatial outliers (Local Moran's I) in the study areas.

Especially for noise distribution in parks, most of the studies deal with a combination of measured noise levels (Zannin et al., 2006) and perceptual parameters based on users' experience (Aletta et al., 2015; Brambilla & Maffei, 2006; Filipan et al., 2014; Liu et al., 2014a; Nilsson & Berglund, 2006; Szeremeta & Zannin, 2009). In particular, Brambilla et al., (2013) found that non acoustical parameters, such as vegetation and natural sounds improve the soundscape quality of parks, even when these sites exceed the objective acoustic threshold of "quiet" areas (50 dBA). A similar study in Milan by Brambilla, Gallo, & Zambon, (2013) revealed that "soundscape quality" prevailed over "quietness", confirming that the latter parameter is just one aspect of soundscape appraisal. These examples led Brambilla & Gallo, (2016) to develop a new index for assessing the environmental quality of urban parks using the perceived overall quality and objective noise indices. Finally, interesting studies on the same topic used active soundscape interventions in order to mask the unwanted sounds from traffic in parks (Kang et al., 2013; Schulte-Fortkamp & Jordan, 2016).

However, very few studies have tried to describe the perception of tranquillity in green areas based exclusively on physical parameters related to green space features. For example, González-Oreja et al., (2010) used the park size and the tree canopy as predictors for noise levels, while Pheasant et al., (2010) introduced the "Tranquillity Rating Prediction Tool" (TRAPT), which predicts perceptual tranquillity based on the sound pressure levels and the ratio of natural features in the scene. Although this tool has been validated, it is designed to assess specific sceneries within a restricted visual depth. Nevertheless, the assessment of tranquillity and noise distribution when investigating parks as entities needs to be broader, considering also the urban morphology of the surrounding environment.

Hence, the aim of this Chapter is to investigate the influence of vegetation and traffic-related parameters on the sound environment in urban parks based on physical data. This aim is achieved through the following objectives: (1) investigation of noise level distribution in the park scale caused exclusively by the surrounding traffic, (2) investigation of noise level distribution in point scale according to the recorded noise levels inside the parks, (3) identification of possible clusters in the noise measurements based on the inside-outside relationship and (4) identification of possible correlations between the green space attributes of the parks and other morphological parameters.

6.2. Methods

6.2.1. Case study sites

The data presented in this study were collected in eight urban parks in Antwerp, Belgium. Antwerp is the largest city in Flanders and the second largest city in Belgium. A big part of the city's economy is a major European harbour, which has its incoming and outgoing traffic routes along the city. Additionally, Antwerp's ring road is integrated in the Trans-European Traffic Network (TENtec) as shown in Fig.6.1. Therefore, traffic creates substantial noise problems for the surrounding urban areas.

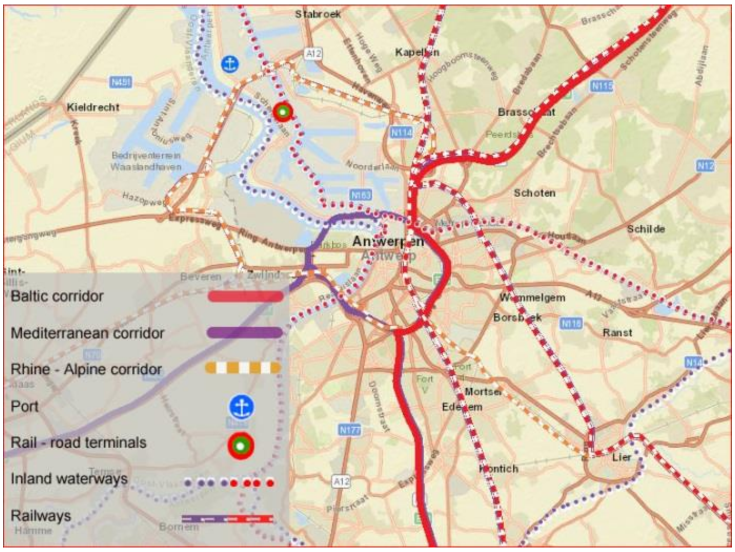

Fig.6.1. Infrastructure network in Antwerp, Belgium (source: European Commission, 2016) *http://ec.europa.eu/transport/infrastructure/tentec/tentec-portal/map/maps.html,*

All data were collected in cooperation with the Environmental Authority of Antwerp's City Council. The investigated parks shown in Fig.6.2 spread over the whole city and are accessible to a large number of people. Additionally, they present significant variations in the distance from the ring road, as well as the variability in size and green space coverage, which renders them representative for the whole study area. In particular, Bischoppenhof, which is the smallest one, has an area of 3ha, while Rivierenhof - the largest one - measures 129ha. The rest of them cover an average area of 14ha. Finally, four of the parks (Rivierenhof, Den Brandt, Nachtegalenpark, Domein Hertoghe) are located relatively close to the ring road within a distance between 6m and 320m, while the rest (Sorghvliedt, Te Boelaerpark, Stadspark, Bisschoppenhof) are relatively far with ranges from 830m to 3,800m.

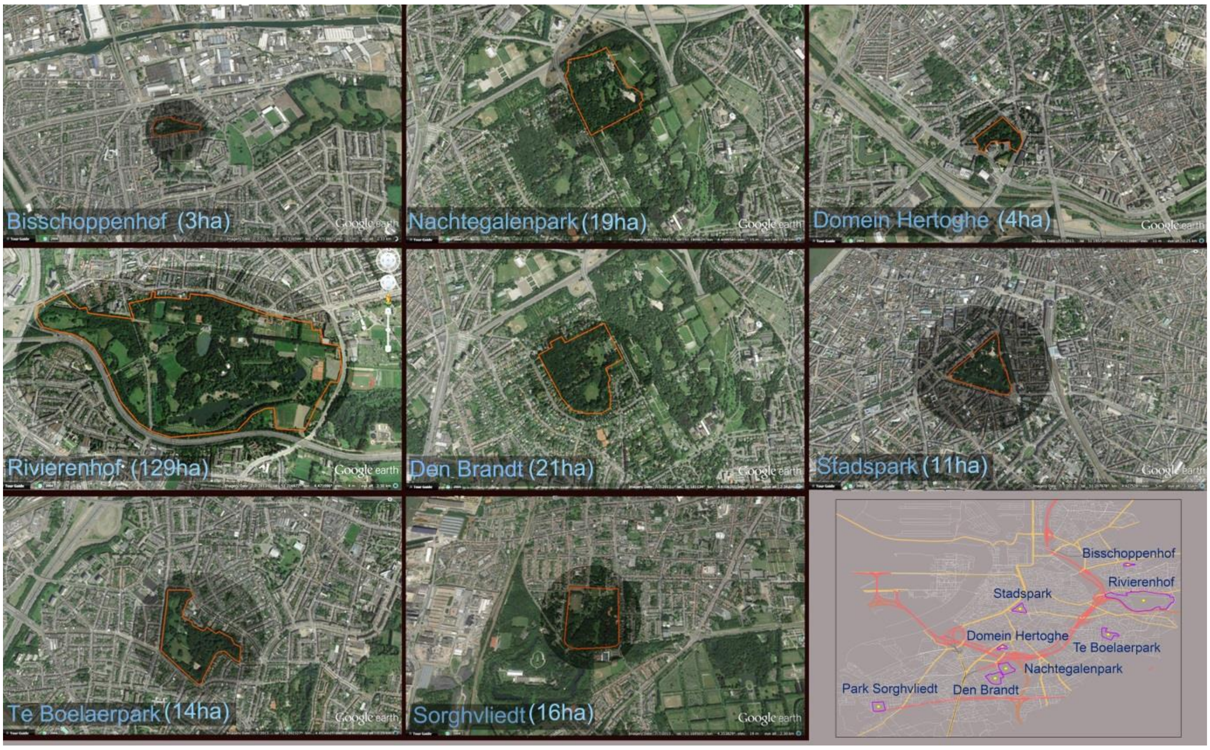

Fig.6.2. Aerial images of the eight investigated parks in Antwerp, Belgium, from an altitude of 2km above ground. The size of the parks is listed next to their names. In bottom right map, the spatial distribution of the eight parks relatively to the city's road network.

6.2.2. Green space and morphological data

The green space data for this study were selected from tree and grass coverage identified from the World Imagery basemap available by ESRI. This layer provides an imagery resolution of "0.3m" regarding Western Europe and at least "1m" in many parts of the world (ESRI, 2016d). The green space characteristics were recognised for each park using the ArcGIS software (v. 10.3.1) and the Maximum Likelihood Classification tool (ESRI, 2016e).

At first, all park images were imported in Photoshop, where particular filters were applied to eliminate the unwanted tree shadows and facilitate the classification process. All images were then georeferenced in accordance with the park borders. In the next step, the green space classes were distinguished along with the results of the classification process, which involved the collection of training samples for each category. The final recognized classes were formed as follows: "trees", "grass" and "other" all built in a raster of 30cm x 30cm in order to comply with the basemap resolution. In the final step, the new dataset was converted from a raster to a vector format, which allowed the calculation of additional parameters. An example of the classification process can be seen in Figs.6.3a, 6.3b, while the green space coverage for each class per park can be seen in Fig.3c.

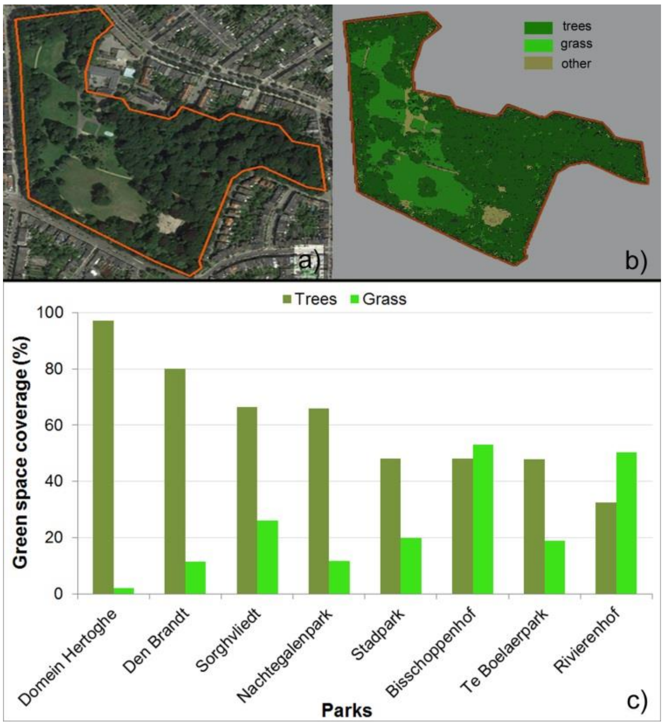

Fig.6.3. a) Initial satellite image from Imagery basemap (ESRI) for Te Boelaerpark, b) Corresponding results after the Maximum Likelihood classification, c) Green space coverage (ratio) for trees and grass in all parks.

6.2.3. Green space and morphological indicators

The indicators presented in Table 6.1 refer to vegetation-related and morphological variables relevant to the parks themselves or their surrounding environment. The first three indicators refer exclusively to park features, namely: park size (*CA*), tree coverage (*Tree_COV*) and grass coverage (*Grass_COV*). The road (*RCOV_100*) and building coverage (*BCOV_100*) within a buffer zone of 100m around the borders of the parks were also calculated. In particular, all buildings whose centroids satisfied the 100-meter buffer criterion were selected. Road surfaces were digitized in Google Earth, since the road width is easily recognisable.

The distance of 100m was selected as the zone that can directly influence the sound environment of the parks. Other indicators used to describe the surrounding sound environment of the parks were: mean distance from major roads (*Mean_dist_major*) and maximum simulated traffic volume in the adjacent streets of each park (*Max_veh*). Particularly, "*Mean_dist_major"* was calculated by averaging the distances (*d1, d2, d3, d4*) from all four sides of each park (Eastern, Western, Northern, Southern). However, roads had to be classified in one of the following categories: motorway, ring road or national road, as presented in Fig.6.4. Finally, "*Max_veh"* was retrieved from the traffic count database based on the simulated results for the entire network of Flanders (Hoornaert, 2015).

Table 6.1. Vegetation and morphological indicators measured inside and around the parks

Variable	Symbol	Comment
	Vegetation-related indicators	
Park size	*CA*	Total area in hectares.
Tree coverage	*Tree_COV*	Ratio of tree coverage.
Grass coverage	*Grass_COV*	Ratio of grass coverage.
	Morphological indicators	
Road coverage (100m)	*RCOV_100*	Road coverage (m^2) measured in a buffer zone of 100m around the park borders.
Building coverage (100m)	*BCOV_100*	Building coverage (m^2) measured in a buffer zone of 100m around the park borders.
Mean distance from major roads	*Mean_dist_major*	The average Euclidian distance from all sides of the park to the closest major road.
Maximum traffic volume	*Max_veh*	The maximum simulated traffic volume (veh/h) in all the streets adjacent to the park.

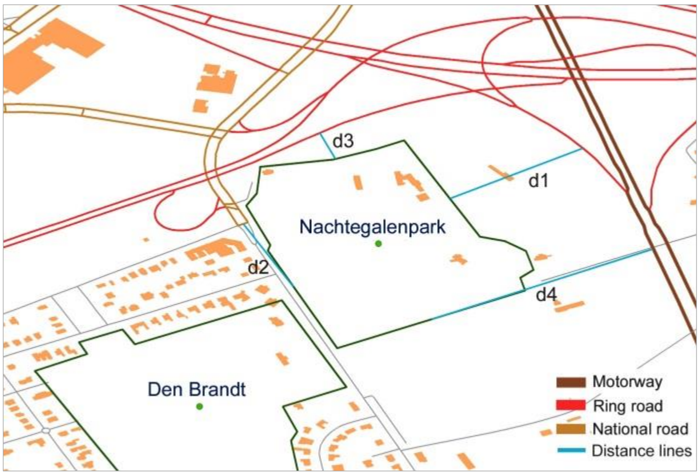

Fig.6.4. Example of the road categories around the Nachtegalenpark and the calculated distances from the centre of each side (*d1*, *d2*, *d3*, *d4*).

6.2.4. Noise levels data

6.2.4.1. Noise mapping

Noise levels were both simulated and measured. In the first case, the impact of the roads surrounding the parks was simulated using CadnaA sound propagation software (v. 4.5). The UK Calculation of Road Traffic Noise (Department of Transport, Welsh Office, 1988) and ISO 9613-2:1996 were used to select the parameters of traffic characteristics and outdoor sound propagation respectively. Traffic data were based on origin-destination matrices built upon automatic and manual traffic counts simulated for the entire road network of Flanders. The final data refers to the number of vehicles per hour (veh/h) for day, evening and night over every road segment of Antwerp's network, during *weekdays* (Hoornaert, 2015).

In the simulation, the surrounding environment of the parks was considered as totally reflective with a zero Ground Factor (G_{out}=0), while for the surface area inside the parks four different cases were tested as a sensitivity analysis. In the first case, the Ground Factor (G_{in}) was kept constant (G_{in}=1) and noise levels were calculated - with and without the effect of terrain - using elevation data. In the second case, noise levels were calculated with and without elevation with G_{in}=0.5 for grass areas and G_{in}=1 for areas covered with trees. *Results showed that the distinction of* *ground absorption between areas of trees and grass had an additional effect between 0.3 and 1.1 dB(A), while the presence of terrain had an effect between 5 and 6.2 dB(A).* Furthermore, Google Earth Street View was used, to check for possible wall barriers around the parks. Finally, receivers in CadnaA were placed every five meters at a height of two meters above the ground, since the aim was to capture the noise variation close to the human scale and not in the building facades.

6.2.4.2. Noise measurements

In the second case, a novel approach using portable devices was applied to capture the sound variability in the parks. Two or three participants - depending on the size of the park - used mobile recording devices carried in backpacks. The walks were made with a common starting point on the existing paths within the parks, while no specific directional guidelines were given in order to provide the participants with the freedom to move arbitrarily. All of them were specifically advised to mind their way of walking in order not to intervene in the recorded sonic environment. Additionally, they were asked to make stationary recordings with 10-minute stops every half an hour by placing the backpack on the bench. Finally, to measure the surrounding sound environment, recordings were also performed by walking along the closest roads outside the parks (Fig.6.5). All noise measurements were accomplished during August and September 2013 between 11:00am and 19:00pm.

The measurement devices were custom-made Linux-based sensor network nodes created to incorporate both sound and location recordings. Therefore, the collected data comprised 1/3-octave band levels saved eight times per second, as well as the GPS positions recorded per second.

To ease the data processing and presentation, spectral levels and GPS data were transferred to the spatial database. Finally, the total amount of points per park during one day varied between 2,800 and 3,800 depending on the park size. For the current analysis, all recordings for a single day within the borders of a park were taken into consideration by accumulating all the measurements points from the corresponding backpack devices.

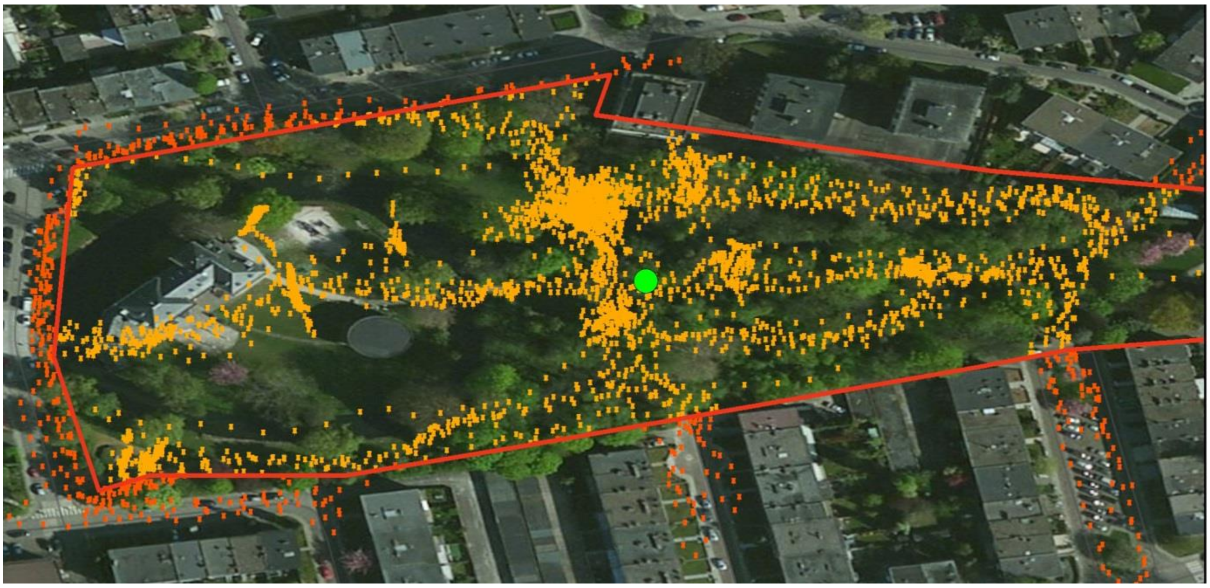

Fig.6.5. Measurement points distribution inside and outside Bischoppenhof park using an Imagery basemap background.

In the final stage, all measurement points were intersected with the two green space classes (*Tree_COV*, *Grass_COV*). Most of the paths in the parks were not recognizable in the image classification; however the points intersected with the main ones were classified to the closest green space class. Water features were not taken into consideration, as they were present only in three parks. On average 2,056 points were attributed in the tree coverage class and 513 in the grass coverage per park.

6.2.5. Noise indicators

The noise level indicators were divided into two categories as displayed in Table 6.2; simulation-based and measurement-based. The first category includes indicators that describe the entire sound environment according to the simulated traffic conditions around them. The second one encompasses widely adopted indicators (Hao et al., 2015a; Wang & Kang, 2011) referring in detail to the noise levels recorded with the portable devices in each park. The indicators were calculated for each 10-second time step by accounting for the 1/3-octave band spectrum values within a moving time window of one minute. Finally, location data (GPS positions) was included and related to the acoustic indicators by interpolating the dataset to the same 10-second division period.

Table 6.2. Description of all the noise indicators applied in the analysis.

Variable	Category	Comment
		Simulation-based indicators
L_d	min, max, avg	Day noise levels based on traffic flows calculated in CadnaA and Matlab.
		Measurement-based indicators
L_{A10}	min, max, avg	A-weighted sound pressure level exceeded 10% of the measurement period.
L_{A50}	min, max, avg	A-weighted sound pressure level exceeded 50% of the measurement period.
L_{A90}	min, max, avg	A-weighted sound pressure level exceeded 90% of the measurement period (background noise).
L_{Aeq}	min, max, avg	A-weighted equivalent sound pressure level.

In the first category, one indicator refers to the minimum and maximum levels of L_d using the noise mapping results, while the other calculates the average value of $L_{d(avg)}$ per park using a Matlab code. The reference area for this calculation is the area only within the park borders. The code was set to recognize the colour range for each noise band and transform the RGB (Red-Green-Blue) values in noise levels. Noise levels were simulated based on a grid of 5x5 m in order to capture also small noise variations in the study areas.

On the contrary, the second category uses detailed percentiles weighted sound levels (Table 6.2). It consists of the following indicators: L_{A10}, L_{A50}, L_{A90}, *and* L_{Aeq}. All of them were initially calculated from the stored measurement data and extracted on the same selected time steps by taking the 1/3-octave band values of one-minute duration.

In order to guarantee a representative sampling strategy in the measurement data, a grid-based approach was also applied. The aim of this approach was to aggregate the measurement values within the same grid so as to avoid any possible bias from the fact that smaller parks are expected to have more sampling points within the same sampling period. The applied grid was 20x20 m covering the maximum possible width of a single path among the eight parks. The grid size in this case was defined based on specific criteria relevant to the area size of the parks and the paths width. As a result, it had to be bigger than the one of 5x5 m applied in the simulated noise levels. An identical grid size for both cases would end up in significant increase in calculation time without improving the accuracy of the final results. Furthermore, it would cause unclassified points in the case where all points would have to be attributed to a single vegetation-related class.

In both cases the percentile indicators were used to get the dynamic characteristics of the sonic environment: L_{A50} illustrates the average, L_{A90} the background noise and L_{A10} the highest values or peaks. Finally, A-weighted equivalent levels (L_{Aeq}) were used due to their overall relationship with the human hearing characteristics.

6.2.6. Noise clusters identification

An additional indicator was extracted to identify possible spatial relationships of the noise levels exhibited inside the parks. The calculation of this indicator was performed in two steps. At first, the “Hot Spot Analysis” tool was used to calculate the Getis-Ord (Gi) index (ESRI, 2016f) for each feature in the dataset. The subsequent *z*-scores and *p*-values provided information on whether there are spatial clusters between points of low or high noise levels. The tool works by examining each point within the context of neighbouring points. A point with a high value can only be considered statistically significant ($p \geq .90$) when surrounded by other points with high values as well. The tool was set to run under the “inverse distance” option; where nearby neighbouring features have a larger influence on the computation than features that are far away. The threshold distance was calculated by the system each time in order to ensure that each point has at least one neighbour. No weighted matrix was applied, since the main aim of this tool was to represent the “raw” clustering pattern for each park. The Gi ranges between -3 for “cold” clusters of low noise levels and +3 for “hot” clusters of high noise levels.

In the second step, the spatial distribution of the points was measured, since the aim was to detect to what extent the difference in sound sources inside and outside the parks can have an effect on the recorded noise levels. For this analysis, only points of marginal values were used (Gi=-3, Gi=+3, p<.01), since they represent the most significant clusters. For simplification reasons, the possible exhibited clusters were divided into three categories: “introverted”, “extroverted” and “random”, with an example of the first two to be given in Fig. 6.6. An “extroverted” cluster (Fig.6.6a) denotes a positive correlation between the distance of each measurement point from the park centroid and the respective noise levels. Practically, this means that higher noise levels have been identified on the borders of the park and there is a decreasing tendency as somebody moves towards the park centroid. On the other hand, an “introverted” pattern (Fig.6.6b) presents a negative correlation with higher noise levels close to the centroid and a decreasing tendency as somebody moves towards the borders. It should also be made clear that the algorithm can also recognise the cluster of points created by the stationary recordings; however the number of points in this category is small and does not affect the overall correlations.

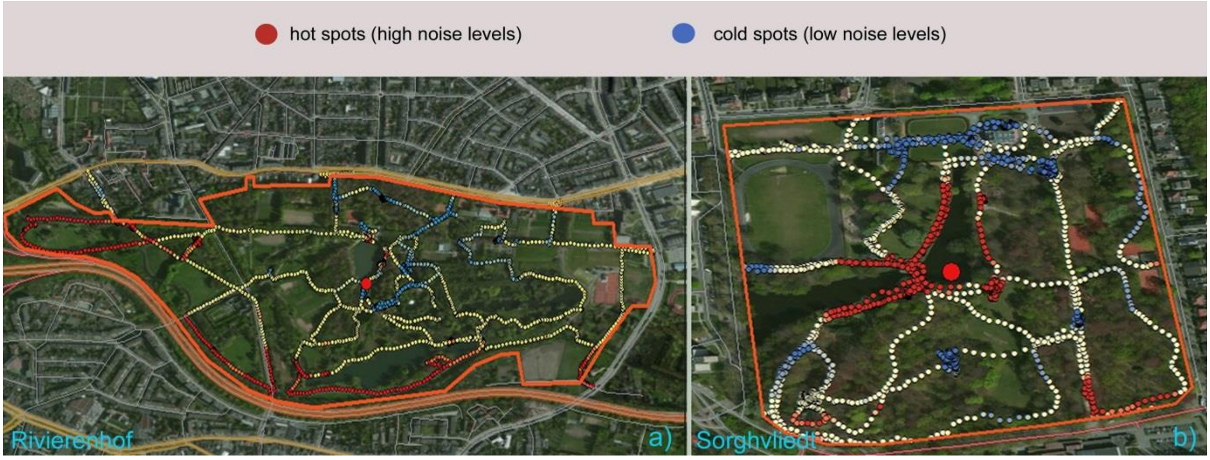

Fig.6.6. Noise clusters identification: a) "extroverted" and b) "introverted" noise clusters in Rivierenhof and Sorghvliedt respectively with the distribution of hot and cold spots.

6.3. Results

6.3.1. Noise distribution at parks scale

In this section, the sound environment inside the parks is assessed based on the traffic noise distribution of the surrounding sound environment. This step is needed in order to have a smooth transition from general to detailed analysis and explore the parameters with a possible contribution to the sound environment. The results from traffic simulation in CadnaA presented in Fig.6.7 show that there is a diverse noise environment inside and outside the parks, with traffic conditions playing a significant role. Each park presents its own particularities, however specific conclusions can be drawn as follow.

In particular, noise levels inside the parks as presented in Fig.6.8 varied between 43 and 78 dB(A) in terms of $L_{d(min)}$ and $L_{d(max)}$, while the range for $L_{d(avg)}$ was restricted between 48.2 and 65 dB(A) as shown in Table 6.3. Based on these noise levels, Te Boelaerpark was found to be the quietest park, while Rivierenhof the noisiest. Also the noise range presented a great variability among the case study areas ranging between 14 dB(A) in Bisschoppenhof and 23 dB(A) in Te Boelaerpark.

