The role of green spaces on urban environmental quality

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Abstract

Urban green areas have the potential to attenuate some of the negative effects of urbanisation, making cities a more pleasant place to live in. In addition to aesthetic value, green spaces improve air quality, reduce noise levels and generate more comfortable micro-climatic conditions, among other benefits, contributing to urban quality of life.
GreenUrbe (POCI/AMB/59174/2004) – The Impacts of Green Spaces on Urban Environmental Quality – is a three year research project, started in October 2005 and aims to assess the impact of green spaces on urban environmental quality (air quality, noise and micro-climatic conditions) and social well-being, in order to formulate recommendations regarding green spaces design, as it is an essential activity in urban planning, using Bragança (Portugal) as the case study.
In order to achieve these objectives an extensive fieldwork is being carried out at an urban area, involving measurements of meteorological parameters, passive sampling of ozone, nitrogen dioxide and COVs, continuous measurements of particulate matter and ozone, environmental noise measurements, experimental designs to evaluate how much vegetation interfere with noise propagation and noise absorption, haze evaluation by means of Small Format Aerial Photography (SFAP) and a survey on population attitudes and perceptions towards the overall urban green spaces.
In this article, emphasis will be given to the methodological aspects and to the first results of the project with regards to urban green structure analysis and quantitative evaluation of environmental noise, air quality and climate comfort at Bragança city.

Introduction

Three quarters of the European population live nowadays in cities, facing various environmental stresses in the form of poor air quality, excessive noise and uncomfortable thermal conditions. Urban greening has been widely recognised as a key factor to mitigate the adverse effects of urbanisation in a sustainable way (Bolund P. and Hunhamar S., 1999; De Ridder *et al.*, 2004; Nowak D. J., 2006). In fact, urban green areas such as public open spaces, private planted parks areas around buildings, street alignments, and others, provide many environmental services that contribute to ameliorate the life conditions in our cities, contributing to high-quality urban environments. These multiple benefits of urban vegetation can be expressed in terms of a broad number of functions: interfering on social/psychological behaviour; improving urban climate; lowering air pollution and urban noise; shaping urban development and services; and general ecological functions (Givoni, 1991; Bolund P. and Hunhamar S., 1999).

The social/psychological functions are much related with the use given by inhabitants, as green spaces can host such activities as playgrounds for children, social meeting spaces and other public activities. Several studies establish links between green spaces characteristics and individual choices, evaluating such characteristics as aesthetic value (Serpa and Muhar, 1996) and accessibility (Pasaogullari and Doratli 2004). Conclusions have also been drawn with regards to human perception on environmental benefits, as green spaces can deliver psychological sense of comfort and environmental quality, as it is the case of human perception on noise annoyance (Carles *et al.* 1999).

The ability of urban green spaces to mitigate air pollution has been also widely reported by scientific literature (Cardelino and Chameides, 1990; Taha, 1996; Nowak *et al.*, 2000 e 2006). Urban vegetation can directly or indirectly affect urban air quality, by altering meteorological conditions, lowering local temperature, blocking solar radiation and by affecting wind characteristics with influences on air dispersion (Givoni *et al.* 2003). Vegetation also influences dry deposition of gases in earth surface, enhancing removal of air pollutants by uptake via leaf stomata and cuticular surfaces. Trees also remove pollution by intercepting airborne particles, which, however, are often resuspended to the atmosphere (Shashua-Bar and Hoffman, 2004). Moreover, emission of volatile organic compounds by trees can contribute to the ozone formation, although indirectly they can reduce atmospheric ozone levels since they can diminish air temperature causing lower overall VOC emissions (Nowak *et al.*, 2000). Another key factor is related to lower energy consumption resulting from lower air temperatures and shading of buildings, reducing anthropogenic pollutant emissions (Akbari, 2002). Givoni *et al.* (2003) show important links between design details of outdoor spaces and different microclimate parameters that influence thermal comfort, these details include planted surfaces, shading elements, colour of urban surfaces, etc.

Green Spaces have also been identified as relevant sound attenuation barriers, as this effect shows deferent efficiency depending on vegetation characteristics. Fang and Ling (2005), evaluating a large set of wide tree belts (with>15 m), identified noise reduction values ranging from 1.5 to 9,5 dBA/20m, having related this parameter with visibility, height, density, width and length of tree belts. It is also known that vegetation is a selective noise frequency filter, as it is generally more effective in sound attenuation for higher frequencies (Tyagi *et al.*, 2006).

Several studies try to establish relations between multiple disciplinary fields in order to understanding better the role of urban green spaces. Over the past five years, several International projects have been developed under EC CORDIS City of Tomorrow and Cultural Heritage Key Action support, such as the BUGS and the URGE, both addressing Green Urban Spaces. Specific investigations on this subject could be also found in the recent literature (Fang and Ling, 2005; Lam *et al.*, 2005; Nowak *et al.*, 2006), making evident the relevance of this issue. However, in Portugal, there is still a lack in scientific research relating green spaces and environmental quality, being the GreenUrbe Project the first integrated study on this area of research.

Using the town of Bragança as our environmental system, this project tries to link three different fields of study, Urban Forestry, Environmental Sciences and Urban Planning, helping to establish a better understanding among these scientific areas of knowledge. Bragança is situated in the Northeast of Portugal and has undergone a significant development, defining different green spaces patterns within the urban limit. Moreover, this system has an appropriate structure and complexity, to allow a better underpinning of the connections between green spaces and their functions. At the end of the project, we hope this research can be a valuable contribution in both methodological guidance to the assessment of green spaces impact on urban environmental quality and adding relevant information on urban design options.

Methodology

Bearing in mind that evaluating green spaces impact on urban environmental quality is a multidisciplinary and complex action, a multipartite methodology was developed supported by a diverse and complementary team.

In order to accomplish this challenge, an integrated methodology was developed based on three stages and eight tasks (Figure 1).

