U.PORTO

FEUP FACULDADE DE ENGENHARIA UNIVERSIDADE DO PORTO

THERMAL RETROFITTING OF PUBLIC SPACES IN COMPACT URBAN AREAS

A bioclimatic approach

JOÃO PEDRO ANTUNES GRANADEIRO CORTESÃO

Thesis submitted in partial fulfilment of the requirements for the degree of

DOCTOR IN CIVIL ENGINEERING

UNDER THE SUPERVISION OF:

Fernando Brandão Alves

Professor at the Faculty of Engineering of Porto University

AND CO-SUPERVISION OF:

Joanne Patterson

Research Fellow at the Welsh School of Architecture, Cardiff University

MARCH 2013

PROGRAMA DOUTORAL EM ENGENHARIA CIVIL

CIVIL ENGINEERING DEPARTMENT

T. +351-22-508 1901/2139

✉ prodec@fe.up.pt

Edited by

FACULTY OF ENGINEERING OF THE UNIVERSITY OF PORTO

Rua Dr. Roberto Frias

4200-465 PORTO

Portugal

T. +351-22-508 1400

F. +351-22-508 1440

✉ feup@fe.up.pt

http://www.fe.up.pt

To my parents

ACKNOWLEDGEMENTS

This research expresses an investment made in the past few years in both professional and personal dimensions. This investment has been followed by Professor Fernando Brandão Alves, who I had the pleasure of being supervised by. It was also a pleasure to be co-supervised by Joanne Patterson. To both my supervisors I endorse my profound gratitude for the support and enthusiasm about my research and for all shared knowledge.

I would also like to express my deep gratitude to the Building Physics Laboratory (LFC) of the Faculty of Engineering of Porto University who kindly provided the instruments composing the meteorological station used for the field survey, in particular to Professor Helena Corvacho who was often a vital support for my research. Also to the Welsh School of Architecture, Cardiff University, I endorse my deepest gratitude for all support given, in particular to Professor Phil Jones, Huw Jenkins, Yan Wang, and Katrina Lewis.

I also had the enormous privilege of discussing this research with several scholars and practitioners. I would like to highlight here the support given by Alexandra Cabral, Andrew Charles, Armanda Abreu, Cecília Silva, Chris Owen, Fergus Nicol, Inês Murghulia Jorge, Isabel Matias, John Worthington, José Patrício Martins, Kevin McGeough, Laura Roldão Costa, Marialena Nikolopoulou, Mark Osborne, Mike Biddulph, Sandy Williams, Vera Palma, Wendy Richards, and Jernej Vidmar. To all I endorse my deepest gratitude for the help given in overcoming countless barriers to the development of the research.

I would like to thank to those without who the undertaken field survey would not have been possible, namely Ana de Castro, Cristina Vaz Santos, and Joana Vieira de Andrade. In addition, my deepest gratitude to all those who kindly accepted answering the field survey’s questionnaire; to Igor Pascoal, for all patience relatively to the web design of the proposed guide; and to Mário Saleiro Filho, who unconditionally supported my research discussing ideas, pointing out ways of overcoming problems, or giving new insights.

My sincere acknowledgements to all my family and friends, for all support, understanding and patience even when I was not there for you as much as I would like. Thank you for listening, for trusting, for sharing this project. My special acknowledgment to Joana Restivo, who made this journey less lonely.

My final acknowledgments to the Portuguese Foundation for Science and Technology, for believing in my research and for providing financial and institutional support (Grant reference SFRH/BD/44417/2008).

RESUMO

De todos os impactes da alteração climática o aumento significativo nos extremos de temperatura é particularmente importante em áreas urbanas. Este fenómeno pode limitar o bem-estar das populações urbanas e a interacção social em espaço público, especialmente em regiões de verões quentes e muito quentes. A criação de espaços públicos pedonais bem sucedidos deverá, pois, lidar tanto com a deslocação da circulação automóvel quanto com a provisão de condições para o conforto térmico. É imperativo que as áreas urbanas possuam as condições necessárias para que a população possa suportar os impactes da alteração climática e para que o espaço público continue a desempenhar o seu papel privilegiado na interacção social. O desenho urbano bioclimático pode ajudar a abordar este desafio por tomar o microclima de espaços públicos como um verdadeiro compromisso projetual.

O desafio é particularmente importante em áreas urbanas consolidadas, dado que nestas áreas o ambiente construído já se encontra definido e, portanto, mudanças estruturais não são tão passíveis de acontecer. A reconversão de um espaço público através de materiais de revestimento 'cool' e vegetação, numa perspectiva bioclimática, pode significativamente influenciar o microclima desse espaço sem a necessidade de intervenções estruturais. A combinação destes dois parâmetros morfológicos pode reduzir a quantidade de radiação solar incidente sobre as superfícies de um espaço e aumentar as perdas de calor ao nível do solo, onde a circulação pedonal se processa. Porém, existe um desfasamento entre teoria e prática nesta matéria.

Esta investigação é desenvolvida em torno da hipótese de que uma metodologia para a reconversão térmica de espaços públicos em áreas urbanas consolidadas baseada em programas de materiais 'cool' e vegetação, numa perspetiva bioclimática, pode tornar este mesmo conhecimento mais operacional. A investigação começou por identificar um problema, definir a questão de investigação e respectiva hipótese, ao que se seguiu uma revisão de literatura. Seguidamente, construiu-se e testou-se a hipótese através de um caso de estudo; do desenvolvimento de uma metodologia para a reconversão térmica de espaços públicos em áreas urbanas consolidadas; e da validação da metodologia proposta. A investigação termina por concluir sobre o contributo que a metodologia proposta poderá dar para o conhecimento relativo à adaptação do ambiente construído aos extremos de temperatura previstos com a alteração climática e para a consolidação da prática do desenho urbano bioclimático.

PALAVRAS-CHAVE: alteração climática, clima urbano, verão, desenho urbano bioclimático, conforto térmico em espaços exteriores.

ABSTRACT

Conspicuous amongst the impacts of climate change, the substantial increase in temperature extremes is quite relevant for urban areas. This phenomenon can hinder people's welfare and social interaction in public spaces, particularly in regions with warm and hot summers. The creation of successful pedestrian public spaces should therefore account with both the displacement of cars and provision of conditions for outdoor thermal comfort. It is vital for urban areas to possess the necessary conditions for urban populations to cope with the impacts of climate change and for public spaces to keep fulfilling their privileged role as stages of social interaction. Bioclimatic urban design can help addressing this challenge by taking the microclimate of outdoor public spaces as a true design commitment.

The challenge is particularly important in compact urban areas since in these areas the built environment is already defined and, thereby, structural changes are not as likely to happen. Retrofitting interventions can thus be useful in these areas. Retrofitting a public space through 'cool' materials and vegetation on a bioclimatic perspective can significantly influence its microclimate without entailing structural changes. The combination of these two morphologic elements can reduce the amount of direct solar radiation striking the surfaces of a space and the increase the heat losses taking place at the ground level, where pedestrian circulation is held. However, there is a gap between theory and practice on this subject.

This research is developed around the hypothesis that a methodology supporting the development of thermal retrofitting proposals for public spaces in compact urban areas based on 'cool' materials and vegetation, on a bioclimatic perspective, can help becoming this knowledge more operational. This research started by identifying a problem, defining the research question and associated hypothesis, and by undertaking a literature review. The hypothesis was subsequently built and tested through a case study; the development of a methodology for the thermal retrofitting of public spaces in compact urban areas; and the validation of the proposed methodology. The research finishes concluding about the capacity of the proposed methodology to contribute to the know-how on the adaptation of the built environment to the substantial increase in temperature extremes brought by climate change, and to the consolidation of bioclimatic urban design practice.

KEYWORDS: climate change, urban climate, summer, bioclimatic urban design, outdoor thermal comfort.

CONTENTS

INDEX OF FIGURES

INDEX OF TABLES

ACRONYMS

T_a – Air temperature [°C]

RH – Relative Humidity [%]

K – Solar radiation [W/m^2]

W – Wind speed [m/s]

MRT – Mean radiant temperature [°C]

M* – Metabolic rate [W/m^2]

1
INTRODUCTION

1.1. BACKGROUND

Climate change has nowadays moved from a theoretical notion marking the future of the planet to a well-established and no longer avoidable phenomenon. Indeed, «climate change scenarios for the 21st century suggest that, up to the midpoint of the century, much of the change is already committed, whatever action is taken to reduce the causes of climate change» (Wilson, Nicol et al., 2008; 31; 32).

Climate change «describes a change in the characteristics which compose the climate and derives from alterations of factors which affect the climatic elements, either on a local or a global scale» (Alexandri, 2005; 34). Irrespective the precise nature of these factors and faced to the impossibility to avoid the impacts of climate change, it is paramount to consider that «delaying action will only increase economic costs and physical damage from climate change in the long run» (Commission of the European Communities, 2007; 2).

Although the impacts of climate change are not determinant or linear, there is an agreement on the fact that this phenomenon is likely to have unprecedented impacts on the physical infrastructure of a city, i.e. its roads, sewers and services but also its social, welfare and amenities (Tunstall, 2006; 354). From all expected impacts of climate change in urban areas, the substantial increase in temperature extremes is particularly relevant. All prediction models for climate change point out a main trend for an increase in temperature of about 1.9 °C to 5.2 °C though most estimates refer a range between 3.5 °C and 4.5 °C (Cuadrat and Pita, 2009; 449). It is believed that this is the impact likely to place higher pressures on the built environment.

Built environment can be understood as all «developed land containing buildings and associated infrastructure» (Tunstall, 2006; 353). More particularly, the built environment can relate to urban structure, namely to the «pattern or arrangement of development blocks, streets, buildings, open space and landscape which make up urban areas» (Llewelyn-Davies, 2000; 33). Lynch (1981; 48) considers that «settlement form is the spatial arrangement of persons doing things, the resulting spatial flows of persons, goods, and information, and the physical features which modify space in some way significant to hose actions, including enclosures, surfaces, channels, ambiences, and objects». The urban environment is created to offer a human group a complete, balanced and to some extent self-sufficient settlement (Benevolo, 1975; 205).

Therefore, the understanding of built environments should surpass a strictly utilitarian and/or physical perspective to encompass a more holistic perspective based in many immaterial realities. There is an extraordinary complexity but at the same time richness in built environments as natural, anthropologic, social and historical assets. The urban environment results from the «interaction between infrastructure and social forces» (Castells, 1984; 84). In its very essence, the city is a powerful symbol of a complex society (Lynch, 1971; 6) and should then be regarded as «the expression of the diversity of social relationships which have become fused into a single organism» (Giedion, 1967; 41), product of a concrete temporality (Choay, 1965; 25). Urban environments, as a social phenomenon, involve ways of expression and communication codes, identification symbols and practices deeply marked by identity-related symbolism (Costa, 2001; 62).

The substantial increase in temperature extremes brought by climate change can hinder both material and immaterial dimensions of the built environment. As far as urban design is concerned, higher temperature extremes may increase people's health vulnerability, reduce the conditions offered for thermal comfort and, consequently, make the use of public spaces more difficult since a higher thermal stress will be placed upon the body, particularly during summer and in regions with warm and hot summers.

Summer conditions are regarded in this research as the typical combination of climatic variables — air temperature, relative humidity, direct solar radiation and wind speed — at given latitude and for a given climate classification that, during this season, tends to place thermal stress upon the human body (Figure 1). The underlying notion is the thermoregulation mechanisms required for the body to maintain its inner temperature which if taken to extreme values can lead to hyperthermia and even death (Oke, 1987; 221). This notion is further related to thermal neutrality, which can be seen as «the condition in which the subject would prefer neither warmer nor cooler surroundings» (Zhang and Zhao, 2008; 49), and to a neutral state of skin moisture, i.e. absence of discomfort from wet skin (Givoni, 1998; 9). Air temperature, relative humidity, direct solar radiation and wind speed are the major climatic variables affecting these parameters, and thus, human thermal comfort (Olgyay, 1963; 15). In turn, warm summers refer to average temperatures of the warmest month lower than 22 °C but average temperatures of at least four months above 10 °C; and hot summers designate average temperatures of the warmest month over 22 °C (Cuadrat and Pita, 2009; 351).

Fig.1 – Different latitudes one same summer phenomenon: heat stress placed upon the body. Bern, Switzerland (top left); Lisbon, Portugal (top right); Florence, Italy (bottom left); and Porto, Portugal (bottom right). Source: João Cortesão, 2008.

Coupling summer thermal conditions with the higher temperature extremes expected with climate change, further worsened by the urban heat island phenomenon, requires acting as promptly as possible in urban areas located in regions with warm and hot summers. Improving the quality of life of people living and working in these regions, ensuring that cities fulfil their central role for civilised life, and attracting inward investment cannot be thought independently from these issues. The pedestrianisation of outdoor public spaces has a particular importance in this context.

Throughout the 20th century there was a permanent adaptation of cities to cars which has suppressed the traditional multifunctional character of streets and other public spaces (Menezes and Farinha, 1983; 6; 9). Nevertheless, faced to its adverse environmental and social consequences, a consensus has been reached that rising demand for car travel must be curbed and that this should underlie the spatial rehabilitation of urban central areas (Marques-Clarke, 1998; 26). The contemporary city has been placing a significant emphasis on the quality of the urban environment as a whole, much of it based on a concern for people's welfare and environmental responsibility (Healey, Cameron et al., 1995; 7). Within this scope, the pedestrianisation of public spaces, i.e. the «removal of vehicles from an urban area allowing free access to people on foot» (Tunstall, 2006; 355), has been given an ever-growing importance. However, pedestrianising may not be as simple as just simply displacing vehicles from an outdoor space.

Faced to the impacts of climate change in urban areas it may not be effective to conceive pedestrian public spaces if the basic conditions for people to cope a given thermal environment are not ensured. People have to be given the conditions for coping with a space's thermal environment or otherwise they are likely to avoid using it. Since increasingly sophisticated forms of home entertainment keep coming up as alternatives to public spaces people perceive as safer (Evans, 1997; 90), for the sake of urbanity it is imperative to reinvent public spaces and inner areas of cities making them more attractive to people. Pedestrianising is about ensuring a wide range of issues if successful, socially significant, public are to be created. Amongst common parameters such as appearance, relaxation, fruition, safety and security, accessibility, character, or legibility, in the context of climate change pedestrianising should necessarily come up with the consideration of microclimate and the conditions offered for people's thermal comfort.

From the urban design viewpoint, designing for outdoor thermal comfort deals with trying to attenuate climatic extremes since this is what pedestrians most want to avoid (Yilmaz, Toy et al., 2007; 295). As Gehl (2010; 174) argues, «if cities are to invite people to walk and bicycle more as well as to develop lively and attractive city areas, then climate between buildings is one of the most important target areas». Acceptable walking distances, say 5-10 minutes walking (Thomas, 2003; 20), «are an interplay between the length of the street and the quality of the route, both with regard to protection and to stimulation en route» (Gehl, 2011; 137).

Considering that man does not possess many natural controls to cope with an unfriendly climate (Olgyay and Olgyay, 1957; 19), the last decades have brought a growing awareness of outdoor thermal comfort as a key element for promoting activity and social interaction in public spaces. Outdoor thermal comfort is then a fundamental attribute of pedestrian public spaces and should therefore be taken as a true commitment during pedestrianisation.

Thermal comfort can be understood as «that condition of mind which expresses satisfaction with the thermal environment» (ISO, 2005; 10). However, its definition is complex because this concept is influenced by several different factors, the main ones being air temperature, air humidity, solar radiation, mean radiant temperature, wind speed, the clothing worn on the body, and activity (Jones, 2001; 113). These factors can vary significantly in space and time. Faced to all variability around thermal comfort, the tangible task of urban design with regard to outdoor thermal comfort is «to create or to provide a reasonable thermal range» (Ahmed, 2003; 108). The adaptive capacity is the keyword here. Public spaces can offer significant adaptive opportunities by being built through climate-conscious planning and design, offering access to, or shade from, wind or sun (Wilson, Nicol et al., 2008; 40).

Since the degree and intensity of the activities held at public spaces «depend on the level of satisfaction or dissatisfaction under the prevailing climatic conditions» (Gaitani, Mihalakakou et al., 2007; 318) and that «people stay in a place if it is a beautiful, meaningful and pleasant place to be» (Gehl, 2010; 147), in the context of climate change the chances created for people to be engaged in physical and social activities in urban public spaces should necessarily deal with the extent to which pedestrians can fit their personal requirements with the surrounding outdoor thermal environment.

This necessarily involves addressing the microclimate of outdoor public spaces since «the energy needs of buildings and the human thermal comfort conditions are mainly affected by the prevailing microclimatic conditions» (Gaitani, Mihalakakou et al., 2007; 317).

Microclimate can be defined as the climate of the air layer adjacent to the Earth's surface and of small places, well defined areas potentially of intense confinement, such as a street, a square or a garden (Cuadrat and Pita, 2009; 344-345). Starting from the notion that «the materials, geometry, and surface properties of the structures around a given place modify the local ambient climate» (Givoni, 1998; 242), the basic morphologic elements determining a space's microclimate are orientation, height/width ratio and Sky View Factor, main colours, public space typologies, architectonic typologies, water elements, public space and buildings' shading devices, facing materials, and vegetation.

Bioclimatic urban design holds important notions for addressing the microclimate of outdoor public spaces since it relates to a form of urbanism concerned with minimising the negative impact of urbanisation on the environment, by adapting each plan to the local unique conditions of climate and territory (Higueras, 2006; 15).

Bioclimatic urban design is a way of conceiving public spaces committed with the mediation between man, climate, and environment, regarding urban microclimates as a fundamental parameter for the creation of high-quality public spaces. Nevertheless, this discipline does not neglect the full spectrum of parameters contributing typical of current, 'classical', urban design.

The combination of current and bioclimatic urban design is the necessary condition for creating high-quality, comfortable, and climate-change-proofed urban public spaces. Principles such as valorisation of the seasonal variation of green masses; convenient, ergonomic and varied seating opportunities; convenient placement of litter bins; separation of areas of heavier activity and noise from quieter areas; convenient street lighting; special physical protections in spaces for vulnerable age or disabled groups; convenient placement of fire hydrants; or the preservation of recognisable landmarks and existing buildings, vegetation, archaeological elements, public art, and paving solutions with symbolic relevance; as well as safety, maintenance and costs issues should be brought together with bioclimatic principles such as thermal comfort, visual comfort, acoustic comfort, or air quality. For simplicity, bioclimatic urban design should hereinafter be regarded in this research as intrinsically comprising both perspectives.

Bioclimatic urban design presents as main benefits: the promotion of more thermally balanced outdoor public spaces; the indirect contribute for more thermally balanced indoor spaces and, thus, for the reduction of the energy consumption and CO_2 emissions from buildings; the improvement of air quality; and, as consequence of the first three topics, the adaptation of the built environment to the substantial increase in temperature extremes brought by climate change and the contribution for meeting the sustainable city goal.

Through morphologic parameters such as orientation, height/width ratio and Sky View Factor, main colours, public space typologies, architectonic typologies, water features, public space and buildings' shading devices, physical properties of materials, or biophysical properties of vegetation, bioclimatic urban design can provide the conditions for more thermally-balanced outdoor urban microclimates. These elements «can contribute to the successful design of urban spaces, by providing protection from negative and exposure to positive aspects of the climate, increasing the use of outdoor space throughout the year» (Nikolopoulou, 2004; 6).

The main challenge posed to the adaptation of the built environment to the expected impacts of climate change is the intervention in compact urban areas. New build is only the tip of the iceberg in what concerns to the urban built environment and it is upon the existing buildings and infrastructures that the main effort should be made if a more sustainable built environment is to be achieved in the future (Jones, 2007; 201). The reason is that, in opposition to new urban expansion areas, in compact urban areas the hard structure cannot, or can hardly, be changed (European Commission, 1996; 178) because the built environment is already defined. In addition, wherever corresponding to urban centres, compact urban areas tend to gather a large amount of people. It follows that in compact urban areas one must try to obtain the greatest benefit from the existing structures (1996, 178).

In this context, from amongst the morphologic elements intervening in the microclimate of outdoor public spaces, materials and vegetation are particularly relevant in compact urban areas. The ability of materials to store heat and the amount of direct solar radiation striking a space are determinant for a microclimate, and directly relate to the physical properties of facing materials and the biophysical properties of vegetation.

The combination of high-albedo and high-emissivity ('cool') materials with vegetation possessing appropriate biophysical parameters is an efficient way of improving microclimates of outdoor public spaces in compact urban areas since in often subtle ways this can help greatly improving microclimates through smaller-scale interventions when compared to other morphologic elements. This combination can reduce the amount of direct solar radiation striking the surfaces of a space and the increase the heat losses taking place at the ground level, where pedestrian circulation is held. Provided facing materials and vegetation are carefully brought together, beyond constituting an easy way to conserve energy, save money and eventually reduce air pollution, the combination of these two elements could also significantly reduce urban air temperatures (Rosenfeld, Akbari et al., 1995; 260).

There is a strong potential to move this theoretical corpus into practice but that, however, there seems to be a gap between its theory and practice. Many previous studies on bioclimatic urban design and concurrent areas are highly valuable sources of information but they have brought about findings that are not immediately useful for urban designers (Lenzholzer and Koh, 2010; 1). Following this trend, there also seems to be a gap between knowledge on the importance of programmes of 'cool' materials and vegetation and its application into practice the urban design practice.

1.2. Research scope

This research focuses on the identified gap between theory and practice of bioclimatic urban design and, thus, on the reduced applicability of programmes of 'cool' materials and vegetation into the urban design practice.

The array of studies undertaken on bioclimatic urban design and concurrent areas (e.g. urban climatology or outdoor thermal comfort) created a consistent theoretical corpus positively valued by experts. However, the highly relevant outcomes of previous researches are at the time either too complex or not available to common design practice (Nikolopoulou, 2004; 12). The urban climatology field, for instance, has evolved towards the deepening of its physical grounding and, in order to do so, recurred to rather complex models applied to simplified urban scenarios in such ways that its results end up being of reduced utility for urban design and architecture (Andrade, 2005; 80). Also, many outcomes are based on steady-state conditions that do not correspond to any real outdoors situation or are «measures of specific case studies or simulations done with complex programmes» (Nikolopoulou, 2004; 12).

For these reasons, and despite the valuable achievements of previous researches, knowledge on bioclimatic urban design seems to ends up not being applied as much as it could potentially be in current practice of urban design. Notwithstanding the existence of some examples of application of bioclimatic urban design principles into real projects, such as the Expo'92 precinct in Seville, the literature review suggests that presently there is a predominant absence of a consistent 'bioclimatic thought' in the creation of contemporary public spaces; the bioclimatic conception of public spaces seems to have not been yet traduced into a seamless vision for the conception of public spaces. In an overall perspective the main reason for the resistance found to the full implementation of sustainable urban development and urban design agendas seems to be the comfort of the known (Calthorpe, 2011; 47).

Designers seem to have not been given yet convenient guidance on how to put forward the theoretical knowledge already existing on bioclimatic grounds. Knowledge on bioclimatic urban design and, specifically, on programmes of 'cool' materials and vegetation needs to be positioned closer to the language commonly used by urban designers. It is then crucial to give designers suitable tools for this; it is necessary to deliver designers and other entities involved in the development of public space projects «alternative adequate techniques or tools for assessing different planning scenarios in terms of thermal comfort conditions and use of space» (Nikolopoulou, 2004; 22); and it is crucial to make ideas clearly understandable and accessible to all parties. In this context, the development of a tool establishing a link between bioclimatic urban design theory and practice of urban design can be relevant.

The promotion of the use of any tool requires improving the information about available tools, providing better data supply of references, baselines and benchmarks by national and local authorities, and developing simpler tools and involve users of the tool in its development (Jensen and Elle, 2007; 246) because the selection of any design option is only possible if designers can analyse the consequences of an idea quickly and effectively and if designers have established clear selection criteria for an idea (Goedkoop, 1995; 5). It might therefore be important to develop bioclimatic urban design supportive tools less centred in complex mathematically-based terms, as it is often the case. This may give the important outcomes of research on bioclimatic urban design a higher applicability to the practice of urban design. Such is the focus of this research.

Based on the literature review, this research conveys a particular vision on the adaptation of the built environment to the substantial increase in temperature extremes brought by climate change, and on the reduction of the gap between theory of bioclimatic urban design and the urban design practice — the thermal retrofitting of public spaces in compact urban areas through programmes of 'cool' materials and vegetation.

Pulling theory of bioclimatic urban design and urban design practice together is regarded as sine *qua non* of the adaptation the built environment to the substantial increase in temperature extremes brought by climate change. In turn, this adaptation is considered in this research as imperative for meeting the sustainable city goals and for creating successful pedestrian public spaces.

1.3. RESEARCH QUESTION

This research has two general objectives underpinning its development:

- to contribute to the know-how on the adaptation of the built environment to the substantial increase in temperature extremes brought by climate change;
- to contribute to the consolidation of bioclimatic urban design practice, supporting urban designers.

Three general assumptions underlie this research:

- Climate change is unavoidable and its impacts on urban areas are likely to affect people's welfare and the way public spaces are used.
- Outdoor thermal comfort conditions are determinant for people's welfare and for the success of pedestrian public spaces, especially in regions with warm and hot summers.
- Retrofitting public spaces in compact urban areas through programmes of 'cool' materials and vegetation, on a bioclimatic perspective, can help adapting the built environment to the substantial increase in temperature extremes brought by climate change but there is a gap between theory and practice on this subject.

Based on these assumptions, the question and hypothesis of this research are:

Research question

How to become the thermal retrofitting of public spaces in compact urban areas through 'cool' materials and vegetation, on a bioclimatic perspective, more operational?

Hypothesis

A methodology supporting the development of thermal retrofitting proposals for public spaces in compact urban areas based on 'cool' materials and vegetation, on a bioclimatic perspective, can help becoming this knowledge more operational.

1.4. METHODOLOGY

The research methodology is based four main steps aimed at testing the research hypothesis:

1. A literature review;
2. An appreciation of the extent to which facing materials and vegetation can influence the microclimate of public spaces in compact urban areas through the case study;
3. The development of a methodology for the thermal retrofitting of public spaces in compact urban areas based on programmes of 'cool' materials and vegetation;
4. The validation of the proposed methodology by simulating a virtual scenario for the case study.

The literature review initiates the research and is oriented towards the comprehension of all phenomena related to its subject as well as to the methodology to propose. Hence the research for references on climate, urban climate, climate change, built environment, sustainable development, public space, thermal comfort and outdoor thermal comfort, bioclimatic urban design, properties of materials and vegetation, and on the development of design supportive tools. The literature review provided the necessary body of knowledge for undertaking the research and understanding that its fundamentals are framed by a well-valued theoretical background.

Once valued by previous researches, the research moves on to the appreciation of the extent to which facing materials and vegetation can actually influence the microclimate of outdoor public spaces in compact urban areas. This was made through a field survey at the spaces selected as case study: Poveiros Square and São Lázaro Garden, Porto, Portugal. These spaces were considered to provide the ideal scenario to assess the importance of facing materials and vegetation in influencing the microclimate of pedestrian public spaces located in compact urban areas since except for paving materials and vegetation, they present no significant morphologic differences and, yet, exhibit a dramatically different pattern of use: during summer, while the square is barely used, the garden presents a significant pattern of use throughout the day. The findings from the undertaken field survey substantiate the importance of facing materials and vegetation, demonstrating that two public spaces can present significantly different microclimates, even when side by side, depending on the nature of the facing materials and quantity and quality of vegetation.

Since the literature review and the field survey give the preliminary cues on the validity of the research hypothesis, the next step is the development of a methodology for the thermal retrofitting of public spaces in compact urban areas based on programmes of ‘cool’ materials and vegetation. This development is anchored in the literature review and on the direct contact with practitioners and scholars. The contact with practitioners and scholars was a rather valuable resource for the development of the methodology since it allowed assessing some of the principles derived from the literature review as well as acknowledging principles not found in the literature review. These latter principles were suggested by both practitioners and scholars derived from their practice of public space building and scientific research, respectively.

The research finishes with the validation of the proposed methodology. Despite being validated by the literature review and contact with practitioners and scholars, it was necessary to subject the methodology to a retrofitting proposal. Since there was not the possibility to actually retrofit a public space during this research, the methodology is validated by simulation. This simulation exercise is applied to Poveiros Square, shown by the field survey to present an unpleasant microclimate. By following the structure, principles and guidelines of the proposed methodology, by testing virtually different combinations of facing materials and vegetation levels through the use of a microscale climate model (ENVI-met), and by being followed by practitioners, this exercise allowed testing the validity of the proposed methodology and, simultaneously, inferring some aspects concerning programmes of ‘cool’ materials and vegetation.

The following figure summarises the methodological steps adopted for this research.

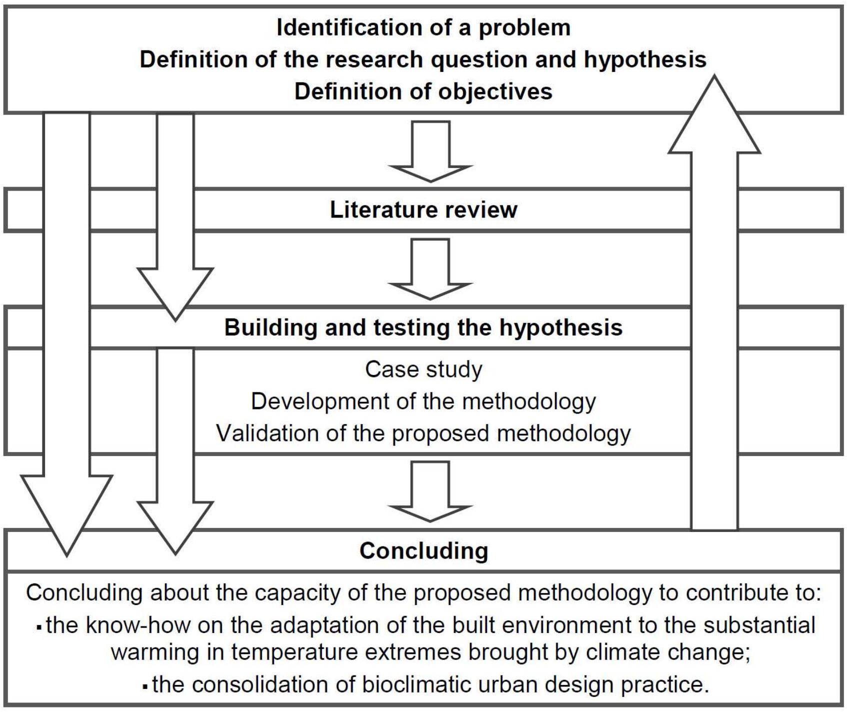


Fig.2 – The adopted research methodology

Installing a retrofitting scheme developed with consideration to the proposed methodology, delivering the intervened space to users, waiting for the design scheme to mature with time and use, and obtaining feedback of beneficiaries are further methodological steps to address in future research.

1.5. REMARKS AND LIMITATIONS

Four remarks about the scope of this research should be pointed out: (1) despite some climatic variables, such as precipitation, are equally important to bioclimatic studies, these are out of the scope of this research since they tend not to pose major constraints to the microclimate of public spaces during summer; (2) although summer thermal conditions are focused, winter conditions are important as well for outdoor thermal comfort; (3) facing materials and vegetation are just two of the many morphologic elements influencing a space's microclimate; (4) thermal comfort is only one of the parameters influencing global human comfort and should be complemented, for instance, with air quality, lighting, acoustics, or smell.

The limitations this research was faced with are transversal to the majority of studies in the same scientific area. The major limitation found is the impossibility to validate the proposed methodology in a real retrofitting project. There was no chance to actually retrofit Poveiros Square. In addition, the time required for developing and installing an actual retrofitting scheme and, afterwards, the time required for people to use the space and start being able to evaluate its microclimate, often encompassing several years, was not compatible with the time available for developing this research.

A second limitation is the absence of a consensual reference for the prediction of outdoors thermal comfort conditions, such as for indoors (e.g. the International Standard ISO 7730). If on one hand there is currently a considerable volume of researches, standards and regulations addressing indoor thermal comfort, on the other hand there is less understanding of this subject outdoors (Handley and Carter, 2006b; 58).

Spagnolo and de Dear (2003; 721) present four reasons that might explain the fact that most thermal comfort studies, standards and policies focus indoor spaces: firstly, the authors argue that «people in developed countries where most research has been conducted to date spend a larger proportion of their life indoors than out»; secondly, «in work environments, thermal comfort is assumed to be directly related to productivity» in such ways that thermal comfort has been only seen as an economical concern envisioning the productivity of workers of a given company; thirdly, the outdoor thermal environment «is considerably more difficult to engineer and control than the indoor counterpart»; and finally, the «ownership of, and responsibility for, many outdoor spaces are not so clearly defined as indoor built environments».

In addition, the generalised use of air conditioning determined many thermal comfort studies to be focused on the characterisation of thermal environments mainly in artificially-controlled spaces. Since outdoor spaces tend to be neither warmed up nor cooled down artificially, they do not present a problem for extra energy consumption related to thermal comfort, so efforts in the thermal comfort field have been centred in the «thermal design and efficient use of energy in building indoors, banishing the landscape microclimatic design» (Ochoa, Marincic et al., 2006; 1).

The main differences between indoor and outdoor thermal comfort are that, contrarily to indoor spaces, in outdoor open spaces «there is less human control; the climatic conditions display more variability; the spaces themselves are more diverse, and they are used for a wider range of purposes» (Wilson, Nicol et al., 2008; 36). Nagara, Shimoda et al. (1996; 497) state that thermal environment of outdoor spaces is not of a uniform nature as indoor spaces. Tseliou, Tsiros et al. (2010; 1346) add that «the correspondence between the physiological response and thermal comfort is markedly different when we move outdoors».

Together, these parameters become evaluations of thermal comfort outdoors more subjective than in indoor spaces (Höppe, 2002; 362). It follows that it is not possible to directly adopt indoor criteria for outdoor thermal comfort evaluations because often these conditions lie outside the indoor comfort zone (Stathopoulos, Wu et al., 2004; 297). The variability of intervening parameters is encountered in a much wider range for outdoors than for indoors.

It is noteworthy here that there might be some conflicts between the provision of conditions for thermal comfort outdoors and indoors. The interaction between the necessary conditions for better microclimates of outdoor and indoor spaces can be intricate — a good option for an outdoor microclimatic does not necessarily mean a good option for an indoor space and vice-versa.

Finally, a third limitation is the impossibility of obtaining global solutions. Considering that the environmental/microclimatic characteristics and requirements of an urban public space vary significantly from city to city and within a same city as well, it is not possible to generalise assumptions, principles, or procedures with regard to the microclimate of outdoor public spaces and, to an even higher extent, to thermal comfort conditions.

1.6. STRUCTURE OF THE THESIS

This thesis starts by presenting the theoretical background of the research. Within this first part, Chapter 1 sets the background of the research, presents its scope, research question, research methodology, as well as remarks and limitations about its development. Chapter 2 to 5 address in detail the theoretical background of the research, tackling issues of climate and climate change in urban areas, current urban development and public space, the microclimate of outdoor public spaces, bioclimatic urban design, and programmes of ‘cool’ materials and vegetation. The body of information conveyed by these chapters allows to understand and justify the opportunity this research can represent to its scientific field, and to pave the way to the development of the methodology.

Chapter 6 addresses the undertaken field survey at the spaces selected as case study. Together with the information conveyed by the previous four chapters, the findings presented in this chapter keep on substantiating the pertinence of this research and, in particular, of developing the methodology.

The second part of this thesis addresses the proposal of the methodology. Chapter 7 presents the methodology while Chapter 8 addresses its validation. These two chapters allowed understanding that the proposed methodology can actually be relevant for the adaptation of the built environment to the substantial increase in temperature extremes brought by climate change, and for pulling together theory of bioclimatic urban design and urban design practice.

The last part of the thesis, Chapter 9, concludes the research by presenting its conclusions, answering the research question, as well as presenting some clues for future research.

2
CLIMATE AND CLIMATE CHANGE IN URBAN AREAS

The development of a methodology supporting retrofitting proposals based on facing materials and vegetation, on a bioclimatic perspective, aimed at help adapting the built environment to the substantial increase in temperature extremes brought by climate change, must start with an understanding of the basic issues around climate, urban climate, and climate change in urban area. This chapter will then approach which present and future aspects of urban climates should be taken into consideration during current urban development, particularly in what concerns to public space.

Sections 2.1 and 2.2 relate to the findings of the literature review on the subjects of climate, urban climate and climate change, respectively. Through these findings it will be presented the overarching concerns to which the adaptation of the built environment to the substantial increase in temperature extremes brought by climate change should refer to. It will be shown how the general Earth-atmosphere system govern the energy exchanges taking place at the meso and microclimatic systems near the Earth's surface; theoretical evidence on how urban climates reflect the general Earth-atmosphere system but also how these can be modified by the activity of mankind; and theoretical evidence on the likely impacts of climate change on urban areas which, irrespective their cause, are prone to place serious limitations to people's welfare not only but especially during summer. Some concluding remarks on these subjects are presented in section 2.3.

2.1. THE URBAN CLIMATE

The Earth-Atmosphere system refers to the relationships of the ensemble Earth plus its Atmosphere (Oke, 1987; 401) which largely governs the heat and mass exchanges occurring at the Earth's surface. The radiation outcoming from the sun interacts with both atmosphere and the Earth's surface and it is at the atmosphere level that most interactions take place. According to Cuadrat and Pita (2009; 388; 391), the components of the global mass and energy system are interconnected and exert multiple influences on each other through intricate loops; it is through them that the energy emitted by the sun circulates.

The Earth-atmosphere system is a balanced system which however is not static — to achieve balance, the planetary system transfers heat between latitudes, i.e. it redistributes the planet's energy from the lower latitudes (with a surplus of energy) to the higher latitudes (*idem*; 193). This brings stability to the systems and defines the planetary climates as we know them today. However, the planetary climates are nothing but a moment in the continuous history of climates because the earth's climatic system is dynamic system in transient balance (*ibid.*).

According to the first law of thermodynamics, all energy reaching the Earth's surface will necessarily have to be converted somehow — energy «can be neither created nor destroyed, only converted from one form to another» (Oke, 1987; 7). The entire Earth-atmosphere system «is in radiative equilibrium because the solar input is matched exactly by the sum of the short-wave scattering and reflection and the long-wave emission from the Earth and its Atmosphere» (*idem*; 19). It follows that the radiation incident upon a substance/surface «must either be transmitted through it or be reflected from its surface, or be absorbed» (*idem*; 11). In the end, the whole Earth-atmosphere system defines a value between 0.30 (Santamouris, 2001, 21; Gore, 2009, 45) and 0.42 (Geiger, 1950; 2) for the planetary albedo, i.e. the reflectivity of the Earth. There are three main ways through which the exchange of energy within the Earth-Atmosphere system is possible: conduction, convection and radiation.

Conduction

Conduction is the process according to which heat is transmitted within a solid substance by the collision of rapidly moving molecules (*idem*, 7). Heat is passed from one molecule to the next in the direction of decreasing temperature (Hall, 2005; 102).

Convection

Convection is a process that «involves the vertical interchange of air masses and can only occur in liquids and gases» (Oke, 1987; 16). It describes the process according to which air in contact with a surface hotter than itself will warm up and, as it becomes less dense, will rise up the surface carrying energy away with it (Hall, 2005; 102). When this airstream contacts with a surface that is cooler than itself, then the heat it carries will be transferred to that surface (*ibid.*). Convection may be free or forced. Free convection happens whenever a parcel of air is at different density than the surrounding fluid: if a parcel of air is warmer than its surroundings it will be at a lower density and will tend to rise, whereas if it is cooler it will be denser and tend to sink (Oke, 1987; 16). In turn forced or mechanical convection «is set when the atmosphere near the Earth's surface is physically thrown into motion when flowing over obstacles» (*idem*, 17). Convection may also occur by a combination of both free and forced convection, in this case being termed as mixed convection.

There are two main forms of heat exchange by convection: sensible heat (Q_H) and the latent heat (Q_E). Sensible heat «relates to the sensed rise or fall in a body's temperature resulting from the addition or subtraction of energy to that body», while latent heat «is that heat not sensed as a temperature change» since it is «related to the additional heat necessary to enable a substance to change from a liquid at a given temperature to vapour at the same temperature» (Oke, 1987; 16). The magnitude of sensible heat flux depends on the temperature difference between the Earth's surface and the atmosphere, as well as on wind speed, whereas latent heat flux is related to the water vapour transport.

According to Oke (*idem*; 23), «any surface radiative imbalance is accounted for by a combination of convective exchange to or from the atmosphere, either as sensible (Q_H) or latent heat (Q_E), and conduction to or from the underlying soil (Q_G)», so that the surface energy balance is:

$$Q^* = Q_H + Q_E + Q_G \qquad (1)$$

where

Q^* is the net all-wave radiation flux density

According to the same author (*idem*, 69-70), the ratio of Q_H and Q_E is called the Bowen's ratio (β). If β is greater than unity, Q_H is more active than Q_E in dissipating heat. This is usually associated to situations where water in a surface is somewhat scarce and where thus the climate is likely to be relatively warm because Q_H represents the main way of convective heat losses to the atmosphere. In turn, if β is less than unity, Q_E is more active than Q_H in dissipating heat. Although this is not likely to directly warm up the lower atmosphere it can increase its humidity so that the climate is likely to be relatively cool and moist. Finally, if β is negative it indicates that these two fluxes have different signs. This is a common situation at nigh «when the sensible heat flux is downwards (negative), but evaporation continues so that Q_E is carried away from the surface (positive)» (*ibid.*).

According to Oke (*idem*; 29-31), in the Earth-atmosphere mass and energy system, water is evaporated from free open water surfaces, from the soil pore water, and from water transpired by vegetation. In this process, water vapour is carried away up to the atmosphere either by free and forced convection. Once at the atmosphere level, water can be cooled down to its dew-point and condense as a cloud droplet or ice crystal which remain in suspension. Whenever cloud droplets or crystals grow to a size no longer bearable to remain in suspension they fall to the Earth's surface as precipitation. The main difference between evaporation and precipitation is that while the former happens in a continuum, the latter occurs in short-period bursts. Evaporation is almost continuously depleting soil moisture even if there is no precipitation. It follows that soil moisture is a crucial parameter of the Earth-atmosphere system, namely in what concerns to the surface energy balance. Soil moisture «can affect radiative, conductive and convective partitioning» (*idem*, 31).

Radiation

Radiation is «the process by which electromagnetic radiation is propagated through free space due to joint undulatory variations in the electric and magnetic fields in space» (*idem*, 403). It is noteworthy that «the energy flow from the sun that reaches the earth's surface during one hour corresponds to the energy consumption of the whole world in one year» (Klooster, 2009; 85). The solar constant (I_0), i.e. the magnitude of the annual solar radiation input on Earth, is of around 1.397 W/m^2 for a plane area perpendicular to the solar beams (Cuadrat and Pita, 2009; 42). However, due to the spherical shape of the planet, before reaching the Earth's surface the solar constant is reduced to an annual average energy equivalent to 348.7 W/m^2 at the upper layer of the atmosphere (*idem*, 44). Moreover, the Earth's axial tilt and sphericity, topography, atmospheric composition, and cloudiness are factors affecting the amount of solar radiation reaching the Earth's surface.

The Earth's axial tilt and sphericity determine the exposure time of a terrestrial surface to the sun and the incidence angle which, thus, varies accordingly to latitude and season. Basically, the larger the time of exposure the higher the amount of direct solar radiation reaching that surface; in turn, the 23.5° angle established between the Earth's axis and the ecliptic plane will determine different positions of the Earth relatively to the Sun throughout a year (idem; 45). Four moments mark these different positions: the summer solstice (21 June), autumn equinox (23 September), winter solstice (22 de December) and spring equinox (21 March).

Relatively to topography, it is important to consider that «variations in the slope and azimuth angles presented by topography determine the radiant loading differences across the landscape» (Oke, 1987; 171-172). As a general consideration, the more a slope directly faces the sun, the more radiation it will receive. In turn, the more oblique the sun beams strike a slope, the less radiation is received.

Atmospheric composition affects the amount of solar radiation reaching the Earth's surface by reflecting and absorbing solar beams as these pass through the atmosphere (diffuse short-wave radiation). These phenomena are due to atmospheric constituents such as water vapour, salt, crystals, dust particles and several gases, which possess their own radiative properties relatively to incident short-wave radiation (Oke, 1987; 13). Together, and according to their radiative properties, these agents make the total amount of solar radiation leaving the sun to be partially reflected/scattered and absorbed within the atmosphere (which together with the multiple reflections of radiation between the surface of the Earth and the atmosphere originates diffuse short-wave radiation), and transmitted to the surface of the Earth.

In the end, only a part of the solar radiation reaching the upper layer of the atmosphere actually reaches the Earth's surface. That part of the solar radiation that ends up effectively striking the Earth's surface without being absorbed or diffused is termed as direct-beam short-wave radiation (*ibid.*). The entire system of interaction between the atmosphere and the Earth is schematically illustrated with the following figure.

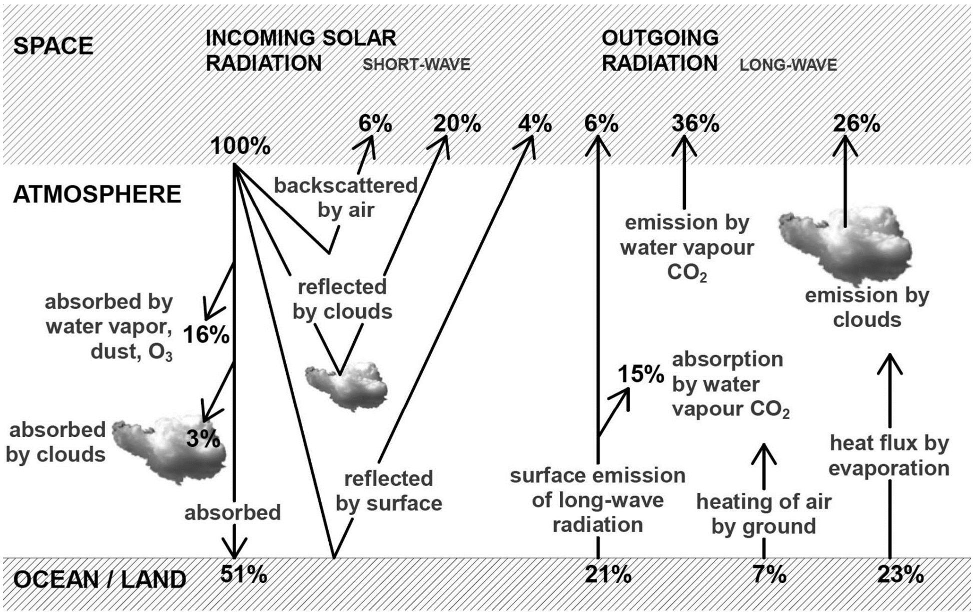


Fig.3 – The energy balance of the Earth. Adapted from Santamouris (2001; 21).

Figure 3 shows that for a 100 % input of solar radiation reaching the top of the atmosphere, 30 % of that radiation is reflected back to the space by clouds (20 %), by particulates in suspension (6 %), and by the surface of the Earth (4 %). From the remaining 70 %, 51 % are absorbed by the surface of the Earth, 16 % by water vapour, particulates in suspension and ozone, and 3 % by clouds. According to Santamouris (2001; 21), in order to maintain the energy balance of the Earth, long-wave radiation (radiation emitted from the surface of the Earth back to the space) should be of around 70 % of the total amount of radiation absorbed at the surface of the Earth. Further losses take place at the surface of the planet: 6 % (19.1 W/m^2) by reflection and 44 % (140 W/m^2) by absorption (Cuadrat and Pita, 2009; 55).

Clouds impact the radiative net by dampening the diurnal surface radiation budget variation as well as by reducing the diurnal temperature range (Oke, 1987; 26). Both daytime solar heating and night-time long-wave cooling are thus reduced. This is why overcast conditions are associated with relatively uniform temperatures between day and night. Also, the surface long-wave radiation budget is strongly affected by clouds since these absorb much of the outgoing long-wave radiation and re-emit it back (*ibid.*).

Regardless these factors affecting the amount of solar radiation reaching the Earth's surface, there are general considerations about solar radiation and its interaction with the Earth's surface that might be taken as a reference for understanding the energy exchanges within the Earth-Atmosphere system with regard to radiation.

Based on Romero (2001; 80; 87) and Cuadrat and Pita (2009; 44; 51) these factors are:

- The balance between incoming short and emitted long-wave radiation varies accordingly to each season. It is positive during summer and negative during winter, i.e. short-wave radiation is higher than long-wave radiation during summer whilst during winter the situation is reversed.
- The total amount of solar radiation reaching the Earth's surface has its maximum value on the Equator line and decreases progressively towards the poles where it reaches its minimum value. Thus, the maximum impact of solar radiation over a horizontal surface takes place at latitude 0° (Equator) and it decreases progressively from this latitude towards latitude 90° (poles) where it relatively equals to the amount of radiation over vertical surfaces. This is due to the Earth's sphericity.
- There are significant differences between the northern and southern hemisphere in what concerns to incident short-wave radiation. These differences are mainly based on different sun angles. Zenith and azimuth are different. Between hemispheres the maximum direct-beam input will be made upon different orientations; the duration of the radiation incident on a slope will be different throughout the day according to the solar azimuth; the times of the day in which differently orientated surfaces receive solar radiation is different; the reception of solar radiation at the equinoxes and solstices is variable; and the illumination each slope receives is consequently different.
- South-facing and north-facing surfaces receive the same amount of solar radiation only at latitude 0° and 90°, reaching a minimum at latitude 40°.
- The orientation of facades towards the south is beneficial in all latitudes.
- From the total amount of radiation reaching the Earth's surface, south-facing buildings' vertical surfaces receive 8 % of radiation, north-facing receive 8 %, east-facing receive 17 %, and west-facing receive 17 %, whilst horizontal surfaces receive 49 % of radiation.
- The intensity of radiation received by the Earth's surface increases with altitude since as the atmosphere losses thickness it absorbs less energy.
- High sun angles determines that the sun rays will be distributed over a small surface, causing a strong intensity of insolation; in turn, low sun angles will be spread out over a larger surface, originating thus a lower intensity of insolation. This can explain why solar radiation does not affect horizontal and vertical surfaces to the same extent. The relationship horizontal (e.g. the ground) and vertical surfaces (e.g. facades of buildings) establish with sun angles determines different intensities of insolation striking each surface.

The ways through which the energy exchanges within the Earth-Atmosphere system take place (conduction, convection and radiation) provide the necessary information from which to start understanding urban climates since these are partially governed by these macro-climatic processes. Understanding these processes is then vital for climate-based studies focused on urban areas.

Macroclimate, mesoclimate, local climate, and microclimate compose the complete picture of the scales used in climatic studies (Figure 4). According to Cuadrat and Pita (2009, 344; 345), macroclimates correspond to large geographical areas governed by the general atmospheric circulation, such as continents; mesoclimates correspond to areas between 200 and 2.000 km where the atmospheric circulation and climate are often determined by the macroclimate; local climates are smaller units of the mesoclimate, between 100 and 10.000 m, of singular characteristics and largely determined by local conditions; finally, microclimates are areas within the air layer near the surface corresponding to confined, well-defined spaces where the meteorological elements are fundamentally conditioned by the immediate surrounding factors rather than by local or mesoclimate factors.

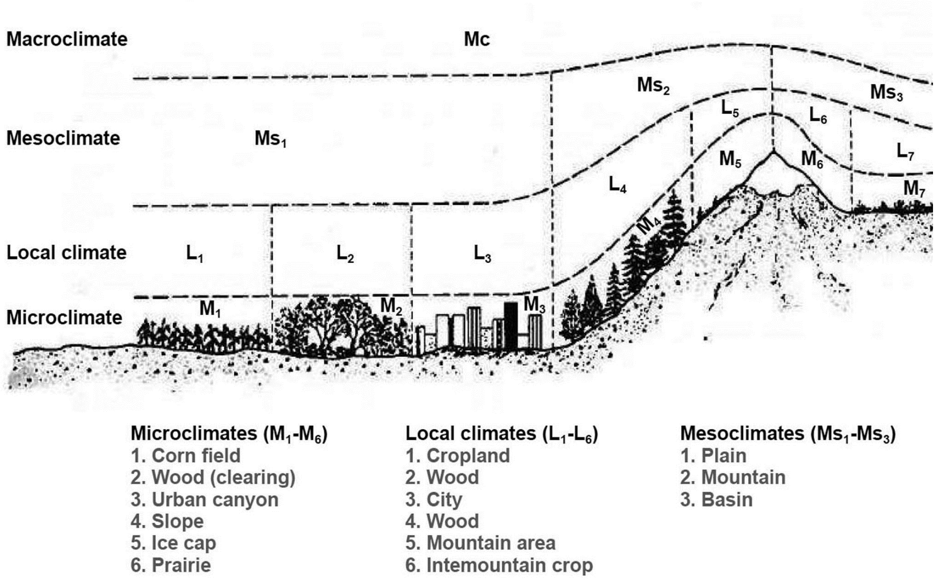


Fig.4 – Scales used in climatic studies. Adapted from Cuadrat and Pita (2009; 345).

The urban climate is included in the local climatic scale. Each urban climate presents distinctive characteristics. Urban climates cannot therefore be regarded as entities of shared characteristics even if within one same macro and mesoclimate since beyond including the general energy exchange processes mentioned above, urban climates results from the interaction between urban factors, macroclimate, and pre-existent physical environment (Andrade, 2005; 69; 70); urban climates are highly variable entities which depend on the function, structure, size, physical environment, and predominant economic activities of cities (Cuadrat and Pita, 2009; 381).

It follows that if on one hand urban climates result from larger scale climatic and geographic contexts, on the other hand urban areas modify the site where they settle in as well as its atmosphere. The urban atmosphere differs from that of the surrounding non-built areas. This is a phenomenon widely approached in the literature review. Amongst the array of developed studies, Oke (1987; 274) provided one of the most disseminated schemes illustrating this phenomenon (Figure 5).

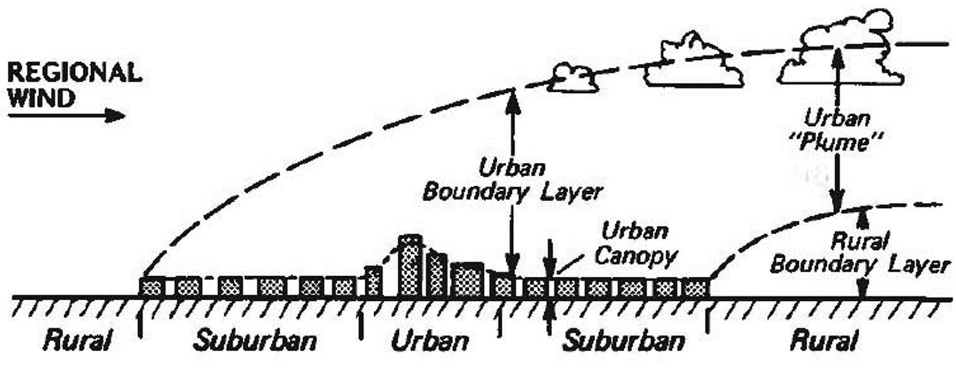


Fig.5 – Schematic representation of the urban atmosphere. Source: Oke (1987; 274).

Oke’s scheme unfolds a series of concepts, definitions and classification that can help understanding and characterising urban climates in what they differ from their rural/natural counterparts. Based on Oke (1987; 274), Andrade (2005; 71), and Arnfield (2003; 3), the different components of this scheme can be defined as follows: the Urban Boundary Layer is a local to meso-scale phenomenon which integrates the whole thermal influence of the city above the Urban Canopy Layer since it is the layer closer to the urban surface; the Urban Canopy Layer corresponds to the air volume between the ground and the roof level which is strongly affected by the surrounding conditions, in particular by microscale characteristics and processes; the Urban Plume consists of the extension of the Urban Boundary Layer leeward the urban area. Additionally, it is possible to consider a fifth component: the Active Surface, which roughly corresponds to the roof level of the city. From the most general (Urban Boundary Layer) to the more particular scale (Active Surface) the consideration of these components can be useful for giving the right picture of how urban climates operate.

Beyond the scale of analysis, understanding urban climates should consider seven main issues namely, according to Oke (1987; 262-281), Taha (1997; 101), Givoni (1998; 241), Romero (2001; 88), Yannas (2001; 282), Alexandri (2005; 48; 50), Higueras (2006; 64; 65), Taylor and Guthrie (2008; 4), and Cuadrat and Pita (2009; 381; 382):

1. **When a city is established it immediately impacts the environment by changing the land cover**. It follows that the settlement of cities in areas previously covered with vegetation necessary leads to changes in the climatic characteristics of that area. The removal of vegetation can impact local water balance since the canopy is lost and with so is the interception of rain, evapotranspiration is reduced, and superficial runoff increased; local radiation budget since a new surface geometry and thermodynamic properties are set; finally, local energy balance partitioning by defining a new set of thermal, moisture and aerodynamic properties. All this has immediate impacts on the energy balance of the area where the city is settled and on local ecosystems.
2. **The building of streets, squares, buildings, and all other artificial man-made bodies which constitute a city, often changes local topography and increases the surface’s aerodynamic roughness**. In fact, wherever buildings and other man-made artificial structures are settled, radiative, thermal, moisture and aerodynamic modifications are set in the local environment.
3. **The natural soil existing prior to the settlement of the city is often replaced by building materials which possess quite different physical parameters from those typical of natural areas**. Building materials commonly used in cities are often denser, more impermeable and with lower albedo than in natural/rural areas. As a result, urban areas tend to store more heat and be more waterproofed than their natural/rural counterparts. As urban surfaces release heat, air temperature is increased. Because urban surface temperatures are generally higher than air, in urban areas sensible heat fluxes during the night assume an ascending direction (from the Earth’s surface to the atmosphere) whereas in rural areas the trend is for descending directions (from the atmosphere to the Earth’s surface).
4. **The emission of large amounts of pollutants from cities into the atmosphere, beyond contaminating the air in urban areas, hinders the access of solar radiation and supplies extra nuclei around which cloud droplets may form**. This can significantly change the radiation balance within urban areas. The short-wave radiation input in urban areas is altered/attenuated during its passage through a city’s atmosphere in a magnitude varying accordingly to the nature and amount of pollutants, as well as accordingly to the seasonal variation of the concentration of pollutants.

As a reference, in heavy industrialized cities incoming short-wave radiation may be reduced by 10 % to 20 % and, in less industrialized cities where vehicles are the main source of atmospheric pollution, this value drops from 2 % to 10 %. Also the spectral and directional composition of the incoming short-wave radiation is changed because pollutants tend to filter out the shorter wavelengths. In these conditions, ultra-violet radiation may be reduced by 40 % or occasionally 90 % due to scattering and absorption.

5. **Human activities within cities generate heat which tends to make cities warmer than its natural/rural surroundings** — anthropogenic heat, i.e. the concentrated heat resulting from human activities within cities such as space heating and cooling, domestic and office appliances, industry, transportation, or artificial lighting. It thus relates to the consumption of all energy sources within cities (e.g. electricity, coal, gas, gasoline, wood). The anthropogenic heat flux density depends upon the average energy use by individuals, and the city's population density. In turn, demands on energy consumption per capita depend on many factors such as household income, the nature of the city's economy, or the need for winter space heating. The anthropogenic heat is one of the main contributors for the urban heat island phenomenon (approached ahead in this text). In some high-density urban areas, anthropogenic heat can be as high as or higher than the solar input in winter. In some cases this may even be true also for summer due to the intensive use of air conditioning systems.
6. **The array of shapes and orientations of the bodies constituting a city (broadly facades, roofs and ground areas) produce multiple beams of reflecting radiation towards several absorbing plans**. Again, this determines that cities store more heat than its natural /rural counterparts where radiation beams turn back more freely to the atmosphere. Thereafter, outgoing long-wave radiation during the night is larger in a city than in a rural area since, as the former stored more heat during the day, it is warmer than the latter. The common block-like geometry of cities often leads to radiation trapping and air stagnation, besides resulting in very rough surfaces.

   In general, the most relevant impacts of the layout of cities on solar radiation reaching the surface level are a reduction of solar radiation reaching shaded surfaces; an increase of solar radiation by reflection from sunlit surfaces; a reduction of net long-wave cooling from surfaces near buildings often as a result of reduced sky view factors, heat losses from buildings, and of the wind shelter provided by buildings. The reflection of short-wave radiation from an urban area is dependent on its albedo and geometrical arrangement.

   The average value of urban albedo is around 0.15 (for mid-latitude cities without snow). This value is often lower than for rural areas except forests and areas with dark soils. As in mid-latitude cities the deficit of incoming short-wave radiation by comparison to rural areas is partially offset by a lower urban albedo, it can be assumed that urban/rural net short-wave radiation differences are not large. Nevertheless, the radiation field in cities tends to be higher than in rural areas.

   The panoply of shapes and orientations of the bodies constituting a city may also significantly affect wind. According to Oke (1987; 297), wind in urban areas has usually lower speeds than in the surrounding non-built areas except if «the air moving at higher speeds in the upper air layers is deflected downwards by a tall building or channelled into 'jets' along streets in the same direction»; and if «the regional winds are very light or calm which enhance a horizontal temperature gradient across rural/urban areas capable to induce a rural-to-urban low-breeze». Buildings are the main reason for this because «when an air mass encounters a building it is forced around it producing a series of eddy flows, due to unsteady separation of the flow from the buildings» which can cause a restriction of air movement at the air layers near the ground level (Taylor and Guthrie, 2008; 4).

The problems raised by the interaction between wind and tall buildings happen in cases when a building is more than twenty-five meters in height (around six storeys) or «if it is more than twice the height of the surrounding buildings» (Oke, 1987; 272). Getting into a deeper detail on this issue, the two main effects buildings in urban areas produce on wind flows are that wind flows are «either deflected downwards by tall buildings or channelled as 'jets' along canyons in the same direction as the flow» (Santamouris, 2001; 38).

Air speed and turbulence at the public space level are dependent on the regional wind speed (i.e. the undisturbed wind flow around an urban area) as well as on urban design features such as the overall density of the urban area; size and height of each building; orientation of streets; availability, size, distribution and design details of open spaces; and green shelter belts (Givoni, 1998; 259-261). Together, these features make urban winds to possess lower mean speeds but higher speed variations and turbulence than winds in open non-urban areas.

7. **Cities often present low humidity rates resulting from the high runoff, i.e. the water from precipitation that runs at surface (not being absorbed by the soil) and that ultimately reaches stream channels** (Oke, 1987; 403)**, over urban (often impermeable) soils**. As a consequence, urban areas have lower rates of heat dissipation by convective cooling (Yannas, 2001; 282). This is partially due to the large amount of impermeable surfaces commonly found in cities, which modifies the superficial runoff of rainwater. Cities can lose as much as 90 % of rainwater, which is directly conducted to sewage systems. These sewage systems are designed to accommodate very large volumes of water in short periods of time. This dramatically reduces evapotranspiration from vegetation and soil (except in gardens, parks, and other irrigated and permeable areas) which in turn tends to reduce heat losses through latent heat fluxes and increase them through sensible heat fluxes. The lower evapotranspiration rate of urban areas is one of the most influential factors for the increase in daytime temperatures.

   The water cycle in urban areas is often conceived to rapidly remove water from the surface of the city and impairing infiltrations into the subsoil (Taylor and Guthrie, 2008; 6). The impervious character of urban areas leads to a dramatic reduction of the levels of infiltration of rainwater into the subsoil and increases superficial runoff of rainwater. This has negative impacts not only for the recharge of aquifers but also for a space's microclimate. In addition, this entails the overload of public water drainage systems, often leading to floods.

   It is also important to bear in mind that as urban environments are often quite contaminated, water reaching underground aquifers may present several contaminants such as heavy metals, nitrates, or chlorine.

Regardless the variability of the elements intervening in the definition of urban climates, the energy exchanges in urban environments can be regarded as processes involving the conjugation of incoming short-wave radiation, emitted long-wave radiation by opaque surfaces, and anthropogenic heat (Santamouris, 2001; 39). This puts into evidence one of the most widely addressed phenomena in the literature review relatively to urban climates which is the urban heat island phenomenon — «probably both the clearest and the best documented example of inadvertent climate modification» (Oke, 1987; 288) whereby air temperatures in dense urban environments are higher than the temperatures of the surrounding countryside basically due to changes in the heat balance (Santamouris, 2001; 7). Scientists have been aware of this phenomenon for many years but it was only until the 19th century that the increasing rates of urbanisation and industrialisation have exacerbated the interest on this phenomenon (Akbari, Davis et al. 1992; XVIII).

The occurrence of the urban heat island in most large urban areas of industrialised countries made possible to generalise a pattern profile relatively to the air temperature of urban areas. This profile is variable in dimension. Notwithstanding, the height of the urban heat island can be limited to an average height three to five times the average of the buildings' heights, matching approximately the urban boundary layer (Romero, 2001; 89). The urban heat island is characterised by a profile similar to that of an island; a profile which is lower in peripheral areas and progressively raises till it reaches a 'peak' in the inner areas of a city. Oke's (1987; 288) cross-section of a typical urban heat island is one of the most widely known illustrations of this phenomenon (Figure 6).

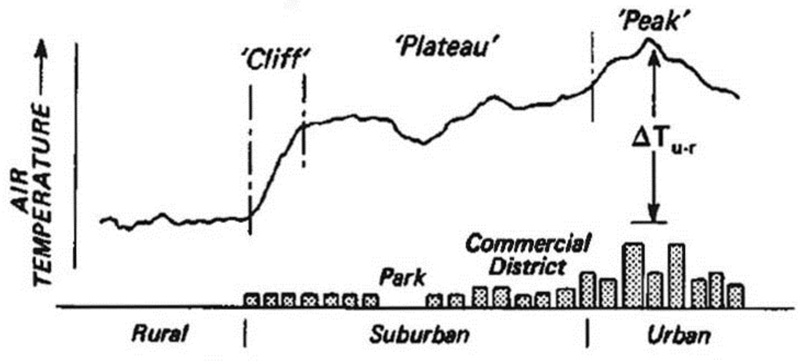


Fig.6 – Typical profile of an urban heat island. Source: Oke (1987; 288).

This figure shows that the urban heat island may be understood in three different parts: 'Cliff', 'Plateau', and 'Peak'. According to Oke (1987; 289), the 'Cliff' relates to the steep temperature gradient established between the rural or urban boundary and the urban heat island; the 'Plateau' designates the areas of warm air presenting a steady though weaker horizontal gradient of temperature that increases towards the city centre being only interrupted by distinct land uses within the urban area (e.g. parks, lakes, industrial areas); finally, the 'Peak' refers to the area where the phenomenon assumes its maximum temperature, i.e. the urban core. It is the difference established between the temperature exhibited by the 'Peak' and the rural boundary that defines the urban heat island intensity. The urban heat island intensity is therefore an indicator of the urban heat island's magnitude.

There are several different potential causes for the urban heat island. Akbari, Davis et al. (1992; XVIII) argue that the replacement of vegetation and soil with concrete and asphalt reduces the ability of an area to lower daytime temperatures. The same authors (*ibid.*) and Bretz, Akbari et al. (1992; 2) also argue that the use of dark-coloured materials on roads, buildings, and other surfaces contributes to the phenomenon since the absorption of incoming solar radiation is favoured rather than its reflection. Alexandri and Jones (2008; 480) add that the predominant lack of vegetation in cities is one of the main contributions for raised urban temperatures. These can be considered the fundamental causes of the urban heat island.

Nevertheless, a much wider range of factors should be considered here such as, according to Givoni (1998; 244), Santamouris (2001; 7), and Kolokotroni, Giannitsaris et al (2006; 383): differences in the overall net radiation balance between the urban area and the surrounding countryside; storage of solar energy in the mass of buildings during the day and its release during the night; anthropogenic heat release; lower evaporation from soil and vegetation in the urban built-up area; seasonal heat sources; topography; thermal properties of materials; microclimate changes brought about by man-made alterations of the urban surface; the urban greenhouse; the canyon radiative geometry; the reduced turbulent transfer of heat from within streets. It is the combination of all these factors that will determine «the way in which heat is absorbed, stored, released and dispersed in the urban environment» (Alexandri, 2005; 49) and therefore the urban heat island intensity.

Since urban areas do not present homogeneity in their land-use and surface characteristics (Hart and Sailor, 2009; 398), the urban heat island does not present regular characteristics throughout a city. In most large cities it might actually be more accurate to consider not one heat ‘island’ but a heat ‘archipelago’ (Alcoforado, 1988; 300). Within an urban fabric there are several warmer and cooler areas varying accordingly to land uses. The same can be said about cities from different latitudes, where additionally the geographic factor sharpens differences between phenomena.

The urban heat island may occur during the day or the night (Santamouris, Papanikolaou et al., 2001; 203). According to Oke (1987; 290) the most important and noticeable features of the urban heat islands are a reduction of the cooling potential in urban areas in the late afternoon and evening which results in higher minimum temperatures during the night, and a slower warming-up of the urban area after sunrise. It follows that the urban heat island is best developed at night, especially during clear and still-air nights (Givoni, 1998; 243). The association of high levels of heat stress during the day and the night shortens the possibilities for people to regenerate during the night (Gulyas, Unger et al., 2006; 1714).

Notwithstanding, it may be important to control the temperature surplus occurring at night upstream, during the day. It is during the day that heat storage is carried out — the more heat stored within the urban fabric during the day, the higher the heat released from urban structures during the late evening and night. Nighttime heat release is the final step of the phenomenon. The less ability of urban surfaces to store heat, the less heat will be irradiated later in the evening and night.

The impacts of urban heat island must be analysed carefully since these can differ considerably between climatic regions as well as during winter and summer in a given region (Givoni, 1998; 254). Taha (1997; 99) and Akbari, Davis et al. (1992; 16) state that depending on geographic location, prevailing weather conditions, and other factors, heat islands may be beneficial or detrimental to people and energy user. The positive impacts might relate, for example, to a reduction of the need for winter heating, while the negative impacts may involve the increased demand on summer cooling.

However, on a global perspective «low and mid-latitude heat islands are unwanted because they contribute to cooling loads, thermal discomfort, and air pollution» (Taha, 1997; 99). The urban heat island entails increased electricity demand, increased smog production, and increased emission of CO_2 and other pollutants (Akbari, Davis et al., 1992; XVIII-XIX) associated to all mechanical devices required for people to meet their comfort needs indoors. Santamouris, Papanikolaou et al. (2001; 295) have found that peak urban electric demand rises by 2 % to 4 % for each 1 °C rise in daily maximum temperature above a threshold of 15 to 2 °C. Yannas (2001; 281) refers that the urban heat island can be a significant source of thermal discomfort and it can foster the further growth in the installation and use of air conditioning systems. Urban heat islands can, amongst other effects, cause thermal stress to humans wherever a city is already located in a warm climate (Oke, 1987; 293).

2.2. Climate change

2.2.1. The phenomenon

Climate change «describes a change in the characteristics which compose the climate and derives from alterations of factors which affect the climatic elements, either on a local or a global scale» (Alexandri, 2005; 34). Cuadrat and Pita (2009; 393) refer that climate change has three main characteristics that should be understood differently from those of a mere anomaly or fluctuation: (1) the climatic system does not return to its former state — it evolves towards a different state till it reaches a new balance; (2) the change affects the entire system due to the interrelations that are established between all its components; (3) local anomalies are no longer compensatory nor maintainer of the global balance because what is being produced is precisely a disruption of balance.

Climate change has nowadays moved from a theoretical notion marking the future of the planet to a well-established and no longer avoidable phenomenon. As Wilson, Nicol et al. (2008; 31; 32) refer, «climate change scenarios for the 21st century suggest that, up to the midpoint of the century, much of the change is already committed, whatever action is taken to reduce the causes of climate change». The reason for this is «the level of carbon already in the atmosphere and the lags in the climate system» (*ibid.*). Taylor (2008; 2) reinforces this idea by stating that «because of the delayed effects from greenhouse gas emissions, we are locked into significant climate change, regardless of any emission reductions that we may secure now».

Climate change is far from being a consensual issue. The definition, causes, and expected impacts of climate change are described by different authors and advocated by different people and entities in a variety, often paradoxical, ways. There are two basic positions from which climate change has been regarded: the first, advocates that climate change is mostly a human-induced phenomenon; the second, argues that climate change is one moment of a natural cycle and that, thus, it is mostly based in natural phenomena which are independent from human activity. As this research does not intend to present a theory of climate change, and faced to the different definitions for climate change, it will keep tight to the definition for climate change given by the Intergovernmental Panel on Climate Change (IPCC 2012; 15) which is:

> *«A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use.»*

Regardless which position is subscribed to explain climate change, a first agreement on this subject is that contemporary concerns about climate change are due to the many climate changes that have occurred throughout the Earth's geological history; to the presumptive imminence of the end of the current interglacial period; the strong impact of the anthropic actions over the climatic system which is leading it towards a progressive warming; the high sensibility of the system when faced to changes in its components; the enormous vulnerability of contemporary societies to slightly relevant climate changes, e.g. the consequences of the sea level rise on coastal urban areas (Cuadrat and Pita, 2009; 458).

A second agreement is that climate change results and exerts an influence from and upon precise components of the Earth-Atmosphere system. Any change to one of these components might cause a new order balance, in other words, a climate change that may or not be favourable for human and natural habitats (Alexandri, 2005; 38). Some of these components are internal and some are external to the system. However, all have the same importance for the final balance of the system. According to Cuadrat and Pita (2009; 428-440), and Santamouris (2001; 19-23) these components are:

- Solar radiation. Changes in solar radiation may lead to significant variations in the amount of heat that penetrates the system. The cycle of these changes is of around eighty to hundred years. During stages of less solar activity (i.e. more tranquillity) the amount of incoming solar radiation is less, thus the Earth should cool down, while during stages of more solar activity the Earth should warm up.
- Atmospheric composition. The atmosphere is the first filter that stands between the sun and the Earth and determines to a great extent the energetic balance of the planet. It follows that a significant variation in these components is expected to alter this balance and lead to significant climatic changes as solar radiation before it reaches the Earth's surface should pass through the atmosphere.
  Alterations in the composition of the atmosphere might be due to human activity, solar activity, the Earth's magnetism (which varies cyclically in strength and direction throughout thousands of years and that ultimately result in the inversion of the poles), and volcanic eruptions (which expel large amounts of gases and particulates into the atmosphere). Any change in the particulates and gases composing the atmosphere is likely to change light absorption and scattering properties of the atmosphere. In turn, this will have an impact on climate change, namely on the greenhouse effect. At an optical level this can be noted, for instance, in the different tone between the blue sky in cities and in the countryside: while in cities the blue sky is paler, in the countryside it is more vibrant.
- The orbital characteristics of the Earth. The orbital characteristics of the Earth with relation to the sun determine the reception of solar radiation by different parts of the planet. These are almost cyclical and are mainly determined by the circumsolar orbit (every 90.000 to 100.000 years), the Earth's axis tilt (± every 40.000 years), and the lateral rotation of the Earth's axis or precession (± every 26.000 years). Presently, the Earth's axis is tilted 23.5° but it may vary between 22.5° and 24.5°. The lower the tilt, the less seasonal variation so that summers become cooler and winters milder.
- The nature of the Earth's surface. Different characteristics of the planet's surface lead to different uses of solar radiation. The Earth's surface will thus determine the amount of heat which is absorbed and stored or lost in different areas. For instance, an excessive amount of impermeable area and massive deforestations significantly modify the surface albedo and may intensify the desertification processes. Urban climate modification originating phenomena such as the urban heat island, higher precipitation, cloudiness and fog, and lower levels of humidity, incoming solar radiation, wind speed and visibility in cities may be included here.
- The atmospheric and oceanic circulation. These circulations are responsible for transferring heat from surplus to deficit regions, ensuring the thermal balance of the climatic system. A major change in their direction or intensity may lead to significant latitudinal imbalances or contribute to a new climatic configuration of the Earth.