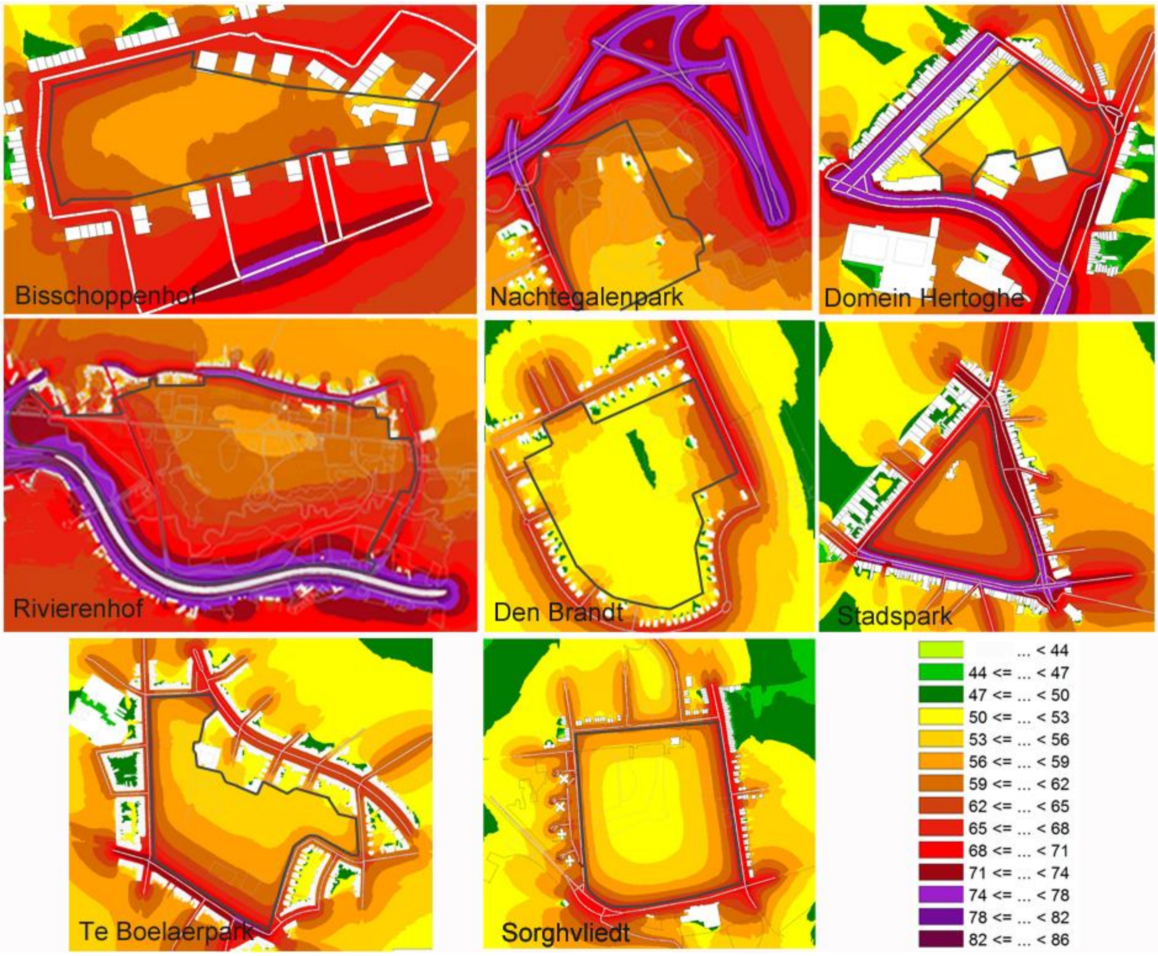

Fig.6.7. Noise level distribution in the parks and their direct vicinity simulated in CadnaA software based on average traffic volume data from Monday to Friday, (Vlaams verkeerscentrum, 2015).

Once the parks were sorted in an ascending form for $L_{d(avg)}$ (Fig.6.8), two groups were distinguished. The first one involved the first four parks, which presented low noise levels combined with high noise range. The common characteristic among them is that three out of four (Den Brandt, Sorghvliedt and Te Boelaerpark) are located far from the ring road or any other national road by at least 256 m.

The effect of location on noise levels for these three parks was also depicted in the structure of the box plots (Fig.6.8), where the minimum noise levels were equal to the 1st quartile (Q1). Practically this suggests that noise variability in these places was very low with high noise levels to appear locally, probably due to the increased traffic volume in one of the surrounding local roads. This contradiction was mostly evident from the outlier points shown over the whiskers of the box plots in park Den Brandt and Domein Hertoghe. The last one can be considered as an exception in this ranking, since it is adjacent both to the ring road and the national road, however simulated noise levels inside this park were relatively low.

The second group of parks (Bisschoppenhof, Nachtegalenpark, Rivierenhof and Stadspark) was found to be the noisiest from the traffic perspective with few outliers and a smaller noise range. In all cases, their borders were very close either to the ring road or any other road belonging to the national network. Finally, for all parks the standard deviation (SD) ranged between 2.8 and 5.4 dB(A).

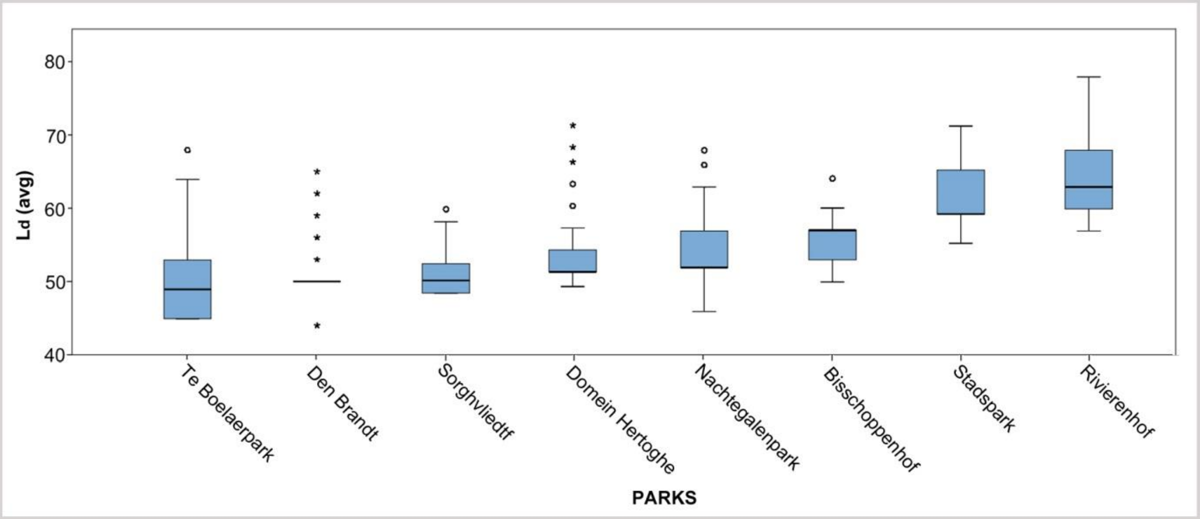

Fig.6.8. Box and whisker plots representing the simulated noise levels within the borders of the eight parks sorted in an ascending form for $L_{d(avg)}$.

Table 6.3. Average simulated and measured noise levels in the eight parks sorted in an ascending form for $L_{d(avg)}$. Standard deviation values are presented in parenthesis in each case. Measured values have been calculated by averaging the point levels inside the parks over the entire measurement period (11:00am - 19:00pm).

Parks	**Simulated**	**Measured**		
	$L_{d(avg)}$	$L_{A10(avg)}$	$L_{A90(avg)}$	$L_{Aeq(avg)}$
Te Boelaerpark	48.2 (±5.4)	56.7 (±4.8)	51.2 (±2.9)	54.92 (±4.6)
Den Brandt	51.1 (±2.8)	51.0 (±5.3)	45.7 (±2.3)	49.21 (±4.6)
Sorghvliedt	51.3 (±4.6)	55.6 (±5.2)	49.2 (±3.5)	53.67 (±5.2)
Domein Hertoghe	53.7 (±4.3)	54.9 (±5.4)	49.4 (±2.7)	53.02 (±5.0)
Nachtegalenpark	55.0 (±4.0)	56.2 (±5.2)	50.3 (±3.4)	54.37 (±5.2)
Bisschoppenhof	56.0 (±2.8)	54.6 (±5.0)	48.8 (±3.6)	53.04 (±5.4)
Stadspark	60.7 (±4.2)	59.6 (±4.6)	52.8 (±2.9)	57.44 (±4.4)
Rivierenhof	65.0 (±5.0)	58.2 (±6.0)	54.6 (±5.2)	56.73 (±5.7)

6.3.2. Noise distribution at point scale

Contrary to the simulated results that investigated the influence of traffic noise from the adjacent roads, measurement noise levels refer to the indicators extracted from the data recorded in each park. For this analysis, L_{A10} and L_{A90} were used to represent the marginal cases of peaks and background noise respectively. Therefore, Figs 6.9a, 6.9b represent the frequency of occurrence of noise levels between 40 and 75 dB(A) for each of the two indicators (99% of measurement points). The same analysis using the grid approach presented in Figs 6.9c, 6.9d showed that although the curves were quite different, noise levels were similar in average values with the initial frequency approach and only differ by 0.1 to 2 dB(A) for both indicators.

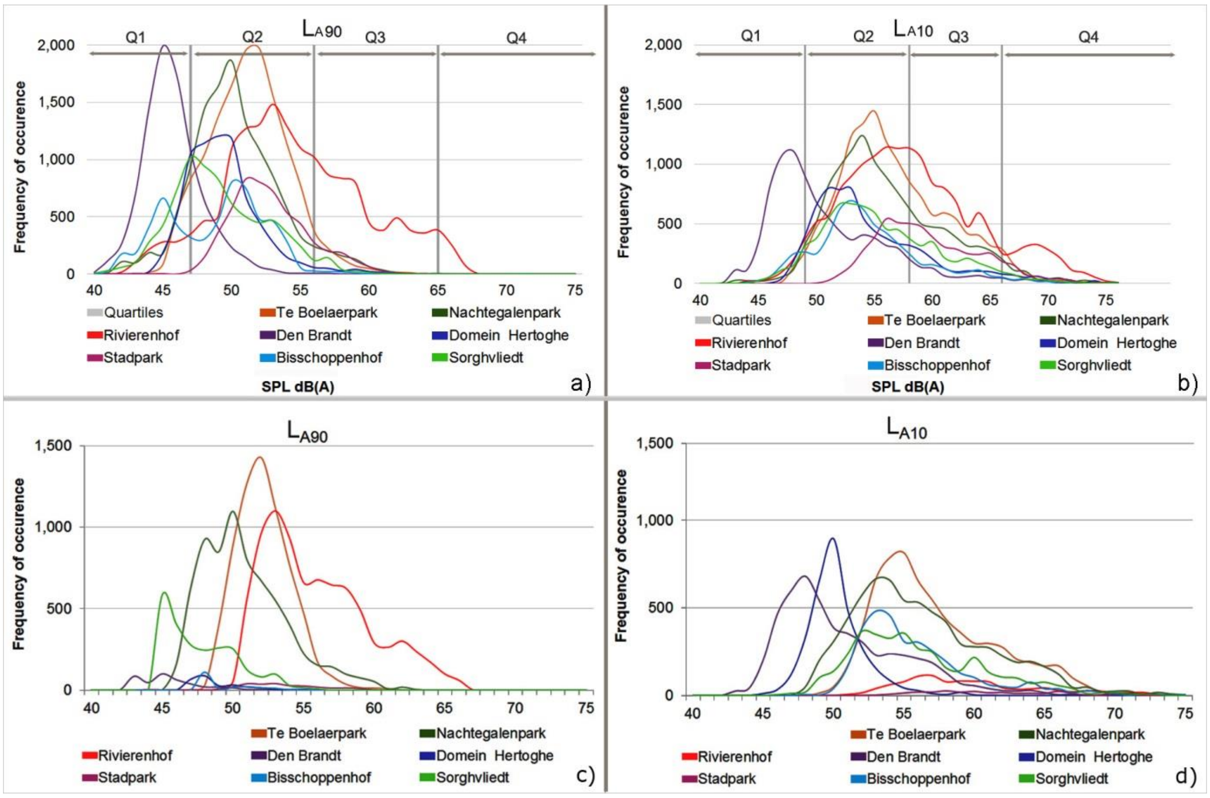

Fig.6.9. (a,b) Frequency of occurrence for L_{A90} and L_{A10} based on values per measurement point, (c,d) Frequency of occurrence for L_{A90} and L_{A10} based on the aggregated values per cell.

It can be seen that each park follows a different bell-shaped distribution in both approaches. Using the quartiles for the specific dataset as a reference it is evident that the distribution of L_{A90} is mostly skewed to the left with maximum noise levels around 60 dB(A) for all parks apart from Rivierenhof. On the contrary, the L_{A10} distribution presents a higher degree of normality in the curves with values that exceed 70 dB(A) in all parks apart from Domein. From both approaches, it is clear that the background noise (L_{A90}) presents more fluctuations than L_{A10}, which further provides an evidence that this can probably be related to traffic.

Two groups of parks can be distinguished according to the grid approach for L_{A90} (Fig.6.9c). The first group (Sorghvliedt, Nachtegalenpark, Te Boelaerpark and Rivierenhof) contains a maximum number of measurement points between 586 and 1,500. On the contrary, the second group (Domein Hertoghe, Den Brandt, Bisschoppenhof and Stadspark) with smaller parks has a maximum frequency of 100 points. The frequency difference between the two groups can be attributed both to the park size, since bigger parks are expected to have higher noise variability and to the proximity to busy roads around the parks as it can be seen in Fig.6.7.

A further comparison between the measurements inside the parks and the ones recorded in the surrounding roads (Fig.6.5) is shown in Fig.6.10. In all cases and for both indicators noise levels were higher outside the parks. These differences ranged between 0.5 and 5.9 dB(A) for L_{A90} and between 1.8 and 14.3 for L_{A10}. The average difference for L_{A90} was 3.2 dB(A), while the corresponding value for L_{A10} 8.5 dB(A). This shows that L_{A10} was much more diversified outside the parks and L_{A90} in terms of background noise inside the parks. Possible reasons for this divergence can be attributed to various sound sources, however traffic is the most probable. Actually passing-by cars can produce short events with high dynamic range, which influence the L_{A10} levels.

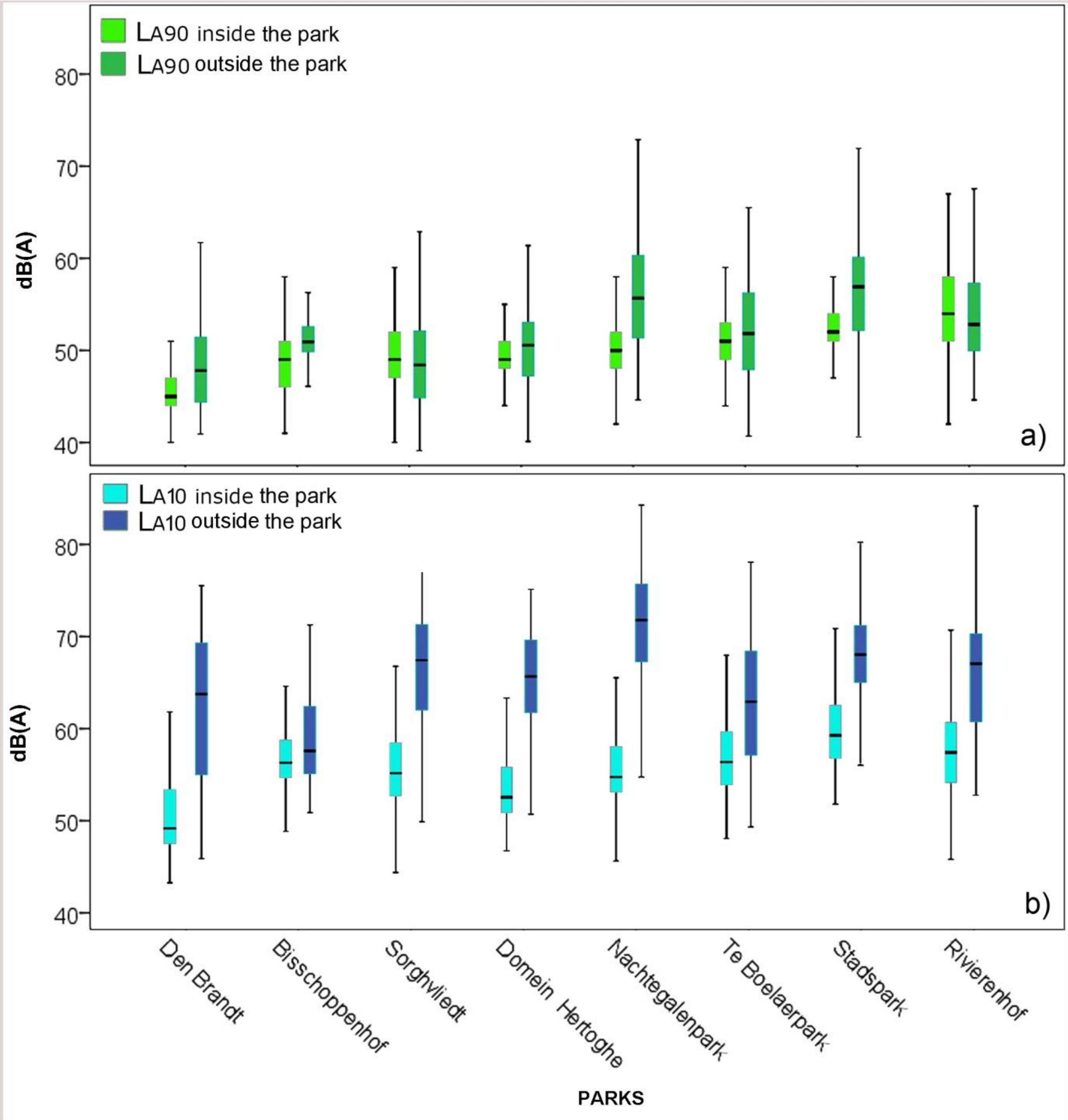

Fig.6.10. Box plots for (a) L_{A90} and (b) L_{A10} describing the sound environment inside and outside the eight parks. Results have been sorted in an ascending form for L_{A90} (inside).

It was also shown that both $L_{A90(avg)}$ and $L_{A10(avg)}$ differ by almost 9 dB(A) between the quietest and the noisiest park, while the $L_{A90(SD)}$ ranged between 2.2 and 5.2 dB(A) and changed independently from the $L_{A90(avg)}$.This happened for various reasons not always related to traffic. For example in some parks such as Bisschoppenhof, Te Boelaerpark, Den Brandt, and Sorghvliedt there were a few points with high levels of L_{A90} close to their borders. Yet, the majority of peak L_{A90}

values were clustered close to park centres (Nachtegalenpark, Sorghvliedt), usually in short distance from architectural or water features.

Human sounds can have a potential contribution in the peak levels of L_{A90}, since traffic noise close to the borders of the parks reduces the acoustic comfort evaluation (Tse et al., 2012) and prompts people's gatherings close to the centres of the parks. Similar differences concerning the acoustic environment of parks and the plurality of soundscapes have previously been reported by Jeon & Hong, (2015). Vegetation-related parameters can also affect noise levels in an indirect way, since large unparticioned grass areas tend to accumulate human activities according to the behavioural mapping outcomes of Goličnik & Ward Thompson, (2010). For tree areas this is less expected, since a minimum distance of 5 meters was observed between users and tree-lined paths in the above-mentioned study.

Out of the eight parks, Bisschoppenhof, Te Boelaerpark, Den Brandt and Sorghvliedt presented the lowest proximity to the ring road or any other national road with an average value of 48.7 dB(A) for L_{A90} and 51.8 dB(A) for $L_{A10.}$ The range for $L_{A10(SD)}$ inside the parks was between 4.8 and 6 dB(A). As expected, L_{A10} had a smaller range than L_{A90} and also smaller variations, since it represents the peak values in the percentile scale and was less susceptible to big fluctuations. The only exception was Rivierenhof park, where the range of values was higher in both noise indices.

6.3.3. Cluster analysis inside the parks

Additional analysis was performed to emphasize the possible patterns exhibited in the measurements data within each park. The pattern investigation was performed only for $L_{A90,}$ firstly because as an indicator it presents the greatest variation compared to the others and secondly in order to capture the background noise from traffic, whenever this was possible. According to Table 6.3 there was only one case (Te Boelaerpark), where the $L_{A90(avg)}$ was higher (+3 dB(A)) than the $L_{d(avg)}$. According to these results the expected cluster at this stage would have to be "introverted" in this park and "extroverted" in the other seven cases.

However, the results from "Hot Spot" analysis as presented in Fig.6.11 revealed that the observed cluster for L_{A90} is quite different from the expected one. In particular, all the three types of clusters ("introverted", "extroverted" and "random") were detected. The R^2 in the eight parks ranged between 0.02 and 0.44 in absolute values. Positive correlations denoting an "extroverted" cluster was detected in four parks, namely: Domein Hertoghe (R^2 = 0.22), Nachtegalenpark (R^2 = 0.34), Rivierenhof (R^2 = 0.36) and Stadspark (R^2= 0.44). Opposite correlations denoting an "introverted" cluster were evident in Sorghvliedt (R^2 = 0.40) and Te Boelaerpark (R^2 = -0.13). Finally, very low positive correlations were detected in Den Brandt (R^2 = 0.02) and Bisschoppenhof (R^2 = 0.15), which can be considered as random.

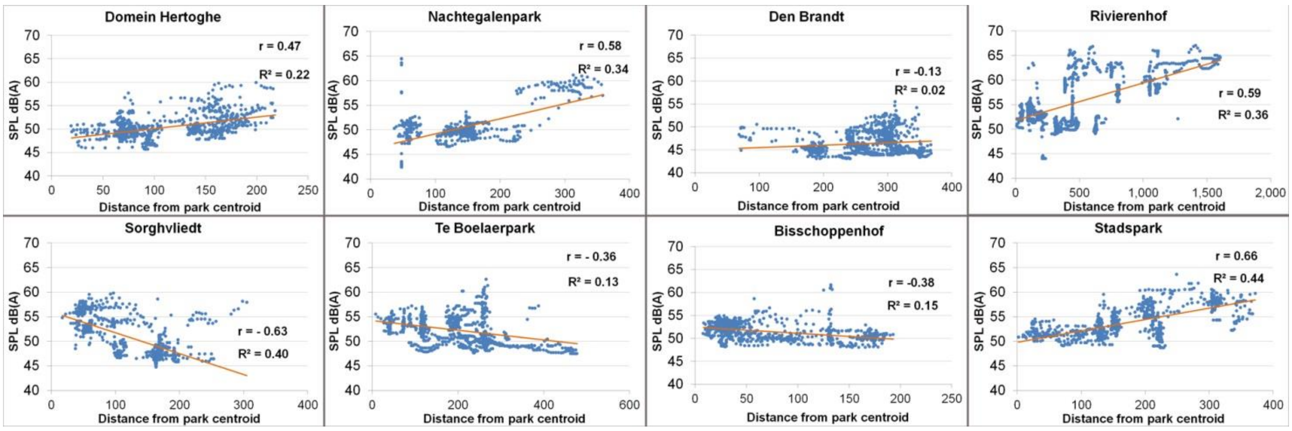

Fig.6.11. Relationship between the noise levels of the selected cluster points and the distance from the park centroid (p-value<0.001). The coefficient of determination (R^2) and Pearson correlation coefficient (r) are reported in each graph.

These results confirm to some extent the hypothesis that the sound environment inside the parks is affected by traffic noise no matter the effect from the inside sound sources. It was shown that parks with low simulated noise levels such as Te Boelaerpark and Sorghvliedt ("introverted") were little or not affected at all by the outside traffic conditions. In the case of Park Den Brandt, the absence of clustering can be attributed to the sound sources distribution, since the park is conceivably divided in two parts with all the “hot” points clustered to the right and all the “cold” to the left. On the contrary, parks with higher simulated noise levels (“extroverted”) were found to be affected by traffic to a lower or higher extent, since R^2 was positive and ranged between 0.22 and 0.44.

The observed cluster confirmed the hypothesis in five out of eight cases. For the rest of the parks three possible reasons for the divergence can be assumed. First of all, some information is lost when values are averaged to a single number representing each park. Secondly, the results can be affected by the sound sources (human, natural) found in the parks as well as by the physical characteristics of the environment. For example, in Sorghvliedt, the lake in the centre of the park attracts both human and natural life, making this part more vibrant.

6.3.4. Relations between noise levels and morphological features

At this level the parks were investigated as single entities. Possible correlations between the green space or morphological features (Table 6.1) and recorded noise levels (Table 6.2) were investigated through the Pearson product-moment correlation coefficient. Out of the five measured noise indicators, three were found to be statistically significant and negatively correlated with “tree coverage” as shown in Fig.6.12. The first was $L_{A10(avg)}$ (r =-0.68, n=8, p<.01), the second one was $L_{A90(avg)}$ (r =-0.74, n=8, p<.01) and the third one was L_{Aeq} (r=-0.66), n=8, p<0.1). Results are depicted in Fig.6.12 with the corresponding R^2 values. It was shown that more variance is explained when “Tree_COV” is used as a predictor for L_{Aeq} (F1,6)=4.8, p=0.07, R^2=0.45) compared to $L_{d(avg)}$ (F1,6)=3.7, p=0.1, R^2=0.28).

Practically, these results reveal that an increase in the tree coverage can potentially reduce noise levels in the parks both for the background noise (L_{A90}) and the high peaks (L_{A10}). Similar outcomes have been found in previous studies (Fang et al., 2003; McPherson et al., 1997;), which show that vegetation and particularly trees can be a substantial parameter in noise distribution. Taking this into account the relationship between vegetation and noise can further be explored in landscape and park design.

Apart from the green space parameters, additional correlations were also detected between the $L_{A90,max}$ and the road coverage, (r=0.89, n=8, p<.01), as well as between the $L_{A10,min}$ and the building coverage (r=0.73, n=8, p<.01). In relation to the building coverage similar results have also been identified by Liu et al., (2014b) and Margaritis & Kang (2016). These correlations provide an evidence base for the importance of the surrounding environment on the overall noise distribution in the parks. Finally, as far as traffic is concerned, a strong positive Pearson correlation was detected (r=.94) between $L_{A90,max}$ and the maximum traffic volume in the roads adjacent to the parks. This is also an evidence that despite the possible presence of human or natural sounds in the parks, background noise from traffic significantly contributes to the maximum levels of L_{A90}. Additional important indicators, such as the mean distance from major roads were found to be correlated with the measured noise at this level of analysis. The overall conclusion of the detected correlations could therefore be that the noise level distribution in the parks can be affected both by green space characteristics and morphological attributes from the surrounding environment.