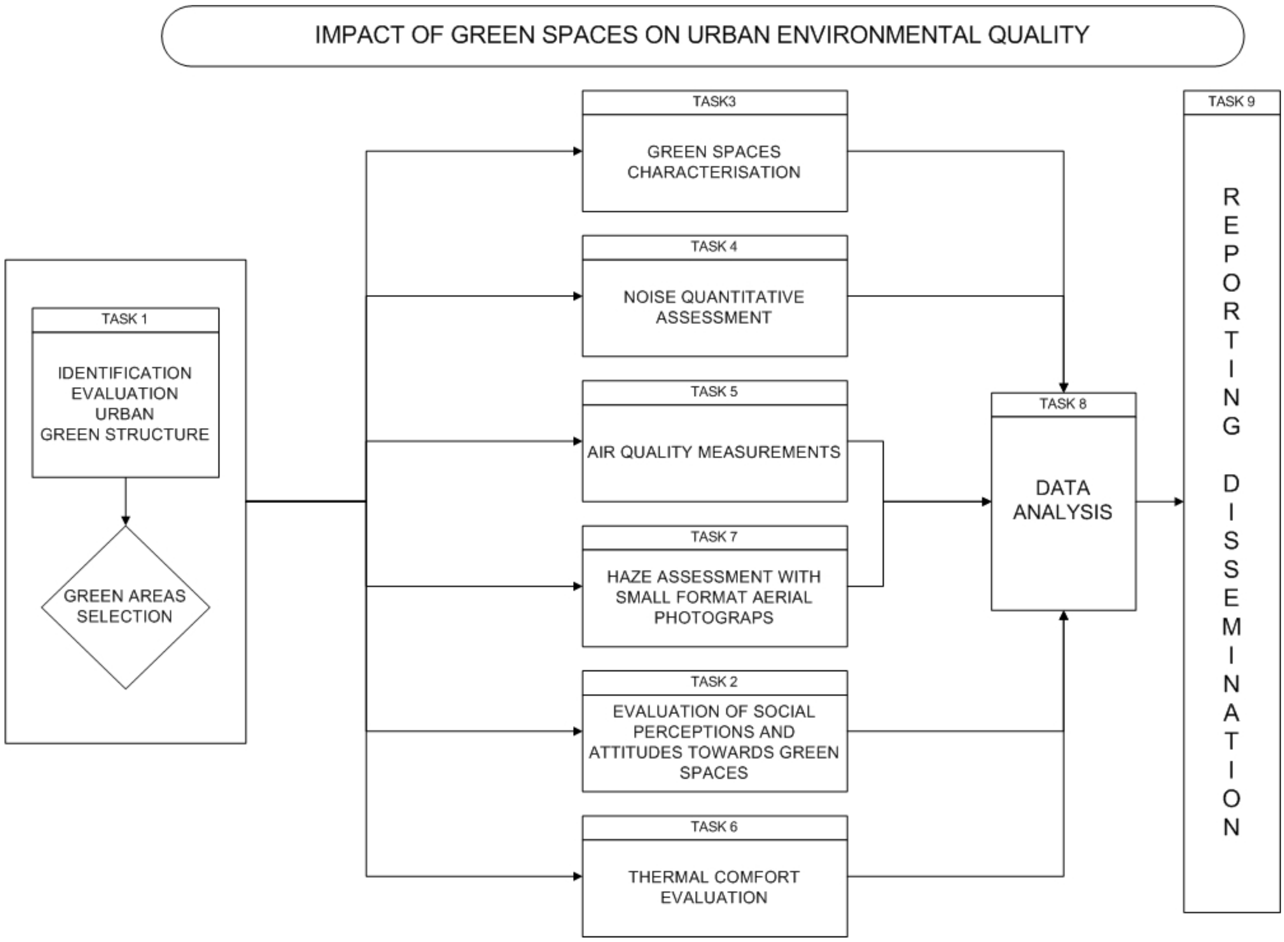

Figure 1: GreenUrbe Project methodology.

The first stage sets the starting basis for the investigation and includes a single task, consisting on the assessment of local open spaces characteristics, in order to evaluate urban green structure, allowing global understanding on both its biophysical and artificial interaction with the urban environment. In order to strength global understanding over human perceptions and attitudes towards urban green spaces, a survey will be developed reinforcing the characterisation by integrating the human dimension. This stage allows full understanding over the urban structure in its complexity and diversity, allowing the selection of contrasting green spaces situations, as a set of individual spaces that will be assessed in micro-scale studies performed in the following stage.

Second stage focus on the evaluating separately environmental variables, at both urban and green space scales, trying to establish potential relations between those variables, urban land use, individual green spaces characteristics and social perceptions and attitudes. This stage is developed around six tasks:

- The first task consists in a deep characterisation of both physical and biophysical characteristics of selected green spaces, without loosing the sense of the urban scale perceptions;

- The second task is developed in order to provide data on acoustic environment and on acoustical energy attenuation by vegetation;

- The third task consist on air quality parameters assessment, namely particulate matter, ground-level ozone (O_3), nitrogen dioxide (NO_2) and, in less extension, volatile organic compound (VOCs), evaluating their levels in relation to green spaces distribution, size and composition in the urban environment;

- The fourth task is somehow related to the previous one, since it involves haze evaluation by small format aerial photograph, seeking to establish links of this atmospheric phenomenon to local air quality;

- The fifth task concentrates on green spaces potential contribution to thermal comfort, evaluating its impact in both environmental and human dimension, crosschecking climate data with human perceptions.

Finally, on a third phase, multiparty results will be evaluated by applying different methods, including multivariate analysis and spatial statistics techniques, trying to establish a set of relations amongst green spaces and its impact on local environmental conditions, as GreenUrbe will try to deliver useful recommendations on urban design.

Early Project Developments

Urban Green Structure Evaluation

Urban spaces are complex and systemic realities, as population, physical structures and biophysical element, interact to produce the contemporary city (Beaujeau-Garnier, 1997, Bettini, 1998; Hough, 1998).

Bragança has grown from its initial limited settlement to become, mostly over the last three decades, a fast growing and spreading urban reality. Throughout this process, landscape was transformed leaving open green spaces and creating some public parks and gardens.

As a mean to evaluate essential landscape characteristics, morphological and structural elements where identified, this information allowed the evaluation of essential attributes. Bragança is located in a mountain region, and as a consequence, landscape has variable forms, as altimetry varies form 560 to 800 meters. Weather conditions range from cold temperatures in the winter, being frequent negative temperatures at nighttime, to very hot summers with temperatures rising up 40 degrees Celsius.

In order to evaluate the green structure, this project examined city's global configuration, identifying existent open spaces, consisting of non-built and unpaved areas. By examining its functionality and its relations with its surroundings, open spaces were classified into ten categories, each defining particular urban element, with distinctive functionality and vegetation (see Table 1 and Figure 2).

Table 1: Green structures elements

Open Spaces Categories	Descriptions	Vegetation	Indicators
Public Parks and Gardens	Especially developed spaces, designed for human leisure, aesthetic value and human recreation, Most of them are managed by the local municipality.	There is a great variety of elements, from endemic to exotic species, most spaces combine trees with grass elements. Most consolidated spaces are situated in the oldest quarters, with the biggest trees.	- 1,5 % of the global area - 8 m2 per hab - 18,6 Hectares
Derelict land	Vacant sites awaiting development, situation that derived from natural causes (neglected woodland or farm land, etc.) or land damaged form construction and other activities	Usually naked ground with few spontaneous vegetation. In many cases establish a transition, from rural and forestry spaces, into paved and constructed grounds. Endemic valuable species can be found in these spaces.	- 8,7% of the global area - 53 m2/ha - 125 Hectares
Corridors	Spaces that establish connections among the urban structure, especially through linear green spaces and waterfronts.	Most corridors are presently associated with local fluvial surroundings and are composed mostly of riparian vegetation, including Alder, Poplar, Ash and Willow.	- 0,7% of the global area - 4,2 m2/ha - 100 Hectares

Table 1: Green structures elements (continuation)