Conspicuous amongst these components is atmospheric composition and its relationship with the greenhouse effect. The greenhouse effect is a phenomenon specifically related to the composition of the atmosphere. The basic principle of the greenhouse effect is that, such as for greenhouses, while incoming short-wave radiation can freely enter into the system (a glasshouse) and be absorbed by the soil and plants, long-wave radiation emitted by these warm surfaces cannot freely leave the glasshouse because it is largely absorbed by the glass, and then re-radiated back inside the system

(Oke, 1987; 250). In the Earth-Atmosphere system the absorptive role of the glass is played by the polluted atmosphere, where the pollutants and suspended particulates block radiation.

From all pollutants contributing to the greenhouse effect (CO_2, CH_4, N_2, O, O_3 and FCCs) CO_2 has been ascribed as that with a higher contribution: 61 % since the Industrial Revolution (Cuadrat and Pita, 2009; 448). Although CO_2 is a natural component of the atmosphere mainly outcoming from volcanic eruptions or the respiration of living organisms, it has been recognised that human activities have been increasing the amount of this gas in the atmosphere. This increase has been made to a level exceeding the capacity of the natural mechanisms to assimilate and offset it.

Once realised the threats raised by the high concentrations of CO_2 in the atmosphere, there has been a growing interest on the reduction of CO_2 emissions by governments around the globe. One of the main reference documents on these grounds is the Kyoto Protocol (United Nations Framework Convention on Climate Change 1996, entering into force in 2005). The compromise of reducing CO_2 emissions is however «somewhat very difficult and it evolves a maximum effort by everyone» (Gaines and Jäger, 2009; 60) because it often entails changes to deeply-rooted habitudes of contemporary societies.

Advocates of the idea that climate change is mostly due to human activities find their main argument on the fact that while till the 19th century the relationship between CO_2 sources and sinks remained balanced, with the development of the industrial revolution CO_2 concentration in the atmosphere starts to progressively increase, making the concentration of CO_2 in the atmosphere to lose its constancy. The advocates of the idea of climate change as a human-based phenomenon believe therefore that the fast and dramatic increase of CO_2 in the atmosphere is undoubtedly anthropic. The anthropic action is basically characterised by all sort of combustions based on the use of fossil fuels and, simultaneously, a continuous process of deforestation. The two processes together have the capacity of significantly increasing CO_2 concentration in the atmosphere: while the combustion of fossil fuels continuously releases large amounts of CO_2, deforestation destroys one of the main CO_2 sinks.

There is a degree of uncertainty about the precise impacts of climate change. Actually, the expected impacts of climate change are qualified in terms of 'likeliness', 'confidence', or 'reliability' and are expected to be more significantly felt in the sectors of agriculture, forestry, fisheries and aquaculture, coasts and marine ecosystems, energy, city infrastructure, tourism, human, animal, and plant health, water resources (quality and availability), and ecosystems and biodiversity. The IPCC (2012; 13) points out as the most likely global impacts of climate change:

- A substantial increase in temperature extremes;
- More frequent heavy precipitation or increase in the proportion of total rainfall from heavy falls;
- An increase on average tropical cyclone maximum wind speed, although increases may not occur in all ocean basins and not necessarily mean an increase in frequency;
- A reduction in the number of extratropical cyclones averaged over each hemisphere;
- An intensification of droughts in some seasons and areas due to reduced precipitation and/or increased evapotranspiration;
- Possible changes in floods due to the projected precipitation and temperature changes, although overall there is low confidence in projections of changes in fluvial floods;
- Mean sea level rise contributing to upward trends in extreme coastal high water levels;
- Alterations in mountain phenomena such as slope instabilities, movements of mass and glacial lake outburst floods resulting from the changes in heat waves, glacial retreat, and/or permafrost degradation.

Faced to the impossibility to avoid the impacts of climate change, it is paramount to consider that «cost-effective measures to prevent possibly serious environmental damage should not be postponed just because of scientific uncertainty about how serious the risk is» (Welsh Assembly Government, 2011; 47). The UN-Habitat (2011; 46) states that if no mitigation action is taken in the next ten years or so, the impacts will exponentially increase, while adaptation will be a continuous process for many decades to come. The Commission of the European Communities (2007; 2) states that «delaying action will only increase economic costs and physical damage from climate change in the long run».

2.2.2. IMPACTS OF CLIMATE CHANGE IN URBAN AREAS

Climate change is likely to have unprecedented impacts on urban areas. In these areas, and according to the UN-Habitat (2011; 20), the impacts of climate change are expected to be mainly felt in the physical infrastructure of a city, i.e. its roads, sewers and services but also its social, welfare and amenities (Tunstall, 2006; 354). According to the UN-Habitat (UN-Habitat, 2011; 20-23), urban areas may be faced with:

Infrastructural issues

- Substantial damage to residential and commercial structures due to increased climate change-related hazards and disasters;
- Disruption of transportation systems due to, for instance, heavy precipitation and its effects in the form of flooding and landslides, or to the increased decay of paved roadways due to higher air temperature and drought periods;
- Increased energy demand and related resources for cooling due to higher air temperatures and more severe and frequent heat waves worsened by the urban heat island phenomenon;
- Loss of efficiency of sanitation systems due to climate change-related disasters. In addition, the climatic shifts entailed by climate change can alter the range, life cycle and rate of transmission of certain infectious diseases;

Economic issues

- Damage to buildings, infrastructure and other assets which might affect industry;
- Higher vulnerability of retail and commercial services due to disruptions in supply chains, network and transportation, and changes in consumption patterns;
- Alteration of regional temperature distributions which can consequently affect the tourism industry and associated services due to the transformation of season-related recreational opportunities. Furthermore, tourism is highly dependent upon reliable transportation infrastructure;
- Higher vulnerability of the insurance industry since climate change could result in increasing demand for insurance while reducing insurability;

Environmental issues

- Contribution for the acceleration of loss and degradation of ecosystem services.

The impacts herewith mentioned indicate possible future trends which however are not determinant or linear. For instance, it has been suggested that «mean global warming does not exclude the possibility of cooling in some regions and seasons» (IPCC, 2012; 121). There have been even mentioned some positive aspects related to climate change, such as for example the increase of precipitation in some areas of the globe — because of its various processes and associated uncertainties, «mean global warming does not necessarily imply warming in all regions and seasons» (*idem*, 141).

From all IPCC’s (2012) expected impacts of climate change, in urban areas the main concerns should fall over the substantial increase in temperature extremes; the more frequent heavy precipitation or increase in the proportion of total rainfall from heavy falls; and the intensification of droughts in some seasons and areas due to reduced precipitation and/or increased evapotranspiration. These impacts are expected have serious impacts in the welfare and health of urban populations, as well as in the integrity of the physical infrastructures and in the cooling energy demand of cities. In turn, this is determinant for help meeting the goals of sustainable development, in particularly, the ‘sustainable city’.

The increase on average tropical cyclone maximum wind speed, the reduction in the number of extratropical cyclones, possible changes in floods, mean sea level rise, and alterations in mountain phenomena are probably better suited to scientific areas such as geography, climatology, agriculture, forestry, livestock, or fishing which are out of the scope of this research.

All prediction models for climate change point out a main trend for an increase in temperature of about 1.9 °C to 5.2 °C though most estimates refer a range between 3.5 °C and 4.5 °C (Cuadrat and Pita, 2009; 449). It is believed that this is the impact that in urban areas is likely to place higher constraints to people’s welfare and health, and to the use of public spaces, especially during summer: higher temperature extremes may increase people’s health vulnerability such as it is clearly illustrated by the death rates during heat wave periods, beyond making the use of public spaces more difficult since a higher thermal stress will be placed upon the body.

The urban heat island phenomenon should further be considered here since it can exacerbate extreme weather events (UN-Habitat, 2011; 20); the importance of the urban heat island should not be neglected in a climate change scenario since it has the potential «to compound and accelerate temperature rises in urban centres» (Carter 2006, 9); «global climatic change in addition to the heat island phenomenon increases the temperature in the urban environment, augments the duration of hot spells and increases the frequency of heat waves» (Santamouris, Synnefa et al., 2011; 3098).

If in some climates the urban heat island can have positive effects, in regions with warm and hot summers it is fair to say that this phenomenon is eminently negative. For someone in an outdoor cold environment it is often simple to get protected from excessive exposure to cold by increasing the clothing level, whereas for warm/hot conditions there is a cultural and legal limit for taking off clothing; and as heating is often more common and cheaper than air-conditioning systems, in terms of indoor comfort and energy use, the beneficial impacts of the urban heat island during winter are not prone to outweigh its negative impacts during summer (Givoni, 1998; 255; 256).

It is noteworthy that as a consequence of climate change, latitudes presently not exhibiting warm and hot summers may possess in the future the same or similar needs than those of nowadays — «even in the northern hemisphere, where the impact could be less than elsewhere, the effects from a rise of two degrees will be felt by every town and city» (Brown, 2009; 3). Wherever summer thermal conditions already hinder people’s welfare and create constraints to the public realm, i.e. «the tangible physical space where public life takes place» (Moor and Rowland, 2006; 47), the issues around adaptation of the built environment to climate change should promptly start being materialised into real public space projects; and wherever thermal constraints during summer have not yet come to be a significant source of discomfort and disease, these issues should as well promptly start being taken into consideration in order to anticipate the answer to likely future needs.

2.3. CONCLUDING REMARKS

The urban climate has particular atmospheric processes based on the correlation between the energy exchanges within the Earth-Atmosphere system, geography, and surface characteristics which will define the Earth's macroclimates. Macroclimate and mesoclimate are the first determining factors of the urban climate. Two other factors are held accountable here: the particular morphology of the built environment which, in turn, can be seen as a product of the correlation between the pre-existent physical environment and the paradigm of urban development of the society settling and inhabiting the urban area, namely in what concerns to building practices and design codes; and the predominant human activities held at the urban environment, which determine the amount of anthropogenic heat released.

The energy exchanges in urban environments can be regarded as processes involving the conjugation of incoming short-wave radiation, emitted long-wave radiation by opaque surfaces, and anthropogenic heat. In this context, morphologic elements such as location within a region, size, density of the built-up area, land coverage, height of buildings, orientation and width of streets, subdivision of the building lots, and special design details of buildings are determinant.

Climate change is far from being a consensual issue and therefore its expected impacts should be seen as predictions and not as a *fait accompli*. Nevertheless, research in late years has been validating its likely impacts on urban areas to some degree of plausibility. In urban areas the main concerns should fall over the substantial increase in temperature extremes; the more frequent heavy precipitation or increase in the proportion of total rainfall from heavy falls; and the intensification of droughts in some seasons and areas due to reduced precipitation and/or increased evapotranspiration. Conspicuous amongst these impacts is the substantial increase in temperature extremes because this is likely to place higher constraints to people's welfare and health, and to the use of public spaces, especially during summer: higher temperature extremes may increase people's health vulnerability such as it is illustrated by the death rates during heat wave periods, beyond making the use of public spaces more difficult since a higher thermal load will be placed on the human body.

If it is true that the built environment and the activities of mankind within that environment can alter a site's atmosphere in a negative way, it may also be argued that action may be taken to reverse and attenuate these impacts (Figure 7). This requires knowing the fundamentals of the energy exchanges within the Earth-Atmosphere system and within the urban environment since it will allowed to define a course of development and intervention on the city's public spaces and knowing which parameters to work with for the cooling of the built environment; and knowing what do present climate change theories foresee with respect to the likely impacts of this phenomenon over the built environment because this is fundamental to ensure that people's welfare and health as well as the quality of the public realm are perpetuated.

Fig.7 – A public space with good conditions for a pleasant thermal experience. Lyon, France. Source: João Cortesão, 2009.

This chapter covered the basal knowledge on climate and climate change in urban areas. This knowledge will be an important reference for the development of the methodology supporting retrofitting proposals based on facing materials and vegetation, on a bioclimatic perspective, aimed at help adapting the built environment to the substantial increase in temperature extremes brought by climate change. The proposal of such methodology should start by understanding the relationships established between the energy exchanges within the Earth-Atmosphere system, the urban climate, and the likely impacts of climate change on urban areas since addressing the present climate challenges requires understanding how urban climates operate in the present and will likely operate in the future.

3
CURRENT URBAN DEVELOPMENT AND PUBLIC SPACE

This chapter approaches the main goals of current urban development and the notion of contemporary public space in order to explore the extent to which the adaptation of the built environment to the substantial increase in temperature extremes brought by climate change can suit current urban development and public space trends. Section 3.1 will present the main goals of current urban development while section 3.2 will present the way in which presently public spaces tend to be conceived. Finally, section 3.3 presents some concluding remarks.

3.1. CURRENT URBAN DEVELOPMENT

3.1.1. SUSTAINABILITY AND THE SUSTAINABLE CITY

Cities are nowadays faced with several environmental problems with important impacts on human welfare (Table 1). Since cities are the areas where man has most evidently altered his environment (Gomez, Jabaloyes et al., 2004; 94), the importance that environmental issues have on a city is more evident than in any other area. For Santamouris (2006; 3) the increase in urbanisation has deteriorated the urban environment and deficiencies in controlling the urban development have seriously impacted the urban climate and environmental performance of buildings. In addition, the concentration of an ever-growing number of people with increased average life expectancy in urban areas makes the urban environmental problems to be felt by a number of people larger than in any other area in the planet.

The several environmental challenges presented nowadays by cities can be broadly brought together in the definition of their ecological footprint. The ecological footprint of cities «represents the land area necessary to sustain current levels of resource consumption and waste discharge» by a given population on nature (Wackernagel and Rees, 1998; 5). If all countries were to be developed accordingly to current parameters of development we would need several planets to satisfy all contemporary needs, since their ecological footprint would be increased (Higueras, 2006; 65).

The contemporary city consumes secondary energy to a great extent and under a linear dynamic, rather than under a closed cycle energy system able to convert waste into new energetic resources, suitable for maintaining the functioning of urban areas (*ibid.*). This culminates with the fact that although cities occupy only 2 % of the planet's surface, they use around 75 % of worldwide resources and expel equivalent amounts of waste (Girardet, 2007; 13).

Table 1 – Urban environmental pathologies. Based on Higueras (2006; 66).

Urban cycle	Symptoms of the urban pathology
Atmospheric	Higher environmental contamination, pollution Increase of CO_2 and CO emissions Urban atmosphere overheating Urban heat island Lower rate of air renewal
Hydrologic	Environmental imbalance Lower relative humidity in dense urban areas Alteration of the natural aquifers Increase in superficial runoff Salinization of soils by intensive irrigation Contamination of superficial and underground water Alteration of the urban climate (precipitation and temperature)
Organic matter and waste	Increase of organic matter urban solid waste Alteration of the soil composition Contamination of underground water by infiltration Salinization of soils, loss of fertility
Energetic	Depletion non-renewable energy sources Energetic cost and contamination

Several moments have marked the present shape and situation of cities. In Europe, from the late 19th century till the present, evolution of the concept of urban development was made up of the following main moments and associated visions of progress:

- Late 19th century. Cities were surpassing their high-density walled perimeters and a hygienist way of thinking arose influenced by the Haussmann's intervention in Paris. It is here that the accommodation of the first motorised vehicles within cities was firstly thought in a systematic way. In this context, the first major thoroughfares were conceived (Cladera, 1995; 54-56).
- 1930s. A new range of regulations are created with different degrees or protectionism and different scopes (focused either on culture or housing) (*idem*; 54-56).
- 1950s and early 1960s. The first large-scale urban renewal operations take place, i.e. the demolishment and re-build of parts of a city; the «eradication of the physical problems of the past» (Roberts and Sykes, 2000; 15). These operations were mainly aimed at eliminating derelict areas that had resulted from the countryside-cities emigration, and at placing the emerging powers at the centre of cities while moving poorer classes into new-built housing complexes at the urban fringe (Cladera, 1995; 54-56).
- Late 1960s and early 1970s. The dissatisfaction resulting from the decanting of population to peripheral housing complexes and a more participatory and decentralised approach to government has led to a shift in urban policies resulting in an increased emphasis on improvement and renewal (Roberts and Sykes, 2000; 15). The protection of historical centres also gains strength through a first set of planning policies and tools envisioning the full-rehabilitation of a city, i.e. not only its monuments but all its architectures and inhabitants (Cladera, 1995; 54-56).
- During the second half of the 20th century this expansion of the notion of heritage has also start encompassing public spaces — specific heritage categories such as parks and historical gardens were created and social spaces were considered as «containers of different common practices [of a community] recognised as intangible heritage» (García 2008; 16).

The 1970s were simultaneously a moment when growing number of countries started having significant losses in their inner-city populations (Colquhoun, 1995; 11). This loss of population is related with the «combined effects of recession, economic restructuring and social reactions against the modernist planning agenda» (Couch, Sykes et al. 2011; 2).

- 1980s. In the 1980s the development of urban policies on a postmodern basis became known as 'careful urban renewal' (*ibid.*). There was a move away from the central state as source of all the resources supporting policy interventions which lead to a greater emphasis placed on partnerships (Roberts and Sykes, 2000; 16). During this decade, cities started being aesthetically renewed in order to become more attractive to entrepreneurs, tourists and consumers (Hughes, 1999; 120).

  The postmodern city has expressed the deindustrialisation of the metropolis but at the same time the middle-class abandonment of urban residence coupled with suburban sprawl, the devaluation of public space and an «awe-struck love-affair with an 'inward-looking' architectural style that 'turns its back on' the surrounding cityscape» (Murray, 2004; 139).

  Urban sprawl is a sort of antagonism of the 'traditional' conception of city in the sense that it does not possess clearly defined boundaries between urban and natural/rural areas but rather a diffuse territorial pattern. Although urban sprawled growth is a complex subject related to the specificity of each urban area, it can be characterised by a low-density suburban development pattern (Carruthers and Ulfarsson, 2002; 314). McHarg (1992; 57) refers that the increase of density and extension of peripheries «is totally unresponsive to natural processes and their values».
- 1990s. In the 1990s there were further adjustments to the form and operation of urban policy which lead to the recognition of a series of new problems and challenges (Roberts and Sykes, 2000; 16). The recognition of the long-term environmental benefits of maintaining and improving existing urban areas, on a sustainable perspective, was one of the most important new challenges guiding urban development (Couch, Fraser et al., 2003; 3).
- 2000s. The early 21st century brought sustainable urban development and urban regeneration to the centre of debates on urban development (Couch, Sykes et al., 2011; 4).

After several decades during which the patterns and nature of urban growth were mainly determined by urban growth pressures and the dominance of the modernist planning agenda, and by an ulterior urban sprawl phenomenon, more recently a shift has occurred towards a new set of discourses subsumed under the label of 'sustainability' (Thomas, 2002; 205). Sustainability has actually become the «remedy to achieve economic vitality, social equity and ecological integrity in cities» (Ercan, 2011; 295).

Although presently there seems to be a consensus on how to approach and implement sustainable urban development measures, the understanding of what sustainability actually is may be rather problematic since it can be unfolded into quite diverse ways (Thomas, 2002; 205). The most disseminated definition for sustainable development was offered by the world Commission on Environment and Development (The Brundtland Commission) as the «development that meets the needs of the present without compromising the ability of future generations to meet their own needs» (WCED, 1987; 27). Unsustainable development is, in turn, associated with ozone depletion, poor sanitation, extinction of species and habitat, social conflict, toxic pollution or resource depletion (Myers, 2004; 233).

According to the Brundtland Commission, the definition of sustainable development encompasses three dimensions: environmental, economic and social (Edwards, 2004; 7). Bearing this in mind, anything which is sustainable, beyond entailing energy savings, is also related with the creation of healthy and economically feasible spaces which are sensible to social needs (*idem*, 1). Thinking about sustainability requires addressing each of these dimensions through a holistic approach to the whole range of impacts a proposal, irrespective its area of action, may entail. Sustainability is however a slippery word here since «it is easy to focus on one aspect and lose the value of its holistic meaning» (Worthington, 2009; 1). An energy-efficient proposal per se is of little value (Edwards, 2004; 1).

It is possible to consider two main motivations for the shift occurred in the patterns and nature of urban growth towards sustainability: (1) the recognition that the «environmental conditions today and in the future will be very critical, if not incisive measures are realized» (Brebbia, Ferrante et al., 2000; 9); (2) the growing concern in recent years about global warming (Wheeler and Beatley, 2009; 10). These concerns have been traduced to several moments and documents stimulating international sustainable development such as the Stockholm United Nations Conference on the Human Environment (1972), the Helsinki Protocol (1983), Our Common Future (Brundtland Commission, 1987), the setup of the Intergovernmental Panel on Climate Change (IPCC, 1988), the Earth Summit (Rio Declaration on Environment and Development, 1992), the entry into force of the United Nations Framework Convention on Climate Change (UNFCCC, 1994), the Hague Climate Change Conference (2000), the entry into force of the Kyoto Protocol (2005), amongst many others.

Sustainable urban development is about solving the environmental problems experienced within cities and the problems caused by cities (1996, 5). The former problems relate to the enhancement of the conditions offered for the welfare of urban populations, and the latter to the reduction of the pressure cities place on the environment, namely their ecological footprint. It is however important to understand that the notion of sustainable urban development is rather complex and that it is not a goal able of mitigating the externalities of human activities rather than eliminating them. This relates to the idea of controlling human activity to such levels that the natural productive and assimilative capacity of the planet is not exceeded. The Brundtland Report (1987, 28) refers, for example, that «renewable resources like forests and fish stocks need not be depleted provided the rate of use is within the limits of regeneration and natural growth».

One concept has been brought to discussion in the past few decades as a plausible means of achieving the goals of sustainable urban development: the sustainable city. The sustainable city should be firstly thought as a «holistic approach to reducing demand for space and water heating, power and lighting and use of motorised transport, and increasing self-sufficiency in lifestyle practices» (Jenks, Burton et al., 1996; 42). It follows that the sustainable city should be thought as a holistic, cross-sector concept encompassing environmental, economic and social factors (Jones and Patterson, 2007, 256; Ritchie and Thomas, 2009, 19) with the final goal of creating liveable, productive and inclusive urban areas (UN-Habitat, 2009; 13). This involves a number of fields such as urban planning, urban design, architecture, economic driving forces, management and governance, urban policies, or education.

There are presently some built examples of ecocities, green neighbourhoods or environmental urbanisations all around the globe which incorporate principles such as better indoor comfort conditions, less associated carbon emissions, mitigation of the urban heat island, better integration of the human dimension in public spaces, reduction of waste and consumption of resources, or a stronger bond between people and nature. Some of the most well-known examples are Hammarby Sjöstad, Stockholm; Kronsberg Ecological District, Hannover; Dongtan Eco-city, China; Beddington Zero Energy Development and Greenwich Millennium Village, London; or Nieuwland, Amersfoort.

The sustainable city concept is often associated to another ‘green urbanism’ which is about the combination of «the best of traditional urbanism with renewable energy sources, advanced conservation techniques, new green technologies, and integrated services and utilities» (Calthorpe, 2011; 18). The whole range of concerns around sustainability in the construction sector can be encompassed in one generic term: sustainable construction, which comprises the efficient use of resources, effective protection of the environment, and economic growth that meets the needs of everyone (Myers, 2004; 8-183). These two issues make the sustainable city to require a change in the way how economic drivers operate, i.e. to move from the trend of «a non-sustainable development approach to urban infrastructure», cheap labour and reduced capital costs, to a more cross-sector approach (Jones, 2007; 202).

It follows that raising awareness for the importance these issues have to the environment and for the welfare of urban populations is a crucial step for implementing effective solutions. The action of local authorities might be quite significant in this context due to the proximity these entities have to the sources of environmental problems and also to local populations and their needs. One of the most well-known examples of these actions is the Local Agenda 21.

The sustainable city should be thought with professional responsibility and technical accuracy and not as a stylistic trend. In this sense, it is of utmost importance to ensure that proposals are robust enough to resist to erosive external forces during their development and implementation, and to ensure that proposals do not take the sustainable city as a design whim, as a banner of intellectual distinctiveness, or as a means of political propaganda.

It is fundamental to be aware of the main constraints posed to the full implementation of the sustainable city and foremost the ways in which the ‘sustainability’ of a project might be more a label than a true achievement. According to Jones and Patterson (2007; 256), the range of issues to be considered with respect to this is a poor definition of the sustainable approach in the early stages of a project, further lost when it comes to the real time and cost pressures of the project programme; a poor link between high and low level decision makers and although designers/technicians are often aware of sustainability issues, such issues are not often included at high level and this prohibits their implementation and inclusion in practice; existing tools to assist with incorporating sustainability into design that are often theoretically based and do not take sufficient account of the needs of practice; the valorisation of capital costs at the expense of whole life costs (which can result in large cost savings); a lack of knowledge transfer from one project to another; and a trend for 'greenwash' projects.

The sustainable city requires a «planned change to the way in which cities are spatially configured and serviced» (UN-Habitat, 2009; 13) and comes forth as the specific way sustainable urban development relates to the built environment. Reducing carbon emissions and ensuring security of supply; making buildings more comfortable, safer and cheaper to run; making streets fit for people; rethinking waste; planning for a shortage or excess of water; protecting natural resources; moderating the heat island; and making green spaces work for people and wildlife; protection of social values and public property; safeguarding and retention of capital and values (Hegger, Auch-Schwelk et al. 2006, 22; Brown 2009, 10-20) can be regarded as the main principles of this relationship.

The Compact City has been regarded as a model of urban development with a high potential to help meeting the goals of the sustainable city and, consequently, help countering the environmental problems affecting cities during the past few decades. Very broadly, the compact city model is built upon the idea that it can be beneficial to think about urban development without necessarily and automatically think about urban expansion. The Freiburg Charter for Sustainable Urbanism (The

Academy of Urbanism, 2011; 9) points out the Compact City as the model for new settlements in the future, according to twelve principles which can be considered those of the sustainable city as well:

Space

- Diversity, safety and tolerance
- City of neighbourhoods
- City of short distances
- Public transport & density

Content

- Education, science & culture
- Industry & jobs
- Nature & environment
- Design quality

Process

- Long-term vision
- Communication & participation
- Reliability, obligation & fairness
- Co-operation & partnership

The advantages of the compact model are not however consensual. According to Jenks, Burton et al. (1996; 11; 42), on one extreme of the debate there are those who advocate the benefits of the compact city for a sustainable future, namely the reduction of travel distances and thus the reduction of emissions and greenhouse gases so that global warming can be curbed. Lower energy inputs for transport and heating purposes are seen as the main benefits of the compact city. On the other extreme there are those who argue that the benefits of the compact city may not stand up to scrutiny and thus do not allow assessing the extent to which centralising actually worth the impacts it will have on urban dwellers. The advocates of the latter position believe that some of the benefits of the compact city are questionable. Between these two visions, Worthington (2009; 10) suggests that «the sustainable urban form of the future will be both concentrated and dispersed», i.e. it will consist of «compact nodes in a sub-urbanised landscape, connected by a network of interconnected public and private transport, and telecommunications».

Regardless the understanding of the relationship between sustainable development and built environment, it should be considered that since the notion of sustainability is almost always context-dependent, the ‘best’ solution for a site may not suit another (Brownhill and Rao 2002, 4; Brown 2009, 4). Thereby, it is neither possible nor advisable to find a universally fixed model of sustainable city. A careful evaluation of local circumstances is determinant for outlining strategies around sustainability.

Due to this holistic character of the sustainable city, it is important to consider that sustainable cities «are not created, they emerge and evolve» (Thwaites, Porta et al., 2007; 23; 25). The time-scale for achieving these goals of the sustainable city is rather imprecise — optimists are aiming for environmentally friendly cities by 2020 and realists sometimes refer 2050 (Ritchie and Thomas, 2009; 8).

Change towards the creation of more sustainable communities means re-designing how people think and organise their lives, courage, vision and leadership; it requires the collaboration between public, private and voluntary sectors; a new market model enduring over the long-term because it delivers sustained value; and the engagement of the whole community (Brown, 2009; 4). This involves a commitment with changing people's perceptions and lifestyle, with education for sustainability.

As far as this research is concerned, such challenge involves, firstly, to become the creation of communities adapted to the substantial increase in temperature extremes brought by climate change as a true problem in people's minds, and, secondly, to gain cross-sector enthusiasm for change. Worthington (2009; 9) argues that achieving the sustainability goals «will be as much about changing perceptions and so behaviour, as it is about technological prowess». Changes need to take place both at an individual and organisational level. Jones (2007; 202) refers at this respect that «there need to be lifestyle changes on both an individual and company/municipality level» so that sustainable development can be implemented.

The concept of lifestyle involves how people move, the size of homes, diet, and the quantity of goods consumed (Calthorpe, 2011; 9). For instance, energy consumption is determined not only by the physical characteristics of the built environment but also by societal values and individual lifestyles (Jones, Pinho et al., 2009; IV). At the organisational level, the challenge passes by companies to develop social corporate responsibilities; to escape from the silo approach to urban planning; to develop projects on a holistic and cross-sector basis; and foremost to move from short-term-ism "low cost, quick delivery" to a "high cost, slow delivery" (Jones, 2007; 203).

It should however be outlined that changing perceptions and lifestyle can be better achieved by giving people a sense of personal involvement (by inclusion) rather than forcing them by an administrative fiat (Gaines and Jäger, 2009; 150). People have the right to make their own decisions and decisions are dependent on the knowledge at hand (*ibid.*).

The change necessary for sustainable urban development and urban design agendas to be implemented in a systematic way also involves looking after synergies between all specialists able of putting the individual pieces of community design together (e.g. architects, traffic engineers, landscape architects, civil engineers or planners) and thinking through the trade-offs; as well as the development of comprehensive policies, integrated professions, and whole systems design, which are determined by the structure of governance and the scale at which decisions are made (Calthorpe, 2011; 46). Architecture and urbanism schools should also be responsible for overcoming any lack of communication between professionals, i.e. to recall the importance of networking with other disciplines, of taking holistic approaches, and of cooperating with peers (Gaines and Jäger, 2009; 150).

Unsurprisingly, the political power plays a determinant role in creating the legal and conceptual basis for change to occur. Governments define the legal framework for the development of a country, region and city, which can determine the ease with which the 'sustainable city' goals can be met. According to Miozzo and Dewick (2004; 8), governments can be influential in determining the extent to which sustainability issues integrate national, regional and municipal development policies in five ways: as the largest single client of the building industry; by establishing fiscal and regulatory measures to stimulate innovation; by acting as broker inmarkets for environmental technologies; as chief educator and disseminator of information on sustainable technologies both to the industry and general public; and as market leader, prototyping innovative solutions through demonstration projects. It has however been acknowledged that governments can no longer govern without the co-operation of other actors (Taylor, 2007; 297). This issue entails a more fluid conception of power developed and negotiated between different partners by opposition to the conception of power as a fixed idea of a commodity rooted in particular institutions (*idem*, 299,300).

Community empowerment can be vital in the context of new governance models. Local communities «represent pools of knowledge on how areas function for those that live and work there» (Corbett, 2004; 19). Involving as many actors as possible in the planning and decision-making processes has as main advantages (1) better and more efficient results; (2) reduced conflicts; (3) better cooperation between state and civil society; (4) and more sustainable results in terms of acceptance and ownership (Plass and Kaltenegger, 2007; 210). Evidently a broadening of the parties involved in governance issues carries with it a higher risk of conflicts of interests and development visions. As Corbett (2004; 8) states, «the public realm presents a complex management problem because of the sheer number of legal and professionals involved» all tackling different parts of the problem. Any public or private group might have quite particular interests (Alves, 2003; 263).

3.1.2. Adaptation and mitigation of climate change impacts

As mentioned above, one of the motivations for the shift occurred in the patterns and nature of urban growth towards sustainability was the growing concern in recent years about global warming (Wheeler and Beatley, 2009; 10). Adaptation to climate change is about making towns and cities more resilient (Taylor, 2008; 2). The Intergovernmental Panel on Climate Change (IPCC, 2012; 5) describes adaptation in human systems as «the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities» and resilience as the «ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner».

Adapting the built environment to the expected impacts of climate change has two levels of approach which in many aspects, naturally, overlap to the goals of sustainable urban development: firstly, the reduction of greenhouse gases emissions (mitigation) and, secondly, taking action for dealing with its unavoidable impacts (adaptation) (2009, 3). While the mitigation of climate change involves the sectors of urban development and design, built environment, urban infrastructures, transport, and carbon sequestration (UN-Habitat, 2011; 27), adaptation establishes with the urban design and architecture fields a close connection.

Relatively to mitigation it is noteworthy the array of documents produced in order to start taking action. The United Nations Framework Convention on Climate Change (UNFCC) and the Intergovernmental Panel on Climate Change (IPCC) have issued quite valuable documents addressing climate change, its impacts, management of risks and adaptation strategies, or overall framework for intergovernmental efforts. The UNFCC has set the Convention on Climate Change (1992), the Kyoto Protocol (1998) and, more recently, the “Planning Sustainable Cities” Global Report on Human Settlements (2009) and the “Cities and Climate Change: Policy Directions Global Report on Human Settlements” (2011), amongst an array of other issued and in-preparation documents. In turn, the IPCC issued an array of documents such as the “IPCC Fourth Assessment Report: Climate Change” (2007) or the “Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation Special Report” (2012).

The Commission of the European Communities has also been producing a number of documents such as the “Green paper on the urban environment”, COM(90) 218; the “Charter of European Cities & Towns Towards Sustainability — Aalborg Charter” (1994); the “A Sustainable Europe for a Better World: A European Union Strategy for Sustainable Development”, COM(2001) 264; the “Green Paper on Energy Efficiency or Doing More With Less” (2005); the “Leipzig Charter” (2007); the “Limiting Global Climate Change to 2 degrees Celsius”, MEMO/07/16 (2007); the “White Paper - Adapting to climate change: Towards a European framework for action”, COM(2009); or the “European Research Framework Programme Research on Climate Change” (2009); amongst others.

The 6th and 7th Research Framework Programmes of the European Community have been supporting a number of recently completed and ongoing climate research projects ranging from climate processes and their modelling, to the assessment of climate change impacts and the costs of response measures. Many of these projects were supported by grants provided by the European Research Council. Two examples are the "CIRCE — Climate Change and Impact Research: the Mediterranean Environment" Project, coordinated by the *Instituto Nazionale di Geofisica e Vulcanologia*, Rome; or ADAM — "Adaptation and Mitigation Strategies: Supporting European Climate Policy Project", coordinated by the University of East Anglia, Norwich.

With respect to adaptation, since the problems climate change poses to urban areas are in large part planning, design and management issues, it is vital a well-informed relationship between urban climate and city building (CABE, 2007; 3). Ensuring that urban life may keep providing vibrant, safe and comfortable experiences, requires therefore addressing the expected impacts of climate change in urban areas alongside a stronger commitment with the mediation between man and environment.

According to the UN-Habitat (2011; 28), «the design and use of the built environment is a critical arena for climate change mitigation because in most countries the building sector consumes approximately one third of the final energy used, while absorbing an even more significant share of electricity». Developments should be able of influencing microclimates, minimising the use of energy, and maximising energy efficiency (English Partnerships and the Housing Corporation, 2007; 65). In addition, adaptation to climate change is particularly important in cities due to the «sheer number of people affected, the value of property, infrastructure, historical, political and cultural assets invested in them, and their place as vital elements of a civilized society» (Wilson, Nicol et al., 2008; 34).

The "White Paper on adapting to climate change: Towards a European framework for action" (2009, 6), mentions that «preventive action brings clear economic, environmental and social benefits by anticipating potential impacts and minimising threats to ecosystems, human health, economy and infrastructure». The same document (2009, 6) also refers that although more specific information on the costs of adaptation is needed, the costs of taking action to address climate change are expected to «be much lower than the costs of inaction over the medium to long term». In addition, «adapting for climate change often brings with it surprising extra economic, social and other environmental benefits» (Taylor, 2008; 4).

Climate change is expected to have «profound environmental, economic and social justice implications and failure to address it will make planning for sustainability impossible» (Welsh Assembly Government, 2011; 45). This is especially important when considering that the impacts of climate change will mark at least the next coming 50 years (2009, 3).

Faced to the growing awareness of the likeliness of these impacts on urban areas, adaptation strategies can largely benefit cities especially in what concerns to their place as vital elements of a civilised society. Making cities more resilient to the predicted climate extremes can bring better welfare, safety and health conditions to urban populations, preserve urban infrastructures, as well as positively influence the value of property, and historical, political and cultural assets.

In the wider picture of sustainability, climate change should be addressed alongside other subjects such as protection and enhancement of biodiversity, minimisation of harmful emission of pollutants, and promotion of the sustainable use of resources. Achieving environmental objectives today cannot however be done by considering specific environmental policies only; it is necessary to mobilise the entire economy and the entire society; it is necessary to state climate change first and foremost as an environmental issue to be consistently integrated into all policy areas (Hontelez, 2010; 4; 10).

3.2. PUBLIC SPACE

Public space can be defined as all that normally outdoor and non-built area of open access and collective use (Brandão, Carrelo et al., 2002; 189). Krier (1979; 15) offers a simple perspective on the definition of public spaces which, without considering aesthetic criteria, is that public spaces are «all types of space between buildings in towns and other localities». Hertzberger (2009; 12) complements and deepens this global definition by stating that public spaces are urban areas that are accessible to everyone at all times and whose maintenance responsibility is shared collectively, contrary to private spaces whose accessibility is determined by a group or one person which are responsible for maintaining the space.

The notion of public space can be rather simple and yet complex: simple relatively to its physical delimitation within the urban milieu, and complex concerning its social, symbolic significance. Concerning their physical delimitation, public spaces are defined by morphologic elements such as orientation, height/width ratio, heights of the surrounding buildings, built density, types of buildings, size, colours, vegetation, water features, materials, finishes, detailing, street furniture (e.g. seating elements, drinking water fountains, balustrades, handrails, water features, statues, phone cabinets, mailboxes, bicycle and bus stands, information signs and traffic lights, pergolas, kiosks), urban art, or lighting. A second layer related to spatial composition encompasses parameters as order, balance, scale, proportion, rhythm, contrast, harmony, symmetry among others (Alves, 2003; 15).

The complexity of public spaces, i.e. its social, symbolic significance lies in the fact that public spaces are a result of the interplay of time and physical, social, and political factors which, throughout the history, have supported the needs of the communities creating them (Carr, Francis et al., 1995; 22; 26). In this context, «each built environment, each part of a public space represents the social status of its user, be it individuals or groups» (Dumreicher and Kolb, 2008; 321).

As Hillier and Hanson (1984; 48) refer, «each society will construct characteristic encounter patterns for its members, varying from the most structured to the most random». Lefebvre (1974; 93) states at this respect that neither the nature (climate and site) nor the history are enough for explaining and understanding a social space — a space is not resumed to the objects it contains nor at their sum. These objects are not merely things but also relations which are transformed and given a place in time and space by the social processes (*idem*, 94). Norberg-Schulz (1986; 7) states that a place is *per se* a 'total' qualitative phenomenon that cannot be reduced to any of its singular characteristics. Public spaces are therefore an evolving organism that grows and develops in parallel to society itself. Çelik, Favro et al. (1994; 1) state that, for instance, streets «are as mutable as life itself and are subject to constant alterations through design or use».

Considering the immaterial complexity of public spaces, Lynch (1971; 9) offers a particularly interesting way to analyse the image of an environment. According to this author such analysis may be undertaken by approaching three parameters: identity (in terms of individuality or uniqueness), structure (the spatial or paradigmatic relationship between the object and the observer and the remaining objects), and signification (practical or emotional significance to the observer). Valuating these parameters may allow understanding a public space in its material and immaterial dimensions and therefore provides a holistic appreciation of a public space.

Hayward and McGlynn (1993; 42) state that «the products of urban design are inevitably experienced, they have the potential to engage our feelings, so some part of urban experience is aesthetic experience». Indeed, «experience of space is the foundation and framework of all our knowledge of the spatio-temporal world» (Hillier and Hanson, 1984; 29). The ability to experience a high-quality public space is therefore vital for the enrichment of the public realm. Being able to distinguish and read an environment enhances the potential intensity of the human experience (Lynch, 1971; 6).

According to Sugiyama and Thompson (2007; 1950), the main parameters able of enriching the public realm in cities are land-use diversity, street pattern (connectivity), access to shops, access to recreational facilities, qualities of the ground, aesthetics, safety from traffic (e.g. ease of street crossing, pavement continuity and pedestrian accident locations), and safety from crime. A pleasant space offers protection from crime, vehicular traffic and unpleasant weather, and possesses aesthetic quality (Gehl 2011; 171). The way these parameters influence the extent to which people will be keen to participate in urban public life should be clearly recognised by any urban design vision since in urban areas with no well-used public spaces «public life and civility become seriously eroded» (Corbett, 2004; 10). As Jane Jacobs (1961; 39) refers, «if a city's streets look interesting, the city looks interesting; if they look dull, the city looks dull».

According to Gehl (2011; 9), public spaces generally encompass three categories of activities: necessary activities, optional activities, and social activities. These activities are better established when spaces have a high-quality standard — in areas of poor quality only strictly necessary activities take place since people hurry home (*idem*, 11). Regardless the type of activities, public spaces should be designed for delivering people the utmost conditions for a positive, meaningful, and comfortable experience of the space; the design of public spaces should be foremost human-based and therefore be inspired by the human dimensions of public spaces. The human dimensions of public spaces refer to the rights and needs of users and deal with organising ideas about the social value of a space (Alves, 2003; 219).

Good design of the built environment «plays a key role in economic growth and in raising the quality of the places where we live and work» (2009, 15). Considering that public spaces account for up to half the area of most city centres, and that city centres often shape the urban experience (Evans, 1997; 81; 83), it is fair to say that the creation of high-quality public spaces walks hand by hand with the improvement of the quality of life of urbanites. Marcus and Francis (1998; 9; 10) consider that high-quality public spaces should incorporate the following parameters:

- Location where it is easily accessible to and can be seen by potential users;
- Clear communication that the space is available for use and is meant to be used;
- Beauty and capacity to engage on both the outside and inside;
- Furnishing able of supporting the most likely and desirable activities;
- Provision of a sense of security and safety to would-be users;
- Provision of relief from urban stress and enhancement of the health and emotional well-being of its users;
- Specific approach to the needs of the user group most likely to use the space;
- Encouragement of use by different subgroups without any one group's activities disrupting the other's enjoyment;
- Provision of an environment physiologically comfortable at peak use times, in regard to sun and shade, windiness, and the like;
- Accessibility to children and disabled people;
- Support to the philosophical programme to which managers of the space are committed to;
- Incorporation of components that the users can manipulate or change;
- Engagement of users in the design, construction, or maintenance of the space in order for individuals or groups to become attached to the space and caring for it;

- Ease and economy of maintenance but within the limits of what is expected in a particular public space typology;
- Compatibility between the conception of space as an expression of visual art and place as social setting.

These parameters can be complemented with parameters offered by the British Commission for Architecture and the Built Environment, CABE (2001; 19):

- Character – reinforcement of locally distinctive patterns of development and culture;
- Continuity and Enclosure – promotion of the continuity of street frontages and the enclosure of space;
- Quality of the Public Realm – promotion of public spaces and routes that are attractive, safe, uncluttered and work effectively for all people;
- Ease of Movement – making places easy to access and to move through, putting people before traffic;
- Legibility – provision of recognisable routes, intersections and landmarks to help people find their way around;
- Adaptability – development able of responding to changing social, technological and economic conditions;
- Diversity – promotion of diversity and choice through a mix of compatible developments and uses.

Mean and Tims (2005; 44) point out the parameters of sense of belonging, novelty and surprise, different roles, tolerance, sociability, status and esteem, confidence, mutuality, companionship, learning, beauty, playfulness, escape, curiosity, community, performance, autonomy, personal development and comfort. Moughtin (1992; 25-59) mentions seven basic design concepts that should base of the development of buildings and public spaces projects: order (organisation, creation of references); unity (notion of strength and completeness); proportion (coherent visual statement); scale and proportion (the relation of the parts to each other and to the whole space); harmony and proportion (establishment of proper relations, ratios, and the forth); symmetry, balance and rhythm (compositional balance); and rhythm, harmony and contrast (good compositions are harmonious but the elements of contrast and surprise are vital for creating exciting environments).

The parameters at the basis of a high-quality design standard overlap and exert mutual influences. Seeking good design requires a holistic vision. A high-quality design scheme should encompass as much good design parameters as possible since the investment in good urban design has a number of social, environmental and economic advantages. According to CABE (2001; 8), good urban design adds economic, social and environmental value by:

Economical

- producing high returns on investments (good rental returns and enhanced capital values);
- placing developments above local competition at little cost;
- responding to occupier demand;
- helping to deliver more lettable area (higher densities);
- reducing management, maintenance, energy and security costs;
- contributing to more contented and productive workforces;
- supporting the ‘life giving’ mixed-use elements in developments;
- creating an urban regeneration and place marketing dividend;
- differentiating places and raising their prestige;

- opening up investment opportunities, raising confidence in development opportunities and attracting grant monies;
- reducing the cost to the public purse of rectifying urban design mistakes.

Social and environmental

- creating well connected, inclusive and accessible new places;
- delivering mixed-use environments with a broad range of facilities and amenities available to all;
- delivering development sensitive to its context;
- enhancing the sense of safety and security within and beyond developments;
- returning inaccessible or run down areas and amenities to beneficial public use;
- boosting civic pride and enhancing civic image;
- creating more energy efficient and less polluting development;
- revitalising urban heritage.

The creation of high-quality built environments is the fundamental condition for guaranteeing that the inner areas of cities keep the traditional role of «heart, even the apotheosis, of our urban civilisation, where a multitude of commercial, retail, cultural and governmental activities and functions are uniquely concentrated» (Evans, 1997; 1). It has been inclusively recognised by governments throughout the globe that the performance and quality of built environment is a central issue for sustainable development (Jones, 2007; 201).

The agglomeration of creative and cultural industries, which can be classified as a sort of mark identifying progress in the post-industrial economy, in ‘quarters’ is related to these issues and clearly to improvements, either as a cause or consequence, to the built environment (Bell and Jayne, 2003; 126). The *Museumsquartier* in Wien, the *Viaduct des Arts* in Paris, or the *Plataforma das Artes e da Criatividade* in Guimarães are examples of this. In these ‘quarters’ the enjoyment of a high-quality outdoor environment is crucial due to the focus creative industries place on «aestheticised high-value added consumer products and image-led advertising and marketing expertise» (idem; 132).

High-quality public spaces, good design, relate to the notion of ‘added value’ of public spaces. The basic assumption here is that well-designed and well-managed, mixed-use and easily accessible spaces, «can increase civic pride, improve social cohesion, reduce fear of crime, reduce crime, relatively higher levels of physical and mental health, more efficient land footprint, reduced dependence on the car, reduced waste, improved sense of well-being and belonging, vitality» (English Partnerships and the Housing Corporation, 2007; 109). These are the attributes that surpass the physical features of the space to encompass more immaterial aspects of public life; that give the space more than the mere accomplishment of a functional purpose.

It is believed that urban design should not be reduced to any single metric because it is «part art, social science, political theory, engineering, geography, and economics» (Calthorpe, 2011; 17). Good design «requires a collaborative, creative, inclusive, process of problem solving and innovation - embracing sustainability, architecture, place making, public realm, landscape, and infrastructure» (2009, 6). It is however of utmost importance that the production of high-quality design does not sacrifice the practical feasibility of a proposal (Pressman, 2006; 11). It is the valorisation and further integration of all these vectors that allows an urban design proposal to reach a ‘beyond the expected’ dimension and, through this, add value to the space making it distinctive in its identity and competitive in its attractiveness.

Poor urban design entails the undermining of amenities delivered through planning gain; the imposition of costs which later have to be borne by public and private stakeholders; at the larger spatial scale, the limitation of investment opportunities; and the reduction of the extent to which and the speed at which the regenerative impacts of development ripple through local economies (CABE 2001; 77). Contrary to good urban design, poorly designed spaces «are likely to incur higher costs to individuals and society in the long run» (English Partnerships and the Housing Corporation, 2007; 103).

3.2.1. Pedestrianisation

Throughout the 20th century there was a permanent adaptation of cities to cars which has suppressed the traditional multifunctional character of streets and other public spaces (Menezes and Farinha, 1983; 6; 9), where pedestrian circulation was dominant and, in many cases, the own essence of a space. In line with this perspective, Hertzberger (2009; 48-49) mentions the increase and prioritisation of motorised traffic as one of the reasons for «the devaluation of the street concept as a communal living room». Gordon Cullen (1961; 57) also argues that the excessive valorisation of car access is the main cause for the deterioration of the living conditions in city centres. Throughout the 20th century pre-existing public spaces were «sacrificed to comprehensive redevelopment and road improvements» (Evans, 1997; 88).

The adaptation of cities to cars brought clear benefits for the commodity of transportation and efficiency in the exchange of goods. Nevertheless, the investment made in accommodating cars within cities has been disproportional to the investment made in combining it with a basal need of urbanites: to move on foot and to enjoy the outdoor spaces of a city. Cities have paid a high price for this — the 'voracious' adaptation of cities to cars has had dramatic consequences for public spaces, urban life, social interaction, people's welfare and health, and to the own meaning of 'city'.

Several reasons may be pointed out as contributing to the loss of importance of urban centres and, somewhat intrinsically, of pedestrians. Tolley, Lumsdon et al. (2001; 307) refer that «as trips lengthen and urban areas sprawl, so has the perception grown that walking is an inferior mode of transport in relation to the car». According to Evans (1997; 10; 11; 88; 89), there are three main causes for the progressive deterioration of the physical layout of urban centres: (1) the comprehensive restructuring of town centres for retailing and office uses in the 1960s and 1970s which started encouraging the proliferation of enclosed shopping centres, office complexes, and pedestrian-vehicular segregation; (2) the primary concern of landowners, developers, architects and engineers in designing buildings, structures and roads during the 1960s and 1970s, which has prioritised rapid business expansions and rising car ownership at the expense of the enhancement of public spaces and buildings; and (3) cuts in government grants to local authorities and expenditure controls during the 1980s which have deteriorated the 'abandon' of city centres further because local authorities were forced to cut maintenance budgets or sell-off public spaces.

Beyond this, Gehl (2010; 3) states that «dominant planning ideologies - modernism in particular - have specifically put a low priority on public space, pedestrianism and the role of city space as a meeting place for urban dwellers». The philosophy of the modernist movement has globally been marked by the Universalist welfare state and the machinery for urban planning, approaching housing, work, recreation, and traffic (Healey, Cameron et al., 1995; 5). The functional zoning advocated by the modernist movement, by separating residential, commercial, cultural, industrial uses, etc., led to the reliance on private car for transit between areas of activity, and the pedestrian-vehicular segregation — the main causes for the dependence on private transportation, and its valorisation over public transport and pedestrian circulation. Indeed, it has been long realised that functional zoning has had a negative influence on urban life (Krier 1979; 78). As Calthorpe (2011; 46) refers, our developments and zoning laws «isolate people and activities in an inefficient network of congestion and pollution».

Krier (2006; 27) refers that «the scaleless uniformity, aesthetic poverty, and general vulgarity of contemporary settlements are not due to a reduced social intercourse but to a global metaphysical crisis» and that the «functional zoning is the instrument of this mental and environmental catastrophe». The well-intentioned ideas of modernists were effectively translated into the creation of «disaster after disaster in a surreal and growing detachment of culture from real life» (Thwaites, Porta et al., 2007; 13).

Faced to the evidence of its adverse environmental and social consequences, a consensus has been reached that rising demand for car travel must be curbed and that this should underlie the spatial rehabilitation of urban central areas (Marques-Clarke, 1998; 26). The contemporary city has been placing a significant emphasis on the quality of the urban environment as a whole, much of it based on a concern for people's welfare and environmental responsibility (Healey, Cameron et al., 1995; 7). Within this scope, the pedestrianisation of public spaces, i.e. the «removal of vehicles from an urban area allowing free access to people on foot» (Tunstall, 2006; 355), plays a vital role (Figure 8).

Fig.8 – A traffic street converted for pedestrian use. Brighton, United Kingdom. Source: João Cortesão, 2011.

Since the mid-1980s there has been a reduction or elimination of car access to large parts of urban areas (1996, 197), especially in city centres. Such as once the ease with which the means of transportation was the driving force of city building, nowadays pedestrianisation seems to have come to the centre of discussion on urban development and, more particularly, urban design. There is a new life in many city centres, and their public places, ultimately drawing people back to the city (Calthorpe, 2011; 13). Cities have recognised the need of emphasising «the vitality of their cores and the qualities of urban living» (Hughes, 1999; 120).

This has been evidenced, for instance, with the number of documents developed in the past few decades which give the pedestrian rights a considerable importance such as the European Parliament's European Chart for pedestrian rights - Planning Policy Statement 26 (1988), the European Commission's European Sustainable Cities report (1996), the Congress for the New Urbanism's Charter of the New Urbanism (2001), the European Union Council's Leipzig Charter (2007), the UN-

Habitat's Planning Sustainable Cities report on Human Settlements (2009), or the Academy of Urbanism's Freiburg Charter for Sustainable Urbanism (2011).

Motivated by the quality of the public realm and also by the need for improving the air quality of city centre, a number of actions targeted at reducing and even restricting access and circulation of motorised private vehicles in city centres, such as the London Congestion Charge, have also been created in latest years. Raising awareness campaigns have as well been undertaken, being able, for instance, of engaging a growing number of cities celebrating the European Day without cars. This does not mean that cars are to be banned from cities or that these are inherently destroyers of urban quality of life. As Jane Jacobs (1961; 353) argues, the point is more «how much of the destruction wrought by automobiles on cities is really a response to transportation and traffic needs, and how much of it is owing to sheer disrespect for other city needs, uses, and functions».

According to Menezes e Farinha (1983; 12), the pedestrianisation of public spaces offers a range of benefits for urban areas:

- Facilitation and enhancement of the attractiveness of walking;
- Enhancement of safety by eliminating conflicts between vehicles and pedestrians;
- Regularization of traffic management systems and reduction of traffic jams;
- Contribution for the reduction of the energy spent in transport systems;
- Preservation and increase of the attractiveness of historical and symbolic places;
- Reduction of sound and air pollution.

In environmental terms, the benefits of pedestrianising relate to a reduced energy consumption and generation of waste related to transport systems and, thus, less pressure placed on natural resources as well as better air conditions. This can help meeting important goals of the sustainable city such as the mitigation of the urban environmental problems or the control of their sources.

In social terms, pedestrian public spaces can contribute to improving the quality of life and health of people living and working in urban centres, and to ensuring that cities fulfil their central role for civilised life. As Carr, Francis et al. (1995; 3; 19) state, «public space is the stage upon which the drama of communal life unfolds» and that therefore it should be responsive, democratic, and meaningful. These are qualities that people should be able to experience. Creating high-quality pedestrian public spaces is a vital way of delivering to people the possibility to be involved in such experiences. In addition, it is vital to recognise that society is a resource and that the good design of cities helps generating social cohesion (Edwards, 2004; 9).

Another aspect is an increased sense of safety since the presence of people engaged in different activities in public spaces can dissuade/prevent anti-social behaviours, and reduce/control crime — natural surveillance. This term relates to keeping public spaces safe through design. The improvement of safety and security through environmental design has been actually practised by humans for thousands of years (Marques-Clarke, 1998; 31). High-quality, i.e. well-designed spaces, can help fostering a sense of safety by maximising natural surveillance, defensible space and community interaction which may however have to be complemented with neighbourhood watch, neighbourhood wardens and community support officers (English Partnerships and the Housing Corporation, 2007; 187). Underused public spaces combined with low-quality design standards and underused public transports, in turn, encourage more criminal activity (Evans, 1997; 91). People might avoid using public spaces, especially at night, if they are afraid of being burgled or attacked.

Beyond environmental and social benefits, pedestrian public spaces have also positive impacts on economic terms. The creation of high-quality pedestrian public spaces, as well as high-quality buildings, can help attracting people back into the city, «people who work, consume and run businesses that generate jobs and wealth» (Jones and Evans, 2008; 57). While buildings provide homes, offices, shops, industries, or leisure, public spaces provide vitality, light, amenity, room to travel and room to rest (Ritchie and Thomas, 2009; 4).

3.2.2. Outdoor thermal comfort

Based on the assumption that man does not possess many natural controls to cope with an unfriendly climate (Olgyay and Olgyay, 1957; 19), the last decades have brought a growing awareness of outdoor thermal comfort as a key element for promoting activity and social interaction in public spaces. Outdoor thermal comfort is then a fundamental attribute of pedestrian public spaces.

An extensive body of research on thermal comfort is available since the 1960's, initially for military and aerospace applications (Jones, 2001; 112). Ever since, there has been a growing number of researches on this subject in various climates across the globe and according to several approaches. The significant amount of studies on this subject has brought different definitions for thermal comfort. All these definitions, however, «start from criteria of the energy balance between the human body and its environment» (Gomez, Jabaloyes et al., 2004; 95). Since this is a complex subject out of the scope of this research, thermal comfort should be herewith understood as «that condition of mind which expresses satisfaction with the thermal environment» (ISO, 2005; 10). This definition is provided by the international Standard ISO 7730, one of the main references for thermal comfort studies.

Thermal comfort is a complex concept because it is influenced by several different factors. Air temperature, air humidity, solar radiation, mean radiant temperature, wind speed, the clothing worn on the body, and the activity of the person can be pointed out as the main factors influencing thermal comfort (Jones, 2001; 113). These factors can vary significantly in space and time so that any attempt of standardization can only be developed for «specific, carefully circumscribed conditions without using a model» (*ibid.*).

The different needs of users and eventual changes in the factors affecting the provision of such space should therefore be taken into consideration (Handley and Carter, 2006b; 58). For example, a study undertaken by Aggelakoudis and Athanasiou (2005; 268) has shown that thermal comfort actually differs from males and females, and from overweight, normal and underweight people. Different people perceive the thermal environment in different ways. Due to these differences «it is impossible to specify a thermal environment that will satisfy everybody» and «there will always be a percentage dissatisfied occupants» (ISO, 2005; 10). It follows that thermal comfort is defined by objective/physical and subjective/perceptive parameters.

According to Taylor e Guthrie (2008; 7), the physical and perceptive parameters defining thermal comfort can be understood independently: the former parameters are related to thermal sensation which is the «objective response to an environment as a function of environmental variables»; the latter parameters constitute «psychological factors in addition to the thermal sensation».

Thermal sensation refers to what people feel at the moment, how they perceive a given thermal environment. It constitutes a response given by the direct interpretation of the climatic conditions at a given moment. Thermal sensation is then a holistic experience much more complex than the current physiological basis of comfort standards is able to state (Nikolopoulou, 1998; 69). Thermal sensation is related to the thermal balance of the body as a whole, which is influenced by activity and clothing levels as well as the climatic variables (ISO, 2005; V). Nevertheless, thermal dissatisfaction can also result from «unwanted cooling or heating of one particular part of the body», known as local discomfort (*idem*, 6). Thermal sensation is often graded along the ASHRAE seven-point thermal sensation scale. Although the evaluation of thermal sensation is graded using the categories cold, cool, slightly cool, neutral, slightly warm, warm, and hot, it requires subjective evaluation (ASHRAE, 2010; 3). Psychological, subjective, factors together with thermal sensation define therefore thermal comfort.

As shown in Figure 9, the definition of thermal comfort can be seen as composed of a group of objective parameters (thermal sensation) and to which a group of psychological, therefore subjective, parameters are added. This is why thermal comfort varies considerably from person to person, becoming much more complex to predict than thermal sensation.

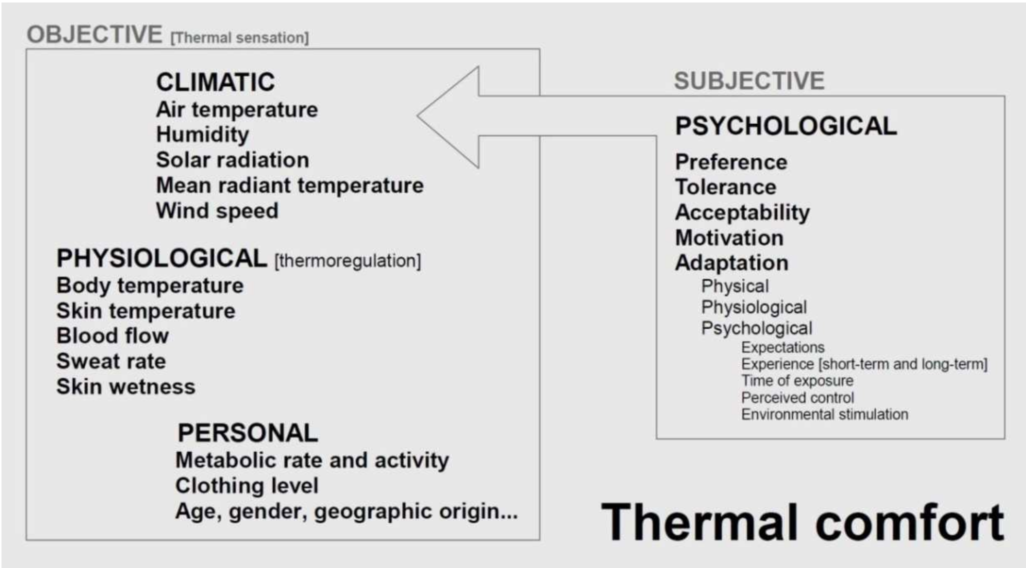


Fig.9 – Parameters influencing thermal comfort. Based on Taylor and Guthrie (2008)

Figure 9 shows that within the objective group there are the categories of climatic, physiological and personal parameters. The climatic parameters directly affect thermal comfort and the extent to which they do it can be objectively measured through a climatic monitoring. Also the personal parameters, i.e. metabolic rate, clothing and activity level can be known through several means. ISO 7730 and ASHRAE 55 standards give a comprehensive guidance on these topics.

The subjective group encompasses variables that cannot be measured nor compared because they relate to highly variable psychological issues. Therefore, empirical data from field surveys on the subjective human parameter in outdoor spaces can provide a broader perspective from which to view thermal comfort in public urban spaces (Nikolopoulou and Lykoudis, 2006; 1455; 1456). It is possible to obtain average votes by asking people specific questions which are then rated on a thermal comfort scale but which are at best an approximation to reality. It follows that in thermal comfort studies «the average response of a group is more significant than the individual response, and the relative response to different environmental factors is more significant than the absolute response in a given combination of these factors» (Givoni, 1998; 8).

3.2.2.1. Climatic parameters

Based on ISO 7726 (ISO, 2001b; 2-45) the main five climatic parameters commonly considered as characterising a thermal environment and therefore influencing thermal comfort both indoors and outdoors are air temperature, relative humidity, direct solar radiation, wind speed, and mean radiant temperature. The influence of these variables on a space's microclimate is commonly determined at a height of 1.1 meters above the ground. This corresponds to the average height of a standing adults' centre of gravity (Gulyas, Unger et al., 2006; 1715). The upper limit for the evaluation of these influences should be two meters above the ground level since this is considered to be «the most effective atmospheric level on the human activities» (Yilmaz, Toy et al., 2007; 290).

Air temperature

Air temperature (T_a) is the temperature of the air surrounding the occupant (ASHRAE, 2010; 3) and it can be expressed in Kelvins (K) or degrees Celsius (°C) for determining heat transfer by convection between the skin and the environment. Increasing or decreasing T_a directly results in a change in thermal sensation, and though humidity and wind speed can modify the magnitude of the temperature effect they do not change its direction (Givoni, 1998; 15).

Relative humidity

Relative humidity (RH) relates to the water vapour content in air in relation to the maximum amount it could hold at a given temperature (ISO, 1998; 3) and it is expressed in percentage (%). The most direct impact air humidity has on human thermal comfort is on the «environmental potential for evaporation and the way by which the body adapts to changes in the evaporative potential» (Givoni, 1998; 15).

Only for extreme values of RH, either very high (dampness) or very low (dryness), and often in conjugation with certain T_a conditions enhancing its effect, thermal sensation of people is affected by this variable (Nikolopoulou and Lykoudis, 2006; 1459). For outdoor spaces, comfort for RH can be established within a range between 30 % and 65 % (Tojo, 2007; 175). For RH below 30 % people will experience dryness and above 65 % dampness. RH values of 20 %, 40 % and 80 % correspond to very dry, average and humid conditions (Nikolopoulou, 2004; 4). High levels of dryness can impact the human body by drying the skin and mucous surfaces which can lead to discomfort by dry nose, throat, eyes, and skin (ASHRAE, 2005; 8.12). In turn, at high levels of dampness discomfort is raised by excessive skin moisture.

Tolerance to RH must be regarded as the response of the human body to variable combinations of RH, T_a and wind speed. In low humidity environments the sweat evaporates within the skin pores, through a small fraction of the skin area, whilst in environments with high humidity, where evaporative capacity decreases, the sweat is spread over a larger skin area in order to maintain the required evaporation rate (Givoni, 1998; 5-6). In general, the lower the T_a or the higher the wind speed, higher values of RH can be more tolerated by people. Determining the exact range of RH people can tolerate is also a function of climate, place, season, the materials constituting the space, and personal variables of the space users (Lstiburek, 2002; 3).

Direct solar radiation

Direct solar radiation ($K\downarrow$) is «the total radiant flux received by unit area of a given surface» (Oke, 1987; 402). It is taken into account for determining the radiant heat exchange between the human body and the environment and it is usually expressed in Watts per square meter (W/m^2). $K\downarrow$ can be responsible for peak discomfort values (Ali-Toudert and Mayer, 2007b; 235). Indeed, the radiative apportionment arrived at a surface is probably the most significant influence on its microclimate (Oke, 1987; 25).

According to Nikolopoulou (2004; 4), $K\downarrow$ values of 100 W/m^2 correspond to low insolation (e.g. overcast or late sunny afternoon), 400 W/m^2 to average insolation (e.g. partly cloudy or winter clear day), and 800 W/m^2 to high insolation (e.g. summer clear sky conditions). Obviously, clear weather will lead to large differences in exposure to $K\downarrow$ whereas overcast weather will lead to smaller differences (Geiger, 1950; 218).

Wind speed

Wind speed (*W*) describes «the rate of air movement at a point, without regard to direction» (ASHRAE, 2010; 2) measured and it is usually expressed in meters per second (m/s). *W* is taken into account when determining heat transfer by convection and evaporation between the body and the environment. Increasing *W* can increase heat loss under higher temperature conditions, especially when the mean radiant temperature is high and T_a is low (ISO, 2005; 45-46).

According to Givoni (1998; 17-18), at T_a below 33 °C the increase of *W* can reduce the warmth sensation by increasing convective heat loss from the body and lowering skin temperature; at T_a between 33 °C and 37 °C, *W* has not a significant effect on thermal sensation though under given RH values and clothing levels it can influence discomfort from excessive skin wetness; finally, at T_a above 37 °C increased *W* can actually increase thermal sensation of heat though it can still reduce skin wetness.

Relatively to the mechanical effects, *W* of 0.1 m/s, 1 m/s, 3 m/s and 5 m/s correspond to stale conditions, slight breeze, and strong wind respectively, and above 5 m/s the mechanical effects of wind are more important than the thermal effects (Nikolopoulou, 2004; 4). Discomfort due to higher *W* may also result from disturbances in walking or blowing of dust and leaves (Givoni, 1998; 295). According to Oke (1987; 272), pedestrians find wind unpleasant at a speed of about 5 m/s, by disturbing hair and causing clothing to flap; uncomfortable at a speed of about 10 m/s, by picking-up dust and litter; and potentially dangerous at a speed of around 20 m/s.

At T_a values above 10 °C, provided there are adaptive opportunities, for users sitting for short periods of time wind will be acceptable as long as it does not exceed a mean value of 5 m/s during no longer than 6 % of the permanence time at the space; for people sitting for long periods of time the mean value of 5 m/s should not be exceeded for more than 0.1 % of the permanence time (Nikolopoulou, 2004; 7). Depending on climate, the same *W* value can be considered desirable or undesirable — in cold climates «wind will almost always decrease outdoor comfort conditions, whereas the opposite is the case of hot climates» (*idem*; 7).

Mean radiant temperature

Mean radiant temperature (MRT) is an «average of all the surface temperatures of the enclosure, weighted by the proportion of the body surface area facing each particular surface» (Spagnolo and de Dear, 2003; 725). It is usually expressed in Kelvins (K) or degrees Celsius (°C). MRT is used to evaluate the radiant heat exchange between the human body and the environment, as well as to the effect of direct contact between the body and a given surface. ISO 7726 defines the MRT as «the uniform temperature of an imaginary enclosure in which radiant transfer from the human body is equal to the radiant heat transfer in the actual non-uniform enclosure» (ISO, 2001b; 2). MRT «can be measured by instruments which allow the generally heterogeneous radiation from the walls of an actual enclosure to be "integrated" into a mean value» (Standardization, 2001; 2).

By the time the literature review was undertaken it was not possible to find any reference about a range of admissible comfort range of values for MRT. However, in a study undertaken by Forwood et al. (*apud* Spagnolo and Dear, 2003; 724) on outdoor thermal comfort in Sydney most people reported to feel comfortable within a MRT range of 24 °C to 30 °C.

For studies developed around the thermal performance of outdoor public spaces and the way how this impacts people's thermal comfort, it may worth further knowing surface temperatures. Surface temperature influences mean radiant temperature — the properties of surfaces govern the partitioning and conversion of heat, mass and momentum (Voogt and Oke, 1997; 1117; 1118). It is important to point out in this context that although surface temperature shows a similar spatial and temporal pattern to that of air temperature, such correspondence is not exact since the former is more directly related to the microclimatic conditions, whilst the latter is influenced by the temperature of the surrounding surfaces and by larger scale atmospheric variables as well (Arnfield, 2003; 5).

3.2.2.2. Physiologic parameters (thermoregulation)

In physiologic terms, thermal comfort can be seen as «the situation in which the human body makes the least effort to maintain its energy balance with its surroundings» (Alexandri, 2005; 431; 432), usually related to a constant deep-body temperature around 36.5 to 37 °C. The feeling of thermal comfort is then optimal «when the production of internal heat is equal to the thermal losses from the body» (Goulding and Lewis, 1997; 11). This equals saying that since the human body cannot store heat indefinitely, the production of heat by the body is equivalent to the heat losses to the environment so that the deep-body's temperature can be maintained constant.

The main physiological parameters in stake here are body temperature, skin temperature, blood flow, sweat rate, skin wetness. These physiological mechanisms govern the production of metabolic heat or the loss of heat by radiation, conduction and convection — thermoregulation (Oke, 1987; 192). According to Olgyay (1963; 16), depending on the variations in the thermal conditions, radiation accounts for about 2/5 of the heat loss of the body, convection for 2/5, and evaporation for 1/5. It is however important to bear in mind that in real situations, i.e. in non-artificially controlled environments, a thermal steady-state condition of the body is hardly achieved even when people remain several hours in outdoor spaces. Figure 10 synthesises the main heat exchange relationships between a man and its surrounding environment.

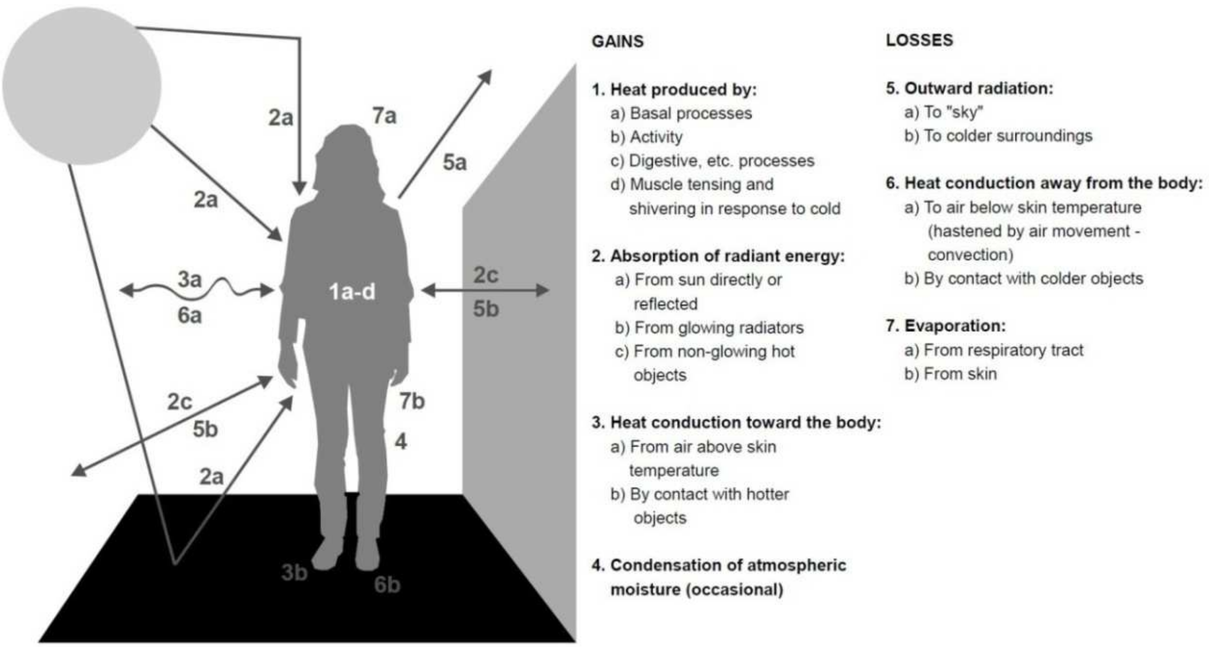


Fig.10 – Heat exchange between man and surrounding environment. Adapted from Olgyay (1963; 16)

If the body's thermal balance is near zero, then it can be considered that a person experiences thermal comfort (Gaitani, Mihalakakou et al., 2007; 319); if the heat losses surpass the heat gains, the body will suffer a decrease of temperature and the mechanisms for reducing heat loss, such as the control of blood vessels (vasoconstriction), come into action (Oke, 1987; 206-208) to prevent an excessive decrease of temperature which can culminate with hypothermia and eventual death; if the heat gains exceed the heat losses, the body's temperature will rise and therefore the mechanisms to increase heat losses will be activated, again through for instance; control of blood vessels (vasodilatation), changes in posture or, ultimately, sweating or panting in order to increase evaporative cooling (*idem*; 221) in order to prevent excessively high body temperature which may culminate with hyperthermia and eventual death. Whenever the physiological responses of the organism cannot offset the temperature shift thermal discomfort is experienced.