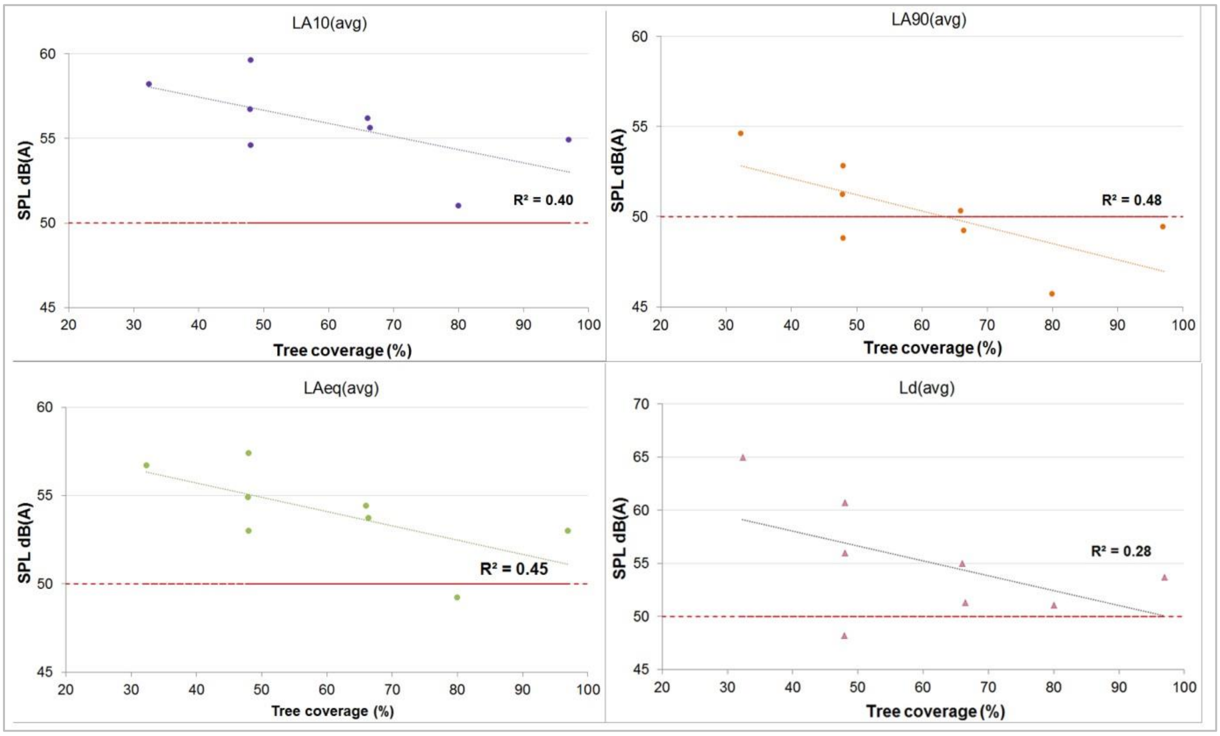

Fig.6.12. Correlations between tree coverage and L_{A10}, L_{A90} L_{Aeq} and L_d with the respective R^2 values. A cut-off line has been added at 50 dB(A) in order to facilitate the comparison among the noise indicators. $L_{d(avg)}$ refers to simulated noise levels, while the other acoustic indicators refer to measured values in the parks.

6.3.5. Comparison between tree and grass areas inside parks

After finding significant correlations between tree coverage and L_{A90}, the next step was to investigate the extent of the difference between the noise levels in tree and grass areas for all the parks. In order to overcome potential bias from the differences among the parks, all measurement points were grouped together for each of the noise indices. As a result, four large datasets were created for L_{A10}, L_{A50}, L_{A90} *and* L_{Aeq} respectively, disregarding the information about the park to which each measurement point belonged to.

An independent sample t-test was then conducted to find out whether the difference between the average noise levels detected in tree areas is significantly different from the noise levels within the grass areas. According to the results, in all cases the level of significance in the equality of variance was below .01 so equal variances were not assumed.

Moreover, results as presented in Fig.6.13 showed that in all cases there was a statistically significant difference (p<.05) between tree and grass areas thus rejecting the null hypothesis of equal means for the two populations. The maximum difference detected between grass and trees was 1.6 dB(A) for L_{Aeq}, (Fig.6.13d) while the minimum was 0.74 dB(A) for L_{A90}. (Fig.6.13b).

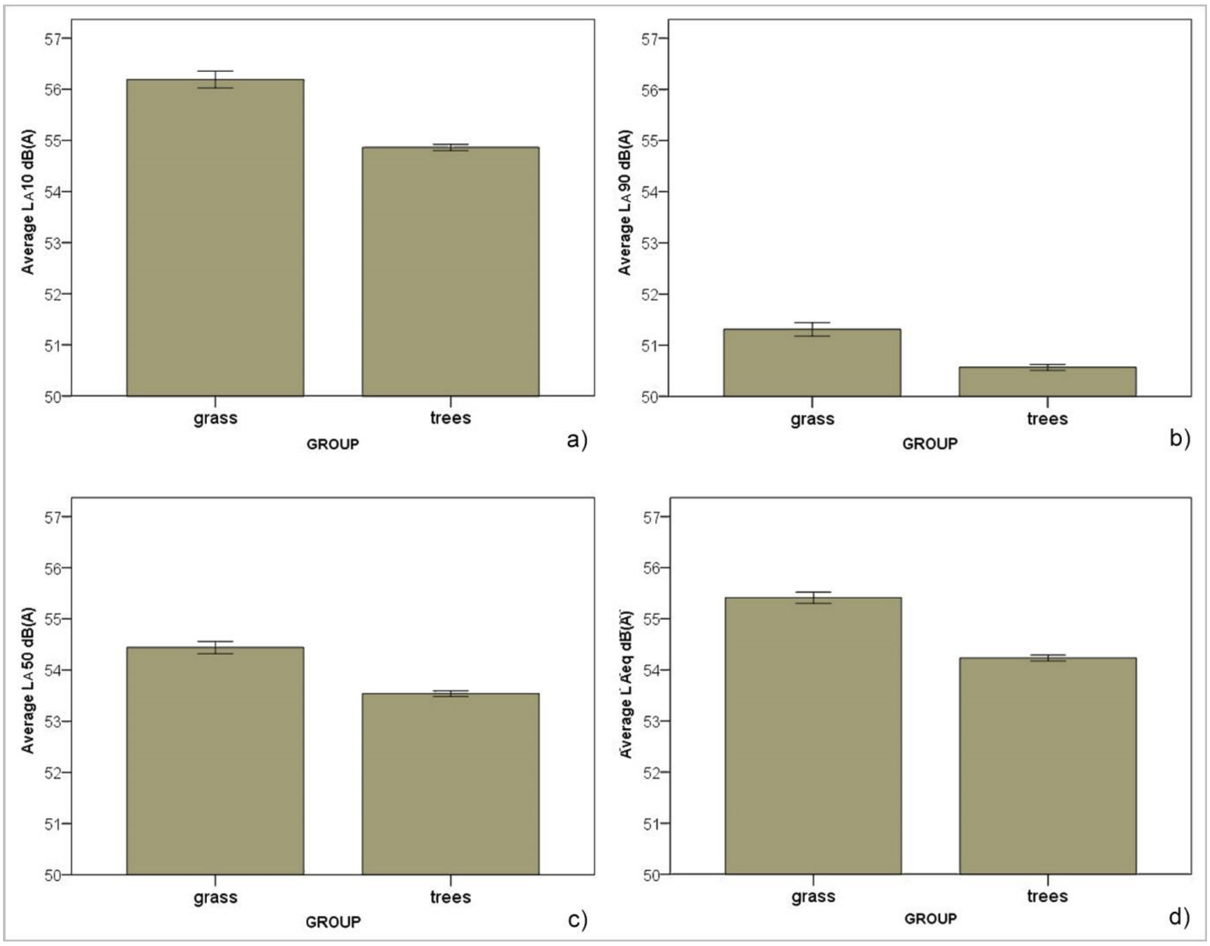

Fig.6.13. Average noise levels per index for the measurement points inside the tree and grass areas using error bars (95% confidence interval).

In spite of the statistical difference between the groups (trees, grass) for all four indicators, it was found that in certain cases this difference had a small effect. In particular, as presented in Table 6.4, the effect size (Becker, 2000) measured with Cohen's *d* (Cohen, 1977) was less than 0.2 for L_{A50} and L_{A90}, which is the cut-off value for a minimum effect. On the contrary, the effect size of L_{A10} was -0.22 showing that there is a significantly small difference between the average values of the two groups. In all cases, the negative sign indicates the direction of the effect, since the mean value for grass was higher than the one for trees. Finally, a higher difference was detected in the L_{Aeq} levels with an effect size of -0.32.

All these findings are important, since they show that despite the noise variability due to the different sources; it was possible to capture the small noise differences between the two green space classes. The importance of this finding could be further strengthened by taking into account the effect from the different park sizes and their surrounding environment as well as the sound sources inside the parks.

Table 6.4. Results of the t-test and Cohen's *d* values for the groups of trees and grass.

Index	GROUP	N	t-test for equality of means	Mean	SD	dB(A) difference: M(grass)-M(trees)	Cohen's (d)	Effect size
L_{10}	trees	29,618		54.9	5.3	1.33	-0.22	-0.10
	grass	6,854	-17.5	56.2	7.0			
L_{50}	trees	26,683		53.4	4.6	0.92	-0.19	-0.095
	grass	5,910	-13.5	54.3	4.8			
L_{90}	trees	16,378		50.6	3.9	0.74	-0.18	-0.087
	grass	3,651	-10.4	51.3	4.1			
L_{Aeq}	trees	26,502		54.3	4.8	1.60	-0.32	-0.163
	grass	6,776	-24.4	55.9	4.9			

6.4. Conclusions

The effect of vegetation and traffic-related parameters on the sound environment was investigated in the eight representative parks of Antwerp. Results were investigated in two different scales and the most appropriate calculation method was used in each scale. Simulated traffic noise levels with higher variation were calculated in park scale and sound recordings of high spatio-temporal resolution and smaller variation at point scale. The innovative feature of this approach was the combination of measurement noise data with advanced GIS analysis tools.

As regards the noise distribution in the parks taking into account only the traffic conditions from the adjacent roads, it was found that noise levels varied between 43 and 78 dB(A) in terms of minimum and maximum values with a range between 14 and 23 dB(A) per park. The $L_{d(avg)}$ was restricted between 48.2 and 65 dB(A) with two groups of parks to be identified. The first one involved parks mainly far from the ring road, which presented low noise levels. On the contrary, the second group of parks - closer to the ring road - was calculated to be the noisiest with few outliers and a high noise range between 53 and 65 dB(A).

For point-based noise levels extracted from on-site measurements, L_{A10} and L_{A90} were used as the representative indicators for peaks and background noise respectively. The maximum range for both indicators in all parks was between 40 and 75 dB(A) in 95% of the cases. However, the noise measurements for L_{A90} were mainly aggregated in the first (Q1) and middle quartile (Q2), while for L_{A10} in all the four quartiles. On the top of that, the frequency of occurrence in measurements below 55 dB(A) was much higher in L_{A90} than in L_{A10}. Both indicators were assessed according to their values inside and outside the parks. For the inside environment the minimum difference between $L_{A10(avg)}$ and $L_{A90(avg)}$ was 3.6 dB(A) and the maximum 6.9 dB(A). From the SD perspective it was calculated that the $L_{A90(SD)}$ varied greater than $L_{A10(SD)}$ and independently from the increase of $L_{A90(avg)}$. For the measured noise levels in the roads around the parks the overall comparison revealed that L_{A10} presented higher variability than L_{A90} and as expected the surrounding environment was noisier than the inside by 14.3 dB(A) for L_{A10} and 6 dB(A) for L_{A90}.

Concerning the identification of possible clusters in the noise measurements it was found that each of the possible patterns (“introverted”, “extroverted” and “random”) was observed in the eight parks. The evidence of an “extroverted” cluster in four parks further strengthens the argument that traffic noise had indeed an effect within some of them. Furthermore, it was made clear that this effect was more recognisable when results were analysed using the measured data and not the simulated ones.

The correlations between morphological and green space attributes of the parks with noise indicators showed that out of all the variables tested, tree coverage was found to be negatively correlated with $L_{A90(avg)}$, $L_{A10(avg)}$ and L_{Aeq}. Additional correlations were also detected between the $L_{A90(max)}$ and the road coverage as well as between the $L_{A10(min)}$ and the building coverage showing that noise level distribution in the parks can be affected both by green space characteristics and morphological attributes from the surrounding environment.

Finally, it was found that there was a statistically significant difference in the noise levels within tree areas and grass areas independently of the park. The maximum difference detected was 1.6 dB(A) and the minimum 0.74 dB(A), while the effect size verified that this difference has a relatively small effect in terms of the acoustic power.

As a first stage, the results of this study can provide evidence on the understanding of the noise environment within the parks and the extent of differences between the inside and the surrounding environment. In a second stage, these results can be taken into account in the design of parks’ acoustic environment coupled with landscape design principles and sound masking tools. If these elements are further combined with automated source identification algorithms so as to have an estimation of the contribution of each source on the overall sound pressure levels, this would further reinforce the design process on making parks more pleasant and attractive to the public.

PART II: TOWARDS DESIGN AND IMPLEMENTATION

Chapter 7

Relationship between land use activities and sound sources in urban environments

The content of this chapter has been submitted as a journal paper and it is under review:

Margaritis E., Kang J., Aletta F., Axelsson Ö., *"A Sheffield case study on the relationship between land use and sound sources in the urban environment",* Science of the Total Environment.

7. Relationship between land use activities and sound sources in urban environments

The three previous chapters dealt with a quantitative approach on noise issues. This approach is insufficient in a planning framework if not combined with soundscape, which takes into account the desirable sounds that people prefer. Consequently, this Chapter and the next one provide a link between the quantitative and qualitative aspects of the outdoor sound environment. Section 7.1 presents the research that has previously been done on the field of urban activities, their role as elements in urban planning models and their connection with acoustic aspects and land use. Sound sources are also reviewed together with their contribution in urban and soundscape planning. Section 7.2 presents the experimental process and the data collection, while Section 7.3 the results from the application of the PCA and the relationship between sound sources and land use activities. The current results are compared with previous studies in the Discussion part presented in Section 7.4. Finally, the ultimate conclusions of the study are drawn in Section 7.5.

7.1. Previous studies and research questions

The initial concept of a successful city arrangement in terms of urban activities was first introduced in the 4th “Congrès Internationaux d'Architecture Moderne” (CIAM) led by Le Corbusier in 1933. At that moment the Architectural tendencies in Town Planning were affected by his ideas and the Ville Radieuse (Corbusier, 1933) with the complete separation of functions and the application of a zoning system. The city was considered as an interaction of four basic urban functions/activities: living, working, recreation and circulation.

Later on, Kilbridge et al. (1969) created a framework for the classification of the existing urban planning models and proposed four basic elements for their analysis: a) subject, b) function, c) theory and d) method. Taking into account this approach the subject of all models consists of four components (land use, economic activity, population and transportation). Consequently, the approach of Le Corbusier (1933) and Kilbridge et al. (1969) present many similarities on the way of perceiving spatial relationships in the urban context.

Nowadays, contemporary planning approaches are mostly based on the application of the Compact City and the Multifunctional Land Use (MLU) concepts (Vreeker et al., 2004). The latter theory especially emphasizes on the creation of synergies by combining a variety of land use functions at the same location. Nevertheless, the basic urban activities as defined in the 4th CIAM remain unchanged in terms of the core meaning. For this reason they have been used in various studies. For example, in terms of pattern analysis, Odland (1976) tried to quantify a single equation model for the distance between residential and employment areas. Other studies used urban activities in connection with residential satisfaction (Bonaiuto et al., 2004), land use pattern analysis (Soto & Frías Martínez, 2011; Al-shalabi et al., 2013) and in conjunction with purpose-driven activity distribution maps (Hasan et al., 2013). Finally, Fistola & La Rocca, (2014) used an extended list of urban activities as components to quantify the sustainability of a city.

In relation to acoustics, Raimbault & Dubois, (2005) have used them as a tool of assessing the sound environment, whereas Aletta et al. (2015) used the Swedish survey protocol by Axelsson et al. (2012) mainly to emphasize on the appropriateness of the overall surrounding sound environment. The structure of the protocol presents many similarities with the outcomes of soundscape preference (e.g *appropriateness, liveliness, naturalness, nature appreciation)* as presented by Brown et al. (2011). It has also been shown that different activities are associated with different land use attributes, which together compose the scenery of urban diversity in the cities (Batty et al., 2004).

Sounds in the urban environment have been approached so far either in terms of classified sources (Brown et al., 2011) and relative sound maps (Hong & Jeon, 2015; Margaritis et al., 2015) or in terms of a noise index as dependent variable (e.g. L_{Aeq}) using land use regression models (Aguilera et al., 2015; Goudreau et al., 2014; Gozalo et al., 2016; Ragettli et al., 2016; Ryu et al., 2017). Correlations with urban geometry features have also been attempted (Hao et al., 2015a; Margaritis & Kang, 2016; Oliveira and Silva, 2010; Salomons & Berghauser Pont, 2012; Wang & Kang, 2011). However, the overall assessment of places was based on objective parameters without taking into consideration the individual evaluation of people.

In the transition from urban planning policies to soundscape policies the emphasis has been transferred from a source-based approach to a context-based approach, where the person interacts with activities and place within a spatio-temporal frame (ISO 12913-1, 2014). Urban planning can influence travel patterns (Burton et al., 2000) and consequently is directly related to the distribution of sound sources within the city, both for traffic and also for humans.

This relationship can be analysed in a dual approach, by examining and linking the two policies. Urban planners frequently approach noise issues only as part of the environmental impact assessment with a primary aim to decrease maximum objective values of sound pressure levels (SPL). On the contrary, the soundscape approach is using sound as an integrated and useful element of the sonic environment. There are many benefits of an early consideration of the sonic dimension in the planning process, using sound as a positive resource (De Coensel et al., 2010; Brown et al., 2011). In this way, the urban design process can be enhanced with appropriate auditory inputs - when feasible - providing a qualitative urban environment in contemporary cities (Brown & Muhar, 2004; Kang, 2007a).

However, there has been little effort so far to integrate soundscape principles into current urban planning and environmental frameworks (Smith & Pijanowski, 2014;

Weber, 2013). Another argument towards this direction is that these two approaches should act in a complementary way without excluding each other (Brown, 2014; Genuit, 2013). Vogiatzis and Remi, (2014) supported and extended this approach by involving also aspects related to culture and social interaction.

Therefore, the aim of this Chapter is to investigate the relationship between sound sources and land use in the urban environment. For this reason the following steps were taken: (1) conducting a Principal Components Analysis (PCA) of how appropriate a short-list of human activities are in different urban environments; (2) identifying variables of urban morphology, to be used as predictors of the PCA components; (3) identifying sound sources profiles; (4) identifying human activity profiles; (5) identifying the relationship between sound sources and activity profiles and finally, (6) identifying which human activities can be best distinguished among groups of urban activity profiles.

7.2. Methods

A listening experiment was conducted at the University of Ghent (Belgium), using audio-visual material collected in Sheffield (UK). This guarantees that the participants did not have any preconceptions with regards to the locations included in the experiment.

7.2.1. Case study area

The city of Sheffield was selected as a characteristic example of a medium-sized UK agglomeration. The case study area, depicted in Fig.7.1, was chiefly located within the circular highway that surrounds the city centre, and delimited by road A61, Netherthorpe Road, Upper Hanover Street, Hanover Way, and St. Mary's Gate. This area includes a variety of land use types, such as the old commercial city centre, small industries, residential areas, and green areas. Moreover, there is a plurality of infrastructure types, including the railway station, tram and bus lines, as well as the four typical UK categories of road network (A roads, B roads, minor and local roads) as classified by the Ordnance Survey (Ordnance Survey, 2014, pp.67). The case study area measured 3.8 km^2. To aid the analysis, a 200×200 m grid was applied, dividing the area into 90 tiles. The centroid of each tile was decided to be the primary measurement point for sound pressure levels and binaural recordings, provided that accessibility was granted. In opposite cases, the closest outdoor publicly accessible point served as an alternative solution.

Morphological variables, presented in Table 7.1B below, were also considered for each point in order to test their effect on the overall acoustic environment. For example, the "Road Width/Building Height" ratio was expected to be lower in areas close to the city centre, where commercial activities take place.

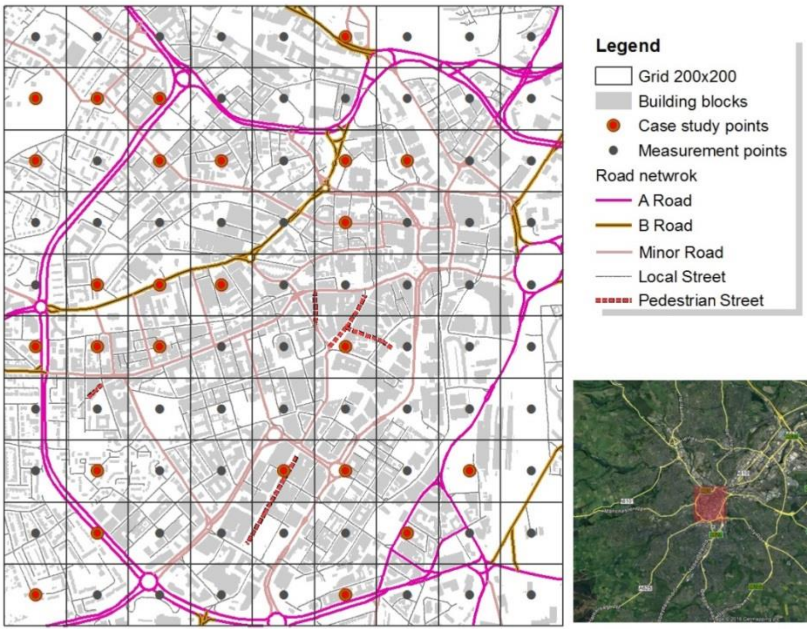

Fig.7.1. Configuration of the case study area including measurement and case study points.

7.2.2. Participants

The participants were 20 undergraduate and postgraduate students from Ghent University, aged 23-33 yrs. (16 males, 4 females; M_{age} = 27.5 yrs. SD_{age} = 2.8). They were recruited as volunteers through an open invitation to all PhD students. The variety of their origin covers mostly Europe (19) apart from one participant from

China. All of them were living in Ghent at that period and six had Dutch as their mother tongue. Sixteen participants had previously visited England at least once in the past. None of them had visited Sheffield. At the end of the experiment they all received a small monetary compensation.

7.2.3. Experimental stimuli

The experimental stimuli were created from auditory and visual material recorded in 25 out of the 90 locations presented in Fig.7.1 (see the 25 red filled circles representing case study points). The selection criterion was to choose sites from all sorts of land use categories (commercial, residential, industrial, and others), as described in the Unitary Development Plan (UDP) of Sheffield (Sheffield City Council, 1998). The 25 locations included three locations in urban recreational areas, nine in urban residential areas, five in urban commercial areas, two in pedestrian streets, one in an education services area, two by major roads, two in light industrial units, and one in a parking area (Table 7.4 below). In addition, a broad range of soundscapes was sought, with a great diversity of sound sources, including the sound of technology, people and nature.

As regards the audio part of the stimuli, a researcher recorded the equivalent sound pressure levels ($L_{Aeq,3min}$) and conducted binaural audio recordings in the morning hours (09:00–12:00), as a peak time period, during four working weeks. The equivalent sound pressure levels varied between 51.1 and 89.9 dB(A). From each binaural audio recording, a 30 s excerpt was selected to represent the local acoustic environment.

For each of the 25 locations, videos were created using Google Street View, making a 360º panoramic camera sweep at each point. The speed of the camera sweep was adjusted so that the duration of each video was 30 s. The audio (wav) and video (mpeg4) were merged together using the Camtasia Studio software.

7.2.4. Equipment

For the on-site audio recordings, the equipment included a stereo microphone kit (DPA 4060) connected to a digital audio recorder (R-44 Edirol), a mini microphone (Micw i436), and a sound calibrator. The "*Audiotool*" Android application, installed on a mobile phone with the Micw i436 attached, was used to record the sound pressure levels at each location.

The experiment was conducted in a sound proof listening room. The soundscape excerpts were reproduced in headphones (Sennheiser HD 280 Pro) feed by a laptop computer (Dell Inspiron 7720) with an IDT sound card (24 bits, 48 kHz) and at the authentic sound pressure levels. The video image was presented in full screen mode on the laptop screen (17") at a distance of approximately 60 cm in front of the participant. The original audio signals were calibrated using a dummy head (B&K 4128-C) and 0.1" microphones (Knowles FG-23329-P07) as shown in Fig.7.2.

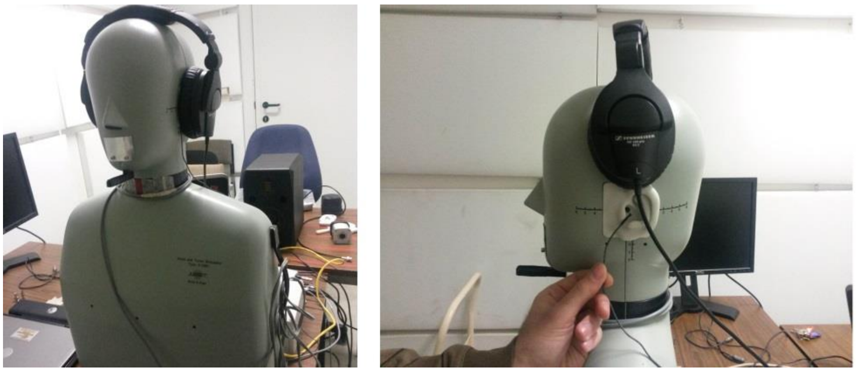

Fig.7.2. Equipment used during the calibration process

7.2.5. Data collection tool

Data was collected through a questionnaire built in the SurveyGizmo platform and accessed through an Internet browser (Appendix C). For each of the 25 stimuli, the participants responded to two questions. First, the participants assessed how dominant they perceived four different sound sources to be: a) natural sounds, b) traffic sounds, c) sounds from people, and d) construction sounds. For each sound source they responded by the aid of a 100-point slider bar, corresponding to a digital version of a visual analogue scale. The four scales were delimited by the end labels “Do not hear at all” and “Completely dominant.”

Second, the participants assessed how appropriate the 16 social and recreational activities as well as the 6 land uses presented in Table 7.1A were for the location. For each of these 22 response items, the participants responded by the aid of a 100-point slider bar, delimited by the end labels “Not appropriate” and “Perfect match.” The 16 social and recreational activities were selected from the Swedish survey protocol by Axelsson et al., (2012). The 6 land uses were added for the purpose of the present study.

The two questions were always presented in the same order for all 25 stimuli and to all participants. However, to avoid order effects in the responses, the order of the response items was randomized for every question and participant (i.e., for the four sounds sources in the first question, and the 16 social and recreational activities and the 6 land uses in the second question).

Table 7.1. Social and recreational activities, land uses and morphological variables

A. Social and recreational activities, and land uses	
Social and recreational activities	**Land uses**
Appreciating cultural heritage	Car parking
Appreciating inland water	Industrial activity
Boating - Fishing	Offices
Escaping city stress	Residence
Experiencing active street life	Road - Rail transportation
Experiencing peace - quiet	Student work (School - University)
Individual outdoor activities	
Nature appreciation	
Outdoor informal games	
Picnic - Barbecue	
Restaurants - Cafes	
Shopping	**Sound sources**
Socialising - Conversing - Chatting	Traffic
Spending time with friends - family	People
Swimming - Bathing	Natural sounds
Walking - Jogging - Running	Construction sounds

B. Morphological variables
Ratio of road width to the average building height around the measurement point (Road Width/Building Height)
Road coverage (m^2) within the 200x0200m tile
Distance (m) to the closest major road
Distance (m) to the closest minor road
Green space coverage (m^2) within the 200x200m tile

7.2.6. Experimental procedure

The two questions were presented in the same sequence for every participant; however the order of answer options was randomized for each question. Moreover, the values in the scale bars (0-100) were invisible so as to avoid possible rounding tendencies from the participants. On average, the experiment duration was one hour. Participants were allowed to watch each of the 25 stimuli as many times as needed. The entire process was completed in eleven days with daily sessions between 10:30am-19:30pm.