Open Spaces Categories	Descriptions	Vegetation	Indicators
Street trees, sidewalks and alleys	Punctual, linear and spatial elements combined along roads, design to ensure protection and shadows to pedestrians.	Spaces composed by street trees and, occasionally, shrubs and narrow turfs. Tree species varies greatly from deciduous to coniferous. (Fig.)	- 0,2% of the global area - 1 m2/ha - 2,2 Hectares
Historical Gardens	Gardens associated with historical elements, such as the local castle and churches.	Consolidated urban sceneries integrating relevant vegetation elements, biggest tree are usually located in these spaces, such as sycamores.	- 0,1% of the global area - 0,4 m2/ha - 1 Hectare
Public and private services grounds	A large diversity of open spaces surrounding public and private services buildings.	A great diversity of situations can be found, from almost derelict lands to quality green spaces. Some spaces, such open air swimming-pools and other sports facilities, are some of the most valuable green spaces.	- 7,4% of the global area - 45 m2/ha - 106 Hectares
Residential gardens and courtyards	Spaces surrounding buildings, with small areas presenting some elements for recreation.	Public spaces have mostly grass and shrubs cover. Courtyards often include trees, and aesthetic elements.	- 4,9% of the global area - 30 m2/ha - 700 Hectares
Industrial Parks	Spaces surrounding industry facilities, mostly unmanaged.	Similar to derelict land, this spaces have little and mostly spontaneous vegetation.	- 1,2% of the global area - 7,4 m2/ha -175 Hectares
Agricultural Fields	Spaces in periurban locations, mostly situated in flat fields.	The most important elements are cereal field crops. Near the water courses and fluvial margins we found pasture lands, called “lameiros”, habitats with a high level of biological diversity. There are some olive groves and very small vineyards as well. Small chestnut orchards and apple groves or dispersal chestnut trees are also elements of the agricultural fields.	- 29,8% of the global area - 181 m2/ha -427 Hectares
Forests	Small woods can still be found in innerurban spaces, as some important forest extent until periurban locations.	Small woods from maritime pine (Pinus pinaster), holm oak (Quercus rotundifolia) and pyrennean oak (Quercus pyrenaica). We also find poplar plantations and areas with chestnut orchards. Additionally and near fluvial margins we find more dense woodlands with alder, ash and poplar.	- 7,3% of the global area - 44,8 m2/ha - 105 Hectares

One of the most representative elements in urban vegetation are street trees, not considered as area elements but rather as punctual and linear. Bragança has over 4 thousand street trees.

Existent dataset shows exotic species as primary elements in this kind of structures. Five species together represent 56% of global trees number, as *Acer pseudoplatanus* and *Platanus hispanica* are the two foremost representative species. Native species contribute approximately with 9% of the total number of street trees and, being the contribution of local native species just about 4%. *Ilex aquifolium* and *Betula celtiberic* are the most representative local native tree species. Very few specimens of other local native as *Olea europea*, *Quercus rotundifolia*, *Castanea sativa*, *Quercus pyrenaica* and *Ulmus minor*. Additionally, small trees with a shrub like structure as is the case of *Taxus baccata*, *Crataegus monogyna* and *Juniperus communis* are also present in the study area.

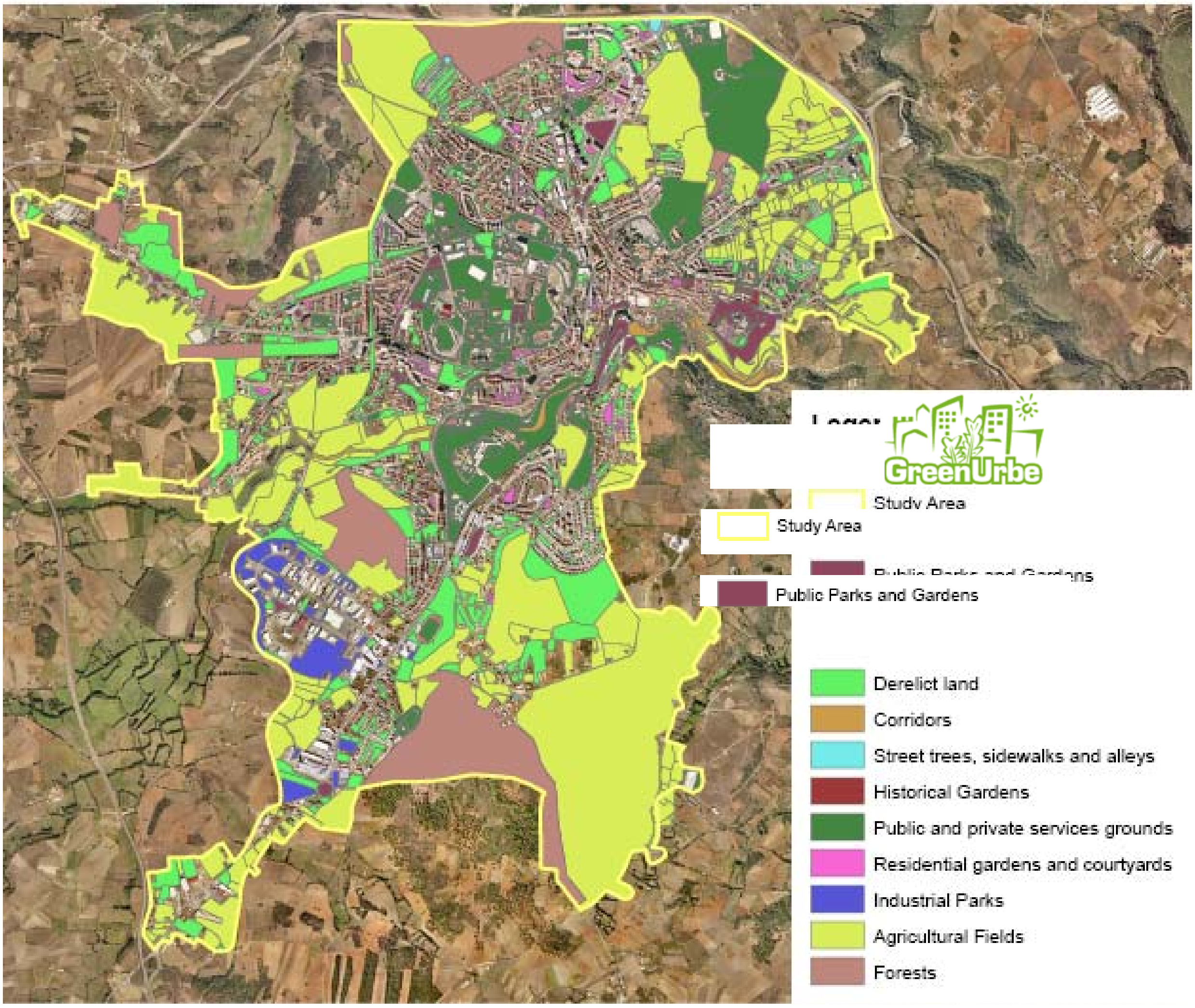

Figure 2: Green structure map.

As efforts underlying vegetation evaluation are expected to be completed during October, this global initial characterization will allow us to establish relations, in an urban perspective, between green spaces and environmental variables.

Air quality measurements

To evaluate the influence of green spaces on air quality, measurements are being developed addressing atmospheric concentration of particulate matter; ozone, nitrogen dioxide and VOCs. This research takes place at two different spatial scales (urban and green space) and throughout different seasons. From these field measurements, seasonal and spatial patterns of the aforementioned pollutants will be inferred, in order to identify and establish potential relations between air quality and urban land use, with special focus on density, shape and composition of green spaces. Meteorological data is obtained from weather stations located in the study area and by using portable automatic stations mounted specifically to serve project purposes.