The thermoregulatory mechanisms can be either voluntary or involuntary. The voluntary mechanisms are related to behavioural responses and the involuntary mechanisms by physiological responses to a given thermal environment. According to Oke (1987; 194), the most common behavioural responses of thermoregulation in humans are: movement, a common capacity of all animals according to which they can choose to place themselves in locations with the least thermal stress possible; posture, through which animals can control the portion and nature of their surface involved in energy exchanges with the environment, e.g. curling-up or stretching-out; ingestion of warm or cold fluids able to affect their body's heat content; and construction of shelter in order to protect themselves from the environment.

3.2.2.3. Personal parameters

Many non-physical factors are expected to affect comfort perceptions (Jones, 2001; 119; 120). These non-physical factors are introduced by personal parameters such as metabolic rate and activity level, clothing level, age, gender, geographical origin, or health conditions:

Metabolic rate

Metabolic rate (M*) is the amount of energy produced by the human body (converting food into heat by inhalation of oxygen) per unit time and expressed in watt per square meter of body surface (Gaitani, Mihalakakou et al., 2007; 318) or often in Met units (1 Met = 58 W/m^2). Except for sedentary activities, M* is likely to vary according to the individual performing the task and the circumstances under which the task is performed (2010, 17). This will significantly influence the body's 'perception' of the surrounding thermal environment.

In one same space it is possible to find a wide range of activities with significantly different associated M*. This is true for both indoor and outdoor spaces. For instance, for indoor spaces a clear example, offered by ASHRAE 55-2010 standard (2010; 17) is a restaurant, where M* of customers and servers can be quite different due to their different activity levels. For outdoor spaces these differences can vary to an even wider extent as here the activities likely to occur can be much more diverse and involve a higher number of people.

Clothing level

Clothing level designates «a unit used to express the thermal insulation provided by garments and clothing ensembles» (*idem*; 3) which can help to adjust the body to the dominant thermal conditions. This means preventing heat losses in cold climates and excessive heat gains in hot climates, in a proportion dependent upon the clothing thickness and permeability to air, as well as on air humidity and wind speed (Oke, 1987; 225-226). As a general notion it can be said that the heat loss from exposed parts of the body is greatly increased with higher air speeds while there is almost no increase for parts that are heavily insulated (Jones, 2001; 116).

The clothing ensemble worn by an individual must be valorised because ensembles may vary significantly within the same space. According to the ASHRAE 55 standard (2010; 20), variability in clothing levels is due to (1) non-thermal reasons, such as clothing style preferences for both men and women or clothing style expected for an individual to wear for a given task; and to (2) thermal reasons, related to the adaptation to individual differences in response to the thermal environment. M*, age, gender, thermal expectation or personal clothing style can play a significant role in an individual's clothing ensemble and therefore on the level of thermal insulation of the body.

Different levels of thermal insulation lead to different thermal sensations and thermal comfort responses. It is possible to find in a same space people wearing clothing ensembles that the large majority of users would consider uncomfortable due to a low or high thermal insulation provided, depending on the season. For instance, it is not rare to find in winter people, especially adolescents, wearing clothing ensembles that the majority of people would only wear in summer.

Age

Age can give a good insight on the way how the appreciation of thermal comfort is subjected to several different interpretations. A research conducted by Krüger and Rossi (2011; 695) showed that for male subjects under heat conditions «younger people showed more sensitivity to heat than older subjects, when compared to cool conditions» and for female subjects «differences were even larger for hot conditions». When compared to a younger individual, older people have a lower M*. Alternative ways of compensating the lower metabolic heat come forward to maintain comfort, such as increasing the clothing levels. Field surveys undertaken by Wilson, Nicol et al. (2008; 38) have shown that people in the >50 years age band were significantly warmer at temperatures below ~15 °C, which might be explained by their use of heavier clothing in cooler conditions — different clothing ensembles lead to different levels of thermal insulation of the body.

A reduced M* and a decrease on the body's ability to 'perceive' thermal conditions and to trigger the physiological mechanisms to maintain the body's heat budget are associated to the advance in age. Older subjects are less sensitive than younger ones to thermal conditions, the loss of thermal sensitivity, correlate with a lower sweat rate, has a local (skin) cause due to «a weaker signal from the periphery to the regulatory centers, suggesting skin aging is the cause of the decrease» (Dufour and Candas, 2007; 25). Both in indoor and outdoor spaces it should be kept in mind that the elderly is in general less capable of adapting to changes in the ambient temperature (Hwang and Chen, 2010; 235) as well as to extreme weather events such as heat or cold waves.

There is a wide range of other personal parameters beyond M* and activity level, clothing level, and age, such as for instance gender, geographical origin, or health conditions. Knez and Thorsson (2006; 259), for example, refer that «we may expect different environment-related behavioural, emotional and cognitive consequences related to thermal comfort assessments of outdoor environments for persons living in different cultures with different environment related attitudes/ schemata». Gehl (2011; 179-180) states that «northern Europeans automatically choose a place in the sun, even at temperatures at which Italians, for example, would have sought the shade long ago».

The variability of personal parameters influencing thermal comfort sheds light on the importance of knowing as much as possible the potential users of a space. In this context, Mean and Tims (2005; 27) have come up with the notion that «people's perceptions, use and navigation of public space cut across these conventional categorisations». It might therefore be important to recognise to utmost the whole diversity of ways in which people can interact with the space under consideration.

3.2.2.4. Psychological parameters

For a same space and time two individuals might feel more or less comfortable depending on psychological parameters such as thermal preference, thermal tolerance, thermal acceptability, and thermal adaptation, as well as expectations, motivation, experience (short-term and long-term), time of exposure, perceived control, type of environment, or environmental stimulation:

Thermal preference

Thermal preference reflects the desire for ideal conditions. It is not a response to the actual thermal conditions of a space but rather a reflection of people's desires, information, or geographical origin which is traduced into a preference between warmer or cooler conditions or for a particular response on a comfort scale.

Thermal tolerance

Thermal tolerance can be defined as the individual's limit beyond which thermal stress takes place. This limit is determined by the extent to which people know or understand the cause of thermal stress. This definition might however vary according to the specificity of the study.

Thermal acceptability

Thermal acceptability can be regarded as the personal judgement an individual makes to describe the extent to which the experienced thermal conditions are acceptable or unacceptable. This definition might however vary according to the specificity of the study.

Motivation

Motivation relates to the reason why people go to a space. For someone at site by its own will (e.g. for meeting a friend or shopping) the microclimate of the space will be more tolerable than for an individual obliged to be at site (e.g. working or waiting for someone for professional reasons). The reason is that people at site by their own choice have decided to expose themselves to its microclimatic conditions and know they can leave the space soon as the exposure to such thermal environment becomes a source of discomfort (Nikolopoulou and Lykoudis, 2006; 1467).

Thermal adaptation

Thermal adaptation can be physical, physiological and psychological. Physical adaptation refers to all changes people make in order to adjust to the environment or alter the environment to their needs. According to Nikolopoulou and Lykoudis (2006; 1464) and Nikolopoulou (1998; 58; 69), physical adaptation processes can be divided into two classes: 'reactive' and 'interactive'. The 'reactive' processes refer only to personal adjustments such as clothing level (helping to adapt to different temperature conditions), induced metabolic rate (e.g. rubbing hands, shivering or consumption of cool or warm drinks), or changes in the spatial position (move between a place more or less exposed to direct solar radiation, wind, etc.). In turn, 'interactive' processes relate to the interaction between an individual and the space according to which the former alters the latter in order to improve its comfort conditions (e.g. as opening/closing a parasol or an awning, switching off/on a radiator, opening/closing a window).

Physiological adaptation can be seen as the gradual decrease of the organism's response to repeated exposure to a stimulus which, in the context of thermal comfort, can involve «all the processes which people go through to improve the fit between the environment and their requirements» (*idem*, 58).

Finally, the main point about psychological adaptation is that «the human response to a physical stimulus is not in direct relationship to its magnitude, but depends on the 'information' that people have for a particular situation» (*idem*, 69). Psychological adaptation involves different, although interrelated, parameters such as:

- Expectations, which are related to what people think the environment should be like, rather than what it actually is (*idem*, 70). This is why, for example, in autumn cool temperatures are seen as uncomfortable due to the proximity of summer and, in spring, the same cool temperatures are seen as more comfortable than in autumn due to the proximity of winter. People's perceptions with respect to the preceding season are «desensitised by their perception of their short-term (hours to days) thermal history» (Spagnolo and de Dear, 2003; 736).
- Experience, which is about the amount of information people have in relation to a particular thermal situation or space (Nikolopoulou, 1998; 71). This can refer to a familiar situation that has been experienced long before (long-term experience) or immediately before (short-term experience). Long-term experience might refer for instance the expected temperatures in summer, or to a particular exceptional climatic period in the year. Short-term experience is related to actions such as leaving an air-conditioned indoor space or a car. The ASHRAE standard 55 refers that «the effect of prior exposure or activity may affect comfort perceptions for approximately one hour» (2010; 20).
- Time of exposure to the climatic conditions, which is related to the time of permanence in a space. This relates to the idea that «when a person is exposed to discomfort [...] knowing that it is only temporary, no significant dissatisfaction is caused» and that «people can therefore modify the time they spend outside, according to their needs» (Nikolopoulou, 1998; 72).
- Perceived control, which is basically the individual notion of the extent to which one can control the environment. People possessing a good degree of control over a source of discomfort «tolerate wide variations, are less annoyed by it, and the negative emotional responses are greatly reduced» (Nikolopoulou and Steemers, 2003; 97). This might involve, for instance, opening a parasol, moving a wind-break, closing an awning, or moving a chair.
- Environmental stimulation. People «see the external environment with the fresh air, the sun and the wind as invigorating stimulation for the senses» (*idem*, 99). The underlying notion here is that «people prefer varying ambient conditions, provided the stressor is understood, and they have adequate objective and subjective resources of meeting the challenge» (Nikolopoulou, 1998; 74).

These parameters give thermal comfort its subjectivity and find in each individual the stage for creating an uncountable amount of different thermal comfort perceptions. In the ASHRAE standard 55 (2010; 4) it is mentioned that «because there are large variations, both physiologically and psychologically, from person to person, it is difficult to satisfy everyone in a space» as «the environmental conditions required for comfort are not the same for everyone».

Faced with the need of finding some standardization in the thermo-physiological parameters affecting thermal comfort, several mathematical models predicting the body's physiological responses (as functions of climatic, metabolic/activity and clothing variables) have been developed and validated in the last decades. These models have been focusing ways of estimating the energy balance of the human body in different environments by combining meteorological and thermo-physiological parameters (Gulyas, Unger et al., 2006; 1713; 1715).

The large majority of thermal comfort models existing nowadays were developed under the consideration of sedentary physical activities, typical of office work. However, in real situations «thermal steady state is never reached even when people spend several hours outdoors», in such ways that steady state comfort models are not able of providing realistic assessments in non-uniform and dynamic environments (Höppe, 2002; 663). The same can be said to for controlled climatic chamber studies that though presenting the advantage of controlling all variables affecting the thermal balance between an individual and its surroundings, do not provide experiments related to real world situations, i.e. to the "experiential realism" (Aggelakoudis and Athanasiou, 2005; 263).

In any case, these models are however at best only an approximation of reality (Jones, 2001; 114). Moreover, as Nikolopoulou (2004; 3) refers, «a purely physiological approach is inadequate to characterise thermal comfort conditions outdoors». The combination of physical microclimatic parameters, past thermal experiences, and expectations in different seasons may, for instance, affect people's thermal preferences in a more complex way than a thermal predictive model can handle (Lin, Dear et al., 2011; 311). Thermal comfort predictive indices are «still facing the critical problem of interpretation caused by the intervention of the human factor» (Tseliou, Tsiros et al., 2010; 1346).

Beyond thermal predictive models and indices, there are also International Standards which address thermal comfort evaluations, such as the ISO 7730 — Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria; ISO 7726 — Instruments for measuring physical quantities; ISO 10551 — Assessment of the influence of the thermal environment using subjective judgement scales; ASHRAE Standard 55 — Thermal Environmental Conditions for Human Occupancy.

Judgement scales are other means of assessing people's thermal comfort evaluations which find in ISO 10551 the main reference document. Judgment scales present the advantage of being direct in the results they provide in such ways that it is not necessary to interpret a physiological or psychological quantity (McIntyre 1976; 296). However, «basic difficulties are encountered in any area which involves the use of language» (ISO, 2001a; 2). Therefore, the usual procedure is to directly ask the interviewee to rate his vote to one of several descriptions (points) that constitute a category scale (McIntyre 1976; 295). A widely known judgement scale is the ASHRAE seven-point thermal sensation scale.

Predictive models and indices, International Standards and judgment scales are mainly limited to indoor thermal comfort. If on one hand there is currently a considerable volume of researches, standards and regulations addressing indoor thermal comfort, there is less understanding of this subject outdoors (Handley and Carter, 2006b; 58). It was not till recently that the first studies addressing the relationships between outdoor public spaces, thermal comfort and human activity from an urban planning and design point of view were developed.

The main differences between indoor and outdoor thermal comfort[1] are that, contrarily to indoor spaces, in outdoor open spaces «there is less human control; the climatic conditions display more variability; the spaces themselves are more diverse, and they are used for a wider range of purposes» (Wilson, Nicol et al., 2008; 36). Nagara, Shimoda et al. (1996; 497) state that thermal environment of

[1] It should be kept in mind that the interaction between the necessary conditions for better microclimates of outdoor and indoor spaces can be intricate — a good option for an outdoor microclimatic does not necessarily mean a good option for an indoor space and vice-versa.

outdoor spaces is not of a uniform nature as indoor spaces. This statement is corroborated by Ochoa, Marincic et al. (2006; 3) which state that the climatic variables are often strictly controlled or very stable indoors, while highly variable outdoors. Tseliou, Tsiros et al. (2010; 1346) add that «the correspondence between the physiological response and thermal comfort is markedly different when we move outdoors». It is also noteworthy that while in outdoor spaces people's permanence is in the range of minutes, in indoor spaces is in the range of several hours (Höppe, 2002; 362).

Current urban development at both the sustainable city and pedestrianisation levels should not neglect the importance outdoor thermal comfort, especially in a climate change context. The built environment and the public realm would benefit from a more conscientious relationship between urban design, the expected impacts of climate change on urban areas, and outdoor thermal comfort. Current urban design is seen in this research as committed with the creation of high-quality public spaces, encompassing a wide range of issues such as robustness, accessibility, security, safety, microclimate, quality of the public realm, character and identity, or adaptability. Alongside other compositional principles assigning a space a high-quality standard, the issues around the microclimate of public spaces and the impacts this may have on thermal comfort outdoors and indoors as well as on the energy efficiency of buildings should start being the driving force of public space projects.

Not too rarely however public spaces «are not designed to offer some degree of comfort, which results in their sub-optimal use or under-use» (Lenzholzer and Wulp, 2010; 375). As referred in the Ljubljana Declaration on Urban Regeneration & Climate Change (European Forum for Architectural Policies, 2008; 2), «adaptation to climate change requires a change in approach to the design of buildings and external spaces to ensure they provide good quality living and working conditions».

In public spaces it is commonly experienced days in which the atmospheric conditions «stimulate and invigorate our activities, while at other times they depress the physical and mental effort» (Olgyay, 1963; 14). As Gehl (2010; 147) refers, «the good city has many similarities to a good party: the guests stay on because they are enjoying themselves». The same author (*ibid.*) further states that «people stay in a place if it is a beautiful, meaningful and pleasant place to be». In the context of climate change, the chances created for people to be engaged in physical and social activities in urban public spaces should necessarily deal with the extent to which pedestrians can fit their personal requirements with the surrounding outdoor thermal environment.

Well-designed, flexible public spaces are the best chance cities have to adapt to the threats posed by climate change (Taylor, 2008; 2). The tangible task of urban design is to help minimising to the utmost the adverse impacts of climate on people's quality of life and health, and on urban infrastructures. With regard to outdoor thermal comfort, the objective of urban design should be «to create or to provide a reasonable thermal range, instead of attempting to create an exacting thermal condition» (Ahmed, 2003; 108). There is actually no optimum level of outdoor thermal comfort that can be identified as a goal. It is possible to understand the processes underlying thermal comfort, the main climatic variables and the body's physiological reactions; but it is more difficult to anticipate accurately the body's response to a microclimate. In this context, giving people the opportunity to adjust to the thermal environment can play a vital role — the adaptive opportunity.

Public spaces can offer significant adaptive opportunities when properly planned designed and maintained (Handley and Carter, 2006b; 64). Adaptive comfort theory was originally developed for buildings. Nevertheless, its central argument can be extended to public spaces as well: «if building occupants were allowed to adapt to their environment, either by adjusting clothing, controls or location, then they could tolerate environmental conditions outside those recommended by 'steady-state' theories» (McCartney and Nicol, 2002; 623). In the context of climate change the adaptive capacity can be defined as «the ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with consequences» (Wilson, Nicol et al., 2008; 32).

Bringing this notion closer to the urban design area, the adaptive capacity «can be built through climate-conscious planning and design of public open spaces offering access to, or shade from, wind or sun» and it might involve the use of high-albedo surfaces, the direct shading of buildings or spaces through physical structures, and solar shading through vegetation (*idem*, 40). It is accepted that analysing the climatic conditions of a site «is the starting point in formulating building and urban design principles aimed at maximising comfort and minimising the use of energy for heating and cooling» (Givoni, 1998; 3).

The creation of successful pedestrian public spaces should account with the displacement of cars and the improvement of the ease with which pedestrians may move around the space, and also with the provision of conditions for outdoor thermal comfort. Outdoor thermal comfort should systematically be addressed in order to deliver urban populations a network of comfortable outdoor spaces and, in turn, to ensure the quality of the public realm. Since urban design is the design of all that which unifies and relates the different morphologic elements or the different parts of a city (Lamas, 1992; 125), this discipline can substantially help creating the conditions for thriving urban settlements in a changing world.

3.3. Concluding remarks

Cities are the cause and stage of a series of environmental problems as well as the areas where the impacts of climate change will be felt by a larger number of people. Nevertheless, cities also present a set of opportunities to address these problems: adaptation, mitigation and resilience are the keywords. The sustainable city comes forth in this context as a goal. Irrespective spatial pattern, the sustainable city should be regarded foremost as a holistic, cross-sector concept encompassing environmental, economic and social factors mainly committed with creating more pleasant, healthier, environmentally friendly, and thriving urban areas. Making cities more resilient to the predicted climate extremes can bring better welfare, safety and health conditions to urban populations, preserve urban infrastructures, as well as positively influence the value of property, and historical, political and cultural assets. It can thus help countering the environmental, economic and social justice implications of climate change on urban areas.

Public spaces are a particular unit composing the built environment. In this sense, public spaces possess physical features (e.g. orientation, height/width ratio, heights of the surrounding buildings, built density, types of buildings, size, colours, vegetation, water features, materials, finishes, detailing, street furniture, urban art, or lighting) and compositional principles (e.g. order, balance, scale, proportion, rhythm, contrast, harmony, symmetry) which give urban climates a second level of definition of a more localised, micro-scale, nature.

Since the quality of public spaces can contribute to the quality of life in cities and the activities held in public spaces take place only when exterior conditions are favourable, microclimate should be given a higher importance in public space projects concerned in adapting the built environment to climate change and committed with the sustainable city goal. The tangible task of urban design within this scope is to help minimising to the utmost the adverse impacts of climate on people’s quality of life and health and on urban infrastructures by delivering well-designed, flexible public spaces where the provision of a reasonable thermal range enhancing the conditions offered for thermal comfort, and adaptive opportunity are the keywords.

This chapter approached the main goals of current urban development and the notion of contemporary public space in order to explore the extent to which the adaptation of the built environment to the substantial increase in temperature extremes brought by climate change can suit current urban development and public space trends. The literature review herewith presented has shown that the adaptation of the built environment to the substantial increase in temperature extremes brought by climate change is actually vital — the goal of the sustainable city and the contemporary pedestrianisation of city centres should necessarily tackle the expected higher thermal stress placed upon the built environment since otherwise (1) the reduction of the ecological footprint of cities may not be achieved, due to an increased cooling energy consumption, and (2) pedestrianisation may not be more than the mere displacement of vehicles since people may not be able to cope with a higher thermal stress placed on public spaces.

The concept of pedestrian-friendly space should be widened from an accessibility and movement viewpoint to encompass outdoor thermal comfort without which, on a climate change context, the public realm may become seriously eroded. A public space project for pedestrians should involve two main stages of concern: firstly, it is necessary to displace cars and deliver the necessary features for pedestrians to move freely and safely throughout the space; secondly, it is necessary to deliver the suitable features for people to stay and to experience a pleasant thermal environment. Comfortable outdoor public spaces can attract people to live, work, and enjoy, especially in a climate change context.

4
THE MICROCLIMATE OF OUTDOOR PUBLIC SPACES

This chapter presents the main elements governing the microclimate of outdoor urban public spaces. The quality of microclimates plays a vital role in meeting the goals of the sustainable city and the provision of conditions for outdoor thermal comfort. Balanced microclimates allow reducing the heat stress placed upon the built environment, particularly on buildings and public spaces. Consequently, the demand on cooling energy of buildings may be reduced and more chances are created for pedestrians to meet their comfort requirements in public spaces. The adaptation of the built environment to the substantial increase in temperature extremes brought by climate change can then be achieved by a careful approach to urban microclimates.

Section 4.1 offers a brief overview on the nature of microclimates; section 4.2 presents the main intervening elements on the definition of microclimates; and section 4.3 focuses on facing materials and vegetation as a way of anticipating the importance of programmes of ‘cool’ materials and vegetation developed in Chapter 5. Section 4.4 presents some concluding remarks.

4.1. MICROCLIMATE

Microclimate can be defined as the climate of the air layer adjacent to the Earth’s surface and of small places, well defined areas potentially of intense confinement, such as a street, a square or a garden (Cuadrat and Pita, 2009; 344-345). The urban canopy layer’s climate «is an amalgam of microclimates each of which is dominated by the characteristics of its immediate surroundings» (Oke, 1987; 274). It follows that in one same city the local climate may uncover countless microclimatic variations resulting from the interaction between physical factors such as topography, wind flows, built density and orientation, materials or vegetation. Urban microclimates greatly vary from city to city and within a city (Elisavet, 2001; 24).

The importance of microclimates is based on the argument that «the energy needs of buildings and the human thermal comfort conditions are mainly affected by the prevailing microclimatic conditions» (Gaitani, Mihalakakou et al., 2007; 317). The microclimatic parameters are indeed «of central importance for the activities that are carried out in the area and to a great extent determine their use» (Nikolopoulou, 2004; 2).

It is vital that public spaces achieve a «sojourn quality for a substantial period of time throughout the outdoor seasons» (Lenzholzer and Koh, 2010; 1). Since there is a strong relationship between microclimate and comfort conditions, the creation of successful public spaces is only possible alongside to common urban design quality parameters «great care is taken to include microclimatic concerns at the design phase» (Nikolopoulou and Lykoudis, 2006; 1468). Santamouris (2006; 2) states at this respect that improving the built environment in terms of energy efficiency involves adapting buildings to the specific environmental conditions of a city and the use of passive and hybrid cooling techniques to decrease cooling energy consumption; and improving urban microclimates in order to counter the effects of the urban heat island phenomenon.

The multitude of microclimates existing throughout a city has the «enormous potential for creating sunnier, warmer spaces in winter and cooler, shaded ones in summer» through design (Ritchie and Thomas, 2009; 9). Designing for more balanced urban microclimates «involves the best use of structural and landscape design elements to maximize or moderate sunlight, shade and air movement» (Meerow and Black, 1991; 1). It is necessary to know and determine which elements can be manipulated to create more pleasant spaces and obtain better conditions for a sustainable environment as well as to reduce the energy consumption of buildings (Marincic and Villa, 2006; 1).

It follows that microclimates are a highly valuable sphere of adaptation of the built environment to the substantial increase in temperature extremes brought by climate change. While at the local climate scale (i.e. the whole city) parameters such as location within a region, density of the built-up area, or subdivision of the building lots determine the general urban climate, the transposition of these parameters to the microclimatic scale (i.e. an urban canyon, square, etc.) involves considering a series of elements.

4.2. INTERVENING ELEMENTS

Starting from the notion that «the materials, geometry, and surface properties of the structures around a given place modify the local ambient climate» (Givoni, 1998; 242), it is fair to say that the basic morphologic elements determining a space's microclimate are orientation, height/width ratio and Sky View Factor, main colours, public space typologies, architectonic typologies, water elements, public space and buildings' shading devices, facing materials, and vegetation. These elements will be presented in the following pages.

4.2.1. ORIENTATION

Orientation is «the position of significant features of buildings [and public spaces] in relation to the site boundary, or to direct sunlight or prevailing winds» (Tunstall, 2006; 355). Together with factors such as altitude and topography, the orientation a public space determines its exposure to solar radiation and to dominant winds (Figure 11). The orientation of streets, for example, influences the mean solar irradiance at the canyon surfaces which, in turn, has an impact on air temperature and comfort of pedestrians (Swaid, Barel et al., 1993; 56).

Fig.11 – Example of how orientation influences the solar irradiation into a public space. Braga, Portugal. Source: João Cortesão, 2010

In new urban areas the most suitable orientation for achieving balanced microclimates may be achieved more easily because public spaces and buildings are created from the scratch; the physical relations between buildings, open spaces and topography can be established from the start.

In the case of retrofitting actions, the situation is different. In previously defined urban areas, those where the hard structure made up of buildings and open spaces cannot be changed, designers have to work with the existing conditions, in this case with the existing orientation. An intervention aimed at improving a space's microclimate should therefore try to make the best out of the existing orientation. As a general reference, it is difficult to mitigate the heat stress in an E–W oriented space in first instance due to the limited amount of shade that the walls of buildings can provide, even for high height/width ratios, i.e. narrow streets (Ali-Toudert and Mayer, 2007a; 106). Other elements such as facing materials, vegetation, water elements or shading devices can be considered in these situations.

4.2.2. Height/width ratio and Sky View Factor

The height/width ratio (H/W) basically expresses the proportion established between the width of the open space and the heights of the buildings or other vertical structures that border it. High H/W ratios correspond to narrow spaces whereas low H/W ratios relate to wide spaces (Figure 12). In general, as the H/W ratio increases the exposure to sun decreases. Only for very low ratios (H/W=4) does protection from the sun becomes effective (Ali-Toudert and Mayer, 2007a; 100). It follows that for low H/W ratios, alternative ways of compensation the high exposure to solar radiation should be sought (provision of shade).

A low H/W ratio means that the facade of a building does not influence the microclimatic behaviour of the opposite facade, while a high W/H ratio means that both sides of the space «have a combined effect on the microclimatic behaviour of the whole section» (Nikolopoulou, 2004; 14). The underlying phenomenon is that the radiative heat emitted between bodies is conversely proportional to the square of the distance between them (Alexandri, 2005; 51). Therefore, the larger the distance between facades, the less will they influence each other and the horizontal surface between them. In turn, the smaller the distance between facades, the more likely they are to influence each other and the horizontal surface between them. Consequently, the wider the space the greater the radiant energy dissipated.

The influence of vertical surfaces on the energy budget of the space is more important for high H/W ratios than for low H/W ratios. In narrower spaces, the net radiation, i.e. the sum of the incident, absorbed and reflected insolation (Chatzikostis, 2002; 18), is more intense as facades are closer and as the emitted long-wave radiation is retained longer within the space. The trapping of energy within a space leads microclimates to progressively warm up as the day progresses. The principle underlying this phenomenon is that the different surface elements of a space have diverse energy budgets leading to mutual interactions by radiative exchange and small-scale advection (Arnfield, 2003; 2).

Vertical surfaces also influence mean radiant temperature of an outdoor space according to its size, orientation and materials (Nikolopoulou, 2004; 12): the larger the facades' the higher the interface were heat transfer can occur; according to orientation facades can receive more or less insolation; the properties of materials determine the amount of thermal energy stored and released by facades.

Fig.12 – A high (top) and low (bottom) H/W ratio public space. Lisbon, Portugal (top); Lyon, France (bottom). Source: João Cortesão, 2009.

The H/W ratio is closely related to Sky View Factor (SVF) which expresses «the ratio of the amount of the sky "seen" from a given point on a surface to that potentially available» (Oke, 1987; 404). Except for vegetation, buildings or parts of buildings (e.g. balconies or canopies) create the main obstacles to the openness of a public space to the sky vault. The SVF determines to a great extent the radiative heat exchange between a surface and the sky. A SVF of 0 expresses a condition according to which the whole sky is fully obstructed whereas a SVF of 1 means that the sky does not present any obstruction (Svensson and Eliasson, 2002; 42). In this context, the SVF can be «seriously restricted by narrow streets and dense built form» (Yannas, 2001; 283). Depending on the orientation of the space and H/W ratio, a near total enclosure may protect the space from an excessive exposure to solar radiation or overshadow it. In turn, too much openness may lead to an overexposure to solar radiation. The same can be said for wind.

Discomfort by wind can be caused by a poor conduction caused by an inadequate exposure of the space itself to the main wind flows, by wind channelling from a nearby space (normally a channel space such as a street) or wind jets by a nearby tall building. Depending on the orientation, H/W ratio, SVF, and dominant winds, it might be necessary to promote summer breezes (to enhance evaporative heat losses) or prevent excessive exposure to winter cold winds (to prevent evaporative heat losses). While wind may not be too problematic in warm and hot regions, since usually higher wind speeds avoid stagnation, in cold climates increased winds and turbulence can create hostile urban environments (Oke, 1987; 271).

Meerow and Black (1991; 2) state that «windbreaks can be used to protect the pedestrian zone in an urban space from high wind speeds and turbulence». Windbreaks may either be solid (e.g. walls or buildings) or flexible/permeable (e.g. wood fences, hedges or vegetation belts) structures. Solid windbreaks provide good protection but tend to create high wind speeds and turbulence in areas relatively far from the windbreak. In turn, flexible windbreaks (e.g. vegetation, ideally trees and shrubs) allow controlling wind flows but at the same time preventing deflecting wind and even accelerating it into other areas of the space. Flexible windbreaks therefore create flows of more even aerodynamic shapes (Oke, 1987; 245).

Within the range of flexible windbreaks, vegetation is particularly effective since instead of being a stiff barrier it «provides greater flexibility in directing air circulation» (Meerow and Black, 1991; 2). A medium density barrier can be said to provide the best overall wind shelter by combining maximum retardation compatible with aerodynamic 'cushioning' in the lee (Oke, 1987; 244). Such a barrier would produce effects to distances of about 20-25 times downwind the barrier’s height or even 40 times (*idem*, 245). Taking this into consideration, and depending on the latitude, it might be important to install double and triple, flexible, staggered vegetal barriers perpendicularly to the direction of prevailing winds (Higueras, 2006; 170), or installing dense vegetation barriers closed on its basis with shrubs (Andrade, 2003; 249).

It is crucial to bear in mind that wind flows is a very complex subject and that «even small changes in the layout of the space or the neighbourhood can dramatically change the wind pattern on the space» (Nikolopoulou, 2004; 8).

4.2.3. Main colours

Colour is an extrinsic property of materials, i.e. materials *per se* do not possess the property of colour since colour is completely dependent on the spectral distribution of the incident light (Addington and Schodek, 2005; 38). Only the primary irradiators or the sources of natural light such as the sun, fire or light bulbs, possess colour of their own.

Public spaces can possess a diversified range of colours, mainly attributed by the building facades and the ground paving (Figure 13). According to Romero (2001; 75; 76), the main ways for colours to influence a public space are through tone — tones should therefore be chosen according to the microclimate aimed to achieve; to the aimed polychromic contrasts; to the desired light-dark effects which will accentuate, homogenise or differentiate spaces; and finally to the aimed saturation, i.e., the choice for bright or neutral colours. The primary function of the use of colours in a design scheme is in first instance visual, aesthetic, and thus psychological. Warm colours are associated to activity, intensity, or stimulation, e.g. red, orange or yellow, whilst cool colours are associated to passivity, quietness, or deceleration, e.g. blue, grey or black (*idem*, 76).

Fig.13 – A public space with diverse colours. Brighton, United Kingdom. Source: João Cortesão, 2011.

However, colours also impact a space's microclimate. For example, a person is expected to feel warmer in a space with a colour scheme predominantly red while in a space predominantly blue a person is expected to feel cooler (Fanger, 1972; 103).

Colours are also associated to albedo: cool/light colours are associated to high albedo values whilst warm and dark colours are associated to lower ones and therefore to higher levels of absorption of solar radiation (*ibid.*). It is therefore argued, for example, that converting dark-coloured to light-coloured surfaces can be included in the range of strategies to counter the urban heat island (Pomerantz, Akbari et al., 1999; 1459). This subject is addressed in more detail in Chapter 5. Considering this and that the radiation striking buildings' walls and the ground level is mutually reflected within the space, it is fair to say that the colours of a public space are to a significant extent determinant of its microclimate.

4.2.4. Function/typology

Typology relates to the usual conformation of urban outdoor public spaces, and associated functions, such as pavements, traffic restricted streets, squares, commercial spaces, waterfronts, public parks, gardens, playgrounds, and greenways (Carr, Francis et al., 1995; 79-84). The typology of a public is closely related to its function. The microclimate of a space should relate to this function, i.e. the nature and amount of microclimatic amenities should be linked to the function a space is expected to receive. These features may relate for instance to permeability degree, facing materials, amount and type of vegetation, density, or presence of water elements (Figure 14).

Fig.14 – Different public space typologies with associated different morphologic characteristics. A garden in London, UK (top); a riverfront in Paris, France (bottom). Source: João Cortesão, 2009.

It is vital to weigh the sort of strategies adopted and associated physical features and the function the space is expected to receive. For example, supposing that the increment of vegetation is beneficial for the microclimate of a square, the amount of vegetation proposed by a design scheme should be weighed with consideration that a square is a hard-surfaced public space from which cars are excluded mainly used for «strolling, sitting, eating, and watching the world go by» and although it may possess trees, flowers or grass, its predominant ground surface is hard (1998, 14). A square and a garden fulfil different functions and thereby the morphologic elements constituting their layouts should be selected and related differently.

4.2.5. Architectonic elements

The buildings bordering a public space may possess elements which can play an important role in the space's microclimate by providing protection from the climatic variables. In regions with warm and hot summers, for instance, solutions such as galleries, colonnades, arcades, within the ground floor of buildings can help improving thermal comfort conditions by providing protection from excessive exposure to solar radiation (Swaid, Barel et al., 1993; 59) (Figure 15). In cold rainy climates such feature may also be important to provide protection from rain or wind.

Fig.15 – A gallery creating protection from the climatic variables. Turin, Italy. Source: João Cortesão, 2009.

The architectonic elements with an impact on a space’s microclimate are not however restricted to galleries, arcades, or porches. Balconies, overhangs, canopies, may also be considered here. These elements are determined by the architecture and not by the urban design field. A joint work between both spheres of action can thus allow defining the best combination of public space and architectonic elements for improving both the microclimate of a public space and the indoor environments of the buildings surrounding it. The articulation between architecture and urban design should further be extended to other elements such as H/W ratio and SVF, heights of the surrounding buildings, buildings’ shading devices, or cladding materials.

4.2.6. Water elements

The use of water elements either by making the best of existing natural resources, either by creating man-made solutions, can then have significant impact on the microclimate of public spaces (Figure 16). From canals, to water films, waterfalls, ponds or fountains, there is a wide range of ways of integrating water in to the urban milieu. Irrespective the specific solution for integrating water into a public space, the general assumption is that for the reasons mentioned above, the use of water surfaces in combination with ventilation strategies can cool down air temperatures (Nikolopoulou, 2004; 37).

Water is usually cooler than surrounding hard surfaces and therefore tends to reduce the radiant temperature and improve comfort (Taylor and Guthrie, 2008; 10). The evaporation of water «enables heat, which ordinarily would become sensible heat of the surface, to be removed and used in the latent heat transfer of the water» (*idem*, 6).

Fig.16 – A fountain providing conditions for thermal comfort. Stuttgart, Germany. Source: João Cortesão, 2009.

The dimensioning and positioning of water elements should then convey a strategy for evaporative cooling which combines the evaporative potential of water surfaces with air movement. For example, the positioning of a large water pond in line with the prevailing wind direction at the edge of the space may help reducing air temperature in the central area of the space. The isolation of the area around the water surface from the surrounding space, especially if with vegetation, may further concentrate this benefit of water in a limited area such as a patio (AAVV, 2001; 58).

4.2.7. Public space and buildings' shading devices

Providing shade to pedestrians and urban surfaces is imperative in mitigating human heat stress (Ali-Toudert and Mayer, 2007a; 235) since they allow controlling the excessive exposure to solar radiation. When properly designed and positioned, shading devices «can effectively control the sun's direct radiation, and partially block diffuse and reflected radiation» (Stack, Goulding et al., 2001; 1).

Shading devices in public spaces often constitute small-scale shading solutions which can be quite effective for providing localised shade and, simultaneously, as these elements are often easily moveable, can be easily adjusted to particular comfort needs. This is an important aspect in the provision of adaptive opportunities in public spaces. Parasols, pergolas, porches, canopies, panels, fences, hedges, or bus shelters can be listed as the most commonly used shading devices in public spaces. The use of these devices is often associated to specific functions within the space, usually leisure long-term activities, such as for example café terraces or playground areas (Figure 17).

With respect to shading devices of buildings (Figure 17), Stack, Goulding at al. (2001; 7-9) mention three main categories: internal devices, external devices and mid-pane devices. Even though the three types of devices have positive impacts in indoor spaces, the external devices are those likely to have the most significant influence on the conditions offered for thermal comfort both indoors and outdoors. According to the same authors (*ibid.*), although having higher installation costs and higher impacts in the aesthetics of the building, external devices are the most effective in reducing heat gains in buildings because they intercept and dissipate most of the heat before it reaches the building's surface. For outdoor spaces, external devices are beneficial because, depending on the type of device, they can directly shade areas of the space.

Fig.17 – Examples of public space (top) and facade (bottom) shading devices. Vaduz, Liechtenstein (top); Porto, Portugal (bottom). Source: João Cortesão, 2009.

The most common types of shading devices for buildings are fixed (e.g. permanent awnings or shutters), moveable (e.g. awnings, shutters or blinds), adjustable (devices able of being operated in such ways that internal lighting is not excessively reduced), and retractable (devices that can be retracted till the upper part of the window or totally removed, such as blinds) (*idem*, 8-9). It is noteworthy that vegetation, when properly planned, may greatly reduce the need for internal and external shading devices since it will shade not only windows but also entire walls and roofs, reducing therefore conductive and radiative heat gains to a higher extent. The use of deciduous species allows adjusting the desired shading level to each season, while evergreen species allow shading year-round.

Facing materials and vegetation are the two morphologic elements left to address. These two elements have been extensively approached in the past few years. The importance of facing materials for the microclimate of public spaces has been widely recognised by authors such as Geiger (1950), Olgyay (1963), Plumley (1977), Oke (1987), Taha, Akbari et al. (1991), Bretz, Akbari et al. (1992), Rosenfeld, Akbari et al. (1995), Asaeda, Ca et al. (1996), Taha (1997), Voogt and Oke (1997), Bretz, Akbari et al. (1998), Givoni (1998), Nikolopoulou (1998), Akbari, Pomerantz et al. (2001), Romero (2001), Santamouris (2001), Akbari (2002), Nikolopoulou (2004), Akbari (2005), Higueras (2006), Gaitani, Mihalakakou et al. (2007), Synnefa, Santamouris et al. (2007), Tojo (2007), Yilmaz, Toy et al. (2007), Hausladen, Saldanha et al. (2008), Taylor and Guthrie (2008), Klooster (2009), or Synnefa, Karlessi et al. (2011).

Vegetation has also been given a significant attention in the past few decades, in what concerns to its influence on a public space's microclimate, either *per se* or in association to materials, by authors such as Geiger (1950), Plumley (1977), Oke (1987), Akbari, Davis et al. (1992), Sailor (1993), Levinson (1997), Voogt and Oke (1997), Givoni (1998), Nikolopoulou (1998), Rosenfeld, Akbari et al. (1998), Shashua-Bar and Hoffman (2000), Taha, Chang et al. (2000), Papadakis, Tsamis et al. (2001), Romero (2001), Santamouris (2001), Yannas (2001), Akbari (2002), Simpson (2002), Dimoudi and Nikolopoulou (2003), Gomez, Jabaloyes et al. (2004), Nikolopoulou (2004), Akbari (2005), Alexandri (2005), Peretti, Marino et al. (2005), Higueras (2006), Yu and Hien (2006), Tojo (2007), Yilmaz, Toy et al. (2007), Taylor and Guthrie (2008), Wong (2008), CABE (2009), Cuadrat and Pita (2009), Lenzholzer and Koh (2010), Monteiro and Alucci (2009).

The ability of materials to store heat and the amount of direct solar radiation striking a space are determinant for a microclimate, and directly relate to the physical properties of facing materials and the biophysical properties of vegetation. Improving urban microclimates can involve using more appropriate materials, more green areas, cool sinks for heat dissipation, or appropriate layout of urban canopies (Santamouris, 2006; 2). Beyond this, these two morphologic parameters establish the most suitable link to the intervention in public spaces located in compact urban areas (Chapter 5).

Considering this, facing materials and vegetation will now be addressed in more detail than the above mentioned morphologic elements. It will be presented the reasons why materials and vegetation can be the most important vectors for the retrofitting of public spaces in compact urban areas and, through this, how these may contribute to the adaptation of the built environment to the substantial increase in temperature extremes brought by climate change.

4.3. SPECIAL FOCUS ON MATERIALS AND VEGETATION

4.3.1. MATERIALS

Building materials possess an array of parameters that should be considered in architecture and urban design projects. These aspects relate for instance density and specific gravity, strength, optical properties, electrical properties, chemical properties, thermal properties and insulation, acoustic properties, deformations, deterioration, fire resistance, or appearance (Everett 1994, 5; Hegger, Auch-Schwelk et al. 2006, 264-266; Domone and Illston 2010, 16-27) amongst others. The mechanical, moisture-related and optical parameters are those more relevant to the microclimate of outdoor public spaces, namely the properties:

- durability and density (mechanical parameters),
- permeability to water (moisture-related parameters),
- reflectance/albedo and emissivity (optical parameters).

The consideration of these properties only does not mean that other properties of materials are less important. It rather means that for the microclimate of outdoor public spaces these are the most influential properties. Other thermodynamic parameters are likely to be more relevant to the architecture field, namely to the way how the building walls work as a mediators between external and indoor environments. Thermal conductivity, specific heat capacity, heat storage capacity, thermal transmittance, total thermal resistance are parameters more related to the building envelope, which is out of the scope of this research. With respect to the microclimate of outdoor public spaces, the buildings' exterior facing materials are the most relevant elements within the architecture sphere. Their contribution to the microclimate of a space is mainly governed by their optical parameters: albedo and emissivity.

The consideration of the mechanical parameters is imperative for a space's robustness while moisture-related and optical parameters are determinant for its microclimate. The properties associated to moisture-related and optical parameters govern the heat exchange mechanisms at the surface of a space: conduction, convection and radiation (Chapter 2). According to Hall (2005; 102), Oke (1987; 7; 25) and Givoni (1998; 267), conduction, convection and radiation can be defined for building materials as follows:

- Conduction is the process according to which heat is transmitted within a solid substance by the collision of rapidly moving molecules, passing from one molecule of the material to the next in the direction of lower temperature zone. Thus, conduction is more easily expected to happen in dense materials, i.e. those where the molecules are packed closely together. The opposite will happen in low density materials as the molecules are spaced further apart.
- Convection can be defined as the process according to which heat is transferred through gases. Air in contact with a surface hotter will warm up and consequently become less dense and rise up from the surface, taking energy away with it. On the other hand, if air contacts with a surface cooler than itself, heat will be transferred downwards from the air to the surface. It must be pointed out that convection constitutes the main process of heat transport from a surface during the day irrespectively if through the form of sensible or latent heat flux. In turn, during the night this situation is reversed as here conduction upwards from the ground is more effective and convection from latent heat is less effective.
- Radiation is the process according to which the exchange of heat does not require solid materials or air to take place. The exchange of thermal radiation is carried out between

the surfaces of hot and cold bodies. This originates the long-wave radiant heat losses. In still-air conditions these are the main source of heat loss, whereas under wind speeds convective heat loss may be more important. The amount of energy transferred is dependent upon the temperature, emissivity and absorptivity of the intervening surfaces.

Taking these definitions into consideration, it is fair to say that if a space's facing materials present the right mechanical, moisture-related and optical parameters they can reduce the capacity of surfaces to store heat or increase their capacity to readily release absorbed heat. This can make surfaces to keep cooler and therefore reduce the thermal stress placed upon microclimate and, thus, people. It is then possible to shape a space's climate through its materials (Romero, 2001; 214). Durability and density, permeability to water, emissivity, and reflectance will now be approached in more detail in order to understand the ways through which these properties can underlie this statement.

4.3.1.1. Durability and density

Durability indicates how able a building material is of withstanding wear and tear over the longest period of use possible. In many cases, durability is related to density, i.e. the volume-related weight of a dry building material including pores and intermediate voids (Hegger, Auch-Schwelk et al., 2006; 264). Dense materials can provide more mechanical resistance, e.g. for paving areas where large loads will be placed upon the ground, and therefore a higher durability. A higher durability often represents longer-term benefits since the amenities of a design scheme can produce the planned effects over a wider time span. Durability should thus be one of the first requisites to pay attention to when selecting the materials for a public space projects alongside other parameters such as strength, stiffness, or toughness (Domone and Illston, 2010; 529).

Design teams should further anticipate the changes likely to occur in a material in service, ensuring a maximum life (Everett, 1994; 15). In the long-term, the basic requirement for surface materials is the withstanding of wear and tear, as well as the action of the climatic variables (Berge, 2000; 307). Deterioration of materials might be a direct or indirect consequence of corrosion of metals, sunlight, biological agencies, water, crystallization of salts, frost, chemical action, loss of volatiles, abrasion and impact, vibration, or fire (Everett, 1994; 15). If on one hand durability should generally be as large as possible, on the other hand longer life spans require the physical layout of a space to be as less subjected as possible to deterioration and obsolescence:

- Physical deterioration is inevitable because it is a function of time and wear. However, deterioration can be controlled through appropriate choices in the design stage and through suitable maintenance operations.
- Susceptibility to pathologies determines the extent to which a given material will be able to cope with different external aggressions. These external aggressions can be of two natures: mechanical, e.g. impacts, loads, disintegration, salt attack, stains or pollution abrasion; or biological, e.g. contamination from biological colonization. The less susceptible materials are to these pathologies, the better.
- Obsolescence is more difficult to approach as it relates with less objective parameters, e.g. design trends, fashion or technological developments (Ashworth and Hogg, 2000; 58).

Higher resistances can represent advantages for life cycle costing, i.e. the consideration of «costs in use over and above costs for design and build» (Tunstall, 2006; 355), since though they might entail higher capital costs, they can represent important long-term savings. In this case, long-term savings are achieved by reducing the need for repair and/or replacement operations. Considering that labour accounts for about a third and materials for around half total building costs (Hillebrandt, 2000; 101-104), this can be quite significant in reducing costs throughout the space's life span.

4.3.1.2. Permeability to water

Permeability to water is the capacity of a material to allow water to flow through its pores. A material's permeability to water determines its moisture content, which is one of the most important parameters for evaporative cooling. Beyond moisture content of the surface, the evaporation process requires the availability of energy «to enable change of state; the existence of a vapour concentration gradient; and a turbulent atmosphere to carry the vapour away» (Oke, 1987; 65-66).

Water absorption coefficient, volume-related moisture content, and mass-related moisture content can be regarded as the main properties governing the moisture content of a surface. According to Hegger, Auch-Schwelk et al. (2006; 265), these properties can be defined as follows: water absorption coefficient is the capacity of materials and coatings to absorb water when in contact with water in its liquid state; volume-related moisture content refers to the quotient (in per cent) of the volume of the vaporisable water and the volume of a material; mass-related moisture content is the quotient (in per cent) of the mass of the vaporisable water and the mass of a material.

For the microclimate of public spaces, the permeability of a surface is particularly relevant for ground pavings since for building walls the requirements concerning permeability to water are quite different. Building walls are expected to reduce the amount of water, either in the liquid or gaseous state, reaching the inner layers of walls so that indoor comfort conditions and the own physical integrity of the building are not compromised. Nevertheless, some facade solutions, such as green walls, may give the building walls a more expressive role in the provision of evaporative cooling to the outdoor space.

Depending on absorption coefficient, volume-related moisture content, and mass-related moisture content, ground surfaces can be deprived of 600 Gcal if one gram of water evaporates, what basically represents an amount of heat necessary enough to heat up 6g of water from 0 °C to the boiling point (Geiger, 1950; 7). The loss of water by evaporation from the soil to the air depletes soil moisture while it reduces soil and air temperature (*idem*, 32). Since increased latent heat losses release stored heat in the soil making it cooler, the ground will irradiate less thermal energy to the air layer near the ground. Whenever latent heat losses are increased, lower air temperatures in the air layer near the ground can then be expected. It follows that the moisture content of a surface is a vital parameter for the microclimate of outdoor public spaces.

In this context, softer, greener, more organic surfaces may provide more thermally balanced outdoor public spaces since these allow storing water and thus cooling down the air layer near the ground by convection/evaporation. It can then be assumed that permeable paving materials allow improving the microclimate of outdoor public spaces (Asaeda, Ca et al., 1996; 425). In a study undertaken by Asaeda, Ca et al. (*idem*; 420-423) it was showed that in E-W oriented spaces the energy budget at the ground surface at noon was always lower for bare soil than for asphalt or normal colour concrete: the sum of the latent and sensible heat from asphalt was of around 350 W/m^2, from concrete 400 W/m^2, and from bare soil 150 W/m^2. Soil temperatures of vegetated areas, for example, can be as 10 °C to 15 °C lower than that of heat-absorbing materials (AAVV, 2001; 58).

Permeable ground surfaces may then be preferable to hard-paved impermeable surfaces — permeable surfaces allow water to be gradually absorbed and evaporated and, with this, to «remove substantial amounts of heat» (Taylor and Guthrie, 2008; 6). Permeable pavings allow air, water, and water vapour into the voids of a ground paving, keeping the material cool when moist (Wong, 2008; 2). Faced to their capacity to significantly contribute to lower surface temperatures through evaporative cooling and, thus, to contribute to mitigate the urban heat island phenomenon (Taylor and Guthrie, 2008; 7), permeable paving solutions are receiving a growing interest and application (Wong, 2008; 2) (Figure 18). Gaines and Jäger (2009; 78) inclusively argue that the existence of large, coherent, open, unpaved spaces is imperative for meeting the sustainable city goals as well as for providing attractive recreational spaces. Ground permeability should however be weighed according to the main function/s a space is expected to hold.

Fig.18 – A permeable paving solution (compacted soil). Lausanne, Switzerland. Source: João Cortesão, 2008.

Beyond enhancing the potential for evaporative cooling, a surface's permeability to water and thus its water content can positively contribute to the natural water cycle in urban areas. The large amount of flat asphalt surfaces of the built environment impairs the penetration of rainwater into the subsoil towards the areas of recharge of aquifers by as much as 90 %, redirecting it directly to sewage systems (Higueras, 2006; 64). It follows that the more permeable a ground surface, the higher the water exchange between the surface and deep layers of the soil.

4.3.1.3. Emissivity

Emissivity describes the heat radiated from a surface in relation to a 'black body' at the same temperature (Hegger, Auch-Schwelk et al., 2006; 264-266). The radiation incident on a body is reflected, absorbed or transmitted. A body that absorbs the entire radiation incident upon it is known as a 'black body'.

For a same reflectance value, low-emissivity materials maintain a higher surface temperature in the sun than high-emissivity materials (Bretz, Akbari et al., 1998; 99). The less heat absorbed by a surface the less heat available for potential release. The literature review has shown that the use of high-emissivity materials can be beneficial to the microclimate of outdoor public spaces, especially if associated to high-reflectance values (Chapter 5).

4.3.1.4. Reflectance/albedo

Albedo is that part of the light incident on a body that is reflected by the body back into the surroundings without having been previously absorbed by the body (Hegger, Auch-Schwelk et al., 2006; 264-266). An albedo of 0.30, for instance, means that 30 % of the solar radiation reaching a surface is reflected back, and 70 % of it absorbed by the surface. The albedo of a surface depends on the wavelength of the incoming radiation, the sun elevation, and the nature of the surface (Alexandri, 2005; 49) and is often associated to light-colours — light colours correspond to low values of absorption of solar radiation whilst dark colours are associated to high values of absorption of solar radiation (Romero, 2001; 76). The relationship between colours and albedo values is due to the fact that albedo values relate to the energy received through solar radiation as visible (wavelength from 0.3 to 0.7 micron) and short-wave infrared radiation (between 1.7 and 2.5 micron) respectively, and since these two types of radiation can be found near the visible part of the solar spectrum (*idem*; 83).

As Yilmaz, Toy et al. (2007; 290) refer, the albedo of surfaces plays the most important role in the heating of the air layer near the ground: the solar energy absorbed by the facing materials warms up the surfaces and, in turn, the surfaces warm up the air. It follows that the higher the albedo the less a surface will heat up and, thus, the less heat it will radiate to the air layer were pedestrian activities are held. As a general reference, high-albedo values can be found between 0.50 and 0.90 (e.g. marble, white plaster, gravel, white/whitewash paint); medium-albedo values can be found between 0.20 and 0.50 (e.g. concrete, stone, red brick, wood, plants, grass, dry soil, sand, red/brown/green paint); low-albedo values can be found between 0.05 and 0.20 (e.g. asphalt, slate, corrugated iron, water, black paint). Albedo of shaded ground surfaces is irrelevant (Plumley, 1977; 154).

The past few decades have brought a growing interest on the energy and environmental benefits resulting from the use of high-albedo/light-coloured surfaces throughout a city (Santamouris, 2001; 12). The basal idea of all researches undertaken within this scope is that «high albedo materials reduce the amount of solar radiation absorbed through building envelopes and into surfaces such as paving and keep surfaces cooler (Taylor and Guthrie, 2008; 10). The advocates of the use of high-albedo materials believe that if urban surfaces are lighter in colour, then «more of the incoming light would be reflected back into space and the surfaces and the air would be cooler» (Akbari, Pomerantz et al., 2001; 305).

The microclimatic benefits of using high-albedo materials can be both direct and indirect. According to Bretz, Akbari et al. (1992; 7), Akbari, Pomerantz et al. (2001; 305-307), Akbari (2005; 10), Synnefa, Santamouris et al. (2007; 1168; 1174), Santamouris, Synnefa et al. (2011; 3087), and Synnefa, Karlessi et al. (2011; 39) these benefits are:

- **Reduction of surface temperatures** (direct contribution). Data collected in a study undertaken by Akbari, Pomerantz et al. (2001; 305-307) about the influence of albedo on ground temperature, indicates a 10 °C decrease on ground temperature for a 0.25 increase in albedo. Lower mean radiant temperatures can then be expected.
- **Reduction of air temperatures** (indirect contribution). Lower air temperatures can create better conditions for thermal comfort during summer, reduce the demand for electricity for air-conditioning of indoor spaces during summer, and reduce the production of smog.

In addition to these contributions to a space's microclimate, and according to the same authors, the use of high-albedo surfaces may also be important due to:

- **Higher durability**. Since high-albedo surfaces absorb less solar radiation, they suffer less thermal expansion and contraction and may therefore last longer than other surfaces. This can reduce the need for replacement and repair operations, and associated costs. Additionally, if high-albedo surfaces reflect damaging ultra-violet radiation, a higher durability can be further achieved as well as reduction of waste from maintenance.
- **Higher sense of security at night**. Reflective surfaces improve visibility at night and in wet weather, which may additionally reduce the demand for street lighting.

Despite these advantages, some drawbacks of using high-reflective urban surfaces have been found in the literature review. These relate to glare, weathering, soiling, and wear. Relatively to glare, although improving the visibility at night and in wet weather, high-reflective materials may cause glare to pedestrians during the day. This may however be not entirely problematic since raising the albedo of an urban surface can be made to a medium value, such as 0.35 (e.g. cement or concrete) (Akbari, Pomerantz et al., 2001; 307). Special design details of the ground paving and building's walls (e.g. volumetric projections and setbacks, difference of levels, or surface finishes) alongside vegetation and man-made shading devices can further help controlling glare. With respect to weathering, soiling, and wear, after some time in use light-coloured surfaces tend to darken because of dirt (Akbari, 2005; 10) and wear/exposure to the climatic variables (Sleiman, Ban-Weiss et al., 2011; 3394). This may affect the final albedo of a surface (Taha, Sailor et al., 1992; 14), which may become lower. However, Akbari (2005; 10) states that for cement concrete roads experience suggests that the light colour of the ground persists after long usage.

The advantages high-albedo materials have for the microclimate of outdoor public spaces can be felt all year round. A study undertaken by Yu, Chen et al. in the University of Xi'an Jiaotong showed that high-albedo walls could provide heat protection during summer but also heat insulation during winter (Yu, Chen et al., 2008; 950). For the same solar radiation input in summer, the authors verified that light coatings absorbed less heat than deep coatings due to their high-albedo and that, thus, the heat exchanged inwards an indoor room was relatively small. In turn, in winter it was observed that heat radiating outward was relatively small due to the low capacity high-albedo wall-facing materials possess to absorb heat.

4.3.1.5. Innovative materials

Research on materials engineering in the past few years has brought a whole new range of building materials under the label "environmentally friendly". The term "environmentally friendly" relates to the «development, process or use of materials which minimises environmental damage» (Tunstall, 2006; 354). The recognition of the serious environmental problems humanity currently faces coupled with the significant ecological footprints of construction and manufacturing make new, more sustainable materials a necessity rather than a luxury (Brownell, 2010; 6).

Environmentally friendly materials have been developed towards a reduction of the ecological footprint of the manufacturing and construction processes have been involving low-embodied energy and zero-energy processes; the resurrection of vernacular material traditions into new forms; new pervious paving and geotextile systems; optimisation of properties in structural terms so that materials may support maximum loads over the longest spans; biomimicry; the combination of living and non-living materials (e.g. green walls); materials able of undoing the damage caused by polluting industrial practices; and responsive material systems able of transforming based upon shifting values beyond certain thresholds (idem; 7-8).

This last class is particularly relevant for a public space's microclimate since it breaks through the conventional way of looking at the aforementioned physical parameters of building materials with the concepts of 'smart materials' and 'smart technologies'. In the particular case of albedo, for example, smart materials come to question the conventional association of reflectance to colour. On a microclimate perspective, smart materials can either «decrease the penalty of low absorptivity during the winter period, or further decrease the surface temperature in summer» (Karlessi, Santamouris et al., 2011; 570-571).

The use of smart materials and smart technologies can give a surface various functions such as for instance protective, energy-generating, light-generating, climate-regulating, or information-providing (Klooster, 2009; 85). The protective and climate-regulating functions of a surface are especially important in the context of this research. Some examples are vacuum insulation systems (VIS), thermoactive building systems (TABS), and property change materials (PCMs). PCMs are particularly relevant for the microclimate of outdoor public spaces since they undergo a change in phase: during the day they absorb part of the heat through the melting process and, at night, solidify and release the stored heat (Karlessi, Santamouris et al., 2011; 571). PCMs «are very good at preventing overheating in summer» (Hegger, Auch-Schwelk et al., 2006; 30) and can be encompassed in passive cooling strategies. Furthermore, «properly integrated into the energy design criteria, their use results in lower capital outlay [...] and lower operating costs» even though they are more expensive (*ibid.*).

Within PCMs it is possible to find chromics or chromeogenic materials, i.e. materials that change their optical parameters (colour) due to an external stimulus (Kiri, Hyett et al., 2010; 87). Amongst these, those with a potential higher relevance for urban design projects concerned with the microclimate of public spaces, and based on the definitions provided by Addington and Schodek (2005; 83), are photochromics (materials that change colour when exposed to light); thermochromics (materials that change colour due to temperature changes); mechanochromics (materials that change colour due to imposed stresses and/or deformations); chemochromics (materials that change colour when exposed to specific chemical environments); and electrochromics (materials that change colour when a voltage is applied).

Irrespective of conventional or innovative, materials play a vital role in the microclimate of outdoor public spaces. This role is inseparable from the concept of surface since «all materials are bounded by surfaces, which are interfaces of varying nature» (Domone and Illston, 2010; 45). In addition, «the effect and aura of a surface is essentially determined by the properties of the material, by the interaction of different building materials, by the alternation between closed an open zones, or even by movable elements» (Hegger, Auch-Schwelk et al., 2006; 13).

4.3.2. Vegetation

The literature review showed that the benefits from vegetation in urban areas is quite wide, involving many different though interrelated functions. Givoni (1998; 304-305) offers a comprehensive listing of advantages of vegetation and green areas in urban areas:

- **Improvement of the urban climate**
  - Improvement of the urban climate in general;
  - Improvement of urban natural ventilation;
  - Provision of shade along streets in hot regions;

  - o Provision of open areas with shade and lower temperatures in ‘hot’ cities;
  - o Provision of protection from cold winds in winter.
- **Urban ecological functions**
  - o Reduction of air pollution;
  - o Reduction of the impact of noise generated by traffic and other activities;
  - o Retention and absorption of rainwater;
  - o Flood control;
  - o Protection of natural flora and fauna.
- **Social/psychological functions**
  - o Provision of playgrounds for children;
  - o Provision of areas for sport and recreation for the youth, adults, and elderly;
  - o Provision of meeting places for small groups;
  - o Provision of a chance for isolation and escape from tensions of urban life;
  - o Provision of aesthetic enjoyment from the landscaped areas of the city;
  - o Provision of perspectives for viewing public buildings and streets
  - o Creation of a feeling of spaciousness.
- **Urban development and services**
  - o Determination of the direction of future urban expansion;
  - o Land reserve for future development and public institutions;
  - o Ground base for urban transportation and service systems;
  - o Increase on the safety of motor traffic by open-space margins alongside roads;
  - o Separation between areas of incompatible land uses;
  - o Territorial separation between neighbourhoods where such separation is desirable;
  - o Provision of pedestrian and motorized access to various areas within the city.

Focusing the microclimate of outdoor public spaces, through its biophysical parameters vegetation can screen and reflect solar radiation (shade), promote evaporative cooling (evapotranspiration), and reduce and diffuse wind speed (wind-sheltering), affecting not only the microclimate of outdoor public spaces but also the energy demand of surrounding buildings for heating, cooling and lighting (Dimoudi and Nikolopoulou, 2003; 69). Under clear skies during summer a stand of trees in urban areas can block solar radiation in about 20-60 %, reduce air temperature by 1 °C to 2 °C, and reduce wind velocity in about 0.2 (Nikolopoulou, 2004; 5). Gomez, Jabaloyes et al. (2004; 97 *apud* Fukuoka, 1997) refer that, depending on the amount of striking solar radiation and on the characteristics of each species, such as branches, shape, distribution, density of the foliage, and the foliation characteristics, from the total amount of solar radiation reaching the Earth’s surface (100 %) a tree «absorbs between 5 and 20 % for photosynthesis, reflects 5–20 %, dissipates 20–40 % by evapotranspiration, emits 10–15 %, and transmits 5–30 %».

Due to these properties, green spaces can work as «correctors of some climatic characteristics, dampening or moderating these variables and providing conditions of greater comfort» (*idem*, 94) as well as constitute the most economical means of modifying microclimates around a building and, thus, contribute to energy conservation (Meerow and Black, 1991, 3; Akbari, Davis et al., 1992, 40; Papadakis, Tsamis et al., 2001, 836; Akbari, 2002, S120-S122). Increasing urban vegetation can be an effective way of mitigating the heat island phenomenon by creating an ‘oasis effect’ (Rosenfeld, Akbari et al., 1995, 260; Shashua-Bar and Hoffman, 2000, 234; Dimoudi and Nikolopoulou, 2003, 75; Yu and Hien, 2006, 105). It follows that the adaptation of the built environment to the substantial increase in temperature extremes brought by climate change can be as well achieved through the increase of urban vegetation.

Despite its many advantages, some problems have been ascribed concerning vegetation in urban areas. Meerow and Black (1991; 304), Akbari (2002, S125; 2005, 13), and Akbari, Davis et al. (1992; XXIV) refer the following main problems the use of vegetation in urban areas may entail: the emission of volatile organic compounds (VOC) by some species, which can exacerbate the smog problem; increase in the amount of water consumption and solid waste; susceptibility to fire; damage to other physical elements; and risks to safety (e.g. accumulation of leafs on the ground or falling branches) and health (e.g. allergies resulting from pollination).

The weighing of each advantage and drawback of urban vegetation should be made through the estimation and implied valuation of its advantages for a specific urban, social, economic and environmental contexts. It is important to understand the relationship between environment and the specific role of vegetation, as well as all the characteristics of the individual plants since only through this is it possible to design correctly (Peretti, Marino et al., 2005; 782).

While the mechanical, moisture-related, and optical parameters of materials govern the heat exchange mechanisms at the space's surfaces, vegetation can reduce the amount of direct solar radiation reaching the space's surfaces and favour evaporative cooling. The biophysical parameters of shading and evapotranspiration underlie these facts. As Rosenfeld, Akbari et al. (1995; 260) state, trees cool the surroundings by shading surfaces and through evapotranspiration.

4.3.2.1. Shading

Shading is a physical property of trees according to which the direct solar radiation striking any tree ensemble is either reflected, absorbed by the foliage, or transmitted through to the ground level, therefore affecting the proportion arriving as diffuse radiation, and its spectral composition (Oke, 1987; 144). The ability of trees to reduce the direct solar radiation transmitted to the ground level depends upon parameters such as density, height, species, or the angle of solar incidence. Nevertheless, it can be taken as a general reference that «less than 20 % (it may be as little as 5 %) of the incoming short-wave radiation effectively reaches the ground of a mature tree stand» (Oke, 1987; 144). Givoni, Noguchi et al. (2003; 79) showed that radiation under a tree was around 10 % of the radiation at unshaded spaces in summer and fall, whilst in winter and spring 20 % was the value of reduction under a leafless tree. Thereby, shading constitutes one of the best ways to control de summer heat gains (Papadakis, Tsamis et al., 2001; 835).

Shading is convenient not only for the microclimate of outdoor public spaces but also to indoor spaces since plants intercept solar radiation before it warms a building (Akbari, Pomerantz et al., 2001; 302) (Figure 19). In an experiment undertaken by Papadakis, Tsamis et al. (2001; 833-835) which assessed the effect of shade provided by trees on the control of the solar radiation striking a SE oriented facade, it was shown that the peak in the non-shaded area reached almost 600 W/m^2 whilst in the shaded area it was under 100 W/m^2. The experiment also showed that the indoor space corresponding to the shaded portion of the facade provided better thermal comfort conditions than the non-shaded portion. In winter, vegetation can «decrease the wind speed under their canopy and shield buildings from cold winter breezes» (Meerow and Black, 1991; 3).

Fig.19 – An almost entirely shaded (ground surface and building facades) outdoor public space. Zurich, Switzerland. Source: João Cortesão, 2008.

By shading the ground and building walls, trees also help controlling the thermal radiation from these surfaces — vegetation possesses many ways «by which it may lessen the harmfulness of too much outgoing radiation» (Geiger, 1950; 275). Shaded ground surfaces and building walls can then offer significantly less radiant heat to people.

4.3.2.2. Evapotranspiration

Evapotranspiration is a biologic function common to all plants consisting in a combined loss of water to the atmosphere by evaporation and transpiration (Santamouris, 2001; 145-146). Plants release water through pores in their leaves as vapour — transpiration. This is a process plants must continuously do in order to live. As «the amount of evaporation depends on the temperature of the evaporating surface, not on that of the air» (Geiger, 1950; 299), when the hot air passes through the surface of the leaves, the moisture on the leaves absorbs part of this heat and evaporates. The air surrounding the leaves is thus cooled down — evaporation or evaporative cooling.

The cooling potential of evapotranspiration is highest close to the centre of the plant (the trunk). It is noteworthy that vegetation also contributes to evaporative cooling by, even if dead, delaying the removal of the water vapour given off by the soil (Geiger, 1950; 297). For these reasons, «evapotranspiration, alone or in combination with shading, can help reduce peak summer air temperatures» (Wong, 2008; 3).

By increasing latent heat losses over sensible heat losses, evapotranspiration can also directly influence mean radiant temperature. As Nikolopoulou (2004; 14) argues, the globe temperature under a large tree can be as much as 15 °C to 20 °C lower than globe temperature of the same unshaded area.

Shading and evapotranspiration are properties of vegetation dependent on a number of biophysical parameters (category, vegetative cycle, growth rate, height, crown shape, root system, and resistance), and on quantity and placement.

4.3.2.3. Biophysical parameters

Category

Vegetation can basically be classified as trees, shrubs and herbs. The combination of trees, shrubs and herbs is often quite beneficial for the microclimate of outdoor public spaces. Plant covers possess a high vertical space for heat exchange between soil and air and this can modify «the temperature fluctuation of the climate near the ground» (Geiger, 1950; 287). The combination of trees, shrubs and herbs may also work as effective sound barriers, or significantly control wind flows. For instance, green belts can reduce wind speeds up to 50 % for distances, downwind, around 10 to 20 times their height (AAVV, 2001; 58).

Combining the three categories of vegetation may further be important to promote urban biodiversity because when faced with an adversity a complex and varied vegetal ensemble is more likely to recover than an area without diversity (Higueras, 2006; 176).

Vegetative cycle

Vegetative cycle refers to the seasonal cycle of vegetation’s leaf-on and leaf-off. The two fundamental categories are deciduous and evergreen species. Deciduous species are subjected to the annual process of vegetation leafing and senescence while evergreen species present foliage year-round.

Deciduous species are generally beneficial for the microclimate of outdoor public spaces «they can provide shade in summer, while in winter they hardly affect the irradiation» (Gulyas, Unger et al., 2006; 1716). More particularly, during summer deciduous trees provide some protection from direct solar radiation thus minimising the extreme heat stress in the midday hours, whereas during winter they reduce the cold stress because the low-angle solar radiation can reach a surface unhampered (*idem*, 1721) or, depending on the species, be reduced by as much as 30 % only (Alves, 2003; 189). This can represent an important strategy wherever large thermal differences between summer and winter entail contrasting thermal requirements.

Mixing deciduous (predominantly) and evergreen species can also be beneficial for the microclimate of outdoor public spaces since evergreen vegetation has a beneficial action in the defence against cold winds in winter, while deciduous vegetation combines the need for shade in summer with the penetration of solar radiation in winter (Higueras, 2006; 82).

Growth rate

The time required for a plant to reach maturity determines the moment onwards vegetation starts impacting the microclimate of a public space because shading and evapotranspiration potentials are best developed once plants achieve their climax. Growth rates of plants depend on the supply of solar radiation and carbon dioxide through the photosynthesis and respiration processes (Oke, 1987; 112). Growth rates are further dependent upon factors such as placement, soil, fertility, or moisture.

Height

The maximum height species can achieve once mature determines the extent of the shading casted over the ground and over the building walls. The larger the tree the larger the ground area and the number of floors of a building affected by the shade casted. It is however important to ensure that the height and mass of planting does not cut of the view of an activity or performance area for some space’s users (Marcus and Francis, 1998; 45).

Crown shape

Similarly to the height of plants, the shape, whether more upright or more spread out, and maximum width a given species is able of achieving when mature determines the extension of the shading casted over a space's ground and buildings' walls. Species with the right shape and density of foliage for a space help blocking enough solar radiation without producing overshadowing, i.e. the restriction or denial of direct solar radiation. Wide crowns can shade wider areas of ground and facades.

Wide crowns also mean that species will in general possess a higher density of leaves, which is beneficial for the level of evapotranspiration. Due to their geometry, oval, columnar and upright trees are usually best suited for narrow spaces; rounded, pyramidal, spreading and weeping trees with descending branches for wide spaces; and vase-shaped trees for streets.

It is important to know how to avoid or limit pruning operations by choosing trees with a suitable shape or shaping them adequately (Michau, 1998; 84). A tree planted in a suitable place, subjected to no restrictions to its full and healthy growth, and not presenting any signs of decline or attacks by pests does not need to be pruned beyond (light and frequent) maintenance operations (*idem*; 46). The idea that pruning *per se* is 'good' for trees may not be necessarily so. On the contrary, it may be dangerous to the tree — drastic cuts should be avoided since they pose risks to the health of trees by making them vulnerable to diseases, and by leading to decay processes that culminate in shortening trees' life spans (*idem*, 47,73).

Root system

The shape and velocity of growth of roots may lead to dysfunctions between specimens and other physical elements of a space. This weighing is dependent upon other morphologic elements amongst which H/W ratio and paving solution. H/W ratio determines which root system can be accommodated in a space whereas paving solution determines the admitted root system. For instance, stronger and more expansive root systems with large surface roots may not be appropriate for hard-paved areas because they may cause significant disruptions on the ground continuity. In turn, for more soft-paved areas such root system may not pose the same problem since materials are more flexible.

Resistance

Resistance relates to vulnerability of a species to diseases, extreme climate conditions or physical damages. Such as for materials, it is important that the specified planting scheme can be in use over the wider life span possible. The durability of vegetation is characterised by a higher vulnerability than that of materials since plants are living organisms and therefore subjected to biological and physiological phenomena. The first concern to prevent the early death of plants is to ensure the compatibility of the specified species with the site. Secondly, it is necessary to ensure the quality of maintenance operations (frequent phytosanitary assessments) and suitable pruning operations.

Plants should be appropriate for the general climate of a city (resistance to local climatic extremes), and to the microclimate and soil of the site. In general terms, native species are more resistant since they are already acclimatised to each territory (Higueras, 2006; 82). As a consequence, native plants do not require supplemental irrigation or fertilization (Meerow and Black, 1991; 3), i.e. require less maintenance.

4.3.2.4. Quantity and placement

The effectiveness of shading and evapotranspiration and the feasibility of a planting scheme as well, are dependent on two important parameters: quantity and placement. The quantity of planting is basically the number of specimens per square meter. Placement relates to the place(s) where specimens are planted. The articulation between one and the other parameter defines the magnitude of the cooling potential from shade (by defining shading patterns) and evapotranspiration (by determining the amount of water available for being evaporated).

Shading patterns must be carefully weighed so that compatibility between them and the function of a space can be achieved. Conflicts between vegetation and other elements of a space should be prevented at all times, such as for instance, blocking sunlight or overshadow solar panels on building roofs. In turn, evapotranspiration levels should be adapted to local climate in order to prevent an excessive increase in air moisture content. Additionally, the quantity and placement of vegetation should be made compatible with all other physical features of the space, aerial and underground services, and building foundations.

It is then vital to carefully choose, place, and orientate the vegetal specimens accordingly to which site (Higueras, 2006; 82-84) in order to foresee tree shadow cast in winter and summer, canopy height, width and shape, roots growing impact on underground infrastructures; it is imperative to weigh «in what locations, climates, and next to what type of buildings are large trees better than small trees, evergreens better than deciduous trees, or trees shading western exposures better than trees to the south» (Simpson, 2002; 1074), for example.