7.3. Results

7.3.1. Components of land use and sound sources

Arithmetic mean values were calculated across the 20 participants for each of the 25 stimuli, and for all of the 26 response items in the questionnaire (sound sources, activities and land uses included). This resulted in a 25×26 data matrix, where the rows represented the 25 experimental stimuli and the columns represented the 26 response items. The matrix was subjected to a Principal Components Analysis (PCA) (SPSS 22 for Windows) with statistically significant results from the Bartlett's sphericity test ($p<.001$). The Components extraction method was based on a fixed factor solution. The number of Components was calculated based on the scree plot, which shows the percentage of variance explained as a function of the number of clusters. Components 1 and 2 explained 49%, and 23 % of the variance in the set of data, respectively.

Fig.7.3 presents the principal component loadings for the 26 response items. Several of them had values close to 1 showing a strong association with the two Components. Variables associated with infrastructure and work-related activities had negative loadings on Component 1, while commercial, social and nature-related activities had positive loadings. Concerning the acoustic environment, there was a negative association between Component 1 and traffic sounds and a positive association with natural sounds. Consequently, Component 1 seemed to represent natural versus manmade environments. For Component 2 there was a positive association with human sounds, which can be interpreted as proximity to city centre locations and associated with the density of people.

Fig.7.4 denotes that human, social and recreational needs can be satisfied based on the proper balance of the two Components. For example, the most appropriate places for "shopping" were proved to be those which were close to the city centre with a balanced natural and manmade environment.

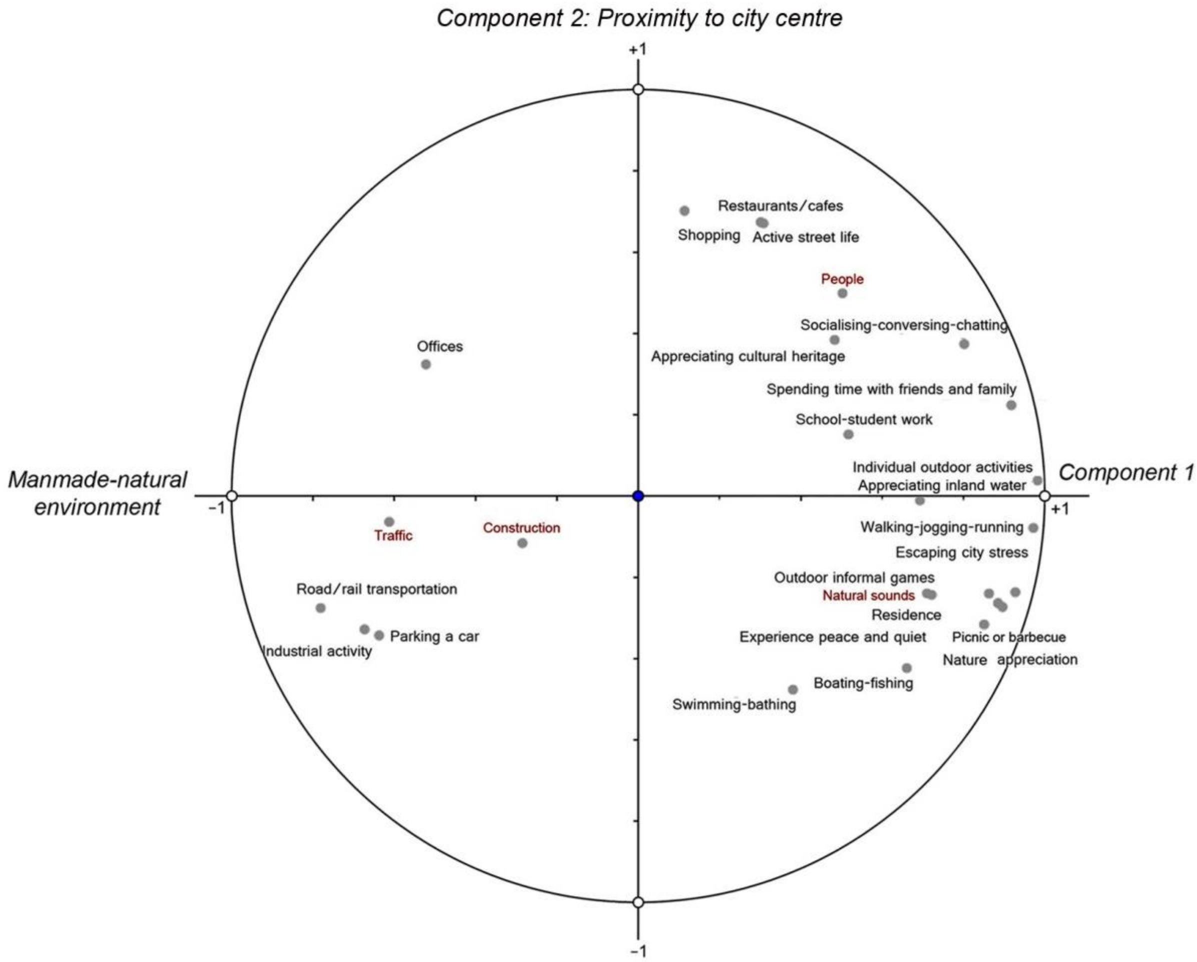

Fig.7.3. Principal Component loadings for four sound sources, 16 social and recreational activities and six land uses.

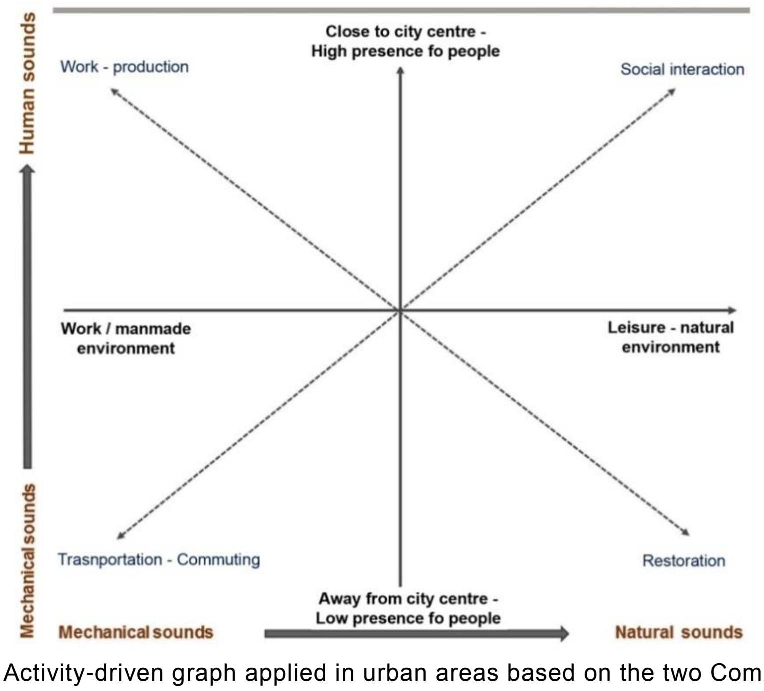

Fig.7.4. Activity-driven graph applied in urban areas based on the two Components.

7.3.2. Relationship between activities, land use and urban morphology

In order to investigate the relationships between activities, land use and urban morphology, data were cleaned from two outlier points and two backward, linear regression analyses were conducted (SPSS 22 for Windows). Component scores of Components 1 and 2 from the PCA were regressed on the five urban morphology variables presented in Table 7.1B. Table 7.3 presents the Pearson's coefficients of correlations.

Component 1 (C1) was best predicted by and positively associated with green space coverage (β = –0.65, t = 4.0, p = 0.001), as well as the distance to minor roads (β = 0.20, t = 1.2, p = 0.24), (F = 13.8, $p < 0.001$, R^2 = 0.58). Thus, the larger the green space coverage and the bigger the distance from minor roads, the more likely it was for a place to be perceived as natural and appropriate for leisure activities, allowing the natural sounds to dominate.

Component 2 (C2) was best predicted and positively associated both with road coverage (β = –0.45, t = –2.6, p = 0.017) and the distance to major roads (β = 0.54, t = 3.4, p = 0.03), (F = 10.1, p = 0.01, R^2 = 0.50). Green space coverage was negatively associated with Component 2 as it can be seen in Table 3 (r = –0.47. p = 0.025), however in the regression model it was excluded as a predictor, since the other two variables could provide a higher R^2 value. Thus, it is deduced that Sheffield city centre is away from green spaces, it presents areas with high road coverage and includes points away from major roads and particularly the Ring Road.

Table 7.2. Pearson's coefficients of correlations between Components 1 (C1) and 2 (C2), and five morphological variables.

	C1	C2	3	4	5	6
C2	-0.04					
3. Road Width/Building Height	-0.16	-0.26				
4. Road coverage	-0.33	0.46*	0.46*			
5. Distance to major road	0.10	0.51*	-0.47*	-0.06		
6. Distance to minor road	0.49*	-0.26	0.22	-0.01	-0.21	
7. Green space coverage	0.74**	-0.47*	0.31	-0.51*	-0.24	0.46*

*p < 0.05 (two-tailed test of statistical significance)
**p < 0.001 (two-tailed test of statistical significance)

7.3.3 Typology of sound sources

The next step following the PCA was the clustering process for the sound sources. The main aim of formulating clusters was to group the 25 sample points (rows) - based on the presence and the variability of each one of the four sound sources (columns) - and identify possible profiles.

The matrix of 25×4 was initially used for a hierarchical clustering. The rows represented the 25 experimental stimuli and the columns represented the four categories of sound sources (traffic, people, nature, construction) as shown in Table 7.1A. The data was arithmetic mean values calculated across the 20 participants.

Hierarchical methods can be proved useful in cases where the number of clusters to form in unknown and needs to be calculated as an output variable. In particular, for Ward's method, distance is measured as the distance of all clusters to the grand mean of the sample. An idea of the suitable number of classes can be provided by the dendrogram, which shows the progressive grouping of the data through multiple iterations as the sum of squared distances is minimized at each step. For the current study, the agglomeration schedule and the dendrogram presented in Fig.7.5a denoted that three clusters is the optimal number of groups according to this algorithm.

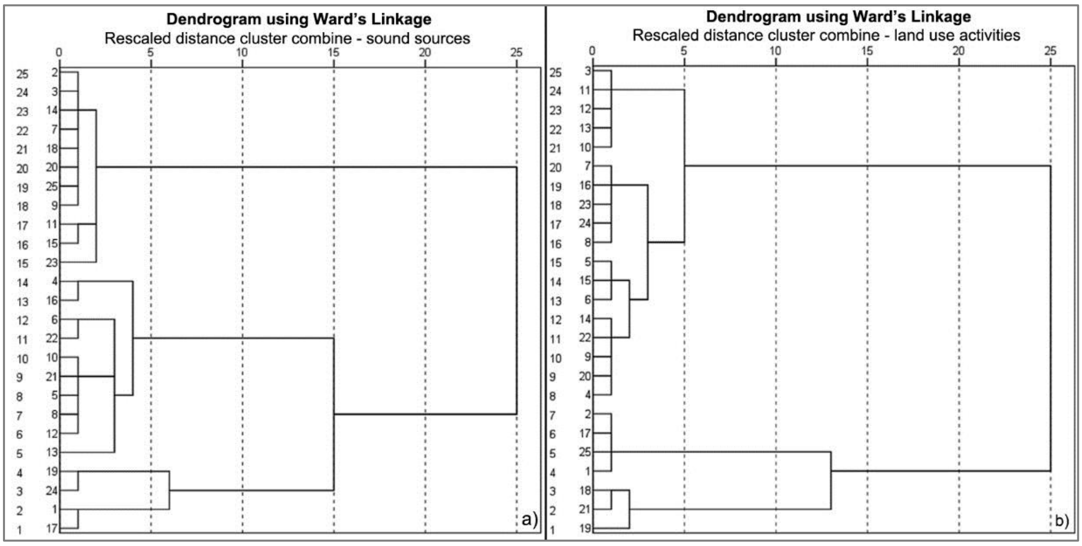

Fig.7.5. Dendrograms for the identification of the optimal number of groups for: (a) sound sources, (b) land use activities based on the results of the hierarchical analysis (Ward's method).

In the second step, a k-means clustering algorithm was applied in the matrix to identify the cluster membership and cluster centres for each one of the 25 case study points using a fixed solution of three groups (Fig.7.5b). In the first stage of the algorithm three random cluster centres are defined and all data points are allocated to one of them. In the second stage, each cluster centre is moved to the average location of the points in the cluster. This process iterates until to form the final cluster centres. The outcome of this method for the current dataset is presented in Fig.7.6 showing the cluster centres for each sound source in the three profiles. According to the results, places belonging in cluster "profile 1" presented average traffic (25.3) and construction sounds (20.2), while natural sounds were the most prevalent (50.9). In this profile human presence was limited with the lowest value (11.3) compared to all other sources.

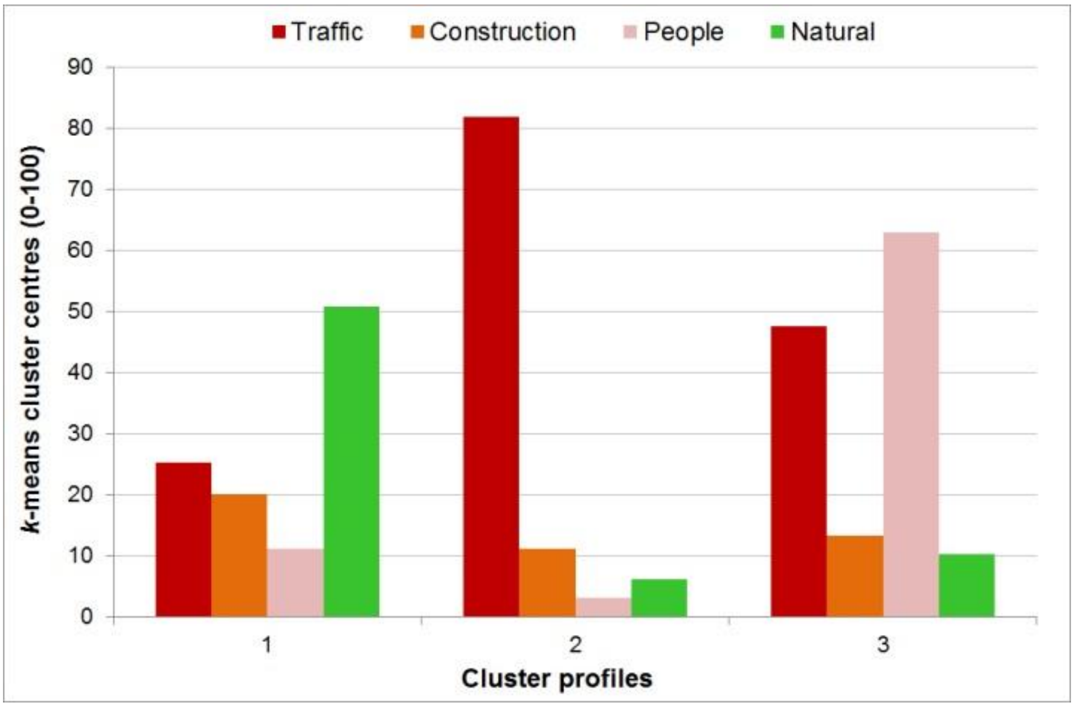

Fig.7.6. *k*-means cluster centres for sound sources profiles.

In cluster "profile 2" traffic noise was the dominant source (81.9) with the rest of them to present minimum variations and range in a very low level. Similar to the first cluster, human sounds presented the minimum cluster centre (3.2) with natural sounds and construction sounds to follow. Contrary to the previous two cases, cluster "profile 3" was dominated by human sounds (63.1) with the presence of traffic (47.6) to be also significantly evident, but to a lower extent. In this case construction and natural sounds presented slightly higher values compared to cluster "2", but lower compared to cluster "1". In total four (4) places belonged to the first profile, eleven (11) to the second and ten (10) to the third.

7.3.4. Typology of places

To explore what type of places the 25 experimental stimuli represented, a 25×22 data matrix was created. The rows represented the 25 experimental stimuli and the collumns represented the 22 social and recreational activites and land uses as shown in Table 7.1A. The data was arithmetic mean values calculated across the 20 particpants.

First, the data matrix was subjected to a hierarchical cluster analysis, using the Ward's method with Squared Euclidian distances (SPSS 22 for Windows). It was applied to the 25 stimuli in order to identify the optimal number of clusters. Through inspection of the agglomeration schedule and the dendrogram, three clusters were identified.

Second, the data matrix was subjected to a k-means cluster analysis. As presented in Table 7.3 (*column: land use*), four of the experimental stimuli were located in "cluster 1", 18 in Cluster 2, and 3 in Cluster 3. Fig.7.7 presents the components score plot based on the PCA. The data points represent the 25 experimental stimuli, marked according to the three clusters they belonged to.

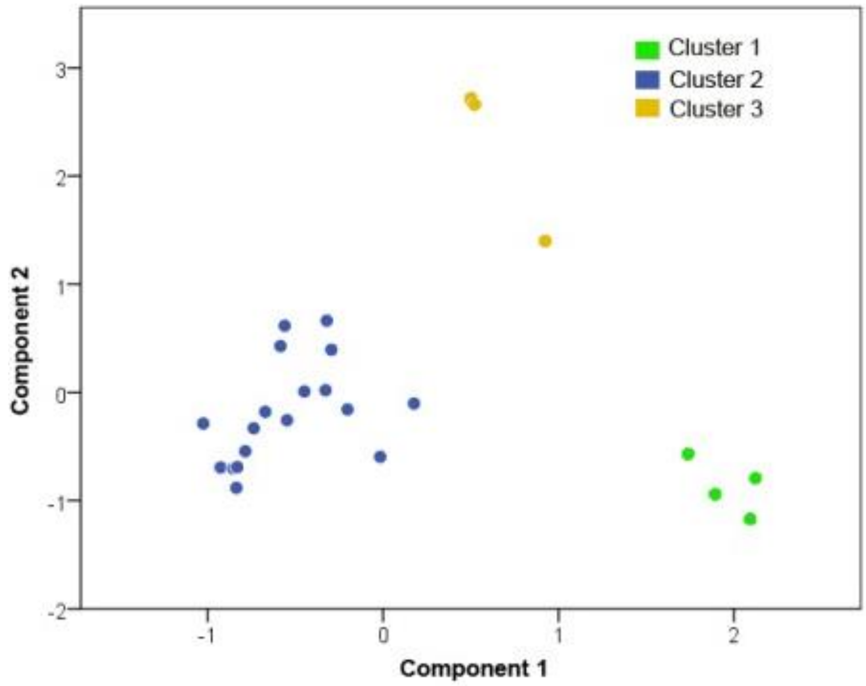

Fig.7.7. Principal Component scores for 25 experimental stimuli divided into three clusters.

Table 7.3. Distribution of case study points by cluster sorted according to land use variables cluster membership. In the land use column the following matches are: “1”: Residential, “2”: Economic and Industrial, “3”:Commercial.

Point ID	Type	$L_{AEq,3min}$	Cluster	
			Sound sources	Land use
1	Recreational area	51.1	1	1
20	Residential area	60.9	3	1
64	Recreational area	69.6	1	1
73	Recreational area	72.5	3	1
6	Recreational area	77.1	2	2
11	Recreational area	71.5	2	2
16	Residential area	62.6	3	2
24	Commercial area	76.3	2	2
37	Education services area	59.6	2	2
38	Residential area	62.7	3	2
39	Education services area	54.3	2	2
47	Recreational area	58.5	3	2
48	Commercial area	73.6	2	2
49	Commercial area	56.2	2	2
60	Recreational area	66.9	3	2
66	Parking area	71.3	2	2
67	Light industrial unit	74.1	1	2
69	Parking area	67.4	2	2
74	Residential area	77.9	2	2
75	Residential area	89.9	1	2
87	Residential area	80.1	2	2
70	Residential area	73.1	3	2
23	Commercial area	76.9	3	3
26	Recreational area	57.6	3	3
42	Commercial area	61	3	3

7.3.5. Relationship between sound sources and land use activities

The association between sound sources and land use activity profiles was tested using a chi-square test of independence (SPSS 22, for Windows). The two variables tested refer to: a) the cluster membership of sound sources and b) land use activities. This resulted in a matrix of 25×2. Rows represented the case study areas and columns the predicted cluster membership.

A significant association between these two variables was found χ^2 (4, 25) = 11.39, p<0.05. As shown in the crosstabulation of Table 7.4, areas in Cluster 1 were mainly residential and consequently more likely to present natural (+1.4) and human sounds (+0.4) than expected. Areas in Cluster 2 presented a mixed land use character and thus more likely to be associated with traffic sounds (+3.1) and less probable with natural (-0.9) and human sounds (-2.2). In this cluster the observed and expected difference of traffic was the highest among all the three profiles. Finally, areas belonging in Cluster 3 were mainly commercial spots more likely to appear human sounds (+1.8) and less likely to be affected by traffic sounds (-1.3). Natural sounds in these areas were almost imperceptible (-0.5).

Table 7.4. Crosstabulation table in the chi square test between sound sources and activity profiles. In parenthesis the difference between count and expected values.

			Land use activities profiles			**Total**
			Cluster 1	Cluster 2	Cluster 3	
Sound Sources Profiles	Natural sounds	Observed	2(1.4)	2(-0.9)	0(-0.5)	4
		Expected	0.6	2.9	0.5	4
	Traffic sounds	Observed	0(-1.8)	11(3.1)	0(-1.3)	11
		Expected	1.8	7.9	1.3	11
	Human sounds	Observed	2(0.4)	5(-2.2)	3(1.8)	10
		Expected	1.6	7.2	1.2	10
Total		Observed	4	18	3	25
		Expected	4	18	3	25

7.3.6. Relationship between activities, land use and type of place using multivariate analysis

In order to investigate which of the 22 activity and land use variables (Table 7.1A) best differentiated between the three clusters, a one-way multivariate analysis of variance was conducted (MANOVA in SPSS 22 for Windows). It was selected as an alternative to Multinomial Logistic Regression, which was not possible to apply due to “complete separation of data.” The error occurred because of the small sample size in two out of the three clusters.

The assumption of normality was tested, using the Shapiro-Wilks test and the histograms of the standardized residuals for each variable. The homogeneity of variances was tested using the Levene’s test. Finally, the assumption of multicollinearity was assessed using the VIF factor, by eliminating the violating predictors. For this process, a regression model was applied using the equivalent sound pressure level (Table 7.3) at each case study point as the dependent variable and the 22 activity and land use variables as predictors. In total, seven variables were discarded, resulting in a data matrix of 25×15. Then, the variable of land use cluster membership was added to the data matrix (Column “land use” in Table 7.3). The data matrix was subjected to MANOVA using an unbalanced model due to the different number of sites in each cluster.

The effectiveness of the model was assessed using the Pillai’s Trace index. It showed that, overall, there were statistically significant mean value differences between the three clusters for the land use variables ($F_{30,18} = 26.3$, $p < 0.001$, Pillai’s Trace = 1.95, $\eta_p^2 = 0.97$). Details for all statistically significant variables are reported in Table 7.5. It includes the mean values (M) for each cluster, the standard errors of the means (±1 SE), F-values, p-values, and partial eta squared (η_p^2). The variable “Student work (School - University)” was not statistically significant ($F = 2.08$, $p =$

0.149) and omitted. The effect size (partial η^2) was large for all cases and above the cut-off value of 0.14 according to Cohen, (1988).

Table 7.5. Mean values (*M*) and standard errors of the means (±1 *SE*) for three land use types, as well as *F*-statistics from MANOVA test of between-subjects effects with land use variables. The table is sorted in descending order by partial eta squared (η_p^2).

	Land use type [M (SE)]					
Land use activities	**Cluster 1**	**Cluster 2**	**Cluster 3**	**F(2,13)**	***p***	**η_p^2**
Spending time with friends - family	46.6 (2.6)	7.8 (1.1)	44 (4.9)	128.5	< 0.001	0.92
Walking - Jogging - Running	63.4 (2.8)	14.8 (1.4)	31.8 (2.7)	124.5	< 0.001	0.92
Nature appreciation	44.1 (7.1)	2.9 (0.8)	3 (1.3)	77.6	< 0.001	0.88
Restaurants - Cafes	15.4 (1.9)	13.7 (1.4)	58.4 (9.1)	50.0	< 0.001	0.82
Socialising - Conversing - Chatting	43.5 (7.7)	13.2 (1.7)	51.6 (5.9)	35.1	< 0.001	0.76
Experiencing active street life	16.1 (4.6)	14.4 (2)	59.7 (6.7)	33.1	< 0.001	0.75
Shopping	7.8 (0.9)	15.8 (2.2)	67.1 (13.7)	32.1	< 0.001	0.75
Residence	77.3 (6.4)	30.4 (3.6)	20.2 (6.2)	19.4	< 0.001	0.64
Road - Rail transportation	11.8 (2)	47.6 (3.6)	8.4 (1.7)	18.8	< 0.001	0.63
Appreciating cultural heritage	13 (4.1)	6.6 (0.9)	30.9 (8.8)	18.6	< 0.001	0.63
Car parking	17.3 (3)	39.2 (3.9)	6.3 (4.3)	8.4	0.002	0.43
Appreciating inland water	15.2 (3.6)	3 (0.5)	13.2 (10.3)	8.2	0.002	0.43
Industrial activity	1.2 (0.5)	31.8 (4.8)	2.3 (1.1)	7.2	0.004	0.40
Offices	13.3 (2)	43.5 (4.1)	33.4 (0.7)	6.6	0.006	0.37

* *Note: The table only includes statistically significant variables.*

Results graphically presented in Fig.7.8 showed that Cluster 1 was statistically significantly more when associated with "Residence," "Walking-Jogging-Running," and "Nature appreciation" and less associated with "Offices" than Clusters 2 and 3. This means that on average the 20 participants perceived the former activities and lands uses as appropriate, and the latter as inappropriate in the locations grouped into this cluster. It was interpreted as to represent residential areas.

Cluster 2 was more associated with "Road - Rail transportation," "Car parking," "Industrial activity," and less associated with "Walking - Jogging - Running," "Socialising - Conversing - Chatting," "Spending time with friends - family," and "Appreciating inland water." It was interpreted as to represent employment or industrial areas. Cluster 3 was more associated with "Shopping," "Experiencing active street life," "Restaurants - Cafes," and "Appreciating cultural heritage" compared to Cluster 1 and 3. It was interpreted so as to represent the Sheffield city centre. Finally, for each of the three clusters, Fig. 7.9 presents three examples of footages from the 25 videos used in the experiment.