Gaseous pollutants

Ambient concentrations of ozone (O_3), nitrogen dioxide (NO_2) and volatile organic compounds (VOCs) are being measured at various locations (40 sampling points for O_3 and NO_2 and 21 for VOCs) selected within a sampling grid of over 140 ha, going beyond urban perimeter. Figure 3 shows spatial distribution of sampling points. Criteria as source distribution, source type, land use, green space structure and composition were taken into account in the grid point definition. Air samples are collected at approximately 2,5 m height by means of passive sampling devices, more precisely passive diffusing tubes. In each sampling point three diffusing tubes are disposed for O_3

and NO_2, assuring higher levels of confidence on sampling and analysis. In relation to VOCs just one absorbing tube is placed at each sampling site. Tubes are protected from bad weather conditions by using PVC shelters easily assembled. Diffusing tubes not exposed to ambient air are also placed at several points, in more than fifty percent of the total sampling points, for blank correction. Ozone atmospheric levels are also continuously monitored in the urban area by using an UV photometric analyser (Horiba, model APOA 360). In 2007, efforts will be done to extend continuous measurements to other aforementioned pollutants.

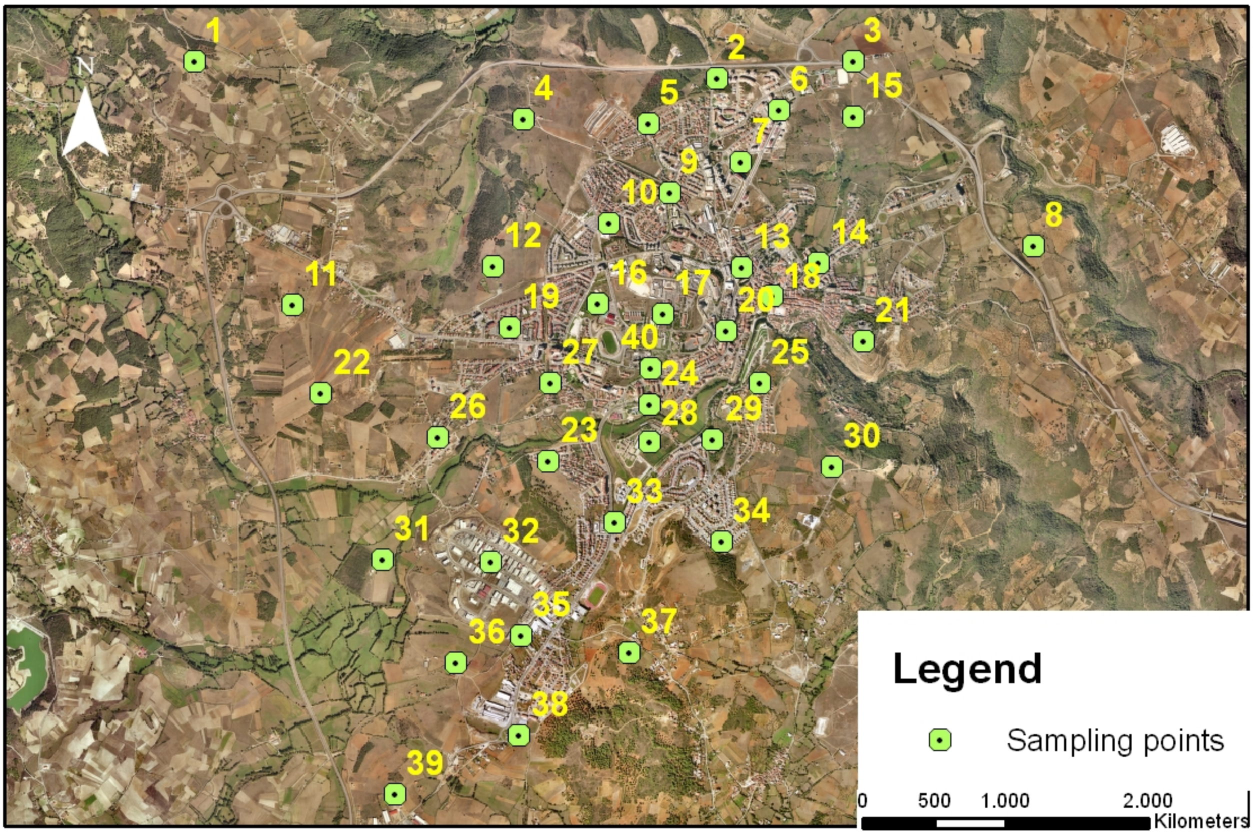

Figure 3: Urban sampling grid defined for ozone, NO2 and COVs.

Excepting some situations, sampling is performed on weekly basis for ozone and on fortnightly basis for NO_2 and VOCs, allowing, from May to July 2006, a total of nine exposure periods: five to ozone (17/05/06 to 23/05/06; 25/05/06 to 30/05/06; 06/06/06 to 13/06/06; 12/07/06 to 18/07/06; 18/07/06 to 24/07/06); three for NO2 (17/05/06 to 30/05/06; 06/06/06 to 13/06/06;); one to VOCs (12/07/06 to 24/07/06). At the end of each period, tubes are retrieved and transported, in proper conditions, to the laboratory for analysis. Samples of Ozone and NO_2 are analysed in our chemical laboratory by using visible spectofotometry, while VOCs samples are sent to Gradko International Lab to be analysed by gas chromatograph/mass selective detector (GCMS). After concentration data validation, geo-statistical methods, such as "kriging" or other spatial integration methods will be applied to generate gaseous pollution maps.

Spatial distribution of NO_2 concentration is shown in Figure 4, exhibiting a pattern strongly correlated with the distribution and intensity of the mobile sources (road traffic). In fact, NO_2 is majority a secondary pollutant, since it is chemically produced by oxidation of NO directly emitted by automobiles, being a good indicator of local and global air quality.

Concerning VOCs, the ten most abundant volatile organic compounds were identified for each sampling point. In total, 33 VOCs species were found, being toluene, bezene, xylene, ethylbenzene, benzene 1,2,4-trimethyl, hexane, naphthalene and D-limonene the most commonly compounds present in the Bragança atmosphere (see Table 2). The first seven are generally associated to traffic road and industrial emissions (Mohamed *et al.*, 2002; Parra *et al.* 2006).

Naphthalene is used as an antiseptic and insecticide, especially in mothballs and D-Limonene works as paint stripper when applied to painted wood and is also used as botanical insecticide.