It should be acknowledged that small green areas throughout the built environment are more effective in improving urban climates than large green spaces concentrated in one large area (Elisavet, 2001, 27; Handley and Carter 2006a, 14; Taylor, 2008, 6). No matter how large a green space within an urban area is its influence «extends only a short distance into the surrounding, densely built, urban area» (Givoni, 1998; 319). Shashua-Bar and Hoffman (2000; 234) have found that the cooling effect of green areas is rather narrow, up to 100 m from the site boundary. Consequently, «the division of the entire space allocated for parks into a large number of small parks, spread over the whole urban area, will have a greater effect on the overall urban climate, than would the creation of a small number of large parks» (Givoni, 1998; 320). Assuming that the cooling effect of green areas is only felt up to 100 m from the site boundary the creation of small green areas of around 0.1 ha parted by 200 m can be a potential effective way of improving urban climates (Shashua-Bar and Hoffman, 2000; 235). These smaller scale solutions may encompass, for instance, public and private gardens, small parks, or green corridors running across a city.

The role vegetation plays in the microclimate of outdoor public spaces should be made by addressing the extent to which a given species and planting scheme can better mediate the microclimate of a space and the functions expected to be held there. Increasing vegetation in the built environment should not be regarded in a ‘decorative’ way. Vegetation is an active parameter for the quality of life and health of urban populations and therefore should be approach in a responsible a holistic way. In this context, two of the most fundamental parameters to acknowledge are that plants are dynamic and thus grow, and the importance of estimating the terms of integration and contrast between all the proposed elements by analysing the landscape (Higueras, 2006, 82; 106).

Mutual dysfunctions between plants and other physical components of the space should be prevented at all times. This might be more intricate than for materials since vegetation tends to have less linear characteristics. Specific and in-depth knowledge about the biophysical and physiological characteristics of a given species can be provided by technicians in these areas, such as landscape architects. Also, local nurseries, botanical institutes, or university forestry departments can provide more detail on the characteristics and appropriateness of species to a site. Designers need not to be experts in arboriculture or botanic in order to address vegetation in public spaces. However, designers should be able to appreciate the long-term foreseeable results of the vegetation species they select. Knowing how to plant, where to plant and when to plant are important notions to bear in mind when conceiving a planting scheme.

4.4. CONCLUDING REMARKS

This chapter presented the main elements governing the microclimate of outdoor urban public spaces. It was presented a brief overview on the nature of microclimates, the main intervening elements on the definition of microclimates, and the properties of materials and vegetation that will base the importance of programmes of ‘cool’ materials and vegetation developed in Chapter 5. It was shown that the microclimate of an outdoor public space is a complex entity based on the interaction between the climatic variables and the morphologic elements of public spaces. This interaction is *sine qua non* of climate-conscious, sustainable, urban design. One of the main outputs from this interaction is the conditions offered for thermal comfort. Successful pedestrianisation proposals should therefore take microclimates as any other design parameter contributing to the quality of the space.

Microclimates can be worked out through a number of morphologic parameters that, together, determine the performance of the climatic variables at the space. Amongst all morphologic elements, facing and materials and vegetation were focused in this chapter. The mechanical, moisture-related, and optical parameters of facing materials largely govern the temperature of the air layer near the ground and near building walls, where pedestrian circulation is mostly held. It is possible to shape a space’s climate through its materials (Romero, 2001; 214) since these can reduce the capacity of a surface to store heat or increase its capacity to readily release absorbed heat. In turn, the biophysical parameters of vegetation allow plants to influence the microclimate of outdoor public spaces as well as the energy use of the surrounding buildings by reducing the amount of direct solar radiation striking the space’s surfaces and favouring latent heat losses/evaporative cooling. These are basic ideas that substantiate the importance of programmes of ‘cool’ materials and vegetation presented in Chapter 5.

The focus made on materials and vegetation does not convey a belief that these two morphologic parameters are more important than the remaining ones. As it will be addressed in detail in Chapter 5, the focus on materials and vegetation is related to the intervention in compact urban areas which do not present the same flexibility as new urban expansion areas. Materials and vegetation can in these areas help making the most with the existing structures in what concerns to the provision of conditions for thermal comfort.

Understanding a material properly involves «mediating the interactions of the technical with the artistic and of the ecological with the social, the results of which incidentally enrich humanity» (Klooster, 2009; 67). The same could be said for plants which, irrespective their aesthetical value, by no means should be regard as mere adornments of urban design grammar. Urban design should tackle the whole range of environmental experience and not consider solely the way things look (Moor and Rowland, 2006; 54). This does not mean that the appreciation of an outdoor public space on microclimatic terms should neglect aesthetical subjects. On the contrary, these subjects are as important for the qualification of urban public spaces as thermally balanced microclimates. Sustainability relates to both ecology and aesthetics and, thereby, the physical stability of public spaces «can only be guaranteed through their lasting aesthetics quality, of necessity surpassing purely utilitarian purposes» (Krier, 2006; 27; 29). The point is that addressing a high-level aesthetics should not undermine ensuring the feasibility of a proposal in environmental, economic and social terms. One of the most important requisites for good design of public spaces is the integration of aesthetics, amenity, accessibility, community, vitality and sustainability (Moor and Rowland, 2006; 51).

The information presented in this chapter provides some of the central notions for the development of a methodology for supporting retrofitting proposals in compact urban areas based on facing materials and vegetation. The literature review on the microclimate topic has therefore substantiated the basal assumptions for the conception of such sort of interventions.

5

PROGRAMMES OF 'COOL' MATERIALS AND VEGETATION

This chapter approaches a particular way of addressing the microclimate of outdoor public spaces, valorising the role of materials and vegetation: programmes of 'cool' facing materials and vegetation. It will be addressed the potential that the combination of these two morphologic elements has for the adaptation of the built environment to the substantial increase in temperature extremes brought by climate change.

Section 5.1 addresses bioclimatic urban design as a way of framing programmes of 'cool' materials and vegetation within its knowledge field; section 5.2 presents the fundamentals and goals of these programmes; section 5.3 addresses additional issues that should base the appreciation of materials and vegetation, namely ecological and environmental impacts, life cycle costing, and socio-cultural aspects; and 5.4 presents some concluding remarks.

5.1. BIOCLIMATIC URBAN DESIGN FRAMEWORK

5.1.1. OVERARCHING ISSUES

Bioclimatic urban design relates to a form of urbanism concerned with minimising the negative impact of urbanisation on the environment, by adapting each plan to the local unique conditions of climate and territory (Higueras, 2006; 15). Starting from this definition, bioclimatic urban design can be regarded as a way of conceiving public spaces committed with the mediation between man, climate, and environment, taking microclimate as a fundamental parameter for the creation of high-quality public spaces (Figure 20).

Romero (2001; 28) states that bioclimatic architecture constitutes one of the contemporary 'energetic-climatic movement' which is defined by a concern given to adequate a proposal to the site and to the local materials and culture. Givoni (1998; 3) argues that the «analysis of the climatic conditions of a given place is the starting point in formulating building and urban design principles aimed at maximizing comfort and minimizing the use of energy for heating and cooling». At this respect, Goulding and Lewis (1997; 9) refer that «to take best advantage of and to build in harmony with the environment, a good knowledge of the local climate and a detailed analysis of the chosen location are desirable before a strategy for bioclimatic design is embarked upon».

Fig.20 – A high-quality, thermally balanced public space. Basel, Switzerland. Source: João Cortesão, 2009.

Bioclimatic urban design is described «as a potential subject for research in which the combined skills of the climatologist and the designer can be beneficially employed» (Eliasson, Knez et al., 2007; 72). These skills can be employed in the creation of more comfortable and healthier environments within the urban milieu. The physical layout of the space plays the central role here. In turn, the layout of the space should result from a careful weighing around the morphologic elements presented in Chapter 4. Some of these elements are common to current and bioclimatic urban design, others are bioclimatic-specific.

By no means is bioclimatic urban design regarded as a discipline competing or opposed to current urban design. On the contrary, bioclimatic urban design is herewith considered to be deeply-grounded in current high-quality urban design theory. Such as current urban design, bioclimatic urban design is committed with the high-standard experience of the space, placing a special focus on the conditions offered for a comfortable thermal experience at site. Bioclimatic urban design shares with current urban design a large majority of principles and goals — both current and bioclimatic perspectives of urban design have as ultimate goal people's welfare and the quality of the public realm.

Southworth (2005; 249) mentions that the creation of high-quality outdoor pedestrian public spaces should account with the following attributes: (1) connectivity of path network, both locally and in the larger urban setting; (2) linkage with other modes such as bus, subway or trains; (3) fine grained and varied land use patterns; (4) safety both from traffic and crime; (5) quality of path, including width, paving, landscaping, signing, and lighting; and (6) path context, including street design, visual interest of the built environment, transparency, spatial definition, landscape, and overall exploration. Bioclimatic urban design, as a branch of the urban design discipline, is intrinsically committed with these attributes but adds an attribute that high-quality public spaces should possess in current climate change scenario: (7) the mediation between man, environment and climate, envisioning the minimisation of the ecological footprint of cities, and thermally balanced outdoor thermal environments able of fostering a sense of wellbeing amongst urbanites.

The goal is to achieve fully qualified urban public spaces, not only from a bioclimatic perspective — if a public space provides a good level of shade and evaporative cooling, as well as low absorptive surfaces but does not present, for instance, good detailing, lighting, accessibility, safety or functional or symbolic relevance for the area, then the initial intention to make the space as attractive as possible loses strength or even purpose since basic attributes of good design are not addressed. Consequently, there will be nothing significantly valuable for people to experience at site. Delivering conditions for people to cope with a space's microclimate then ends up being somewhat pointless.

Bioclimatic urban design presents as main benefits: the promotion of more thermally balanced outdoor public spaces; the indirect contribute for more thermally balanced indoor spaces and, thus, for the reduction of the energy consumption and CO_2 emissions from buildings; the improvement of air quality; and, as consequence of the first three topics, the adaptation of the built environment to the substantial increase in temperature extremes brought by climate change and the contribution for meeting the sustainable city goal.

Promotion of more thermally balanced public spaces

Bioclimatic urban design relates to the global comfort of public spaces or, in other words, to the idea of 'environmental comfort' or 'comfort in the built environment' which, in addition to temperature, encompasses lighting, acoustics, and air quality (Schmid, 2005; 1). Comfort should be regarded in a holistic way and not restricted to microclimate only. Nevertheless, it is believed that in a climate change context, thermal comfort should be given more attention than usually since the activities held in public spaces take place only when exterior conditions are favourable, when weather and place are attractive (Gehl 2011; 11). In any outdoor public space thermal comfort conditions are paramount because otherwise people will avoid using them (Nikolopoulou, Baker et al., 2001; 228). Corbett (2004; 48) states that «when people move at a pedestrian pace they are more aware of the intrinsic qualities of their environment, and are therefore more concerned about the quality of the public realm».

Creating a variety of sunny, shady, sheltered and exposed sub-spaces in outdoor public places can increase both the physical and psychological adaptation, which will result in an increase in the usage of outdoor public spaces throughout the year (Thorsson, Lindqvist et al., 2004; 155). Mean and Tims (2005; 44) have shown in a field survey that what made the spaces public was not their ownership status, physical design or aesthetic appearance but rather the experiences people are able to create within it.

Comfortable outdoor public spaces can attract people to live, work, and enjoy, especially in a climate change scenario. The promotion of more thermally balanced public spaces is important not only for people's welfare but also to their health. For instance, delivering convenient green spaces for the elderly and the very young could be a lifesaver (CABE, 2009; 17). A clear example of the correlation between microclimatic conditions and health is the impact heat or cold waves have on death rates. Spagnolo and de Dear (2003; 722) suggest in this context the following conception of thermal environment:

> *«Conceptually we can regard the human thermal environment as a set of concentric "zones" with thermal preference at its centre, Ranked by a wider band of thermally comfortable conditions, which in turn may be Ranked by wider bands of acceptable thermal conditions, then uncomfortable, then moderately stressful, then stressful conditions, and finally, hazardous thermal environments».*

It is then fair to say that beyond being able to deliver the conditions for a more pleasant thermal experience of the city, bioclimatic urban design can reduce the health risks triggered by the exposure to more extreme climatic conditions. In summer, bioclimatic urban design strategies, especially around the increase of urban greenery, can help reducing the rate of hyperthermia, heat stroke, respiratory disorders, heat exhaustion, or sunburn events — during summer the shade provided by trees can help lowering indoor air temperatures and minimise the health impacts from heat waves as well as reducing direct exposure to UV rays which may cause, for instance, skin cancer or cataracts (Wong, 2008; 7). In winter, bioclimatic strategies controlling wind speed, air temperature, and rainfall can help reducing the probability of pathologies such as hypothermia, heart attack, or flu.

Indirect contribute for more thermally balanced indoor spaces — Reduction of energy consumption and CO_2 emissions from buildings

Bioclimatic urban design can create a 'first line of defence' of the building from the outdoor climate. This will allow help improving the energy efficiency of buildings and, consequently, reduce the energy consumption related to the use of mechanical devices to control indoor air temperature and associated CO_2 emissions. Regarding the building's energy use and design, «the demand for a comfort temperature regime indoors would be reasonably attenuated by a comfortable ambience outdoors» (Ahmed, 2003; 109). As Alves, Cortesão et al. (2009; 163) argue, «if an outdoor space is thermally improved so will an indoor one be improved as well, reducing CO_2 emissions related to mechanical devices to control air temperature». Therefore, the improvement of the microclimate of public spaces constitutes a strategy to help promoting a low carbon urban environment (*ibid.*).

The creation of conditions for outdoor thermal comfort and the notion of a 'first line of defence' from the outdoor climate to buildings relates to the idea of passive design of the city. Within this scope, Taylor e Guthrie (2008; 1) offer a hierarchy of measures for improving the energy efficiency of buildings and thus reducing CO_2 emissions, which starts with the idea of the «passive design of the city, or of a group of buildings, as 'the first line of defence' in this hierarchy». The urban scale passive design is followed by the building scale passive design, district systems, building systems, and renewables.

The achievement of long-term reduction on CO_2 emissions is dependent in first instance of reducing energy demands. Buildings are the most influential aspect here so several energy Certificate System have been developed in the past few years worldwide. Some well-known examples are the LEED (USA), BREEAM (UK), eco-bau (Switzerland), Total Quality (Austria). Whenever addressed as a series of environmentally sensible principles «sustainable design can create a new baseline for high-performance building and urban development, appropriately adaptable to location, culture, and time» (Kauffman, 2006; 13). It is however vital to highlight that pursuing energy efficiency is not only about buildings. While «buildings must be designed to be as near 'zero carbon' as possible, existing buildings must be modified to make considerable reductions in energy use, urban transportation must be designed in harmony with building development, and renewable energy supply and storage mechanisms must be applied to the urban built environment» (Jones, Pinho et al., 2009; VII).

Improvement of air quality

Many of the bioclimatic urban design strategies can help improving air quality, i.e. reduce/control air pollution, especially those involving trees. Trees affect air quality by cooling temperatures and hence slowing the smog formation process, and by filtering dust and airborne pollutants through the leaves – 'dry deposition' (Mayer and Höppe, 1987, 48; Goulding and Lewis, 1997, 10; Romero, 2001, 94; Akbari, 2002, S122; Wong, 2008, 6). Each tree specimen sequesters CO_2 from the atmosphere through photosynthesis, absorbing carbon and releasing oxygen to the air (Akbari, 2005; 3; Higueras, 2006, 83; Wong, 2008, 6).

Adaptation of the built environment to the substantial increase in temperature extremes brought by climate change and contribution for meeting the goals of the sustainable city

Together, the promotion of more thermally balanced — thus comfortable and healthy — outdoor public spaces, the indirect contribute for more thermally balanced indoor spaces and, thus, for the reduction of the energy consumption and CO_2 emissions from buildings, and the improvement of air quality allow adapting the built environment to the substantial increase in temperature extremes brought by climate change and help meeting the goals of the sustainable city.

Since bioclimatic urban design is framed by the sustainable development agenda (Higueras, 2006; 16), it comes forward as an efficient way of meeting many of the challenges related to sustainable urban development and, more specifically, sustainable urban design. This cannot be neglected as it will not be possible to address climate change and our energy challenge in urban areas without a more sustainable form of urbanism (Calthorpe, 2011; 8). Sustainable urban design is indeed «vital for this century — it is not too much to say that our health, welfare and future depend on it» (Ritchie and Thomas, 2009; 10).

Framed by the sustainable development, bioclimatic urban design should not be thought as capable of eliminating the environmental problems currently posed to cities or of avoiding the impacts of climate change in urban areas but rather of minimising their impacts. It is important to acknowledge that bioclimatic urban design is merely one of the many aspects converging to the concept of sustainable city and to the enhancement of quality of life in urban areas — «design alone will not be sufficient to improve the urban environment» (Riverside, 1999; 49).

Bioclimatic urban design and architecture should work together with aspects as compactness, shared mobility, public transport, responsive dialogue with surroundings, diversity of public realm, interconnected places of encounter, architectural diversity, social cohesion, communal infrastructure, use of renewable energy sources, complete water cycle management, waste management and treatment, integration of new and clean technologies, and identity of place (Grossop and Alves, 2009; 184) in order to achieve more sustainable cities. Moreover, the parameters contributing to the whole environmental experience include access, security, safety, health, civility, comfort, vitality/sociability, housing and habitat, urban design, provision of public services, natural features, or local culture both in the immediate and the longer term (Marques-Clarke 1998, 35; Brownhill and Rao 2002, 4; Moor and Rowland, 2006; 55).

Even though climate change is bringing less certainty and less defined ‘borders’ between climatic regions, bioclimatic urban design should not be approached in the same way in different latitudes; microclimate will necessarily be different in different latitudes and thermal comfort needs as well. Attention should be paid to the particular requirements of the world’s four great climatic regions: cold, temperate, hot-arid, and hot-humid. It is, however, imperative to never consider climatic requisites or thermal improvement solutions applied in different climatic areas (Higueras, 2006; 153).

The main morphologic elements with which bioclimatic urban design works with are related to the microclimate of outdoor public spaces and have thus been presented in Chapter 4: orientation, height/width ratio and Sky View Factor, main colours, public space typologies, architectonic typologies, water features, public space and buildings’ shading devices, physical properties of materials, or biophysical properties of vegetation. The fundamental idea is that these elements «can contribute to the successful design of urban spaces, by providing protection from negative and exposure to positive aspects of the climate, increasing the use of outdoor space throughout the year» (Nikolopoulou, 2004; 6). These elements should be worked out to give people adaptation opportunities in terms of shade in summer and rain and wind sheltering in winter (Handley and Carter, 2006a; 61).

The range of bioclimatic strategies affecting the microclimate of outdoor public spaces is also encompassed by the urban planning scale. Bioclimatic urban planning involves integration; passive conditioning techniques, bioclimatic architecture and urban rehabilitation; water cycle; pedestrian circulation; public participation; different levels of action; incorporation of local features; the abandon of the functional zoning; more and more coherent urban free spaces; high or moderate urban densities; and the use of the city's natural resources (Higueras, 2006; 17-20). It follows that the two scales of bioclimatology are subsidiary.

Although the implementation of bioclimatic strategies is likely to require the involvement of qualified experts and the public sector, small-scale private-lead solutions may also have an impact on the microclimate of outdoor public spaces. Some examples are the increment of vegetation in a backyard, the placement of potted plants and vines in balconies, or the application awnings, canopies or wind-breaks in facades.

The literature review allowed understanding that there is presently a solid and comprehensive body of research on bioclimatic urban design. Some of the main studies in this context were developed by Olgyay (1963), Humphreys (1977), Rosenfeld, Akbari et al. (1995), Nagara, Shimoda et al. (1996), Voogt (1997), Givoni (1998), Akbari, Pomerantz & Taha (2001), Santamouris, (2001), Nikolopoulou, Baker et al. (2001), Romero (2001), Yannas (2001), Höppe (2002), Ahmed (2003), Givoni, Noguchi et al. (2003), Nikolopoulou and Steemers (2003), Spagnolo & De Dear (2003), Nikolopoulou (2004), Stathopoulos, Wu, & Zacharias (2004), Gaitani, Santamouris et al. (2005), Ali-Toudert & Mayer (2006), Gulyas, Unger, & Matzarakis (2006), Higueras (2006), Nikolopoulou and Lykoudis (2006), Ali-Toudert and Mayer (2007a), Eliasson, Knez et al. (2007), Tojo (2007), Katzschner (2010), or Lenzholzer and Wulp (2010).

Some 'classical' urban design books also dedicate entire sections to the importance the microclimatic conditions of outdoor public spaces have for their enjoyment by people. One of these references is the well-known Gehl's "Life between Buildings". Other references in this context are, for instance, Alexander (1977), Lynch (1981), Jacobs (1995), Marcus and Francis (1998), Llewelyn-Davies (2000), Alves (2003), or English Partnerships and the Housing Corporation(2007).

If on one hand there are references directly approaching bioclimatic urban design, on the other hand other references do it indirectly: much of the knowledge presently existing on bioclimatic urban design has been offered and developed by the areas of urban geography, climatology and urban climatology, sustainable urban development, or energy efficiency of buildings. Some references are Geiger (1950), Oke (1987), Alcoforado (1988), Santamouris (2001), Tojo (2007), or Cuadrat and Pita (2009).

There seems to exist a common denominator between all developed studies in this field — there is a direct correspondence between the layout of the space, its microclimate, outdoor thermal comfort and, thus, usage patterns throughout the year.

There are presently also a number of concluded and ongoing projects committed with the quality of the urban environment in both an urban design and sustainable perspective. In this context, bioclimatology, either directly or indirectly, has been given a growing importance. Some of the many projects that could be mentioned here are:

- ASCCUE - Adaptation Strategies for Climate Change in the Urban Environment (University of Manchester) - UK
- Project for Public Spaces - USA

- LCUBE - Strategies for a Low Carbon Urban Built Environment (Cardiff University) – UK
- RUROS - Rediscovering the Urban Realm and Open Spaces (Centre for Renewable Energy Sources) – Greece
- SCORCHIO - Sustainable Cities: Options for Responding to Climate Change Impacts and Outcomes (University of Manchester) – UK
- World Urban Campaign (UN-Habitat)
- UTCI Universal Thermal Climate Index (International Society of Biometeorology)

It is also worth mentioning that the importance of bioclimatic issues has presently jumped out from the scientific and technical spheres to the public, daily life sphere. A good example is the array of messages and images available and discussed in virtual social networks, such as Facebook, or internet blogs (Figure 21).

Fig.21 – Bioclimatic-related messages on internet blogs (left) and virtual social networks (right). Source: ArchDaily and Facebook, 2012.

Due to the benefits it may bring to the built environment, people's comfort and health, and for help meeting the sustainable city goal, the incorporation of bioclimatic principles into the urban design practice should start being the backbone of contemporary public space projects. Bioclimatic urban design *per se* can effectively improve the microclimate of public spaces towards better thermal comfort conditions and, through this, help adapting the built environment to the substantial increase in temperature extremes brought by climate change. However, the systematic inclusion of bioclimatic urban design principles may require a bioclimatic urban planning behind.

Urban development and re-development would benefit from starting to be systematically planned in such ways. The final result would be that of urban design proposals expressing a different way of conceiving public spaces which takes the adaptation of cities to the substantial increase in temperature extremes brought by climate change as a true commitment.

5.1.2. BIOCLIMATIC URBAN DESIGN AND VERNACULAR BUILDING PRACTICES

The relationship established between bioclimatic urban design and vernacular building practices, i.e. the «use of materials and construction techniques which are typical of a locality or region» (Tunstall, 2006; 356), is plain. Each country, eventually each region within a country, possesses vernacular building practices that, throughout the history, have provided exemplar mediations between man and local climate; a mediation which is necessarily different from a site to another and related to different natural, climatic, cultural, and economical contexts (Figure 22).

Several indigenous architectures around the globe convey intelligence in design, often without the incorporation of any intelligent technologies; these architectures are intrinsically intelligent rather than a mere assembly of intelligent components (Wigginton and Harris, 2002; 24). Irrespective building codes, the archetypal forms of human dwellings, such as the Japanese wood and paper houses, the Eskimo Igloo, or the Middle East mud huts, have in common the facts that (1) their external forms follow the consideration of energy optimisation in terms of heating and cooling; (2) and that materials and construction techniques constitute pragmatic reactions to the climatic environment which ultimately has a crucial influence on the architectural expression (Hausladen, Saldanha et al., 2008; 29). The exemplarity of past architectures lies exactly in the almost perfect adaptation to the environment through the use of materials and building techniques considered as conditioning but not determining the architectonic object (Romero, 2001; 28).

In cities «a sense of history informs any sense of future» and therefore it may be important «to find ways of meaningfully combining that history with the present, pragmatically connecting the past with rational insights for the future» (Gaines and Jäger, 2009; 20). As stated by Mumford (1961; 11), «we must understand the historic nature of the city, and distinguish between its original functions, those that have emerged from it, and those that may still be called forth». It is possible to build on the successes of the past (English Partnerships and the Housing Corporation, 2007; 195).

Fig.22 – An example of Mediterranean traditional building practices. Light-colours, small openings, and high H/W ratios for providing protection from direct solar radiation. Marvão, Portugal. Source: João Cortesão, 2010.

Bringing the discussion to the urban planning scale, designers of the past understood local climate-related requirements in planning their streets, often intuitively (Jacobs, 1995; 276). In the cities of antiquity climate was even one of the decisive factors for the own location of the settlement (Higueras, 2006; 55).

Good examples of public spaces embody traditional urbanism and there are lessons to be learned «from the past and from generations of refinement and experience because urbanism and locale mattered more and were more in the collective consciousness than they are today» (2006, 49). Krier (2006; 25) refers that vernacular architecture and urbanism constitute a global theory of organising human settlements in intelligent and aesthetic ways.

Public spaces of the traditional city are characterised by an understanding of the microclimatic mechanisms and by resource sparing (Sarandeses, Molina et al., 1990; 131). Making the most of resources, which were either limited or difficult to obtain, is actually one of the central characteristics of vernacular building practices (Higueras, 2006; 57). Based on Meerow and Black (1991; 3), Marcus and Francis (1998; 45), Berge (2000; 307), Llewelyn-Davies (2000; 59), Alves (2003; 194), Thomas (2003; 20; 93), Hall (2005; 272; 273), Higueras (2006; 56; 82; 84; 106), Gaitani, Mihalakakou et al. (2007; 322), Tojo (2007; 292; 293), and Calthorpe (2011; 15), and for both summer and winter conditions, it can be said that bioclimatic urban design shares with the traditional building of public spaces the following topics:

- Diversity of users and activities;
- Pedestrian circulation as a design priority;
- Incorporation of local features such as climate, topography, materials or vegetation, and design details and symbolic elements;
- Fit between the space and its surrounding context, i.e. other public spaces and buildings;
- Public spaces, buildings, and neighbourhoods with human scale;
- The use of locally available building materials;
- Efficient use of materials, minimising the amount of materials used and preventing waste;
- Durable and low-maintenance materials;
- The use of materials close to their natural state;
- The use of indigenous vegetation species;
- The careful choice, positioning, and orientation of vegetation specimens;
- The consideration of vegetation as a dynamic parameter changing with seasons and time.

Despite its large advantages, the incorporation of vernacular building practices has been largely absent from the design of public spaces during the past few decades — while in the past climate has been a strong influence on urban planning, in the past few decades, «cheap road and rail transport and specialised land-use zoning have encouraged dispersed settlement patterns which have resulted in increased energy consumption» (Goulding and Lewis, 1997; 9). During the 19th century cities ceased being well bounded physical entities to give rise to urban sprawl. This was the first major rupture with traditional urban morphologies which was later followed by the rupture produced with the Modern city (Lamas 1992, 203; Higueras, 2006, 55). The line of continuity of urban life that existed through centuries and millennia till the industrial city, technological differences apart, was broken with the first decades of the 20th century, the cradle of the Modern city (Thwaites, Porta et al., 2007; 12).

The costs this reasoning had for cities in terms of character, identity and social bonds have been high. When it comes to urban development killing is not to healing and destroying is never a wise way for fostering love (Çelik, Favro et al., 1994; 22). Notwithstanding the well-intentioned principles of the Modern city, this city model seems to have failed in its social dimension. Modernism, through its top-down processes and masterplans, and the mono-functional and sterile urban environments produced, has been accused of being outdated, inappropriate and, foremost, ineffective; its spatial and architectural forms «tend to reinforce spatial and social exclusion, and produce cities which are not environmentally sustainable» (UN-Habitat, 2009; 57; 59). With respect to the microclimate of public spaces and the subsequent conditions offered for outdoor thermal comfort, the modernist agenda for public spaces was also not able of ensuring minimal conditions for the enjoyment of outdoor public spaces throughout most of the year (Sarandeses, Molina et al., 1990; 133).

Also the pace at which urban transformations began taking place after the industrial revolution has influenced the schism between the pre- (more vernacular) and post-industrial (more globalised) conception of public spaces. As Romero (2001; 44) refers, in pre-industrial periods public spaces had the common characteristic of resulting from slow historical changes, which clearly contrasts with current urban practices. According to the same author (*ibid.*), current urban practices are based on the construction of new and immense urban expansion areas where apparently it is intended to include in a short period of time all parameters contributing to the quality of public spaces. The conception of public spaces in recent years seems to have been oversimplified and costs to be imperative. Carmona, de Magalhães et al. (2002; 146) argue that «commercial pressures often seem to militate against long-term investment in design quality».

Faced to the environmental challenges presently posed to cities and to the need of promptly adapting the built environment to the substantial increase in temperature extremes brought by climate change, it might be relevant to re-discover the building knowledge from past periods of city-making. Vernacular building practices «provide an understanding of how similar problems have been approached in the past, and this can serve as a basis for new directions even if it means adaptation of time-tested solutions» (Nikolopoulou, 1998; 13).

Notwithstanding, vernacular building practices should not be seen a catalogue of ready-made solutions for contemporary urban problems. Thwaites, Porta et al. (2007; 12) refer that the growing interest for vernacular building practices, is a side-effect of globalisation which «strengthens both the existence of, and the claim for, sense of place and localisms». Nevertheless, the search for a sense of place should not be regarded as a set of mimetic actions attempting to reproduce urban environments from the past; as a way of conceiving public spaces which is more concerned about aesthetics, nostalgia, romanticism and less with the effectiveness of public spaces in addressing the needs of urbanites in the present.

There is nothing about seeking a sense of place which is compulsorily related with mimesis — references from the past should and can be reinterpreted, reinvented; other references should be invented in order to provide forward-looking spaces with which people may establish an emotional bond. Part of the own concept of sustainability is the creativity that should link processes within a particular context (Dimitrova, 2007; 222).

5.2. Fundamentals and goals

New build is only the tip of the iceberg in what concerns to the urban built environment and it is upon the existing buildings and infrastructures that the main effort should be made if a more sustainable built environment is to be achieved in the future (Jones, 2007; 201). Compact urban areas are built urban areas which are stabilised in terms of urban morphology and infrastructures, such as a city centre, and which therefore present a number of legal (e.g. patrimonial regulations) and physical constraints (e.g. surrounding buildings heights, H/W ratios, orientation, built density) to building operations. In turn, new expansion areas tend to have less physical constraints than compact urban areas. Therefore, the creation of thermally balanced urban microclimates is potentially easier in new urban expansion areas than in compact urban areas.

Presently there is actually a lack of solutions for compact urban areas, where the environmental welfare needs are a priority but where simultaneously it is rather difficult to plan whole solutions due to the characteristics of the urban fabrics within these areas (Higueras, 2006; 17). In compact urban areas the hard structure cannot, or can hardly, be changed (1996, 178) because the built environment is already defined. Whenever corresponding simultaneously to historical areas, compact urban areas are often further protected by strict regulations ensuring their patrimonial integrity, which generally does not allow many interventions to take place (Figure 23).

In compact urban areas changes in topography, street and building orientations, built density or other structural physical parameters are not likely to take place easily. For instance, the demolition of an entire block to improve wind flows or solar access into a public space or to buildings is not prone to happen. At this respect, Marques-Clarke (1998; 7) states that the urban fabric has changed slowly except for wholesale destruction caused by natural disasters, wars, etc., and for the massive changes brought by the 19th/20th centuries (Industrial Revolution or Post-World War II). It follows that in compact urban areas one must try to obtain the greatest benefit from the existing structures (1996, 178). This can be applied to both architecture and urban design fields.

Fig.23 – Example of a compact urban area. Venice, Italy. Source: João Cortesão, 2003.

Beyond the morphological aspect, compact urban areas are also quite important in social terms. Wherever corresponding to urban centres, compact urban areas tend to gather a large amount of people due to the array of different activities held there; and wherever corresponding to urban centres and simultaneously to historical areas, the indirect effects of tourism (e.g. increased of road traffic, more people circulating in the streets or more demand for leisure space in addition to the day-to-day activity of its inhabitants) place even more emphasis on the importance of ensuring thermally-balanced public spaces in these urban areas.

Amongst all morphologic elements defining microclimates, facing materials and vegetation are potentially the most easily and likely workable in compact urban areas — facing materials and vegetation in often subtle ways can help greatly improving a microclimate (as seen in Chapter 4); they can produce effective microclimatic results through smaller-scale interventions when compared to other morphologic elements (Figure 24). Smaller-scale interventions should be seen here as changes that do not require major infrastructural site works such as for instance resurfacing of facades, replacement of ground surfaces, provision of water elements and other urban furniture, or tree planting. These changes can be incorporated into routine maintenance operations (Rosenfeld, Akbari et al., 1995, 256; Akbari, Pomerantz et al., 2001, 308). In addition, comparatively to more structural interventions, small-scale changes may not entail major site operations and this may reduce the disruptions on the normal functioning of a space and its surrounding buildings.

If on one hand, given aspects of the quality of the built environment are only possible to achieve through structural changes to its physical layout (e.g. sewage, electricity or telecommunications systems), on the other hand, small-scale interventions at the level of materials and vegetation can be enough for the thermal retrofitting of public spaces. Furthermore, in economic grounds this can be quite relevant since renovation and reuse of buildings often seems to be a better solution than demolition (Bragança, 2007; viii). The same is certainly true for public spaces as well.

Fig.24 – Different combinations of facing materials and vegetation. Clockwise from top left: Brighton (United Kingdom), Friburg (Switzerland), Zurich (Switzerland), and Lyon (France). Source: João Cortesão, 2010.

Adapting the built environment to the substantial increase in temperature extremes brought by climate change can then be materialised in the combined use of materials and vegetation in retrofitting interventions over outdoor public spaces in compact urban areas. Recalling the information presented in Chapter 4, this combination should account with high-albedo and high-emissivity ('cool') materials and vegetation with appropriate biophysical parameters because shade trees reduce the insolation on a surface and cool surfaces absorb little of the incident insolation (Rosenfeld, Akbari et al., 1995; 256). Provided facing materials and vegetation are carefully brought together, beyond constituting an easy way to conserve energy, save money and eventually reduce air pollution, the combination of these two elements could also significantly reduce urban air temperatures (*idem*; 260).

Programmes of 'cool' materials and vegetation have then two main goals: **the reduction of the amount of direct solar radiation striking the surfaces of a space; and the increase of the heat losses taking place at the ground level, where pedestrian circulation is held**. These goals can be achieved through three key-actions:

- **To increase shading by trees and/or man-made shading devices**. This will in first instance reduce the amount of direct solar radiation striking urban surfaces since plants can reduce the amount of incoming solar radiation. It is generally preferable to provide shade through vegetation than by man-made shading devices since vegetation presents the advantage of absorbing direct solar radiation without entailing an increase in surface temperature (Taylor and Guthrie, 2008; 4). This is due to the biological processes of vegetation, such as photosynthesis or evapotranspiration. In addition, vegetation possesses psychological benefits that man-made shading devices cannot or can hardly achieve. These psychological benefits are related to the mental sense of connection with nature which is «a basic human satisfaction, the most profound aspect of sensibility» (Lynch, 1981; 257). Nevertheless, man-made shading devices may work together with vegetation to provide good levels of shade to the space.
- **To use 'cool' materials**. According to the albedo and emissivity value, building materials may be grouped into two different groups: 'cool' and 'warm' materials. 'Cool' materials are associated to high albedo and high emissivity, whereas 'warm' materials are those with low albedo and low emissivity. 'Cool' materials aim «to reduce heat gain by reflecting away as much solar irradiation as possible, while at the same time having properties that allow to release any heat in the material» (Halewood and Wilde, 2008; 1). Santamouris (2001; 43; 71) states that high-albedo materials reduce the amount of solar radiation absorbed by urban structures and thereby keep their surfaces cooler, and that high-emissivity materials readily release the energy absorbed as short-wave radiation by emitting long-wave energy. The combination of high solar reflectance and infrared emittance values results in lower surface temperatures (Synnefa, Karlessi et al., 2011; 38-39). 'Cool' ground surfaces are made of a range of existing and new materials that tend to store less heat than conventional products (Santamouris, Synnefa et al., 2011; 3087). The definition of 'cool' ground surfaces may as well be expanded to include permeable ground pavings (Wong, 2008; 2).
- **To increase evaporative cooling through vegetation**. Evaporative cooling can enhance convective heat losses within a space. Since evapotranspiration can increase latent heat losses over sensible heat losses, evaporative cooling can be responsible for lowering air temperatures surrounding a tree by as much as 5 °C (Meerow and Black, 1991; 7).

The whole conception of programmes of 'cool' materials and vegetation, its goals and key-actions, point out the importance of a space's surfaces. A surface can be defined as a plane separating two different media containing, of itself, no energy or mass (Oke, 1987; 33). Nevertheless, it is in the surface that the main sources and sinks of heat, mass, and momentum can be found (Voogt and Oke, 1997; 1117; 1118). Consequently, «most temperature changes take place at or through surfaces» (Domone and Illston, 2010; 45). The appreciation of how surfaces influence a space's microclimate should account with the performance of the whole ensemble of surfaces. A space's ensemble of surfaces, i.e. its horizontal and vertical surfaces, should be considered as a unique body of analysis and intervention since it possesses all elements confining, shaping and assigning an identity to the space.

Horizontal surface — ground

Horizontal surface may be understood as the area where the pedestrian functions of the space are held. According to Romero (2001; 155), on a microclimatic viewpoint the horizontal surface involves considering parameters such as soil use and occupation (main functional vocation and effective use), orientation (positioning face to topography, direct solar radiation, wind and sounds), texture (surface characteristics of facing materials), physical parameters of materials (mechanical, moisture-related, and optical parameters), colour (characteristics, intensity, ensemble effects and psychological impact on people, as well as the amount of direct solar radiation absorbed or reflected), and vegetation (biophysical parameters and the specie's suitability to the site). Ground surfaces of different characteristics have different visual and microclimatic impacts (Figure 25).

Fig.25 – Different urban ground surfaces with different visual and microclimatic outputs. Brighton, United Kingdom (top); Lyon, France (bottom). Source: João Cortesão, 2010.

The microclimatic impacts of ground surfaces are based on the Stefan-Boltzmann law: all bodies emit radiant heat according to their own temperature. According to Geiger (1950; 35; 131; 217), there are three main considerations relative to the role that ground surfaces play in the microclimate of outdoor public spaces based on the Stefan-Boltzmann law:

- The ground itself acts as a regulating reservoir of heat that during summer, or at times of heat surplus at midday, absorbs significant amounts of heat (thereby avoiding unduly high temperature) while during winter or at night will give up its savings and therefore keep the temperature from falling too far;
- High-reflective ground surfaces heat up by day much less than high-absorptive ones;
- The way how the ground interacts with solar radiation, and thus influences the space's microclimate, depends upon the amount of radiation reaching the ground which, in turn, depends on time of day, season, cloudiness, direction of slope, and the angle of slope.

Vertical surface —building facades

The influence of building outer walls on a space's microclimate involves, according to Romero (2001; 155), parameters such as openings (level of permeability of the facade to air according to the number, position and size of the openings), transparency (relationship between the glazed and opaque surface), tension (volumetric projections and setbacks with relation to the plan of the facade), texture (final surface treatment which will determine the level of friction offered to air), colour (characteristics, intensity, ensemble effects and psychological impact on people, as well as the amount of direct solar radiation absorbed or reflected), and variety in the skin's characteristics (flexibility to eventual changes in the facade's component elements). Vertical surfaces of different characteristics have different visual and microclimatic impacts (Figure 26).

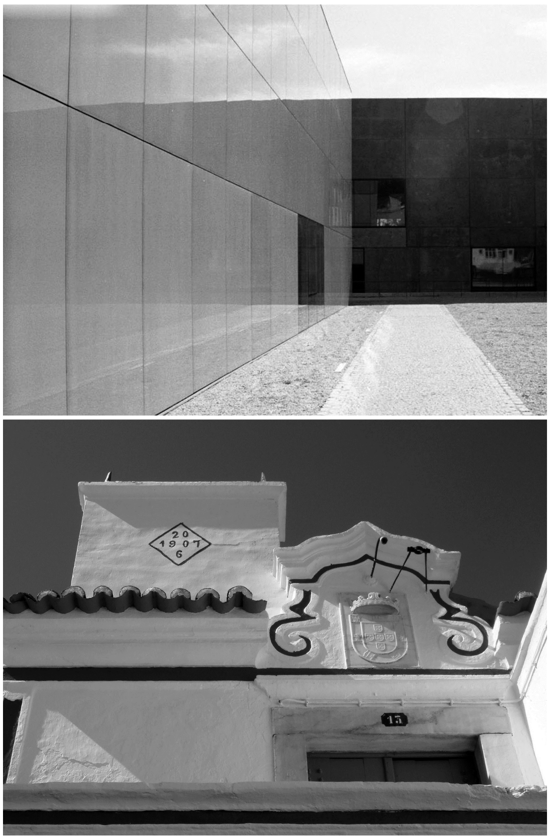


Fig.26 – Different urban facades with different visual and microclimatic outputs. Guarda, Portugal (top), and Aviz, Portugal (bottom). Source: João Cortesão, 2008.

Conversely to ground surfaces, the outer walls of buildings possess two opposed surfaces which delimitate the outdoor and the indoor spaces. There are thus two environments to be influenced by a wall. Indoor environments are related to the architecture field and, thus, are out of the scope of this research. Nevertheless, the basic issues to bear in mind about this subject is that a building envelope should minimise heat flow from indoor to outdoor environments and vice versa; minimise or completely prevent vapour transfer across the building structures; and minimise or prevent the influence of solar radiation on indoor thermal conditions (Borodinecs and Kreslins, 2008; 2). In this sense, building walls should work as selective barriers to the outdoor climatic conditions so that the indoor comfort conditions can be kept constant, eliminating or at least significantly reducing the need for mechanical devices to control indoor temperature (Mendonça, 2005; 3.13-3.15).

Three main factors affect the way how a building facade acts as a selective barrier to the outdoor climatic conditions: type of wall, order of assembly of components, and composing materials. The type of wall, the assembly of its components and its inner and outer/surface materials determine the basic terms through which solar radiation will be transmitted indoors. Walls can mainly be opaque heavy or light, transparent and translucent light, or composite. The assembly of components may be broadly divided into single- or multi-layer assemblies and, in the particular case of facades, single-skinned, double-skinned, alternating, and double-skinned with direct ventilation (Hegger, Auch-Schwelk et al., 2006; 95-112). The materials composing a wall in non-air conditioned buildings determine the relationship of temperature and solar radiation between outdoors and indoors, while in air-conditioned buildings determine how much energy will be consumed to maintain the indoor temperature within comfortable limits (Givoni, 1998; 107). The basic properties of materials governing these processes are density, conductivity, specific heat, absorptivity, reflectance, transmittance, and emissivity.

Relatively to roofs, in warm climates high roof temperatures increase air-conditioning energy use and/or reduce indoor comfort (Berdahl, Akbari et al., 2008; 482). Notwithstanding its importance, the thermal performance of roofs is not focused in this research since roofs are more relevant for the thermal performance of indoor spaces than to the microclimate of outdoor spaces. Nevertheless, as in many cities ground surfaces and roofs account for over 60 % of urban surfaces, 40 % and 20-25 % respectively (Akbari, Menon et al., 2007; 1), both surfaces should be considered in citywide bioclimatic interventions combining urban planning, urban design and architecture.

The outer facing materials of building walls are here the most influential parameters to a space's microclimate. The underlying physical processes are basically the same as for horizontal surfaces — the mechanical, moisture-related, and optical parameters of facing materials govern the temperature of the air layer near the ground, or in this case, near the wall. Bringing together good thermal insulation systems with exterior 'cool' facing materials can lead to better microclimates and better indoor thermal performances. Again, this requires a close articulation between the options made for public spaces and buildings; between urban designers and architects.

These notions around the surfaces of public spaces can be taken as general principles from which to conceive the 'climatic skin' of outdoor public spaces. As Lenzholzer (2006; 6) refers, «just like good clothing and good shelter, (our "Second and Third skins") protects and serve our body, the "Fourth skin", being the urban environment, needs to be comfortable». The 'climatic skin' relates to the whole body of horizontal and vertical surfaces defining an outdoor public space.

The concept of ‘climatic skin’ encompasses principles governing the heat exchange between the sun and the terrestrial surfaces, and between this and the conditions offered for outdoor thermal comfort. These principles are quite relevant to programmes of ‘cool’ materials and vegetation:

- Ground and vertical surfaces can be sources of radiant heating or cooling depending on their surface temperatures, surface dimensions, proximity to the person, and the person's activity level (Plumley, 1977; 156).
- Ground surfaces usually receive more solar radiation and provide more radiant exchange than vertical surfaces (Ali-Toudert and Mayer, 2007a; 231). During summer, sunrays establish with horizontal surfaces a high angle which determines that the sun rays will be distributed over a small surface, causing a strong intensity of insolation; in turn, sunrays establish with vertical surfaces a low angle which will be spread out over a larger surface, originating thus a lower intensity of insolation (Cuadrat and Pita, 2009; 44).
- During warm weather, shaded ground surfaces offer significantly less radiant heat to people than unshaded surfaces, except for vegetative ground materials; and vertical surfaces shaded by dense-foliage trees offer significantly less radiant heat to people than unshaded walls (Plumley, 1977; 156).
- A very low H/W ratio, 0.06, means that one urban front «does not influence the microclimatic behaviour of the opposite front», while for relatively high H/W ratios, 0.72, both sides of a space «have a combined effect on the microclimatic behaviour of the whole section» (Nikolopoulou, 2004; 14).
- The radiative heat emitted between bodies is conversely proportional to the square of the distance between them (Alexandri, 2005; 51).

Whenever applied throughout a city, the retrofitting of public spaces in compact urban areas through programmes of ‘cool’ materials and vegetation may lead to significant changes in the energy balance of the entire city. ‘Cool’ surfaces and vegetation can significantly reduce air temperature and thus reduce cooling-energy use (Akbari and Konopacki, 2004, 192; 2005, 3). Santamouris (2011; 3086) states that ‘cool’ materials «are a cost effective, environmentally friendly and passive technique that contributes to achieving energy efficiency in buildings by lowering energy demand for cooling and improving the urban microclimate by lowering surface and air temperatures». Reducing energy consumption in the building sector can be quite relevant not only in environmental grounds but also in economic grounds since in most countries it represents about one third of the total energy consumption (Synnefa, Santamouris et al., 2007; 1167). These strategies «not only assure cost savings to individual homeowners and commercial consumers, but also reduce energy consumption citywide» (Akbari, 2002; S119).

There is hence almost no doubt that cities in hot regions would benefit if their ground surfaces were as light-coloured as possible (Pomerantz, Akbari et al., 2003; 11). Romero (2001; 85) argues at this respect that in warm regions the combined effects of reflectance and emissivity can lead to better living conditions.

Since the surfaces of a space may account with several different cladding materials or non-homogeneous paving solutions, it is important to acknowledge eventual exceptions in the continuity of horizontal and/or vertical surfaces (Figure 27). This will allow knowing which surface(s) will need corrective measures and those which will not; exactly where to intervene and to which extent; and selecting the type of corrective measures.

Fig.27 – Contrasting facing materials in an urban front. Paris, France. Source: João Cortesão, 2010.

While it is likely for ground surfaces to be fully-intervened, as these are in most cases owned by public entities, vertical surfaces might present more restrictions to a complete intervention since they are more prone to have a private ownership. The opportunity of intervening simultaneously in all ground and vertical surfaces is, from a practical point of view, of an exceptional character. In theoretical terms, this would only be possible if the space was completely owned by a public entity and the improvements made part of the local urban development agenda. This can become the application of programmes of 'cool' materials and vegetation a long-term process entailing the management of all ownerships and public/private interests converging (and eventually conflicting) to one same public space.

5.3. Additional issues

5.3.1. Environmental impacts

In addition to the potential for microclimatic improvement, programmes of ‘cool’ materials and vegetation should be weighed according to environmental concerns. This is *sine qua non* to any intervention rooted on sustainability. Capital and operational costs, availability, fabrication, energy required for production, maintenance requirements, and capacity for reuse and/or recycling (Domone and Illston, 2010; 529) are aspects that beyond the ability to fulfil structural requirements should be taken into consideration.

Many aspects are obviously more related to materials than to vegetation. This is due to the fact that, for instance, the use of vegetation not only does not threaten natural stocks as it can help enhancing ecosystems; vegetation is easily reusable and/or recyclable; vegetation produces less, biodegradable and/or easily reusable and recyclable waste during construction and demolition. Nonetheless, both morphologic elements should be carefully brought together whenever the improvement of a space’s microclimate is in stake.

The environmental reasoning around the specification of materials for a project should be established from the early design stages, continue throughout the detailed design and the pre-construction stage, to the hand-over of the design waste management plan to the main contractor (Nelson and Powers, 2011; 16). Conspicuous amongst the main criteria and indicators to weigh is life cycle assessment (LCA).

LCA is a procedure developed over the last few decades, standardised in the DIN ISO 14040-14043, which can be used as a method for the evaluation of the environmental impacts of construction or buildings materials alternatives — LCA is a cradle-to-grave analysis of a building element (Hegger, Auch-Schwelk et al., 2006; 24; 98). The environmentally-oriented LCA of products must deal with understanding the environmental aspects of products throughout their life cycle (Goedkoop, 1995; 5).

Bearing in mind LCA, the environmental concerns around the choice of materials can be seen from two different perspectives: on one hand the impacts related to extraction, processing, transportation, installation, maintenance, demolition and recycling or disposal; on the other hand the influence the selected materials have on the environmental performance of a building as a whole (AAVV, 2001; 113). In the context of the first perspective, that with which this research is more concerned, Domone and Illston (2010; 539; 540) mention a hierarchy of overarching environmental concerns around materials:

Reduce:

- use of materials
- energy for production and construction
- energy during use

Reuse:

- components
- adapt structures for change of use

Recycle:

- materials after demolition
- waste

Recover:

- energy from materials with few recycling options

Dispose:

- only if no other alternative

According to the LCA procedure, the construction or materials alternatives must be analysed from the ecological viewpoint and quantified relatively to environmental impacts (Hegger, Auch-Schwelk et al., 2006; 24). Bearing this in mind, the main environmental parameters to weigh when specifying a programme of ‘cool’ materials and vegetation are primary energy consumption, capacity for reuse/recycling, stock of raw material/stock of species, waste, and pollution and toxicity.

Primary energy consumption (PEC)

Primary energy consumption or embodied energy is «the total energy consumed in the extraction, manufacture, transport and assembly of building materials and products» (Tunstall, 2006; 354). The process of transformation of materials from raw material to processed material to waste product typical from the building industry requires energy, which is partially stored in the product and partially released again (Hegger, Auch-Schwelk et al., 2006; 21). The primary energy incorporated in a building material is associated to direct energy consumption (extraction of raw materials and processing methods), indirect energy consumption (HVAC, equipments and lighting at the production site), and transportation of materials (Mendonça, 2005; 2-24).

In environmental grounds it is preferable to choose materials little transformed and/or able of fulfilling their function with a minimum consumption of resources (*idem*, 7-12) since materials close to their natural state tend to have less associated energy consumption, waste generation and pollution (Hall, 2005; 272). In addition, «limiting the design to just a few materials generally results in a longer lifetime for a structure because it is easier to coordinate the maintenance and repair cycles» (Hegger, Auch-Schwelk et al., 2006; 20).

Transportation needs should also be minimised to the utmost as well. The energy required for transporting materials is often dependent on the distance, the means of transportation and the mass of the transported material (AAVV, 2001; 114). Large distances between the production and the installation site might not be advisable in energetic terms (Mendonça, 2005; 2-25). In both cases resulting pollution levels must be considered as well. The less centralised production sites are the less transport needs to the installation site and associated combustion of fuel.

In what concerns to vegetation, PEC is mainly related to transportation needs because plants used in urban areas are often raised in local tree nurseries, which entails often short distances and do not involve major energetic consumptions or emission of pollutants.

Capacity for reuse/recycling

The choice for reused or recycled materials is usually an advisable option because these materials can save primary non-renewable resources (Hall, 2005; 272). In addition, it might worth encouraging reuse or recycling of materials at the end of their life, namely through appropriate design and construction practices (*idem*; 273). Reuse is better than recycling which in turn is better than incineration or transportation to landfills (AAVV, 2001; 113).

With respect to vegetation, the same can be said. Although vegetation does not have the same environmental impacts as most building materials when it comes the time for disposal, as it is biodegradable, plants can be used in other applications in the space in order to reduce the environmental impacts of transportation. It may also be weighed the extent to which vegetation can be reused by local households, agriculture, or even industries. For instance, leaves can be composted and branches and trunks can be used for firewood, large-scale composts, or boiler fuel (Akbari, Davis et al. 1992, XXIV).

Stock of raw material/stock of species

When selecting materials and vegetation species, attention should be given to natural stocks as well as to the ability for nature to replenish them. A balance must be found between «the resources used to achieve a good quality of life and the pollution and waste created as a result of using these resources» (Jones and Patterson, 2007; 255). Materials should come from renewable sources as far as possible in order to avoid depleting stocks of non-renewable materials (Hall, 2005; 272). Whenever materials come from non-renewable sources, it is fundamental to ensure that such sources are well managed such as, for timber, by the Forestry Stewardship Council or Pan European Forest Council (*idem*; 273).

It is possible to moderate the use of natural resources by building less, building long-lasting and recyclable buildings, or by using renewable natural resources (AAVV, 2001; 132). The amount of materials used should be minimised to the utmost (Hall, 2005; 272). Jones (2007; 202) states at this respect that future technologies need to be focused on minimising material use, which involves designing waste, reusing and recycling waste, and emphasising a material life cycle approach to the built environment. In addition to using a material sparingly, «the choice of material, the combinations and their proper interconnection determine the overall ecological outcome» (Hegger, Auch-Schwelk et al., 2006; 20).

Waste

The waste generated during construction and demolition or, in the case of vegetation, during planting and removal, should be minimised through co-ordinated design and site practices (Hall, 2005; 273). It is important to «take into account the later dismantling of the building in the initial planning and choosing the materials and forms of construction accordingly» (Hegger, Auch-Schwelk et al., 2006; 21). The same can be said for public spaces.

Reducing waste reduces the amount of material lost and to be removed after installation or demolition. This can provide important economic and environmental benefits associated to the reduction of the amount of waste being incinerated or going to landfill as well as of the need of transportation to landfill or incineration sites. While the waste associated to materials has usually negative impacts on the environment, since it is often made of assembled and non-degradable products which need somehow to be given a final destination (disposal), the waste generated by vegetation is biodegradable so it can be used for other applications with no or few transformation needs. Building materials posing higher risks are those «containing heavy metals and other poisons, and also plastics which are slow to decompose» (Berge, 2000; 27).

Pollution and toxicity

Pollution related to production, construction process and completed buildings «consists of emissions, dust and radiation from materials that are exposed to chemical or physical activity such as warmth, pressure or damage» (idem; 26). For the sake of the quality of the environment and of human health, it is important to avoid hazardous materials (Hall, 2005; 273). Materials should not contain environmentally-contaminating substances in order to preserve the quality of the soil or groundwater or to prevent the emission of irritating gases (Berge, 2000; 307).

A harmless material is expected not to contain or give off any hazardous substances or compounds. Hazardous substances might include arsenic, asbestos, chlorofluorocarbons, (CFCs), pentachlorophenol (PCP), or volatile organic compounds (VOCs), carcinogenic substances, winter smog (dust and SO2), summer smog (VOCs and NOx), airborne heavy metals, waterborne heavy metals, or pesticides in groundwater and surface water (Goedkoop 1995, 24; Hegger, Auch-Schwelk et al., 2006; 268; 269). Although there is a degree of tolerability to hazardous substances, as long as within limited amounts and concentrations, «there is a social consensus that says the intake of pollutants or hazardous substances should generally be prevented» (Hegger, Auch-Schwelk et al., 2006; 21).

Toxicity of materials and building components has a more significant impact on human health indoors than outdoors. In outdoor environments only a reduced number of toxic substances can cause health problems (Goedkoop, 1995; 23) since by comparison to indoor spaces, the higher openness and the more varied and intense air fluxes in outdoor spaces can keep the concentration of these substances to a low, not harmful, level. Evidently under the combination of specific morphologic and topographic characteristics the concentration of air pollutants and toxic substances can rise to potentially harmful levels. For instance, the combination of a low altitude with an urban fabric made up of narrow streets bordered by high buildings can favour the concentration of pollutants and toxic substances in high-traffic areas or areas near industries.

Relatively to vegetation, the concentration of eventually allergenic substances, e.g. pollen or the emission of VOCs (Akbari, 2002; S125) should be considered, especially during spring. The use of chemical fertilizers and/or pesticides for enhancing growth and health of specimens can as well represent some environmental impacts.

5.3.2. Life cycle costing

The aim of life cycle costing is to optimise the value of a building project throughout its in-use lifetime, taking into consideration all its direct and indirect costs (AAVV, 2001; 140). Life cycle cost involves capital/initial costs, usage/operational costs, and environmental costs (*idem*, 141):

- Capital costs relate to purchase and installation costs: purchase cost is the price a financial market determines for an item; installation costs are the costs associated to the necessary technical, instrumental and human resources for building a design scheme.
- Operational costs relate to all actions ensuring the continued quality of a space throughout its in-use lifetime. Maintenance systems should be considered since the early stages of a proposal so that the design is feasible in the long-term (English Partnerships and the Housing Corporation, 2007; 173). For materials, operational costs generally relate to repair, replacement, and cleaning operations. For vegetation, operational costs may deal with health assessment, replacements, trimming and phytosanitary operations. Additionally, human labour and transport workforce should be considered relatively to operational costs.
- Environmental costs relate to the aforementioned relatively to ecological and environmental impacts on air, soil and water, i.e. primary energy consumption, capacity for reuse/recycling, stock of raw material/stock of species, and pollution and toxicity.

Life cycle costing should be considered from the outset, especially at the early design stages rather than in final stages since in final stages designers are likely to feel reluctant to redesign the proposal (Ashworth and Hogg, 2000; 55). Nevertheless, it is important to consider that life cycle costing «is at best a snapshot in time; in the light of present-day knowledge and practice and anticipated future applications» (*idem*; 69). Indeed, «it is extremely difficult to assess accurately the cost of every single item in a large project and it is virtually certain that there will be mistakes and errors of judgement» (Hillebrandt, 2000; 163). Major problems can actually be found in life cycle costing, especially around the estimation of the cost of usage since this requires knowledge about the anticipated costs of maintenance and renewal (Hegger, Auch-Schwelk et al., 2006; 25). A plausible way of approaching life cycle costs can then be to target those areas where capital benefits can more easily be reached (Ashworth and Hogg, 2000; 54).

Understanding cost requires understanding value. Value is an extremely subjective judgement as it is «not intrinsic within an item but it is the relationship placed by someone on a particular item» (idem; 1; 2). The definition of cost is also related to each particular economic situation, prices, market forces, inflation, discount rates or taxations of a region. As Gruneberg (1997; 5) argues, «there is no such thing as a single economic solution for all societies, that could be applied to all countries».

With respect to urban design, «any answers about the value of urban design are only relative, given the varying contextual and market conditions at a local scale and the peculiarities of the different sectors within which decisions on design are made» (Carmona, de Magalhães et al., 2002; 145). As for many other areas, «the benchmarking of quality, as opposed to finite acts, has always proven difficult; design is no exception» (Brown, 2001; 115). As the architectural field is fundamentally related to experiences of pure delight, its value is subjective (Emmitt, Prins et al., 2009; 6). For someone possessing all its senses, the experience of architecture is firstly visual and kinaesthetic (Meiss, 1990; 25). Therefore, although feasibility and economic viability cannot be disregarded in public space projects, there is a need for giving the less objective criteria of a project the same importance than to more objective aspects.

Programmes of facing materials and vegetation tend not to entail major costs. High-albedo urban surfaces and shade trees constitute inexpensive measures for reducing summertime temperatures (Taha, Sailor et al., 1992, 4; Bretz, Akbari et al., 1998, 95; Taha, Chang et al., 2000, 5; Akbari and Konopacki, 2005, 3; Prado and Ferreira, 2005, 300). In what concerns to facing materials, resurfacing operations can be economical when undertaken during maintenance operations of both ground surfaces and building facades. Due to external factors such as a dull image or poor technical quality it is often necessary to pay attention to the building's envelope (Bragança, 2007; viii). This can represent an opportunity to alter a building's wall facing materials. Relatively to vegetation, the engagement of local communities in planting and maintenance operations can lead to savings in planting and aftercare operations. In addition, depending on each site, the increase in vegetation may not require massive changes to the space. For instance, the simple removal of some paved areas may be enough for planting a tree (Figure 28).

Fig.28 – Ground paving partially removed for tree planting. Cardiff, United Kingdom.
Source: João Cortesão, 2011.

'Cheapness' does not necessarily mean economic optimisation — cheapness in itself is of no virtue and it is worthwhile paying more initially if the longer-term gains in what concerns to the overall value of a space exceed the initial higher capital costs (Ashworth and Hogg, 2000; 2). Too many 'cheap' options «can lead to poor standards in the finished building» (Briscoe, 1988; 146). The same can be said to outdoor public spaces. Economic optimisation is the result of determining the most economical solution in terms of both effectiveness and efficiency (Ashworth and Hogg, 2000; 5). Whenever efficiency and effectiveness bring excellence to a public space, making it environmentally and economically profitable and socially thriving, eventual high capital costs can be outweighed.

Many of the costs associated to initial cheapness in the long run related to durability and resistance. Where durability and resistance are low, frequent maintenance and replacement operations are often required. These operations entail higher economic and environmental costs in the longer-term, eventually undermining the initial savings provided by cheaper solutions. Nevertheless, choice can fall over a solution presenting financial savings in both short and long-term: it is possible to choose a combination of materials and vegetation entailing low capital and operational costs. If on one hand making a choice merely based on how cheap an item is should be avoided, on the other hand good options do not compulsory entail 'expensive' solutions.

The easiest way to calculate the actual cost of an investment is to determine the revenue period (AAVV, 2001; 140). The revenue of the intellectual and capital investment around sustainability often takes years to become significant enough to make it attractive to decision-makers, investors and stakeholders — the common construction industry tends to have a short-term vision and a resistance to the adoption of innovation and to the adaptation of practice through experience, whereas sustainable construction has a long-term vision and entails change (Myers, 2004; 240).

Faced to the invariable difficulty in quantifying the value of design in architecture grounds, the point is then determining the architectural value «by the realisation of a long-lasting, multifaceted, pluralist and dynamic object» (Emmitt, Prins et al., 2009; 7). Good urban design, on a bioclimatic perspective or otherwise, establishes a direct relationship to the capacity of a site to attract residents, public services, and businesses. As Healey, Cameron et al. (1995; 7; 18) refer, «the quality of a city can become an economic asset in the struggle to capture and retain [...] company investment». Companies are attracted to places «that offer well-designed, well-managed public places and these in turn attract customers, employees and services» (Woolley, Rose et al., 2009; 5). Through good design important economical revenues from the initial investment can be achieved during the in-use period of a space.

Programmes of 'cool' materials and vegetation are no exception to this. The capacity for the specified materials and vegetation to effectively improve the microclimate of public spaces, and thus to enrich the public realm by attracting people and businesses, can outweigh the costs of retrofitting a space which, eventually, for other parameters of qualification of public spaces presented a good situation. Any extra-cost entailed with a programme of 'cool' materials and vegetation should be considered according to the expected benefits outcoming from its application in the long-term in environmental, economic and social terms.

The investment in programmes of 'cool' materials and vegetation can make the final satisfaction of beneficiaries of a retrofitting intervention go beyond simple 'satisfaction'. It can help creating pedestrian public spaces which people feel impelled to use, to enjoy; pedestrian public spaces to which people may give a high spatial, and therefore social, significance rather than a space where cars were merely taken off and where the ground surface was though as to receive pedestrian activities which end up not taking place in a socially relevant way. Together with the conditions offered for parameters such as relaxation, active and passive involvement, exploration, access, freedom to act, fruition, transformation, individual and group connections, legibility or relevance, programmes of 'cool' materials and vegetation, on a bioclimatic perspective, can add value to public spaces.

However, since there may be a substantial time lag before initial capital investments can be recouped, it is fundamental for all parties involved in the conception of public spaces to consider that creating high-quality public spaces involves effort, commitment, and eventually greater initial risks but also greater rewards in the long term (English Partnerships and the Housing Corporation, 2007; 119).

5.3.3. Socio-cultural aspects

It may be important to choose materials and vegetation species able of reinforcing the character and identity of an urban area and of cultivating a sense of belonging between all users — «effective urban design policies have the potential to reinforce local character and create places with a real sense of identity» (*idem*; 41). The importance that fostering a sense of place has is that in order to obtain an existential foothold, man should be able of become oriented, to know where he stands, but also be able to identify himself with the environment (Norberg-Schulz, 1986; 19).

The stronger the bond between people and space, the more likely people will be driven to naturally enjoy and care of public spaces. Facing materials and vegetation play an important role here as they can be easily identified by people: both parameters are amongst the morphologic elements with a higher impact on a space's visual identity.

A sense of place «grows as we become accustomed to it and learn to know its peculiarities» (Jackson, 1994; 151). In this context, locally available materials and indigenous vegetation have the potential to establish a strong bond between the space and people. The incorporation of these elements can bring important benefits in economic and environmental terms:

- The use of locally available materials and indigenous vegetation can reduce transportation needs. The closely materials and vegetation are from an intervention site, the less need will be for transport from the production to the application site. The need to travel is unnecessary when a same type of work is available in a firm's own neighbourhood or catchment area (Myers, 2004; 11). The advantages of considering locally available materials are especially relevant for heavier elements (Mendonça, 2005; 7-12).
- The less time required for transportation will allow a faster progress of the site works and to more efficiently manage the ordering and delivery process of materials and vegetation. The management of the ordering and delivery process is considerably important because if materials and vegetation arrive on site too early they may deteriorate, be stolen, or cause access problems around the site; if materials and vegetation arrive late the completion of a scheme may be delayed. Eventually this can result in financial penalties from the client and higher interest charges on borrowed capital as the time for completion is extended (Briscoe, 1988; 147).
- Using 'local' materials and vegetation can reduce the costs related to taxes in the case of international importations.
- The use of indigenous vegetation can reduce maintenance costs since native species require less maintaining and are more resistant, as they are already acclimatized to each territory (Higueras, 2006; 82).

Despite these advantages, relatively to vegetation it is important to bear in mind that the use of indigenous vegetation may not necessarily represent a good option: although requiring less maintenance and being more resistant, indigenous species might not be suitable for use in urban areas due e.g. to their shape, root system, attraction of aphides, or production of staining or allergenic substances. This may have substantial impacts on the way vegetation will relate to the other physical elements of the space such as the evenness of pavings or the integrity of aerial and underground services; on the health of urbanites namely in what concerns to allergies during spring; or on the maintenance of spaces since, for instance, staining substances may entail more regular cleaning operations and the eventual use of chemical products for washing.

In addition to help reinforcing the character and identity of an urban area, of cultivating a sense of belonging between all actual and potential users, and to the aforementioned economic and environmental benefits, the use of locally available materials and indigenous vegetation may as well help incorporating local human resources. This incorporation means «sharing powers and resources as well as accepting know-how and competence of non-experts» (Plass and Kaltenegger, 2007; 210). Incorporating local human resources has as main benefit helping to enhance job and training prospects for local people, incorporating local know-how in the building of public spaces, and enhancing the participation of locals in the design process. Furthermore, «supporting local building crafts enlivens the culture, and building with the materials and talents of the region strengthens local economies» (Elizabeth and Adams 2000, 8-9).

5.4. CONCLUDING REMARKS

Adapting the built environment to the substantial increase in temperature extremes presents higher difficulties in compact urban areas — in compact urban areas the hard structure cannot, or can hardly, be changed because the built environment is already defined. It follows that, conversely to new urban expansion areas, in compact urban areas one must try to make the best out of the existing structures. Amongst all bioclimatic urban design morphologic elements, facing materials and vegetation are potentially the most easily and likely workable in compact urban areas: facing materials and vegetation in often subtle ways can help greatly improving microclimates; they can produce effective results through smaller-scale interventions when compared to other morphologic elements.

Programmes of high-albedo and high-emissivity materials (‘cool’ materials) and vegetation with appropriate biophysical parameters can deliver important microclimatic amenities to public spaces during summer and, thus, help adapting the built environment to the substantial increase in temperature extremes brought by climate change. Bearing this in mind, these programmes have two main goals: the reduction of the amount of direct solar radiation striking the surfaces of a space; and the increase of the heat losses taking place at the ground level, where pedestrian circulation is held. This can be achieved by increasing shading by trees and/or man-made shading devices, by using ‘cool’ materials, and by increasing evaporative cooling through vegetation.

Horizontal and vertical surfaces can be considered as the two most relevant vectors for understanding and intervening over the microclimate of outdoor public spaces because these vectors possess all elements confining, shaping and characterising the space. The characteristics of the horizontal and vertical surfaces of a space can largely determine the processes through which the climatic variables act at site defining its microclimate. The concept of ‘climatic skin’, as the whole body of horizontal and vertical surfaces defining an outdoor public space, can be particularly relevant here. Beyond the potential for microclimatic improvement, materials and vegetation should also be appreciated bearing in mind environmental impacts, life cycle costing, and socio-cultural aspects.

This chapter addressed the potential that the combination of materials and vegetation has for the adaptation of the built environment to the substantial increase in temperature extremes brought by climate change. The literature review showed that faced to the rather positive contribute bioclimatic urban design can give for adapting the built environment to climate change, the development of a methodology for supporting retrofitting proposals in compact urban areas based on ‘cool’ materials and vegetation can benefit from being shaped according to its principles.

Each case is unique so although in this research equal importance is assigned to facing materials and vegetation, each project can/should focus more or less on one or the other parameter, according to its climatic, topographic, morphological, socio-cultural, and functional specificities. The consideration of local specificities will determine the ability of a scheme based on a programme of ‘cool’ materials and vegetation to help adapting the built environment to the substantial increase in temperature extremes brought by climate change and to help achieving the goals of the sustainable city.

At a time when climate change is placing an ever-growing challenge to the quality of life in urban areas, countering the substantial increase in temperature extremes brought by climate change is paramount. Programmes of ‘cool’ materials and vegetation can play a significant role here by reducing the amount of direct solar radiation striking the surfaces of a space and by increasing the heat losses taking place at the ground level. These strategies can help making the pedestrianisation of public spaces more successful, since people will be more able to cope with a public space’s microclimate.

6
CASE STUDY

This chapter addresses the case study of this research. An undertaken field survey at two public spaces in Porto, Portugal, will be presented as a means of quantifying the extent to which facing materials and vegetation can actually determine the microclimate of outdoor public spaces in compact urban areas and, through this, the validity of programmes of ‘cool’ materials and vegetation as a means for help adapting the built environment to the substantial increase in temperature extremes brought by climate change.

Section 6.1 contextualises the spaces selected as case study; section 6.2 addresses the general options and selected tools for undertaking the field survey; section 6.3 presents the results from the field survey; and finally, section 6.4 presents some concluding remarks about the field survey.

6.1. CONTEXTUALISATION

6.1.1. POVEIROS SQUARE AND SÃO LÁZARO GARDEN

Poveiros Square and São Lázaro Garden (Figure 29) are two public spaces in Porto selected as case study. These spaces were considered to provide the ideal scenario to illustrate the importance of facing materials and vegetation in influencing the microclimate of pedestrian public spaces located in compact urban areas during summer since except for paving materials and vegetation, these two spaces present no significant morphologic differences — these are two spaces in visual and physical continuity, both presenting a practically flat topography; an east-west orientation; a similar physical configuration though with different dimensions; the same W/H ratio (2>2/1); same placement; same surrounding built average heights, density and morphologic characteristics (e.g. colours, facing materials or type and size of openings); centrality with regard to pedestrian circulation; adjacent functions. Still, these spaces exhibit a dramatically different pattern of use: during summer, while the square is barely used, the garden presents a significant pattern of use throughout the day.

Fig.29 – Aerial view of the analysed spaces (top), Poveiros Square (bottom left), and São Lázaro Garden (bottom right). Source: GoogleEarth, 2009 (top); João Cortesão, 2011 (bottom).

The present layout of Poveiros Square dates back to 1997, to the time that an underground public car park was built to release the square from traffic and parked vehicles and, therefore, recover an important pedestrian area of the city, and also to increase the parking offer at the city centre. Although knowing several different shapes throughout the years and with the exception of the mid-20th century when a surface car parking was built, this square has always been an important area for the meeting and enjoyment of local residents. The underground car parking which is presently owned, managed and maintained by the private company EMPARQUE. The square is owned, managed and maintained by Porto City Hall.

São Lázaro Garden is a typical enclosed and formal Romantic garden built for several purposes which according to Madureira (2000; 41) are: firstly, for providing a space for the contact with nature, lessening the urban rhythm; secondly, the garden is the result of a municipal plan of 1757 targeted at planting trees in a former an open field as a way of valorising the fairs that used to be held at that site; finally, to provide the city with a public garden with a strong architectonic identity for leisure activities much associated to a bourgeoisie culture demanding for new life styles. Presently, São Lázaro Garden constitutes a fundamental part of the public green system of vegetated streets in the eastern part of Porto’s city centre (*idem*, 51), and it is not surprising that its historical importance as the city’s first public garden (opening to public in 1834) and as a privileged space for leisure have make the garden an appealing and prestigious urban public space in the city centre till the past few decades. The management and maintenance of São Lázaro Garden is also the responsibility of Porto City Hall.