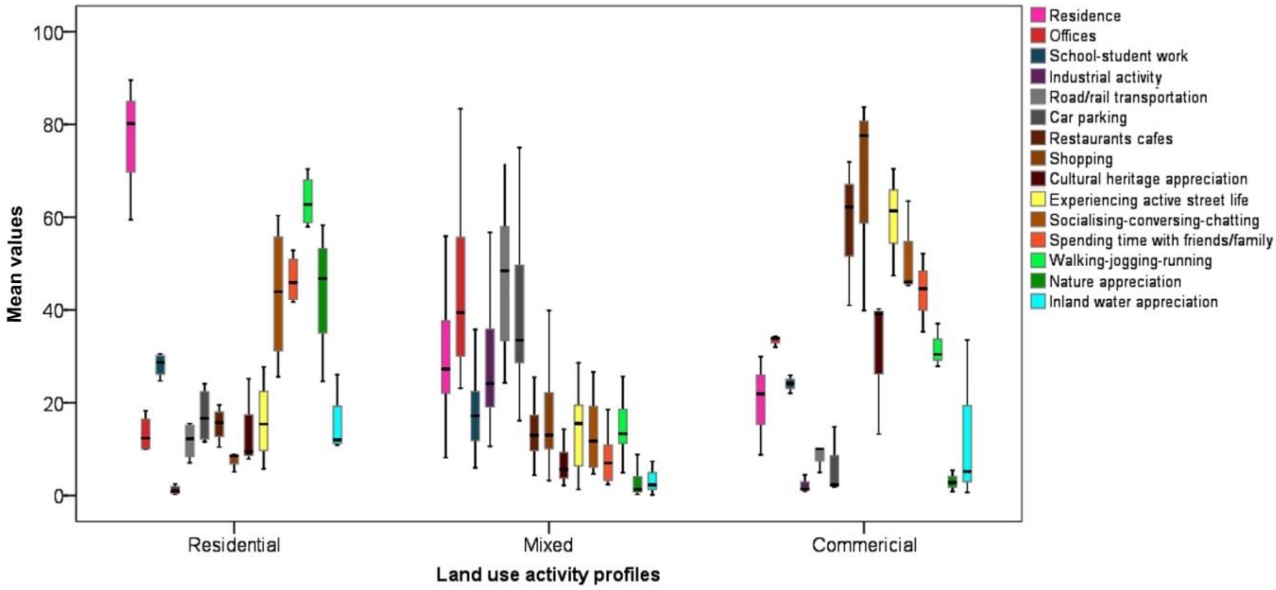

Fig.7.8. Box plot and error bars for the 15 land use activities, which were used it the MANOVA test. Higher values denote a higher impact on each cluster.

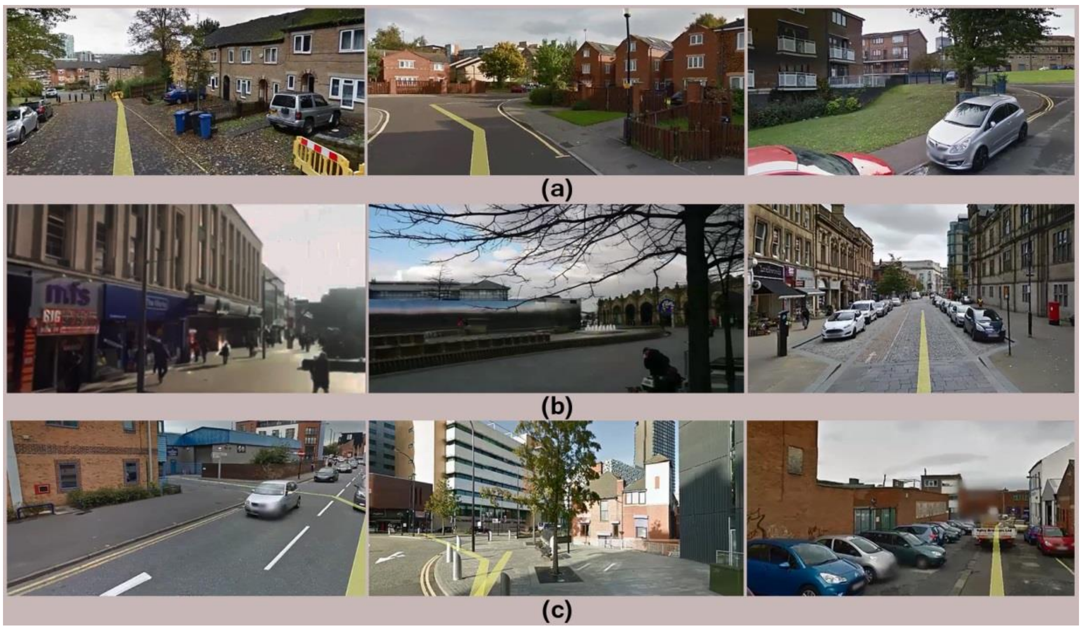

Fig.7.9. Examples of footages from the videos used on the experiment, divided on the three clusters: a) Cluster 1, b) Cluster 2, c) Cluster 3.

The Games-Howell post hoc test was used to identify where statistically significant mean differences existed between the three clusters. This test was applied since the sample size was relatively small, and equal variances could not be assumed. Table 7.6 presents the mean differences and p-values for the statistically significant variables.

Table 7.6. Mean differences (*MD*) of land use types, and *p*-values based on Games-Howell post-hoc test based on land use variables.

Land use type combination	Land use variable	MD	*p*
Cluster 1-3	Residence	46.922*	0.003
	Offices	-30.219*	<0.001
	Industrial-activity	-30.640*	<0.001
	Road/rail transportation	-35.871*	<0.001
	Car parking	-21.910*	0.002
	Shopping	-8.045*	0.007
	Spending time with friends/family	38.796*	<0.001
	Walking-jogging-running	48.662*	<0.001
	Nature appreciation	41.218*	0.019
Cluster 1-2	Residence	57.104*	0.003
	Offices	-20.160*	0.002
	Experiencing active street life	-43.632*	0.015
	Walking-jogging-running	31.654*	0.001
	Nature appreciation	41.108*	0.018
Cluster 2-3	Industrial-activity	29.578*	<0.001
	Road/rail transportation	39.263*	<0.001
	Car parking	32.861*	0.003
	Experiencing active street life	-45.267*	0.028
	Socialising-conversing-chatting	-38.420*	0.031
	Spending time with friends/family	-36.200*	0.026
	Walking-jogging-running	-17.008*	0.022

According to Table 7.6, the mean score for “walking-jogging-running” is the only variable that proved to be significantly different in all the three profiles. Then, "residence", "offices" and "nature appreciation" were significantly different for the pair combination of “Cluster 1-3” and “Cluster 1-2”, but not for the Cluster pair “2-3”. Between the first and the third cluster combination significant differences were observed for the following variables: “industrial activity”, “road/rail transportation”, "car parking" and "spending time with friends/family". Between the second pair (Cluster 1-2) and the third pair (Cluster 2-3), significant differences were detected only for the variable of "experiencing active street life". Finally the variables of "shopping" and "socialising-conversing-chatting" were proved significantly different only in the first and the third profile combination respectively.

Finally, a quality check was performed, investigating the stability of the cluster solution based on the 14 statistically significant variables presented in Table 7.5, compared to the original 22 variables. In a k-means cluster analysis, all experimental stimuli, apart from one, retained their cluster membership (see cluster "Land use" in Table 7.3).

7.4. Discussion

The current results primarily suggest that the outdoor environment in terms of land use activities and sound sources can be described with two major Components: C1 (manmade vs natural environment) and C2 (proximity to the city centre / presence of people). The meaningful association between PCA communalities, activities and sound sources confirms the above Component's interpretation. The overall results can be discussed organised in the following sections:

- *Components interpretation (C1, C2) based on human activities and predictors of urban morphology*

The manmade vs nature relationship as denoted by C1, confirms the nature tranquillity hypothesis, which supports the beneficial psychological effects from nature contemplation. Previous results towards this conclusion were drawn based on experiments both on reporting people's feelings from selecting scenery images (Kaplan et al., 1972; Ulrich, 1979) and also in terms of direct exposure to such environments (Alcock et al., 2014; Ward Thompson et al., 2012). On the same wavelength, the positive association between C1 and the distance from minor roads confirms that higher values of this Component were expected away from the city centre, where minor roads were dominant. Although, it has been found that places with natural elements are also preferred within the urban realm (R. Kaplan, 1983) the main interpretation for C1 is more likely to be applicable in cities that follow a separation strategy in the urban form (Kühn, 2003). In such cases, green spaces shape a green belt around the city without being an internal part of it. Nevertheless, different results for C1 can be extracted when investigating cities with an integration strategy following the doctrine of the "Garden City" model introduced by Howard (1902). In these cases, public green spaces have prestigious positions in the city centres and not in the outskirts.

The connection of C2 with the proximity to the city centre and the presence of people, is in line with the study from Yang and Kang (2005, p69) who also recognised the prevalence of human sounds in particular areas of Sheffield city centre. Similarly, Davies et al. (2013) considered vibrancy from human voices as one of the two principal components for soundscape descriptors. Despite the absence of green, places where human sounds prevail have been considered as an evidence of ideal urban soundscapes (Guastavino, 2003 cited in Raimbault & Dubois, 2005). Moreover, easily accessible and walkable areas have been found to boost social interaction and the attractiveness of such locations. As regards the correlation of C2 with major roads, this association can be considered more likely to be found in radial cities – as categorised by Margaritis & Kang (2016) – where the main commercial activities are explored within the traditional city centre. In these cases, major roads usually constitute a ring around the broader city centre.

- *Identification of sound sources, activity profiles and their interrelationship*

Concerning the cluster analysis, three groups were recognised per category both for the sound sources and the urban activity profiles with a significant association among them. Natural sounds prevailed in residential areas, traffic sounds in mixed land use areas and human sounds in commercial areas. This diversity of the urban environment is related to the semantic properties of sound sources, which further allow us to assess the urban soundscape, as noted by Raimbault & Bubois (2009). From the planning viewpoint, this perspective should further be explored and established, since semantic properties of sound sources emphasise more on "human presence" or social activities and less in the conventional approach of absolute noise level limits.

- *Identification of suitable human activities for different activity profiles*

At last, the MANOVA results revealed the significant differences among the three clusters in terms of specific land use activities. It is important that at least in one cluster there was a significant difference in the mean values of road/rail transportation; as a proof that traffic-related land use and consequently traffic noise was not always the obvious outstanding sound source of the urban environment as Raimbault & Dubois (2006) found. Also "residence" and "nature appreciation" were significantly different in the same clusters, showing the effective integration of housing policy and nature preservation within the Ring Road area. However, the mixed land use character of Cluster 2 constitutes a proof of the area's complexity and diversified character. This element is important in all cities for the further consideration of positive soundscapes in terms of vibrancy or calmness (Davies et al., 2013).

In comparison to previous soundscape research (Aletta & Kang, 2015; Aletta et al., 2016; Jeon, et al., 2013; Liu et al., 2014a) used more points within the city. The land use activity dataset was broad enough to cover all possible combinations of activities. Moreover, a comprehensive set of binaural recordings from outdoor soundscapes was applied as well. All these factors are likely to support the stability and generalization of the proposed relationships in other cities. This can provide a useful framework for future combined research and practice.

Despite possible limitations, such as the drawbacks of a laboratory experiment and the different morphological features of each city, the connection of land use activities with sound sources through a functional viewpoint can be used as a tool for urban planners and designers. Moreover, similar examples can form the structure of pilot studies, where citizens can be involved, raising the importance of participatory planning.

7.5. Conclusions

The primary aim of this study was to investigate the relationship between sound sources and land use in the urban environment. For this reason binaural recordings from various spots in Sheffield city centre were combined with visual stimuli in a listening test. Several intermediate steps were followed towards the final aim, primarily including a PCA analysis on the appropriateness of various land use and social activities in the urban environment.

It was found that land use activities and sound sources can be combined and described in terms of two basic Components (C1, C2). It was also found that a better environment close to nature (high C1) is more likely to be achieved when both the green space coverage and the distance from minor roads is increased. On the contrary, places closer to the local city centre (high C2) or with high presence of people were associated and best predicted by low green space coverage and high distance from major roads.

In the cluster analysis, three groups (typologies) were recognised per category both for the sound sources and the land use profiles. According to the association between land use and sound sources, Cluster 1 was mainly dominated by residential places and was likely to present natural and human sounds. Areas in Cluster 2 presented a mixed land use character and were more likely to be associated with traffic sounds. Finally, areas belonging in Cluster 3 were mainly commercial spots, which were more likely to appear human sounds.

The last part of the analysis showed that there were statistically significant differences in the mean values between the three clusters of land use activities and all of them were related to the physical and social environment. Overall, it was shown that human, social and recreational needs can be satisfied based on the proper combination of two components. Such an approach between land use activities and sound sources is meaningful for the interpretation and the design of the urban environment in a holistic way.

Chapter 8

Positioning soundscape mapping in environmental noise management and urban planning. Case studies in two UK cities.

The content of this chapter is ready to be submitted as a journal paper in the journal of Noise Mapping

8. Positioning soundscape mapping in environmental noise management and urban planning. Case studies in two UK cities.

The previous investigated the sound sources in terms of intensity and prevalence in the acoustic environment in combination with land use activity profiles for specific spots. This Chapter also refers to sound sources and profiles, but from a more pluralistic perspective enriched with predictive perceptual maps. A detailed review of previous studies dealing with mapping in the design process and soundscape is described in Section 8.1. The suggestion for an improved planning framework where soundscape is included is described in Section 8.2. Additionally, Sections 8.3 and 8.4 refer to the model development for sound source maps and soundscape maps respectively, including data profiling and identification of similar areas. A discussion on model effectiveness is presented in Section 8.5 with the final conclusions to be mentioned in Section 8.6.

8.1 Previous studies

The current European practice in noise policy the last fifteen years is primarily focused on the application of guidelines and measures related to noise reduction as described in the Environmental Noise Directive (END), (2002/49/EC). In the same wavelength, noise action plans and all the supportive documentation for strategic noise mapping (Environmental Protection Agency, 2011) are focused mainly on improving the accuracy of the END and increase the precision of the reported population exposed at high noise bands.

In this framework, mapping is a useful tool to aid the planning and design process (Kang & Schulte-Fortkamp, 2015). Some studies have tried to formulate a better traffic model by using dynamic noise mapping techniques (Szczodrak et al. 2013; Wei et al., 2016) or even data extracted from participatory noise mapping techniques (D’Hondt et al., 2013; Guillaume et al., 2016). Moreover, the need to combine a holistic approach in environmental noise policy - by combining the noise mapping with the soundscape approach - has recently been raised by the European Environmental Agency (EEA) in the Good Practice Guide on Quiet Areas (EEA, 2014).

However, the ultimate aim is a gradual incorporation of the soundscape design in the planning process in a successful way. This process can be brought into reality starting from a top-down approach initially in the policy stage and then elaborating the process in the macro-scale. At that level, prediction maps refer to a specific landscape and cover areas larger than streets or squares. Through this process, thematic maps can be developed as an additional layer of landscape information (Kang & Schulte-Fortkamp, 2015). As Kang (2007b) mentions: "…*it is important to put soundscape into the intentional design process comparable to landscape and to introduce the theories of soundscape into the design process of urban public spaces"*. Lately, suggestions of applied soundscape practises were introduced in the Master plan level thanks to the initiative of the local authorities. Easteal et al. (2014) presented this approach for the city of Brighton, while more examples of cooperation between Municipalities and Universities around Europe were presented by Alves et al. (2015) highlighted in the EU SONORUS project.

Therefore, this Chapter has a dual aim. Primarily, the development of a mapping model to aid soundscape planning and secondly the implementation and the assessment of its effectiveness in two UK cities with similar land use characteristics and different road network structure. The same cities were analysed from the morphological viewpoint in Chapter 5.

8.2. Planning framework

In terms of a common framework for soundscape in the planning process Adams et al. (2009) have described the stages in the UK urban planning system, where soundscape can be incorporated in. De Coensel et al. (2010) inspired by the previous model divided the acoustic planning process in two phases, as shown in Fig.8.1. The first one (Phase 1) refers to the achievement of general noise objectives, such as the maximum noise levels in facades and the second one (Phase 2) refers to the detailed acoustic design process through the combination of appropriate urban activities and sound sources as previously investigated by Margaritis et al. (2015).

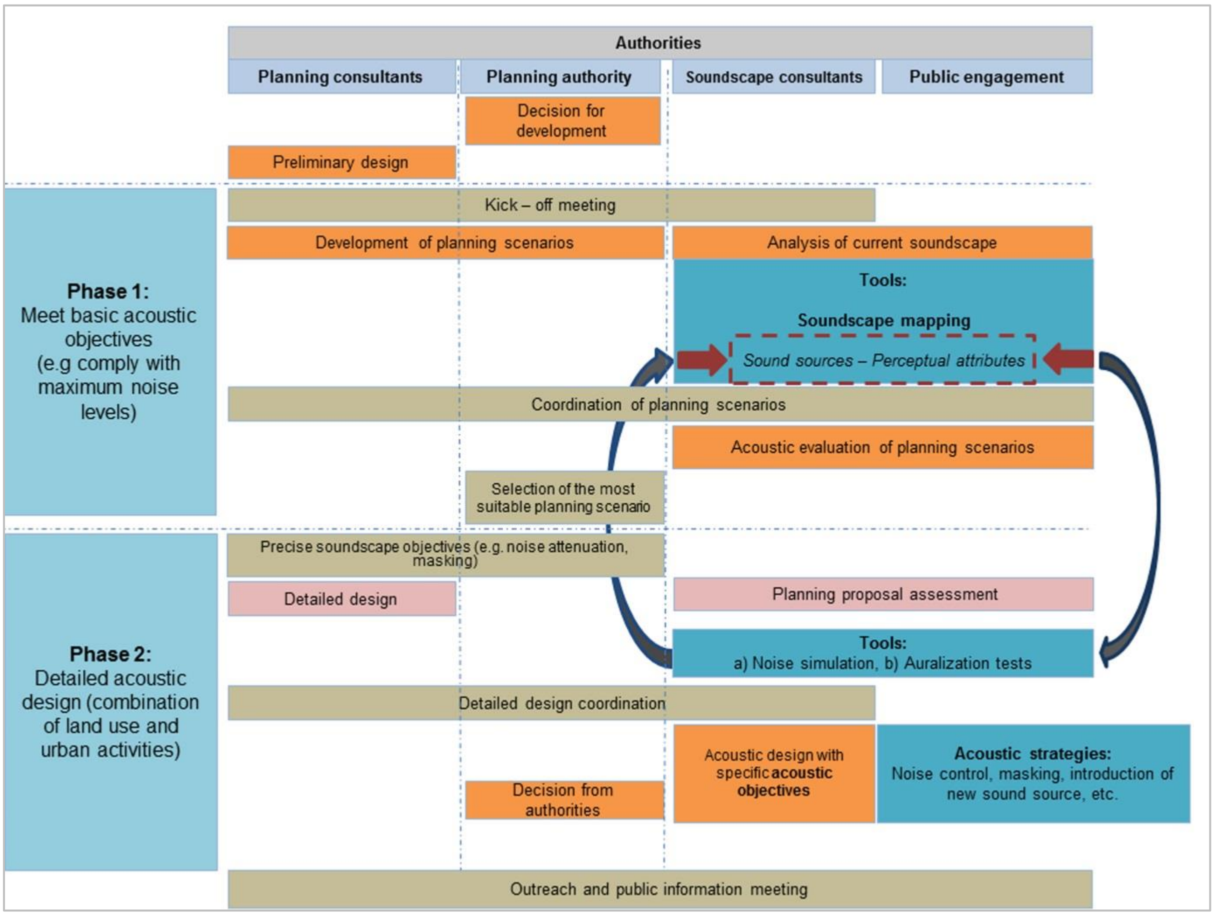

Fig.8.1. A suggestion for the incorporation of soundscape mapping in the planning framework and the authorities involved based on the model of De Coensel et al. (2010).

In this process, soundscape consideration and in particular soundscape mapping is more suitable in the first phase (see Fig.8.1), where the analysis of the existing situation is required. However, the assessment process can also follow a feedback routine between “Phase 1” and “Phase 2” depending on the number of the planning scenarios. In this process, the most widely applied tools for soundscape mapping in terms of content include the spatial variability of sound sources and the variability of perceptual attributes (Fig.8.1). A detailed representation of the individual steps in the soundscape mapping framework is presented in Fig.8.2 and in the following sections. Although there are five main steps, soundscape profiling is presented as an additional sixth provisional stage, since it comes naturally in the whole process and can provide specific details relative to the character of the area.

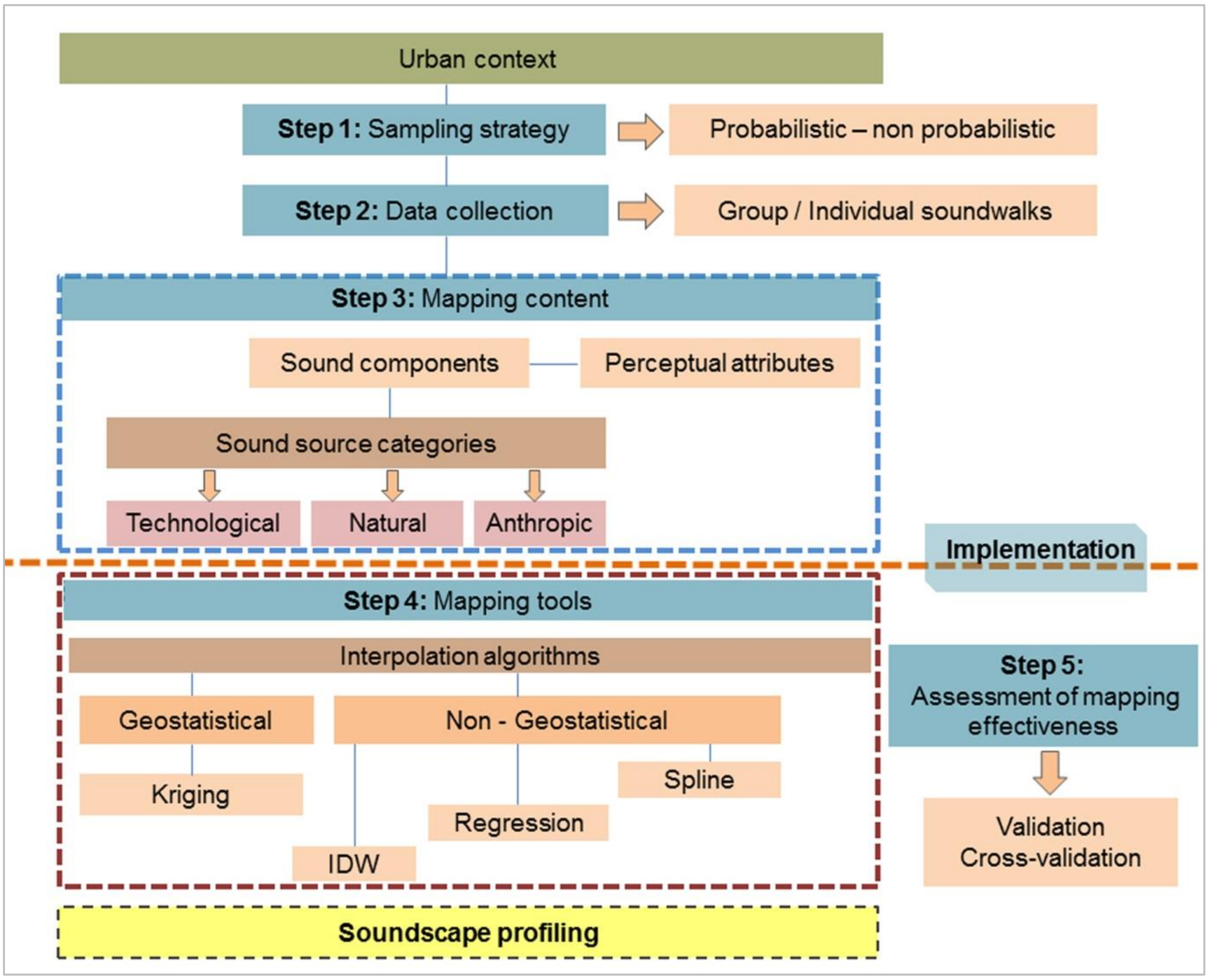

Fig.8.2. Individual steps in the soundscape mapping process starting from the sampling strategy and ending in the assessment of the mapping effectiveness. Soundscape profiling is an optional step in this process.

8.2.1. Sampling strategy

Depending on the geometry of the case study site, the sampling method and location points should be adjusted accordingly. For practical purposes, sampling points outside the main sampling area should also be considered to allow the interpolation algorithm to produce a broad enough raster surface. Both the sample size and the position (density) of the evaluation points are guides for a successful interpolation (Negreiros et al., 2010) and consequently for a representative soundscape map. In that way, also the objective of equal spatial coverage is satisfied (Wang et al., 2012).

Emphasising on soundwalks for data collection, the different sampling techniques that can be applied include probabilistic methods, such as random, systematic, stratified or cluster sampling and non-probabilistic or selective methods. The latter comprise various options with purposive, diversity and judgment sampling to be indicated. In particular, diversity sampling is used when it is essential to depict a wide range of values (Derthick et al., 2003).

For a priori designed soundwalks, systematic sampling methods impose a limit on the minimum distances among points; however they can be more accurate than random sampling methods. The latter offer better representation of the variability, but less representative surfaces (Negreiros et al., 2010) in terms of soundscape. On the other hand, diversity sampling is essential when there is a good knowledge of the area and various types of urban spaces or elements of the sound environment are included (Jeon et al., 2013).

8.2.2. Data collection

Soundwalk methods can be clustered in two clusters. The first one diversifies them according to the time of selecting the measurement points, which varies either before (a prioir) or during the measurement period. The second cluster distinguishes soundwalks based on the data collection process from the participants, which can take place either in groups or individually.

Concerning the first cluster, sample points in previous soundwalks were based both on a priori (Adams et al., 2008; Aletta et al., 2016; Berglund & Nilsson, 2006) and on-site decisions (Adams et al., 2006; Jeon et al., 2011) depending on the objectives of the investigation. Both approaches have advantages and disadvantages. In reference to the second cluster, group soundwalks usually include a small amount of points based on a landmark or a specific place attribute; however results can be more robust compared to individual assessment. Biased results can occur, if the study is focused solely on the researchers' intentions by underestimating the participants' experiences (Jeon et al., 2013), which is the primary aim of the soundwalk. On the other hand, individual soundwalks (Jeon et al., 2011) offer higher number of sampling points; However, they can lead to biased results when locations are chosen in an arbitrary way from the researchers.

8.2.3. Mapping tools

Soundscape mapping depends on the use of interpolation tools, which can predict cell values in unknown locations based on the cells with known values in the study area. There are various interpolation tools in mapping softwares such as ArcGIS depending on the nature of the phenomena to be modelled. What can be taken for sure is that almost in all cases different interpolation methods will produce different results (Childs, 2004). Since there are no hard and fast rules for soundscape mapping, previous studies have used several interpolation algorithms such as: Kriging (Aletta & Kang, 2015; Can et al., 2014), Inverse Distance Weighted (IDW) (Hong & Jeon, 2017) or Spline (Liu et al., 2013).

Kriging belongs in the group of geostatistical mapping methods, while IDW and Spline in the group of non-geostatistical interpolation methods. The main advantages of Kriging compared to the latter group are the use of semivariogram (Myers, 1991), which measures the strength of statistical correlation as a function of distance and also provides an uncertainty estimation. Semivariogram provides the level of spatial smoothing in the predicted values based on the actual observations and the uncertainty is given for the predicted values taking into account the spatial autocorrelation (Aalto et al., 2013).