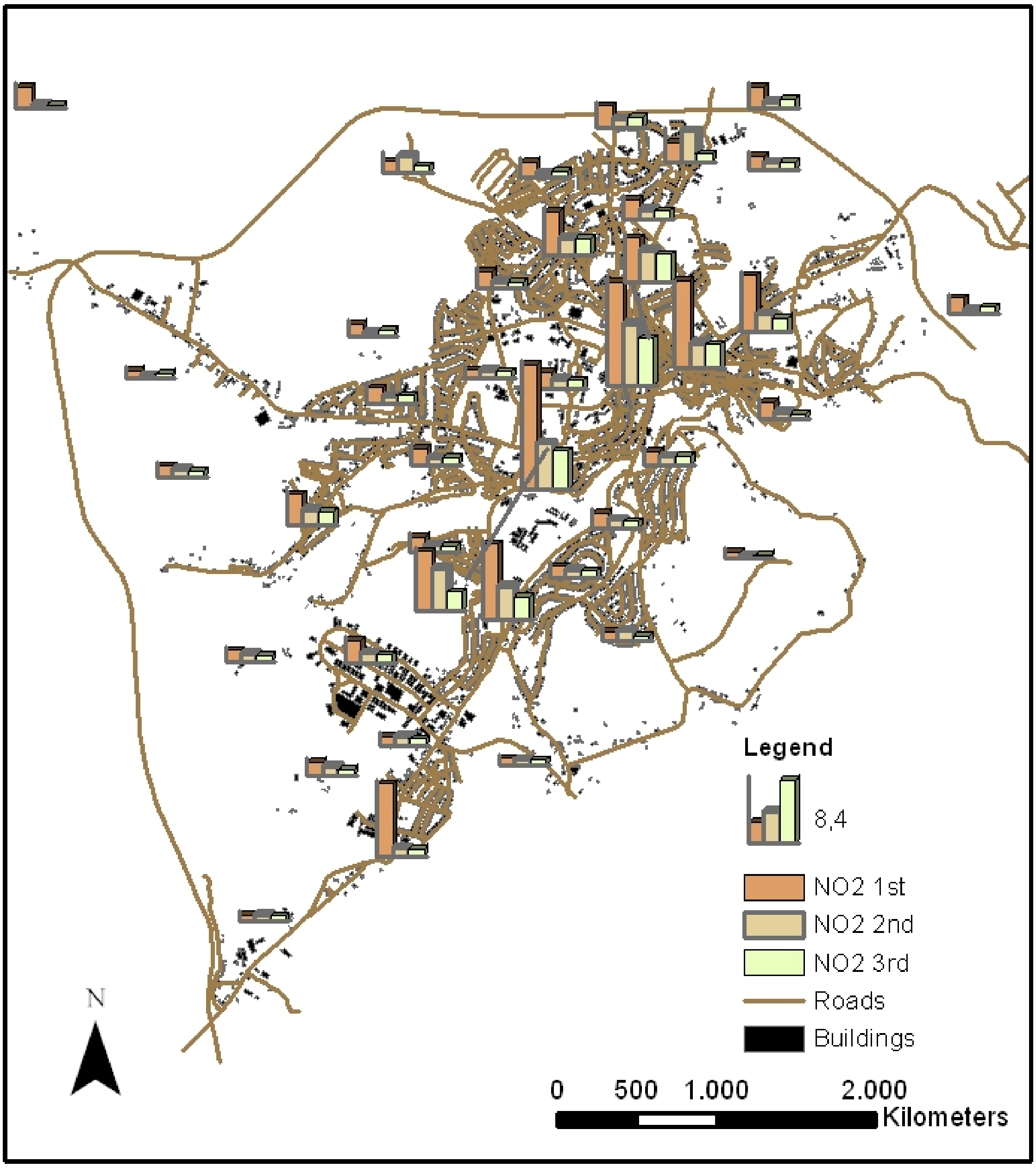

Figure 4: Spatial pattern of long-term NO_2 concentrations (μg m^{-3}) at urban scale.

The most abundant species were toluene, xylene and D-limonene, exhibiting systematically higher values than other species detected. As expected, toluene and xylene were observed, at higher concentrations, near relatively high traffic roads, while D-limonene exhibit a more complex spatial pattern, because it was detected both near intense traffic roads and inside green spaces relatively far from mobile sources. Although cars can be a large contribute in the observed spatial pattern, estimates of Pearson correlation coefficient between pair of VOCs species showing good correlations between TEX (toluene, ethylbenzene and xylene), but poor correlation between benzene and TEX suggest an additional contribution of other VOCs sources as painting and industrial solvents . Moreover, toluene/benzene ratios ranging between 2 and 15, also indicates that mobile is not the only VOC source (Lee *et al.*, 2002).

Table 2: Long-term concentration of the top ten VOC species, in µg m^{-3}, at each sampling point.

	Sampling Points ID																				
VOCs Species	**2**	**7**	**9**	**12**	**13**	**15**	**17**	**18**	**19**	**20**	**21**	**24**	**25**	**26**	**28**	**30**	**31**	**32**	**33**	**34**	**40**
1R-alfa-pinene	0,67														0,17						
1S-alfa-pinene	0,53																				
alpha-methylstyrene		0,87															0,83				
Benzene	0,06	0,51	0,17	0,1	0,38	0,15	0,1	0,22		0,34	0,33	0,45	0,08	0,1			0,5	0,11		0,08	0,24
Benzene 1,2,3-trimethyl																0,27					0,9
Benzene 1,2,4-trimethyl	0,69		0,92		1,38		0,99	0,81	0,15	1,5	0,95	1,18	0,5	0,72		0,55		0,7	1,26	0,52	
Benzene, 1,2,4,5-tetramethyl											0,78										
Benzene, 1-ethyl-2-methyl								0,51		0,74											
Benzene, 1-ethyl-2,3-dimethyl			0,81																		
Benzene, 1-ethyl-3,5-dimehyil																0,38					
Benzene, 1-methyl-3-propyl											0,71										
Benzene, propyl													0,47			0,16				0,27	
Benzeno, 1-ethyl-3-methyl				0,1												0,33					0,66
Cyclohexane, isothiocyanato			0,95	1,46	0,81	0,88			0,39					0,68			0,76	0,56			
Decane		0,3		0,17		0,41	0,91		0,26					0,41	0,22					0,34	
D-limonene	0,91	0,67	1,15	1,22	2,05	1,88	1,6		0,89	2,02	1,61	1,1	0,89	0,91	1,05	0,24	1,05	1,33	0,58	1,18	0,95
Dodecane				0,72																	
Ethylbenzene	0,13	0,5				0,11	0,18	0,19		0,34		0,29		0,09			0,63	0,32	0,24	0,07	0,18
Formamide, N,N-dimethyl-					0,84	0,88		1,11	0,38		0,79				0,49		2,8	1,32	0,69	0,63	
Heptane								0,69													
Heptane							0,44														
Hexadecane		0,25									0,76		0,68		0,64	0,39					
Hexane	1		0,72			0,58		0,83	0,83	0,96		0,62	4,16		0,34		0,97		0,71	0,91	0,63
Methenamine					1,63																
Naphthalene	0,55	0,51	0,46	0,14	1,08	0,16	0,52		0,53	0,46		0,29	0,49	0,25	0,11				0,38	0,5	
Naphthalene, 1-methyl											1,67										
o-Xylene			0,66				0,75	0,64		0,96		0,69	0,54	0,53				0,72			0,59
p-Xylene	0,37	0,47	0,69		0,92	0,2	0,48	0,94		1,38	0,23	0,84	0,29	0,41			0,32	1,04	0,5		0,52
Phenol, 2-ethyl-				0,92	0,81									-			1,09	0,6			0,66
Tetradecane		0,27										0,68			0,52	0,31			0,82		
Toluene	0,93	1,05	1,31	0,73	1,87	0,8	0,92	1,56	0,83	2,35	0,76	1,52	0,94	0,92	0,57	0,39	1,06	1,58	1,36	0,63	1,19
Tridecane				0,45																	
Undecane				1,24																	

Long-term ozone concentrations obtained during first two campaigns are also depicted in figure 5. Values obtained in the first exposing period show a spatial trend marked somehow by higher values near sources of the principal ozone precursors, nitrogen oxides and VOCs. Inversely, values gathered in the second campaign show a different pattern, becoming evident an ozone concentration increase in places farther from sources. This distinct behaviour may be associated to meteorological conditions, which were quite different in both periods, mainly with regards to wind speed and wind direction. In the other three sampling periods, ozone concentrations suggest the existence of probable sampling/analysis mistakes, requiring a further validation period.