6.1.2. THE CLIMATE OF PORTO

Porto is located in a climatic region classified as Warm Temperate, subtype Csb, according to Köppen-Geiger classification (Kottek, Grieser et al., 2006; 261). This classification entails warm and dry summers. The climate of Porto is also influenced by the ocean, which results in softened extreme temperatures; high air humidity and precipitation in all seasons; strong winds and instable weather (Cuadrat and Pita 2009, 372). More particularly, according to Monteiro (1997; 81-161), the climate of Porto can be characterised as follows:

- July presents the highest temperatures so summer in Porto begins by later June till later August. However, considering the maximum temperatures (which present a great irregularity of values between late June and early July), summer can be said to extend definitely and with some constancy from between the end of July to late August.
- The most probable maximum temperatures during this period are between 24ºC and 26ºC. Temperatures above 32ºC and under 18ºC are not likely to occur.
- Minimum temperatures in summer may go down between 14 °C and 16 °C.
- Winter period is established with some consistency from late November to late February reaching minimum temperatures between 4 °C and 6 °C and maximum temperatures between 12 °C and 14 °C. The transition from summer to winter is calmer, slower and gradual than the transition of winter to summer.
- According to Köppen's classification the wetter month in Porto receives a volume of rain three times superior to that of the driest month, and the overall average temperatures are higher than -3 °C for the coldest month and lower than 22 °C for the hottest month (Góis, 2002; 3.22). In June, July and August rain values rarely go above 50mm. July and August present the lowest monthly values of precipitation while for the rest of the year considerable levels of rain are expected.
- Relative humidity presents high values (≥ 75 %, at 9 a.m.) year-round due to the proximity of the seashore and to the absence of obstacles for the humid air coming from the ocean. However, from the data collected in different meteorological stations, Monteiro (1997; 129) points out July as the month presenting the highest levels of evaporation year-round.
- In what concerns to wind speed, there is a slow reduction of wind velocity during summer season with its minimum in August. From April to September the northwest winds are the strongest and more frequent. In terms of dominant wind directions in summer, between June and August the west, northwest or southwest directions are the most frequent while in winter east winds are predominant. Wind speeds recorded at the city centre are usually around 20 Km/h (5.5 m/s).

Notwithstanding the predominant order in the summer characteristics of Porto, Monteiro (*idem*, 294,206) argues that the worsening of 'local greenhouse effect' caused by the intense urbanisation phenomenon in the last decades has introduced some changes in temperatures and precipitation regimes, namely a trend for a gradual rise in air temperatures and higher levels of rain during the wet season as well as lower levels during the dry season.

Field surveys undertaken by Góis (2002; 7.3) with respect to the urban heat island phenomenon in Porto have shown that the city's central core and central core's periphery systematically exhibited the highest temperatures, irrespectively the season when the measurements were made (Figure 30). This is likely to be due to the high urban and populational density of the central core of Porto, to the proximity to the river, to the near absence of green areas, to the dramatic topography, and to the intense traffic (Monteiro, 1997, 285; Góis, 2002, 7.5). The southern limit of the city centre presents a particularly dramatic topography and a high density urban pattern constituted of old (built before 1945) and high (normally up to three or more floors) buildings as well as narrow streets and few green spaces (Monteiro, 1997; 57). Poveiros Square and São Lázaro Garden are both located in this area of the city centre and therefore are directly under the influence of its urban heat island (Figure 30).

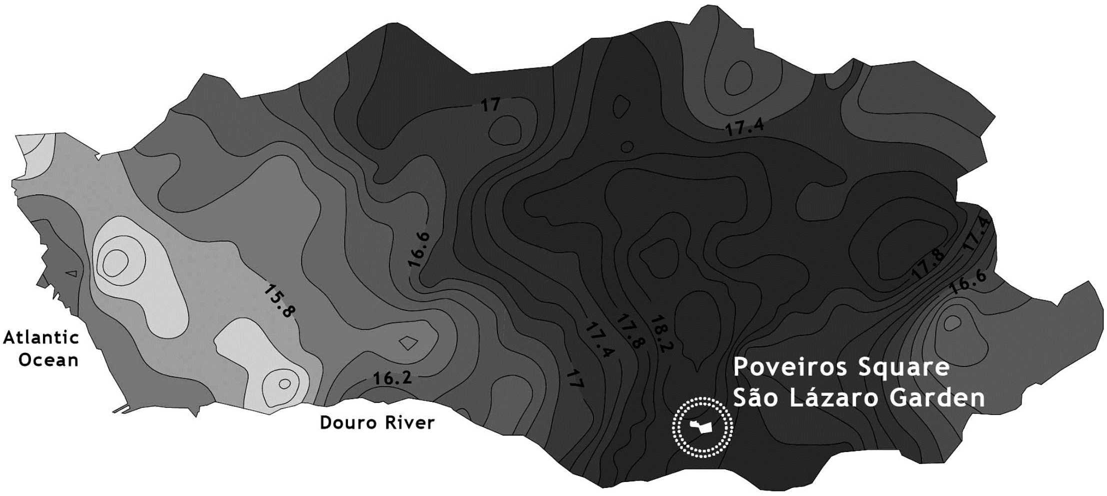


Fig.30 – The case study within Porto's urban heat island. Adapted from Góis (2002; 6.11).

In addition, due to its location, between the parallels 41°08'N and 41°11'N and the meridians 8°33'W and 8°41'W Greenwich, Porto will most probably be seriously affected by climate change (Monteiro, 1997; 39). Correspondently, at the national scale the SIAM II Project has verified a considerable increase and in the same magnitude in the average maximum and minimum temperatures in Portugal mainland in the last twenty-five years of the 20th century (Santos and Miranda, 2006; 51).

The combination of the effects of Porto's heat island with the expected impacts of climate change suggest that summer thermal conditions in Porto can be problematic in the future. Under the predicted climate change scenarios summer thermal constraints in this city are likely to be exacerbated. Even though it is possible to account with eventual mitigations provided by the influence of the sea and river breezes, Porto will most probably be faced with higher thermal stress placed upon buildings, public spaces, and people.

6.2. FIELD SURVEY

6.2.1. GENERAL OPTIONS

The field survey has combined the collection of objective (microclimatic monitoring) and subjective (observation and questionnaires) data. In addition, the importance of empirical data on the (subjective) human parameter in outdoor spaces has been acknowledged. This allowed addressing the analysed microclimates on the perspective of how people actually 'perceive' it.

July has been the warmest month in Porto for the past few decades. Additionally, July is the only summer month presenting the normal year-round pattern of activities in the city because in August many people are out on holidays. The field survey was then undertaken during the first two weeks of July 2011. Two initial preparation field surveys were carried out in July 2009 and 2010.

The field survey covered a 15-day period though data collected refers to 10 days, 5 days per space, because only days of clear or predominantly clear skies were considered for analysing data. This was intended to provide, as much as possible, data related to 'typical summer days' in Porto. The delimitation of the 15-days period of analysis was established considering: (1) the availability of equipment to perform the microclimatic monitoring; and (2) the outcomes of the previous field surveys which showed that after 15 days data collected would start providing no new insights. This was to prevent lack of accuracy in the obtained results since «the longer the time period covered the less representative the survey may be of the entire period» (American Society of Heating 2010, 25).

The field survey was undertaken between 11 a.m. and 2 p.m. This corresponds to the daily period when absolute values for air temperature and solar radiation are higher (Monteiro, 1997; 229; 244); and to one of the daily periods when pedestrian activity outdoors is more significant (lunchtime and, at around 11 a.m., coffee-breaks).

The field survey consisted of a functional, morphologic, social/personal and microclimatic analysis of one and the other space. Each analysis was targeted at characterising and making a diagnosis of both spaces. The functional analysis focused the way how each space effectively functions and the activities they held; the morphologic analysis was aimed at collecting detailed information about their physical layouts; the social/personal analysis was concerned with gathering information on the spaces' users, the way they were acting at site, as well as their personal evaluations about the microclimate of the space they were in at the moment of the interview; finally, the microclimatic monitoring was aimed at quantifying the extent to which, under the same general climatic conditions, the physical layout of Poveiros Square and São Lázaro Garden (with a special focus on facing materials and vegetation) were at the basis of their contrasting attractiveness to pedestrians.

6.2.2. SELECTED TOOLS

The tools selected for undertaking the field survey were observation, questionnaires, and a portable meteorological station. Each of these tools had a specific purpose: the observation exercise served the morphologic, functional, and social/personal analysis; the questionnaires served the social/personal analysis; and the meteorological station served the microclimatic monitoring.

In order to undertake the four analyses simultaneously in each space, a team of three elements was gathered. This team shared responsibilities in collecting data: two elements were responsible for collecting data concerning the social/personal analysis, namely the filling in of the observation datasheet and the conduction of the interviews; the third element was responsible for collecting data related to the functional and morphologic analysis as well as data of some instruments of the meteorological station, and for ensuring their proper functioning.

6.2.2.1. Observations

The observation exercise comprised the filling in of three datasheets: one for functional, another for morphologic, and another for personal parameters. These three datasheets are presented in Annex A.

The datasheet for functional parameters was conceived to provide a complete comprehension of the main functional characteristics of the spaces and its relation with the usage patterns of each space. It was aimed to assess how effectively pedestrian each space was. Several references were at the basis of the gathering of parameters, such as Carr, Francis et al. (1995), Romero (2001), Santamouris (2001), Alves (2003), or Nikolopoulou (2004).

The datasheet for morphological parameters was aimed at characterising the layout of both analysed spaces. This datasheet was prepared based on previous studies on the same research field, such as Carr, Francis et al. (1995), Romero (2001), Santamouris (2001), Brandão, Carrelo et al. (2002), Alves (2003), Nikolopoulou (2004), or Higueras (2006). Additional parameters about facing materials and vegetation were introduced.

The datasheet for social/personal parameters was conceived collecting personal data during the interviews, namely parameters which were not asked to respondents such as behaviour, clothing and activity level, gender, position or movements. The main references for the development of this datasheet were Spagnolo and de Dear (2003), Nikolopoulou (2004), Mean and Tims (2005), Higueras (2006), Nikolopoulou and Lykoudis (2006), or Oliveira and Andrade (2007).

The social/personal observation datasheet has valued two crucial issues: types of users and clothing level. The types of users were empirically defined by the observation exercise and the questionnaires. The identified types of users do not constitute an exhaustive nor definite categorisation but rather a way of trying to know the diversity of ways in which people interact with the square and the garden. In what concerns to the clothing levels, three clothing ensembles for man and women were considered having as reference the clothing insulation values for typical ensembles presented in the ASHRAE Standard 55 (2010; 18). Simultaneously, the considered ensembles represent the three main types of clothing usually worn during summer in Porto. Detailed information on these ensembles is presented in Annex B.

6.2.2.2. Questionnaire

A structured questionnaire (Annex C) was prepared to evaluate the thermal comfort conditions people experienced and their perception of the thermal environment of the space they were at. A total of 110 interviews, 55 per space, were carried out. The number of interviewees was limited to the number of people present at each space willing to be interviewed. Each interview comprised 21 questions and took around 8 minutes to complete. Interviewees were randomly selected between people passing through or sitting in each space. The sample of users was then heterogeneous in terms of age, gender, social group, activity, and clothing level. As a consequence, the interviews were held in different locations within the analysed spaces. These options allowed having a broader and more realistic perspective of the spaces' users.

The questionnaire was mainly prepared with consideration to the ISO 10551:2001 standard (Ergonomics of the thermal environment — Assessment of the influence of the thermal environment using subjective judgement scales). A short-answer and closed questions format was considered. In order to comply with ISO 10551 standard, attention was given to the terminology and wording used. The questionnaire was structured in two parts: questions and pictures.

The first part of the questionnaire constituted the questionnaire itself and it was sub-divided into seven interrelated sections. The first five sections were based on the considerations of the ISO 10551 standard and refer to five different judgement scales — thermal perceptual scale, thermal evaluative scale, thermal preference scale, acceptability scale, and tolerance scale. According to ISO 10551 standard (ISO, 2001a; 3,1), the combination of answers on these scales provides the required information for judging the subjective human parameter, namely through «reliable and comparative data on the subjective aspects of thermal comfort or thermal stress». In more detail:

- Thermal sensation votes were rated on the ASHRAE seven-point thermal sensation scale.
- Thermal evaluation, or thermal comfort, votes were rated on a proposed scale. Though not entirely complying with the three to four-point one-pole scale presented by ISO 10551 for the evaluative scale, the herewith considered scale was considered to be better suited to this research. Instead of considering a point of origin (comfort) and a point of highest effect (discomfort), it was opted to distribute the rating points symmetrically in a both a positive and negative direction of thermal comfort conditions, i.e. in the direction of warm or cold temperatures. This bipolar scale allowed qualifying people's thermal evaluations, either associated to cold or warm conditions.
- The adopted thermal preference scale, also from the ISO 10551 standard, is a seven-point bipolar scale that presents the highest effects on the poles and several degrees between them and the central point.
- Based on the ISO 10551 standard, the four-point acceptability scale is based on the rejection or acceptance of the thermal conditions of an environment, on a personal level.
- The five-point tolerance scale, based on the ISO 10551 standard, expresses the difficulty, or not, of people in tolerating the thermal conditions of an environment.

The sixth section of the questionnaire consisted of questions for evaluating the extent to which people could perceive the role facing materials and vegetation were playing in their thermal experience. Finally, the seventh section related to general personal parameters, aimed at gathering additional information about the interviewees that could eventually help understanding their votes in depth, and clarify less clear votes, i.e. votes apparently contradictory. These two last sections were based in previous studies in the same research field, such as from Spagnolo and de Dear (2003), Nikolopoulou (2004), Nikolopoulou and Lykoudis (2006), or Oliveira and Andrade (2007).

The second part of the questionnaire was targeted at knowing people's capacity to associate given ensembles of materials and vegetation to the conditions offered for thermal comfort. This was made by means of three pictures of different public spaces (Annex C) with contrasting facing materials and amount of vegetation. No contextualisation or description was made for any picture. People were shown the pictures and asked to select the potentially most pleasant and most unpleasant space from a thermal viewpoint in a typical summer day. Selecting the potentially most pleasant and most unpleasant space from a thermal viewpoint, would allow people to unconsciously confirm (or not) their previous votes for the judgement scales, as these were unknown spaces for them.

At a later stage, the owners of the 14 businesses surrounding the square were contacted in order to know how the square was influencing the business. This *in loco* contact consisted of a short questionnaire (Annex D) and of the same three pictures shown to people found at the square.

6.2.2.3. Microclimatic monitoring

A portable meteorological station was used for the microclimatic monitoring of the analysed spaces (Annex E). The ISO 7726 standard (Ergonomics of the thermal environment - Instruments for measuring physical quantities) was considered for the preparation of the microclimatic monitoring, namely the methodology and instruments for measuring the selected physical quantities.

The microclimatic monitoring was undertaken simultaneously with the interviews in order to associate the answers given by each interviewee (subjective data) to a specific microclimatic condition (objective data). The meteorological station was placed next to the interviewee irrespectively if sitting, standing or passing by. When passing by, people were asked to stop near the station in a sufficient distance for not influencing data recording (e.g. shading by the body). Measurements were performed at a height of 1.1 meter above the ground level. This level corresponds to the average height of the abdomen level of a standing adult (ISO, 2001b; 11).

The climatic variables chosen to monitor were those related to the basic physical quantities that characterise an outdoor environment presented by the ISO 7726 standard: air temperature, relative humidity, direct solar radiation, wind speed, and mean radiant temperature. Annex E lists the climatic variables monitored during the field survey with relation to the instruments composing the used portable meteorological station. All the equipment was kindly provided by the Building Physics Laboratory (LFC) of the Faculty of Engineering of Porto University.

Air temperature

Air temperature was measured in degrees Celsius (°C) through a dry-bulb thermometer. Care was taken in order to prevent that the sensor was exposed to direct solar radiation and nearby heat sources through the use of a solar radiation shield.

Relative humidity

Relative humidity was measured in percentage (%) through a hygrometer which was protected from wind through the use of the same shield as for air temperature.

Direct solar radiation

Direct solar radiation was measured in watts per square meter (W/m^2) through the use of a pyranometer. Data provided by SolTerm 5.0 (software used as a reference for assessing and pre-dimensioning solar systems in Portugal) confirms that July usually presents the highest values of solar radiation in Porto, with an average monthly value of 823 W/m^2. According to the same source, daily heat peak hour (11 a.m. to 2 p.m.) can be of as much as 1.010 W/m^2. Through the use of a solar chart, it was possible to determine that for the field survey period solar elevation reaches 71° at 12:30 p.m. local time — solar noon.

Wind speed

The measurement of wind speed was made in meters per second (m/s) through a hot-wire anemometer. Care was taken to prevent any obstruction of wind flow near the sensor.

Mean radiant temperature

Mean radiant temperature was measured in degrees Celsius (°C) with a standard matt black globe thermometer. The adopted procedure complies with ISO 7726. After collecting globe temperature values, MRT was calculated through the expression for determining it by natural convection and for the use of a standard globe (D = 0.15m, εg = 0.95) presented in ISO 7726:

$$t_{\mathrm{r}} = \left[\left(t_{\mathrm{g}} + 273\right)^4 + 0{,}4 \times 10^8 \left|t_{\mathrm{g}} - t_{\mathrm{a}}\right|^{1/4} \times \left(t_{\mathrm{g}} - t_{\mathrm{a}}\right)\right]^{1/4} - 273 \quad (2)$$

where
t_{r} is the MRT, in degrees Celsius;
t_{g} is the temperature of the black globe, in degrees Celsius;
t_{a} is the air temperature, in degrees Celsius.

It is noteworthy, according to ISO 7726 (ISO, 2001b), that the use of a black globe thermometer for estimating MRT is only an approximation due to the difference in shape between a person and a globe. Therefore, and also due to the large physical, climatic and personal variability taking place in outdoor environments, any attempt to assess the long-wave component of the MRT acting on the human body was seen from the start only as an indicative rather than absolute value.

Due to the unavailability of equipment it was not possible to work with two meteorological stations. This impaired undertaking simultaneous measurements. The option for countering this limitation was to perform measurements in one space and the other in alternate days. Despite undertaking the measurements in different days it was considered that as long as these presented similar climatic conditions a comparison of the results obtained for one and the other space would be reliable. Climatic data provided by the meteorological station of the Faculty of Engineering of Porto University (FEUP) and by the Portuguese Institute of Meteorology[2] (IM) was considered for assessing the 'climatic compatibility' between the different days of the field survey. The average values for the data collected from these sources are presented in the following table.

Table 2 – Climatic characterisation of the field survey period. Source: FEUP's meteorological station and IM*.

	T_a (°C)	RH (%)	$K\downarrow$ (W/m^2)	W (m/s)	Wind direction*
Average values for the square	21	63.8	578.9	1.30	NW
Average values for the garden	21	67.6	535.4	1.20	NW

The average values observed for each climatic variable presented significant similarities between the square and the garden. These average values were considered to show the 'climatic compatibility' between the different group of days of the field survey with a fair reliability: the values for air temperature (T_a) are exactly the same; relative humidity (RH) presents a slight difference of 3.8 %; direct solar radiation ($K\downarrow$) presents a difference of 43.51 W/m^2; wind speed (W) only differed by 0.10 m/s between the two groups; and finally wind direction was the same. None of these differences were considered to undermine the comparison between the two groups of days, at least not to the extent of explaining the sharp differences found *in loco* for some variables.

[2] https://www.meteo.pt/pt/index.html (acceded during July 2011)

6.3. Results

6.3.1. Functional analysis

Poveiros Square

The square and its surrounding area accommodate a considerable proportion of through traffic in the east-west and west-east directions. The highway system serves the eastern and western halves of the city as a way to reach to the main roads to exit/enter the city. The square also connects important areas of the city centre such as office complexes, the central administrative district and northern and southern core residential areas, as well as to the main commercial street. This space is then the crossing point between numerous pedestrian destinations for a large number of people.

From the functional viewpoint, the square was designed to accommodate pedestrian activities. The present scheme has provided a calmer ambient to the area since traffic has become less disturbed by entering in or leaving vehicles from the car parking. The built underground car parking conceals the vehicles way in and out with the surrounding traffic flows. There are three crossing points connecting the square to the surrounding pavements. All crossings suit the main desire lines, i.e. «the shortest route between A and B created through use, ignoring a longer formally constructed route» (Tunstall, 2006; 354), one at the northwest side, one at the north side, and another at the south-east side. The square was designed for safe, convenient and seamless use for pedestrians by displacing parked vehicles and barriers associated to car parking and providing well-dimensioned stair steps, ramps, handrails, and lifts to and from the underground car parking.

Nevertheless, the pedestrianisation of Poveiros Square was not able to attract pedestrians and engage them in long-term activities. Pedestrians merely cross the square while heading to somewhere else. With the exception of the cafe terrace existent at the square's northern edge, the square lacks attributes to make it a destination in its own right. In addition, the square was not successful in achieving a 24 hours-use environment: safety and security are not promoted by parameters as lighting, openness, and contiguous buildings' functions. As a consequence, a CCTV system has been introduced in the square's northern edge.

São Lázaro Garden

São Lázaro Garden was designed as a proximity garden (i.e. a space with frequent use by people due to its proximity to the place of residence) and it accommodates a range of different activities. Though there are no specific features encouraging spontaneous public meetings and gatherings, except a bandstand, the garden presents an expressive usage pattern. This usage pattern is coupled with what seems to be a strong sense of community. The area around the bandstand and between it and the central pool concentrate most users. Leisure activities are dominant in these two sub-spaces, especially undertaken by the elderly organised in large groups. The remaining areas of the garden are generally used for strolling, relaxing or simply seeing people passing by.

São Lázaro Garden accommodates a considerable proportion of through traffic in the East-west and West-east directions, connecting the same areas as Poveiros Square. The street bordering the garden's western edge was pedestrianised some years ago. More recently, in early 2012, the pavements surrounding the garden were widened as surface car parking places were partially removed.

São Lázaro Garden is the crossing point between numerous pedestrian destinations for very large number of people throughout the day. There are five crossing points connecting the garden to the surrounding pavements, all well suited to the main desire lines (two at the northern edge, two at the eastern edge, and one at the southern edge). Although the garden is enclosed it provides several crossing opportunities, especially in the East-west direction. There are four entrances positioned in each corner of the garden, each of them establishing an adequate relationship with movement patterns outside the garden.

The garden is safe, convenient and seamless for pedestrians since two of its four entrances are levelled with the surrounding pavements, since the garden is flat, and since the stairs connecting two of its entrances are well-dimensioned. During the night no activity is held in the garden as it is closed. No CCTV system is available. Thus, this space and its surrounding areas are not suitable for 24 hours-use.

Summary of findings [functional analysis]

Although both spaces were conceived as long-term permanence spaces for pedestrians, they present completely different usage patterns: while the square is barely used the garden exhibits an expressive pattern of use all day long. Therefore, the square seems to have failed as a pedestrian space where people gather and stay, whilst the garden has successfully accomplished the goal of providing an open space for people to gather and enjoy. No significant pedestrian activities are held at the square and, thus, its public realm is poor.

The findings from the functional analysis suggest that the sharply different usage patterns of the analysed spaces is not due to the parameters needed for ensuring pedestrian activity since these basically present the same condition in both spaces (more detail on these parameters is provided in Annex F). The parameters at stake here are space function/typology, specific functional requirements, special activities, access and equality, vehicular access, parking places, drainage, water and power supply, night environment, highway systems, buses, taxis stands, coach facilities, bicycle facilities, pedestrian facilities, public facilities and services.

6.3.2. Morphologic analysis

Poveiros Square

Delimitated by *Rua de Santo Ildefonso* (north), *Rua de Passos Manuel* (north), *Rua do Campinho* (west) and *Passeio de São Lázaro* (south), Poveiros Square is a 2.050 m^2 space with a slightly trapezoidal shape, an East-west orientation, and a soft (4 %) north-south gradient. Consequently, the south-facing facades are permanently exposed to direct solar radiation, the north-facing facades only receive some direct solar radiation in the early morning, the west-facing facade receives direct solar radiation only during the morning hours, while the east-facing one only during the afternoon.

The square is bordered by a compact urban fabric of high density mainly composed of terraced buildings up to three to five storeys high. These buildings define a regular urban front around the square. The only exception are the East and West sides that, as being narrower than the North and South sides, are only occupied by one single building each. The buildings composing this urban fabric date back from the late 18th to early 20th centuries, with the exception of the West side where the existing single building dates back from mid-20th century, and fulfil housing and commercial functions: the upper floors receive housing functions whereas varied commercial activities are held on the ground floors.

Soft-coloured ceramic tiles, renders painted in a wide range of colours and granite applications outstand as the more extensive facing materials of facades at site. The general output in terms of colours is a balanced, equally mixed ambience where several different colours co-exist. The facing materials of facades are very rich in terms of colours and patterns as each building possesses a different facing material or ceramic tile pattern. However, it dominates the regularity in terms of surface continuity, alignments and rhythm of openings, tension, texture or level of adjacency. Facades also present a high level of settlement, robustness as well as a low level of flexibility to eventual changes as there are patrimonial regulations aiming to preserve their characteristics (rhythm of openings and ceramic tiles mainly). The only exceptions are the ground-floor levels, where commercial activities are held.

The paving solution of the square is dominated by granite stone cubes which are only interrupted at a raised flowerbed and a pool at the northern edge, as well as at a flowerbed along the square's eastern edge.

Vegetation in Poveiros Square is constituted of 10 medium-adult specimens (3 *Acer palmatum* and 1 *Trachycarpus fortune* at the northern flowerbed, 5 *Ligustrum lucidum* at the eastern edge, and 1 *Tilia platyphyllos Scop.* at the centre of the cafe terrace); of one species of shrubs concentrated in the square's eastern edge in a limited number of adult but trimmed specimens; and of grass in its northern raised flowerbed. However, these are few planted specimens in an inadequate position: five specimens are grouped in the northern flowerbed so their shade is projected to the road bordering the square's northern edge instead than into the square; the remaining five specimens are aligned in the eastern edge of the space but their shade is projected into the square mostly during the morning; finally, all specimens are positioned in the square's perimeter only. This seems to be one of the main reasons why the crossings of pedestrians are made along the square's edge and not through its centre.

Additional elements of public space such as lighting, street furniture, the quality and position of sitting elements, urban art or shading devices present a very weak, absent or inadequate situation. Lighting is unpleasant and trivial since it has not been developed to provide a good luminous quality nor to create interest lighting effects into the space at night (lighting only provides the basic and overall lighting of the space); street furniture is limited to the essential (litter bins, lampposts, handrails and bollards); sitting elements are not only ergonomically uncomfortable as inadequately positioned and in a limited number (three stone seats facing south and one facing west); urban art elements are inexistent; shading devices do not exist except few parasols at the cafe terrace and, in buildings, awnings only exist in ground floor levels with trade activities.

Relatively to local constraints it is relevant to mention that the square is totally within the historical core of Porto, classified as a World Heritage Site by UNESCO, namely within the parish of Santo Ildefonso that corresponds to a city's expansion area of the 18th and 19th centuries; the two single buildings at the east and west edges of the square are listed by Porto City Hall as buildings of architectural importance; and practically the entire built area extended to the western and to the south-eastern side of the square is within a (either Special or Archaeological) Protection Area. Beyond the underground car parking, the square accounts with no relevant physical constraints.

São Lázaro Garden

São Lázaro Garden is delimitated by *Avenida Rodrigues de Freitas* (south), *Passeio de São Lázaro* (north) and *Rua de Dom João IV* (east). This is a 4.500 m^2 flat space with a slightly trapezoidal shape and an East-west orientation. The East-west orientation generates North and South-facing facades which, therefore, present the same exposure to direct solar radiation as facades around the square. However, the trees existing at the garden provide shade to the south-facing facades and pavements ahead.

The garden is surrounded by a compact urban fabric with the same characteristics as that of Poveiros Square. The only difference is that its southern and eastern edges are bordered by two single public buildings which reduce the diversity of wall finishes. The wall finishes of these two buildings are render painted in white and granite applications around doors, windows, and corners. The buildings composing the urban fabric surrounding the garden date back from the 18th, 19th and 20th century and receive housing functions in the upper floors and commercial activities on the ground floors.

The paving materials of the garden present more diversity than those of the square: bare soil for footpaths, grass and seasonal flowers for flowerbeds, a pool with a fountain at its centre, and some granite for the stair steps connecting the garden to the lower-levelled south-bordering street.

Vegetation at this space is characterised by a mature and large ensemble of centenary trees, encompassing both deciduous and evergreen species. Five different species of trees, in a total of 64 adult specimens (2 *Acer palmatum*, 30 *Camellia japonica*, 2 *Cedrus libani*, 12 *Magnolia grandiflora*, 17 *Tilia platyphyllos Scop.*, 1 *Trachycarpus fortune*), four species of shrubs (*Camellia japonica, Gardenia jasminoides, Hydrangea macrophylla*, and *Rhododendron simsii*) throughout the space in a large number of adult specimens, grass or different types of seasonal flowers in the flowerbeds provide a shaded atmosphere, visual relief from the urban milieu, as well as attenuation of noise and atmospheric pollution.

Lighting at São Lázaro Garden is unpleasant and trivial as it merely provides the basic and overall (and still weak) illumination of the space; street furniture is limited to the essential (litter bins, lampposts and benches), however sitting elements are adequate, ergonomically comfortable, sufficient and randomly distributed throughout the space; the garden possesses 7 sculptures from the 19th and 20th century positioned in suitable visual locations; shading devices do not exist in both horizontal and vertical surfaces.

In what concerns to local constraints it is important to highlight that, such as Poveiros Square, São Lázaro Garden is located in an area accounting with a number of constraints related to heritage: the garden is totally within the historical core of Porto, classified as a World Heritage Site by UNESCO, namely within the parish of Santo Ildefonso that corresponds to a city’s expansion area of the 18th and 19th centuries; there are four single buildings around the garden that are listed by Porto City Hall as buildings of architectural importance: one at the southern edge; one at the eastern edge; two at the northern edge; there is one fountain listed by Porto City Hall as buildings of architectural importance at the northern border of the garden; there are seven sculptures throughout the garden listed by Porto City Hall; the garden is within a (either Special or Archaeological) Protection Area; and one of its trees is listed as a protected specimen by Porto City Hall. The garden accounts with no relevant physical constraints.

Summary of findings [morphological analysis]

The morphologic analysis allowed understanding that there are many similarities between the two spaces: these are two spaces in visual and physical continuity both presenting a practically flat topography; an east-west orientation; a similar physical configuration though with different dimensions; low H/W ratios; the same placement, surrounding built average heights, and density and morphologic characteristics (e.g. colours, alignments, facing materials or type and size of openings); the same centrality with regard to pedestrian circulation; and adjacent functions. Both spaces also present similarities in what concerns to other aspects such as lighting, street furniture, or ground level shading devices.

It is in the nature of the paving materials and in the quantity of vegetation and the quality of the planting scheme that sharp differences are established between one space and the other. While the square has hard impermeable facing materials and the near absence of vegetation, the garden presents soft permeable natural facing materials and intense vegetation.

More precisely, while the square accounts with 5 % of permeable and 95 % of impermeable area, the garden presents 97 % of permeable area and 3 % impermeable area. Additionally, though both spaces possess a similar area occupied with water elements (1 % to 2 %) the position of these elements within the spaces makes the garden's pool more effective from a microclimatic and visual point of view. In addition, the discontinuous green coverage of the square is 3 % whereas the garden presents a continuous green coverage occupying 77 % of its area. Also the percentage of green surfaces assumes quite sharp values: 5 % in the square and 40 % in the garden. The 60 % of non-green surface of the garden relates to soft-paved (bare soil) areas and few granite steps whereas the 95 % of non-green surface of the square relates to hard-paved (granite) areas.

Whilst the absence of shading devices in the garden is offset by the shading provided by diverse and well positioned trees, in the square the lack of shade is only offset for a limited time by the row of *Ligustrum lucidum* at the eastern edge and by the parasols of the cafe terrace. Yet, most of the square, especially its central area, remains fully-exposed to direct solar radiation throughout the day. Further differences between one space and the other are observed for the quality and position of sitting elements and urban art, with the garden presenting the best situation.

It was also observed that the square presents no adaptive opportunity, on a thermal perspective. The only 'controllable' devices at place are the parasols of the cafe terrace which end up not being effective due to their positioning and to the fact that benefiting from their shade entails consuming goods. In turn, the garden presents adaptive opportunities to a great extent due to the balance between sunlit and shaded areas where people may choose to position themselves.

Summarising, the findings from the morphological analysis (more detail on the observed parameters is provided in Annex F) showed that the physical features of the analysed spaces are practically the same, except paving solutions and amount of vegetation. This analysis started then suggesting that if there was any correlation between the usage patterns and the physical features of the spaces, that correlation would be related to their paving solutions and amount of vegetation: while the square has hard impermeable paving materials throughout its entire area and the near absence of vegetation, the garden presents soft permeable natural facing materials and intense vegetation.

6.3.3. Social/personal analysis

6.3.3.1. General personal parameters

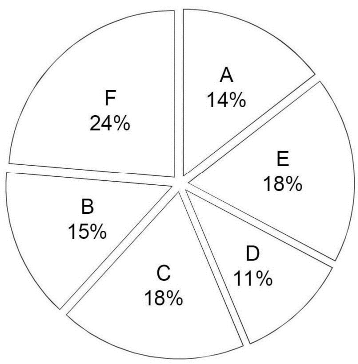
The general personal parameters of users of Poveiros Square and São Lázaro Garden were derived from the observation exercise. Types of users, age, gender, activity, clothing level, position, food/drink consumption, company, and exposure to sun were the considered parameters.

Types of users

The identified types of users and their general characteristics were:

- A - Adolescents and young adults using the square as a 'theatre' for their social relationships (e.g. meeting friends).
- B - Elderly, mainly women, who rarely come into contact with the outdoor space unless for performing essential daily tasks.
- C - Adults, mainly retired people, who use the space to a large extent.
- D - Adults and elderly, mainly retired people, that establish with the space such a strong emotional bond that feel somehow partially responsible for its preservation and maintenance; people showing a behaviour close to that of 'natural surveillance'.
- E - Youngsters, mainly students from the nearby Faculty of Fine Arts, interested in exploring authentic and secluded places; people mainly found at the most secluded cafe terrace at the square.
- F - Adults working in firms and shops in the area surrounding the square that only use the square's main cafe terrace during lunchtime for having a meal or coffee.

Figure 31 puts into evidence the significantly different distribution of types of users within each space: from the six types identified at site, all were found in the square whilst only three (B, C and D) were found in the garden. In the square it was also observed a somewhat more homogeneous distribution of types of users varying from 11 % (group D) to 18 % (group C and E). Group F presented a higher percentage (24 %) relatively to the other groups. In turn, the garden presented a more contrasting distribution of groups: group C predominates with 80 % of representation at site, while group D has a representation of 15 % and group B of only 5 %.



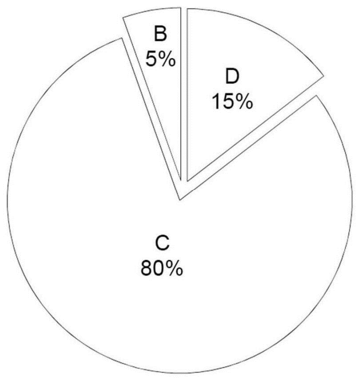


Fig.31 – Distribution of types of users at Poveiros square (left) and São Lázaro Garden (right).

This suggests that the square has a latent social variety, eventually even higher than the garden. However, in practical terms the three groups found at the garden gather more people for longer periods of time than the square's five groups together.

During the interviews it was possible to understand that the existence of fewer groups in the garden could be related to the fact that many people tended to avoid passing through the garden due to some situations of prostitution and alcohol abuse. Group C, which has the highest representation at the garden, was found to be largely composed by retired men that by some reason seemed to be less intimidated by such situations. It is noteworthy that many interviewees mentioned they would like to use the square more often in summer provided it was more thermally comfortable, and that though the garden was a comfortable space they were not keen to use because of its social ambience.

Age

In line with the findings for the type of users, the square was found to have diverse age groups than the garden. As shown in Figure 32, the square is mainly used by people between 25-34 years of age (45 %). The categories of '35-44', '45-54' and '55-64' years of age share relatively equal percentages (14 %, 13 % and 16 % respectively), whereas the '>65' years of age category had 4 % of representation. Children, adolescents and people between 18-24 years of age together represented 8 % of the sample.

In the garden people above 55 years of age predominate. The categories '55-64' and '>65' years of age, together, account for 45 % of the sample. The remaining 55 % is fairly shared between the '18-24', '25-34' and '45-54' years of age categories, with the exception of the '35-44' which accounts for 4 %.

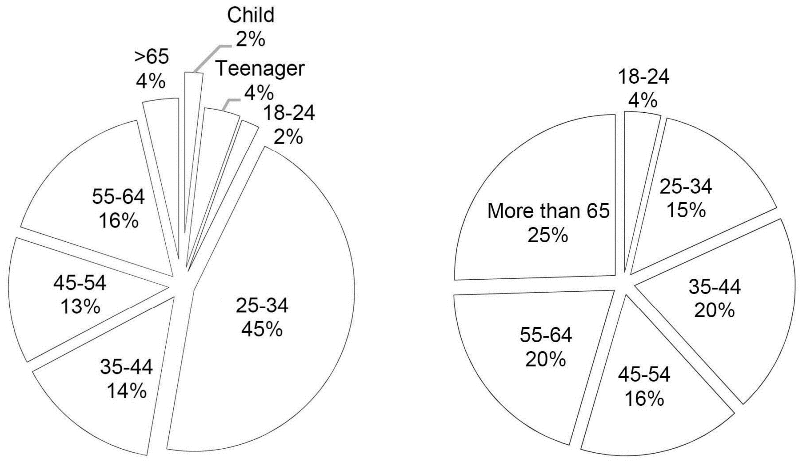


Fig.32 – Age distribution at Poveiros square (left) and São Lázaro Garden (right).

Youngsters seemed to more easily tolerate peak-hours temperatures in the square than the elderly. Nevertheless, even this tolerance was not traduced into permanences beyond 10 minutes. As the potential users for each space vary to the same extent it is not that the square has less older adults or the garden less youngsters willing to use them. The significant difference between the prevalence of users' age groups in one and the other space seems to be related to the conditions these offer for permanence. Older people referred to be unable of coping with the square's thermal conditions in summer and to use the garden since there they could feel more comfortable. In turn, younger people stated not to use the garden as much as they would like due to the referred prostitution and alcohol abuse situations.

Activity

Relatively to the activities held at one space and the other, 64 % of people were found sitting quietly in the garden and 27 % walking slowly, while only 9 % were found walking moderately. In turn, in the square 64 % of people were found walking moderately, 18 % walking slowly, 14 % standing, and 4 % sitting (Figure 33).

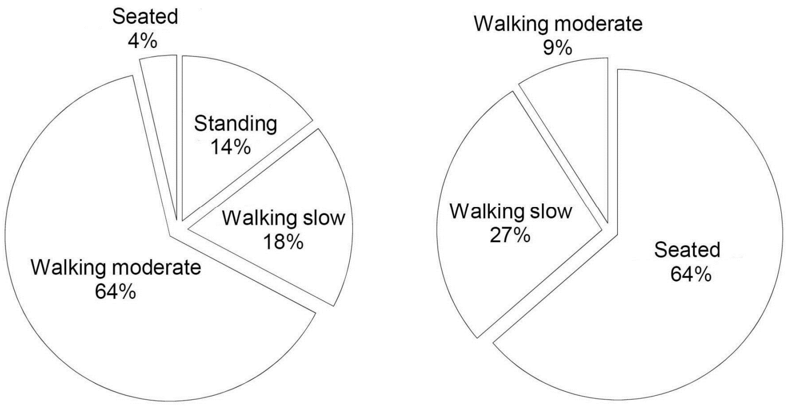


Fig.33 – Activities held at Poveiros square (left) and São Lázaro Garden (right).

These values suggest that in the garden the majority of people are engaged in long-term activities whereas in the square they are mainly involved in short-term activities. Short-term activities are herewith related to short-term permanences at site (e.g. walking fast or moderately, standing while waiting for meeting someone) and may vary from less than 5 minutes to 5-15 minutes. In turn, long-term activities correspond to long-term permanences at site (e.g. walking slowly, standing relaxed, seated quietly, reclining while reading a newspaper, sleeping) and comprehend three intervals: 15-30 minutes, 30-60 minutes, and more than 1 hour.

The type of activities held at the garden show that this space has more people spending there longer periods of time than in the square. This is especially notorious with respect to the amount of people found sitting in the square (4 %) and in the garden (64 %). Within the long-term activities it is noteworthy that these ranged from sitting quietly/resting for reading a newspaper to group activities engaging some dozens of individuals such as card games. In turn, the short-term activities held at the square were related with waiting for someone, taking a dog for a walk or just passing by. People sitting (4 %) and standing (14 %) in the square have not been at space for longer than 10 minutes.

Gender and clothing level

At the square, 36 % of respondents were men while 64 % were women and, at the garden, 40 % of respondents were men and 60 % were women. As Figure 34 shows, in the square 46 % women were found to be wearing ensemble Bf (underwear, long-sleeved shirt, jeans/long shirt, sandals - Clo 0.45) and 18 % wearing ensemble Af (underwear, sleeveless blouse, shirt, sandals, - Clo 0.32). In the garden 49 % of women were wearing ensemble Cf (underwear, long-sleeved shirt, long-sleeved sweater, jeans/long shirt, shoes and socks - Clo 0.73), 7 % ensemble Af, and 4 % ensemble Bf.

With respect to men, in the square 20 % were found wearing ensemble Am (underwear, short-sleeved shirt, shorts, and sandals - Clo 0.31) and 16 % wearing ensemble Bm (underwear, long-sleeved shirt, straight trousers, shoes and socks - Clo 0.49). In the garden, 31 % of men were wearing ensemble Cm (underwear, long-sleeved short, long-sleeved sweater, straight trousers, shoes and socks - Clo 0.74), 5 % ensemble Am, and 4 % ensemble Bm.

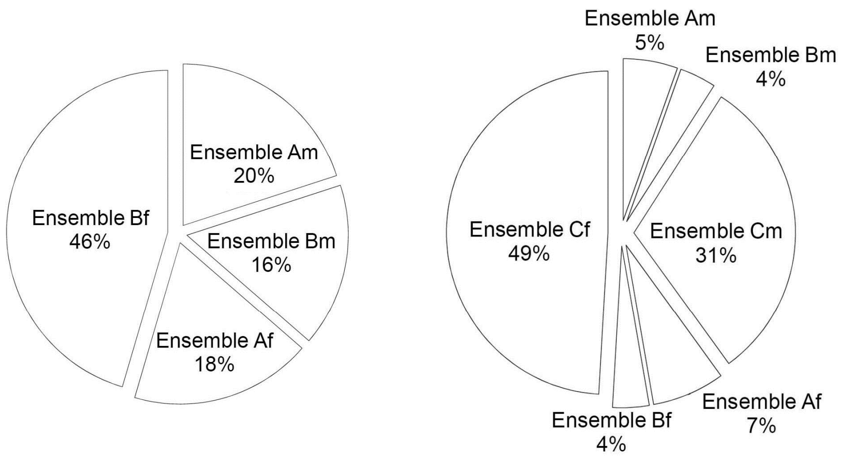


Fig.34 – Clothing ensembles worn by respondents at Poveiros square (left) and São Lázaro Garden (right).

These values are in compliance with previous studies showing that as the metabolic rate of women is less than that of men, women may feel cooler than men (Aggelakoudis and Athanasiou, 2005; 267). However, considering the global evenness of the thermal comfort evaluations respondents made about the space they were in, gender and associated clothing level worn do not seem to have had a substantial influence on people’s thermal experience.

It is noteworthy that as an older individual’s temperature is lower than that of the average individual (Novieto and Zhang, 2010; 44), for the same thermal environment the elderly is likely to feel colder than youngsters. Clothing levels worn by the interviewees comply with this: people below 55 years of age were found wearing the same clothing types in both spaces whereas in the garden a significant number of individuals above 55 years of age were using more garments than individuals of the same age in the square.

Food/drink consumption, company, and exposure to sun

The analysis of these parameters in the square revealed that 93 % of respondents were not consuming any drink or food; 62 % were found alone, 31 % with one person, and 7 % with more than two persons; and 89 % were interviewed directly exposed to direct solar radiation and 11 % under a parasol. In the garden, the analysis of these parameters revealed that 93 % of respondents were not consuming any drink or food; 60 % of people were found alone, 26 % with one person, 14 % with more than two persons; and 90 % were interviewed on a shaded place.

Again, considering the global evenness of the thermal comfort evaluations respondents made about the space they were in, these results suggest that the ingestion of food or drinks as a means to improve comfort conditions by directly influencing the body’s metabolic heat production seems to have not been relevant for people’s thermal experience. The same can be said about the number of people respondents were with.

The most remarkable difference is between the percentages of people directly exposed/protected from direct solar radiation: while in the square 89 % of respondents were directly exposed to direct solar radiation, in the garden 90 % were protected from the sun. This difference is directly correlated to the level of shade in one space and the other, in particular shade provided by trees.

6.3.3.2. Thermal comfort evaluations

The thermal comfort evaluations of users of Poveiros Square and São Lázaro Garden were derived from the questionnaire. Thermal sensation, thermal evaluation, thermal preference, thermal acceptability, thermal tolerance; additional personal parameters, namely reasons to be at place, time of permanence, frequency of use, long-term thermal experience, short-term thermal experience and health conditions; and appraisal of the role of materials and vegetation were the considered parameters.

Thermal sensation

The votes respondents gave on the thermal sensation scale have significantly differed between the square and the garden. Figure 35 shows that in the square, 53 % of respondents stated to feel hot, 40 % to feel warm, and 7 % to feel neutral. In turn, the garden had 82 % of respondents stating to be neutral and 18 % slightly cool.

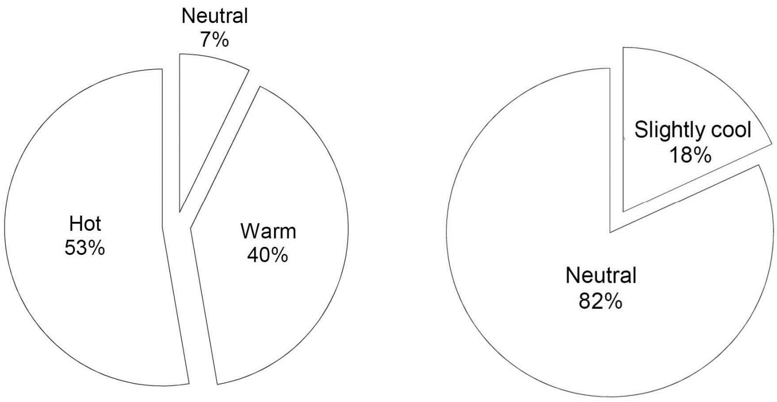


Fig.35 – Thermal sensation votes for Poveiros square (left) and São Lázaro Garden (right).

The most contrasting values here are the 93 % of respondents stating to be uncomfortable in the square (53 % feeling hot and 40 % feeling warm) against the 82 % stating to be neutral in the garden. Since the votes given for the square were on the warm discomfort side of the thermal sensation scale and the neutral category voted for in the garden indicates a condition in which the subject would prefer neither warmer nor cooler surroundings (Zhang and Zhao, 2008; 49), it is fair to say that the votes given in the thermal sensation scale reflect sharply different microclimates between the analysed spaces.

Nevertheless, the 7 % respondents voting for the ‘neutral’ category in the square and the 18 % for the ‘slightly cool’ category in the garden open an exception to this main trend of votes. The likely reasons for these exceptions can be related to personal thermal preferences and age group. The 7 % respondents voting for the ‘neutral’ category in the square correspond to the ‘child’ and ‘18-24’ years of age categories that tend to better tolerate hot and warm conditions. In turn, the 18 % voting for the 'slightly cool' category in the garden are associated to respondents belonging to the '>65' years of age category.

Thermal evaluation

The votes given for the thermal sensation scale comply with those for the thermal evaluation scale: 93 % of respondents at the square were feeling uncomfortable due to hot conditions, whereas 91 % of interviewees at the garden were feeling comfortable (Figure 36). Nonetheless, there were some exceptions to these major trends of votes: 7 % of respondents at the square stated to be comfortable and 9 % at the garden stated to be slightly uncomfortably cool.

The reasons for these exceptions are the same as for the aforementioned exceptions to the thermal sensation scale: in the square younger individuals feeling neutral and in the garden older individuals voting for the 'slightly cool' category. The remaining 9 % of people included in the 18 % voting for the 'slightly cool' thermal sensation category stated, in the thermal evaluation scale, to feel comfortable. This might suggest that although these respondents were feeling slightly cool, that was still within a comfort zone.

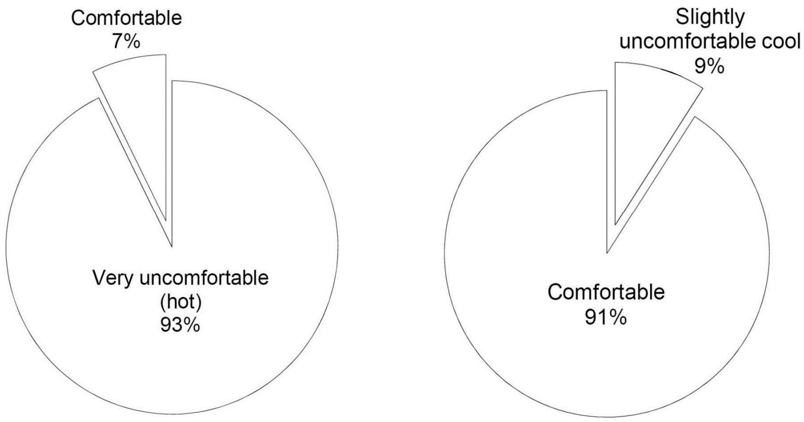


Fig.36 – Thermal evaluation votes at Poveiros square (left) and São Lázaro Garden (right).

In order to know what people considered to be the main source of discomfort, interviewees were asked about the most unpleasant climatic variable at the moment of the interview. Air temperature, relative humidity, direct solar radiation, wind or no variable were the given options. At the square, direct solar radiation accounted with 67 % of votes. This value is followed by the 25 % attributed to air temperature. Only 6 % of respondents stated that no climatic variable was causing them discomfort at the square and 2 % referred wind. This percentage of votes broadly matches the percentage of respondents stating to feel neutral in the thermal sensation scale and comfortable in the thermal evaluation scale.

In the garden, 85 % of respondents stated that there was no climatic variable causing discomfort. In turn, 9 % referred wind and 6 % referred humidity as the most unpleasant variable and this is again likely to be related to the age group: these percentages match the 15 % of representation at site of type of users D, i.e. a group spending several hours at the garden with no activity beyond sitting and observing, which equals saying with a low metabolic heat production.

Thermal preference

The votes obtained for the thermal preference scale are also consistent with the findings for the thermal sensation and thermal evaluation scales. Considering that 93 % of respondents stated that the square was as a very uncomfortable (hot) space, and that 67 % referred direct solar radiation and 25 % referred air temperature as the main sources of discomfort at the moment of the interview, it was not surprising that 93 % of respondents at the square stated their preference for a lower temperature (Figure 37).

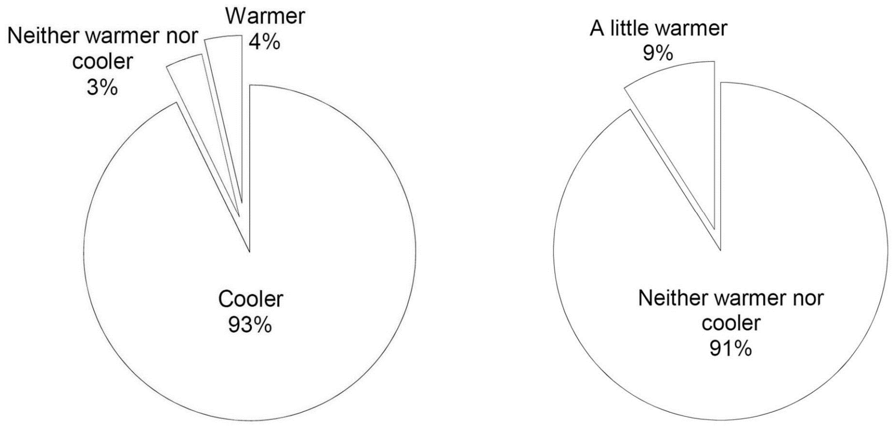


Fig.37 – Thermal preference votes at Poveiros square (left) and São Lázaro Garden (right).

In the garden it was also found a correspondence between the votes for the thermal sensation, thermal evaluation and thermal preference: to the 91 % of respondents qualifying the garden as comfortable, there were 91 % stating a neither warmer nor cooler environment.

Thermal acceptability

Figure 38 shows that the answers to the thermal acceptability scale were divided between 93 % of respondents stating that the square was a clearly unacceptable thermal environment, and 91 % considering the garden as a clearly acceptable thermal environment. The ‘just acceptable’ category was voted by 7 % of respondents at the square and, in the garden, by 9 %.

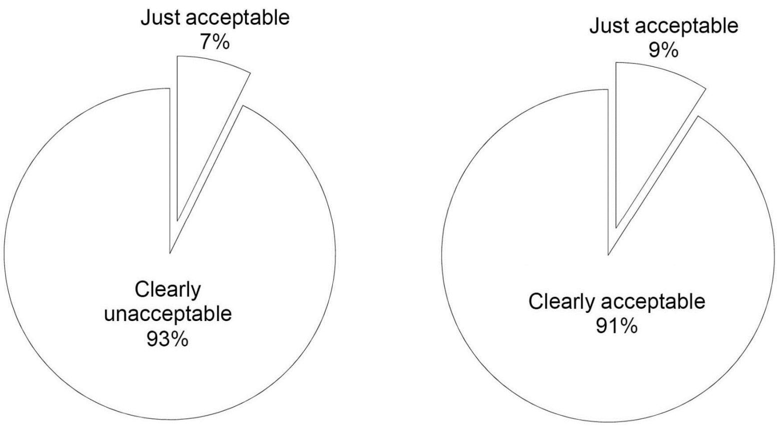


Fig.38 – Thermal acceptability votes at Poveiros square (left) and São Lázaro Garden (right).

The 7 % people voting for the ‘just acceptable’ category at the square match the percentage of people who stated to feel neutral in the thermal sensation scale, and comfortable in the thermal evaluation scale. The 9 % people voting for the ‘just acceptable’ category at the garden, in turn, match the percentage of respondents referring to be slightly uncomfortably cool in the thermal evaluation scale. It is fair to say that, as the ‘just acceptable’ category still expresses satisfaction with the thermal environment, 100 % of respondents have considered the garden as an acceptable space.

Thermal tolerance

The votes on the thermal tolerance scale present contrasting values between the two analysed spaces that comply with the findings for the previous scales. As Figure 39 shows, while the garden was considered to be a perfectly tolerable thermal environment at the moment of the interview by 100 % of respondents, the square was considered to be intolerable by 73 % of respondents and very difficult to tolerate by the remaining 27 %. Considering that ‘intolerable’ and ‘very difficult to tolerate’ are both within the range of thermal discomfort, it can be said that 100 % of respondents could not tolerate the thermal environment of the square.

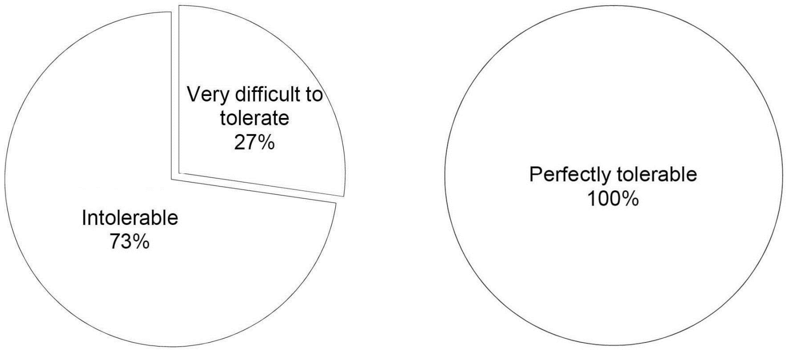


Fig.39 – Thermal tolerance votes at Poveiros square (left) and São Lázaro Garden (right).

The votes given on all scales, but especially on the thermal preference, tolerance and acceptability scales give a first insight on how attractive the analysed spaces were to users: beyond being almost a functionless space, with relation to microclimate the square was little attractive to the interviewees while the garden was highly attractive. This was further confirmed with the questions made around additional parameters.

Additional parameters

When questioned about for how long have they been at place, at the square 73 % of respondents stated to be (and were not going to stay for longer) at place for less than 5 minutes. In the garden, 45 % of respondents stated to be at place for about 15-30 minutes (Figure 40). The answers given for the remaining categories further sharpen the difference between the two spaces: for the square, if the 73 % of respondents at place for less than 5 minutes is added to the 18 % at place for ‘5-15 minutes’, a total value of 91 % for short-term permanences is obtained. In turn, the sum of the percentages obtained for the remaining categories gives a value of 9 % for long-term permanences.

For the garden, the short-term permanences account for 17 %: 13 % for 5-15 minutes and 4 % for less than 5 minutes. In turn, the sum of the 45 % attributed to the ‘15-30 minutes’ category to the 27 %

attributed to the ‘more than 1 hour’ and to the 11 % attributed to the ‘30-60 minutes’ categories, comes up with a total of 83 % for long-term permanences.

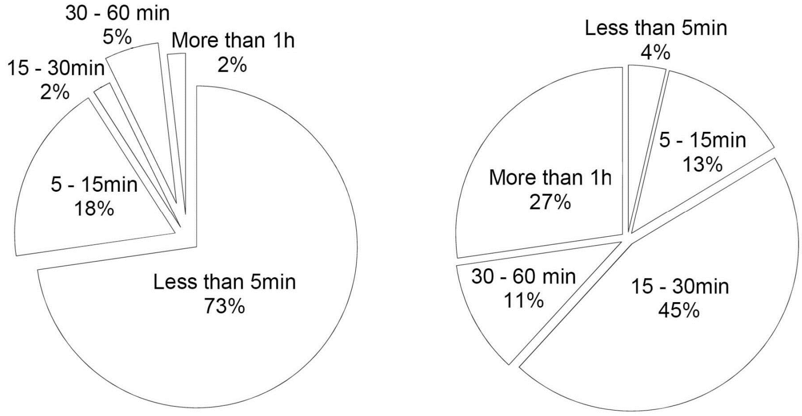


Fig.40 – Time of permanence of people at Poveiros square (left) and São Lázaro Garden (right).

Another issue suggesting the higher attractiveness of the garden was the frequency of use. As Figure 41 shows, in the square 51 % of respondents stated that they used the space daily, 25 % weekly, 13 % monthly, 7 % annually, and for 4 % it was the first time at the space. In the garden 33 % of respondents stated that they used the space daily, 16 % weekly, 22 % monthly, 9 % annually, and 20 % were there for the first time. Conspicuous amongst these findings are the percentages for the ‘daily’ and ‘first time’ categories. Although the square possesses a higher percentage of daily use (51 %) than the garden (33 %), the large majority of people merely pass through the space. In turn, people using the garden on a daily basis tended make good and extended use of it.

The percentage of respondents stating that they were for the first time at the square (4 %) and at the garden (20 %) corresponds mainly to people waiting for someone. These respondents referred to have chosen the garden for waiting since it was cool and comfortable. Considering that the garden and the square are in visual and physical continuity, this shows the higher attractiveness of the garden faced to the square.

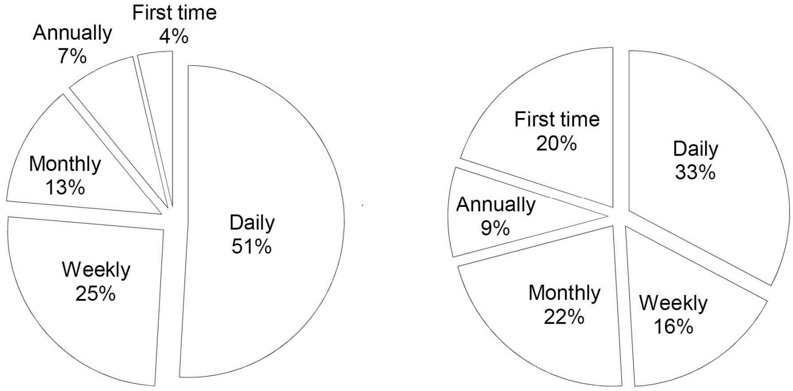


Fig.41 – Frequency of use of Poveiros square (left) and São Lázaro Garden (right).

Moving to people’s long-term thermal experience, Figure 42 shows that 84 % of respondents stated that the square was usually uncomfortable during summer while only 16 % considered it as usually comfortable. In turn, in the garden 100 % of respondents stated that this space was usually comfortable during summer. Two main issues are to be outlined here: firstly, the notorious difference between the votes for one and the other space; and secondly, the uniformity of the votes given for the garden. The 16 % of votes considering the square as usually comfortable in summer are again associated to age groups, namely to the 'adolescents' and '18-24' age groups.

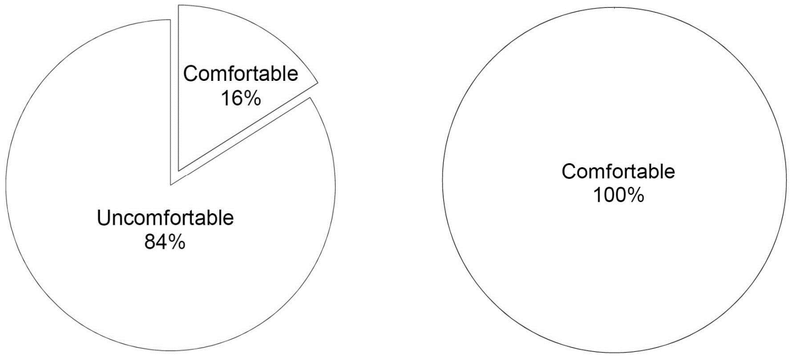


Fig.42 – Usual summer thermal comfort conditions at Poveiros square (left) and São Lázaro Garden (right).

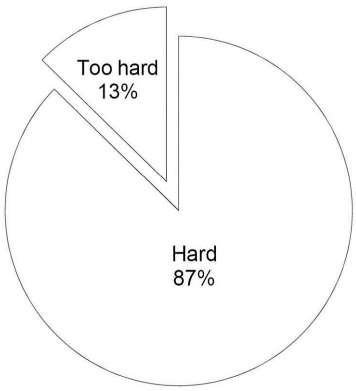
The questionnaires made to the owners of the square's surrounding businesses have also shown that the usual thermal comfort conditions at the square are negative. All 14 local traders stated that the square's microclimate during summer influences negatively their businesses and that these could benefit from a cooler summer thermal environment. All traders referred that a cooler microclimate could work as an attractive for people to stay and, therefore, as a way of fostering the visibility and thrive of local businesses.

Relatively to people's short-term thermal experience and health conditions, the consistency between the findings for the thermal comfort judgement scales suggests that these parameters were not a major influence on people's votes.

6.3.3.3. Appraisal of the role of materials and vegetation

Materials

As Figure 43 shows, the ground paving of the square was considered by 87 % of respondents as hard and the remaining 13 % considered it too hard; in the garden, 96 % of respondents described its ground surface as soft and 4 % as mixed.



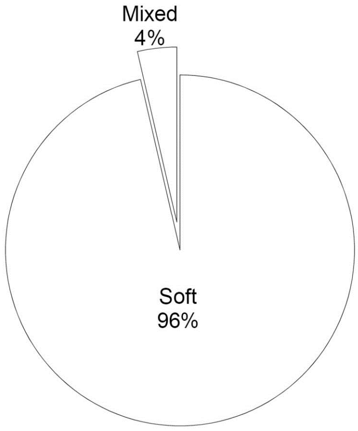
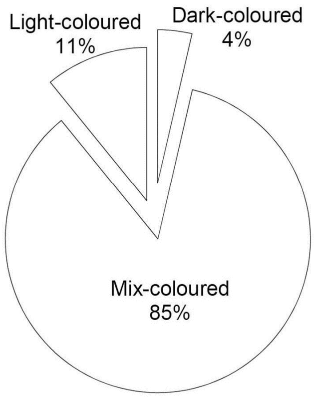


Fig.43 – Nature of the paving materials of Poveiros square (left) and São Lázaro Garden (right).

The differences between one space and the other become even more significant when bringing together the percentage of people voting for the ‘hard’ category (87 %) with that voting for the ‘too hard’ category (13 %) in the square. The votes on both categories convey a dissatisfaction of all respondents relatively to the ground paving of the square. In the garden both votes on the ‘mixed’ category (4 %) and on the ‘soft’ category (96 %) convey the satisfaction of respondents relatively to the nature of the ground surface of the garden.

There were no substantial differences in the votes for the facing materials of facades between one space and the other. This can be attributed to the fact that the built fabrics surrounding both spaces presents the same morphologic characteristics. Figure 44 shows that 85 % of respondents in the square and 93 % in the garden voted for mix-coloured facing materials. The remaining percentage of votes was divided between light-coloured, 11 % at the square and 2 % at the garden, and dark-coloured, 4 % at the square and 5 % at the garden.



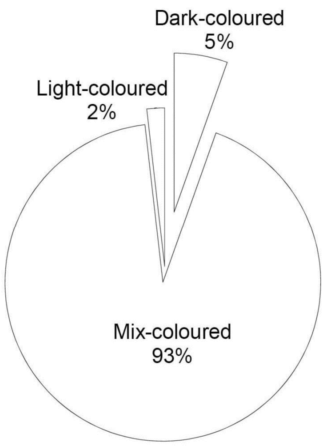


Fig.44 – Facing materials of facades at Poveiros square (left) and São Lázaro Garden (right).

With respect to glare, Figure 45 shows that 73 % of respondents stated to feel glare by the ground in the square, 18 % felt glare by the facades, and 9 % felt no glare. In the garden 98 % of respondents felt no glare, and the remaining 2 % stated to feel glare by the buildings facades.

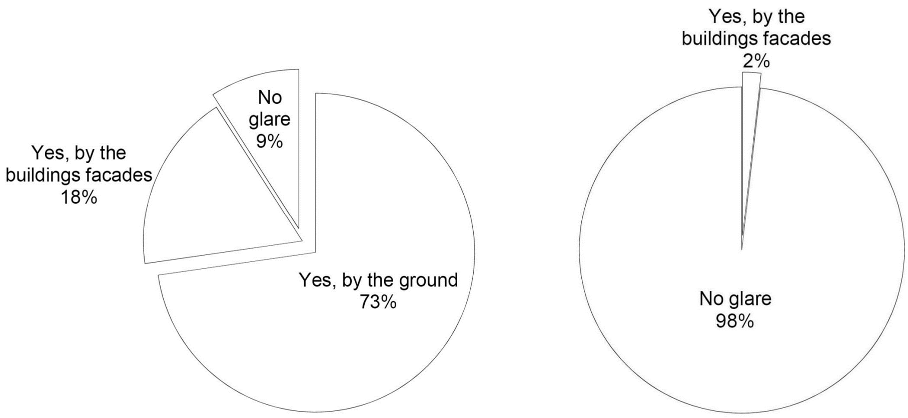


Fig.45 – Glare at Poveiros square (left) and São Lázaro Garden (right).

There seems to be a global correspondence between the votes given for ground surfaces and buildings facades and glare in one space and the other. The predominant votes concerning glare in both spaces were for the ground surface. The higher percentage of people experiencing glare by the facades in the square can be explained by a total exposure of all surfaces to direct solar radiation. In turn, the garden's mature greenery blocks much of the views over the surrounding facades.

Vegetation

The interviewees also seemed to recognise the impacts of the quantity and quality of vegetation in one and the other space. Figure 46 shows that, in the square, 100 % of respondents stated that they could not count at all on the space's vegetation to meet their comfort requirements. In the garden, 96 % of respondents made the opposed statement. It should be outlined that the 4 % of respondents stating that vegetation in the garden did not provide any protection from climatic variables comes down to just two individuals above 65 years of age.

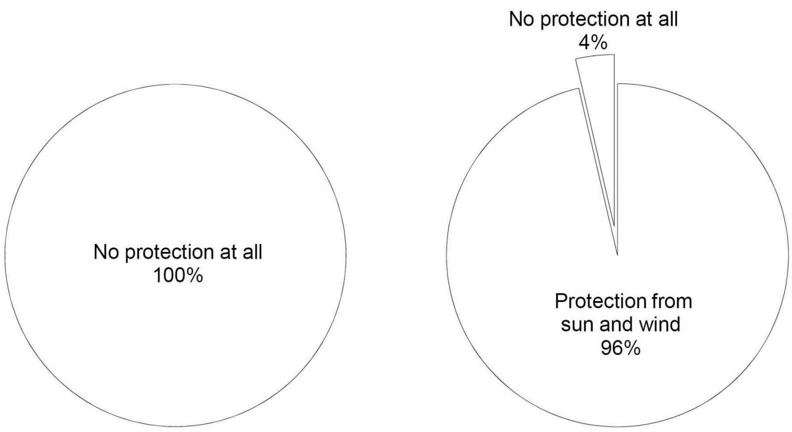


Fig.46 – Protection provided by vegetation at Poveiros square (left) and São Lázaro Garden (right).

Bearing in mind that direct solar radiation was referred as the most unpleasant climatic variable at the square by 67 % of interviewees, it is fair to consider the shade provided by trees as determinant of the higher attractiveness of São Lázaro garden. Some respondents in the square, even though not asked, mentioned that the garden was a pleasant public space to be in during summer due to its greenery, not knowing it was under analysis as well.

The awareness people had about the role facing materials and vegetation play in the microclimates of the analysed spaces was confirmed when the three final pictures of the questionnaire were shown. As shown in Figure 47, the potentially most comfortable space was voted by 89 % of respondents to be that of picture C (a pedestrian public space with mixed-paving materials, dense vegetation, water, and shading devices). 83 % of respondents stated that the potentially most uncomfortable space was that of picture B (a pedestrian public space with hard paving materials, no vegetation, no water, and no shading devices). The questionnaire made to local businesses' traders also provided important cues on this subject: all respondents voted for picture C as the potentially most comfortable space and picture B as the potentially most uncomfortable.

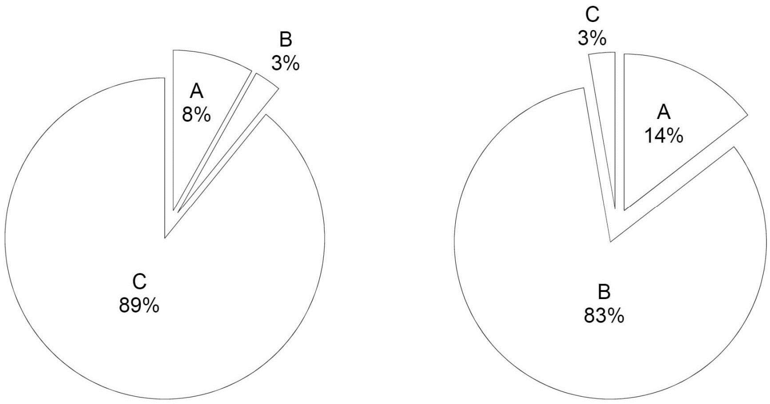


Fig.47 – The potentially most comfortable space (left) and the potentially most uncomfortable space (right) conveyed by the final pictures of the questionnaire.

Beyond suggesting that people have 'mental ideas' of thermal comfort, these votes suggested that people can recognise the physical features of a space influencing the thermal environment they are immersed in. People could associate outdoor spaces paved with a mixture of different materials, densely vegetated, with water features and shading devices to a thermally comfortable space for enjoyment in summer. In turn, an extensive hard paving solution combined with the absence of vegetation and/or shading devices was 'perceived' by people as very uncomfortable in summer. These findings comply with the notion that thermal sensations are suggested visually (Schmid, 2005; 235). As Lenzholzer and Koh (2010; 2) refer, the «interpretation and schematization of visible environmental cues with respect to microclimate might therefore be a common sense solution to get to grips with the complex invisible phenomenon of microclimate».

Summary of findings [social/personal analysis]

The findings from the social/personal analysis start shedding light on the likely possibility of a correlation between the sharply different usage patterns, microclimate, and paving solutions and amount of vegetation of the analysed spaces:

- There are practically no differences (type and number) between the potential users of each space.
- Practically all interviewees at the garden (82 %) were feeling neutral whereas the majority of interviewees at the square were feeling warm (40 %) and hot (53 %).
- The large majority of users of the square were uncomfortable due to hot conditions (93 %) while most users of the garden were comfortable (91 %).
- The most unpleasant climatic variable at the moment of the interview at the square was referred to be direct solar radiation (67 %) and air temperature (25 %). In the garden, the majority of respondents (85 %) stated that there was no climatic variable causing discomfort.
- The majority of respondents would prefer a 'cooler' temperature at the square (93 %) whilst most respondents stated their preference for a neither warmer nor cooler environment at the garden (91 %).
- Most respondents (93 %) stated that the square was a clearly unacceptable thermal environment whereas most respondents (91 %) at the garden considered it as clearly acceptable.
- Respondents stated that the thermal conditions of the square were intolerable (73 %) and very difficult to tolerate (27 %) while the garden was 100% considered as a perfectly tolerable thermal environment.
- The majority of respondents (84 %) stated that the square was usually uncomfortable during summer whilst the garden was considered by all respondents to be a usually comfortable during summer.
- The ground paving of the square was considered by a majority of respondents as hard (87 %) and too hard (13 %) whereas in the garden 96% described its ground surface as soft and permeable.
- Most respondents considered that the buildings facades around the square (85 %) and the garden (93 %) were mainly composed of mix-coloured facing materials.
- Most respondents at the square stated to feel glare by the ground (73 %) and some respondents by the buildings facades (18 %) whereas in the garden the large majority of respondents felt no glare (98 %).
- In the square, all respondents stated that they could not count at all on the space's vegetation to meet their comfort requirements whilst the garden presented the reverse situation (96 %).
- The absence of shade combined with the hard nature of the square's ground surface seemed to be 'perceived' by respondents as the main source of discomfort. In turn, respondents seemed to acknowledge that the combination of soft-permeable paving materials and an appropriate amount of vegetation underlies the garden's comfortable thermal environment.
- Local traders believe their businesses are hindered by the square's summer microclimate and that an intervention delivering a cooler environment, closer to that of the garden, could reverse this situation.

6.3.4. Microclimatic monitoring

The microclimatic monitoring of Poveiros Square and São Lázaro Garden collected values for the five considered variables. In order to synthesise all values recorded and to keep them in line with the above mentioned FEUP's and IM's reference data format, only the average, maximum and minimum values for each variable and for the totality of days of the microclimatic monitoring will be considered.

6.3.4.1. Air temperature (T_a)

The garden systematically presented values around 1 °C lower than the square for average, maximum and minimum T_a values. The sharpest difference was in maximum values: 1.79 °C. People can sense temperature differences within a range of 1 °C to 2 °C (Lstiburek, 2002; 3). Thereby, relating people's thermal evaluation votes, particularly the referred most unpleasant climatic variable at the moment of the interview, with the measured climatic variables suggests that T_a influenced the thermal environment of the analysed spaces. Nevertheless, T_a values are not as contrasting as the values recorded for other variables, namely direct solar radiation or mean radiant temperature.

6.3.4.2. Relative humidity (RH)

Considering a comfort zone for RH in outdoor spaces within a range of 30 % to 65 % (Tojo, 2007; 175), RH seems not to have been a major contribution to the microclimates of neither the square nor the garden because the recorded values, except for maximum values, were mostly within this range: 53.58 % in the square and 58.26 % in the garden. This is further suggested by people's votes about the most unpleasant climatic parameter at the moment of the interview: in the square RH was not mentioned at all, and in the garden only 6 % of respondents mentioned it.