Despite their differences, spatial interpolation tools comply with some general rules for the expected outcomes. For example, IDW should be used when there is an initial dense set of points, since it can capture the local surface variation. On the other hand, Spline can predict ridges and valleys in the data (Childs, 2004) and is the optimal method for a smooth representation of phenomena such as temperature. Both IDW and Kriging can recognise "*warm*" and "*cold*" areas, however, IDW is more deterministic and more likely to produce "bull's-eyes" around data location. On the other hand, Kriging assumes a stationary and stochastic approach and provides the user with more options when controlling for the final outcome.

8.2.4. Mapping content

So far, soundscape mapping in different scales has been perceived as a process of visualizing three main parameters: a) sound sources, b) psychoacoustic parameters and c) perceptual attributes relevant to soundscape quality. In particular, previous studies for mapping the variability of sound sources (Aiello et al., 2016; Margaritis et al., 2015; Rodríguez-Manzo et al., 2015) lack a common semantic categorization for the sources and use various geostatistical and non-geostatistical mapping techniques. A few studies have dealt with the representation of psychoacoustic parameters (Hong & Jeon, 2017; Lavandier et al., 2016) such as loudness, sharpness or pleasantness in the urban environments. However, very few studies (Aletta & Kang, 2015; Kropp et al., 2016) have dealt with the overall assessment of the sound environment as a holistic process and in cooperation with the local planning authorities or City Councils.

8.2.5. Assessment of mapping effectiveness

The evaluation of the interpolation results and the performance of the model in unknown locations can be performed using the validation or the cross-validation process. Both processes work under the same concept by consecutively removing one or more data points and predicting the respective values using the remaining data entries (Dubrule, 1983). This method can assess the quality of the model and compare different models until to find the optimal one, which best fits with the error diagnostic criteria. The degree of bias and uncertainty that makes a prediction successful is automatically assessed in the cross-validation process using the Geostatistical Wizard to run the interpolation. The conditions that should be met in both cases are presented in Table 8.1 below:

Table 8.1. Error diagnostics during the cross-validation process in Kriging interpolation

Prediction errors	Optimisation target
Bias assessment	
Mean Prediction Error (MPE)	MPE→0
Mean Standardised Error (MSE)	MSE→0
Root Mean Squared Prediction Error (RMSPE)	RMSPE→ min
Uncertainty assessment	
Average Standard Error (ASE)	ASE≈RMSPE
Root Mean Square Standardised Error (RMSSE)	RMSSE≈1

In the first case, the bias assessment can give an insight on how close are the predicted values to the true values. In unbiased models the MPE and the MSE should be very close to zero with a minimum RMSPE. In the second case, the uncertainty assessment measures the prediction standard errors so as to estimate the correct variability. When the ASE is similar to the RMSPE, the variability is correctly assessed. In different cases it is either underestimated (ASE< RMSPE) or overestimated (ASE> RMSPE). Finally, similar values in these two error indices can evoke optimal values close to "1" for the RMSSE (Table 8.1).

Finally, it is worth mentioning the role of the semivariogram in the cross-validation process. The semivariogram, as shown in Fig.8.3, practically provides a graphic representation of the spatial correlation of the data points and their neighbours. The distances between pairs at which the variogram is calculated are called lags. Then, the lag size is the maximum distance into which pairs of points are grouped in order to reduce the large number of possible combinations. The nugget represents the small-scale variability of the data and a small part of the error represented in the y-axis. The range represents the distance over which pairs of points are not spatially correlated. Lastly, the sill represents the maximum detected variability between pairs of points.

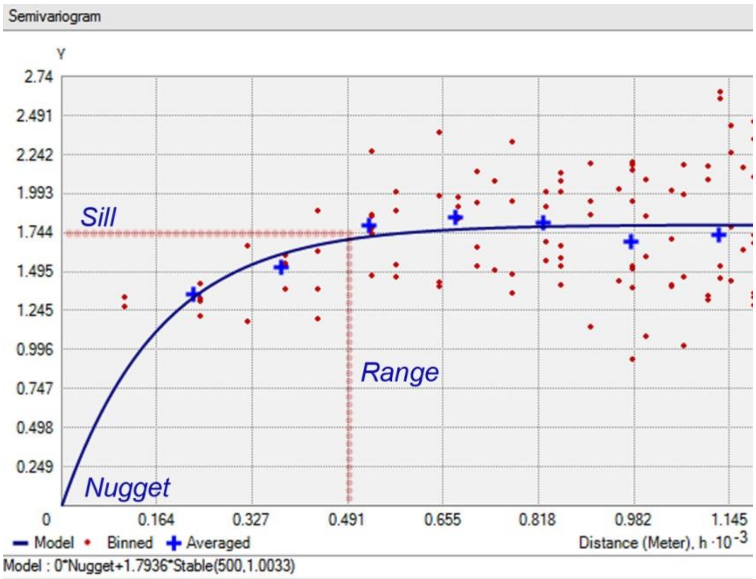

Fig.8.3. Typical example of semivariogram with the basic components of nugget, range and sill. The red dots represent groups of points (bins) within the lag distance.

8.3. Model development for sound source maps

In the current case study, cities of Sheffield and Brighton are compared following the methodoly, which refers to the two soundwalk approaches as explained in

Section 8.2.2. In particular, the data in Sheffield was collected based on an individual assessment by a single person, while in Brighton a group soundwalk was followed with an a priori consideration of the selected points.

8.3.1. Case study site

The study area in Sheffield covers the inner city centre, since it combines many different land use characteristics and can also be considered a typical example of a post-industrial average-sized European city. Furthermore, the area is characterised by a dense and varied network of local and national level of streets as well as transport infrastructures (e.g. railway, tram, buses). The total area extends to 3.6 km^2. A grid of 200 × 200m was implemented, segregating the region in 90 tiles as it can be seen in Fig.8.4. The measurement points were defined using a systematic sampling method with a fixed distance interval of 200 meters from one measurement point to the other. Since the first point corresponds to the tile centroid all the following points refer also to centroids. In this way, a smooth and accurate prediction surface was created compared to a random sampling method (Griffith & Layne, 1999). In case a centroid resulted to be non-accessible due to legal or physical obstacles (e.g. buildings), the closest publicly accessible point was selected.

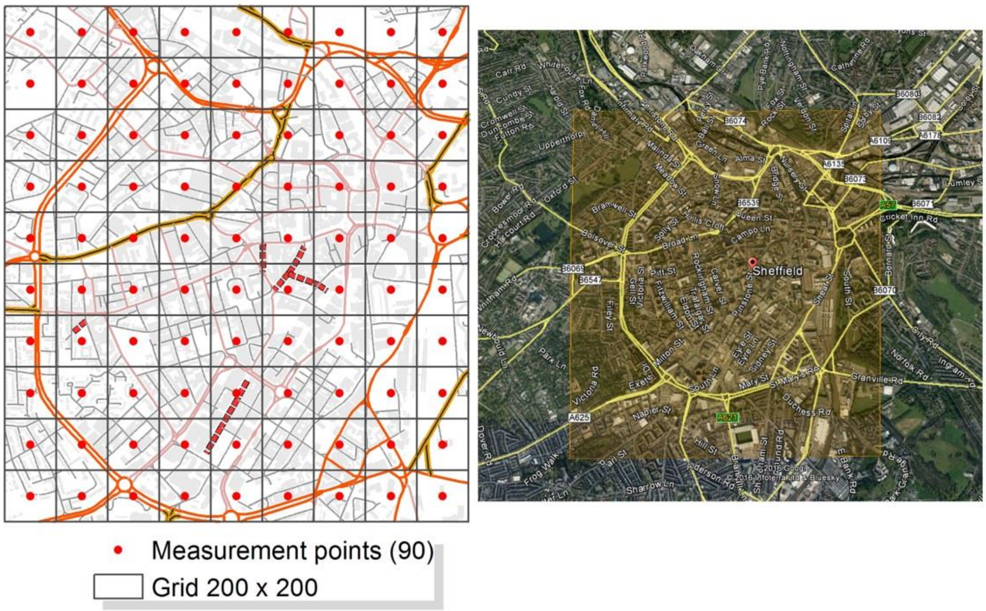

Fig.8.4. Representation of the study area in Sheffield with the 90 measurement points and the applied grid.

8.3.2. Data collection

Initially, a researcher performed daily measurements in all the 90 centroids (Fig.8.2) for four working weeks. The measurement period was divided in two time slots: morning (09:00-12:00) and afternoon (14:00-17:00). For the on-site audio recordings, the equipment included a stereo microphone kit (DPA 4060) connected to a digital audio recorder (R-44 Edirol), a mini microphone (MicW i436), and a sound calibrator. The "*Audiotool*" Android application was installed on a mobile phone with the microphone MicW i436 attached. This application was used to record the sound pressure levels at each location. The final L_{Aeq} levels per spot were the average levels of both measurement sessions (morning-evening). During this time period the researcher had to mark the number of audible sound sources at each point (Appendix E1) by checking a form with multiple options as shown in Fig.8.5. All sound sources were divided in three general groups ("Technological", "Natural", "Anthropic") and further subdivided in subcategories according to the taxonomy followed by Brown et al. (2011) for soundscape studies.

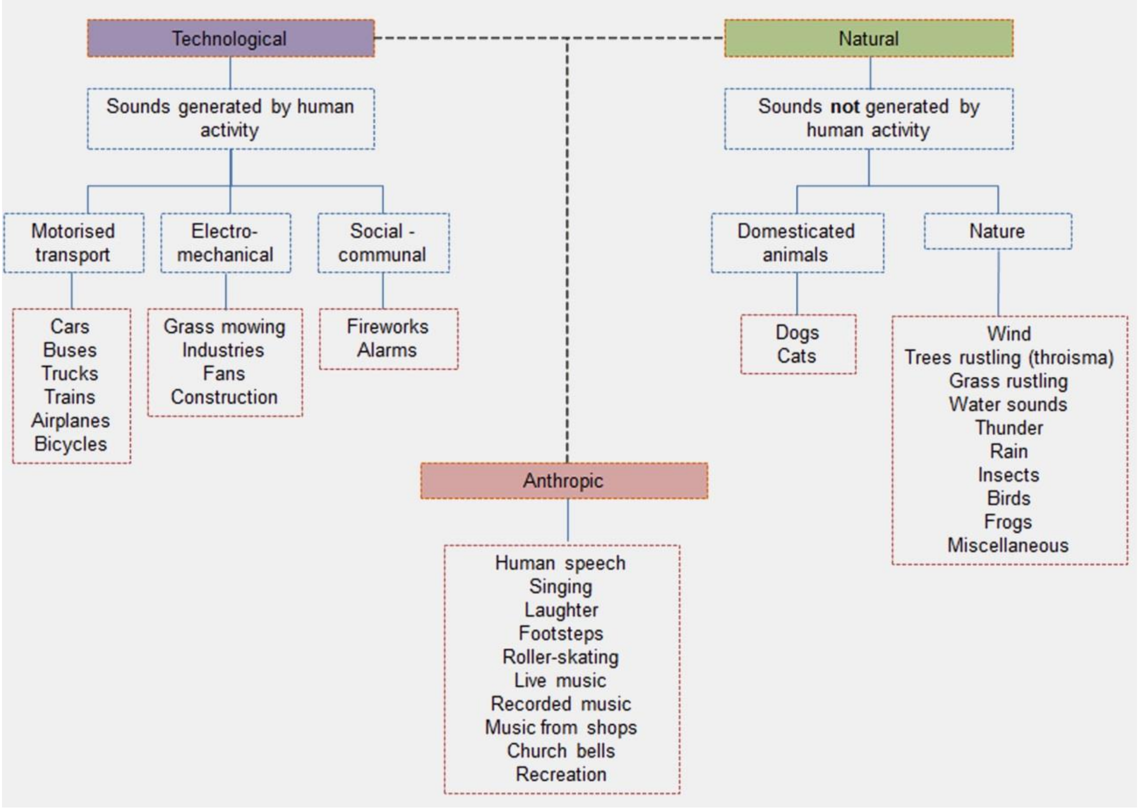

Fig.8.5. Three main types of sound sources with subcategories used during the measurement campaign. The classification taxonomy follows the suggested paradigm of Brown et al., (2011).

8.3.3. Mapping tools

After the data collection was finalised, all the information related to the audible sound sources was transferred in the ArcGIS software (v.10.1) for further processing. The audible sources' occurrences were aggregated per type and these values were averaged over morning and afternoon ($Technological_{AVG}$= 5, $Natural_{AVG}$ = 5, $Anthropic_{AVG}$ = 5.5). Then a prediction surface was created using the Kriging interpolation method for the technological, natural and anthropic sound sources accordingly. The surfaces were created based on the Ordinary Kriging method and the spherical semivariogram model, considering all the 90 points of the study area.

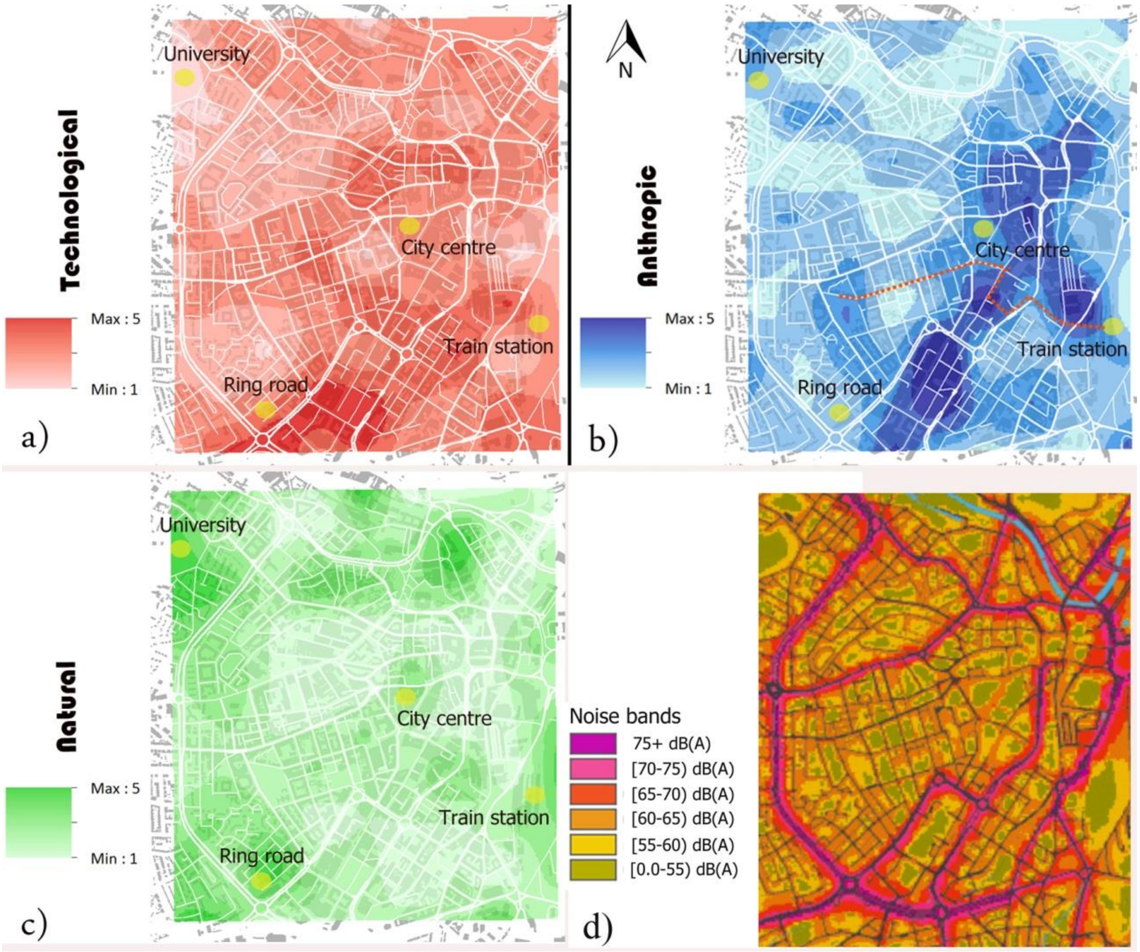

Fig.8.6. Spatial variability of the audible sound sources (technological, anthropic, natural) in comparison with the corresponding noise map for the area from the first round of noise mapping.

8.3.4. Mapping content

Three soundscape maps were created for the study area. Fig.8.6 shows the spatial variability of audible technological, anthropic and natural sound sources respectively. As it can be seen in Fig.8.6a, areas on top left side - mainly covered by University buildings, parks and residencies - present low levels of technological sources. The same happens in the site above the Ring Road A61, which is a purely residential area. Low technological sources were also present in the right side close to the train station, since it is a space with many natural elements. Similarly, another site with low levels of technological sounds can be identified around the city centre, where pedestrian streets prevail. On the other hand, high concentration of technological sources was observed in the roundabouts of the Ring Road in St.

Mary's Gate and along the main streets in the central zone of the study area. The highest number of technological sources was observed in the southern part, which was expected, since it is the main entrance to the city centre and also combines light industrial and commercial activities.

Anthropic sources presented in Fig.8.6b, can provide a very representative idea of Sheffield city centre. They create a corridor from the North, where Park Square and river Don are placed, up to the South, where the Moor market is located. Along this line there are many commercial activities, services, entertaining activities and active social life during the greatest part of the day. Evident high values of anthropic presence can be seen also around the area of the train station. This area is partly common with the famous "gold route" of fountain stops around the city (Sheffield City Council, 2012) and is expected to attract more people as it is very friendly - designed for pedestrians. The presence of human sources is limited on the rest of the study area and especially on the south close to the ring road. What is interesting is the extensive degree of intersection between the high values of "anthropic" and "technological" sources, which can be justified by the commercial character of the area.

Then, in Fig.8.6c it can be seen that increased number of natural sources is evident in specific areas around the ring road which constitutes parks, exclusive residential areas or places close to river Don on the North. The West side of the study area is more privileged in terms of natural sounds, because of the proximity to urban green spaces and playgrounds, while the house type with backyards or front yards enhances the presence of birds and small animals. The city centre presents the lowest aggregation of natural sounds with a small presence in various squares. It is also surprising that most of these places are along the main highway creating a contradictory soundscape environment with increased number of technological and natural sources very close to each other.

Another point to consider is the comparison between the noise map of Sheffield city centre as shown in Fig.8.6d and the sound sources maps. There are expected similarities between the representation of technological sources (Fig.8.6a) and the traffic noise levels in the noise map. However, there is an extra source of information that refers to natural and anthropic sources, which cannot be represented in the noise maps. Complementary characteristics like those constitute a positive example of soundscape planning with further perspectives in the planning or design process.

8.3.5 Mapping effectiveness and implementation

As discussed in section 8.2.5 it is important to know the model's performance after implementing the interpolation. For the above sound source maps the effectiveness was assessed using the Geostatistical Wizard and the cross-validation process. The optimal fit of the semivariogram model was achieved using a lag size of 200 meters in accordance with the grid size. This approach is also supported by Isaak & Srivastava (1990) for areas where the samples follow a (pseudo) regular grid. The number of lags was kept to 12 and the nugget was adjusted to 500 meters. The final results of the cross-validation process can be seen in Table 8.2.

Table 8.2. Error diagnostics using the cross-validation process for the sound sources

Conditions	Errors	Anthropic	Natural	Technological
MPE→0	MPE	0.011	-0.025	0.005
MSE→0	MSE	0.010	-0.019	0.005
RMSPE→min	RMSPE	1.200	1.182	0.941
ASE=RMSPE	ASE	1.170	1.182	0.890
RMSSE≈1	RMSSE	1.030	1.000	1.050

The model presented small error values in all the three sound source categories with the best performance to be presented in the technological sources. Overall, the predicted values were close to the measured ones with the highest errors to be present only in the extreme cases of outlier measurements either close to 0 or close to 6 in a six-point scale. Finally, the fact that the ASE was lower than the RMSPE in all cases provides evidence that the variability was slightly underestimated.

8.3.6. Soundscape profiling

A step forward after the cores five steps that are included in the proposed framework (see Fig.8.2) the visualisation of the sound sources variability as presented above was the identification of possible profiles, which would provide further information on the character of the area. The analysis was performed on the initial grid level of 200x200 meters and the individual steps towards the profile creation are described below.

Initially, the values for all sound sources in every measurement point were standardised to range between (–2) and (+2) using integer numbers. Afterwards, the minimum and maximum values were selected for each sound source in order to create the “High” (H) and “Low” (L) profiles. All the (H) represent cases where the value for each sound source in the respective tile is equal to (+2). Correspondingly, the (L) values represent cases where the value for each sound source in the tile is equal to (–2). Based on the three sound source categories a maximum combination of eight pairs was formed as presented in Fig.8.7.

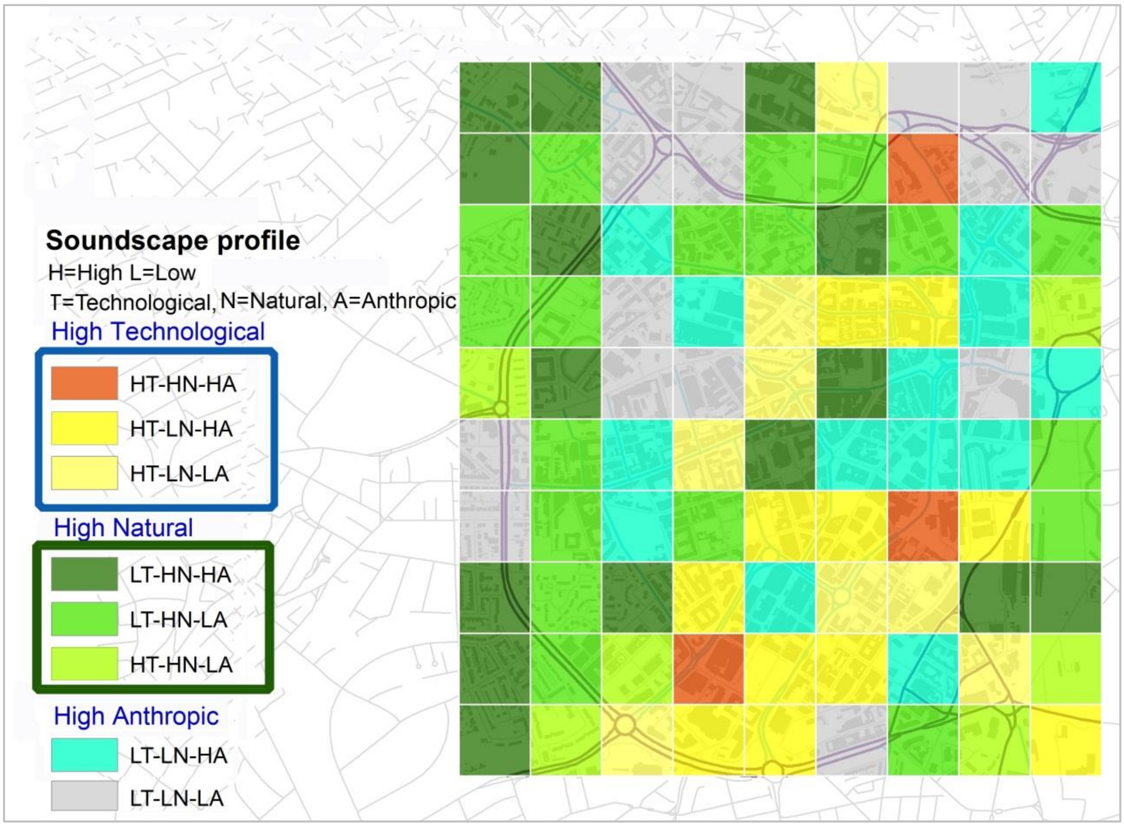

Fig.8.7. Representation of the eight “High” (H) and “Low” (L) profiles of the sound sources and arranging them into three larger groups based on the maximum levels per sound source within the study area.

The first group includes three classes and refers to grids with maximum values for technological sources, classified as “High Technological”. The second group refers to profiles with maximum values for natural sources, classified as “High Natural”. Then, the next group with a single profile was classified as “High Anthropic” due to the maximum levels detected in the respective sound source. Finally, the last profile with minimum values in all sound sources (grey colour) was left out as an outlier in the current analysis with no need for further classification.

It was found that the majority of the tiles (43%) belong in the “High Natural” profiles showing that there were areas with various natural sources that outnumbered technological and anthropic sources. These areas were mainly located outside or in the borders of the Ring Road. Another 24% of the tiles represented one of the three combinations in the “High Technological” profile. These places were located either in some central locations close to the city centre or in the middle and southern zone of the case study area, where technological sources are numerous. There were also fourteen tiles (16%) spread in the study area representing a prevalence in anthropic sources. These tiles were distributed in residential areas close to the left side of the A61, on the western side of the Ring Road, the pedestrian areas of the city centre, the Moor market area and close to the train station. Finally, 17% of the total area was covered by tiles characterised by the minimum score in all sound sources. These places were mainly located in the northern part of the study area around the Ring Road, covering old industrial sites or areas close to river Don. Similar places were identified in mixed educational and tertiary service zones close to University premises, presenting low noise variability during the measurement period.

8.4. Model development for soundscape maps

A first conclusion that can be drawn from the literature review is the lack of studies in the field of soundscape mapping compared to noise mapping. As Rodríguez-Manzo et al., (2015) mention, one possible reason is the absence of objective data to generate such maps compared to noise maps. Previous works in this field refer to the spatial representation of loudness and soundscape quality (Hong & Jeon, 2017; Lavandier et al., 2016), or the soundscape ecology in parks (Liu et al., 2013) and rural areas (Papadimitriou et al., 2009). As expected, the majority of these studies are disconnected from the planning process or present the potential to be integrated in this field. Apart from the current study, also Alves et al. (2015) and Aletta & Kang (2015) made an attempt to bridge this gap in cooperation with local City Councils or planning authorities.

8.4.1 Case study site

The test site of this model is placed in the city centre of Brighton & Hove (UK). It corresponds to the Valley Gardens area and extends from the seafront roundabout (Brighton dock) up to 1.5 km into the city. The site is a key access point for entering and leaving the city and also for accessing the seaside; consequently it is substantially affected by high noise levels from traffic. Overall, the green areas within the site are currently used by the residents only as a transition point and not for their leisure activities. Within the study area, eight locations were selected as shown in Fig.8.8, namely: the Seafront (1), the Old Steine (2), the Royal Pavilion (3), the statue in Victoria Gardens South (4), the Mazda Fountain in Victoria Gardens South (5), Victoria Gardens North (6), St. Peter's Church (7) and the Level (8). The concept for selecting such places was to provide a sufficient variability of different urban contexts and corresponding acoustic environments within the study area.

Fig.8.8. The eight locations selected for the soundwalk and the binaural recordings.

The current study refers to the assessment of the present condition of the acoustic environment before any intervention. Key areas for the next stage include specific measures towards noise absorption or masking interventions and the provision of positive soundscape elements.

8.4.2. Data collection

Twenty-one people between 25 and 68 years old, participated in the soundwalk (16 men; 5 women, Age_{AVG} = 38.7 years, SD = 11.5). The soundwalk took place during a week day (Monday morning) from 09:30 am to 10:30 am. The researchers led the participants by walking through the study area and making stops at the eight selected locations. The basis for selecting eight points was to provide the participants with a relatively limited number of spots that were able to inform them about the overall sound environment of the site. This is in line with conventional group soundwalk methods (Adams et al., 2008).