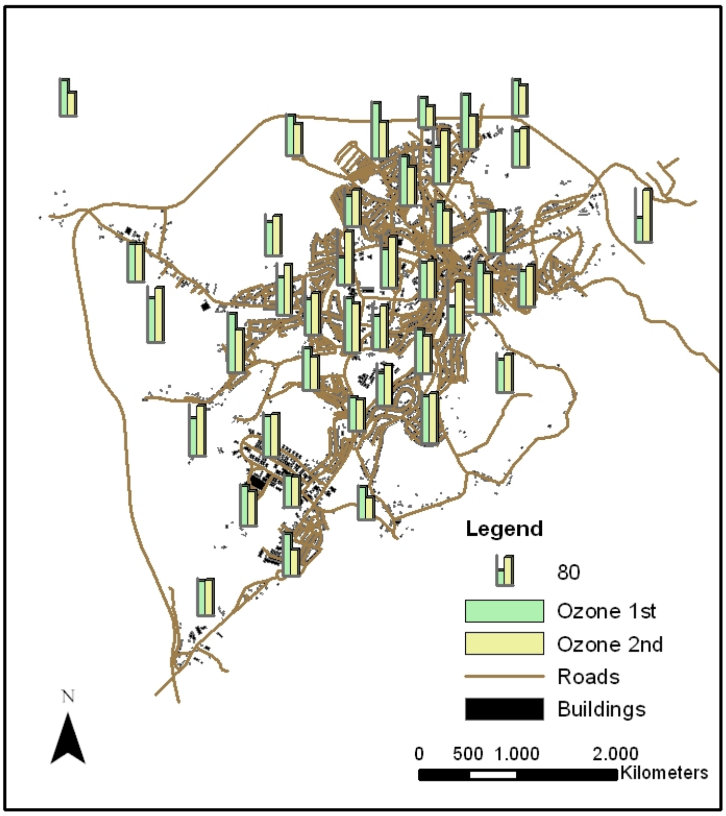

Figure 5: Spatial pattern of long-term O_3 concentrations (µg m^{-3}) at urban scale.

Particulate matter

In relation to particulate matter, the experimental design consist in measuring concentrations of PM10 at different places of Bragança's city, at least twice at each place, throughout the project time, with the purpose of obtaining spatial and temporal pictures of this atmospheric pollutant. However, spatial measurements can not be performed at same time in all selected locations. To overcome this limitation, PM10 will be measured for a long period in order to catch a representative concentration value at each location.

Additionally, another experimental design to underpinning the role of urban vegetation as filtration elements of particulate matter will be put in practice. This field experiment consists in carrying out short-term or very short-term measurements at specific selected green areas, both upwind and downwind of the vegetation wind break zone, preferably during periods characterised by stable wind conditions. Control test runs will also be set up on open ground near green area being tested, in order to compare the differences between ground covers with and without vegetation.

PM10 field measurements are accomplished by using a particulate sampler Tecora ECHO PM, equipped with head PM10 LVS, and a real time monitor of particles ADR 1200S (ThermoElectron), very versatile, adapting to the multiple types of experimental design.

Finally, with the purpose of interpreting measured values with higher accuracy, modelling studies involving either back-trajectories or air quality models (CALINE 4 and CAL3QHC) will also be performed. Available internet satellite images can also be used as a fundamental tool to infer the relative contribution of atmospheric aerosol sources.

Particulate matter measurements started some months before project beginning, involving PM10 concentrations measurements at three urban locations: a) in a green space surrounding the superior education institution (IPB); b) in the main street of Bragança, Sá Carneiro Avenue, at about 6 m from roadway central axis (three sampling periods – SCp1, SCp2, SCp3); c) near a crossroad with semaphores, at approximately 20 m from road (SEM).

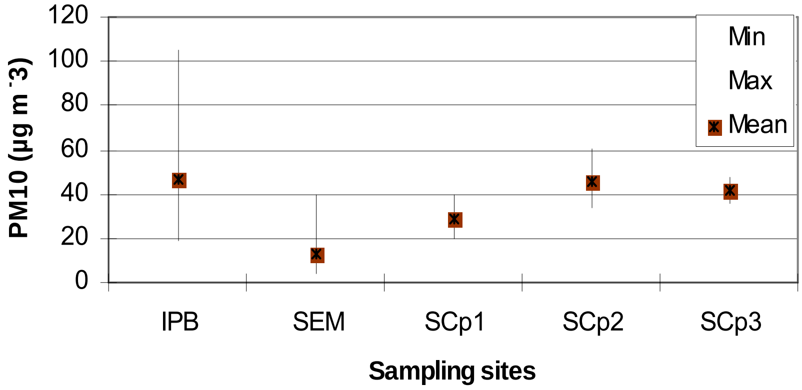

Figure 6: PM10 concentrations at urban atmosphere of Bragança

Results obtained are depicted in figure 6, which shows that Bragança is sometimes exposed to significant levels of PM10, with concentrations reaching values sometimes higher than 100 µg m^{-3}. Among all sampling places, the Sá Carneiro Avenue is maybe the street with higher road traffic intensity exhibit values systematically elevated of particles (> 40 µg m-3), foreseeing some difficulties in executing legal criteria in future. The concentrations of PM10 seem to be well correlated with the automobile emissions, although dust transport from neighbourhood locations and long range transport of particulate matter have been also identified as potential sources.

At this moment, an intercomparison test between the particulate sampler and the particulate monitor is elapsing, as it is expected that by the end of September field measurements will be retaken.

Haze evaluation

Although Bragança is a city with relatively good air quality, under some summer conditions atmosphere visibility decreases drastically. Based on the occurrence of this phenomenon, a technique using High Quality Small Format Aerial Photography (SFAP) will be applied.

A flight navigation system and a camera rig is used to obtain these photographs, which will then be used to estimate haze content in the study area, by using image processing technology normally used in remote sensing (RS). We will try to find positive relationship with the haze content and the air quality evaluated on the ground, as well as, with superficial biophysical elements, as green spaces.

The Small Format Aerial Photography (SFAP) constitutes an alternative to the standard aerial photography, being a very promising technology with many fields of application that should be investigated. Moreover, the light high wings aircrafts like Cessna 172 (available model in the airfield of Bragança) are appropriate to the SFAP.

A camera rig (small portable housing for the cameras 35 and 70 mm), and diverse accessories, already designed and constructed, will be installed outside the pilot cabin and attached to the aircraft structure without modifying it and satisfying the Civil Aviation Authorities.

The quality of aerial photography and survey flight efficiency can be greatly improved by automatic compensation of the angular aircraft movements. Nevertheless, our system provides a good accuracy at a reasonable price, including a GPS-based survey flight management system, already tested in similar studies.

The flight lines planning takes in account the film magazine capacity, especially in the 70 mm format that still can be used to capture high quality images. So, each flight line extent must be adequate to the number of photographs of each film, considering a 60 % overlap of two successive photos. Even considering the existence in the market of the CCD back to 70 mm cameras, this solution is technically inefficient because of the low speed of images transferring. Moreover, the cost is also very high. The 35 mm digital cameras provide already good chromatic and geometric quality of the images with adequate speed of data transferring according the use of modern UltraCompactFlash systems. Several authors propose the CIR digital cameras in vegetation monitoring. We intent to include this kind of cameras in the platform rig.

The camera shooting will be controlled by an intervalometer wish require a very uniform flight speed to get constant overlaps between pairs of photographs. A skilled pilot can do that efficiently.