RH was the only variable exhibiting higher values in the garden than in the square. As expected, the difference of average, maximum and minimum RH values between the two spaces was significant at all times. Maximum values exhibited the clearest difference: from 68.6 % in the square to 76.3 % in the garden. The higher RH values recorded at the garden are likely due to the increased evapotranspiration provided by vegetation. In the square the absence of vegetation and the hard impermeable nature of its paving materials lead to the reverse situation.

6.3.4.3. Direct solar radiation ($K\downarrow$)

There is a dramatic difference in the amount of $K\downarrow$ reaching the ground level of each space. Considering 800 W/m^2 as an admissible general $K\downarrow$ value in a typical summer cloudless day, and that this corresponds to high insolation (Nikolopoulou, 2004; 4), the average value of 826 W/m^2 recorded in the square is high. In turn, the low insolation level in the garden is closer to that of an overcast day or a late sunny afternoon, 100 W/m^2 (*idem*, 4).

Since the solar input is the same for both spaces and that these present the same morphologic and topographic characteristics, the square and the garden are likely to share the 826 W/m^2 of average $K\downarrow$. Nevertheless, the average difference between $K\downarrow$ in the analysed spaces reached 771 W/m^2. Again, the garden presented the lowest values. Similarly to the other measured climatic variables, the sharpest difference was observed in maximum values: 1.004 W/m^2, established between the 1.104 W/m^2 recorded at the square and the 100 W/m^2 at the garden. These values make $K\downarrow$ to be one of the climatic variables presenting the sharpest differences between the square and the garden.

The differences established between the two spaces with regard to $K\downarrow$ are most probably associated to their amount of vegetation — bearing in mind that in general less than 20 % (eventually as little as 5 %) of $K\downarrow$ reaches the ground level under a mature trees canopy (Oke, 1987; 144), the garden's dense vegetation stands out as the main contributor to its lower levels of $K\downarrow$. For the recorded average $K\downarrow$ values, the difference between the 826 W/m^2 in the square (unobstructed sky vault) and the 55 W/m^2 in the garden (partially or mainly obstructed sky vault) indicates that only around 6 % of the available $K\downarrow$ above the trees canopy could reach the ground level at the garden.

6.3.4.4. Wind speed (*W*)

Despite the differences in wind speed measured at one space and the other, since in general wind starts being unpleasant to people at speeds of about 5 m/s, uncomfortable at a speed of about 10 m/s, and potentially dangerous at a speed of around 20 m/s (*idem*, 272), wind did not constitute a major influence on the microclimates of the analysed spaces. Average values of 1.13 m/s in the square and 0.60 m/s in the garden are well below these threshold values and correspond to slight breezes. The only exception to this was observed in the square where the maximum value recorded was of 5.69 m/s. In turn, the maximum *W* value recorded in the garden was of 1.8 m/s. The recorded minimum values were basically the same for both spaces: 0.08 m/s for the square and 0.06 m/s for the garden.

If on one hand average *W* values were not too different and minimum values were the basically same for one space and the other, on the other hand maximum values recorded were significantly different. It is highly probable that, such as for $K{\downarrow}$ values, these different *W* values are due to the presence of vegetation in the garden and to its near absence in the square. In the garden, vegetation acts as a wind-break to the dominant wind direction (NW).

6.3.4.5. Mean radiant temperature (MRT)

MRT was the variable presenting the sharpest differences between the analysed spaces, with the garden presenting significantly lower values. The most remarkable difference for MRT between the two spaces was observed for maximum values: the garden presented a maximum MRT value 14.17 °C lower than that of the square. Average values presented a difference of 11.81 °C and minimum values a difference of 7.51 °C. The reason why minimum values presented the smallest difference between MRT values is likely to be explained by the fact that these correspond to measurements made at 11 a.m., when the ground was still warming up. In turn, maximum values correspond to measurements made between 1.30 p.m. and 2 p.m., when the potential for warming up the ground surface resulting from the combination of $K{\downarrow}$ and the physical parameters of the paving materials were close to a maximum.

The sharp differences in the values recorded for MRT in one and the other space are likely to be correlated with the relationship between the high levels of $K{\downarrow}$ at each space and the moisture-related and optical properties of their ground surface materials and less of the surrounding facades.

Recalling the principles governing the radiant heat exchange between the sun and the terrestrial surfaces referred in Chapter 5, facades were indeed expected not to be a determinant variable in the microclimates of the analysed spaces. In particular, the notion that a very low H/W ratio (0.06) means that one urban front «does not influence the microclimatic behaviour of the opposite front» (Nikolopoulou, 2004; 14) and that the radiative heat emitted between bodies is conversely proportional to the square of the distance between them (Alexandri, 2005; 51), are particularly relevant for the analysed spaces. The low H/W ratio of both analysed spaces, 0.34 for the square and 0.16 for the garden, is likely to make facades surrounding the spaces little significant to the recorded MRT values.

Based on this idea, and aiming to develop it, an additional measurement of ground surface temperature (T_s) was undertaken through a non-contact infrared thermometer. At the square, the sensor was calibrated having as reference the general emissivity value attributed to granite (0.96) for the ground; and for vertical surfaces, due to the heterogeneity of their facing materials, an average value of 0.90, a middle ground between the values generally attributed to ceramic tiles (0.85) and cement renders (0.95). At the garden, the sensor was calibrated to 0.92 which is generally attributed to dry soil, for the ground; and for vertical surfaces again a value of 0.90.

These measurements showed that the differences between MRT and T_s of sunlit areas of the ground were of 0.78 °C for average values, 0.36 °C for maximum values, and 2.25 °C for minimum values. In turn, the differences between MRT and T_s of facades exposed to sun was of 12.22 °C for average values, 13.64 °C for maximum values, and 8.75 °C for minimum values. The more significant differences between the values for T_s of facades and MRT than the values for T_s of the ground and MRT suggest that T_s of the ground is the main influence on the high MRT values recorded at the square: T_s of the ground and MRT values are very close to each other.

Between the two spaces there were significantly different values for T_s of the ground with the garden systematically presenting the lowest values. The average T_s value in sunlit areas of the ground varied by 6 °C, between 37 °C recorded at the square and 31 °C at the garden. Maximum values in sunlit areas also exhibited a 6 °C difference, between 42 °C in the square and 36 °C in the garden. Minimum values in sunlit areas differed by 5 °C, between 31 °C in the square and 26 °C in the garden. In turn, there was practically no variation in the values obtained for T_s of facades. The average T_s value for facades exposed to sun was of 24 °C and for shaded ones 17 °C. This was an expected outcome as, contrarily to ground surfaces, the facing materials of the surrounding facades are basically the same in one space and the other.

The differences between MRT values in one space and the other are due to the combination of different levels of $K\downarrow$ reaching the space (due to the different shading levels provided by vegetation), to the nature of the paving materials, and to evapotranspiration provided by vegetation. In the garden, vegetation reduces the amount of $K\downarrow$ reaching the ground level. The ability of ground and facades to work as heat reservoirs is thus reduced from the start. Together with the soft nature of the paving materials, less $K\downarrow$ reaching the space keeps the ground cooler.

It was not possible to find any reference about an overall comfort zone for MRT in the literature review. Notwithstanding, considering the values recorded for T_a and MRT, it is believed that the thermal comfort evaluations people made were more related to MRT than to T_a. This assumption is based on the differences recorded for these variables.

Table 3 synthesises all data presented above for each measured variable. A comparison between the values measured for each variable, quantified in terms of the difference between the values recorded in the garden and in the square, is provided on the far right column.

Table 3 – Microclimatic values recorded at Poveiros Square (PSquare) and São Lázaro Garden (SLGarden).

Variable		PSquare	SLGarden	SLGarden ^{PSquare}
T_a (°C)	Average	22.60	21.50	-1.10
	Maximum value	24.79	23	-1.79
	Minimum value	20.57	19.42	-1.15
RH (%)	Average	53.58	58.26	+4.7
	Maximum value	68.6	76.3	+7.7
	Minimum value	37.5	43.3	+5.8
$K\downarrow$ (W/m^2)	Average	826	55	-771
	Maximum value	1104	100	-1004
	Minimum value	310	25	-285
W (m/s)	Average	1.13	0.60	-0.53
	Maximum value	5.69	1.8	-3.89
	Minimum value	0.08	0.06	-0.02
MRT (°C)	Average	36.22	24.41	-11.81
	Maximum value	41.64	27.47	-14.17
	Minimum value	28.75	21.24	-7.51

This table shows that the values recorded for each variable systematically presented different values in one space and the other. Amongst the measured variables, wind speed and especially direct direct solar radiation and mean radiant temperature presented the most distinctive values.

Since the only remarkable morphologic differences between the two spaces are paving materials and vegetation, these results suggest that materials and vegetation substantiate these differences. Correlating the remarkable differences between the values obtained in one space and the other with the also sharply different thermal evaluations to the questionnaire, it is possible to draw a correspondence between the microclimate of each space and the obtained votes. To lower microclimatic values corresponded mostly positive thermal evaluations (garden) whilst to higher microclimatic values corresponded mostly negative thermal evaluations (square). Considering that the only differences between the square and the garden are their paving materials and amount of vegetation, it becomes clear that such correspondence is based on these morphologic elements.

Summary of findings [microclimatic monitoring]

The findings from the microclimatic monitoring confirmed that in the absence of significant functional, morphological or social differences, the correlation between the nature of paving materials and the amount of vegetation was the main reason for the significantly different thermal comfort evaluations respondents to the questionnaire made and, thereby, for the remarkably different patterns of use of each space during summer. Facing materials and vegetation were able of significantly influence the microclimate of one space and the other. It was observed that:

- Air temperature was lower in the garden than in the square. Average air temperature in the square was 22.60 °C and in the garden 21.50 °C.
- Relative humidity presented different values in one space and the other but it was not a major contribution to the microclimates of the spaces. Average relative humidity in the square was 53.58˚C and in the garden 58.26˚C;
- Direct solar radiation reaching the ground level was one of the climatic variables presenting the sharpest differences. Average direct solar radiation input in the square was 826 W/m^2 and in the garden 55 W/m^2;
- Wind presented different values in one space and the other with the garden presenting the lowest values. Average wind speed in the square was 1.13 m/s and in the garden 0.60 m/s;
- Mean radiant temperature was one of the variables presenting the sharpest differences. Average mean radiant temperature in the square was 36.22˚C and in the garden 24.41˚C;

Although each variable systematically presented different values in one space and the other, with the garden presenting a better overall performance, direct solar radiation and mean radiant temperature presented the most distinctive values. This is mostly due to the dramatically different amount of vegetation and nature of paving materials of one space and the other. Vertical surfaces were found to have little or no influence on the microclimates of the analysed spaces due to their low H/W ratio.

6.4. Concluding remarks

This chapter presented the undertaken field survey at the two public spaces selected as case study for this research aiming to quantify the extent to which facing materials and vegetation can actually determine the microclimate of outdoor public spaces in compact urban areas and, through this, the validity of programmes of ‘cool’ materials and vegetation as a means for help adapting the built environment to the substantial increase in temperature extremes brought by climate change.

The findings of the undertaken field survey demonstrate that two public spaces can present significantly different microclimates and thus usage patterns, even when side by side, depending on the nature of the facing materials and on the level of vegetation. The dramatically different microclimates of the analysed spaces were found to underlie the failure of Poveiros Square in holding pedestrian activities and the success of São Lázaro Garden as a vibrant pedestrian public space during summer. The reason is that the former does not provide any control over the climate variables whereas the latter does. The conditions for outdoor thermal comfort are then very few in the square while the garden presents the reverse situation.

The functional analysis showed that although both spaces were conceived as pedestrian spaces, the square was observed to be a mainly functionless space whereas the garden presented a vibrant public realm. This sharp difference between the usage patterns is not due to the parameters needed for pedestrian activities to be held since these are basically the same in both spaces.

In turn, the morphologic analysis showed that the only significant morphologic differences between the analysed spaces are paving materials and vegetation: while the square has hard impermeable paving materials throughout its entire area and the near absence of vegetation, the garden presents soft permeable natural facing materials and intense vegetation.

The social/personal analysis then revealed that the different patterns of use and attractiveness degree of one space and the other are directly related to their microclimates. It is remarkable that 93 % of users of the square were uncomfortable due to hot conditions while 91 % of users of the garden were comfortable; that 84 % of respondents at the square considered it usually uncomfortable during summer whereas the garden was considered by 100 % of respondents as usually comfortable. Bearing in mind that thermal comfort is «that condition of mind which expresses satisfaction with the thermal environment» (ISO, 2005; 10), the answers obtained to the questionnaire are doubtless in expressing the dissatisfaction of respondents relatively to the conditions for thermal comfort offered by the square, and their satisfaction face to the conditions for thermal comfort at the garden.

Finally, the microclimatic monitoring confirmed that there is actually a correlation between people’s thermal evaluation votes, usage patterns, and the microclimates of the analysed spaces, and that these are related to their paving solutions and amount of vegetation. The dramatically different values obtained for direct solar radiation and mean radiant temperature between the square and the garden are direct consequences of the nature of their paving solution and level of vegetation: the mechanical, moisture-related and optical parameters of materials in association to the biophysical parameters of vegetation are responsible for the average less 771 W/m^2 direct solar radiation, and the average less 11.81˚C mean radiant temperature recorded at the garden by comparison to the square.

It is fair to say that the significantly different obtained thermal comfort evaluations walks hand in hand with these sharply different values recorded for direct solar radiation and mean radiant temperature. This illustrates how the chances created for people to be engaged in physical and social activities in outdoor public spaces should deal with the extent to which pedestrians can fit their personal requirements with the surrounding outdoor thermal environment, especially in a climate change context.

The undertaken field survey has confirmed that the microclimate of outdoor public spaces can then be largely influenced by paving materials and amount of vegetation and that this can determine the success of a pedestrian public space. It was shown that a soft, light-coloured, permeable ground surface coupled with a significant level of vegetation, the garden, can lead to more well-balanced microclimates in compact urban areas during summer. Poveiros Square is a good example of how a high-absorptive ground paving and the absence of shade can reduce the liveability, the use, and thus the success of an outdoor pedestrian public space during summer; of an outdoor public space considered by the large majority of respondents to the questionnaire as a space to avoid during summer.

By showing how largely the microclimates of public spaces in compact urban areas can differ, even when contiguous, due to contrasting paving materials and levels of vegetation, the undertaken field survey confirmed that the adaptation of the built environment to the substantial increase in temperature extremes brought by climate change can be conceived as a set of retrofitting actions over the ‘climatic skin’ of outdoor public spaces in compact urban areas based on programmes of ‘cool’ materials and vegetation. The development of a methodology for the thermal retrofitting of public spaces in compact urban areas may then be valid.

7

A METHODOLOGY FOR THE THERMAL RETROFITTING OF PUBLIC SPACES IN COMPACT URBAN AREAS

This chapter addresses the proposal of a methodology supporting the development of thermal retrofitting proposals for public spaces in compact urban areas based on programmes of ‘cool’ materials and vegetation. This methodology was conceived as a tool contributing to the adaptation of the built environment to the substantial increase in temperature extremes brought by climate change. A guide for help specifying programmes of ‘cool’ materials and vegetation will be proposed within the methodology.

Section 7.1 addresses the overarching issues about this methodology; section 7.2 presents the methodology through its structure, layout, and contents; section 7.3 presents the guide proposed within the methodology, namely its structure, layout, and contents; and section 7.4 presents some concluding remarks.

7.1. OVERARCHING ISSUES

This research conveys a belief that the creation of successful pedestrian public spaces requires a bioclimatic vision; it is believed that bioclimatic urban design can be determinant for ensuring that public spaces keep fulfilling their roles as the main stages of social interaction in a climate change context. The undertaken field survey confirmed that the adaptation of the built environment to the substantial increase in temperature extremes brought by climate change can be conceived as a set of retrofitting actions over the ‘climatic skin’ of outdoor public spaces in compact urban areas based on programmes of ‘cool’ materials and vegetation. Adaptation to climate change is not obviously limited to the intervention in compact urban areas. Notwithstanding, it is believed that adaptation should immediately address these urban areas which present the main challenges to building operations.

Different interactions between the physical parameters of materials, biophysical parameters of vegetation, and climatic variables can result in significantly different urban microclimates. Recognising these interactions is the first step to design spaces able of mediating man, climate and environment. The second step is to know how to address the microclimate of outdoor public spaces, through which principles, as well as how to choose materials and vegetation.

Approaching the microclimate of outdoor public spaces in compact urban areas through programmes of ‘cool’ materials and vegetation requires addressing a whole range of issues not commonly considered nowadays in public space projects. The gap that seems to exist between theory and practice of bioclimatic urban design has consequences on the inclusion of programmes of ‘cool’ materials and vegetation into public space projects.

Taking this into consideration, this research proposes a methodology for the thermal retrofitting of public spaces in compact urban areas through programmes of ‘cool’ materials and vegetation. A guide for help specifying programmes of ‘cool’ materials and vegetation is proposed within the methodology. It is important to highlight that the proposed methodology is not a full urban design tool. Instead, it is a methodology developed for supporting the retrofitting of public spaces in compact urban areas committed with the adaptation of the built environment to the substantial increase in temperature extremes brought by climate change. This methodology does not replace other previously developed methodologies, guidelines or tools for the conception of high-quality public spaces. On the contrary, the proposed methodology should be cross-related with other available references. Also, the methodology is specifically targeted to regions with warm and hot summers.

The methodology was designed to help paving the way to a simple and quick way of adapting the built environment to the substantial increase in temperature extremes and, simultaneously, to contribute to the consolidation of bioclimatic urban design practice by supporting urban designers and decision-makers. The proposed methodology was then developed according to the following premises:

- **Addressing key work stages of the design process**. The methodology can assist the whole development of urban design retrofitting schemes committed with the improvement of the microclimate of outdoor public spaces within compact urban areas, by incorporating referential work stages.
- **Merging of common and bioclimatic urban design principles**. The methodology does not establish a boundary between one and the other approach to urban design.
- **User-friendly and straightforward character**. Based on the idea that developing simple tools and involving potential users in their development can promote the use of a tool (Jensen and Elle, 2007; 246), the methodology was developed to present an utmost simplicity and plainness namely through the following topics:
    - **Optimisation of information**. Information was conceived as a straightforward listing of guidelines for quick decision-making.
    - **Simple sentences**. Short sentences less centred in overly technical-specific concepts and closer to the language of urban design.
    - **Simplicity of layout**. The layout of the methodology was thought to be as simple as possible so that designers could easily and quickly use it.
- **Flexibility**. It was acknowledged that whenever new ideas are called for into any area with well-established procedures the acceptance of these new ideas is more likely to happen by raising awareness than by imposition. Thus, the methodology was conceived to be flexible rather than prescriptive. The information encompassed in the methodology does not point out ‘ideal’ solutions but principles for weighing the extent to which the retrofitting of a public space based on a programme of ‘cool’ materials and vegetation can help improving its microclimate. The work stages, structure, headings and contents of the methodology should then be regarded as a way of prompting thoughts rather than a prescriptive listing of requisites a proposal should comply with. All proposed principles are merely indicative in order to allow the creative freedom of designers and adapting the methodology to specific project requirements.

The basis for the proposal of this methodology was the literature review. The parameters incorporated into the methodology were assembled, derived and developed from various sources such as books, journals, guidelines, standards, and contact with practitioners and scholars. The main references from the literature review were Olgyay (1963), Kozlowski (1971), Alexander, Ishikawa et al. (1977), Plumley (1977), Mayer and Höppe (1987), Godet (1988), Sarandeses, Molina et al. (1990), Meerow and Black (1991), Taha, Akbari et al. (1991), Akbari, Davis et al. (1992), Rosenfeld, Akbari et al. (1995), Asaeda, Ca et al. (1996), Allinson (1997), Taha (1997), Voogt and Oke (1997), Bretz, Akbari et al. (1998), Givoni (1998), Marcus and Francis (1998), Michau (1998), Nikolopoulou (1998), Emmitt (1999), Jefferies (1999), Ashworth and Hogg (2000), Berge (2000), Llewelyn-Davies (2000), Akbari, Pomerantz et al. (2001), Blyth and Worthington (2001), Cowan (2001), Europe (2001), Gray and Hughes (2001), Romero (2001), Santamouris (2001), Akbari (2002), Brandão, Carrelo et al. (2002), Brownhill and Rao (2002), Haupt and Kubitza (2002), Simpson (2002), Alves (2003), Andrade (2003), Dimoudi and Nikolopoulou (2003), Thomas (2003), Nikolopoulou (2004), Mean and Tims (2005), Mendonça (2005), Higueras (2006), Tunstall (2006), Cremasco (2007), Gaitani, Mihalakakou et al. (2007), Jensen and Elle (2007), Jones and Patterson (2007), English Partnerships and the Housing Corporation (2007), Tojo (2007), Yilmaz, Toy et al. (2007), Taylor and Guthrie (2008), Yu, Chen et al. (2008), Planning Policy Wales: Technical Advice Note 12: Design (2009), CABE (2009), Ritchie and Thomas (2009), Lenzholzer and Koh (2010), Gehl (2011), Lorenz and Staub (2011), Nelson and Powers (2011), and Sinclair (2011). Together, the whole group of references for developing the methodology provided relevant information which was continuously critically analysed, compared and synthesised.

7.2. THE METHODOLOGY

7.2.1. STRUCTURE AND LAYOUT

Structure

Based on the analysis, comparison, and synthesis of information provided by the references acceded during the literature review, the structure of the proposed methodology is anchored in four key work stages:

- **Preparation**. The Preparation stage deals with identifying the client's intentions, preparing site and feasibility studies, identifying key-needs and constraints, as well as defining the fundamentals for the intervention.
- **Design**. The Design stage is about developing the proposal in terms of its physical expression through the design policy, the specification of programmes of 'cool' materials and vegetation, and spatial design.
- **Construction**. The Construction stage is about the installation of the final design scheme and it is divided into two main moments — pre-construction organisation and site operations.
- **Use**. The Use stage is associated to the administration of the space after the completion of site operations, to the final inspections, and to the assessment of the project performance in use (evaluation and feedback).

The proposed stages are merely indicative and do not relate to any national planning system. These stages are referred to as "key work stages" because these correspond to overarching moments of the design process. Therefore, the proposed key work stages are not mandatory steps to be fulfilled as a requisite for obtaining planning approval.

These key work stages are at the basis of the main headings of the methodology and unfold a number of related sub-headings and topics. Since bioclimatic urban design constitutes a branch of the general urban design discipline both perspectives present many common points. Therefore not all stages present specific bioclimatic principles. According to their specificity and, thus, to the categories encompassed, each key work stage has different degrees of inclusion of bioclimatic principles. For instance, while the appraisal (Preparation stage) may incorporate a large number of bioclimatic principles since it relates partially to characterising the site, other aspects such as site operations (Construction stage) deal with issues which are transversal to any approach to urban design. Table 4 presents the structure of the proposed methodology.

Table 4 – Structure of the proposed methodology.

PREPARATION		
APPRAISAL	Client's intentions Functional characterisation Morphological characterisation Social characterisation Microclimatic characterisation Design constraints	
FUNDAMENTALS FOR THE INTERVENTION	Statement of need Attraction of investment Management & maintenance policy Community engagement policy	
DESIGN		
DESIGN POLICY	Premises	
SPECIFICATION OF PROGRAMMES OF 'COOL' MATERIALS AND VEGETATION	Specification of programmes of 'cool' materials and vegetation. Guide available at www.budsum.com [GUIDELINES - selection of materials and vegetation] Concept design Virtual simulation Discussion of alternatives	
SPATIAL DESIGN	Robustness Ease of movement Relevance & legibility Maintenance requirements	Guide for the specification of programmes of 'cool' materials and vegetation available at www.budsum.com [GUIDELINES - spatial design]
CONSTRUCTION		
PRE-CONSTRUCTION ORGANISATION	Team Planning the impacts of site operations	
SITE OPERATIONS	Build quality Construction management Impacts of site operations	
USE		
EVALUATION & FEEDBACK	Monitoring policy Post-completion review Post-occupancy review	

Notwithstanding the importance of all proposed stages, on the perspective of delivering the space a high-quality standard the Design stage has a special importance: it is during this stage that the specific options for the space's physical layout are made. Beyond general quality parameters such as robustness or relevance and legibility, on a purely bioclimatic perspective, a space's microclimate is specifically addressed in this stage through the options made for materials and vegetation. It is fundamental to know how to choose materials and vegetation envisioning a thermally balanced microclimate, as well as how to relate this with other design elements contributing for a high-quality space. This is specifically addressed by the proposed guide.

Layout

The option was to develop a group of tables (Table 5), one per each proposed key work stage. These tables could be termed as checklists. However, it was deliberately decided not to do it since the term checklist, by its own definition, could eventually lead practitioners to regard it as requiring a compulsory fulfilment of requisites. The option for tables is directly associated to the goal of providing a flexible methodology. The layout of these tables is presented in the following table.

Table 5 – Layout of the tables constituting the proposed methodology.

SUB-STAGE UNFOLDING THE KEY WORK STAGE	
Topic	**Principles**
Field of considerations to which parameters refer to	▪ Proposed issues to weigh, both common and bioclimatic.

In more detail, this layout is constituted by three sections: sub-stage, which unfolds from a main stage of the design process; topic, indicating the general field of considerations to which the proposed principle refers to; and principles, which encompasses the bioclimatic and common urban design issues to weigh for a specific topic and, thus, to meet the general aim of a sub-stage.

The proposed tables do not entail any specific instructions of use. These should be regarded as desktop notes to support the development of the project. Annex G presents the proposed methodology as is was conceived for being visualised and used.

7.2.2. CONTENTS

The parameters and principles incorporated into the methodology were assembled, derived and developed from two sources: the literature review and the direct contact with practitioners and scholars. The literature review encompassed the references mentioned above.

With respect to the direct contact with practitioners and scholars, the contacted entities were urban planners, urban designers, architects, and landscape architects working in public and private bodies committed with the creation of public spaces, namely private design offices, urban rehabilitation agencies, local authorities, and government bodies; and scholars belonging to public universities and from different expertise fields. Representatives of these entities were chosen in Portugal and the United Kingdom. The option for these countries is merely illustrative: these countries have different planning and design backgrounds, and different legal, social, historical, and climatic contexts. These differences were thought as to provide an unbiased appreciation of principles to include. The contacted entities are listed in Table 6.

Table 6 – Practitioners and scholars consulted for the development of the methodology.

Design office	
Entity	**Field**
Chris Owen – Chris Owen Architect	Architecture and sustainable urban design
Isabel Matias – Vastus	Architecture and urban planning
John Worthington – DEGW	Architecture
Inês Murghulia Jorge – Schindler Seko Architects	Architecture
Laura Roldão Costa – Laura Roldão Costa Arquitectura Paisagista	Landscape architecture
Urban regeneration agency	
José Patrício Martins – Porto Vivo	Architecture, urban design and urban planning
Kevin McGeough – Homes & Communities Agency	Architecture, urban design and urban planning
Local authority	
Armanda Abreu – Porto City Council	Architecture and c
João Pestana – Porto City Council	Urban design
Sandy Williams – Cardiff City Council	Urban design
Government body	
Alexandra Cabral – CCDRN	Landscape architecture
Andrew Charles – Welsh Government	Urban Planning
Wendy Richards – Design Commission for Wales	Urban design and landscape architecture
Scholars	
Entity	**Expertise field**
Ana Monteiro – Universidade do Porto	Urban climate
Dulce Almeida – Universidade Lusófona	Bioclimatic urban design
Fergus Nicol – London Metropolitan University	Architecture and thermal comfort
Joanne Patterson – Cardiff University	Sustainable urban development
Marialena Nikolopoulou – Kent University	Sustainable architecture and bioclimatic urban design
Mike Biddulph – Cardiff University	Urban design

7.2.2.1. Preparation

The Preparation stage deals with identifying the client’s intentions, preparing site and feasibility studies, and identifying key-needs and constraints (appraisal). In this stage it is also important to define the fundamentals for the intervention, namely to develop an initial statement of requirements, and to define entities to engage as well as their contribution for the proposal. Together, these elements may help informing the development of briefs which should express the characteristics and needs of a space and state a vision committed with its improvement at all levels. Table 7 presents the proposed full range of contents for the Preparation stage.

Table 7 – Proposed methodology. Contents of the Preparation stage.

APPRAISAL	
Topic	**Principles**
Client's intentions	▪ Identification of the client's needs and objectives.
Functional characterisation	▪ Analysis of the space's functioning irrespective the initially planned function.
Morphological characterisation	▪ Analysis of the space's morphology in global and microclimate terms.
Social characterisation	▪ Identification of types of users; ▪ Knowing users' thermal comfort evaluations and personal parameters eventually influencing these; ▪ Identification of people's wishes and expectations for the site.
Microclimatic characterisation	▪ Collection of data about the climatic variables at the microclimatic scale by alternatively: o using a portable meteorological station; o running a microscale climate model (e.g. ENVI-met); o using the proposed guide, available at www.budsum.com (for an empirical assessment which can be correlated to people's thermal comfort evaluations).
Design constraints	▪ Identification of eventual design constraints (e.g. physical and regulative constraints, ownership).
FUNDAMENTALS FOR THE INTERVENTION	
Topic	**Principles**
Statement of need	▪ Stating and justifying why is it worth improving the space's microclimate.
Attraction of investment	▪ Showing how the thermal retrofitting intervention can benefit people's welfare and bring revenues from the initial investment.
Management & maintenance policy	▪ Definition of activities and their distribution throughout the space; ▪ Definition of maintenance policy suitable to the intervention vision; ▪ Definition of who is going to manage and maintain the space and through which means.
Community engagement policy	▪ Definition of the extent to which community will be involved; ▪ Conciliation of the client's and users' expectations.

The Preparation stage encompasses the first steps for the retrofitting of a public space towards a more balanced microclimate. Should microclimate and subsequent conditions offered for thermal comfort not be concerns to the client, these can be approached and communicated to the client as any other quality requisite. Stating the need for investing in the improvement of a space's microclimate involves commitment in communicating why it is important to do it, why it constitutes a need which can no longer be postponed.

There may not be one single solution for a need neither one single way of perceiving what a need is. Therefore, uncertainty should be reduced as much as possible which, in turn, requires clearly showing why a given need is worth pursuing in the development of the project. Raising awareness about the importance of adapting cities to the substantial increase in temperature extremes brought by climate change is crucial for stating the need for investing in the thermal improvement of public spaces. This requires bringing these concerns into the centre of discussions on urban design, to discuss its pros and cons, to identify its opportunities and threats, to make it a true need amongst decision-makers and stakeholders. For understanding between the different parties to take place there has to be a common ground, and it is this common ground and the development of a shared understanding that makes communication possible (Emmitt, Prins et al., 2009; 53).

Whenever new ideas are called forth, it is fundamental to provide relevant and clear information about these, especially performance specifications since it will help explaining ideas with which the client is not familiarised with. Care should be taken in showing the client that the proposed ideas do not hinder its expectations and may even help achieving better goals. This can influence the extent to which the client will be willing to accept new ideas. Well-informed clients can more easily contribute for the achievement of good design. The design team should, in turn, be able of plainly communicating opportunities back to the client.

Appraisal

The appraisal is about identifying the client's needs and objectives for the project. The client's intentions should be informed by a comprehensive characterisation of the site. The site appraisal allows identifying the space's potentialities and weaknesses, what needs to be improved and not, as well as managing conflicting interests between different uses. It therefore provides both a characterisation and diagnosis of the space which is a vital step for critically assessing the client's intentions, either substantiating or questioning them. The appraisal will thus underlie the entire development of the design proposal.

The first consideration when planning a site appraisal is to ensure the balance between the efforts needed to collect the data and its impact and relevance. The selection of sources of information should follow this principle and provide the most comprehensive characterisation possible of the site. Sources of information can vary from existing sources (e.g. local or national libraries and museums, universities, newspapers, national organisations, local societies, land registry, technical laboratories, specialist consultants) to new sources (e.g. sketches, photography, video, calculations, observations, questionnaires, or workshops). The collection of information depends on parameters such as the work force available, types of decisions required, and scale of project.

It is vital to state the extent to which the space needs to be improved in microclimatic terms and exactly which morphologic elements should be acted upon. This requires a deep characterisation of the space in all its dimensions. Characterising a microclimate should involve obtaining information on (1) how the space actually works and the relationship its functioning establishes with its microclimate; (2) the morphologic elements influencing its microclimate; (3) the thermal evaluations of users; and (4) the influence climatic variables have on its microclimate. Envisioning these goals, a functional, morphological, social/personal, and microclimatic characterisation should be undertaken.

A **functional characterisation** allows knowing the actual use people make of a space irrespective the initial intended function. This should be given attention since it will point out what are the true needs of the space and, thus, to decide the best ways of improving it. In pedestrian public spaces it is fair to say that the capacity of a space to attract and retain users is the best indicator of its success. The first analysis to undertake should then be targeted at understanding the use pedestrians make of a space.

A **morphological characterisation** identifies which morphologic elements have a tighter relationship with the space's microclimate. General elements (e.g. dimension, topography, orientation, buildings' average heights, architectonic typologies, or urban furniture) should be accompanied by elements more directly related to the space's microclimate such as height/width ratio, Sky View Factor, main colours, water features, shading devices, materials, or vegetation. The morphological characterisation will allow knowing over which morphologic elements the retrofitting intervention will have to focus.

A **social characterisation** allows knowing the thermal comfort evaluations of users, i.e. identifying people's thermal sensation, evaluation, preference, acceptability, and tolerance votes and to relate these votes with the type of users and their personal parameters (e.g. age, gender, activity level, clothing level, food/drink consumption, reasons to be site, time of permanence, or long-term thermal experience). This will allow knowing people's appreciation of the thermal environment of a space, their degree of satisfaction with it, as well as their wishes and expectations. Questionnaires and observations are effective tools for collecting this information.

A **microclimatic characterisation** characterises a space's microclimate and correlates it with the social characterisation. This characterisation is crucial for understanding the conditions offered for thermal comfort and, thereby, for determining the quality and quantity of the corrective measures needed for improving a space's microclimate. Ideally, these should be done through a portable meteorological station. Nevertheless, since this can be time-consuming, involve the acquisition of expensive instruments, and require good knowledge on the use of the instruments, an alternative is to use a microscale climate model (it requires accessing official climatic data as specific as possible to the site as well as knowing the properties of materials and vegetation at site). A second alternative is the use of the proposed guide which allows an empirical characterisation of a space on a microclimate and bioclimatic perspective. The principles listed in the guide can be useful for giving a picture of the general situation of the space, especially if correlated to people's thermal comfort evaluations.

In addition, the constraints posed to the retrofitting intervention should also be clearly identified. The nature of these constraints can be twofold: physical, e.g. underground or aerial services, surrounding functions, or flooding areas; or regulative, i.e. listed buildings, sites of special scientific interest, local, regional or national plans, programmes, and policies. Also the ownership associated to the surfaces of the space, especially for buildings, should be identified. Considering all eventual design constraints posed to the application of a programme of 'cool' materials and vegetation from the outset can reduce the probability of a proposal having to be revised during the attainment of planning consent.

The correlation of all these topics can provide an understanding of how a given microclimate affects a space's usage patterns. Identifying people's thermal comfort evaluations and correlating it with the space's function and morphology can be determinant for setting a vision for the microclimatic improvement of the space. Microclimate should then be addressed in the characterisation and diagnosis of the space, be integrated in the statement of need for the project and expressed within the fundamentals for the intervention.

Fundamentals for the intervention

The appraisal provides the information needed for defining the fundamentals for the intervention. These start with a **statement of need** which is basically a «concise statement which defines in operational and business terms the need or opportunity» (Blyth and Worthington, 2001; 15). In the context of the proposed methodology, the statement of need is about stating the critical issues to address for the improvement of a microclimate; it is about defining the direction towards which action will be taken to improve the space. The adaptation of the built environment to the substantial increase in temperature extremes brought by climate change should be taken into consideration in urban design projects as much as commonly considered issues such as safety, security, or accessibility. The definition of what is worth pursuing, according to the site's characteristics and nature of the project, is vital for developing a robust statement of need.

On a bioclimatic perspective the statement of need may require a deviation from common concerns underlying the development of public space projects. Whenever this is the case, it can be relevant to raise awareness about the importance of such deviations. Addressing a public space's microclimate is an issue involving important parameters people are likely not to be familiar with.

Conspicuous amongst the issues to weight as fundamentals for the intervention is the attraction of investment, the management and maintenance policy, and the community engagement policy. These are issues that relate to the organisation of the project and its associated entities. The fundamentals for the intervention may then be regarded as the necessary agreed platform for client, stakeholders, designers, and users to plan the retrofitting of a public space envisioning its better microclimate. It might therefore inform the preparation of strategic briefs. These fundamentals are the common ground for understanding between the different parties involved in the project to happen.

In this context, it is vital for the fundamentals of the intervention to continually refer back to the appraisal stage. It is also important that the definition of these fundamentals is realistic and feasible, which may involve making no unrealistic prospects for the project's achievements, the identification of priorities/objectives and milestones, or the definition of how decisions and responsibilities will be managed amongst the different parties involved. Plainness is the keyword here and is about ensuring that the fundamentals for the intervention provide all relevant information for decisions to be made in a straightforward, realistic, and informed way.

Attracting investment is paramount for ensuring the successful implementation of a retrofitting intervention because it allows gathering financial and human resources, sharing risks, and ensuring a continued supply of financial and human resources. The chances for a scheme to be aborted by lack of resources can therefore be minimised. Conspicuous amongst the array of issues that may help attracting investment to urban design project concerned with the improvement of a microclimate is showing stakeholders, landowners, developers, investors, management agents, and beneficiaries how the design scheme can significantly contribute to deliver a high-quality standard and provide financial reward, even if over the medium and long-term.

In a climate change scenario, fighting the substantial increase in temperature extremes brought by climate change in urban areas should be regarded as a parameter actively contributing a degree of extra-satisfaction with a space and thus to its added value. This requires ensuring that the quality of the scheme is demonstrated since the early stages of the proposal: e.g. the efficiency of an intervention in helping people to cope with higher temperatures and thus in attracting users, residents, and businesses.

Post-completion and occupancy are often determinant for measuring the success of a scheme. In a bioclimatic intervention based on programmes of 'cool' materials and vegetation in addition to completion and use, the time required for vegetation to mature and start producing effective bioclimatic results makes the timescale of appreciation of benefits to be widened. It is then fundamental for all parties to be aware of the likely time lag between capital investment and the attainment of microclimatic amenities and financial rewards. In addition, it is important to bear in mind that the aim of a bioclimatic intervention is not achieving an 'ideal' thermal environment pleasing 100 % of users but, instead, an 'improved' thermal environment pleasing a majority of users. Realistic expectations about the design scheme should be kept by all parties at all times.

The **management and maintenance policy** should set a robust aftercare of the space since this is vital for ensuring that the initial aims of a design scheme are not undermined. The management and maintenance policy should encompass the full extent of elements to control since the establishment of an effective management and maintenance system has an utmost importance for the success of a public space by keeping it 'in good shape' in the long-term and, thus, for fostering a sense of welfare, safety and security. For programmes of 'cool' facing materials and vegetation the management and maintenance policy is determinant for their contribution to the microclimate of the space since lighter surfaces and plants must be properly kept in order to maintain their full range of beneficial properties.

Defining who is going to manage and maintain the space and through which means are vital issues when defining the management and maintenance policy. Local authorities, through their maintenance schemes, play here the most important role. Maintenance responsibilities might however be shared with other entities. For instance, it is highly relevant encouraging community management and maintenance since this will tend to reduce charges to local authorities and foster a sense of civic participation.

Community engagement policy deals with promoting the involvement of community in the decision-making process so that people's needs, ideas and knowledge are taken into account in the design scheme. Involving the community is crucial for guaranteeing that the proposal will be adapted to its beneficiaries. Engaging the community may however require providing support and guidance to people. It might as well be important to know what resources are locally available to help people getting involved. Considering that the retrofitting of public spaces through programmes of 'cool' materials and vegetation may be associated to rather simple and quick operations (e.g. re-colouring walls or planting trees), local communities are likely to be integrated without major difficulties.

In addition to these topics, it is highly important to coordinate the team. This involves ensuring the harmonious and efficient collaboration of the several disciplines concurring to the development of a proposal. The limits for the integration of different specialists are determined by the specificity of a project. A public space retrofitting intervention based on a programme of 'cool' materials and vegetation may require the inclusion of experts on materials and vegetation, namely on their physical, moisture-related and optical, and biophysical parameters, respectively.

7.2.2.2. Design

The Design stage defines three levels of approach to the development of a proposal: the design policy, specification of programmes of 'cool' materials and vegetation, and spatial design. The design policy implements the fundamentals for the intervention previously defined and prepares the concept design. It therefore establishes the way according to which the project is to be developed. The specification of programmes of 'cool' materials and vegetation, in turn, is about specifying the programme of 'cool' materials and vegetation to a site by selecting materials and species, developing the concept design and eventual alternatives, undertaking virtual simulations and discussing the alternatives. Finally, spatial design is about including into the concept design basic 'classical' urban design issues so that the proposal may reach a convenient degree of overall spatial quality and, thereby, be robust. The following table presents the proposed full range of contents for the design stage.

Table 8 – Proposed methodology. Contents of the Design stage.

DESIGN POLICY

Topic	Principles
Premises	▪ Integration of all issues relevant to site and project defined in the Preparation stage; ▪ Definition of the general vision for the intervention and how it meets the client's expectations; ▪ Definition of whether or not facing materials and vegetation will have the same importance; ▪ Definition of which surfaces will be acted upon (ground and/or facades) and to which extent (%); ▪ The fit between the retrofitting strategy and the activities planned at the fundamentals for the intervention.

SPECIFICATION OF PROGRAMMES OF 'COOL' MATERIALS AND VEGETATION

Topic	Principles
Selection of materials and vegetation	▪ Using the guide for the specification of programmes of 'cool' materials and vegetation available at www.budsum.com [GUIDELINES - selection of materials and vegetation] ▪ Collection of technical information about the physical, moisture-related and optical parameters of materials and biophysical parameters of vegetation.
Concept design	▪ Development of planning drawings providing outline sizes, quantities, layout, and design, paying attention to the optimisation of the amount of materials and vegetation required; ▪ Definition of suitable alternatives.
Virtual simulation	▪ Running a microscale climate model (e.g. ENVI-met) for simulating the expected microclimate of the concept design and of alternatives.
Discussion of alternatives	▪ Choosing the solution presenting the best correlation between potential for microclimatic improvement and cost.

SPATIAL DESIGN

Topic	Principles	
Robustness	▪ Addressing appearance and ensuring relaxation, people's active involvement, people's passive involvement, exploration, fruition, adaptability, safety and security.	Guide for the specification of programmes of 'cool' materials and vegetation available at www.budsum.com [GUIDELINES - spatial design]
Ease of movement	▪ Ensuring access and fitting movement patterns.	
Relevance & legibility	▪ Ensuring visual/spatial relevance and legibility.	
Maintenance requirements	▪ Addressing the maintenance requirements of materials, vegetation and water drainage.	

The Design stage has the most fundamental role in determining the physical layout of the space: on one hand, it gives physical expression to the fundamentals of the intervention, which shall include the strategic bioclimatic principles governing the whole intervention; and on the other hand, it is during this stage that the physical elements of bioclimatic urban design will be specified and brought together.

The Design stage further deals with preparing the project information, i.e. sufficiently detailed written documents, technical drawings, and specifications to obtain planning consent and tender(s). All data required for planning application should enable a comprehensive understanding of the design proposal in order to avoid delays in the planning approval process and reduce the probability of time and capital costs outcoming from ulterior submission of lacking data or redesigns.

Design policy

The design policy expresses the general intervention principles agreed between all parties. The establishment of the design policy should therefore be built upon the discussion of the proposal with the appropriate parties before more detailed design options are made and, especially, before site operations are initiated; upon the consideration of all possible alternatives for achieving the main vision for the intervention; upon the identification of potential conflicts which may occur between different groups of interest; and upon the integration of all issues relevant to site and project defined in the Preparation stage. All these topics contribute to the definition of robust proposals.

Discussions about design do not focus on detailing but on the general options guiding the development of the project in ulterior stages. The general urban design principles contributing to the quality of the space should be defined here and refined during spatial design. It is vital to ensure that the design policy is plain and functionally, technically and financially feasible.

On bioclimatic terms, the design policy should encompass the ways through which the proposal addresses the space's microclimate and, consequently, the conditions offered for outdoor thermal comfort. The general design options for the retrofitting strategy should be made. This involves, for example, defining whether or not facing materials and vegetation will be given the same importance or if one of these will not be considered at all, defining which surfaces of the space will be acted upon (i.e. both ground and facades or only one of these) and to which extent, or weighing the fit between the retrofitting strategy and the activities planned in the fundamentals for the intervention.

Specification of programmes of 'cool' materials and vegetation

Planning a space's microclimate in a compact urban area is about selecting materials and vegetation with the parameters potentially better suited to the site. The design team should therefore be able of specifying a programme of 'cool' materials and vegetation by appreciating its long-term global effects on the space's microclimate.

The **selection of materials and vegetation** should be made by appreciating the physical, moisture-related, and optical parameters of facing materials as well as the biophysical parameters of vegetation. This is as important for the space's microclimate as, for instance, the evenness of a ground paving important for ease of movement. These issues are covered by the proposed guide for the specification of programmes of 'cool' materials and vegetation, namely in the first part of the "guidelines" section ("selection of materials and vegetation"). This guide is addressed in detail ahead in this chapter.

Design teams should however bear in mind that there are no 'recipes' for choosing materials and vegetation. An increase in greenery, for instance, might not necessarily be the best option due, for instance, to the confinement of the space or underground services. Detailed knowledge on materials and on the mechanics of planting and growth of plants can be obtained from specialists in these areas. It is therefore vital to collect good technical information about materials and vegetation. It may also be important to identify contractors and suppliers allowing for best practices to be met at all times and for all fields of the project. Contractors and suppliers should be strongly committed with the goals of the project. It may also be important to identify firms with environmentally friendly practices. In addition, environmental costs should be weighed during the specification of programmes of 'cool' materials and vegetation. The lower the environmental costs associated to the specified materials and planting scheme, the more sustainable the retrofitting intervention is likely to be.

The **concept design** relates to the development of the design policy into more detailed building terms. Such as for the design policy, concept design should be plain and provide relevant, realistic and feasible information to make decisions — it is of an utmost importance to present information in such a way that can be acted upon. The definition of suitable alternatives may also be fundamental as a way of testing the concept design.

The concept design gives the options for the retrofitting strategy a convenient degree of formalisation without however entering into spatial design issues but rather through planning drawings providing outline sizes, quantities, layout, design, construction method, specifications, and services systems. These elements should acknowledge the client's requirements and expectations in order to avoid the likeliness of later disagreements about the direction of the proposal. This may involve acknowledging to the client that the design team understood its expectations and earlier agreements, or ensuring that the design team understood its priorities in respect of quality, time and cost.

After defining the concept design and eventual alternatives, a **virtual simulation** should follow. This relates to the use of a microscale climate model for simulating the expected microclimate of the concept design and eventual alternatives. Support may be given in this task by microclimate experts, software programmers, or University departments. These models are useful tools for planning a microclimate improvement since they can provide a range of potential values for an array of variables. It is thereby important that such tools may start being integrated into the development of public space proposals committed with bioclimatic subjects as much as other currently existing tools such as computer-aided design (CAD) software.

The **discussion of alternatives** succeeds the virtual simulations and deals with choosing, amongst concept design and eventual alternatives, the solution presenting the best correlation between microclimatic improvement and cost. On one hand, there is the potential for improving the space's microclimate during summer; on the other hand, there is cost. Can the costs conveyed by a given proposal be as advantageous as its potential for microclimatic improvement? The costs associated to different proposals can be different and therefore determine the choice for one or another alternative as much as the potential for microclimatic improvement. The key is to carefully weigh the advantages of using a given material and vegetation species not only in the short-term but in the long-term. Anticipating what the in-use requirements of a given combination of facing materials and greenery will be and defining a robust maintenance scheme is paramount here.

In addition, the time required for installation may also be considered since the less time required for installation, the less disruptions to the normal functioning of an area and the sooner the achievement of the planned amenities.

Spatial design

Spatial design is about undertaking the design of all components of the space bearing in mind 'classical' urban design quality parameters. Since the quality of a public space is not restricted to microclimate only, planning a programme of 'cool' materials and vegetation should account with bioclimatic and 'classical' urban design principles.

Beyond knowing the importance of programmes of 'cool' materials and vegetation, and beyond knowing how to choose between one and another material and one and another vegetation species, it is fundamental to know how to bring both elements together into a retrofitting intervention in order to propose a high-quality public space. Achieving a high-standard spatial quality is dependent upon the importance given to each of the components of the space and to the way these relate to the main parameters assigning quality to public spaces, i.e. robustness, ease of movement, relevance and legibility, and maintenance requirements. These issues are covered by the proposed guide for the specification of programmes of 'cool' materials and vegetation, namely in the second part of the "guidelines" section ("spatial design").

Robustness is about ensuring that the basic human needs in public spaces are met and perpetuated; it relates to the basic issues determining the relationship between what a space offers and people's expectation on the sort of amenities to be found conscientious or unconsciously; it is about ensuring that everyone can have an enjoyable, safe and stimulating experience of the space. This involves guaranteeing that the specified programme of 'cool' materials and vegetation incorporates principles related to appearance, relaxation, people's active involvement, people's passive involvement, exploration, fruition, adaptability, safety and security.

Ease of movement is about how easily can people access and move around a public space; about ensuring that everyone can easily, directly, and safely access and move through the space. Relatively to vegetated areas, it should be acknowledged that «people will take shortcuts across lawns or even planting to get to where they want to go as quickly as possible» (Marcus and Francis, 1998; 51).

Accessibility and movement of people with mobility and sensory impairments has an utmost importance here. Public spaces free of physical barriers and with a high-density can ensure viability of, and accessibility to, sub-spaces and surrounding facilities. Bearing this in mind, the specification of programmes of 'cool' materials and vegetation should account with its impact on the access to the space and on the movement patterns within the space, especially the desire lines.

With respect to **relevance and legibility**, a proposal should help assigning meaning to a space. The design team should pay attention to site-related needs and characteristics and develop proposals contributing to the reinforcement of the *genius loci*. This reinforcement has a number of social, economic and environmental benefits amongst which the fostering of a sense of belonging and social cohesion. This reinforcement may encompass locally available human, technical and natural resources, local culture(s) as well as economic feasibility.

The careful specification of a programme of 'cool' facing materials and vegetation alongside a careful global design having present relevance and legibility issues (e.g. surfacing, changes in level, enclosure, lighting, landmarks, public art, or ease of comprehension through the space), can help reaching a high-quality intervention. The elements composing a public space, as well as their relationships, should be selected bearing in mind the creation of a stimulating environment. This stimulation can foster a sense of wellbeing and an emotional connection to the space.

Maintenance has an utmost importance for the success of public spaces but its requirements should be kept as low as possible. Irrespective of who is going to be in charge of maintaining a space, the two most fundamental requisites relatively to programmes of 'cool' materials and vegetation are: to have a clear notion of the maintenance requirements associated to the specified materials and vegetation, and to ensure that people defined to be in charge of maintenance operations know how and have the means to maintain paving materials and vegetation in an appropriate condition for meeting safety and visual requisites and for not undermining their full bioclimatic potential. For materials this might relate, for instance, to resurfacing operations changing the moisture-related or optical properties and, for vegetation, inappropriate trimming operations changing trees' crown profiles.

This can allow saving money by reducing the frequency of maintenance operations and the human resources required, as well as by simplifying the means through which maintenance is operated. The integration of well-suited, cost-effective, and easy workable maintenance instruments as well as locally available natural, economical and human resources might be useful.

7.2.2.3. Construction

The Construction stage is divided into two main moments: pre-construction organisation and site operations. Pre-construction organisation deals with programming all site operations whilst site operations relates to undertaking the installation of the project. Table 9 presents the proposed full range of contents for the Construction stage.

Table 9 – Proposed methodology. Contents of the Construction stage.

PRE-CONSTRUCTION ORGANISATION	
Topic	**Principles**
Team	▪ Letting the building contract, appointing the contractor; ▪ Issuing information about the proposal to the contractor; ▪ Ensuring the quality of construction by promoters before contracts are signed; ▪ Handing over the site to the contractor.
Planning the impacts of site operations	▪ Phasing site operations carefully, bringing its duration down to a minimum; ▪ Anticipating the likely impacts of site operations.
SITE OPERATIONS	
Topic	**Principles**
Build quality	▪ Accurate installation of all material layers in order to ensure good mechanical resistance, durability, visual aspect, and contribution to the space's microclimate; ▪ Proper planting of vegetation complying with all culture specificities; ▪ Tight delimitation between areas of hard and loose pavings; ▪ Proper tightness of water features, preventing leaks.
Construction management	▪ Incorporation of best-practices at all times; ▪ Ensuring that the workforce is skilled enough to undertake installation with technical accuracy; ▪ Ensuring that the workforce is well informed about the aims of the intervention; ▪ Restricting working hours and deliveries; ▪ Ensuring that there is not a supply exceeding the predicted quantities; ▪ Optimisation of the use of natural, human and capital resources; ▪ Minimisation of equipment renting and transportation of people and/or components; ▪ Definition of a robust waste, energy and water management during site operations.
Impacts of site operations	▪ Reducing the amount of physical and visual barriers; ▪ Reducing the production of noise, smoke, dust, vibrations and so on.

Good technical execution is imperative for achieving excellence in a public space and for ensuring the consistency between the initial vision for the space and the actually built solution. Unpredictable situations to be solved may take place during the Construction stage. Nonetheless, these should be reduced to utmost by carefully addressing the Design stage and the pre-construction organisation. Changing any parameter of the specified programme of 'cool' materials and vegetation can have a significant impact on the actual delivered microclimate amenities. Any change to the retrofitting intervention should preferably be made during the Design stage by the design team only and after a full appreciation of the likely effects that change will have. If changes have to be made during the Construction stage this should happen under the supervision of the design team.

Pre-construction organisation

Pre-construction organisation addresses all issues around the preparation of the joint work with the contractor, and the preparation of the site. It thus involves organising the building team attributing responsibilities to all parties involved in the installation process. The appointed contractor and the way how project information is communicated to him are vital for ensuring a good quality of building operations.

It is also fundamental to plan the impacts of site operations on the normal functioning of the area. The disruptions caused by site operations on the normal movement patterns of people, local economic activities, access to services, facilities, visualisation of storefronts, etc. should be reduced down to a minimum. The scale of site operations, in terms of duration, presence of machinery or movement of vehicles should be as reduced as possible. Beyond directly impacting the site's functioning, the duration of site operations determines the moment when stakeholders and final beneficiaries start having revenues from the investment and expectations placed upon the proposal.

Site operations

Site operations relate to undertaking the installation of the final proposal for the space, which results from the best correlation between microclimatic improvement and cost with spatial design issues. Good technical installation of any design scheme is determinant for achieving its objectives, for its physical and visual integrity, and life span.

Relatively to programmes of 'cool' materials and vegetation, good technical installation involves the settling of ground pavings and the convenient planting of vegetation. The build quality of ground pavings is determinant for its life span, for accessibility and safety, and also for the visual qualification of a space. In turn, good planting practices are determinant for the healthy growth of plants.

An upstream, well-planned site work strategy can ensure that the technical installation of a proposal meets a high-quality standard, that building costs are controlled, and that the contracted firms are committed with the creation of a high-quality public space. Additionally, well-planned site operations can represent important economic and environmental savings by optimising the need for transporting work force and materials, waste production, and use of energy and water. It is fundamental to ensure that the work force has the necessary skills for undertaking best-practices at all levels.

Following the premises established in the pre-construction organisation, the impacts of site operations on the site's normal functioning should be reduced down to a minimum. The most important concerns here are the reduction of the amount of physical and visual barriers; and the reduction of noise, smoke, dust, vibrations and other consequences of building operations.

7.2.2.4. Use

The Use stage is associated to the administration of the space after the completion of site operations; it relates to making final inspections to the built space and to assessing its performance in use by comparison to the initially defined goals. This stage is therefore related to evaluating and obtaining feedback about the space after people have start using it. The following table presents the proposed full range of contents for the Use stage.

Table 10 – Proposed methodology. Contents of the Use stage.

EVALUATION & FEEDBACK	
Topic	**Principles**
Monitoring policy	▪ Definition of the parameters to be monitored and associated key-performance indicators; ▪ Definition of who is going to monitor; ▪ Definition of how will the monitoring results be collected and reported, and to whom; ▪ Definition of the periodicity of monitoring; ▪ Definition of the source of funding for the monitoring system; ▪ Elaboration of design status schedules, progress reports or annual monitoring reports.
Post-completion review	▪ Robustness of the built physical layout; ▪ Effectiveness and appropriateness of the specified materials and vegetation; ▪ Effectiveness and appropriateness of additional bioclimatic urban design principles and elements; ▪ Technical accuracy of the construction details; ▪ Suitability of the chosen consultants and contractor; ▪ Compliance with cost and time targets; ▪ Identification of elements leading to eventual ulterior failures.
Post-occupancy review	▪ Analysis of the space's functioning; ▪ Analysis of the space's morphology in global and microclimate terms; ▪ Identification of users' thermal comfort evaluations; ▪ Assessment of the capacity of the space to attract and retain pedestrian activities; ▪ Compliance with the client's goals and the initially stated business goals; ▪ Efficiency of the management and maintenance policy; ▪ Identification of eventual failures.

The main objectives of evaluating and feed backing progress are to ensure that the built space meets the planned quality standards and to learn from what has been done. Conclusions about the achievements of a proposal can inform future projects and help consolidating knowledge on bioclimatic urban design amongst design teams, stakeholders, construction industry, and the client.

Evaluating and feed backing involves defining a monitoring policy and undertaking a post-completion and a post-occupancy review. The monitoring policy is about the way how the performance of the space will be monitored by comparison to its initial objectives and to the opinions of users. The post-completion review involves evaluating the fit between the whole design process and the way how the scheme was actually built. An assessment of the way how parameters such as design and construction processes, construction details, cost and time targets, or weaknesses likely to lead to future failures should be carried out. Finally, the post-occupancy review is about comparing the defined intervention strategy with the extent to which the built space actually meets the initial aims for the intervention, the client's goals, users' needs and expectations, and ability of attracting and retaining pedestrian activities.

All performance criteria suitable for a specific project should be addressed during evaluation and feedback. As far as the retrofitting of public spaces in compact urban areas is concerned, the extent to which the specified programme of 'cool' materials and vegetation actually delivers to the space a more balanced microclimate should be given attention; it is vital to understand if and how the intervention made the space more attractive to people; how the intervention actually provided conditions for thermal comfort. This can be done by obtaining information on (1) how the space actually works and the relationship its functioning establishes with its microclimate; (2) the morphologic elements influencing its microclimate; (3) the thermal evaluations of users; and (4) the influence climatic variables have in the space's microclimate.

7.3. A GUIDE FOR THE SPECIFICATION OF ‘COOL’ MATERIALS AND VEGETATION

As mentioned above, the proposal of the methodology for the thermal retrofitting of public spaces in compact urban areas encompassed a guide for help specifying programmes of ‘cool’ materials and vegetation. Sharing goals, premises, and references with the broader methodology, this guide will now be presented.

7.3.1. STRUCTURE AND LAYOUT

Structure

The guide was structured according to five headings: overview, key-actions, guidelines, exemplars, and glossary. These headings were thought as to provide the most relevant information in a straightforward way; to provide concise guidance without however being too dense. Each heading has originated a menu conveying a different type of information:

- **Overview**. The overview provides the most relevant issues concerning the aim, characteristics, and use of the guide. It was conceived as a section for introducing the guide to those who are going to use it.
- **Key-actions and guidelines**. These two sections constitute the central part of the guide since it is here that all guidelines are presented. The difference between both is the level of detail provided. The key-actions menu conveys the most fundamental issues to consider for conceiving more thermally balanced public spaces during summer in compact urban areas. In turn, the guidelines menu provides the full range of guidelines unfolding from the key-actions. The advantage of creating this division is that it will allow progressively familiarise designers with the issues conveyed by the guide — the key-actions menu will allow an overall, quick and succinct insight on the main principles for conceiving programmes of ‘cool’ materials and vegetation, whilst the guidelines menu provides a more detailed approach for specifying such programmes.
- **Exemplars**. This section consists of images illustrating the sort of layouts that might eventually result from applying the presented guidelines. The displayed pictures do not necessarily refer to public spaces conceived on a bioclimatic perspective but that somehow incorporate principles related to programmes of ‘cool’ materials and vegetation.
- **Glossary**. The glossary presents definitions for the most important terms encompassed by the guide, in particular, and by the bioclimatic urban design area, in general. Since bioclimatic urban design deals with some terms not commonly familiar to urban designers, this section was aimed at help improving the comprehension of the notions associated to the bioclimatic strategies encompassed by the guide.

Each menu starts with a short sentence highlighted through the use of a large font. These sentences are aimed at introducing the menus so that the navigation through the guide can be as straightforward as possible. For instance, the guidelines menu starts with the sentence “guidelines for specifying combined programmes of materials and vegetation”.

Such as the methodology, the guide is somewhat similar to design checklists. The guide was conceived as a list of guidelines aimed at simplifying the decision-making about programmes of ‘cool’ materials and vegetation, irrespective national/regional variations in terms of availability, production or cost. There is thus no commercial propaganda/interest behind any content of the guide. The guide was also conceived for providing data for reviewing project information.

All headings converge to one same purpose: the ease with which urban designers could access and interpret a range of practical measures for creating thermally balanced public spaces in compact urban areas without having to undertake additional researches on bioclimatic urban design. Also, the reduction of the time required for covering all guidelines was determinant for the development of the guide.

Layout

Although integrating the methodology the guide has some degree of autonomy. The guide was developed to be a resource for raising awareness about the importance of creating more congenial public spaces in compact urban areas. This can more easily help disseminating the information conveyed with the guide. Dissemination was seen as vital for help pulling together theory and practice of bioclimatic urban design.
In this sense, the guide is proposed according to a distinctive layout relatively to the methodology. This envisioned (1) the quick and user-friendly identification of key-bioclimatic urban design principles directly committed with the thermal retrofitting of public spaces in compact urban areas, which was thought as a way of promptly start retrofitting public spaces in these areas even if designers are not totally or at all familiarised with the bioclimatic urban design area; and (2) the ease of communication of these principles to all parties involved in a project, across international borders.

Relatively to the first topic, the guide and the broader methodology were conceived to be easily accessible and little time-consuming. Tools are inappropriate for a task if useless or making the time spent in trying to use them to result in botched work that must be done over, and also overly complex tools can distract designers from the conceptual essence of the task (Mann, 2004; 139). With respect to the second topic, the guide and the broader methodology were developed as a way of help establishing a common ground amongst all parties so that understanding on the need to adapt the built environment to the warming brought by climate change, irrespective national borders, can take place. This common ground and development of a shared understanding makes communication either possible or, if absent, difficult (Emmitt, Prins et al., 2009; 53).

The guide can therefore assist the specification of programmes of 'cool' materials and vegetation, and thus the thermal retrofitting of public spaces in compact urban areas, and simultaneously constitute an adaptable element of communication and organisation of potential relevance for informal communication and formation sessions on the thermal retrofitting of public spaces in compact urban areas, i.e. on part of the adaptation of the built environment to the warming brought by climate change.

It was bearing in mind these general principles that the guide was developed according to a distinctive layout, namely as a web-based tool. Websites are presently one of the most powerful means for disseminating information worldwide. The growing efficiency of the Internet and the growing dependency on this means of communication make a website one of the best and flexible ways to communicate a message. Also, the option for developing a website in English was considered to be a suitable way of making the guide accessible across international borders. The distinctiveness of the guide faced to the remaining methodology is itself part of the flexibility with which the methodology was conceived.

The developed website/guide is named "THERMAL RETROFITTING OF PUBLIC SPACES IN COMPACT URBAN AREAS. Guide for the specification of programmes of 'cool' materials and vegetation" and it is available at **http://www.budsum.com/**. Bearing in mind the aforementioned four premises for the development of the methodology, this website was developed according to:

- A straightforward and direct provision of contents;
- Easily interpretable contents associated to specific issues of the Design stage;
- Flexibility for either the development of public space projects and educational activities;
- A simple and fast navigation scheme;
- An attractive though discreet styling;
- The utmost reduction of navigation windows;
- The utmost reduction of the need for clicks, scrolls, or skipping pages;
- The utmost reduction of accessory shapes and animations.

Within this scope, the design solution was built upon the creation of a clear, soft, comfortable and 'light' visual environment. This was achieved through the joint work with a web designer. A soft chromatic range was used. Contrasting colours were selected for highlighting the website's main heading and the navigation menus. To keep it formal, a neutral sans serif typography, namely Helvetica, was adopted. Images are displayed in light-box galleries with an integrated navigation. This allows a convenient and in-depth appreciation of the images. Finally, the website's layout was structured using HTML5 and CSS3, with some animations in JQuery and, for the generation of the guideline's pdf file, some programming in PHP.

7.3.2. Contents

7.3.2.1. Overview

The overview section provides the most relevant issues concerning the aim, characteristics, and use of the guide. It was conceived as a section able of introducing the guide to those who are going to use it. The option was to present information as a listing of questions to which answers are given. These questions and associated answers will now be addressed in more detail as a way of not only presenting the contents of the overview section, but also as a way of presenting specific aspects of the guide.

What is the guide?

This guide is a DSS (Decision Support System) for urban design projects. It can help establishing priorities from a range of options given for facing materials, vegetation, and other current urban design elements contributing for a high-quality standard of public spaces.

Who is supposed to use the guide?

The guide has been developed for the professionals involved in the conception of public spaces such as urban designers, architects, or landscape architects working in different entities. It has been a primary concern that the proposed guide was written through codes familiar to these professionals and intelligible to local communities.

Is the guide flexible or prescriptive?

The guide is flexible since it was designed to prompt thoughts, not to be an exhaustive list of what to consider; all presented parameters must be thought as indicative references rather than prescriptive solutions. It is necessary that users make appropriate judgements about what the local circumstances are and use the guide in conformity with that. 'Exceptions to the rule' should be considered at all times.

How is information within the guide structured?

The guide is structured according to five distinct sections: overview, key-actions, guidelines, exemplars, and glossary. Although all sections are relevant in providing information and, thus, in help reducing the gap between theory and practice of bioclimatic urban design, the key-actions and guidelines menu are those with a higher importance since they convey all notions and guidelines that will directly allow specifying a combined programme of facing materials and vegetation.

How to use the guidelines?

1. To select the "guidelines" menu and assess the full range of guidelines;
2. To select, through a click, the guidelines considered as important and suitable to incorporate into a project;
3. To click the "confirm selections" button at the end of the page, after ensuring that all selections have been correctly made;
4. Finally, to click the "generate summary" button at the end of the page, in order to generate a simple sheet summarizing all selected guidelines. This report will be generated as a PDF file which may then be printed and used as desired.

What types of development is the guide suitable for?

The guide was developed for rehabilitation public space projects within compact urban areas and. However, many of its guidelines may as well be considered for projects for new urban expansion areas.

Is the guide specific for a particular climatic region?

This guide was thought for warm and hot climates, where commonly summer conditions create constraints to the usage of public spaces. Nonetheless, its use might eventually be suitable to other latitudes either presently or in the future (considering climate change impacts).

How can the guide be adapted to each particular context?

The guide can be adapted to each particular context by selecting which guidelines to incorporate into a project: the parameters proposed by the guide can be totally or partially considered. Choosing which parameters to work with is a question of deeply knowing the site's characteristics and needs.

Weighing which parameters to consider rules out a successful proposal?

Weighing which parameters to consider does not impair the possibility of achieving a successful, fully-integrated proposal; it simply means that the guide is being adapted to a particular context. Considering all parameters may even be counter-productive if these are not suitable to a site because it can lead, for instance, to an unnecessary time and financial investment in changing something that was right from the start or that will probably be wrong in the future.

Are the parameters within the guide ranked or are there minimum standards?

The parameters within the guide are not ranked so that the guide can be flexible enough to allow designers to choose the most suitable parameters to a project. All parameters within the guide constitute potential good ways of achieving thermally balanced public spaces. The importance given to one or another parameter should be the result of adapting the guide to local characteristics and needs.

How does the guide relate to other guides or tools?

This guide constitutes a particular contribute in the field of sustainable urban development and bioclimatic urban design. It has a global objective of contributing for the mitigation of the impacts of the substantial increase in temperature extremes brought by climate change in urban areas through a very specific way: programmes of 'cool' materials and vegetation. Due to this specificity the guide may be complemented with other guides and tools committed with delivering a space a high quality standard.

Can the guide be used where such is not required by a local planning authority?

The use of the guide is independent of whether planning authorities are concerned or not with bioclimatic issues. The guide was developed to help design proposals to meet the basic requisites of more thermally balanced public spaces. Whether or not planning authorities consider these issues is a matter of the opportunities created for more consistent strategies for mitigating the impacts of the substantial increase in temperature extremes brought by climate change. Yet, with respect to the use of the guide, whether a planning authority considers these issues or not is irrelevant.

7.3.2.2. Key-actions

As far as the literature review has shown, many thermal comfort studies undertaken throughout the globe are relatively unanimous in what concerns to the main strategies to improve summer thermal comfort conditions — as a general consideration, to reduce the amount of direct solar radiation striking a space and to increase the heat losses taking place at the ground surfaces is vital for the improvement of the microclimate of outdoor public spaces during summer. This can be achieved by blocking incoming direct solar radiation and by increasing the capacity of surfaces to reflect direct solar radiation and emit absorbed thermal energy.

The thermal radiation reaching the surfaces of a public space must (1) be rapidly transferred from their inner layers to their surface; (2) from their surface to the air layer near the ground; and finally (3) from the air layer near the ground to the upper layers of the atmosphere. The final goal is to improve a space's microclimate by reducing the thermal stress placed upon people at the air layer where pedestrian circulation is held and, through that, improve outdoor thermal comfort conditions. Bearing this in mind, the "key-actions" conveys the three most fundamental issues to achieve such goal:

1. **To increase shading by trees and/or man-made shading devices**. Increasing shading by trees and/or man-made shading devices can reduce the amount of insolation directly striking people, ground surfaces and walls. Vegetation can also reduce air temperatures through evapotranspiration. Thus, lower surface temperatures, mean radiant temperature, and air temperature are likely to result from the use of shading trees. The benefits from evapotranspiration (as well as other psychological benefits) make trees preferable to man-made shading devices though these might be useful as well. Except for vegetated areas, during summer shaded ground areas possess significantly less radiant heat than sunlit areas, and shaded facades possess significantly less radiant heat than unshaded facades. Less direct solar radiation reaching the ground surface is therefore the first step for ensuring a lower thermal load placed upon people and public spaces.
2. **To use 'cool' materials – high-albedo and high-emissivity**. The use of 'cool' materials can increase the capacity of surfaces to reflect direct solar radiation and to readily release stored heat, i.e. to reduce the capacity of surfaces to work as heat reservoirs. The less direct solar radiation a surface absorbs, the less it will warm up and consequently the less heat will transmit to the air layer where the pedestrian activities are held. 'Cool' materials are associated to high-albedo and high-emissivity materials: high-albedo will ensure that less radiation is absorbed and high-emissivity will ensure that stored radiation is readily released back to the atmosphere. The use of permeable ground paving materials in outdoor spaces is as well beneficial since it fosters evaporative heat losses.
3. **[depending on local air humidity] To increase evaporative cooling through vegetation**. Increasing the evaporative cooling through vegetation can increase the amount of heat released by convection, which can help cooling down air temperatures.

The more evapotranspiration the more heat released by convection at the leaves surface. This can represent an important contribution to the two previous actions since it will help cooling down air temperatures. It is however important to ensure that the increase in evapotranspiration is made to appropriate levels. The increase of evapotranspiration should not impair the evaporative potential of the environment — while increasing evapotranspiration in dry regions is a suitable measure, in damp regions and in association to given conditions of air temperature and wind speed, evapotranspiration may not be so desirable.

These three key-actions are associated to three images which illustrate the type of spatial solutions related to the principles they convey.

7.3.2.3. Guidelines

The listed guidelines allow knowing how to choose materials and vegetation for improving a space's microclimate in summer and how to relate these elements with other common elements delivering a high-quality standard to public spaces. For this reason, the guidelines menu is divided into two parts: "selection of materials and vegetation" and "spatial design". The first part is constituted by principles for guiding through the specification of programmes of 'cool' materials and vegetation. The second part lists principles of 'classical' urban design that the development of a proposal based on bioclimatic premises should not neglect.

The information displayed in the website does not have to be gone through slavishly: the total or partial inclusion of the proposed guidelines should be weighed according to specific project requirements and the creativity of designers. There might not be the opportunity or the need for addressing all listed guidelines.

A general aim and a background issues section are provided for each heading and sub-heading of the key-actions and the guidelines menus: the general aim provides a general insight on what is expected to achieve, while the background issues provides a brief explanation of why it is important to achieve the general aim. The Guidelines menu also accounts with a list of useful links for each heading. These Internet links provide complementary and/or additional information to the guide. Similarly, the references/further reading section presented at the beginning of the key-actions and guidelines menus is aimed at indicating the references used for the development of the guide as well as at indicating complementary and/or additional information.

For the large majority of guidelines an additional section containing relevant additional information about the guideline (e.g. reference values, succinct fundamentals, precautions or caveats) is provided. These popover sections work as a sort of 'be aware' information directly related to each guideline and can be optionally displayed by hovering the "+" symbol at the end of the guideline.

All contents of the guidelines section will now be presented.

Selection of materials and vegetation

Materials

Albedo

- **High-albedo materials**. High albedo surfaces reflect more direct solar radiation and thus remain generally cooler. As a general reference, high-albedo values are roughly ≥0.50 (e.g. marble, white plaster, gravel, white/whitewash paint); medium-albedo may be found between 0.30 and 0.50 (e.g. concrete, granite, red brick, wood); and low-albedo values are roughly ≤0.30 (e.g. asphalt, slate, water, black paint). Albedo of shaded ground surfaces is irrelevant. The use of medium-albedo materials can be important in wide spaces in order to prevent glare.

Emissivity

- **High-emissivity materials**. High emissivity generally means a higher capacity for a surface to readily release absorbed heat. As a general reference, high-emissivity values can be found between 0.50 and 0.95 (e.g. asphalt, concrete, wood, plants, grass, soil, sand, white/red/brown/green/black paint); medium-emissivity values can be found between 0.20 and 0.50 (e.g. building brick, gravel); low-emissivity values can be found between 0.04 and 0.20 (e.g. bright aluminium foil, bright galvanized iron).
  High-emissivity should be associated to high-albedo otherwise the heat fluxes outcoming from the space's surfaces might be too high. An option is to shade high-emissivity but low-albedo surfaces in order to reduce the amount of direct solar radiation striking those surfaces from the start. In general terms, surface temperatures, surface dimensions, people's location, and people's activity level determine the extent to which surfaces can be sources of radiant heat; and ground surfaces provide more radiant exchange than vertical or overhead surfaces.