For each location, participants were asked to listen to the sonic environment for a period of two minutes and fill in a structured questionnaire (Appendix E2). The current research refers to the question: "*For each of the eight scales below, to what extent do you agree or disagree that the present surrounding sound environment is…*". In all cases, a scale of no fixed answers was used in order to avoid bias or rounded answers. Participants had to put in a mark on a 10-cm continuous scale assessing eight perceptual attributes namely: "pleasant", "chaotic", "exciting", "uneventful", "calm", "unpleasant", "eventful" and "monotonous" following the soundscape model suggested by Axelsson, Nilsson, & Burglund, (2010). The marking scale ranged from "*strongly disagree*" to "*strongly agree*".

8.4.3. Mapping tools

A different approach for the characterization of the sound environment was applied in Brighton. In contrast to Sheffield, the data collection for this city was based on a 60min-group soundwalk, emphasizing more on perceptual characteristics and not on sound sources. Also the soundscape protocol that was followed in this case was different as described in detail in Section 8.4.2. The input data for the current implementation in Brighton were based on the mean values of the individual responses provided by the 21 people who assessed the perceptual attributes and sound sources' profiles throughout the area. Specifically, the mean values of the attributes: "pleasant", "calm", "uneventful", "monotonous", "unpleasant", "chaotic", "eventful" and "exciting" were used as input variables for the Kriging interpolation method in order to produce the corresponding prediction maps using the Spatial Analyst tool in ArcGIS. The analysis was performed using the Ordinary

Kriging, which assumes a stationary and stochastic approach with a constant mean value and random errors. The degree of spatial autocorrelation among the data was assessed by the semivariogram. In this case a spherical semivariogram was selected, since there were no directional effects among the eight sample points.

8.4.4. Mapping content

The spatial distribution of perceptual attributes in the study area was visualised using a colour ramp as depicted in Fig.8.9. It ranges from 0 to 10, following the ten-point scale of the soundwalk questionnaire. For graphical purposes the colour ramp consists of 20 colours, each representing a 0.5 step in the ten-point scale. In that way all maps were rendered comparable to each other with graphically visible variations. It is worth noting that interpolation processes do not take into account the physics of sound propagation such as reflections from ground or buildings nor the actual sound distribution. They rather aim at mapping a likely distribution of sound's perception by interpolating aggregated individual assessments over a set of discrete points. Similar approaches have been reported in Section 8.1.

The perceptual attributes can be better described by comparing two groups. The first one includes the reference points 3 and 8, while the second group comprises the rest of the places. In total, six out of the eight perceptual attributes were represented and analysed, since the values for 'vibrant' and 'uneventful' were not spatially autocorrelated.

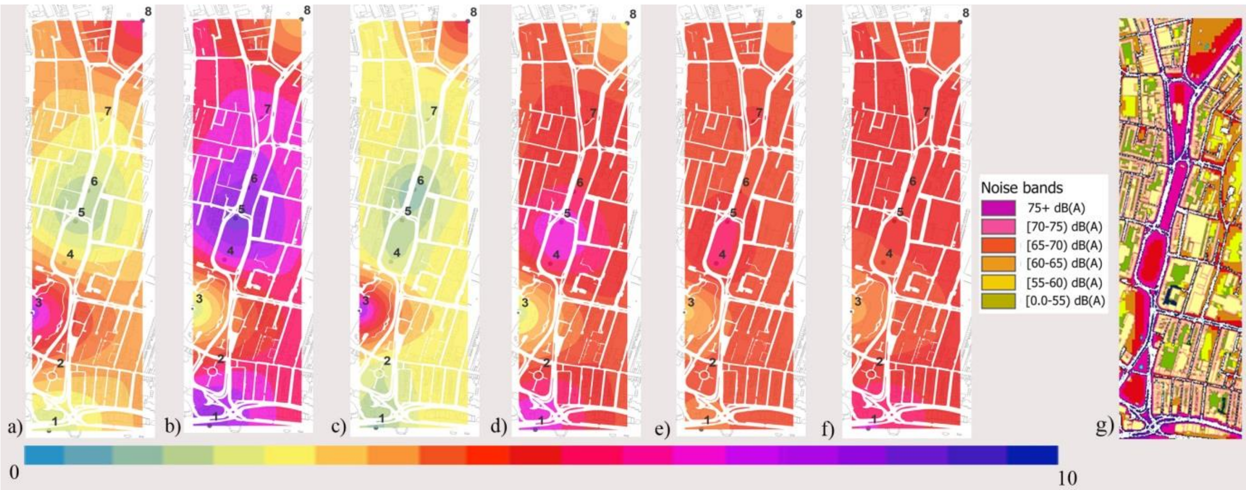

Fig.8.9. Soundscape maps of the study area according to the selected perceptual attributes rating in a 0-10 scale with 0="very low" and 10= "very high". The represented attributes are: a) Pleasant, b) Unpleasant, c) Calm, d) Chaotic, e) Eventful, f) Monotonous, g) Noise map of the study area.

Overall, the entire area in Fig.8.9a was poorly characterised as 'pleasant' with a low area average (M_{1-8} = 3.5) and values ranging between 1.6 and 6.8. Points 3 (M=6.8) and 8 (M=6.1) were identified as the most pleasant places in the entire site, while points 5 (M=1.6) and 6 (M=1.6) as the least pleasant. The attribute 'unpleasant' in Fig.8.9b ranged from 1.9 to 7.8 with values above the area average (M_{1-8} = 5.8) among all the attributes. Chaotic in Fig. 8.9d follows also the same pattern with slightly lower levels ranging from 2.0 to 6.6 and an area average of M_{1-8} = 5.0. The attribute 'calm' in Fig.8.9c ranged from 1.0 to 7.2 presenting the highest variation (SD_{1-8}=2.28) and the lowest mean value in the area (M_{1-8}=2.8). The lack of calmness was mostly evident in points 1 and 6. Generally, 'calm' followed the same pattern as 'pleasant' with slightly lower levels in all the positions. In point 3 both parameters had their maximum (M=7.2 and M=6.8, respectively), possibly enhanced by the sense of enclosure provided by the trees in that location.

The attributes 'eventful' and 'monotonous' (Figs 8.9e, 8.9f) presented the lowest variation in the area, respectively (SD_{1-8} = 0.86, SD_{1-8} = 0.72), with no significant peaks or lows and levels close to 5.0. Points 4 and 5 were the only ones characterised as slightly more 'eventful' than 'monotonous', while point 3 was characterized as the least eventful and monotonous in the entire area. However, low variation in these two attributes is not necessarily a negative characteristic as it can provide a general picture for the whole area, which is deprived of a particular sonic identity due to the vulnerability to traffic noise.

It can also be seen that there are similarities and differences between the maps of perceptual attributes and the noise map of the study area as shown in Fig.8.9g. In particular, there is a correspondence in the areas that were rated as “unpleasant” and the areas with high noise levels. Nevertheless, areas that were rated as “pleasant” or “calm” in the perceptual maps (points 3,8) are still represented in a high noise band in the noise map. This comparison can be used as an evidence to show the complementary nature of objective and subjective attributes of the outdoor sonic environment.

Overall, the current appraisal of the sound environment in the area was mostly negative, except for points 3 and 8. High traffic volumes around the park had a negative impact with the situation to be aggravated by the linear shape of the Valley Gardens and the absence of enclosure features of green infrastructure. Future intervention should target at the increase of “pleasantness” and “calmness” in the area, connecting the natural elements of the seafront - which also received negative assessments (chaotic, unpleasant, and monotonous) - with an improved land use and network structure.

8.4.5. Mapping effectiveness and implementation

In the last stage of the GIS implementation, a cross-validation process was used to evaluate the performance of the interpolation in ArcGIS. According to the results of Table 8.3, it can be seen that most of the conditions were met to a great extent, making sure that the predictions are centred to the true values and have a low uncertainty.

Table 8.3. Error diagnostics using the cross-validation process for the perceptual attributes.

Conditions	Errors	Pleasant	Unpleasant	Calm	Chaotic	Eventful	Monotonous
MPE→0	MPE	-0.27	0.22	-0.23	0.16	0.13	0.01
MSE→0	MSE	-0.08	0.07	-0.07	0.06	0.10	-0.01
RMSPE→min	RMSPE	1.92	2.26	2.61	1.93	0.96	0.77
ASE≈RMSPE	ASE	2.02	2.25	2.48	1.80	0.97	0.75
RMSSE≈1	RMSSE	0.90	0.98	1.03	1.05	0.99	1.00

In particular the Mean Prediction Error (*MPE*) and the Mean Standardised Error (*MSE)* were very close to zero (max_{MPE} = -0.27, max_{MSE} = 0.10). A small underestimation in the variability of the predictions was evident, since the Root Mean Square Prediction Error (*RMSPE)* was slightly higher than the Average Standardized Error (*ASE)* in four out of six cases, with a maximum difference of 0.13 in “unpleasant” and “calm”. Definitely, a lower *RMSPE* (max=2.61) would have been achieved if some extra points would have been included between points 3 and 4 as well as between points 7 and 8. Nevertheless, the current results suggest that the sample size was sufficient for the purposes of this analysis. On the top of that, all points - apart from the reference ones - were uniformly distributed so as to have an objective description of the area.

8.4.6. Soundscape profiling

One of the main assets in the above soundscape maps and overall in the field of interpolation is the ability to apply more complex and combined queries retrieving the areas, which satisfy specific criteria. For instance, using the “extract by attributes” tool in ArcGIS it is feasible to represent such areas. Fig.8.10 depicts a characteristic example of the potential queries that can be built. Areas in points 3 and 8 represent cases, which were rated as “calm” and “pleasant” with a score above 5 / 7.5. On the other hand, areas in the rest of the points correspond to places characterised as “chaotic” and “annoying” with a score higher than 5 in a scale from 1 to 8.

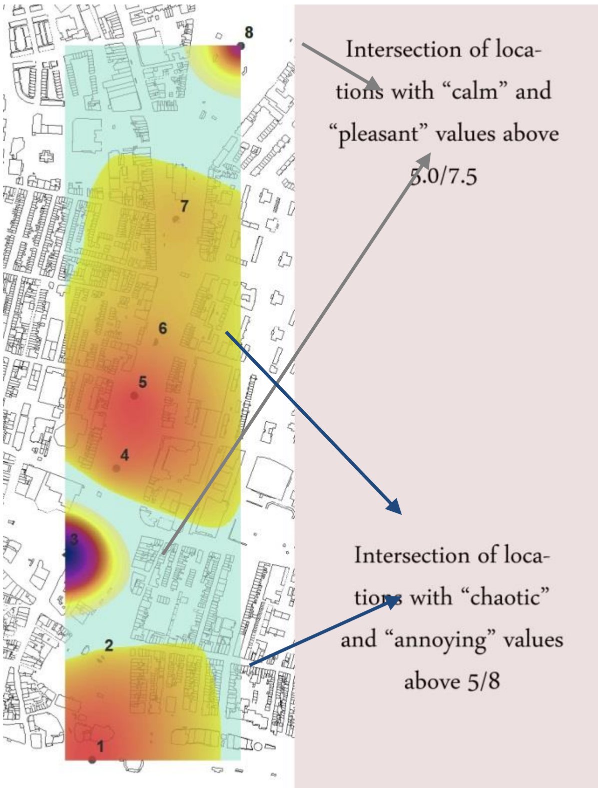

Fig.8.10. Spatial queries with combined results contributing to the recognition of “quiet” and “noisy” areas based on perceptual parameters assessed during the soundwalk.

This kind of combinations can give a more detailed picture of the current condition of the acoustic environment. Hence, the local City Councils or the planning authorities have a tool to assess the current soundscape quality of the study area and design the future interventions according to a particular acoustic strategy as presented in Fig.8.1.

8.5 Discussion

8.5.1. Model effectiveness

As regards the model effectiveness in Sheffield, small error values in all the three sound source categories were found with the most accurate and unbiased interpolation to be presented in the technological sources (Table 8.2). Overall, the predicted values per point were close to the measured ones with the highest errors (+2.5) to be present only in outlier values during the soundwalk. In Brighton soundwalk the interpolation model had an optimal performance for the "monotonous" perceptual variable with very low error values. On the other hand, the highest errors (RMSPE = 2.61, ASE=2.48) were detected for "calm" and "unpleasant" (RMSPE = 2.26, ASE=2.25). Overall, it was shown that a geostatistical model such as Kriging can be applied successfully in soundscape mapping with unbiased models both in the small-scale mapping - where parks or squares are considered - and in the large scale of a typical city centre.

The accuracy in soundscape mapping as presented in the results section for both case studies depends on various parameters. The most crucial include the size of the area, the number of points measured as well as their spatial distribution and the way of selecting them (a priori, on site). Although the use of spatial interpolation methods has not been always successful in the prediction of noise levels (Can et al., 2014), it has been shown that they can be useful for mapping soundscape quality or particular perceptual attributes in the urban context (Aletta & Kang, 2015; Hong & Jeon, 2017). Definitely the proper soundscape data collection method should be applied according to the scope of the study. Moreover, in terms of sampling strategy, purposive (non-probability) sampling is generally considered more efficient than probability sampling (de Gruijter et al., 2006). However, systematic sampling seems to be an option that provides more representative results compared in larger areas.

In terms of mapping content, for parks or rural areas, a suitable categorization of sound sources can follow the example of Papadimitriou et al. (2009) or Liu et al. (2013), which is nature-oriented (anthropophony, biophony, geophony). Nonetheless, for urban environments a categorization that can be more representative is closer to the taxonomy of human, natural and technological sources previously used in other studies as well (Lavandier et al., 2016; Pijanowski et al., 2011; Yang & Kang, 2005).

8.5.2. Implementation - advantages of soundscape mapping and complementarities with noise maps.

Concerning the advantages of soundscape mapping in the implementation stage, according to the described framework, there are two main points worthwhile to be mentioned. The first one refers to the data collection step and the other one in the profiling stage. The individual data collection method in Sheffield - highlighted also by Jeon et al. (2013) - is the appropriateness of this method for broad areas with flexibility in assessments at diverse times and days (Semidor, 2006). Typically, traditional soundwalks are fulfilled in one day with limited duration between 10' (Adams et al., 2006) and 90' (Berglund & Nilsson, 2006). Another asset is the extensive noise variability with a large dataset, which helps to create a smoother interpolation surface with equal coverage.

In the profiling stage, the group soundwalk method applied in Brighton and the quantification of perceptual attributes visualized in Valley Gardens offers the chance to recognize areas that needed to be acoustically improved or were already quiet. It was proved that there were critical areas in the noise maps classified in high noise bands, but characterized as "calm" during the soundwalk. This can partly be explained by factors, which cannot be taken into account in noise mapping, such as the masking effect of traffic by other sources such as birdsongs (Hao et al., 2016) and the dense vegetation in the area. The advantage of the group soundwalk method is the provision of more representative results as all spots are assessed by a group of people, so they tend to be more popular according to the latest studies (Aletta et al., 2015; Aletta et al., 2016; Jeon et al., 2011). However, the short-term duration of listening in every spot can only capture a small fraction of the dynamic and temporal pattern of urban soundscapes compared to individual soundwalks.

8.6. Conclusions

The aim of this study was primarily to develop a mapping model to aid soundscape planning and secondly to assess its effectiveness. After the entire process a framework for soundscape mapping was established based on specific steps and flexible to handle with different input data.

- Firstly, a sound source mapping technique was established using a probabilistic sampling strategy and an individual data collection method combined with Ordinary Kriging interpolation technique. The model was based on input data from the initial classification of sound sources. The prediction map of the study area displayed that areas close to University buildings, parks and residential sites - well protected from green belts - presented low technological sources. On the contrary, high concentration of the same sources was evident - as expected - in congested roundabouts around the Ring Road and along the main roads towards and around the city centre.

A high number of natural sources was evident close to parks, exclusive residential areas and other places with a high degree of naturalness, such as districts close to the river. The presence of natural sounds was also enhanced in areas, where the housing type included vegetated backyards or front yards. Finally, an unexpected high number of natural sounds were recorded in areas close to the Ring Road with the coexistence of technological and natural sources.

Anthropic sources were mainly evident in proximity to natural elements such as parks or water features, since they provide a source of relaxation and restoration. These findings are also in line with the results of Chapter 7 and in particular the relationship between "Component 1" (*naturalness*) and the presence of people. Then, a high number of anthropic sources was also detected close to the main market and in proximity to commercial and social activities. Such findings comply with the interpretation of "Component 2" (Chapter 7), which dealt with the presence of people and the proximity to the city centre. These results do not account for sound source intensity, since the main aim was to capture the plethora and the number of different sources.

- Secondly, a perceptual soundscape mapping technique was established using a purposive sampling strategy. A group data collection soundwalk method was applied using the geostatistical Ordinary Kriging interpolation technique. The model was based on input data from perceptual attributes collected in Valley Gardens, Brighton. It was found that the overall appraisal of the sound environment in the area was mostly negative, except for points 3 and 8, which were the most pleasant. High traffic volumes around the park had a negative impact on the listener's perception with the situation to be aggravated possibly by the absence of enclosure features of green infrastructure.

In terms of profiling, it was found that out of the 90 tiles in Sheffield the majority of them (43%) belonged in the profile where natural source prevailed. Technological sources dominated in 24% of the tiles and another 16% of the tiles was characterised by the high presence of anthropic sources. The profiling in Brighton case study was based on combined query satisfaction of specific attributes, such as "calm-pleasant" and "chaotic-annoying". More criteria and queries can be applied depending on the purpose of the analysis and the acoustic objectives that should be met. Generally, the outcome from both case studies was that the proposed soundscape framework can be applied in environmental noise management and the soundscape planning process in different urban scales.

Chapter 9

Conclusions and future work

From an objective viewpoint, this study initially explored the quantitative effects of green spaces in traffic noise distribution using regression models, correlations and profiles identification. Then, from the subjective viewpoint, it moved towards the perception and design implementation, by exploring the relationship between land use and sound sources. In the same wavelength, it also explored the spatial representation of perceptual and sound source attributes using a soundcape mapping model.

9.1. Main findings

9.1.1. Relationship between green space-related morphology and noise pollution (agglomeration level).

The study revealed in which cases greener cities can also be quieter. The analysis was applied in European agglomerations with a primary focus in three levels (administrative, urban, kernel) from a broader to a smaller scale as described in Chapter 4.

- *Administrative level*

The percentage of green space per person in the two clusters (high green-low green) did not validate the first hypothesis that agglomerations with higher amount of green would present more people exposed to the low noise band of 55-59 dB(A) compared to agglomerations with low values in the green space index.

Also, the second hypothesis that more people will be exposed to noise levels over 70 dB(A) in the cluster with the low green was not proved. However, in this case the variance in the cluster of agglomerations with low green was higher than in the cluster with high green. This was evidence that there was a tendency towards the validation of this hypothesis.

- *Urban level*

In the urban level, three different trends in terms of noise and green were recognised in the six cities. The first one refers to cities, where noise and green follow an inversely proportional relationship with a higher amount of green spaces in the lower noise bands (55 dB(A)) and a gradual decrease in both indices as we move towards the higher noise bands. The second trend involved cities where green space coverage was found to be less affected by noise. Finally, the third trend involved cities, where green space coverage is relatively high and constant in most noise bands with noise to present proportional increasing tendencies from the lowest to the highest bands.

From this analysis it can be deduced that cities, which present low noise levels can potentially be greener, however this conclusion does not work vice versa. On top of that, the analysis showed that lower noise levels can possibly be achieved in cities with a higher extent of porosity and green space coverage. Between the two variables, the extent of porosity was proved to have a higher contribution in the prediction of noise levels than the extent of green space coverage.

- *Kernel level*

In the kernel level (500x500m) it was shown that a Geographically Weighted Regression (GWR) model can be highly effective in the prediction of noise levels using green space coverage as the only predictor. R^2 values between 60% and 79% were found for the six cities.

Ranking of cities

The cities ranking as regards the extent of quietness was found to be little affected by the transition from urban to kernel scale. This fact shows the effectiveness of the index in different levels of analysis. Out of the three groups that were formed in the kernel level it was found that the majority of areas presented a neutral “Low green-Low noise” pattern (48%), followed by deprived areas of “Low green-High noise" pattern (31%) and the rest of them to be in the privileged "High green-Low noise" pattern (21%).

Land cover analysis

Noise levels were minimized in the Cluster with the highest percentage of forest and agricultural areas in combination with the minimum coverage in infrastructure. On the contrary, noise levels were maximized in the areas with very high coverage in infrastructure and industrial land cover.

Overall, the transition from one level to the other showed that the relationship between noise and green can vary according to the scale of analysis. However, some core relationships especially in the urban and kernel level remained the same.

9.1.2. The effects of urban green spaces and other features of urban morphology on traffic noise distribution (city level).

This study revealed the relationship between traffic noise distribution and urban morphology in eight UK cities of different settlement forms. Results were analysed in three scales (macro, meso, micro) as discussed in Chapter 5. Conclusions can be summarized as follows:

- *Macro-scale*

The macro-scale analysis showed that radial and linear cities are usually liable to a different Green Space Pattern. In particular, a dispersed Green Space Pattern combined with the proper road and building attributes - under similar traffic conditions - is positive evidence for lower noise levels, as opposed to a clustered one.

Secondly, higher internal network connectivity was also linked to higher traffic noise levels, since more connections are created along the network.

Radial cities in this investigation were associated with a significantly higher Natural Urban Green Ratio than linear cities, allowing for a generalization of this conclusion also to other urban areas with similar settlement forms in UK. The geographical location of the cities also contributes to this conclusion, since all linear cities were close to the seaside.

The majority of radial cities followed a dispersed green space pattern, while the majority of linear cities followed a clustered one. The previous two conclusions and the fact that dispersed patterns were related to lower noise levels in these settlements leads to the indirect inference that radial cities are more likely to be "quieter" than linear cities under similar traffic and demographic conditions.

- *Meso-scale*

In the meso-scale analysis two cities were involved. In Sheffield, an increase in Building Perimeter, the Local Road Intersections or the Primary Roads Length can infer a rise in traffic noise levels. On the contrary, green space parameters such as "Gardens ratio" or "Natural Urban Green ratio" were found to reduce traffic noise up to 38%. In Brighton, Local Road Intersections, Primary Roads Length and Car Availability ratio were found to be positively correlated to traffic noise. The above-mentioned indices managed to explain more than 70% of the variance for traffic noise levels in the regression models for the two cities.

- *Micro-scale*

In the micro-scale level, it was shown that an increase in the Number of Buildings can infer an increase in traffic noise levels. It was also found that cities with similar values in the "Building Coverage ratio" had different noise levels.

9.1.3. The influence of vegetation and traffic-related parameters on the sound environment in urban parks (park level).

This study revealed the effect of vegetation and traffic-related parameters on the sound environment of eight parks. Results were analysed in two scales (park-based, point-based) as discussed in Chapter 6.

- *Park-based scale*

It was found that in the park-based scale, the simulated L_d presented a high range of values between 43 and 78 dB(A) for the eight parks. The range was also high within each park with noise differences between 14 and 23 dB(A) per park. In average values ($L_{d(avg)}$) there was a difference of almost 17 dB(A) between the quietest and the noisiest park.

Almost all parks close to the Ring Road presented higher $L_{(davg)}$ values than the ones further away, however the difference between the two groups was not significant.

The distinction of ground absorption between areas of trees and grass had an additional noise effect between 0.3 and 1.1 dB(A), while the presence of terrain, compared to a flat surface, had an effect between 5 and 6.2 dB(A).

- *Point-based scale*

For the environment inside the parks the minimum difference between $L_{A10(avg)}$ and $L_{A90(avg)}$ was 3.6 dB(A) and the maximum 6.9 dB(A). From the SD perspective it was calculated that the $L_{A90(SD)}$ varied greater than $L_{A10(SD)}$ and independently from the increase of $L_{A90(avg)}$.

The comparison between the inside and the outside environment of the parks showed that in all cases noise levels in the nearby roads outclassed those inside the parks. These differences ranged between 0.5 and 5.9 dB(A) for L_{A90} and between 1.8 and 14.3 for L_{A10}

In four out of eight cases, it was found that noise levels inside the parks tend to increase when moving away from the park centroid (extroverted pattern) confirming the hypothesis that the sound environment is affected by the surrounding traffic, no matter the effect from other inside sound sources.

An increase in "tree coverage" had the highest effect on the reduction of L_{A90} out of the three negatively correlated indices, $L_{A90(avg)}$, $L_{A10(avg)}$, L_{Aeq}. It was also found that an increase in road coverage around the parks can infer an increase in $L_{A90(max)}$. The same tendency was detected between building coverage and $L_{A10(min)}$, showing that noise level distribution in the parks can be affected both by green space characteristics and morphological attributes from the surrounding environment.

Ultimately, there was a significant difference in the noise levels within tree areas and grass areas independently of the park. This difference ranged between 0.74 and 1.6 dB(A) in favour of grass areas. The same approach in the simulated noise levels provided an identical tendency slightly underestimated ((0.3 – 1.1 dB(A)) with G_{grass}= 0.5 and G_{trees}=1.

9.1.4. Relationship between land use activities and sound sources in urban environments.

The study found how sound sources interact with land use and urban activities in the urban environments as discussed in Chapter 7.

It was found that the (urban) outdoor environment, in terms of land use, urban activities and sound sources can be described by two Components. The first one was indicative of the relationship between natural versus manmade environments (C1). The second one was relevant to the proximity to the city centre and the presence of people (C2). For Component 1 (C1) it was found that the larger the green space coverage and the further away from minor roads, the more likely it is for a place to be perceived as natural and appropriate for leisure activities, allowing the natural sounds to dominate.

Component 2 (C2) was related to the proximity to the city centre and the presence of people. It presented higher values when the road coverage and the distance from major roads were increasing. Green space coverage was negatively associated with this Component.

Three groups (profiles) were found both for the sound sources and the human activities. Natural sounds prevailed in residential areas, traffic sounds in employment or industrial areas and human sounds in Sheffield city centre, which is the commercial zone of the city.

Significant differences among the three clusters were also identified. In particular, “Residence” as a land use type and activities related to nature such as “Walking-Jogging-Running” or “Nature appreciation” presented the highest differences between “Residential” and “Economic–Industrial” areas. On the contrary, “Shopping” presented the lowest differences between the two types of areas. Similar results were observed between “Residential” and “Commercial” places with the highest differences to be noted in “Experiencing active street life” and the residence suitability. Ultimately, the lack of social activities was also distinctive in the comparison between “Commercial” and “Economic–Industrial” areas, coupled with the predominance of activities related to road and rail transportation in the latter case.

9.1.5. Positioning soundscape mapping in environmental noise management and urban planning. Case studies in two UK cities.

A mapping tool to aid soundscape planning was developed with additional information concerning its effectiveness and profile identification of two investigated areas. The study was discussed in Chapter 8 of this thesis.

Mapping content

- As regards Sheffield, a sound source mapping technique was established using a probabilistic sampling strategy and an individual data collection method combined with Ordinary Kriging interpolation technique. With respect to the mapping content, it was found that areas close to University buildings, parks and residential sites presented a low number of technological sources. On the contrary, high concentration of the same sources was evident in congested roundabouts around the Ring Road and along the main roads towards and around the city centre.