To evaluate the haze component we intend to measure the reflectance of several ground control targets and also air quality at different times in a single summer day. Simultaneously will be acquired SFAP for further comparing. This process will be repeated 3 times each year. To perform the evaluation of the haze content, captures of the study area will be taken in SFAP colour infrared films (CIR) and normal colour. Just after this moment the same kind of images will be captured but covering large areas of clean deep water. It's important to include also some ground control targets near the water that could be directly compared with some similar targets of the study area.

The poor reflectance of the infrared light in clean deep water could be used to estimate the haze contents by the methodology initially proposed by Chavez (1988) (Dark Object Subtraction) to the atmospheric correction of remote sensing images.

To complement aerial photographs analysis, a camera installed in a high building will be used to take daily panoramic photos, mainly during summer season.

This task was foreseen to start-up in July 06, but first flight was just performed at 20 September. Preliminary conclusions of this task are expected to the next month.

Environmental Noise Quantitative Analysis

The absorbing capacities of the urban green cover regarding acoustical energy will be investigated through an experimental design that involves noise measurements, noise attenuation tests and modelling techniques of sound behaviour.

Noise measurements are being performed at specific urban sites, at two different spatial scales, urban and green space scale. On urban scale, various locations covering a wide range of urban land use, without obeying to any regular grid, were selected for noise measurements. At green space scale, higher spatial resolution measurements are conducted in a set of points disposed on a grid varying in size and shape, as a function of local characteristics, namely noise sources and types of vegetation. Taking into account the seasonal variability of the green coverage, measuring campaigns will be performed at each site, in both summer and winter conditions, with the objective to underpinning the real contribution of vegetation on sonorous environment.

Concerning the sound attenuation tests, a stable point source (loudspeaker) is used together with a sound meter at specific and contrasting vegetation barriers. At each vegetation barrier, global sound pressure levels and sound pressures associated to each 1/3 octave frequency band, are measured along transect lines perpendicularly crossing the belt, following an experimental design similar to that described in Fang and Ling (2003). At each transect, measuring sites will be define in regular gaps, starting at the edge of the green area, near the noise source. The number of transect lines and measuring points will be a function of the green area size and morphology. Control test runs will also be set up on open ground near tested green area, in order to compare the differences in sound pressure levels between two types of ground cover. Measurements at different seasons will be also assured whenever biometric parameters of vegetation undergo significant seasonal changes.

Finally, with the purpose to complement the information provided by measurements, a sound pressure modelling computer tool (CADNA A) is used both for mapping noise levels concerning existent situations, properly validated by existent measurements, and for evaluating interesting links between future urban land use scenarios and sound environment predicted scenarios.

Up to now, a large environmental noise dataset has already been constructed, although it is expected that next year there will be a strong impulse to accomplish all pre-established objectives.

Measurements at the urban scale show that environmental noise ranges between 40 dBA, at places relatively far from roads, to 75 dBA at residential areas near roadways with higher traffic intensity, showing a potential conflict between existent noise sources and sensible receptors. Similarly to described air emission, noise is also generated principally by mobile traffic, creating adjacent areas with significant noise annoyance. This situation is illustrated by spatial noise pattern shown in Ricafe and IPB green spaces (Figure 7). The first place is a tree belt located between a roadway and a residential area; the second, is a green area surrounding Bragança Polytechnic Institute. Comparing both locations, a noise gradient decreasing from the area border to its centre is quite visible. Moreover, taking into account the principal differences between both locations, with regards to vegetation characteristics, results show that green coverage could act as an effective biotechnology in reducing noise.

To help our analysis, a preliminary test was already carried out at the Ricafe area, one of the most wide tree belt located in city periurban location, acting as a sound barrier between a roadway and a residential area. This is a green area of about 7,1 ha of pure regular Maritime pine (*Pinus pinaster* Ait.), about 32 years old. Through a systematic sampling of 30 temporary 100m2 plots, mean stand density was estimated in 876 trees per hectare. The spacing between trees is regular about 4 x 2.5 meters. Wilson factor present an average value of 20. The average height of dominant trees is 16.1 meters, with a crown length about 10 m. Density values of 157 ton/ha were obtained by applying Lopes (2005) biomass equations.

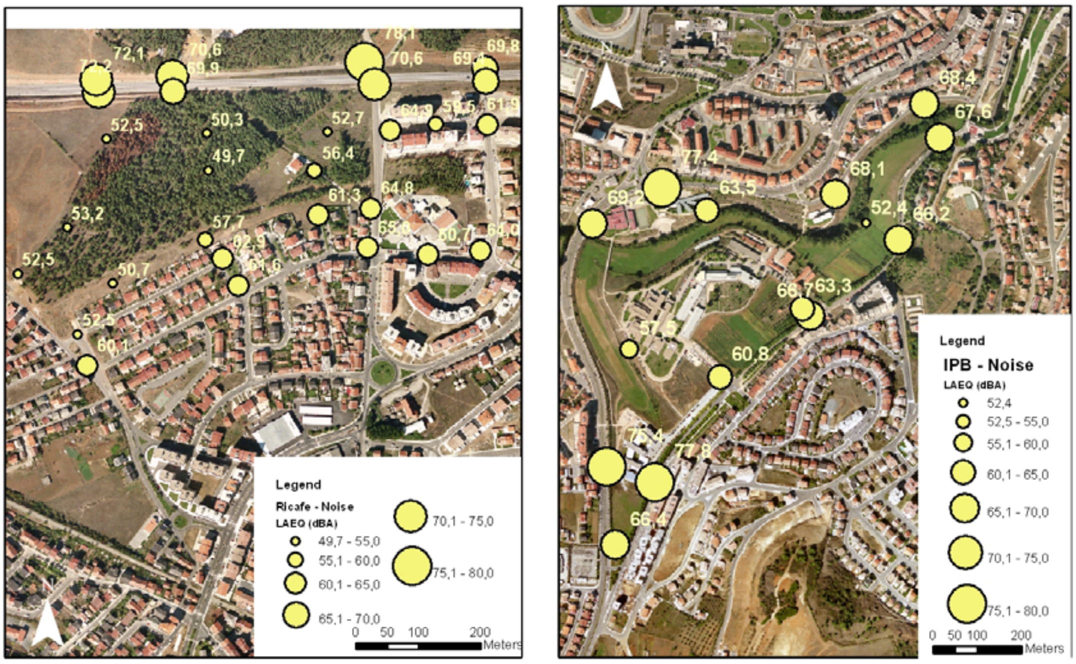

Figure 6. Noise levels at Ricafé and IPB green spaces.

Under canopy, various shrubs were found (Rosa sp., Rubus sp., Crataegus monogyna, Daphne gnidium, Lonicera peryclimenum, Cytisus scoparius, Genista falcata and Quercus rotundifolia) and herbaceous of the graminae family. The coverage density was experimentally quantified and was estimated in 400 kg/ha.

Results from this preliminary test (figure 7) shows that Pinus pinaster enhances noise attenuation by 3 dBA/20m, which are within the range reported by Fang and Ling (2003) for a large set of tree belts (1,5-9,5 dBA/20m). Attenuation analysis by 1/3 octave band frequencies do not show any substantial difference between high and low frequencies attenuation.