Permeability

- **Permeable paving solutions**. Permeable materials allow water exchange between the surface and deep layers of soil as well as evaporative cooling at the surface. As a general reference, permeable surfaces such as lawns, bounded gravel, or grasscrete paving have an impermeability degree between 0.50-0.40 (bounded gravel) and 0.10-0.00 (general vegetated areas); whereas impermeable materials such as asphalt, concrete or paving with mortar joints have an impermeability degree of 1.00.
  The percentage of pervious area should be adapted to the functions a space is expected to receive. Another general reference is that permeable areas should be of ≥40 % and at least 80 % of permeable areas should be covered by tree and shrub canopies. It might be useful to totally or partially remove paved surfaces that should not have been paved. Permeable paving solutions should not create dust in summer or slurry in winter. Alternatively, it might worth to consider laying paving units spaced by 3cm in order for grass, mosses and small flowers grow in between. There should be no use of cement or mortar in between paving units. This solution may not be suitable to all situations because it might cause discomfort to people with mobility impairments, baby carriages or using high-heels. Compacted soil paving might constitute a low-cost and still effective solution for paving urban spaces.

Durability

- **Good resistance to weathering, soiling, or damage**. Public spaces are usually expected to be in use for decades. While properly planted and well-suited vegetation species may live for centuries in a space, materials are often less durable. Materials with longer in-use lifetimes should thus be chosen: as general references, asphalt has an estimated service life of 7-20 years, concrete 15-35 years, pervious concrete or paving blocks 15-20 years, and grass or gravel >10 years.

Environmental cost

- **Materials with low PEC**. Low PEC materials have reduced impacts on the environment during production (extraction, processing) and transportation to the installation site. As a general reference, one of the most processed products, aluminium, has a 160.128 MJ/kg PEC value while for compacted earth, one of the less processed materials, this value is of 0.097 MJ/kg. PEC values vary greatly with geographical, environmental, and economic contexts.
- **Materials easily reusable and/or recyclable**. If recycled materials are the option, locally reclaimed and green materials are preferable.
- **Materials and vegetation species outcoming from reasonable natural stocks**. This will help preserving natural resources and prevent damaging ecosystems.
- **Materials with as less associated pollution and toxicity as possible**. This will allow reducing impacts on the environment, preserving human health and ecosystems.

Vegetation

Category

- **Combination of different types of vegetation (trees, shrubs and herbs)**. Non-competing species should be chosen so that the health and life of plants are not harmed. It is also crucial to know the best ways to plant a species and how much maintenance different species require. Local nurseries or university forestry departments for instance may help deciding which species are most appropriate for a specific site and budget. As a general reference, trees are species formed by a single stem and are ≥7-8m in height; shrubs have multiple stems and grow from 0.50 to 4.50m; and grasses and subshrubs grow from 0.25 to 0.50m.

Vegetative cycle

- **Combination of deciduous and evergreen species**. This will provide shade during summer and access to solar radiation in winter. Evergreen trees in winter may be pruned for allowing the low-angled sun to pass under the lowest branches. Vegetation can reduce air temperatures to as much as 5 °C under a full-crown tree and 2.7 °C under a pruned tree.

Growth rate

- **Moderate-growth species**. This will allow achieving results relatively rapidly without compromising the tree’s resistance to storm damage, insects or diseases (fast-growing species are generally less resistant). Growth rates are highly variable according to e.g. placement, soil, fertility, or moisture, and different parts of plants grow at different rates and often at different times of the year. A very broad reference is that a tree can take 10 to

15 years to reach maturity — medium-growth species may grow 30 to 60cm in height a year, fast-growth species ≥60cm, and slow-growth species ≤30cm.

Height

- **Maximum heights compatible with the space's layout, aerial services, and planned activities**. Large species shade larger areas of ground and buildings. As a general reference, large tree species have a mature height of >15m (e.g. Plane), medium species 6 to 15m (e.g. Birch), and small species <6m (e.g. Sweet orange). Pre-existent trees should be kept since adult trees need less maintenance and are, generally, stronger and better established.

Shape

- **Vegetation of the right shape and density of foliage**. This will help blocking enough direct solar radiation without overshadowing spaces nor/or buildings. A tree with the right shape can block solar radiation up to 95 %, and that even leafless trees in winter can block solar radiation up to 50 %. As a general reference, oval, columnar and upright trees are usually best suited for narrow spaces; rounded, pyramidal, spreading and weeping trees with descending branches for wide spaces; and vase-shaped trees for street.

Root system

- **Root systems compatible with the space's layout and underground services**. This will help preventing mutual dysfunctions. As a general reference, roots should not be entombed by other systems of the space because this can contribute to the tree's early death, and trees should not be planted right next to or above other systems in order to prevent e.g. damages to the foundations of buildings or to underground services. It is generally preferable to plant trees in open areas rather than in constrained tree pits because trees growing in pits tend to be less healthy than those standing free. Cutting and ditching for underground services should preserve and protect the root systems of existing trees

Resistance

- **Resistance to breakage, pests and diseases**. Local nurseries, computer software, or university forestry departments may help deciding which species are most appropriate for a specific site.

Spatial design

Robustness

Appearance

- **Glare from highly visible surfaces prevented**. Mid-tone colours or an appropriate shading level are usually good options for controlling glare
- **Too much shade prevented**. A planting scheme should not provide an excessive amount of shade since this can impair the access to direct solar radiation (eventually desired by some users) and create a dark environment which might not be attractive to people, for instance, for safety reasons.

Relaxation

- **Seclusion, privacy and intimacy, as well as containment and infinity opportunities**. Planting should not create hidden areas within the space.

People's active involvement

- **Direct/physical contact with nature.**
- **Varied activity opportunities for children, adolescents and adults.**

People's passive involvement

- **Indirect/visual contact with nature.**
- **Possibility to observe different actions and less usual events.**

Exploration

- **Provision of surprise, mystery, familiarity and novelty**. Ground paving solutions and planting scheme should provide different sub-spaces associated to successive changing of sights.

Fruition

- **Provision and/or preservation of quality green areas, landscaping features and relevant sights.**
- **Water features combined with ventilation strategies**. This will help cooling down air temperatures since the isolation of the space around a water surface concentrates the cooling potential of water.
- **Combination of solid and permeable windbreaks**. This can redirect the air into specific areas. Solid windbreaks might be panels or walls, and permeable windbreaks might be vegetation or fences.
- **Climbing plants in buildings corners**. This can attenuate wind effects and protect wall materials.

Adaptability

- **A layout able to receive long and short-term transformations associated to special events.**
- **Paving and planting scheme able to receive several functions without compromising their integrity.**
- **Adaptive opportunities**. As a general reference, adaptive opportunities deal e.g. with the provision/blockage of direct solar radiation, shaded/sunlit ground and vertical surfaces, enlargement and blockage of sky views, provision of calm, low (0.3 m/s to 1.5 m/s), and moderate (1.5 m/s to 3.4 m/s) wind speeds. Seeking a thermally-balanced public space is much about weighing the relative importance of controlling or not the climatic variables at the microclimatic scale. For instance, if direct solar radiation is aimed, breezes and reduced Sky View Factors should be sought in order to offset the higher exposure to solar radiation.

Safety & security

- **Good visualisation within and outside the space**. This will foster a sense of shared ownership and responsibility (natural surveillance).
- **Ground paving not subject to standing water or to the accumulation of snow or slush, and to be slippery.**

Ease of movement

Access

- **Even paving solutions and soft surface gradients**. This will allow the movement of pedestrians, manual traction objects, or water flow. Cobblestones, sand, loose gravel or other forms of uneven paving are generally unsuitable for people with mobility impairments and that ramps may be preferable to stairs.
- **Landscaping located at least at 90cm from the edge of access way areas.**

Movement patterns

- **Paved areas and greenery set after people have defined their desire lines**. This can prevent people to step on flowerbeds positioned in main natural crossing routes. The space should accommodate different types of movements.
- **Vegetation not hindering the main access points to the space**. As a general reference, tree branches need to be 3m higher than pavements and 4m higher than streets to allow people and vehicles to move freely.

Relevance & Legibility

Relevance

- **Reinforcement of the character and identity of the space**. This can enhance the relationship space and people's culture. This may be achieved by providing symbolic, cultural, and narrative elements but that reinterpretation, innovation and detailing are fundamental. Locally available materials, native vegetation species, and traditional building practices might be useful here. It is however important to bear in mind that native vegetation might not be suitable in all cases — though native species are already acclimatized to each territory and are thus more resistant and require less maintenance, in some cases they might not be desirable due e.g.to shapes, root system, attraction of aphides, or production of staining substances.
- **Preservation of recognisable existing ground pavings and vegetation specimens.**

Legibility

- **Ease of comprehension and navigation through the space**. Paving materials and vegetation may allow distinguishing different uses within the space through differentiated texture, shapes, and colours.
- **Stimulation of all human senses by a careful approach to aesthetics/styling**. Programmes of materials and vegetation should result in a stimulating environment. This can be achieved through weighing parameters such as elements of composition (focal points, duality, unity, vitality), form (additive form, subtractive form, size and scale, unity, repetition and rhythm, logic and ambiguity, symmetry, static and dynamic forms, effects of sunlight, visual weight), proportion (balance, visual strength, visual force), detail (materials, patterns, textures, finishes, transformation of shape, contrast and enhancement, elaboration, and ornamentation), or colour (analogous colours, complementary colours, warm and cool colours).

Planting scheme

Quantity

- **An amount of specimens beneficiating the thermal performance of the space but compatible with its typology and function**. As the number of trees increases evapotranspiration becomes more effective than shading: a single mature tree transpires up to 378 litres of water per day (the cooling equivalent of 9 room air conditioners operating at 8440 kWh for 12 hours).

Placement

- **Placement and orientation of specimens with respect to the shadow cast at the most critical times of the day during summer and winter**. The distances between trees should form a complete canopy able of shading the width of an entire street, pedestrian path or bikeway within 10 years. Vegetated ground surfaces may not be shaded.
- **Compatibility between shading patterns and indoor thermal performances**. For example, the planting scheme should not create shade across south-facing windows, because this will block sunlight in winter, nor cast shade on solar collectors. Increasing vegetation cover by just 10 % to 30 % may reduce cooling energy of a building by as much as 10 % to 50 %, depending on the building's characteristics such as typology, age, construction system, etc. Improperly positioned trees can increase the demand for warming energy in winter. Above the trees' canopies, buildings may possess alternative solutions such as potted plants, green walls or awnings.
- **Clusters of trees rather than individual wide-spaced trees**. Trees clumped together share soil, help keeping each other cool, and create broader shading patterns. As a general reference, large trees should be spaced from each other by 10m and small trees by 7m. Other general references are that for trees reaching 6 to 7m in height a safe distance between trees and buildings is 8 to 10m; near maturity, tree branches should reach within 1.50m of buildings' west or east walls and overhangs, and 0.90m of south walls or overhangs.
- **Spaces designed to fit trees rather than trees forced to fit inadequate spaces**. This has a direct impact on how well a tree will grow and on the need for pruning operations. Whenever there is the need to hold a tree's volume, the choice should fall over frequent (every year or every 2-3 years) but light operations (e.g. removal of dead, diseased, or rubbing branches) rather than drastic cuts. Drastic cuts usually pose risks to the health of trees by making them vulnerable to diseases, and by leading to decay processes that culminate in shortening trees' life spans. As a general reference, it takes 5 to 10 years till a tree recovers its natural shape from drastic pruning operations. It might be important to amend deformations resulting from previous drastic and incorrect pruning operations, restoring the tree's natural shape, whenever trees are in good health.
- **Trees and man-made shading devices combined where continuous shading is required but the space does not allow for continuous direct planting**. As a general reference, man-made shading devices might be e.g. metal trellises, concrete or wood pergolas, or tensile awnings fixed in opposed facades of buildings (these last elements should be set at a minimum height of 4.50m).
- **Raised boxes when direct planting is not possible due to underground services or shallow depth**. As a general reference, large trees require a minimum of 6 m^3 of earth and small trees 2.25 m^3. It is important to bear in mind that building raised boxes often entails additional costs.

- **Large trees holes**. Large tree holes benefit the tree's health. The volume of earth required by a tree is proportional to its dimension. As a general reference, large trees require a minimum of 6 m^3 of earth and small trees 2.25 m^3; tree grids should have a minimum diameter of 2 m for large trees and 1.5 m to small trees; mulches should be applied in tree holes at a depth of 0.05 m within the dripline of trees and shrubs.

Maintenance requirements

Materials

- **Easily cleanable and replaceable surfaces**. Materials with moderate and nearly spontaneous maintenance might be useful. Providing separation elements in the limits between paved and planted areas might be useful to prevent the migration of earth, gravel, mulch or other loose materials.

Vegetation

- **Easily maintained and replaceable planting scheme.**
- **Low-water-use vegetation**. Vegetation, especially grass, must have sufficient water year round which, depending on the location, may entail significant costs. Usually lawns need more water than trees, and trees need more water than shrubs and groundcovers. Moving from lawns to prairies can be quite relevant since prairies are more resistant and require less maintenance.
- **Vegetation species with leaves, berries and blossoms not subject to dripping or staining.**
- **Acceptance of spontaneous vegetation. Spontaneous vegetation does not require supplemental irrigation or fertilization**. A complex vegetal ensemble is more resistant than an area without diversity maintained with artificial processes.

7.3.2.4. Exemplars

All images displayed at the exemplars section (Figure 48) were taken during summer months, July and August, in different locations: Slovakia (Bratislava), France (Lyon and Paris), United Kingdom (London), Portugal (Ponte Lima, Santa Maria da Feira, Chaves, Aviz, Castelo Branco, Marvão, and Covilhã), Switzerland (Basel and Lausanne), Italy (Turin and Milan), Liechtenstein (Vaduz), Morocco (Chefchaouen), Germany (Rosenhelm), and Austria (Salzburg and Vienna).

The images are presented according to six headings: shading through trees, shading through man-made shading devices, shading through trees and man-made devices, 'cool' materials, evaporative cooling through vegetation, and evaporative cooling through water. These categories were given a higher weight for displaying the images than the places where the images were taken since what is in stake is the sort of solution.

Fig.48 – The categories and associated images displayed at the exemplars menu.

7.3.2.5. Glossary

The presented definitions were assembled, derived and developed from the following references: Geiger (1950), Fanger (1972), Oke (1987), Akbari, Davis et al. (1992), Bretz, Akbari et al. (1992), Everett (1994), Baker and Standeven (1996), Allinson (1997), Givoni (1998), Development (1999), Jefferies (1999), Berge (2000), Roberts and Sykes (2000), Blyth and Worthington (2001), ISO (2001a), ISO (2001b), Papadakis, Tsamis et al. (2001), Santamouris (2001), Brandão, Carrelo et al. (2002), Chatzikostis (2002), Haupt and Kubitza (2002), Arnfield (2003), Charles (2003), Piotto and Noi (2003), Nikolopoulou (2004), Alexandri (2005), Hall (2005), ISO (2005), Mendonça (2005), Hegger, Auch-Schwelk et al. (2006), Higueras (2006), Moor and Rowland (2006), Tunstall (2006), CEMAT (2007), Gaitani, Mihalakakou et al. (2007), Tojo (2007), Taylor and Guthrie (2008), Zhang and Zhao (2008), CABE (2009), Cuadrat and Pita (2009), ASHRAE (2010), Domone and Illston (2010), RIBA (2010), and Sinclair (2011).

7.4. CONCLUDING REMARKS

At a time when designers and other parties involved in the development of public space projects seem to have not been given convenient knowledge/guidance on bioclimatic urban design and faced to the urge of adapting the built environment to the expected impacts of climates change, a methodology communicating the vital principles to promptly start retrofitting public spaces in compact urban areas towards more balanced microclimates during summer can be useful. The previous chapter has shown that the adaptation of the built environment to the substantial increase in temperature extremes brought by climate change can be conceived as a set of retrofitting actions over the 'climatic skin' of outdoor public spaces in compact urban areas based on programmes of 'cool' materials and vegetation.

Bearing this in mind, this chapter addressed the proposal of a methodology supporting the development of thermal retrofitting proposals for public spaces in compact urban areas based on programmes of 'cool' materials and vegetation. A guide for help specifying programmes of 'cool' materials and vegetation within the methodology was also proposed.

The methodology gathers the most relevant information in such a way that designers may quickly, clearly and effectively establish selection criteria for a retrofitting proposal. These criteria are related to the identification of key-bioclimatic urban design principles for key-work stages as well as to the specification of programmes of 'cool' materials and vegetation.

The proposed methodology conveys a belief that bioclimatic urban design should presently incorporate the development of public space proposals. The methodology then aims to help assisting the transition from the way urban design is currently conceived to bioclimatic urban design. In this context, the methodology was developed as a simple design supportive tool helping to give the outcomes of research on bioclimatic urban design a higher applicability to practice. The methodology and guide were conceived to be easily accessible and little time-consuming, and as a way to help establishing a common ground amongst all parties on the need to adapt the built environment to climate change and on possible ways to do it. The involvement of practitioners and scholars in the development of the methodology was particularly relevant here since it was one of the main ways to tackle the applicability of the proposed methodology to practice.

It is important to highlight that methodology is flexible rather than prescriptive. The information encompassed in the methodology does not point out 'ideal' solutions but rather principles for weighing the extent to which the retrofitting of a public space based on a programme of 'cool' materials and vegetation can help improving the space's microclimate. The methodology should then be regarded as a way of prompting thoughts rather than a prescriptive listing of requisites a proposal should comply with. Also, the proposed guide does not mention which materials and vegetation species to use in a project but rather which criteria should govern such decision.

It is then the responsibility of design teams to use the methodology with professional judgement and design sensibility. Firstly and foremost, designers «should pay attention in the climatic consequences of their projects and the solution of possible problems» (Marincic and Villa, 2006; 1). The provided information does not have to be gone through slavishly: the total or partial inclusion of the listed principles and, relatively to the guide, the proposed guidelines, should be weighed according to specific project requirements and the creativity of designers.

8
VALIDATING THE METHODOLOGY

This chapter addresses the validation of the proposed methodology by simulation. A virtual improvement proposal for one of the spaces of the case study, Poveiros Square, will be presented following the structure, principles and guidelines of the proposed methodology. A virtual simulation of the microclimate of Poveiros Square for different combinations of facing materials and vegetation levels will be explored through the use of a microscale climate model: ENVI-met.

Section 8.1 addresses the main options for the validation/simulation exercise; section 8.2 defines the objectives and fundamentals for the proposal; section 8.3 addresses the development of the proposal; section 8.4 presents a discussion of alternatives to the proposal; and finally section 8.5 presents the final proposal. Section 8.6 resumes this exercise by presenting some concluding remarks on the proposed methodology and on the relevance of programmes of ‘cool’ materials and vegetation.

8.1. MAIN OPTIONS

Since the undertaken field survey showed that comparatively to São Lázaro Garden Poveiros Square presented a lower attractiveness to pedestrians due to its unpleasant microclimate, this space seemed the ideal scenario for validating the proposed methodology: this square is a pedestrian public space in a compact urban area of a region with warm summers which does not present a balanced microclimate during summer due to its paving solution and amount of vegetation. Retrofitting the square through a programme of ‘cool’ materials and vegetation could eventually improve it by delivering a more thermally-balanced microclimate to people and, thus, to improve the conditions offered for outdoor thermal comfort.

Amongst the proposed methodology’s key-work stages, only the first two, Preparation and Design stages, were possible to be assessed with this exercise. The Construction and Use stages were not possible to test because there was not the chance to actually retrofit Poveiros Square.

The alternative was then validating the proposed methodology by simulation, by suggesting a virtual scenario of improvement. This simulation has encompassed two main actions: (1) the definition of the project’s ‘client’ and the contact with this entity, Porto City Hall, and with practitioners/experts on public space building; (2) the use of a microscale climate model, ENVI-met 3.1, for quantifying the extent to which the programme of ‘cool’ materials and vegetation specified with the methodology could potentially improve the microclimate of the square. Both actions were not fixed chronologically. On the contrary these were overlapped and interspersed according to the development of the proposal and its needs. The development of the proposal followed the sequence, stages and principles of the proposed methodology.

The contact with Porto City Hall and with practitioners/experts was a continuous and step by step process. This joint work allowed setting the framework for the improvement of Poveiros Square, finding the most advantageous solution for the improvement of its microclimate, testing the effectiveness of the proposed methodology and, thus, refining it. The first meeting was held with Porto City Hall and allowed establishing the objectives of the intervention and discussing general urban design issues according to the vision this entity had for the space. The remaining meetings with this entity and the practitioners/experts were scheduled via email on an ongoing basis according to the development of the proposal.

The contacted practitioners/experts were chosen in specific topics considered relevant for the development of the proposal: impacts of the proposal on the underground car parking, planting scheme, services, cost estimate, and impacts of the foreseeable site works. Although all meetings assumed an informal character, they were structured around these topics; each meeting allowed clarifying the issues around the discussed topic and, in some cases, pointed out ways for the refinement of the methodology. The consulted practitioners/experts, topic of discussion, and number of meetings are listed in Table 11.

Table 11 – Practitioners/experts consulted for the development of the virtual scenario of improvement for Poveiros Square.

#	Name	Expertise field	Associated entity	Topic of discussion	No. of meetings
1	Armanda Abreu	Urban design	Porto City Hall	Objectives for the proposal, discussion of alternatives, discussion of the proposed methodology	3
2	João Miranda Guedes	Civil engineering	Faculty of Engineering of Porto University	Impacts on the underground car parking	2
3	Mariana Abranches Pinto	Landscape architecture	Not applicable	Planting scheme	1
4	Alexandra Cabral	Landscape architecture	CCDRN	Planting scheme	1
5	Manuel da Silva Costa	Civil engineering	Porto City Hall	Cost estimate and services	2
6	Rolando Correia	Contractor	Fases e Cubos, Lda.	Impacts of site works	1

In parallel to these meetings, and at the appropriate moment according to the proposed methodology, the simulations with the microscale climate model were undertaken. These simulations allowed assessing the potential for the proposed methodology to support the development of thermal retrofitting proposals. The selected microscale climate model allowed quantifying the expectable microclimatic conditions of the space resulting from a group of programmes of ‘cool’ materials and vegetation specified with the methodology. This microscale climate model was ENVI-met, version 3.1.

As displayed at the model’s webpage[3], ENVI-met is a three-dimensional microclimate prognostic model developed by Michael Bruse & Team (University of Mainz). This model was designed to simulate the surface-plant-air interactions in urban environment and is suitable for different areas amongst which urban climatology, architecture, building design or environmental planning. ENVI-met includes the simulation of flow around and between buildings, exchange processes of heat and vapour at the ground surface and walls, turbulence, exchange at vegetation and vegetation parameters, bioclimatology, and particle dispersion.

[3] http://www.envi-met.com/ (accessed on the 12.12.2012)

This chapter presents the validation of the methodology according to its structure but also according to the sequence of meetings held with the abovementioned practitioners/experts. The condition of the proposed methodology as a supportive tool rather than an absolute sequence of pre-determined steps to be compulsory followed is then put into evidence. In this case, the proposed stages and principles within the methodology are intersected with a sequence of procedures found to be the most suitable to the development of a proposal for Poveiros Square.

8.2. OBJECTIVES AND FUNDAMENTALS FOR THE PROPOSAL

8.2.1. APPRAISAL

8.2.1.1. Client's intentions

In the first meeting with Porto City Hall the following objectives for the intervention were defined:

- To make the previous investment in pedestrianising the space more profitable by:
  - Enriching the public realm;
  - Enabling the creation of terraces and other ways of developing local economic activities and attract new residents and businesses;
  - Enabling a 24-hours use and ensuring the safety and security of the space;
- To rethink the lighting strategy, paying attention to the energy consumption of lamps (these should be as low as possible);
- To ensure the sustainability of the chosen materials.

8.2.1.2. Functional, morphologic, social, and microclimatic characterisation

The characterisation of Poveiros Square has been presented Chapter 6, in the context of the undertaken field survey. The conclusions brought by this field survey were those considered for the development of the retrofitting proposal.

8.2.1.3. Design constraints

The main design constraints presented by Poveiros Square are:

- Poveiros Square is totally within the historical core of Porto (classified as a World Heritage Site by UNESCO), namely within the parish of Santo Ildefonso that corresponds to a city's expansion area of the 18th and 19th centuries;
- The two single buildings at the east and west edges of the square are listed by Porto City Council as buildings of architectural importance;
- Practically the entire built area extended to the western and to the south-eastern side of the square is within a (either Special or Archaeological) Protection Area;
- The underground car parking.

Amongst these constraints, the underground car parking is likely to condition the proposal of improvement for the Square to the greater extent, namely by conditioning planting. Since the sort of interventions conveyed by the proposed methodology are not about structural changes to a space but, on the contrary, about small-scale actions over its surfaces and/or level of vegetation, the first three constraints are not likely to be major concerns to the intervention.

8.2.2. FUNDAMENTALS FOR THE INTERVENTION

8.2.2.1. Statement of need

The microclimate of Poveiros Square needs to be improved. This improvement is vital for making the square more attractive to pedestrians, especially in a climate change context were higher temperature extremes are expected during summer.

8.2.2.2. Attraction of investment

A programme of ‘cool’ materials and vegetation applied to Poveiros Square can improve its microclimate during summer, and thus positively enrich the public realm by attracting users. New households and businesses can also be attracted. In turn, this can bring revenues from the initial investment during the in-use period of the space. In addition, local economies can be benefited: good urban design establishes a direct relationship to the capacity to attract residents, public services, and businesses to an area since people tend to stay in a place which is beautiful, meaningful and pleasant; companies are attracted to places offering well-designed and well-managed public spaces. In the medium and long-term, the investment made in retrofitting Poveiros Square can be significantly offset by the benefits brought by its increased capacity to work as a successful pedestrian public space and of making its surrounding area to flourish.

8.2.2.3. Management & maintenance policy

As required by the client, the management policy for the square should be based on the compatibility between the daily use of locals (e.g. strolling) and special events (e.g. concerts). The management and maintenance of the space are the responsibility of Porto City Council.

Cleansing and maintenance of green areas are the responsibility of the Environment and Estate Services Directorate, which is organised into two forms: under a contract for cleansing works firmed with a firm; maintenance of vegetation and pool is made by the direct administration of this Directorate. Repair works are the responsibility of the Street Services Directorate that will operate in two ways: small repairs/amendments by direct administration; large repair or improvement projects either by direct administration, either by a tender or a direct agreement to an external team. The materials for repairs are bought by Porto City Council directly to producers or suppliers in a continuous supply regime of 3 years. With respect to vegetation, specimens used for municipal public spaces come from municipal plant nurseries.

Durability, sustainability and economy and resources are the keywords referred by the client for the maintenance policy. This policy shall ensure the proper condition of facing materials and vegetation so that their life spans can be as wide as possible and that their benefits for the space’s microclimate are not eroded. In turn, the specified programme will entail low maintenance requirements or a nearly spontaneous maintenance.

8.2.2.4. Community engagement policy

Local community was engaged in the appraisal stage with the undertaken social/personal analysis. This characterisation allowed integrating people’s opinion, needs and expectations about the square. Both pedestrians and businesses owners referred that Poveiros Square needs to be cooler during summer. Identifying this need next to those who live the space was the main way of engaging local communities in the proposal. Client and users share the same expectations for Poveiros Square.

Local communities will be further engaged in the maintenance of the space. The option for low maintenance requirements or nearly spontaneous maintenances can foster such aim. Beyond fulfilling a client’s objective, this can enable a feeling of belonging amongst local communities which will then be more prone to naturally care and watch over the space.

8.3. DEVELOPING THE PROPOSAL

8.3.1. DESIGN POLICY

8.3.1.1. Premises

This intervention will help making the previous investment in pedestrianising the space more profitable; countering the functional and morphologic weaknesses of the square and enabling its strengths; meeting the needs and expectations of the users and potential new users of the square, namely a cooler microclimate during summer, by decreasing $K\downarrow$ and MRT values. The general vision for the intervention over Poveiros Square will then be that of creating a more shaded and less paved environment; that of increasing shading levels and evaporative cooling through a more 'natural', permeable, organic solution without however transforming the square into a garden. The utmost preservation of existing features will be sought, i.e. changes will be proposed only to the strictly necessary. This will further allow meeting the 'client's' objectives:

- Enriching the public realm. A cooler microclimate will enable more people to be engaged in outdoor activities for longer periods of time. Permanence and diversity of pedestrian activities can greatly enrich the public realm of Poveiros Square.
- Enabling the creation of terraces and other ways of developing local economic activities and attract new residents and businesses. Cooler environments during summer are more pleasant and thus more attractive to people; they can foster an emotional bond between people and space and thus give it a high social meaning. New households and businesses are then likely to be attracted to the site and the existing ones maintained or improved.
- Enabling a 24-hours use and ensuring the safety and security of the space. The attraction of more people to the space for longer periods of time coupled with the settlement of more and varied businesses can be the anchor for a more vibrant and safer nighttime environment of Poveiros Square. More people strolling, sitting in cafe terraces, more light from new shops and a better lighting scheme may help preventing criminality.
- To rethink the lighting strategy, paying attention to the energy consumption of lamps (these should be as low as possible). There is a need of providing better lighting at night for safety reasons. In addition to the increment of more (low-energy) lighting, the definition of a high-reflective ground surface and the articulation between planting scheme and public lighting can make the space brighter at night.
- To ensure the sustainability of the chosen materials. It is *sine qua non* of bioclimatic urban the design to adopt materials, technologies and procedures deeply rooted on sustainability, namely on reduction, reuse and recycling. The proposal shall take these issues into consideration.

Through these topics, improving the microclimate of the square can allow making the previous investment in pedestrianising the space more profitable. The retrofitting intervention over Poveiros Square will assign the same importance to both materials and vegetation since it is the lack of shade and evaporative cooling that more significantly define its unpleasant microclimate. The intervention will be applied to ground surfaces only, since vertical surfaces do not have an expressive impact on the space's microclimate. The whole ground surface will be encompassed by the proposal.

The creation of a more permeable environment in the square will be made with consideration to the planned activities. Paved areas will be applied to desire lines; the planting scheme will be dense enough to provide shade without impairing the installation of temporary structures.

In terms of design constraints, the intervention will be compatible with the inclusion of the space within the area classified as World Heritage Site by planning the planting scheme in such ways that it does not cut off views on the two listed buildings, and by selecting species and materials with a visual/symbolic connection to site. The proposal will therefore be integrated with the existing context. Relatively to the classification of the space within an Archaeological Protection Area, the proposal has no impact. The underground car parking does not allow direct planting throughout its whole area. Alternative measures for the planting scheme will thus be included.

8.3.2. Specification of programmes of 'cool' materials and vegetation

8.3.2.1. Selection of materials and vegetation

After settling the general vision for the space, preliminary possible alternatives for programmes of 'cool' materials and vegetation for the square were developed. These alternatives were defined taking into consideration the client's objectives, the square's functions, and the guidelines presented at the proposed guide. Each alternative was subsequently subjected to a virtual simulation. For materials, the selected principles from the proposed guide were:

1. High-albedo materials, albedo values >0.50. Since the space is wide, the use of medium-albedo materials (0.30-0.50) may also be considered.
2. High-emissivity materials, emissivity values between 0.50 and 0.95.
4. Good resistance to weathering, soiling, or damage.
5. Materials with low PEC.
6. Materials easily reusable and/or recyclable.
7. Materials outcoming from reasonable natural stocks.
8. Materials with as less associated pollution and toxicity as possible.

For vegetation, the selected principles from the proposed guide were:

10. Combination of deciduous and evergreen species, for providing shade during summer and access to solar radiation in winter.
11. Moderate-growth species, for achieving results relatively rapidly without compromising the tree's resistance to storm damage, insects or diseases (fast-growing species are generally less resistant).
12. Maximum heights compatible with the space's layout, aerial services, and planned activities, namely through the choice of medium (6 m to 15 m when mature) species. Pre-existent trees will be kept.
13. Vegetation of the right shape and density of foliage, namely rounded and spreading trees with a density of foliage able of blocking solar radiation during summer.
14. Root systems compatible with the space's layout and underground services, for preventing roots to become entombed by other systems of the space. Plants will not be planted right next to or above underground services, buildings foundations or in areas where the depth till the underground car parking slab is too shallow. Minimum depth to the underground car parking slab is 0.50m, whilst maximum depth is 1.50 m.
15. Resistance to breakage, pests and diseases.

With respect to materials, the range of options for the square's ground paving were granite cubes and slabs (pre-existent), limestone cubes, bounded gravel, and asphalt. It is important to refer that while limestone cubes and bounded gravel were taken as actual scenarios of improvement, asphalt was not an option for improving the microclimate of the square since it does not fall on a 'cool' category. This material was just considered as an experimental alternative since it presents significantly contrasting parameters relatively to the other selected materials.

Relatively to vegetation, the selected species were, for trees, the pre-.existent *Acer palmatum* (Japanese Maple) and *Ligustrum lucidum* (Glossy Privet), and the proposed *Betula papyrifera* (White Birch). The selected shrubs were *Lantana camara* (Lantana) and *Hydrangea macrophylla* (Hydrangea). No herbs were selected due to the function of the space: at times of intense use herbs might be vulnerable to physical aggressions such as stepping.

Subsequently to the selection of materials and vegetation, technical information about their physical, moisture-related, optical, and biophysical parameters, respectively, was collected. Following the principles of the proposed guide, environmental costs were added. The collected information for both materials and vegetation is presented in Annex H.

8.3.2.2. Concept design

The concept design (Figure 50) is built upon the preservation of the pre-existent paving solution and the increase of vegetation, according to the design policy (minimal changes as much as possible) and specified programme of materials and vegetation. Figure 49 shows the current situation of Poveiros Square.

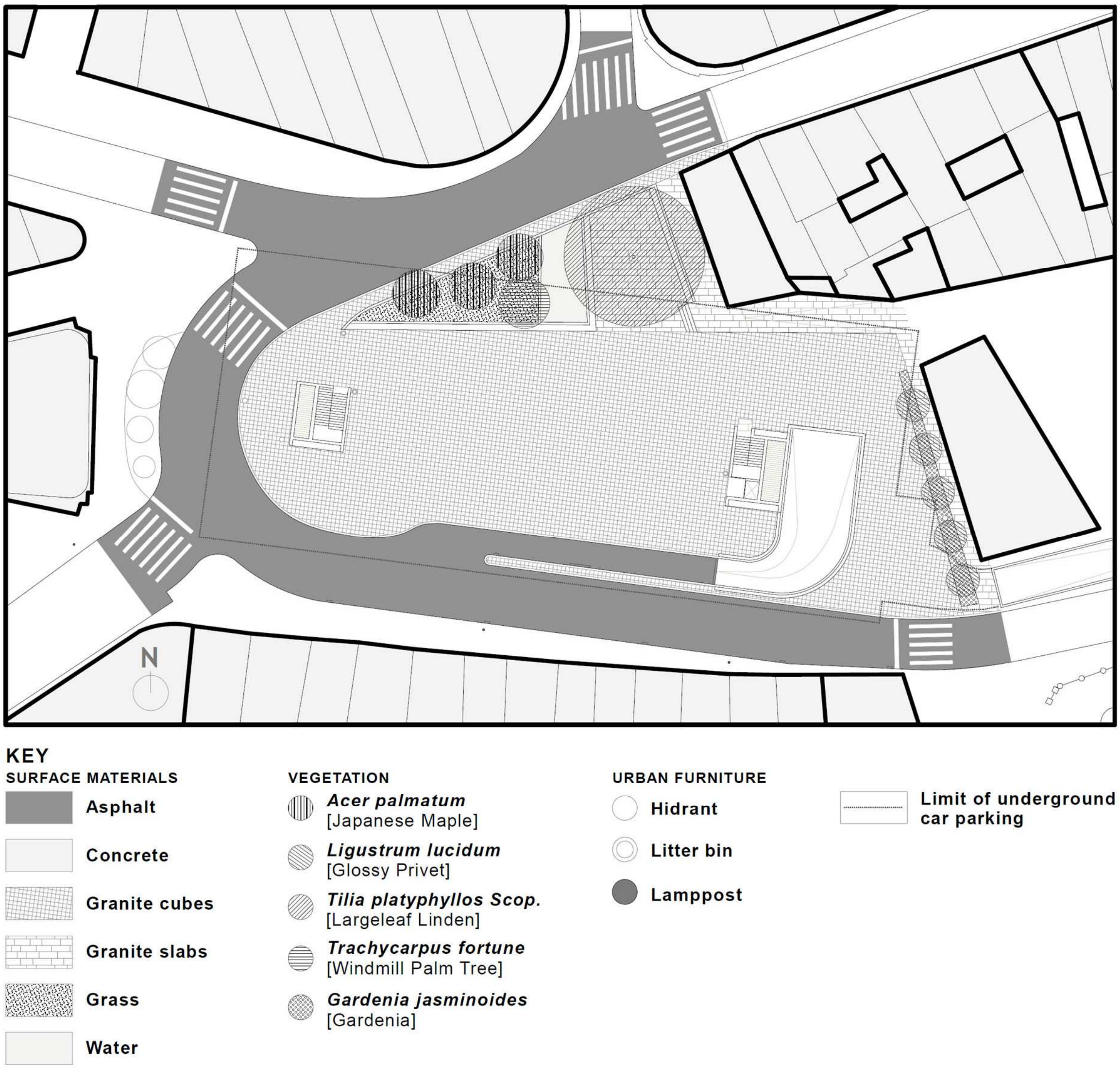


Fig.49 – Plan of the current situation of Poveiros Square.

It was decided to preserve granite, the current paving material, in the concept design since it is a material possessing a medium-albedo value (0.40) and high emissivity (0.90). Additionally, granite has a high PEC, potential serious environmental impacts and some entailed pollution and toxicity during extraction; granite can be reused or recycled; and granite presents good resistance to weathering, soiling, or damage. These are characteristics making the preservation of the pre-existent paving solution desirable. Preserving current paving solution may also represent a lower cost since there is no need for removing granite cubes and to buy new paving materials. This is not negligible since bringing costs down to a minimum is one of the client's objectives. In addition, this may also lead to less time required for undertaking site works as there is no need for removing granite and installing a different material; less disruption in the normal functioning of the area; less waste generated; and less energy consumed.

Although it was aimed to explore bioclimatic issues only, the concept design had to account with some spatial design issues in what concerns to vegetation. Defining the amount and placement of vegetation should be related to the desire lines and the underground car parking. Bearing this mind, the concept design increases vegetation in the square according to basic urban design principles such as desire lines, connection with pre-existent elements, and compatibility between space, chosen species, and planting scheme. This was relevant for weighing the areas were planting was necessary and the areas where planting was possible and through which means.

The underground car parking was remarkably important for planning the increment of vegetation. Two main issues were related to this structure and the way it could condition the intervention: firstly, the volume of earth between the surface and the parking's slab; secondly, the weight placed upon the parking structure and its ability to resist to an increment of vertical forces. Relatively to the first issue, through the acceded drawings[4] it was possible to know that the minimum distance between the surface of the square and the parking's slab was 0.50 m and maximum depth to slab was 1.50 m. It was then considered that although these depths were surprisingly enough for planting grasses or small shrubs, the planting of trees however would require a larger volume of earth. The option felt over raised flowerbeds. In what concerns to the second issue, it was a concern the load these flowerbeds, as an ensemble of concrete walls, earth (sometimes saturated) and plants, would place on the underground car parking. It was not possible to access any design and access statement, brief or technical report about the car parking. Consequently, it was not possible to know precisely which loads was this structure dimensioned to withstand, which would have been otherwise the ideal situation.

Faced to this limitation the option was then to propose an intervention placing the less potential weight on the underground car parking without however constraining neither the design quality nor the proper development of plants, i.e. presenting a balance between safety (to the underground car parking) and profit (to the microclimate and legibility of the square). Should the weight of the proposed elements be above that admissible to the underground car parking, its structure could be reinforced. However, beyond the technical difficulties this could arise and the eventual ownership conflicts, such reinforcement would certainly increase the costs of the intervention. Considering that the methodology proposed with this research is about retrofitting public spaces in compact urban areas on a bioclimatic perspective with the least cost possible without compromising the quality of the proposal, this hypothesis was from the beginning refused. This was an option corroborated by Porto city Hall. Considering this, the proposed flowerbeds traduce the articulation between a reasonable volume of earth with minimum weight possible on the underground car parking, while ensuring the proper growth of plants and avoiding reinforcing the parking's structure.

It was acknowledged that the ideal situation for the proper growth of trees would be the provision of as much available soil as possible so that the roots could expand freely. Notwithstanding, considering the physical constraints of Poveiros Square and also the benefits of planting trees, this would not be possible. The volume of earth provided with the proposed flowerbeds coupled with the already existent volume of earth between the surface of the square and the parking's slab was considered to be generous. If the roots of trees come to pose any problem to any physical structure of the space, it is likely that this will happen at medium-term which, considering the global characteristics of the space, is likely to concur with need for global and cyclic maintenance operations in the square. Any eventual problem caused by trees may be assessed and amended at any time. This was an issue discussed with and validated by the consulted landscape architects.

It is also important to refer that the amount of vegetation proposed in the concept design corresponds to a maximum that the space could hold bearing in mind its typology and expected activities.

Derived from the proposed guide, and bearing all above mentioned issues, the concept design for the proposal of improvement of Poveiros Square results from the following bioclimatic strategies:

[4] This information was kindly provided by the company owning the car parking, EMPARQUE.

- Preservation of the pre-existent ground surface, granite cubes and granite slabs.
- Planting of a row of 6 *Betula papyrifera* on concrete raised flowerbeds at the square's southern edge. It is likely that due to the impossibility of trees to freely expand their roots these specimens will not be able of achieving their maximum potential height (around 20 m). A 10 m height was considered to be a reasonable height for these specimens considering the relative confinement of their roots. Each flowerbed possesses an understory of shrubs, more precisely 6 *Lantana camara*. These flowerbeds were conceived as the main strategy to improve the microclimate of the square: by placing a vegetal mass on the southern edge of the square, since this space has an E-W orientation, shade is provided to the centre of the space all day long. The underground car parking has determined the need for these flowerbeds to be raised 1 meter high from the ground level;
- Creation of a concrete raised flowerbed at the northern edge of the underground car parking eastern staircase. This flowerbed is planted with 1 *Betula papyrifera* and 16 *Lantana camara*, and was created to provide shade along the initial/terminal part of the main desire line across the square (along its western and northern edge);
- Creation of a flowerbed at the eastern end of the southern row of raised flowerbeds, planted with 5 *Hydrangea macrophylla*. This element is proposed in order to establish a link between the proposed raised flowerbeds and the pre-existent staircase volume, as well as to reduce the visual impact of the access ramp to the underground car parking;
- Replacement of grass at the pre-existent raised flowerbed at the square's northern edge by 20 *Hydrangea macrophylla*. This replacement is proposed in order to provide more shade and evaporative cooling to the northern cafe terrace area, an important sub-space, based on the dominant wind direction in summer (NW). In addition this is aimed at reducing maintenance costs related to the mowing of grass which, due to the shape of the flowerbed can be at some points difficult;
- Removal of the pre-existent *Tilia platyphyllos Scop*. Considering the mature height, crown diameter and root system of this species, this specimen is likely to be removed in the future due to the likely structural problems it can bring to the underground car parking and contiguous buildings. In this context, the option was to remove it to another, more suitable, space rather than having to cutting it down later in time. As discussed with Porto City Hall, the cost of removing the specimen for another site is similar, eventually lower, to the cost of cutting down the tree, removing roots, and repairing the damaged underground car parking structure.
- Creation of a concrete raised flowerbed in the continuity of the pre-existent northern edge flowerbed. 1 *Betula papyrifera* and 4 *Hydrangea macrophylla* are planted here. This flowerbed is proposed to provide shade (the *Betula papyrifera* replaces the pre-existent *Tilia platyphyllos Scop.*) and evaporative cooling to the northern cafe terrace;

Beyond these proposed changes, and the preservation of the pre-existent paving solution, all other morphologic parameters of the square are kept. The options listed above resulted in the layout presented in the following figure.

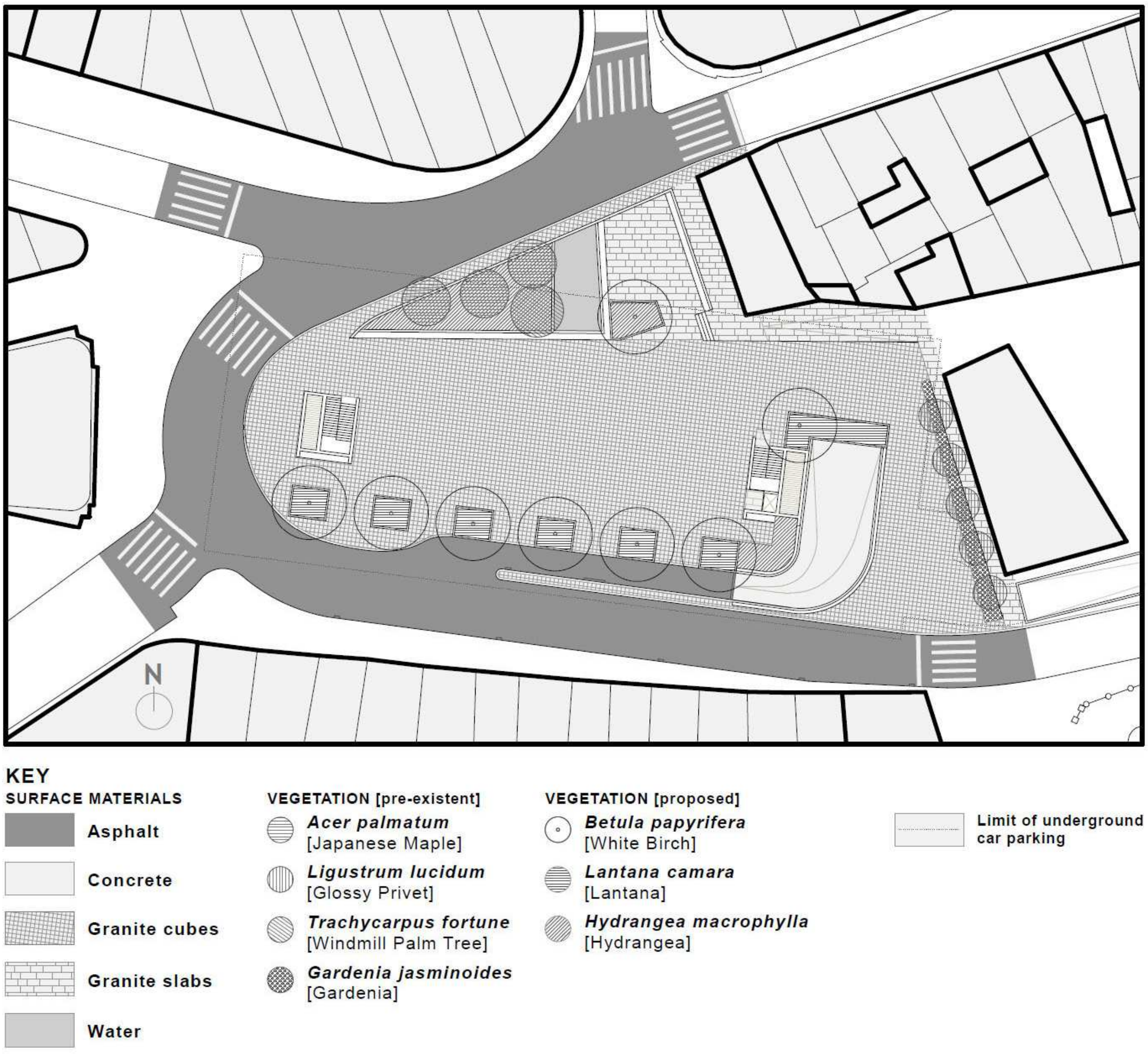


Fig.50 – Plan of the concept design for the intervention in Poveiros Square.

The concept design was tested against three alternatives/scenarios. The planting scheme defined for the concept design was kept in all scenarios. The only difference from scenario to scenario was the paving solution. These scenarios were weighed according to the potential to improve the square's microclimate (through the ENVI-met simulations) and according to the square's function. It was weighed how better each scenario was against the current situation of the square.

8.3.2.3. Virtual simulation

All alternatives were tested with the selected microscale climate model, ENVI-met, in order to quantify their potential for microclimatic improvement. Four virtual scenarios were defined based on the planting scheme of the concept design and on the following paving materials:

- Scenario 1 - granite cubes (concept design);
- Scenario 2 - limestone cubes;
- Scenario 3 - bounded gravel;
- Scenario 4 – asphalt.

The albedo, emissivity and impermeability values for all tested paving solutions are presented in the following table.

Table 12 – Tested paving solutions and associated albedo, emissivity, and impermeability values.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Paving Material	Granite cubes with mortar joints	Limestone cubes with mortar joints	Light-grey polymer resin bounded gravel	Asphalt
Albedo	0.40	0.45	0.72	0.05 (new) 0.20 (aged)
Emissivity	0.90	0.93	0.28	0.90
Impermeability	1.00	1.00	0.40	1.00

The simulations were run for the 13th July 2011, which is representative of the day when the climatic variables recorded at Poveiros Square exhibited the highest values. The simulations were run for the 11 a.m. to 2 p.m. period, in line with the undertaken field survey, although the model was run from 9 a.m. to 15 p.m. in order to fulfil the minimum 6 hours required by ENVI-met. All the presented values report to 12:30 p.m. (which corresponds to solar noon in Porto in July and, thus, to the heat peak) and were determined at a height of 1 meter above the ground.

The average values recorded for each climatic variable during the microclimatic monitoring were taken as the baseline for running the simulations. These values were plotted into the ENVI-met Configuration File amongst all other required data of a more general scope such as latitude, sun angle, or reference time zone. Taking the values of the microclimatic monitoring as a reference required a preliminary simulation of the square’s current situation. This simulation was then aimed at calibrating the ENVI-met Configuration file with the values collected during the undertaken field survey.

A fair correspondence between the values recorded at site and those obtained with the ENVI-met simulation was observed. Therefore, the data plotted into the ENVI-met Configuration file was the same for all simulations. The only changes from simulation to simulation were for paving materials. For simplicity, the references made to current situation will have in consideration the values obtained with the ENVI-met simulation.

All values presented in the “discussion of alternatives” section refer to range of values provided by ENVI-met for the totality of the space. The maps presented below are vital for the full comprehension of the microclimate changes resulting from each scenario: the spatial distribution of a range of values for a variable may differ from scenario to scenario.

8.4. DISCUSSION OF ALTERNATIVES

8.4.1. POTENTIAL FOR MICROCLIMATIC IMPROVEMENT

The next step for validating the proposed methodology was to analyse the defined alternatives for the Square based on the results obtained with the virtual simulations. The first overall conclusion was that comparatively to the space's current situation all defined scenarios have the potential for improving Poveiros Square's microclimate, with the exception of scenario 4.

Figure 51 presents the spatial distribution of T_a for the square's current situation and for the four simulated scenarios. As could be foreseen, the new vegetation at the southern edge of the square, considered in all scenarios, creates an area where there is a significant decrease T_a, due to shading and also due to evapotranspiration. This area corresponds to T_a values between 21 °C and 22 °C. As opposed to this, the minimum T_a values for current situation were found between 22 °C and 23 °C. This means that all scenarios, in shaded areas, have the potential reduce T_a by 1 °C to 2 °C. Considering that people can sense temperature differences within a range of 1 °C to 2 °C (Lstiburek, 2002; 3), this reduction can produce important benefits to the square's microclimate.

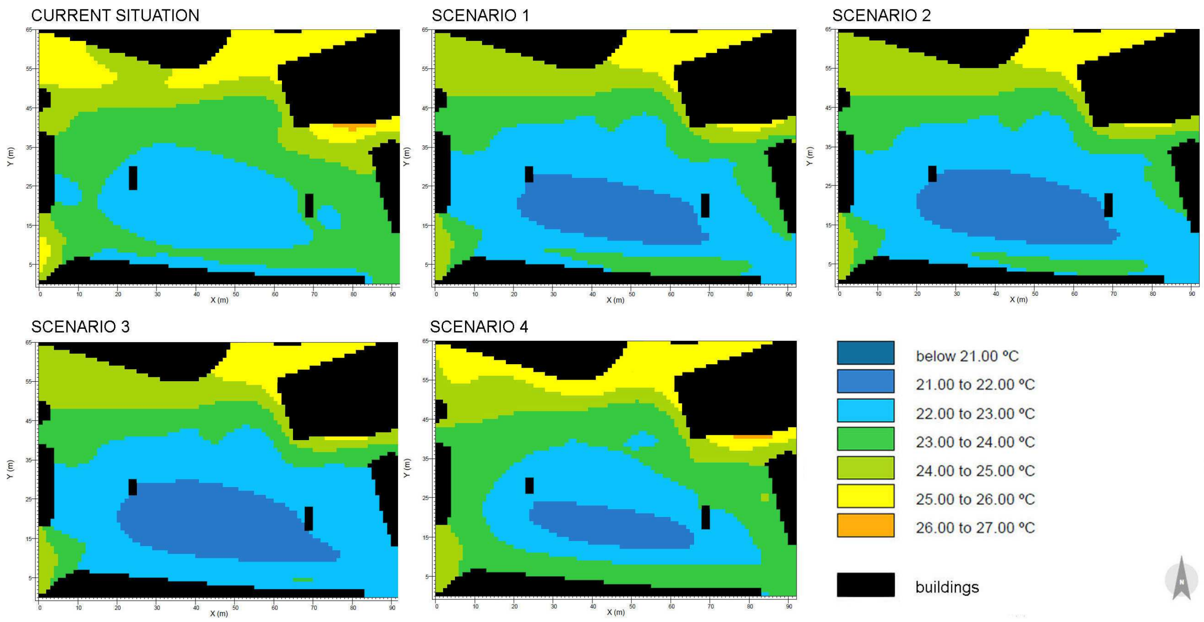


Fig.51 – Outputs from the ENVI-met simulation for air temperature.

The paving materials have also an influence on T_a, particularly in sunlit areas. Comparatively to scenario 1 (where the existing paving material is kept), the choice of limestone cubes in scenario 2 leads just to a slight decrease in T_a : the shaded area between 21 °C and 22 °C is slightly enlarged; and the area encountered between 22 °C and 23 °C is practically unchanged. Nevertheless, beyond the lowest T_a values in shaded areas, both scenarios present a much wider spatial distribution of temperature between 22 °C and 23 °C than current situation.

The decrease in T_a is more expressive in scenario 3 with an extension of cooler areas between 22 °C and 23 °C. Finally, as expected, scenario 4 does not improve comfort conditions outside the shaded areas. In this scenario there is an extension of warmer areas between 23 °C and 25 °C, and the spatial distribution of T_a between 21 °C and 22 °C of the southern shaded areas is even decreased. This suggests that the use of asphalt can hinder the benefits of vegetation.

These results suggest that for T_a the most advantageous scenario is scenario 3 and the least advantageous is scenario 4. More than emissivity or impermeability, differences in the albedo values of the tested materials seem to be the main reason for the observed differences.

The spatial distribution of the obtained values for RH is presented in Figure 52. Comparatively to the current situation, RH suffers an increase in all scenarios except 4. It should be mentioned that this increase goes up, at maximum, to a range between 55 % and 57.50 %, which is within the comfort zone for RH in outdoor spaces, i.e. 30 % to 65 % (Tojo, 2007; 175).

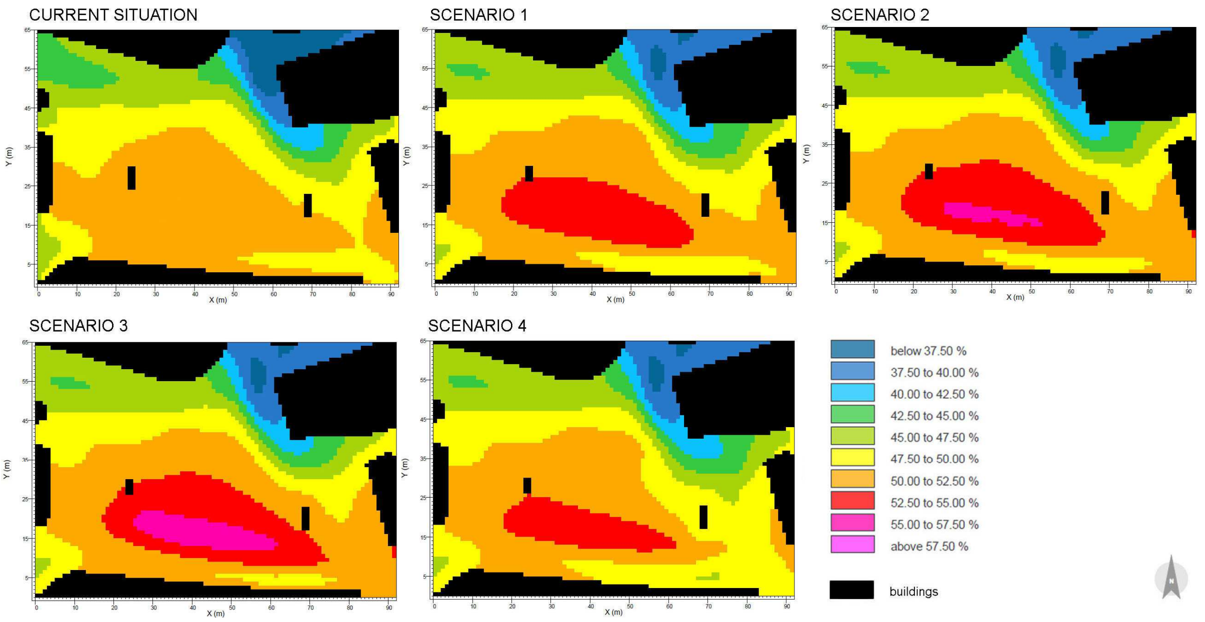


Fig.52 – Outputs from the ENVI-met simulation for relative humidity.

Scenario 3 is the one exhibiting the highest RH values. This scenario has the potential for creating an area with values between 55 % and 57.50 % surrounded by another area with values between 52.50 % and 55 %. These values correspond to the square's southern shaded area resulting from new vegetation. Scenario 2 presents a similar situation as scenario 3 although the range between 55 % and 57.50 % presents a smaller spatial distribution. Notwithstanding scenarios 1 and 4 increase current situation's RH values from 50 % to 52.50% to 52.50 % to 55 % in the square's southern part, these scenarios exclude the 55 % to 57.50 % range.

The most advantageous situation for RH then seems to be that of scenario 3. Scenario 4, in turn, is likely to be the less favourable situation. The observed increase in RH is due, in the first place, to the decrease of T_a and possibly also to a slight increase of absolute humidity resulting from the new vegetation.

The spatial distribution of $K\downarrow$ reaching the ground surface of the square at the time chosen for the simulations is presented in Figure 53. The reduction of $K\downarrow$ under and near the proposed plants is quite significant.

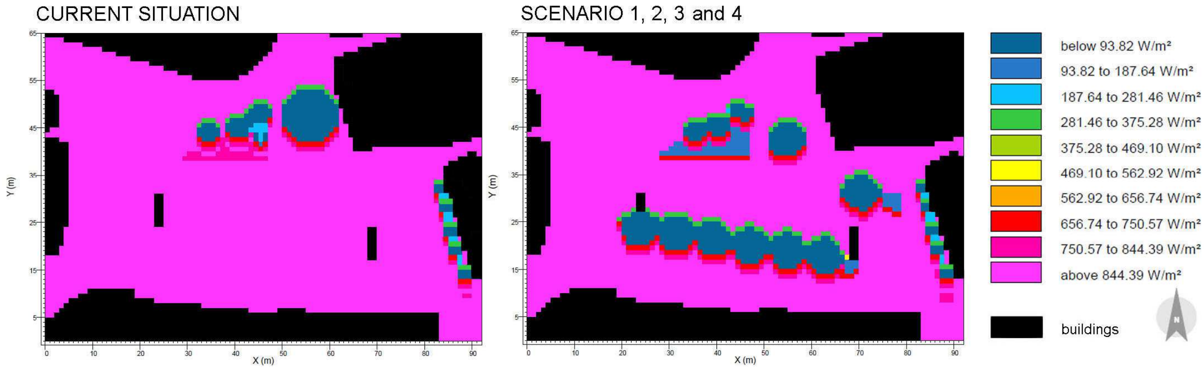


Fig.53 – Outputs from the ENVI-met simulation for direct solar radiation on ground surface.

It can be observed that for all scenarios the output for $K\downarrow$ was the same: while currently there is mostly an exposure to $K\downarrow$ values above 844.39 W/m^2, all scenarios can create areas where this value drops to around 93.82 W/m^2 or less. The reduction observed for $K\downarrow$ for the defined scenarios is directly related to the increase of shade from the proposed vegetation, which is the same for all scenarios. It is noteworthy that the calculations were done at a time close to solar noon when the sun is at its highest point in the sky. Therefore, the shading areas herewith referred are at their minimum expression.

Recalling the findings of the field survey which point out $K\downarrow$ as one of the climatic variables placing the higher constraints to the square's microclimate, this reduction is not negligible. For all scenarios, $K\downarrow$ values in shaded areas can be of $\leq$100 W/m^2, which corresponds to a low insolation value (Nikolopoulou, 2004; 4). Consequently, the opportunity for people to meet their comfort requirements with respect to this variable is increased in all scenarios.

Figure 54 gives the spatial distribution of *W* throughout Poveiros Square. The wind speed value introduced into ENVI-met was 1.13 m/s. This value corresponds to the average value measured at site during the filed survey. Comparing the simulated scenarios with the current situation, the influence of the row of plants in the southern edge of the square is very clear, working as a wind barrier.

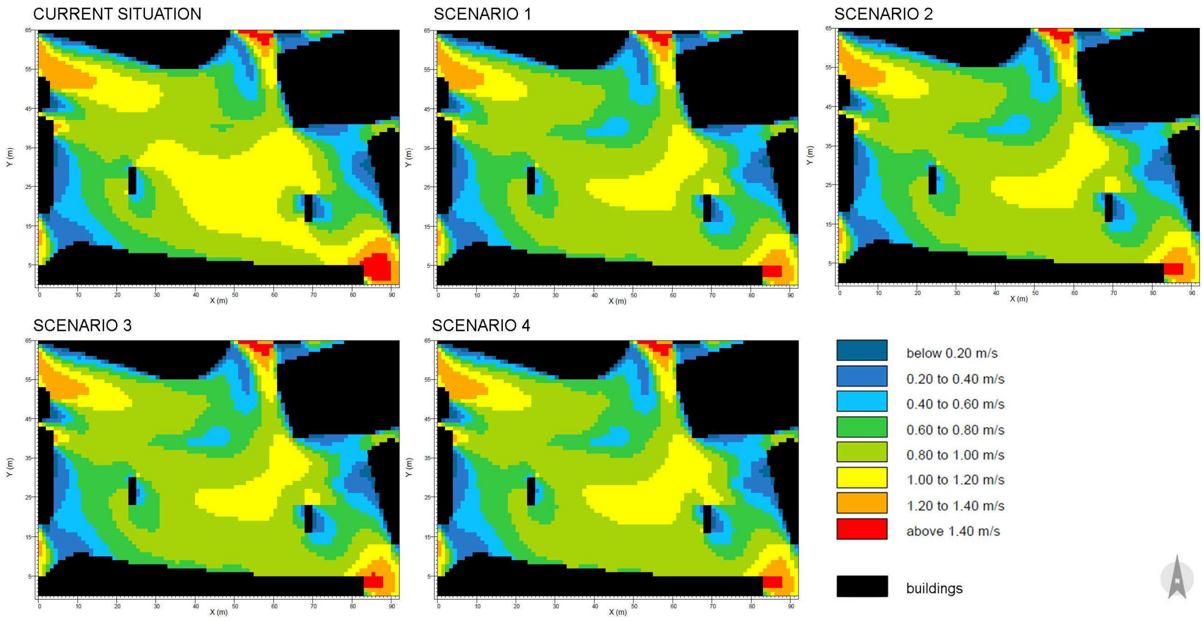


Fig.54 – Outputs from the ENVI-met simulation for wind speed (for a NW direction).

Comparing the map for current situation and for the defined scenarios it is possible to observe that the trees planted at the square's southern edge block wind from the NW direction and, thus, create a more sheltered area in the southern limit of the space. This attenuation can be very important during winter. The proposed vegetation has then the potential for attenuating the increase in *W* at the square's southeast corner.

At the central area of the square, as expected, the defined scenarios bring no variation to *W* values which, by comparison to current situation, remain at maximum between 1.00 m/s and 1.20 m/s. *W* values around 1 m/s correspond to a desirable slight breeze during summer (Nikolopoulou, 2004; 4). In addition, pedestrians find wind unpleasant only at a *W* of about 5 m/s (Oke, 1987; 272). Bearing in mind that during the undertaken field survey *W* was not a major constraint to the microclimate of the square, keeping its values close to current situation can be advantageous. *W* does not change significantly with the variations of paving materials between scenarios.

Relatively to MRT, Figure 55 shows that in all alternative scenarios this variable is significantly reduced beneath and around vegetation.

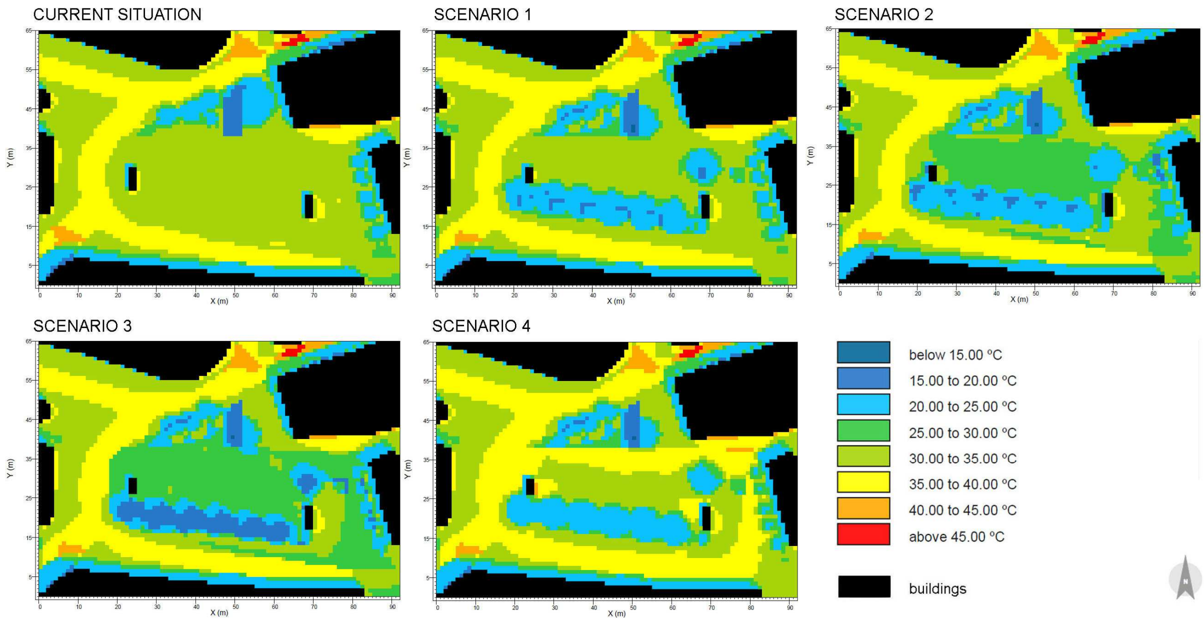


Fig.55 – Outputs from the ENVI-met simulation for mean radiant temperature.

Figure 54 shows that scenario 1 does not have the ability to reduce MRT values in sunlit areas comparatively to current situation, which is obviously related to the maintaining of the existent paving material. The capacity of this scenario to significantly reduce MRT values is restricted to shaded areas. In sunlit areas MRT is kept within a 30 °C to 35 °C range, and in shaded areas this range can drop to 20 °C to 25 °C.

Scenario 2 leads to a reduction of around 5 ºC in a great extent of the central part of the square, i.e. a 25 °C to 30 °C range gains spatial expression comparatively to current situation and scenario 1. In scenario 3, this phenomenon is enlarged reaching other parts of the square. In turn, in scenario 4, MRT increases in large areas. Some of these areas can present values 5 °C to 10 ºC above those of scenarios 2 and 3 or than even current situation.

Considering that during the field survey it was observed that MRT caused significant constraints to the square’s microclimate, the potential reduction conveyed by scenarios 2 and 3 can be rather valuable for improving the conditions offered for people’s thermal comfort. Scenario 4, in turn, constitutes a harmful situation for the square’s microclimate since although it may lead to a reduction of MRT in shaded areas, this reduction is less than in all other scenarios and, foremost, may even lead to an increase of MRT in sunlit areas.

Scenario 3 is the most potentially advantageous since it can reduce MRT in sunlit areas by around 5 °C (according to the wider and most continuous spatial distribution) and, in shaded areas, by as much as 15 °C. This scenario comprehends the paving solution with the highest albedo value and the lowest impermeability degree. Therefore, it can lead to lower values than all other scenarios even in sunlit areas. The lower MRT values presented by scenario 3 (particularly remarkable in shaded areas) are likely to be due to the high albedo of gravel. Also, the impermeability degree of bounded gravel can explain this: an impermeability degree of 0.40 is likely to enhance evaporative heat losses, especially in areas of higher humidity such as under a canopy of trees.

The consideration of the same planting scheme in all scenarios seems to be the main reason for the substantial reduction on MRT values observed in all scenarios since the lowest values refer to shaded areas. The different physical, optical and moisture-related parameters of materials also play a determinant role, which can be observed when comparing the MRT values for the sunlit areas of scenario 3 and those of the remaining alternatives.

Combining the results obtained with the simulations described above it is possible to conclude that **the most potentially favourable scenario for improving the microclimate of Poveiros Square — and therefore on strictly microclimatic terms the scenario to be considered as the final improvement proposal for Poveiros Square — is scenario 3**. Comparatively to current situation, and amongst the tested scenarios, this scenario presents the best potential performance for all variables in terms of values and their spatial distribution.

Notwithstanding, the choice of the final proposal for the improvement of Poveiros Square is an issue to be clarified by moving to the next step of the proposed methodology: weighing the correlation between potential for microclimatic improvement and cost.

8.4.2. COST

Can the correlation between potential for microclimatic improvement and cost be as advantageous as the potential for microclimatic improvement alone? In order to answer this question, a cost plan was defined for each scenario (Table 13). Through this exercise it was possible to reach the final proposal by weighing the alternative combining the best potential for microclimatic improvement with cost control, as required by the ‘client’.

The costs presented in Table 13, and further specified in Annex I, refer to the common prices and associated taxation (VAT 6 %) applied to Porto City Hall, the project’s ‘client’. These prices relate to 2013, include capital cost and workforce, and encompass four generic topics: building site (assembly and disassembly of building site structures and maintenance of safety conditions, work identification sign), demolitions (removal of granite cubes, removal of granite slabs, demolition of concrete walls and transportation of waste to landfill, removal of earth, earthwork with selected soils, transplantation of the pre-existent *Tilia platyphyllos scop*.), installation (granite cubes, 0.15 m concrete walls, waterproofing with anti-root asphalt felt, drains, 0.15 m gravel laid on geotextile, trench opening and paving replacement, connection to gutter), and green areas (humus, 5 m high *Betula papyrifera*, 0.30 m high *Lantana camara*, 0.40 m high *Hydrangea macrophylla*, 0.15 m granite kerbs and foundation).

The taxation applied to Porto City Hall is considerably lower than for a common private client, to which a 23 % VAT would be applied. These costs are provided in Annex J. Although the 'client' of the proposal was Porto City Hall, it was intended to give a picture of how much would the defined scenarios cost to a private entity if such would have been the case. The values obtained varied, as expected, in the same proportion as for Porto City Hall but to a higher range.

The cost estimate for the defined scenarios constituted an exercise foremost concerned in tracing a range of likely costs associated to each defined scenarios. More important than pointing out absolute sectorial or final costs, this exercise was concerned in understanding the extent to which the different defined alternatives would vary in terms of cost.

Table 13 – Costs associated to the defined scenarios.

Cost [average prices in the Portuguese market for 2012. VAT=6 %]				
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**
Building site	2.544€	2.544€	2.544€	2.544€
Demolitions	1.384.26€	6.875.96€	6.875.96€	6.875.96€
Installation	13.425.57€	53.382.19€	61.863.25€	37.631.65€
Green areas	3.055.85€	3.055.85€	3.055.85€	3.055.85€
TOTAL	**20.409.68€**	**65.858.00€**	**74.339.06€**	**50.107.46€**

Table 13 suggests that in terms of cost scenario 1 stands out as the clearly most advantageous solution. According to Table 13, the total cost associated to scenario 1 is 20.409.68€ while, in ascending order, for scenario 4 is 50.107.46€, for scenario 2 is 65.858.00€, and for scenario 3 is 74.339.06€. These values represent a difference of +45.448.32€ from scenario 2 to scenario 1, of +53.929.38€ from scenario 3 to scenario 1, and +29.697.78€ from scenario 4 to scenario 1. It follows that, in opposition to the potential for microclimatic improvement, scenario 3 represents the less advantageous cost situation.

The comparison between the values for demolitions and installation reveals that the remarkable cost differences between scenario 1 and the remaining scenarios are due to different demolition costs but foremost to different installation costs. The costs associated to building site and green areas are the same for all scenarios. Because scenario 1 has entailed minimum demolitions and no replacement of paving material it becomes remarkably more affordable than the other scenarios, which imply larger scale demolitions. The costs associated to demolitions for scenario 1 are 1.384.26€, and for scenario 2, 3 and 4 are 6.875.96€. The difference between the first scenario and the remaining is directly related to the removal of granite cubes, being all other parameters and associated costs the same. The cost associated to the removal of granite cubes, in turn, relates to the area to be worked upon: scenario 1 entails the removal of 106.83 m^2 of granite paving, which entails an estimated cost of 566.20€; while the remaining scenarios increase this area to 1.143 m^2 and the cost to 6.057.90€.

Relatively to the installation costs, the differences observed between scenarios are directly related to the cost of each specified paving material and to the area of its application. For scenario 1 only 0.86 m^2 are proposed to be paved with granite cubes which entails a cost of 25.52€; for scenario 2, the application of limestone cubes to 1.143 m^2 has an estimated cost of 39.982.14€; the application of bounded gravel conveyed by scenario 3 would cost of 48.463.20€; and the cost of asphalt was estimated to be 24.231.60€. It is noteworthy that even though asphalt has the lowest capital cost (21.20€/m^2), still the final cost of scenario 4 is much higher than for scenario 1 due to the costs associated to removing granite cubes and to applying asphalt to 1.143 m^2 of the square's ground surface.

It can thus be concluded that the replacement of the square's current paving material by a different material entails significantly higher costs than preserving its current paving. In addition to these capital costs, scenario 1 is expected to have lower operational costs since it accounts with well-established maintenance procedures, know-how and equipment of Porto City Hall services.

It is then clear that the final scenario of improvement for Poveiros Square, the final proposal for its thermal retrofitting, should be based in scenario 1. Although this scenario does not present the highest potential for microclimatic improvement (this condition is held by scenario 3), it can still provide important microclimatic amenities and combine them with the lowest cost among the tested scenarios.