There was also evidence that a high number of natural sources was present close to parks, exclusive residential areas and other natural places, such as districts close to the river. The presence of natural sounds was also enhanced in areas, where the housing type included vegetated backyards or front yards. Unexpectedly, natural sounds were recorded in areas close to the Ring Road with the coexistence of technological and natural sources.

Anthropic sources were mainly evident in proximity to natural elements such as parks or water features, since they provide a source of relaxation and restoration. These findings are also in line with the results of Chapter 7 and in particular, the relationship between "Component 1" (*naturalness*) and the presence of people. Then, a high number of anthropic sources was detected close to the main market and in proximity to commercial and social activities. Such findings comply with the interpretation of "Component 2" (Chapter 7), which dealt with the presence of people and the proximity to the city centre.

- For Brighton, a perceptual soundscape mapping technique was established using a purposive sampling strategy. A group data collection soundwalk method was applied using the geostatistical Ordinary Kriging interpolation technique. It was found that the overall appraisal of the sound environment in the area was mostly negative except for two points.

Profiling areas

In terms of profiling, it was found that out of the 90 tiles in Sheffield the majority of them (43%) belonged in the profile where natural source prevailed. Technological sources dominated in 24% of the tiles and another 16% of the tiles was characterised by the high presence of anthropic sources.

In Brighton the greatest proportion of the park was covered by a combination of "chaotic" and "annoying" values above the average levels with only two places to present a simultaneous combination of "calm" and "pleaseant" attributes.

Overall, it was shown that a geostatistical model such as Kriging can be applied successfully in soundscape mapping with unbiased models both in the small scale mapping - where parks or squares are considered - and in the large scale of a typical city centre. Finally the effectiveness of the geostatistical techniques in both cities showed that there were small error values very close to the optimal conditions.

9.2. Implementation

In the administrative level of agglomerations as presented in Chapter 4 it is not always feasible to identify correlations between green and noise indices due to the nature of data and the broad scale of analysis. For this reason, it is more meaningful to compare agglomerations in the urban and kernel level. In particular, for planning proposals, it is suggested that the relationship between green and noise in the urban level can be better assessed by the ratio between green (porous) and built-up (non-porous) surfaces compared to the green space coverage index. The ranking of different cities as regards the extent of “quietness” - given the respective noise maps - can be performed with the developed noise index (*Δnoise6*). The advantage of this index is that it uses all the noise bands to end up in a single value, so it can be considered more representative compared to the other options discussed in Chapter 4.

The results of Chapter 5 can provide evidence of better green space allocation in the planning stage. At first, in the macro scale, noise mitigation policies can be adjusted according to the settlement form of the cities (linear, radial). For example, linear cities were shown to be more car-dependent than radial cities and the latter were found to be more affected by the green space allocation. Secondly, in the meso scale, green space strategies can consider the finding that a higher noise mitigation effect can be achieved when the same green area is distributed in many small and dispersed patches than less and larger ones. The level of segmentation depends also on accessibility issues, but this can be the scope of a future study. Residential policies can also consider that fact that housing types with gardens favour the mitigation of traffic noise, not only because of vegetation, but also due to land use issues related to the exclusive residential character of these areas. Similarly, it is important to apply measures towards the reduction of an increased car availability ratio since it was found that this index hinders the effectiveness of green spaces in noise mitigation. The indirect effects of green spaces - apart from their ground attenuation attributes - come to the conclusion that they prevent high population densities and car usage.

Significant differences up to 5.9 dB(A) for L_{A90} and up to 14.3 dB(A) for L_{A10} were found between the inside and outside environments of the parks, as described in Chapter 6. These findings in combination with the identified pattern (introverted, extroverted) can help landscape architects to identify intrusive and annoying areas for an a priori successful soundscape design. Moreover, urban sound planners can better define the acoustic objectives for the critical areas inside the parks and arrange the various activities accordingly. For example, parks close to major roads can have a higher percentage of tree coverage compared to grass coverage. Also, the position of sound sources with positive masking effects, such as fountains can be arranged so as to be closer to the side with increased road traffic. Finally, for Master Plans, it is crucial to consider the findings suggesting that building and road coverage in the areas surrounding the parks can affect noise levels inside them.

The results of Chapter 7 are based on the interaction between sound sources and land use attributes, taking into account previous findings mentioning that urban planning influences the urban form and mobility patterns and consequently the distribution of sound sources within the city. The current findings can be used to assess the quality of life in cities based on the values of Principal Component

Loadings for sound sources and land use activities. The fact that a better environment is more likely to be achieved when both the green space coverage and the distance from minor roads is increased can also be used for the assessment of planning proposals and as input in multi-criteria or impact-assessment analysis.

Implementation of soundscape mapping in urban spaces (Chapter 8) can provide visual and spatial information for perceptual attributes in areas of small resolution (e.g 200x200m). Additionally, these results can be combined with information derived from noise maps as well. This tool can add extra value in the holistic approach of urban sound planning, since the new planning proposals are moving towards a more person-oriented direction, where simple noise mapping results are inadequate. Additional applications of the mapping model include the assessment of an urban environment before and after design interventions (see Chapter 8.4.1), as well as the effectiveness of different acoustic strategies, such as controlling of the transmission path or sound source modification. Eventually, the identified sound source profiles can help in the detection of vulnerable or privileged areas calling for further interventions.

9.3. Limitations and future work

The noise maps of EU agglomerations have been constructed under different extent of detail by the relevant authorities. The analysis in Chapter 4 has used only those that cover the entire agglomerations and not only the areas around major roads. As a result, those agglomerations can be the topic of a next stage analysis. Then, the number of noise classes per agglomeration was not always the same allowing for data merging, which can reduce the accuracy of the relevant maps. A future consideration for the analysis in Chapter 4 can include different parameters for the GWR, such as the selection of an adaptive kernel type, as well as a specific neighbour count. The porosity index measured for each agglomeration can also be correlated with the urban heat island phenomenon, which is also caused by the mismatch between porous and concrete surfaces. Furthermore, in the agglomeration level the analysis can be repeated with the latest updated results from EIONET concerning noise and population exposure data. An interesting parameter here is that in the future, the traffic composition - taking into consideration the high rising technology of hybrid and electric vehicles – is expected to have a significant impact on traffic noise levels. Although this effect might not be directly evident in highways, in the neighbourhood level the balance changes rapidly.

The investigated study areas as presented in Chapter 5 (macro-scale) can include larger areas with an extended number of tiles. The latter approach can further help towards the validation of the current findings for the green space pattern using the Average Nearest Neighbour Index (ANN). In all cases, updated noise data from the second round of noise mapping can be used. In the meso-scale, noise prediction can possibly be improved through the application of a Land Use Regression (LUR) model, with the inclusion of extra variables apart from the green space-related ones. Apart from this, future research can investigate optimization techniques using genetic algorithms as regards the spatial distribution of green space patches under different urban configuration scenarios.

In Chapter 6, the simulated results in CadnaA have been extracted, using an extreme value of G_{out}=0 for the outside environment in order to highlight the differences between the parks surfaces and the surroundings. This value can be increased in a future research in order to be more realistic. Apart from this, the height for all adjacent buildings was simulated using an average value of 8 meters. The current sample technique, in order to obtain all the measurement noise data per park, was recorded on the existing paths with a disproportional coverage of the parks' surface. In a future research, a systematic sampling method can be more appropriate. Another issue was the inability to connect the noise levels with a particular type of sound sources. Towards this direction, algorithms of automated source identification can be proved very useful. Furthermore it would be useful for the park design process to compare the current findings with other parks, where successful examples of soundscape interventions have been applied. Finally, the traffic data used to simulate the noise levels are expected to change in the future especially for the urban areas thanks to the integrated urban mobility plans and the significant contribution of public transport towards car dependency. This is already reflected in the new incorporated tools for smart cities.

The data collection for the 25 points in Sheffield as described in Chapter 7 was performed by a single person, who kept a record only for the number of different sound sources that were audible. Then, the visual experience in the laboratory test presented a high dependency on the availability of Google Street View. New tools, such as virtual reality, are now offered in the market in order to enhance the overall experience and create more interactive conditions. Another point is that the current research was confined in Sheffield city centre. An improved research can build on the current results and test the stability of the Principal Component Loadings distribution. The whole concept can be used to raise the importance of participatory planning.

As regards the analysis conducted in Chapter 8 the road classes refer to the applied system in UK. Then, the current soundscape maps of Brighton refer to the pre-intervention stage. Consequently the next step would involve the comparison of the soundscape environment between the “before” and “after” state. Further investigation in Sheffield can improve the sound source profiling, using a smaller grid size and also investigate the connection between sound source profiles and real estate.

Overall, the future work based on the predictive methods and the results described in Chapters 4-6 (Part I) can be used for the development and simplification of noise level regression models. Since most of the current models include a lot of predictors, it is difficult to replicate the process in different cities and establish a fixed regression formula. The current research helps towards this direction, since it provides the evidence to what extent this achievement is possible and what levels of accuracy can be achieved.

The future work for the second part of this research (Chapters 7,8), which is towards design and implementation, can be based on the current findings for urban activities and sound sources and work towards their implementation in the urban design process. There is already a particular example of such an approach where green spaces were considered as an additional parameter for the assessment of an urban design project in Sweden. More can be done towards this direction in combination with the soundscape mapping examples presented in Chapter 8. Since, urban contents can be acoustically described as a combination of sound sources and activities, there is a chance to use these results in the assessment of different transport scenarios and counterbalance possible negative effects using a proactive planning approach.

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Appendix A: Main outcomes of this PhD research per Chapter.

Neighbourhood level (Chapter 3)

- In the neighborhood level, square configurations of green space patches seem to be more effective when placed parallel to the inner roads.
- For rectangular configurations, green space patterns can possibly maximize the quiet areas when placed vertically to the inner road(s) and parallel to the peripheral main roads.

Agglomeration level (Chapter 4)

- For planning proposals, relationship between green and noise in the urban level can be better assessed by the ratio between green (porous) and built-up (non-porous) surfaces compared to the green space coverage index.
- It is feasible to quantify effectively the extent of “quietness” of different cities - given the respective noise maps – using the newly introduced noise index (*Δnoise6*).

City level (Chapter 5)

- The settlement form of each city (linear, radial) should be taken into consideration in the noise mitigation policies, with the latter to be adjusted accordingly.
- A higher noise mitigation effect can be achieved when the same green area coverage is distributed in small and dispersed patches than fewer and larger ones. The level of segmentation depends on accessibility issues as well.
- Housing types with gardens (backyards, front yards) in urban areas favour the mitigation of traffic noise, not only because of vegetation, but also due to land use characteristics such as the exclusive residential character of these areas.

- It is important to apply measures towards the reduction of the car availability ratio since it was found that this index hinders the effectiveness of green spaces in noise distribution.
- In terms of land use, green spaces prevent high population densities and car usage.

Park level (Chapter 6)

- The identification of an introverted or extroverted pattern in urban parks can help landscape architects to identify intrusive or annoying areas for an a priori successful soundscape design at this level.
- The acoustic objectives for soundscape design in the park level should be defined in combination with the proximity to major roads.
- For this reason parks close to major roads can have a higher percentage of tree coverage compared to grass coverage.
- The position of sound sources with positive masking effects, such as fountains, can be arranged so as to be closer to the park side with increased road traffic.
- High building and road coverage in the areas surrounding the urban parks can lead to high noise levels in their internal environment.

Land use activities (Chapter 7)

- Land use activities and sound sources are correlated. Policy makers can follow the results of this research to standardise the combinations found for residential, mixed and commercial areas.
- Residential areas were combined with natural and human sounds. Mixed land use areas were associated with traffic sounds and commercial areas with human sounds.

- A better urban environment with more natural elements is more likely to be achieved when both the green space patches and the distance from minor roads is increased. This depends on the road classification system applied in each city.
- In the investigated cities, human, social and recreational needs were satisfied based on the proper combination of green space availability and proximity to the city centres. Such an approach can be generalised also to other cities.

Soundscape mapping (Chapter 8)

- The soundscape mapping model can be used for the assessment of an urban environment (perceptual attributes) before and after an urban design intervention.
- Soundscape mapping can also be used to assess the effectiveness of different acoustic strategies, such as controlling of the transmission path (e.g vegetation screening, quiet sides).
- Finally, the sound source profiles formed with help of the individual soundwalk can help in the detection of vulnerable or privileged areas calling for further sound interventions.

Appendix B: Publications and Outreach

Journal papers in peer-reviewed journals

- Margaritis, E., & Kang J. (2017). *Relationship between green space-related morphology and noise pollution*. Ecological Indicators, 72, 921-933. http://doi.org/10.1016/j.ecolind.2016.09.032

- Margaritis, E., & Kang, J. (2016). *Relationship between urban green spaces and other features of urban morphology with traffic noise distribution*. Urban Forestry & Urban Greening, 15, 174-185. http://doi.org/10.1016/j.ufug.2015.12.009

- Margaritis, E., Kang, J., Filipan K., Botteldooren D. (2018). *The influence of vegetation-related parameters on the sound environment in parks". Applied Geography, 94, 199-212.* https://doi.org/10.1016/j.apgeog.2018.02.017

- Margaritis E., Kang J., Aletta F., Axelsson Ö. *A Sheffield case study on the relationship between land use and sound sources in the urban environment*, Environment and Planning B. (*to be submitted*).

- Margaritis E., & Kang J. (2017) Soundscape mapping in environmental noise management and urban planning: case studies in two UK cities". *Noise Mapping*, 4(1), 87–103. http://doi.org/https://doi.org/10.1515/noise-2017-0007.

- ***Book chapter***

  - Sánchez G.E., Mauriz L.E., Margaritis E. 2016. Controlling the sound environment at mesoscale level, in Kropp W., Forssén J., Mauriz L.E., eds. Urban Sound Planning – the SONORUS project. Sweden: Chalmers University of Technology, pp. 25-36

Conference papers

- Margaritis, E., Kang J. (2016). *Relationship between green space-related variables and traffic noise distribution in the urban scale, an overall approach*. In Proc. of Internoise Conference, August 20-25, 2016. Hamburg, Germany.

- Margaritis, E., Kang, J., Filipan K., Botteldooren D. (2016). *The influence of vegetation and shape-related features in making parks more noise resistant*. In Proc. of Internoise Conference, August 20-25, 2016. Hamburg, Germany.

- Margaritis, E., Aletta, F., Axelsson Ö., Kang J., Botteldooren D., Singh, N, R. (2015). *Soundscape mapping in the urban context: a case study in Sheffield*. In Proc. of AESOP Conference, July 13-16, 2015. Prague, Czech Republic.

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- Margaritis, E., and Kang, J. (2014) *Effects of open green spaces and urban form on traffic noise distribution*. In Proc. of Forum Acusticum Conference, September 7-12, 2014. Krakow, Poland.

Ecological Indicators 72 (2017) 921–933

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Original articles

Relationship between green space-related morphology and noise pollution

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A R T I C L E I N F O

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A B S T R A C T

Green spaces have been proved to have a positive effect on traffic noise pollution in the local scale; however their effects have not been explored on the urban level. This paper investigates the effects of green space-related parameters from a land cover viewpoint on traffic noise pollution in order to understand to what extent greener cities can also be quieter. A triple level analysis was conducted in the agglomeration, urban and kernel level including various case study cities across Europe. The green space parameters were calculated based on land cover data available in a European scale, while traffic noise data were extracted from online noise maps and configured in noise indices. In the first level 25 agglomerations were investigated, six of which were further analyzed in the urban and kernel levels. It was found that the effect of green spaces on traffic noise pollution varies according to the scale of analysis. In the agglomeration level, there was no significant difference in the cluster of the higher green space index and the percentage of people exposed in the lowest (55–59 dB(A)) or the highest noise band of more than 70 dB(A). In the urban level it was found that lower noise levels can possibly be achieved in cities with a higher extent of porosity and green space coverage. Finally, in the kernel level a Geographically Weighted Regression (GWR) analysis was conducted for the identification of correlations between noise and green. Strong correlations were identified between 60% and 79%, while a further cluster analysis combined with land cover data revealed that lower noise levels were detected in the cluster with higher green space coverage. At last, all cities were ranked according to the calculated noise index.

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Relationship between urban green spaces and other features of urban morphology with traffic noise distribution

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A B S T R A C T

The effect of greenery on traffic noise mitigation has been extensively studied on the level of single plants, green walls, berms and hedges, but not considering whole sample areas within the cities. Therefore, the aim of this paper is to investigate the relationship between features of urban morphology related to green spaces, roads or buildings and traffic noise distribution in urban areas. The analysis was applied in eight UK cities with different historical and architectural background, following two different settlement forms (radial, linear). In each city a 30 km^2 grid was defined and three different levels of approach were considered (macro-scale, meso-scale, micro-scale). The first level regarded the eight cities as single entities, while in the second one every single tile of the applied grid was investigated in two different cities. In the third level only the eight city centres were analyzed. Statistical analysis was used combined with GIS tools. In total 18 variables were constructed and tested for possible relationships with noise levels (L_{den}). It was found that in spite of the fact that each city has its own dynamic and form, features of urban morphology were related to traffic noise levels to a different extent at each scale. At the macro-scale, the green space pattern was related to the structure of the city as well as the traffic noise levels in combination with the rest of the morphological parameters. At the meso-scale, an increase in internal road connectivity contributed to higher traffic noise. Green space variables explained part of the variance in traffic prediction models. Finally, at the micro-scale, it was also proved that different areas can have the same building coverage but different noise levels. Therefore, these indexes could be profiled and used as an "a priori" tool for urban sound planning.

Appendix C: Statistical terms and tools applied in this research

Independent variable: (predictor): the variable that is changed or controlled in a scientific experiment to test the effects on the dependent variable.

Dependent variable (outcome variable)**:** the variable being tested and measured in a scientific experiment.

Effect size (d): quantitative measure of the strength of a phenomenon. Examples of effect sizes are the correlation between two variables, the regression coefficient or the mean difference.

Null hypothesis (H_0): A hypothesis stating that there is no effect between two variables and the observation results are purely by chance. Researchers work to reject, nullify or disprove the null hypothesis.

Alternative hypothesis (H_1): The identification of an effect between two variables resulting in the rejection of the null hypothesis, since the findings are not based on random phenomena.

Categorical variable: A categorical variable (sometimes called a nominal variable) is one that has two or more categories, but there is no intrinsic ordering to the categories. For example, gender is a categorical variable having two categories (male and female) and there is no intrinsic ordering to the categories.

Ordinal variable: An ordinal variable is similar to a categorical variable. The difference between the two is that there is a clear ordering of the variables. For example, a variable of economic status has three categories (low, medium and high). In addition to being able to classify people into these three categories, you can order the categories as low, medium and high.

Chi square test: it generally refers to Pearson's chi-square test of the independence of two categorical variables. Essentially it tests whether two categorical variables forming a contingency table are associated.

Multivariate Analysis of Variance (MANOVA): Similar to ANOVA but with several dependent variables. There might be only one independent variable or several, so we can look at interactions between them.

Independent sample t-test: The independent-samples t-test compares the means between two unrelated groups on the same continuous, dependent variable.

Appendix C

Chi square test: It generally refers to Pearson's chi-square test of the independence of two categorical variables. Essentially it tests whether two categorical variables forming a contingency table are associated.

Principal Components Analysis (PCA): Principal components analysis (PCA, for short) is a variable-reduction technique that aim is to reduce a larger set of variables into a smaller set of "composed" variables, called 'principal components', which account for most of the variance in the original variables.

K-means algorithm: Technique that aims at partitioning *n* observations into *k* clusters in which each observation belongs to the cluster with the nearest mean.

Pearson correlation (r): Measure of the linear correlation between two variables *X* and *Y*

Coefficient of determination (R^2): The proportion of the variance in the dependent variable that is predictable from the independent variable(s).

Games-Howell post-hoc test: Another non-parametric test to compare combinations of groups or treatments. It does not assume equal variances and sample sizes.

Appendix D: Questionnaire used for the laboratory acoustic stimuli presented in Section 7.2.5.

Urban activities questionnaire

Personal details

1. What year were you born in?

   Year -- Please Select --

2. Are you male or female ?

   ○ Male

   ○ Female

3. Occupation type (e.g PhD student, Postdoctoral researcher, etc.)

4. City of residence

5. Have you ever visited Sheffield?

   ○ Yes

   ○ No

6. How many times have you visited Sheffield?

7. Have you ever visited United Kingdom?

   ○ Yes

   ○ No

8. How many times have you visited United Kingdom?

9. To what extent do you hear the following four types of sounds in the video?

Provide a response for each type of sound.

	Not at all (0%) — Perfectly (100%)
Traffic (e.g., cars, buses, trains, air planes).	
Sounds of people (e.g., conversation, laughter, children at play).	
Natural sounds (e.g., singing birds, flowing water, wind in vegetation).	
Construction, maintenance, industry, loading of goods, etc.	

Urban activities questionnaire

Site 6

Video 6

Appendix D

10. To what extent do you believe that the place presented in the video is appropriate for each of the 23 activities / land uses listed below? Provide a response for each activity / land use.

	Not at all (0%)	Perfectly (100%)
Offices		
Residence		
Industrial activity		
School and student work		
Shops		
Restaurants or cafés		
Outdoor informal games (e.g. frisbee, rounders, kite flying)		
Walking, jogging or running		
Individual outdoor activities in general		
Appreciating cultural heritage (e.g. architecture, historic sites, monuments, art)		
Road or rail transportation		
Parking a car		
Spending time with friends or family		
Shopping		
Socialising, conversing, chatting		
Experiencing peace and quiet in general		
Experiencing active street life		
Escaping city stress		
Appreciating inland water (e.g. ponds, lakes, fountains)		
Nature appreciation		
Swimming or bathing		
Picnic or barbecue		
Boating or fishing		

Appendix E1: Data collection sheet for the sound sources identification in Sheffield as presented in Section 8.3.2.

Source	Sub-group	Did you hear it? (Y/N)		Sub-group	Did you hear it? (Y/N)
Technological	Cars		Natural	Wind	
	Buses			Trees Rustling	
	Trucks			Grass Rustling	
	Trains			Water Sounds	
	Airplanes			Thunder	
	Bicycles			Rain	
	Fireworks			Birds	
	Alarms			Dogs	
	Grass Mowing			Insects	
	Industries - Fans			Frogs	
	Industries - Other Machines			Miscellaneous	
	Construction				
	Domestic		Anthropic	Human Speech	
	Recreation			Human Singing	
	Miscellaneous			Human Laughter	
				Crowd of People	
				Footsteps	
				Roller-skating	
				Music - Live	
				Music - Recorded	
				Music - Shops	
				Church Bells	
				Miscellaneous	

Appendix E2: Questionnare used for the soundscape analysis in Brighton as presented in Section 8.4.2.

Brighton Valley Gardens

= 2014 =

This questionnaire is designed to take approximately 5 minutes to complete, at each study site. Please, trust your intuition and respond as quickly as possible. In return, the questionnaire may make you more aware of the environment around you.

This questionnaire is part of the Sonorus project on urban sound planning. In Brighton & Hove the project is conducted by the University of Sheffield in collaboration with the Brighton & Hove City Council. It is financed through the EU 7th Framework Programme.

The information collected will be processed statistically and treated as strictly confidential. It will not be possible to identify any individual from the reported results. Results may be presented and discussed in international scientific meetings, and published in scientific journals.

Please observe that participating in a scientific study is voluntary and you are free to withdraw at any time without there being any negative consequences. This study has been approved via the ethics review procedure of the School of Architecture, University of Sheffield.

Thank you for helping to improve outdoor space!

Kind regards,

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The University Of Sheffield.

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Demographics

Are you male or female?

- ☐ Male
- ☐ Female

What year were you born?

1 9 ☐ ☐

What is your current main occupation?

- ☐ Employed
- ☐ Self-employed
- ☐ Student
- ☐ Retired (old-age, disability or early retirement)
- ☐ Long-term sick (more than 3 months)
- ☐ Leave of absence or parental leave
- ☐ Unemployed or in labour market policy measures
- ☐ House wife/husband, manages the household
- ☐ Other

What is the highest level of education you have completed?

- ☐ No formal education
- ☐ Primary (or elementary) education (Year 1–6)
- ☐ Secondary education (Year 7–11)
- ☐ College/Sixth form education (Year 12–13)
- ☐ Higher education (university) less than 3 years
- ☐ Higher education (university) 3 years or more

Your postcode: If you live in the UK, what is the postcode of the address where you currently live?

☐☐☐☐☐☐☐☐ ☐ I do not live in the UK

Postcode will be used to identify whether study participants live in Brighton or Hove, and how far from the study area they live.

Study Site 1 — Brighton Seafront

How often do you visit this place?

- ☐ Every day
- ☐ At least once every week
- ☐ At least once every month
- ☐ Less than every month, but at least ten times every year
- ☐ At least once every year, but less than ten times
- ☐ Less than every year
- ☐ This is the first time

How suitable is this location (within sight) for each of the 15 social and recreational activities listed below?

	Not at all (0 %) — Perfectly (100 %)
Outdoor informal games (e.g. frisbee, rounders, kite flying)	
Appreciating parks and gardens (e.g. flowers, shrubs, trees)	
Boating or fishing	
Experiencing peace and quiet in general	
Experiencing active street life	
Individual outdoor exercise in general	
Enjoying time with friends/family	
Escape city stress	
Appreciating inland water (e.g. ponds, lakes, fountains)	
Socialising, conversing, chatting	
Swimming/bathing	
Walking, jogging, running	
Picnic/barbecue	
Shopping	
Cultural heritage (e.g. architecture, historic sites, monuments, art)	

Study Site 1 — Brighton Seafront

Overall, how would you describe the present surrounding sound environment?

Very bad |—|—|—|—|—|—|—|—|—|—| Very good

To what extent do you presently hear the following five types of sounds?

	Do not hear at all	Dominates completely
Traffic noise (e.g., cars, buses, trains, air planes)	|—|—|—|—|—|—|—|—|—|—|	
Other noise (e.g., sirens, construction, industry, loading of goods)	|—|—|—|—|—|—|—|—|—|—|	
Sounds of individuals (e.g., conversation, laughter, children at play)	|—|—|—|—|—|—|—|—|—|—|	
Crowds of people (e.g., passers, restaurants, sports event, festival)	|—|—|—|—|—|—|—|—|—|—|	
Natural sounds (e.g., singing birds, flowing water, wind in vegetation)	|—|—|—|—|—|—|—|—|—|—|	

Overall, to what extent is the present surrounding sound environment appropriate to the present place?

Not at all (0 %) |—|—|—|—|—|—|—|—|—|—| Perfectly (100 %)

For each of the 8 scales below, to what extent do you agree or disagree that the present surrounding sound environment is ...

	Strongly disagree	Strongly agree
- pleasant	|—|—|—|—|—|—|—|—|—|—|	
- chaotic	|—|—|—|—|—|—|—|—|—|—|	
- vibrant	|—|—|—|—|—|—|—|—|—|—|	
- uneventful	|—|—|—|—|—|—|—|—|—|—|	
- calm	|—|—|—|—|—|—|—|—|—|—|	
- annoying	|—|—|—|—|—|—|—|—|—|—|	
- eventful	|—|—|—|—|—|—|—|—|—|—|	
- monotonous	|—|—|—|—|—|—|—|—|—|—|	