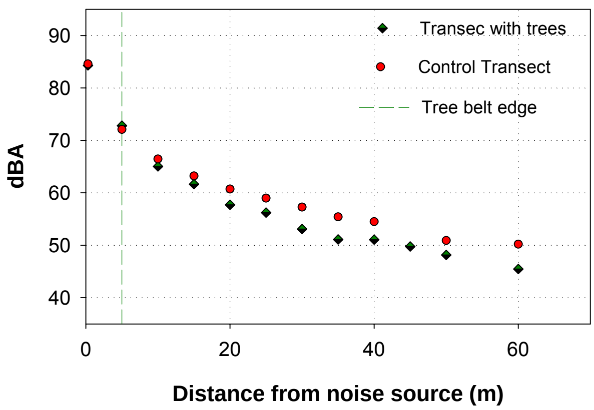

Figure 7: Sound levels measured along two linear transects.

In the near future, other type of tree belt will be investigated, especially narrow structures because they are more common in landscape planning.

Thermal Comfort

As an initial research, the thermal component of urban climate was evaluated, as it affects the quality of life in cities by its influence over thermal comfort, heath, energy consumption and air quality. Within the framework of the GreenUrbe project, a network of 4 fixed data-loggers (Testo 175-H1) and 2 automated weather stations (Campbell Scientific Inc., Logan, UT, USA) were installed in 6 places with different microclimatic conditions. Air temperature and relative humidity were measured in all places, wind speed and wind direction in two places and solar radiation in just one place. The measurements were made in March during a 30 day period. This preliminary study shows relevant spatial variability, however it's still soon establish relations with the urban structure and green spaces elements. Complementary studies will be developed in winter and summer conditions, allowing further knowledge on most contrasting situations.

However, the development of comfort studies implies the acknowledgement of other elements rather than traditional climate variables (generally designated as environmental comfort), with the evaluation of the human dimension related to de rate of activity and clothing. Together these variables will be used to evaluate human thermal comfort using Fanger (1972) indicators: Predicted Percentage Dissatisfied (PPD) and Predicted Mean Vote (PMV). Other indicators may be developed during the process of variables interpretation.

In order to assess thermal comfort under different green spaces conditions, and bearing in mind studies developed by Givoni et al. (2003), experiments were conducted during the summer of 2006, in a grassed surface open space and in a concrete surface area, in an urban park. Three places, with different microclimatic conditions: (1) under a large shade tree (grass), (2) in an open area exposed to the sun (concrete), (3) in an open area exposed to the sun (grass) and (4) behind a vegetation wind shelter of evergreen shrubs (grassed), were selected in order to understand how physical factors such as radiation, wind and temperature influence thermal sensation and comfort level.

The measured environmental factors included air temperature, wind speed and direction, wet and dry-bulb temperature and radiation balance.

A questionnaire was applied in order to obtain personal sensory responses, evaluating both thermal sensation and overall comfort. Twelve persons participated in the study, equally numbered males and females, ranging from twenties to sixties and wearing white T-shirt and trousers, commonly used clothes in this region's summer conditions. They participated in four subgroups of three persons, distributed according to age classes (20-30; 30-40, 40-50 and 50-60 years old), each subgroup stayed in each location for 20 min (15 min to get used to thermal condition and 5 min to fill individual questionnaires) and then moved to a different one, in a rotation schedule. After each 80 minutes, all subgroups had gone trough all four places. This procedure started at 9 a.m. and finished at 6 p.m. (local time) and was repeated four times during the day. Further thermal comfort studies will be developed in selected green spaces under summer and winter conditions.

Both urban and micro-scale studies will be used to evaluate of green spaces' influence on urban environmental and thermal comfort.

Despite gathered data are still under analysis, first interpretations show thermal comfort responses in good agreement with onsite environmental conditions.

Population Attitudes and Perceptions Evaluation

As some green spaces' environmental benefits are well understood by the scientific communities, urban population may not be aware of its importance in daily living. Recent studies concentrate on human attitudes and perceptions towards urban green spaces, including the interpretation of its environmental benefits (DTLR, 2002; Sanesi and Chiarello, 2005).

In order to address this component of our study, two types of studies were carried out: the first one concentrates on a global population approach, as the second focus on individual spaces users.

Scheduled for October 2006, a residential survey will be developed to a representative sample, both in socio-demographic as in geographic terms, assessing 400 inhabitants, around two per cent of adult population, living in diverse city locations. This survey will be developed by domiciliary contact and will focus on the following evaluation elements:

- Sample characterization – Characterization of the surveyed population, including age, gender, profession, education level and family characteristics;

- Relation with green spaces – Individual relation with this spaces, including such elements as frequency in use, means of transport, distance traveled, time spent and developed activities;

- Daily meaning – Identification of inhabitants perceptions on green spaces importance, evaluating the acknowledgement of its benefits;

- Limitations to use – Identifications of elements representing important constraints to use, such as pollution, safety and others;

- Quality elements in green spaces – Inhabitants preferences in vegetation, aesthetics elements and others;

- Quality evaluation – Quality evaluation over different kinds of green spaces.

Data resulting from this survey will provide relevant information allowing global understanding on the relevance of different green spaces, and thus allowing cross-examination on the relations between environmental quality and individual choices.

Starting in next winter, and executed in summer and winter, surveys will be developed under a different perspective, trying to assess casual user perceptions, wile under the influence of selected green spaces environmental conditions. This survey will be undertaken while simultaneously assessing environmental parameters (noise, thermal comfort and air quality). This study will bring relevant information about inhabitant's perceptions over green spaces influence on environmental conditions.

Final Remarks and Future Developments

The first year of GreenUrbe Project was concentrated on the development of a set of preliminary researches with four fundamental purposes: knowing better the system, i.e., Bragança's city and its green structure; improving general methodology; refining all experimental designs; and, in preliminary basis, because it still needs a larger and properly validated data set, extracting preliminary conclusions regarding the role of green spaces on environmental quality.

Concerning the first purpose, Bragança can be defined as small city, with a fragmented green structure, composed predominately by agricultural areas, few urban forest spaces and abundant young street trees alignments, which must be optimised to meet other sustainable requirements.

Preliminary results on environmental quality open good perspectives to future developments. Measurements of air quality seem consistent, although the data set is still under evaluation. Atmospheric pollution in the city it is not drastic, but a spatial profile was clearly identified, in which polluted areas are mostly associated with traffic roads, since vehicles are the main emission sources. It is expected that winter time measurements can identify domestic heating as another relevant source. Analogous traffic source relations are established with noise levels. Preliminary measurements are still scarce to allow confident interpretations on quantitative causal relationships between environmental quality and green spaces characteristics.

During the next two years, much is still to be done in order to scientifically understand the role of green spaces on environmental quality. The achievement of this overall objective requires further measurements at urban scale, intensification of inner green spaces experimental designs and human perception evaluation. Moreover, further efforts will concentrate on establishing correlations among variables by applying different methods, including multivariate analysis and spatial statistics techniques, trying to establish a set of relations amongst green spaces and its impact on local environmental conditions.

Acknowledgement

This work was supported by the Portuguese Science and Technology Foundation and by European Fund for Regional Development (FEDER). The authors are grateful to the Climatological Group of the Bragança Polytechnic Institute especially to A. Araújo for providing meteorological data and authorising equipment installation in the group facilities. Authors also thank to public institutions and private owners for having made possible the placement of equipment and sampling devices in their properties. Special reference has to be made to several Bragança Polytechnic Institute students who much have helped in the development of this research.

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