Would this mean that selecting scenario 1 as the final scenario of improvement for Poveiros Square would be primarily based in cost rather than in potential for microclimatic improvement? Within the sustainably field, bioclimatic urban design is about weighing solutions entailing the best overall performance while mediating man, climate and environment. Considering this, if on a microclimatic perspective scenario 3 is the best solution, on the environmental, economic and social dimensions of sustainability, scenario 1 presents the best performance: although less than scenario 3, scenario 1 can still significantly improve the square's current microclimate during summer; scenario 1 has entailed lower environmental costs since there is no need for removing and transporting granite cubes away, no need for transporting and applying a new paving material, less impacts during site works, and less waste generated; it is the alternative presenting the lowest cost estimate; its entailed site works cause less disruptions to the normal functioning of the area than the other alternatives; Porto City Hall has already well-established know-how on the maintenance of granite pavings; and granite makes part of the visual identity of the city.

The remarkable potential for scenario 3 to improve the microclimate of the square should however not be neglected. Nevertheless, as initial cost is often decisive (Pomerantz, Akbari et al. 1997, 13; Akbari, 2005, 11) and, furthermore, cost control was one of the main requirements for the proposal, the sharp cost difference between scenarios 1 and 3 could not be circumvented while weighing alternatives for the square. The final proposal for Poveiros Square was, then, chosen to be based in scenario 1.

8.5. Definition of the final proposal

8.5.1. Spatial design

Being all options on bioclimatic terms, namely on the programme of ‘cool’ materials and vegetation, the same as for scenario 1, the final scenario of improvement for Poveiros Square results from a refinement of that scenario. This refinement was made with consideration to the guide’s spatial design section: robustness, ease of movement, relevance & legibility, planting scheme, and maintenance requirements. The options made on each of these parameters will now be addressed. It is important to highlight that since the proposed guide is not prescriptive, some guidelines were not considered while others were replaced by options made for the specific case of Poveiros Square. In the second case, the guidelines marked with “—“.

Robustness

Appearance

16. Glare from highly visible surfaces prevented through an appropriate shading level;
17. Too much shade prevented through a planting scheme that does not create an excessive amount of shade but only the necessary for allowing people to be either exposed to sun either protected;

Relaxation

18. Seclusion, privacy and intimacy, as well as containment and infinity opportunities through a planting scheme that does not create hidden areas within the space and by re-shaping some southern flowerbeds in order to make the square’s central area more secluded but yet not enclosed;

— The dimensioning of the southern flowerbeds as a means of reducing the visual impact of cars and the entrance to the underground car parking;

People’s active involvement

19. Direct/physical contact with nature, although to limited levels due to the function/typology of the space. Nevertheless, faced against current situation the final scenario is able of enhancing the direct/physical contact of people with natural elements such as trees and shrubs;
20. Varied activity opportunities for children, adolescents and adults, allowed by the preservation of the central area of the square as a void space able of receiving varied activities such as fairs, football matches, or the installation of cafe terrace;

People’s passive involvement

21. Indirect/visual contact with nature which is processed as the direct/physical contact with nature albeit at this level the visual continuity between the square and São Lázaro Garden can be beneficial;
22. Possibility to observe different actions and less usual events, which is ensured by keeping the central area of the square free of visual obstacles beyond the flowerbeds, trees and shrubs at it southern edge (which still present some degree of flexibility);

Exploration

23. Provision of surprise, mystery, familiarity and novelty. The pre-configuration of the square coupled with the proposed planting scheme are able of providing different sub-spaces associated to successive changing of sights within the square. Three main areas

may be distinguished at the square — the eastern entrance (a sort of 'lobby'), the central area (the main room for multiple activities), and the cafe terrace at the northern edge (a more secluded sub-space). These three complementary sub-spaces provide different sights over the square and surrounding buildings;

Fruition

24. Preservation of quality landscaping features and relevant sights, namely the preservation of most of the pre-existent vegetation specimens amongst which the *Acer Palmatum* is of an outstanding beauty, and the definition of a planting scheme not blocking views on the two listed buildings around the square, one at its east end and the other at its west end;
25. Water features combined with ventilation strategies at the square's northern edge in order to help concentrating the cooling potential of the water pool near the cafe terrace;

Adaptability

28. A layout able to receive long and short-term transformations associated to special events through the preservation of the square's central area as an open space;
29. Paving and planting scheme able to receive several functions without compromising their integrity. The preservation of the pre-existent paving does not alter the current resistance of the square's ground paving, and the planting of trees and shrubs in raised flowerbeds positioned in places compatible with the main desire lines are likely to withstand eventual physical aggressions resulting from more busy activities;
30. Adaptive opportunities. The final scenario can create the conditions for its potential users to find a whole range of exposure to the climatic variables: warmer and cooler T_a, more or less exposure to $K\downarrow$, wind, and MRT;

Safety & security

31. Good visualisation within and outside the space. Since the centre of the square is kept free of obstacles and the southern flowerbeds are spaced to a convenient distance (4.25m), there are no hidden areas of the square neither from outside nor from inside. In addition, the increment of public lighting is a means of improving 24h safety and security;
32. Ground paving not subject to standing water or to the accumulation of snow or slush, and to be slippery. The pre-existent granite paving possesses a convenient roughness and the square's 4 % gradient prevents the accumulation of standing water or slush;

Ease of movement

Access

33. Even paving solutions and soft surface gradients which result from the preservation of the pre-existing paving solution. Additionally, no stairs, cobblestones, sand, loose gravel or other forms of uneven paving are proposed;

Movement patterns

35. Paved areas and greenery set after people have defined their desire lines. If on one hand the square's paving has been previously determined, on the other hand the proposed planting scheme was developed from the outset with consideration to people's desire lines, especially the E-W crossing along the eastern and northern edge but also other crossings that sporadically occur in the S-N direction;

36. Vegetation not hindering the main access points to the space since the proposed planting scheme encompasses trees possessing their crowns 3 m above the pavements and 4 m above traffic roads, allowing people and vehicles to move freely;

Relevance & legibility

Relevance

37. Reinforcement of the character and identity of the space. The preservation of the granite paving and the introduction of *Betula Papyrifera*, *Hydrangea macrophylla* and *Lantana camara* constitutes a way of providing microclimatic amenities but also of establishing a link to space and people's culture since these are all elements often used in public spaces and private gardens in Porto;

Legibility

39. Ease of comprehension and navigation through the space. The pre-existent paving solution already defines the areas within the square possessing different uses through differentiated stone shapes. The proposed vegetation further reinforces the functional character of the existing sub-spaces by alignment (at the square's centre) and enclosure (at the cafe terrace). Also, for legibility reasons, the removal of the pre-existent *Gardenia jasminoides* at the eastern edge and the *Trachycarpus fortunei* at the northern edge is proposed since these do not have any significant microclimatic role;

— The repositioning of some pre-existent urban furniture, namely litter bins which were relocated to less visually impacting areas and closer to main desire lines;

40. Stimulation of all human senses by a careful approach to aesthetics/styling which was addressed by the repetition and rhythm at the centre of the square through the 6 planted *Betula papyrifera* which, beyond improving the space's microclimate, create a 'scenario' for events held at the square as well as an visual axis whose focal point is São Lázaro Garden (east) and the listed building of the square's west top.

    The provision of shade which is entangled with bioclimatic purposes plays also an important visual/aesthetic role by introducing to the square currently inexistent sunlight effects which change with seasons. The choice for *Betula papyrifera* also relates to the provision of an aesthetical value to the square in terms of form (its delicate shape which may contrast with the roughness of the surrounding built environment), colour (from the silver-coloured trunk to the autumn-golden leaves) and sound (resulting from the passage of wind through the leaves).

    The aesthetical effects intended with the *Betula papyrifera* are complemented with the deep-green leaves of *Hydrangea macrophylla* and *Lantana camara* and their, in this case, white-coloured flowers. The idea is that since the built environment is already colourful, and since there are pre-existent species with strong colours, the proposal could introduce more vegetation without however creating too much visual information. White flowers were then chosen. Furthermore, this colour can help psychologically giving a sense of coolness to the square. In terms of smell, since the *Ligustrum Lucidum* is strongly scented when blossomed, it was decided not to propose any extra-scented species.

— The final form of the proposal was intended to be of a unity composed of balance and visual strength. Relatively to details or ornamentation, there are no special features to be highlighted. Materials and finishes were planned to be as low as possible in order to reduce costs to the utmost;

Planting scheme

Quantity

41. An amount of specimens beneficiating the thermal performance of the space but compatible with its typology and function. The trees and shrubs encompassed in the proposal were planned in a quantity suitable to induce to a microclimatic improvement without however transforming it into a garden. In this sense, the number of specimens was reduced down to a minimum;

Placement

42. Placement and orientation of specimens with respect to the shadow cast at the most critical times of the day during summer and winter. Trees are placed as close as possible (by 7.85m) in order to create a shading pattern as continuous as possible considering the species crown profile;
43. Compatibility between shading patterns and indoor thermal performances. The planting scheme does not shade neither south-facing windows nor solar collectors;
45. Spaces designed to fit trees rather than trees forced to fit inadequate spaces;
47. Raised boxes when direct planting is not possible due to underground services or shallow depth. The proposed flowerbeds were only taken into consideration due to the existence of the underground car parking. Still, it was intended to make them as large as possible considering the contingencies presented by the underground car parking. Bearing in mind that large trees require a minimum of 6 m^3 of earth, the proposal provides a fair volume of earth in each flowerbed. The smallest flowerbed possesses 10.50 m^3 of earth whereas the largest 25.40 m^3;

Maintenance requirements

Materials

49. Easily cleanable and replaceable surfaces. The preservation of the pre-existing paving material has associated maintenance requirements which are already well introduced into Porto City Hall’s practices;

Vegetation

50. Easily maintained and replaceable planting scheme which was sought by choosing species with an acceptable resistance to physical impacts, pests and diseases, and by placing specimens in areas where these are not prone to conflict with other physical elements of the space so that pruning needs can be reduced to the utmost. Since all trees are spaced from buildings in a distance greater than 8 m to 10 m (the minimum distance is 10 m and refers to the *Betula papyrifera* placed at the northern cafe terrace but still, when mature, its crown diameter will be spaced by 5.50 m from the nearest facade), it is not likely for the planting scheme to represent major constraints to the foundations and/or facades of surrounding buildings;
51. Low-water-use vegetation. *Betula papyrifera* as a moderate need for watering, *Hydrangea macrophylla* requires frequent watering, and *Lantana camara* has low water requirements. It follows that *Hydrangea macrophylla* are the species requiring an eventual higher volume of water and periodicity of watering. Nevertheless, the highest number of this species is proposed for the northern edge flowerbed which means that the water from the contiguous water pool can be used for watering the plants.

52. Vegetation species with leaves, berries and blossoms not subject to dripping or staining, except for the pre-existing *Ligustrum Lucidum*;
53. Acceptance of spontaneous vegetation. The dense planting of shrubs throughout the proposed flowerbeds may allow the growth of spontaneous vegetation which can help retaining humidity levels at the basis of the plants, increasing their resistance and reducing costs associated to flowerbeds cleansing.

These options on spatial design resulted in the layout presented in Annex K. Since the layout of the final scenario is quite similar to that of scenario 1 (only few slight adjustments were made, namely the size of flowerbeds), as expected, the ENVI-met simulation for this scenario provided the same results as for scenario 1. Therefore, the final scenario has the potential for moving the square’s current microclimate from an uncomfortable environment during summer that undermines its potential for pedestrian activities, to a more comfortable thermal environment able of attracting people and make them stay.

The capacity of the final scenario of improvement for Poveiros Square to provide better conditions for outdoor thermal comfort is suggested by the fact that the values obtained with the ENVI-met simulations for each considered variable can be encountered within the same ranges as for São Lázaro Garden during the undertaken field survey. Recalling the findings from the field survey (Chapter 6), it is remarkable how the obtained answers show the dissatisfaction of respondents relatively to the thermal environment of the square and their satisfaction about the thermal environment of São Lázaro garden. The significantly different thermal evaluations for one space and the other were shown to be directly associated to the dramatically different values recorded for $K\downarrow$ and MRT.

It follows that since the bioclimatic strategies encompassed by the final scenario of improvement for Poveiros Square are able of bringing the values of $K\downarrow$ and MRT down to a range of values close to the average values found in São Lázaro Garden in shaded areas, the chances created for delivering better conditions for outdoor thermal comfort at the square can be achieved. Table 14 presents the average microclimatic values recorded at São Lázaro Garden, and the potential values entailed with the final scenario of improvement for Poveiros Square. Both groups of values are restricted to shaded areas.

Table 14 – Comparison between the average microclimatic values recorded at São Lázaro Garden, and the potential values entailed with the final scenario of improvement for Poveiros Square.

Variable	São Lázaro Garden	Final scenario for Poveiros Square
T_a (°C)	21.50	21 to 22
RH (%)	58.26	52.50 to 55.00
$K\downarrow$ (W/m^2)	55.00	≤ 93.82
W (m/s)	0.60	0.80 to 1.20
MRT (°C)	24.41	20.00 to 25.00

Table 14 shows that the range of values obtained for all variables with the ENVI-met simulation do not fall too far from the average values recorded at São Lázaro Garden: average T_a recorded at the garden is within the range of values obtained with the simulation; RH at the garden is slightly above the range obtained with the simulation (this was expected since the garden possesses more vegetation than the final scenario); $K\downarrow$ at the garden is encompassed by the range of values obtained with the simulation for shaded areas, namely ≤ 93.82 W/m^2; measured W is not significantly lower than the lower limit of the range of values obtained with the simulation; and the average value for MRT recorded at the garden is within the range obtained with the simulation.

It is important to maintain realistic expectations about the moment when the proposed scheme will start delivering microclimatic amenities to the same extent as São Lázaro Garden. The potential of the bioclimatic strategies encompassed by the scheme will require some years be fully established. This period is determined by the growth rate of the proposed vegetation species.

The selected *Lantana camara* and *Hydrangea macrophylla* have a fast growth rate. These species may grow as much as 0.60 m a year. For the case of *Lantana camara*, coupling this with the fact that specimens were planned to be planted with a 0.30 m height and to grow up to around 1 m, it is estimated for these proposed shrubs to reach their full bioclimatic potential within 1.3 years. Relatively to *Hydrangea macrophylla*, since specimens were planned to be planted with a 0.40 m height and to grow up to around 1.50 m, it is estimated that these will reach their full bioclimatic potential within 2 years.

The situation for the *Betula papyrifera* had to account with their impacts on the underground car parking. The tree species for this square would have to combine the utmost prompt provision of shade and evapotranspiration with the reduction of risks to the underground car parking structure. Therefore, the option was for a medium-growth species able of providing microclimatic amenities within a reasonable time scale and simultaneously with a rooting system growing in a pace not placing an abrupt and strong load on the underground car parking structure, such as fast-growing species would. Due to the relative conditioning of root growth in flowerbeds, a height of 10 m was considered as a reasonable height for the proposed *Betula papyrifera*. Considering that this species can grow by as much as 0.50 m a year and that specimens were planned to be planted with a 5 m height, it is estimated that these will reach their full bioclimatic potential within 10 years. This is made under the consideration of normal growth and health conditions.

It can then be assumed that the proposed planting scheme is likely to take 10 years to achieve its full bioclimatic potential in terms of shade and evapotranspiration and, thus, to deliver the expected microclimate to Poveiros Square.

With respect to cost, according to the prepared estimate, the final proposal of improvement is likely to have an associated cost of 23.744.43€. This value surpasses the value estimated for scenario 1 by +3.334.75€, which results from the slight enlargement of the two flowerbeds at the western point of the southern row of *Betula papyrifera*, and from the installation of lamp posts. More detailed information on the costs associated to the final scenario is presented in Annex I (for VAT 6%) and J (for VAT 23 %). Still, this value estimated for the final scenario was considered by the consulted practitioners/experts and the 'client' as perfectly reasonable.

The time required for building operations by the final scenario for Poveiros Square was planned to be as short as possible. These resume to building the flowerbeds, installing the planting scheme and associated drainage infrastructures, repositioning some urban furniture items, and installing lamp posts. Based on the common building practices for this type of intervention in Portugal, and for a workforce constituted of four elements, the full installation of the final proposal for the square is likely to require an average period of 30 working days, 45 at maximum. This period of time was considered to acceptable and within the common time required for these building operations.

In addition, the only changes to the site's normal functioning and appearance would be the installation of building site structures and the definition of a safety perimeter around the flowerbeds' areas. This can prevent major disruptions to the site's normal functioning, especially in what concerns to the preservation of people’s main desire lines. The trench opening, installation of drains, and paving replacement required for installing the drainage system required by the proposed flowerbeds might create some obstacles to accessibility and people’s ease of movement. However, the estimated time for this operation was no longer than 24 hours and, still, during this period of time provisional crossing elements could be used.

8.6. CONCLUDING REMARKS

8.6.1. ON THE PROPOSED METHODOLOGY

The development of the proposal of improvement for Poveiros Square allowed reaching a possible solution for its underuse. Since this exercise was structured accordingly to the proposed methodology, it simultaneously allowed validating it.

Throughout the all process, the methodology was continuously amended, especially in what concerns to its contents and their organisation. Each meeting held with the entities mentioned in Table 11 provided a body of notions on the strengths and weaknesses of the methodology. Its refinement after a meeting was then intrinsic to the own exercise of validation and happened on an ongoing basis according to the discussions held. Although the backbone of the methodology remained unchanged, these amendments were crucial for giving it a convenient degree of attachment to the design activity.

The validation exercise allowed understanding that it is possible to consider the proposed methodology for the development of retrofitting projects in public spaces located in compact urban areas envisioning its microclimatic improvement. Simplicity can in many cases underlie the success of a retrofitting scheme and avoid high costs. The significant improving of a space can be achieved through small-scale, slight interventions on its pre-existing layout.

Considering the premises for the development of the methodology presented in Chapter 7, the main conclusions to be drawn from its application to the proposal of improvement for Poveiros Square are:

Addressing key work stages of the design process

- The proposed methodology was able of assisting the whole development of the retrofitting proposal for Poveiros Square through the suggested key-work stages. Each stage encompassed the fundamental issues about the development of a proposal targeted at improving the microclimate of a space. The development of the proposal, either by design or by the discussions with practitioners/experts, allowed however to reposition some principles within each proposed stage.

Merging of common and bioclimatic urban design principles

- The methodology does not establish a boundary between bioclimatic and common urban design. This allowed developing the retrofitting proposal with consideration to a range of issues addressing not only topics related to microclimate but also to broader concerns around spatial quality. This, in turn, allowed having a holistic view on the spatial quality of the proposal.

User-friendly and straightforward character

- The simplicity and plainness with which the methodology was conceived (by optimising information, using simple sentences, and adopting a simple layout) was one of the topics more deeply approached during the validation exercise. Although it was conceived to be simple and plain from the start, the application of the methodology to the retrofitting proposal to Poveiros Square showed that there were still some aspects to amend. The discussions held with practitioners/experts and the application of the methodology to the development of the proposal resulted in a further condensation of information to the essential, shortening of sentences, and simplification of the adopted terminology. The layout of the methodology was an exception since it was considered straightforward from the start.

Flexibility

- The flexibility with which the methodology was conceived was confirmed by the capacity of adapting it to the creative freedom of the designer, to the site's local circumstances, and to specific project requirements. This adaptation made some proposed principles not to be considered, others adapted, and others added. Despite these adaptations, the work stages, structure, headings and contents of the methodology were able of prompting thoughts which allowed reaching a final proposal with the potential for significantly improving the square's microclimate.

It can then be assumed that the proposed methodology can help communicating the principles to promptly start retrofitting public spaces in compact urban areas towards more balanced microclimates during summer. The methodology may then help assisting the transition from the way urban design is currently conceived to bioclimatic urban design.

8.6.2. On the relevance of programmes of 'cool' materials and vegetation

The validation of the proposed methodology provided important conclusions on the relevance of its central issue: programmes of 'cool' materials and vegetation as a means for adapting the built environment to the substantial increase in temperature extremes brought by climate change. The simulations performed with ENVI-met were particularly useful here.

Bearing in mind the findings brought with these simulations, one main conclusion on this topic is about the role of materials and the role of vegetation. The provision of shade and evapotranspiration by vegetation and the physical, optical and moisture-related parameters of materials can be crucial parameters for the improvement of a space's microclimate. Nevertheless, the comparison between the values obtained with the ENVI-met simulations for shaded and sunlit areas and for all scenarios suggest that notwithstanding the importance of materials, vegetation can be more effective in improving a microclimate — the magnitude of reduction on the values for each considered variable was much more significant in shaded areas than in sunlit areas; the most significantly distinct values for all scenarios were achieved through the increase of vegetation and less through the change of materials. In addition, the only difference between the final scenario and current situation is the increased vegetation and, still, in shaded areas the considered climatic variables exhibited substantially lower values than in sunlit areas. The increment of vegetation *per se* seems to have been the most effective measure for the virtual improving Poveiros Square's microclimate.

It is noteworthy that the most sharply different values between current situation and the defined scenarios were for direct solar radiation and mean radiant temperature. The amount of solar radiation striking the space and therefore being placed upon people and surfaces was a direct consequence of the shade provided, or not, by trees.

This does not mean that materials are unimportant. Paving materials were also shown to have the potential to affect the square's microclimate. The results obtained with the ENVI-met simulation for scenario 3 put it into evidence. However, the undertaken simulations suggest that resurfacing is only worthwhile if materials present contrasting parameters, suggested by the results obtained for bounded gravel and asphalt. Moreover, the different tested materials had the potential for significantly affecting mean radiant temperature rather than any other considered variable. This contrasts with the capacity of vegetation to affect all variables. Vegetation has the potential to affect air temperature, relative humidity, direct solar radiation, wind speed and mean radiant temperature. Since these are the main climatic parameters commonly considered as characterising a thermal environment and therefore influencing thermal comfort both indoors and outdoors (2001, 2-45), the higher potential of vegetation for delivering the conditions offered for thermal comfort is clear.

All this substantiates the assumption that the relevance of retrofitting interventions based on programmes of ‘cool’ materials and vegetation is unquestionable. Vegetation may be, in this context, particularly effective. This assumption is further substantiated by the undertaken field survey as well as by the literature review. The importance attributed to materials and vegetation should be weighed according to the site’s characteristics and the specificity of the project. An adaptation of the proposed methodology and guide to local circumstances is consequently required at all times.

9
CONCLUSION

This research is grounded on the efforts currently being undertaken for the mitigation and adaptation of the built environment to the predicted impacts of climate change on urban areas. Fuelled by a personal concern on the urge to adapt the built environment to the impacts of climate change, this research aims to contribute to the know-how on the adaptation of the built environment to the substantial increase in temperature extremes brought by climate change, and to contribute to the consolidation of bioclimatic urban design practice, supporting urban designers.

Three assumptions have based this research:

- Climate change is unavoidable;
- Outdoor thermal comfort conditions are determinant for people's welfare and for the success of pedestrian public spaces, especially in regions with warm and hot summers;
- Retrofitting public spaces in compact urban areas through programmes of 'cool' materials and vegetation, on a bioclimatic perspective, can help adapting the built environment to the substantial increase in temperature extremes brought by climate change but there is a gap between theory and practice on this subject.

The research question has then been defined as: how to become the thermal retrofitting of public spaces in compact urban areas through 'cool' materials and vegetation, on a bioclimatic perspective, more operational? Which means questioning how to help reducing the identified gap and start, therefore, adapting the built environment to climate change.

The research was conducted in order to answer this question by hypothesising that a methodology assisting the development of thermal retrofitting proposals for public spaces (under the circumstances mentioned in last paragraph), can help reducing the identified gap and, thus, become this knowledge more operational. Envisioning the validation of this hypothesis, a methodology for the thermal retrofitting of public spaces in compact urban areas based on programmes of 'cool' materials and vegetation was proposed and tested.

The proposed methodology is grounded on the literature review and on the direct contact with practitioners and scholars from expertise fields concurring to bioclimatic urban design. Its development was focused foremost on its capacity to guide in a simple and quick way through the development of retrofitting proposals based on 'cool' materials and vegetation. The aim was to combine a good level of technical feasibility with attractiveness to practitioners. In this sense, the involvement of practitioners and scholars was of an utmost importance.

The testing of the methodology was made through its application to one of the spaces selected as case study which was shown, by the undertaken field survey, to possess poor outdoor thermal comfort conditions, and thus pattern of use, due to the nature of its paving materials and amount of vegetation. This simulation exercise, followed by practitioners/experts on public space building and quantified through a microscale climate model, allowed concluding that the proposed methodology is able of meeting the objectives of this research.

More than on a personal perspective, the potential of the proposed methodology to achieve the objectives of this research was validated by the consulted entities and, especially, by the microscale climate model. The contact with the mentioned entities allowed continuously developing the methodology. This was an ongoing validation process anchored in the sequence of steps encompassed by the methodology. All contacted entities have expressed their acknowledgment of the robustness, usefulness, and attractiveness of the methodology.

The guide, encompassed by the methodology, is a web-based tool available at http://www.budsum.com/. It was conceived for help specifying programmes of ‘cool’ materials and vegetation but its usefulness was spontaneously referred by many consulted entities as being much broader: the guide, being a quick-access and simple, web-based and easily accessible tool, can constitute a valuable source of information for raising awareness and educating for bioclimatic urban design and for the adaptation of the built environment to climate change. Some entities mentioned how useful the methodology could be for training sessions within municipalities so that best practices on adaptation of public spaces to climate change could start being met since in many cases there is a will to do it but no available straightforward and quick source of information. The proposed methodology, and within it especially the guide, was considered to be a useful way of help overcoming this difficulty.

Many entities have actually demonstrated enthusiasm on the methodology due to the opportunities it opens for the prompt adaptation of compact urban areas to climate change, and for the inclusion of bioclimatic urban design principles into current practice of urban design. This inclusion was considered to support designers, decision-makers, and the broad community.

The simulations performed with the microscale climate model showed how the development of the methodology was conducted in the appropriate direction. These simulations provided valuable insights on the capacity the methodology possesses of guiding a retrofitting intervention towards more thermally-balanced microclimates. It was shown for all microclimatic variables that the final result of applying the methodology to the retrofitting of Poveiros Square led to an improvement of the conditions offered for thermal comfort. The obtained values were significantly close to those measured during the field survey at São Lázaro Garden, a contiguous public space considered by the majority of users as comfortable during summer.

The methodology allows weighing the potential for microclimatic improvement entailed in a given programme of ‘cool’ materials and vegetation alongside environmental impacts, cost, and impacts of site works on the normal functioning of the site.

The final scenario of improvement for Poveiros Square, through the use of the methodology, creates shaded areas with the potential to reduce air temperature, to increase relative humidity within a comfort zone, to widen the range of direct solar radiation to much lower values, to keep wind speed at comfortable levels, and to significantly reduce mean radiant temperature. This can improve the conditions offered for outdoor thermal comfort at the square and, thus, improve its microclimate within 10 years.

The environmental impacts of the solution are low since the pre-existent paving is kept and the building operations are restricted to building few flowerbeds, installing the planting scheme and associated drainage infrastructures, repositioning some urban furniture items, and installing lamp posts.

With respect to cost, according to the prepared estimate, the final proposal of improvement is likely to have an associated cost of 23.744.43€ which was considered by the consulted practitioners/experts and the ‘client’ as perfectly reasonable.

The time required for installation was estimated to be 30 working days, 45 at maximum. This period of time was considered to perfectly acceptable. In addition, the installation of building site structures and the definition of a safety perimeter around the flowerbeds’ areas are the only foreseeable impacts on the site’s normal functioning and appearance.

It became clear that a significant improvement of the square’s microclimate, within clearly acceptable costs and installation period, and with few disruptions on the site’s normal functioning could be achieved through the use of the proposed methodology.

The undertaken field survey also provided important insights on the validity of the methodology by showing that two public spaces can present significantly different microclimates and thus usage patterns, even when side by side, depending on the nature of the facing materials and on the level of vegetation. Beyond the literature review, this was the clearest sign that conceiving a methodology focused on facing materials and vegetation and on compact urban areas was valid. The subsequent development and validation of the methodology provided the final evidences.

The development of the proposal for Poveiros Square showed the flexibility of the methodology to the creative freedom of designers and to specific project requirements. The range of proposed principles does not need to be fully approached for achieving a successful proposal. All principles convey good practices for improving the microclimate of outdoor public spaces.

In summary, the proposed methodology possesses six advantages:

- Assist the whole development of urban design retrofitting schemes committed with the improvement of the microclimate of outdoor public spaces within compact urban areas;
- Weighing the potential for microclimatic improvement entailed in a given programme of ‘cool’ materials and vegetation alongside environmental impacts, cost, and impacts of site works on the normal functioning of the site;
- Contribute to the global quality of a space by mingling common and bioclimatic urban design principles;
- Being user-friendly and straightforward by presenting optimised information, simple sentences, and a simple layout;
- Being flexible to the creative freedom of designers and specific project requirements;
- Inform the design activity but also decision-making and the broad community since it can be a straightforward and quick source of information.

It is concluded that the proposed methodology for the thermal retrofitting of public spaces in compact urban areas based on programmes of ‘cool’ materials and vegetation, by assisting the improvement of urban microclimates in a simple way, presents the ability to become a useful tool contributing to the adaptation of the built environment to the impacts of climate change and to the consolidation of bioclimatic urban design practice.

This research proved that a methodology assisting the development of thermal retrofitting proposals for public spaces in compact urban areas based on 'cool' materials and vegetation, on a bioclimatic perspective, can help becoming this knowledge more operational.

Finally, this thesis contributes to:

- **The know-how on the adaptation of the built environment to the substantial increase in temperature extremes brought by climate change;**
- **The consolidation of bioclimatic urban design practice;**
- **Meeting the sustainable city goals;**
- **Undertaking a successful pedestrianisation of urban areas in regions with warm and hot summers.**

The sooner the strategies conveyed by the proposed methodology are consistently addressed throughout whole urban areas the sooner the adaptation of the built environment to the substantial increase in temperature extremes brought by climate change can be achieved. It is fundamental to start designing public spaces in a climate-responsive way since «the conditions for a better future need to start being thought and built currently so that when the full impacts of climate change arrive, cities are already more adapted» (Worthington, 2009; 8).

At a time when knowledge on the bioclimatic urban design field is conveniently structured through a consistent body of studies developed in the past few decades, it is now important to consolidate bioclimatic urban design practice. It is fundamental to place bioclimatic urban design at the centre of the debate on public space and to fuel an ever-growing concern about the quality of life and health of urban populations in a climate change scenario.

Future research

This research paved the way for a prompt adaptation of the built environment to the impacts of climate change and simultaneously to the consolidation of bioclimatic urban design practice, positively valued by experts and a microscale climate model. Its development suggested three lines of possible future research: validating the methodology in a real situation; making a microclimatic monitoring more operational; and making the use of microscale climate models more operational.

Validating the methodology in a real situation

Notwithstanding its potential, the proposed methodology requires further validation in building terms. The impossibility of undertaking an actual retrofitting intervention shed light on the importance of microscale climate models but also of future researches to assess and improve the robustness, usefulness, and attractiveness of the proposed methodology by subjecting it to the application to a real public space project, from the outset to handover to final beneficiaries.

The undertaken simulation was, say, a first stage of validation of the methodology, addressing the Preparation and Design stages. The two final stages, Construction and Use, can only be validated in practice. The potentialities and constraints of the methodology during these stages should be determined. Building and maturation with time and use are fundamental for assessing the degree of success of a space. Future research could therefore be undertaken on this subject as a way of further developing the methodology.

Making a microclimatic monitoring more operational

The microclimatic characterisation of a space is crucial for understanding the conditions offered for thermal comfort and, thereby, for determining the quality and quantity of the corrective measures needed for improving a space's microclimate. Ideally, these should be done through a portable meteorological station. However, this procedure can be rather time-consuming, involve the acquisition of expensive instruments, and require good knowledge on the use of the instruments. The whole process may be rather intricate. Variable outdoor climatic conditions may also bring difficulties.

Future research could therefore be taken on how to make a microclimatic monitoring more operational. A suitable and potentially appealing route of research could be the development of an application for personal gadgets such as cell phones or tablets. This would open the possibility to easily and quickly gather the necessary microclimatic data to start a project. It would also involve less costs and technical skills for handling instruments as it would only require a download to a gadget. This was mentioned by some of the scholars contacted during the development of the methodology.

Making the use of microscale climate models more operational

One of the main difficulties found in the development of the proposal of improvement for Poveiros Square was the use of the microscale climate model. The difficulty of use is not restricted to this model only. The high value of microscale climate models for the development of bioclimatic urban design proposals ends up being hindered by their difficulty of use to designers. These models involve high skills on computing and, when these are absent amongst a design team, their use may be rather time-consuming. Faced to their value, future research could then be undertaken to improve the ease with which these tools can be accessed by designers.

REFERENCES

AAVV (2001). *A Green Vitruvius - Princípios e Práticas de Projecto para uma Arquitectura Sustaentável*. Ordem dos Arquitectos, Lisboa.

Addington, M. and Schodek, D. (2005). *Smart Materials and Technologies for the architecture and design professions*. Architectural Press, Oxford.

Aggelakoudis, A. and Athanasiou, M. (2005). *Thermal comfort study of occupants in University of Patras*. International Conference Passive and Low Energy Cooling for the Built Environment, May 2005, Santorini.

Ahmed, K. S. (2003). *Comfort in urban spaces: defining the boundaries of outdoor thermal comfort for the tropical urban environments*. Energy and Buildings, 35: 103–110.

Akbari, H. (2002). *Shade trees reduce building energy use and CO_2 emissions from power plants*. Environmental Pollution, 116: 119–S126.

Akbari, H. (2005). *Energy Saving Potentials and Air Quality Benefits of Urban Heat Island Mitigation*. Lawrence Berkeley National Laboratory, Berkeley.

Akbari, H. and Konopacki, S. (2004). *Energy effects of heat-island reduction strategies in Toronto, Canada*. Energy, 29: 191–210.

Akbari, H. and Konopacki, S. (2005). *Calculating energy-saving potentials of heat-island reduction strategies*. Energy Policy, 33: 721–756.

Akbari, H., Davis, S., Dorsano, S., Huang, J. and Winett, S. (1992). *Cooling our Communities—A Guidebook on Tree Planting and Light Colored Surfacing*. Lawrence Berkeley Laboratory, Berkeley.

Akbari, H., Menon, S. and Rosenfeld, A. (2007). *Global Cooling: Effect of Urban Albedo on Global Temperature*. 2nd PALENC & 28th AIVC Conference, 27th to 28th September 2007, Crete.

Akbari, H., Pomerantz, M. and Taha, H. (2001). *Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas*. Solar Energy, 70(3): 295-310.

Alcoforado, M. J. (1988). *O clima da região de Lisboa. Vento, insolação e temperatura*. PhD Thesis, Universidade de Lisboa.

Alexandri, E. (2005*). Investigations into Mitigating the Heat Island Effect through Green Roofs and Green Walls*. PhD Thesis, Cardiff University.

Alexandri, E. and Jones, P. (2008). *Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates*. Building and Environment, 43(4): 480-493.

Ali-Toudert, F. and Mayer, H. (2007a). *Numerical study on the effects of aspect ratio and orientation of an urban street canyon on outdoor thermal comfort in hot and dry climate*. Building and Environment, 41(3): 94-108.

Ali-Toudert, F. and Mayer, H. (2007b). *Thermal comfort in an east–west oriented street canyon in Freiburg (Germany) under hot summer conditions*. Theoretical and Applied Climatology, 87: 223-237.

Alves, F. (2003). *Avaliação da qualidade do espaço público. Proposta metodológica*. Fundação Calouste Gulbenkian, Fundação para a Ciência e a Tecnologia, Lisboa.

Alves, F., Cortesão, J., Patterson, J. and Góis, J. (2009). *Investigation of Potential Bioclimatic Interventions for a Portuguese City*. ISOCARP Review, 05: 160-174.

Andrade, H. (2003). *Bioclima Humano e Temperatura do Ar em Lisboa*. PhD Thesis, Universidade de Lisboa.

Andrade, H. (2005). *O Clima Urbano - Natureza, Escalas de Análise e Aplicabilidade*. Finisterra, XL 80: 67-91.

Arnfield, A. J. (2003). *Two decades of urban climate research: A review of turbulence, exchanges of energy and water, and the urban heat island*. International Journal of Climatology, 23: 1-26.

Asaeda, T., Ca, V. and Wake, A. (1996). *Heat storage of pavement and its effect on the lower atmosphere*. Atmospheric Environment 30(3): 413-427.

ASHRAE (2005). *ASHRAE Handbook of Fundamentals*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta.

ASHRAE (2010). *ANSI/ASHRAE Standard 55-2010, Thermal Environmental Conditions for Human Occupancy*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta.

Ashworth, A. and Hogg, K. (2000). *Added Value in design and Construction*. Pearson Education Limited, Harlow.

Bell, D. and Jayne, M. (2003). *Design-led' Urban Regeneration: a Critical Perspective. Local Economy* 18(2): 121–134.

Benevolo, L. (1975). *Corso di disegno - La descrizione dell'ambiente*. Editori Laterza, Bari.

Berdahl, P., Akbari, H. Jacobs, J. and Klink, F. (2008). *Surface roughness effects on the solar reflectance of cool asphalt shingles*. Solar Energy Materials & Solar Cells, 92: 482–489.

Berge, B. (2000). *The Ecology of Buildings Materials*. Architectural Press/Elsevier, Oxford.

Blyth, A. and Worthington, J. (2001). *Managing the brief for better design*. Spon Press, London.

Borodinecs, A. and Kreslins, A. (2008). *Reduction of cooling and heating loads using building envelopes with controlled thermal resistance* (NCEUB, ed.). Proceedings of Conference: Air Conditioning and the Low Carbon Cooling Challenge, 27th to 29th July 2008, Network for Comfort and Energy Use in Buildings, London.

Bragança, L. (Ed.) (2007). *COST C16 - Improving the Quality of Existing Urban Building Envelopes - Facades and Roofs*. IOS Press BV, Amsterdam.

Brandão, P., Carrelo, M. and Águas, S. (2002). *O chão da cidade. Guia de avaliação do design de espaço público*. Centro Português de Design, Lisboa.

Brebbia, C., Ferrante, A. et al. Eds. (2000). *The Sustainable City. Urban Regeneration and Sustainability*. WIT Press, Southampton.

Bretz, S., Akbari, H., Rosenfeld, A. and Taha, H. (1992). *Implementation of Solar-Reflective Surfaces: Materials and Utility Programs*. Lawrence Berkeley Laboratory, Berkeley.

Bretz, S., Akbari, H. and Rosenfeld, A. (1998). *Practical Issues for Using Solar-Reflective Materials to Mitigate Urban Heat Islands*. Atmospheric Environment, 32(1): 95-101.

Briscoe, G. (1988). *The Economics of the Construction Industry*. Mitchell Publishing Company Limited, London

Brown, P., Ed. (2009). *Hallmarks of a sustainable city*. Commission for Architecture and the Built environment, London.

Brown, S. A. (2001). *Communication in the design process*. Spon Press, London.

Brownell, B., Ed. (2010). *Transmaterial 3 - A catalog of materials that redefine our physical environment*. Princeton Architectural Press, New York.

Brownhill, D. and Rao, S. (2002). *A sustainability checklist for developments. A common framework for developers and local authorities*. BRE Centre for Sustainable Construction, London.

CABE (2001). *The value of urban design*. Thomas Telford Publishing, London.

CABE (2007). *Sustainable design, climate change and the built environment*. Commission for Architecture and the Built Environment, London.

CABE, Ed. (2009). *Grey to Green. How we Shift Funding and Skills to Green our Cities*. Commission for Architecture and the Built Environment, London.

Calthorpe, P. (2011). *Urbanism in the age of climate change*. Island Press, Washington.

Carmona, M., de Magalhães, C. and Edwards, M. (2002). *Stakeholder Views on Value and Urban Design*. Journal of Urban Design, 7(2): 145-169.

Carr, S., Francis, M., Rivlin, L. and Stone, A. (1995). *Public Space*. Cambridge University Press, New York.

Carruthers, J. and Ulfarsson, G. (2002). *Fragmentation and Sprawl: Evidence from Interregional Analys*is. Growth and Change, 33: 312-340.

Castells, M. (1984). *Problemas de Investigação em Sociologia Urbana*. Editorial Presença, Lisboa.

Çelik, Z., Favro, D., Ingersoll, R. and Kostof, S. (Eds.) (1994). *Streets. Critical perspectives on Public Spaces*. University of California Press, California.

Chatzikostis, D. (2002). *An investigation of the effect of small-scale landscaping on human thermal comfort*. MsC Thesis, Cardiff University.

Choay, F. (1965). *L'urbanisme*. Utopies et réalités. Éditions du Seuil, Paris.

Cladera, J. R. (1995). *Rehabilitación urbana. Analisis comparado de algunos países de la Unión Europea*. Ministerio de Obras Públicas, Transportes y Medio Ambiente, Madrid.

Colquhoun, I. (1995). *Urban Regeneration - An International Perspective*. B.T. Batsford, Ltd., London.

Commission of the European Communities (2007). *Limiting Global Climate Change to 2 degrees Celsius*. MEMO/07/16. Brussels.

Commission of the European Communities (2009). *White Paper - Adapting to climate change: Towards a European framework for action*. COM(2009) 147. Brussels.

Corbett, N. (2004). *Transforming cities - Revival in the square*. RIBA Enterprises Ltd., London.

Costa, A. (2001). *Sociologia*. Quimera Editores, Coimbra.

Couch, C., Fraser and C. Percy, S. Eds. (2003). *Urban Regeneration in Europe*. Blackwell Science, Oxford.

Couch, C., Sykes, O. and Börstinghaus, W. (2011). *Thirty years of urban regeneration in Britain, Germany and France: The importance of context and path dependency*. Progress in Planning, 75: 1-52.

Cuadrat, J. and Pita, M. (2009). *Climatología*. Ediciones Cátedra, Madrid.

Cullen, G. (1961). *Townscape*. The Architectural Press, London.

Dimitrova, E. (2007). *Testing PETUS: Expectations and Outcomes of the 'Theory-Practice' Dialogue on Urban Sustainability*. Indoor and Built Environment, 16(3): 216-225.

Dimoudi, A. and Nikolopoulou, M. (2003). *Vegetation in the urban environment: microclimatic analysis and benefits*. Energy and Buildings, 35: 69-76.

Domone, P. and Illston, J. Eds. (2010). *Construction Materials. Their nature and behaviour*. Spon Press, New York.

Dufour, A. and Candas, V. (2007). *Ageing and thermal responses during passive heat exposure: sweating and sensory aspects*. European Journal Applied Physiology, 100: 19–26.

Dumreicher, H. and Kolb, B. (2008). *Place as a social space: Fields of encounter relating to the local sustainability process*. Journal of Environmental Management, CCCA(2): 317-328.

Edwards, B. (2004). *Guía básica de la sostenibilidad*. Editorial Gustavo Gili, SA., Barcelona.

Eliasson, I., Knez, I., Westerberg, U., Thorsson, S. and Lindberg, F. (2007). *Climate and behaviour in a Nordic city*. Landscape and urban planning, 82(4): 363-363.

Elisavet, K. (2001). *Effects of vegetation on cooling urban environments - Special reference to Mediterranean cities*. MsC Thesis, University of Wales.

Elizabeth, L. and Adams, C. Eds. (2000). *Alternative Construction. Contemporary Natural Building Methods*. John Wiley & Sons, Inc., New York.

Emmitt, S., Prins, M. and Otter, A. Eds. (2009). *Architectural Management. International research & practice*. Wiley-Blackwell, Oxford.

English Partnerships and the Housing Corporation (2007). *Urban Design Compendium 2: Delivering Quality Places*. English Partnerships and the Housing Corporation, London.

Ercan, M. (2011). *Challenges and conflicts in achieving sustainable communities in historic neighbourhoods of Istanbul*. Habitat International, 35(2): 295-306.

European Commission (1996). *European Sustainable Cities Report*, Brussels.

European Forum for Architectural Policies (2008). *Ljubljana Declaration on Urban Regeneration & Climate Change*. Brussels.

Evans, R. (1997). *Regenerating town centres*. Manchester University Press, Manchester.

Everett, A. (1994). *Materials*. Pearson Education Limited, London.

Fanger, P. O. (1972). *Thermal Comfort: analysis and applications in environmental engineering*. McGraw-Hill, New York.

Gaines, J. and Jäger, S. (2009). *Albert Speer & Partner - A Manifesto for Sustainable Cities*. Prestel Verlag, Munich.

Gaitani, N., Mihalakakou, G. and Santamouris, M. (2007). *On the use of bioclimatic architecture principles in order to improve thermal comfort conditions in outdoor spaces*. Building and Environment, 42(1): 317-324.

García, A. G., Ed. (2008). *Espacio público, ciudad y conjuntos históricos. PH cuadernos*. Instituto Andaluz del Patrimonio Histórico, Seville.

Gehl, J. (2010). *Cities for people*. Island Press, Washington.

Gehl, J. (2011). *Life Between buildings. Using Public Space*. Island Press, Washington.

Geiger, R. (1950). *The Climate Near the Ground*. Harvard University Press, Massachusetts.

Giedion, S. (1967). *Space, Time and Architecture*. Harvard University Press, Massachusetts.

Girardet, H. (2007). *Criar Cidades Sustentáveis*. Edições Sempre-em-Pé, Águas Santas.

Givoni, B. (1998). *Climate considerations in building and urban design*. John wiley & Sons, Inc., New York.

Givoni, B., Noguchi, M., Saaroni, H., Pochter, O., Yaacov, Y., Feller, N. and Becker, S. (2003). *Outdoor comfort research issues*. Energy and Buildings, 35: 77-86.

Goedkoop, M. (1995). *The Eco-indicator 95. Final Report.* Pré Consultants, Amersfoort.

Góis, J. (2002*). Contribuição dos Modelos Estocásticos para o Estudo da Climatologia Urbana*. PhD Thesis, Universidade do Porto.

Gomez, F., Jabaloyes, J. and Vañó, E. (2004). *Green zones in the future of urban planning*. Journal of Urban Planning and Development, 130(2): 94-100.

Gore, A. (2009). *A Nossa Escolha - Um Plano para Resolver a Crise Climática*. Esfera do Caos Editores, Lisboa.

Goulding, J. and Lewis, J. (1997). *Bioclimatic Architecture*. LIOR E.E.I.G., Dublin.

Grossop, C. and Alves, F. Eds. (2009). *ISOCARP Review 05 - Low Carbon Cities*. International Society of City and Regional Planners, Porto.

Gruneberg, S. L. (1997). *Construction Economics. An Introduction*. Macmillan Press Ltd., London.

Gulyas, A., Unger, J. and Matzarakis, A. (2006). *Assessment of the microclimatic and human comfort conditions in a complex urban environment: Modelling and measurements*. Building and Environment, 41(12): 1713-1722.

Halewood, J. and Wilde, P. (2008). *Simulation-based Assessment of the Prospects of Cool Paints in the Built Environment in the UK*. PLEA 2008 – 25th Conference on Passive and Low Energy Architecture, 22nd to 24th October 2008, Dublin.

Hall, K. (2005). *The Green Building Bible*. Green Building Press, Llandysul.

Handley, J. and Carter, J. (2006a). *Adaptation strategies for the climate change in the urban environment. ASCCUE report to the National Steering Group*. University of Manchester, Manchester.

Handley, J. and Carter, J. (2006b). *ASCCUE Draft final report to the National Steering Group*. University of Manchester, Manchester.

Hart, M. A. and Sailor, D. J. (2009). *Quantifying the influence of land-use and surface characteristics on spatial variability in the urban heat island*. Theoretical and Applied Climatology, (95): 397–406.

Hausladen, G., Saldanha, M. and Liedl, P. (2008). *ClimateSkin. Building-skin Concepts that Can Do More with Less Energy*. Birkhäuser, Basel.

Hayward, R. and McGlynn, S. Eds. (1993). *Making better places. Urban design now*. Joint Centre for Urban Design, Oxford.

Healey, P. Ed. (1995). *Managing Cities. The new urban context*. John Wiley & Sons, Chichester.

Hegger, M., Auch-Schwelk, V., Fuchs, M. and Rosenkranz, T.(2006). *Construction Materials Manual*. Birkhäuser, Basel.

Hertzberger, H. (2009). *Lessons for Students in Architecture*. 010 Publishers, Rotterdam.

Higueras, E. (2006). *Urbanismo Bioclimático*. Editorial Gustavo Gili, SL., Barcelona.

Hillebrandt, P. M. (2000*). Economic Theory and the Construction Industry*. Macmillan Press Ltd., London.

Hillier, B. and Hanson, J. (1984). *The Social Logic of Space*. Cambridge University Press, Cambridge.

Hontelez, J., Ed. (2010). *Future of EU Environmental Policy: Towards the 7th Environmental Action Programme*. European Environmental Bureau, Brussels.

Höppe, P. (2002). *Different aspects of assessing indoor and outdoor thermal comfort*. Energy and Buildings, 34(6): 661.

Hughes, G. (1999). *Urban revitalization: the use of festive time strategies*. Leisure Studies, 18: 119–135.

Hwang, R.-L. and Chen, C.-P. (2010). *Field study on behaviors and adaptation of elderly people and their thermal comfort requirements in residential environments*. Indoor Air, 20: 235–245.

IPCC (2012). *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge and New York.

ISO (1998). *ISO 7726. Ergonomics of the thermal environment - Instruments for measuring physical quantities*. International Organization for Standardization, Geneva.

ISO (2001a). *BS EN ISO 10551:2001. Ergonomics of the thermal environment - Assessment of the influence of the thermal environment using subjective judgement scales*. International Organization for Standardization, Geneva.

ISO (2001b). *BS EN ISO 7726:2001. Ergonomics of the thermal environment - Instruments for measuring physical quantities*. International Organization for Standardization, Geneva.

ISO (2005). *ISO 7730. Ergonomics of the thermal environment — Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria*. International Organization for Standardization, Geneva.

Jackson, J. B. (1994). *A Sense of Place, a Sense of Time*. Yale University Press, New Haven.

Jacobs, A. B. (1995). *Great Streets*. MIT Press, Massachusetts.

Jacobs, J. (1961). *The death and life of great American cities. The failure of town planning*. Peregrin Books, New York.

Jenks, M., Burton, E. Jenks, M. and Williams, K. Eds. (1996). *The Compact City - A Sustainable Urban Form?* E & FN Spon, Oxford.

Jensen, J. and Elle, M. (2007). *Exploring the Use of Tools for Urban Sustainability in European Cities*. Indoor and Built Environment, 16(3): 226-234.

Jones, B. (2001). *Capabilities and Limitations of Thermal Models*. Proceedings of the Windsor Conference, 5th to 8th April 2001, Windsor.

Jones, P. (2007). *Practical Evaluation Tools for Urban Sustainability*. Indoor and Built Environment, 16(3): 201-203.

Jones, P. and Evans, J. (2008). *Urban Regeneration in the UK*. SAGE Publications Ltd., London.

Jones, P. and Patterson, J. (2007). *The Development of a Practical Evaluation Tool for Urban Sustainability*. Indoor and Built Environment, 16(3): 255-272.

Jones, P., Pinho, P., Patterson, J. and Tweed, C. Eds. (2009). *European Carbon Atlas*. Welsh School of Architecture, Cardiff University, Cardiff.

Karlessi, T., Santamouris, M., Synnefa, A., Assimakopoulos, D., Didaskalopoulos, P. and Apostolakis, K. (2011). *Development and testing of PCM doped cool colored coatings to mitigate urban heat island and cool buildings*. Building and Environment, 46: 570-576.

Kauffman, J. (2006). *To LEED or Not to Lead*. Log, (8): 13-20.

Kiri, P., Hyett, G. and Binions, R. (2010). *Solid state thermochromic materials*. Advanced Materials Letters, 1(2): 86-105.

Klooster, T. (2009). *Smart Surfaces and their Application in Architecture and Design*. Birkhäuser, Berlin.

Knez, I. and Thorsson, S. (2006). *Influences of culture and environmental attitude on thermal, emotional and perceptual evaluations of a public square*. International Journal of Biometeorology, 50(5): 258-268.

Kolokotroni, M., Giannitsaris, I. and Watkins, R. (2006). *The effect of the London urban heat island on building summer cooling demand and night ventilation strategies*. Solar Energy, 80(4): 383-392.

Kottek, M., Grieser, J., Beck, I., Rudolf, B. and Rubel, R. (2006). *World Map of the Köppen-Geiger climate classification updated*. Meteorologische Zeitschrift, 15(3): 259-263.

Krier, L. (2006). *Classicus and Vernaculus*. Log, (8): 25-30.

Krier, R. (1979). *Urban Space*. Academic Editions, London.

Krüger, E. and Rossi, F. (2011). *Effect of personal and microclimatic variables on observed thermal sensation from a field study in southern Brazil*. Building and Environment, 46: 690-697.

Lamas, J. (1992). *Morfologia Urbana e Desenho da Cidade*. Fundação Calouste Gulbenkian/JNICT, Textos Universitários de Ciências Sociais e Humanas, Lisboa.

Lefebvre, H. (1974). *La Production de L'espace*. Éditions Anthropos, Paris.

Lenzholzer, S. (2006). *Conceptualizing Urban Places as a "Fourth Skin"*. PLEA 2006 - The 23rd Conference on Passive and Low Energy Architecture, 7th to 8th September 2006, Geneva, Switzerland.

Lenzholzer, S., Koh, J. (2010). *Immersed in microclimatic space: Microclimate experience and perception of spatial configurations in Dutch squares*. Landscape and Urban Planning 95, 1–15.

Lenzholzer, S., Wulp, N. (2010). *Thermal Experience and Perception of the Built Environment in Dutch Urban Squares*. Journal of Urban Design 15 (3), 375–401.

Lin, T., Dear, R., Hwang, R-L. (2011). *Effect of thermal adaptation on seasonal outdoor thermal comfort.* International Journal of Climatology 31: 302-312.

Llewelyn-Davies (2000). *Urban Design Compendium 1: Urban Design Principles*. English Partnerships and the Housing Corporation, London.

Lstiburek, J. (2002). *Systems Engineering Approach to Development of Advanced Residential Buildings - Relative Humidity*. Indoor Air Conference, 23rd April 2002, Austin.

Lynch, K. (1971). *L'image de la Cité*. Dunod, Paris.

Lynch, K. (1981). *Good City Form*. The MIT Press, Massachusetts.

Madureira, H. (2000). *Processos de Transformação da Estrutura Verde no Porto*. MsC Thesis, Universidade do Porto.

Mann, T. (2004). *Time Management for architects and designers: Challenges and remedies*. W. W. Norton & Company, New York.

Manseau, A. and Seaden, G. Eds. (2001). *Innovation in Construction. An international review of public policies*. Spon Press, London.

Marcus, C. C. and Francis, C. Eds. (1998). *People Places: Design Guidelines for Urban Open Space*. New York, John Wiley & Sons, Inc.

Marincic, J., Villa, O. (2006). *Designing Outdoor Spaces with Comfort-Ex*. International Workshop on Energy Performance and Environmental 1 - Quality of Buildings, Milos.

Marques-Clarke, M. (1998). *An Appraisal of Urban Regeneration in Bairro Alto, Lisbon: With Comparative Case Studies in Temple Bar, Dublin and Merchant City, Glasgow*. PhD Thesis, University of Wales.

Mayer, H., Höppe, P. (1987). *Thermal Comfort of Man in Different Urban Environments*. Theoretical and Applied Climatology 38, 43-49.

McCartney, K. J., Nicol, J. F. (2002). *Developing an Adaptive Control Algorithm for Europe*. Energy and Buildings 34, 623–635.

McHarg, I. (1992). *Design with Nature*. John Wiley & Sons, New York.

McIntyre, D. A. (1976). *Thermal Sensation. A Comparison of Rating Scales and Cross Modality Matching*. International Journal of Biometeorology 20 (4), 295-303.

Mean, M., Tims, C. (2005). *People Make Places: Growing The Public Life of Cities*. Demos, London.

Meerow, A. W., Black, R. J. (1991). *Landscaping to Conserve Energy: A Guide to Microclimate Modification*. Energy Information Handbook, Energy Information Document 1028, University of Florida.

Meiss, P. (1990). *De la Forme au Lieu - Une Introduction a l'Etude de l'Architecture*. Presses polytechniques et universitaires romandes, Lausanne.

Mendonça, P. (2005). *Habitar Sob uma Segunda Pele - Estratégias para a Redução do Impacto Ambiental de Construções Solares Passivas em Climas Temperados*. PhD Thesis, Universidade do Minho.

Menezes, J., Farinha, J. (1983). *O Papel das Áreas Pedonais na Renovação Urbana*. Laboratório Nacional de Engenharia Civil, Lisboa.

Michau, E. (1998). *A Poda das Árvores Ornamentais*. Fapas, Porto.

Miozzo, M., Dewick, P. (2004). *Innovation in Construction. A European Analysis*. Edward Elgar Publishing Limited, Cheltenham.

Monteiro, A. (1997). *O Clima Urbano do Porto - Contribuição para a Definição de Estratégias de Planeamento e Ordenamento do Território*. Fundação Calouste Gulbenkian, Junta Nacional de Investigação Científica e Tecnológica, Porto.

Moor, M., Rowland, J. (2006). *Urban Design Futures*. Routledge, New York.

Moughtin, C. (1992). *Urban Design: Street and Square*. Butterworth Architecture, Oxford.

Mumford, L. (1961). *The City in History. Its Origins, its Transformations and its Prospects*. Penguin Books, London.

Murray, M. J. (2004). *The Spatial Dynamics of Postmodern Urbanism: Social Polarisation and Fragmentation in São Paulo and Johannesburg*. Journal of Contemporary African Studies 22 (2).

Myers, D. (2004). *Construction Economics. A new approach*. Spon Press, Wiltshire.

Nagara, K., Shimoda, Y. et al. (1996). *Evaluation of the thermal environment in an outdoor pedestrian space*. Atmospheric Environment 30 (3), 497-505.

Nelson, K., Powers, M. (2011). *Implementing Designing out Waste in Your Company*. *Guidance for Design Practices*. WRAP, Banbury.

Nikolopoulou, M. (1998). *Thermal comfort in outdoor urban spaces*. PhD Thesis, University of Cambridge.

Nikolopoulou, M., Baker, N. and Steermers, K. (2001). *Thermal Comfort in Outdoor Urban Spaces: Understanding the Human Parameter*. Solar Energy Vol. 70 (3), 227-235.

Nikolopoulou, M., Ed. (2004). *Designing Open Spaces in the Urban Environment: A Bioclimatic Approach. RUROS: Rediscovering the Urban Realm and Open Spaces*. Centre for Renewable Energy Sources CRES, Greece.

Nikolopoulou, M., Lykoudis, S. (2006). *Thermal Comfort in Outdoor Urban Spaces: Analysis Across Different European Countries*. Building and Environment 41, 1455-1470.

Nikolopoulou, M., Steemers, K. (2003). *Thermal Comfort and Psychological Adaptation as a Guide For Designing Urban Spaces*. Energy and Buildings 35: 95-101.

Norberg-Schulz, C. (1986). *Genius Loci*. Grupo Editoriale Electa, Milan.

Novieto, D., Zhang, Y. (2010). *Towards thermal comfort prediction for the older population: a review of aging effect on the human body*. Proceedings of Conference: IESD PhD Conference: Energy and Sustainable Development, 21st May 2010, Leicester.

Ochoa, J., Marincic, I. and Villa, H. (2006). *Designing Outdoor Spaces with COMFORT-EX*. International Workshop on Energy Performance and Environmental 1 - Quality of Buildings, Milos.

Oke, T. R. (1987). *Boundary Layer Climates*. Routledge, London.

Olgyay, V. (1963). *Design with Climate. Bioclimatic Approach to Architectural Regionalism*. Princeton University Press, New Jersey.

Olgyay, V., Olgyay, A. (1957). *Solar Control & Shading Devices*. Princeton University Press, New Jersey.

Papadakis, G., Tsamis, P. and Kyritsis, S. (2001). *An Experimental Investigation of the Effect of Shading with Plants for Solar Control Of Buildings*. Energy and Buildings 33 (8), 831-836.

Peretti, G., Marino, D. and Montacchini, E. (2005). *Green Areas in Open Urban Spaces*. International Conference Passive and Low Energy Cooling for the Built Environment, May 2005, Santorini.

Plass, N., Kaltenegger, I. (2007). *Strategic and Practical Implications in Decision Making and Planning for Sustainability*. Indoor and Built Environment 16 (3), 204-215.

Plumley, H. J. (1977). *Design of Outdoor Urban Spaces for Thermal Comfort*. Proceedings of Conference on Metropolitan Physical Environment, 25th to 29th August 1975, New York.

Pomerantz, M., Akbari, H., Chen, A., Taha, H. and Rosenfeld, A. (1997). *Paving Materials for Heat Island Mitigation*. Lawrence Berkeley National Laboratory, Berkeley.

Pomerantz, M., Akbari, H., Berdahl, P., Konopacki, S., Taha, H. and Rosenfeld, A. (1999). *Reflective Surfaces for Cooler Buildings and Cities*. Philosophical Magazine Part B 79 (9),1457-1476.

Pomerantz, M., Akbari, H. Chang, S., Levinson, R., Pon, B. (2003). *Examples of Cooler Reflective Streets for Urban Heat-Island Mitigation: Portland Cement Concrete and Chip Seals*. Lawrence Berkeley National Laboratory, Berkeley.

Prado, R., Ferreira, F. (2005). *Measurement of Albedo and Analysis of its Influence the Surface Temperature of Building Roof Materials*. Energy and Buildings 37, 295–300.

Pressman, A. (2006). *Business Strategies and Case Studies in Architecture*. John Wiley & Sons, New Jersey.

Ritchie, A., Thomas, R. Eds. (2009). *Sustainable urban design. An environmental approach*. Taylor & Francis, New York.

Riverside, R. (1999). *Towards an Urban Renaissance*. Urban Task Force, London.

Roberts, P., Sykes, H. Eds. (2000). *Urban Regeneration. A Handbook.* SAGE Publications, London.

Romero, M. (2001). *Arquitectura Bioclimática do Espaço Público*. Editora UnB, Brasília.

Rosenfeld, A., Akbari, H., Bretz, S., Fishman, B., Kurn, D., Sailor, D., Taha, H. (1995). *Mitigation of Urban Heat Islands - Materials, Utility Programs, Updates*. Energy and Buildings 22 (3), 255-265.

Santamouris, M. (2006). *Natural Techniques to improve Indoor and Outdoor Comfort during the Warm Period – A Review* (NCEUB, ed.). Proceedings of Conference Comfort and Energy Use in

Buildings – Getting Them Right, 27th to 30th April 2006, Network for Comfort and Energy Use in Buildings, London.

Santamouris, M., Ed. (2001). *Energy and Climate in the Urban Built Environment*. James & James, London.

Santamouris, M., Papanikolaou, N., Livada, I., Koronakis, I., Georgakis, C., Argiriou, A., Assimakopoulos, D. (2001). *On the Impact of Urban Climate on the Energy Consumption for Buildings*. Solar Energy 70 (3), 201-216.

Santamouris, M., Synnefa, A., Karlessi, T. (2011). *Using advanced cool materials in the urban built environment to mitigate heat islands and improve thermal comfort conditions*. Solar Energy 85, 3085–3102.

Santos, F., Miranda, P. Eds. (2006). *Alterações Climáticas em Portugal. Cenários, Impactos e Medidas de Adaptação. Projecto SIAM II*. Lisboa, Gradiva.

Sarandeses, J., Molina, M. et al. (1990). *Espacios públicos urbanos. Trazado, urbanización y mantenimiento*. Ministerio de Obras Públicas y Urbanismo - Centro de Publicaciones, Madrid.

Schmid, A. L. (2005). *A Idéia de Conforto. Reflexões sobre o Ambiente Construído*. Pacto Ambiental, Curitiba.

Shashua-Bar, L., Hoffman, M. (2000). *Vegetation as a Climatic Component in the Design of an Urban Street: An Empirical Model for Predicting the Cooling Effect of Urban Green Areas with Trees*. Energy and Buildings 31 (3), 221-235.

Simpson, J. R. (2002). *Improved Estimates of Tree-Shade Effects on Residential Energy Use*. Energy and Buildings 34 (10), 1067-1076.

Sleiman, M., Ban-Weiss, G., Gilbert, H., François, D., Berdhal, P., Kirchstetter, T., destaillats, H. and Levinson, R. (2011). *Soiling of building envelope surfaces and its effect on solar reflectance—Part I: Analysis of roofing product databases*. Solar Energy Materials & Solar Cells 95, 3385–3399.

Southworth, M. (2005). *Designing the Walkable City*. Journal of Urban Planning & Development 131 (4), 246-257.

Spagnolo, J., de Dear, R. (2003). *A Field Study of Thermal Comfort in Outdoor and Semi-Outdoor Environments in Subtropical Sydney Australia*. Building and Environment (5), 721.

Stack, A., Goulding, J. and Lewis, J. (2001). *Shading Systems. Solar Shading for the European climates*. U. C. D. Energy Research Group. ENERGIE program, Dublin.

Stathopoulos, T., Wu, H., Zacharias, J. (2004). *Outdoor Human Comfort in an Urban Climate*. Building and Environment 39, 297 – 305.

Sugiyama, T., Thompson, C. (2007). *Outdoor Environments, Activity and the Well-Being of Older People: Conceptualising Environmental Support*. Environment and Planning A 39, 1943-1960.

Svensson, M. K., Eliasson, I. (2002). *Diurnal air Temperatures in Built-up Areas in Relation to Urban Planning*. Landscape and Urban Planning 61 (1), 37-54.

Swaid, H., Barel, M., Hoffman, M. (1993). *A Bioclimatic Design Methodology for Urban Outdoor Spaces*. Theoretical and Applied Climatology 48 (1), 49-61.

Synnefa, A., Karlessi, T., Gaitani, N., Santamouris, M., Assimakopoulos D. and Papakatsikas, C. (2011). *Experimental Testing of Cool Colored Thin Layer Asphalt and Estimation of its Potential to Improve the Urban Microclimate*. Building and Environment 46, 38-44.

Synnefa, A., Santamouris, M., Akbari, H. (2007). *Estimating the Effect of Using Cool Coatings on Energy Loads and Thermal Comfort in Residential Buildings in Various Climatic Conditions*. Energy and Buildings 39, 1167–1174.

Taha, H. (1997). *Urban Climates and Heat Islands: Albedo, Evapotranspiration, and Anthropogenic Heat*. Energy and Buildings 25(2), 99-103.

Taha, H., Chang, S.-c. and Akbari. H. (2000). *Meteorological and Air Quality Impacts of Heat Island Mitigation Measures in Three U.S. Cities*. Lawrence Berkeley National Laboratory, Berkeley.

Taha, H., Sailor, D. and Akbari, H. (1992). *High-Albedo Materials for Reducing Building Cooling Energy Use*. Lawrence Berkeley Laboratory, Berkeley.

Taylor, B., Guthrie, P. (2008). *The First Line of Defence: Passive Design at an Urban Scale*. Proceedings of Conference: Air Conditioning and the Low Carbon Cooling Challenge, 27th to 29th July 2008. Network for Comfort and Energy Use in Buildings, London.

Taylor, D. (2008). *Adapting Public Space to Climate Change*. Commission for Architecture and the Built Environment, London.

Taylor, M. (2007). *Community Participation in the Real World: Opportunities and Pitfalls in New Governance Spaces.* Urban Studies 44 (2), 297-317.

The Academy of Urbanism (2011). *The Freiburg Charter for Sustainable Urbanism: learning from place*. London.

Thomas, D. C. (2002). *The Transformation of Cities. Urban Theory and Urban Life*. Palgrave Macmillan, New York.

Thomas, R., Ed. (2003). *Sustainable Urban Design: An Environmental Approach.* Spon Press, London.

Thorsson, S., Lindqvist, M., Lindqvist, S. (2004). *Thermal Bioclimatic Conditions and Patterns of Behaviour in an Urban Park in G Teborg, Sweden*. International Journal of Biometeorolgy 48, 149–156.

Thwaites, K., Porta, S., Romice, O. and Greaves, M. Eds. (2007). *Urban Sustainability through Environmental Design. Approaches to Time-People-Place Responsive Urban Spaces*. Taylor and Francis, London.

Tojo, J. F. (2007). *La Ciudad y el Medio Natural*. Akal, Madrid.

Tolley, R., Lumsdon, L., Bickerstaff, K. (2001). *The Future of Walking in Europe: A Delphi Project to Identify Expert Opinion on Future Walking Scenarios*. Transport Policy 8, 307-315.

Tseliou, A., Tsiros, I., Lykoudis, S. and Nikolopoulou, M. (2010). *An Evaluation of Three Biometeorological Indices for Human Thermal Comfort in Urban Outdoor Areas under Real Climatic Conditions*. Building and Environment 45, 1346–1352.

Tunstall, G. (2006). *Managing the Building Design Process*. Butterworth-Heinemann, Oxford.

UN-Habitat (2009). *Planning Sustainable Cities. Global Report on Human Settlements 2009*. Earthscan, London.

UN-Habitat (2011). *Cities and Climate Change: Policy Directions. Global Report on Human Settlements 2011*. Earthscan, London.

Voogt, J. A., Oke, T. R. (1997). *Complete Urban Surface Temperatures*. Journal of Applied Meteorology 36, 1117-1132.

Wackernagel, M., Rees, W. (1998). *Our Ecological Footprint. Reducing Human Impact on the Earth*. New Society Publishers, Gabriola Island.

WCED (1987). *Our Common Future – Brundtland Report*. United Nations, Oslo.

Welsh Assembly Government (2009). *Planning Policy Wales: Technical Advice Note 12: Design*. Welsh Assembly Government, Planning Division, Wales.

Welsh Assembly Government (2011). *Planning Policy Wales*. The Canolfan Gorseinon Centre, Swansea - Boyes Rees Architects, Wales.

Wheeler, S., Beatley, T. Eds. (2009). *The sustainable urban development*. Routledge, New York.

Wigginton, M., Harris, J. (2002). *Intelligent Skins*. Butterworth-Heinemann, Oxford.

Wilson, E., Nicol, F., Nanayakkara, L., Ueberiahn-Tritta, A. (2008). *Public Urban Open Space and Human Thermal Comfort: The Implications of Alternative Climate Change and Socio-economic Scenarios.* Journal of Environmental Policy & Planning 10 (1), 31-45.

Wong, E. Ed. (2008). *Reducing Urban Heat Islands: Compendium of Strategies - Trees and Vegetation, Climate Protection Partnership Division*. U.S. Environmental Protection Agency's Office of Atmospheric Programs.

Woolley, H., Rose, S., Carmona, M. and Freedman, J. (2009). *The Value of Public Space. How High Quality Parks and Public Spaces Create Economic, Social and Environmental Value*. Commission for Architecture and the Built Environment, London.

Worthington, J. (2009). *Urban Form for a Sustainable Future: How Sustainable Is Distributed Working in the Networked City?* Journal of Green Building 4 (4), 148-157.

Yannas, S. (2001). *Towards More Sustainable Cities*. Solar Energy 70 (3), 281–294.

Yilmaz, S., Toy, S. and Yilmaz, H. (2007). *Human thermal comfort over three different land surfaces during summer in the city of Erzurum, Turkey.* Atmosfera 20 (3), 289-297.

Yu, B., Chen, Z., Shang, P. and Yang, J. (2008). *Study on the influence of albedo on building heat environment in a year-round*. Energy and Buildings 40 (5), 945-951.

Yu, C., Hien, W. (2006). *Thermal benefits of city parks*. Energy and Buildings 38, 105-120.

Zhang, Y., Zhao, R. (2008). Overall Thermal Sensation, Acceptability and Comfort. Building and Environment 43, 44-50.

Annex A

FIELD SURVEY — DATASHEETS FOR THE OBSERVATION EXERCISE

The observation exercise undertaken during the field survey comprised the filling in of three datasheets: one for functional, another for morphologic, and another for social parameters. Each of these groups of parameters aimed to provide a comprehensive characterisation of the spaces selected as case study.

The datasheet for functional parameters was conceived to provide a complete comprehension of the main functional characteristics of Poveiros Square and São Lázaro Garden and its development had as main references Carr, Francis et al. (1995), Romero (2001), Santamouris (2001), Alves (2003), or Nikolopoulou (2004). The datasheet for morphological parameters was prepared based on previous studies on the same research field, such as Carr, Francis et al. (1995), Romero (2001), Santamouris (2001), Brandão, Carrelo et al. (2002), Alves (2003), Nikolopoulou (2004), or Higueras (2006) and was aimed at characterising the layout of both analysed spaces. Finally, the datasheet for social/personal parameters was conceived in order to systematize information on the personal data collected during the interviews by observation, according to Spagnolo and de Dear (2003), Nikolopoulou (2004), Mean and Tims (2005), Higueras (2006), Nikolopoulou and Lykoudis (2006), or Oliveira and Andrade (2007).

Although these datasheets were developed for the case study and scope of this research they might base other studies since they present many topics which are transversal to any study on bioclimatic grounds. Depending on the scope and aim of each study, the suitability of these datasheets might be integral or partial.

DATASHEET FOR FUNCTIONAL PARAMETERS

Table A.1 – Datasheet for functional parameters used during the undertaken field survey.

FUNCTION	
Brief characterisation	
Delimitation of the site	
Space typology / function	
Specific functional requirements	
Special activities	
Access and equality	
Vehicular access	
Parking places	
Drainage	
Water supply	
Power supply	
Night environment	
Highway systems	
Buses	
Taxis stands	
Coach facilities	
Bicycle facilities	
Pedestrian facilities	
Public facilities and services	

DATASHEET FOR MORPHOLOGIC PARAMETERS

Table A.2 – Datasheet for morphologic parameters used during the undertaken field survey.

MORPHOLOGY		
Area/size		
Topography		
Orientation		
H/W ratio		
Sky View Factor		
Number of edges		
Number of built edges		
Buildings' average heights [floors]		
Main colours		
Architectonic typologies		
Built heritage		
Effective function		
Effective surrounding buildings age and functions		
Influence of the built surrounding	**Wind conduction**	
	Access to sun	
	Crossings	
Lighting		
Street furniture and urban art		
Quality and position of sitting elements		
Ground level shading devises		
Buildings shading devises		
FACING MATERIALS		
Horizontal surface	**Facing materials**	
	Materials' nature	
	Main colours	
	Permeable area	
	Impermeable area	
	Water elements	
	Water elements area	
Vertical surfaces	**Facing materials**	
	Materials' nature	
	Main colours	
	Flexibility to changes	
	Surface continuity	
	Alignments	
	Openings	
VEGETATION		
Green surface		
Not-green surface		
Green coverage		
Trees	**Planted species**	
	Vegetative cycle	
	Maturity	
	Quantity	
	Position	
	Sizes (approx.)	
	Shape	
Shrubs	**Planted species**	
	Vegetative cycle	
	Maturity	
	Position	
	Sizes	
	Shapes	
Herbs	**Planted species**	
	Position	

DATASHEET FOR SOCIAL/PERSONAL PARAMETERS

Table A.3 – Datasheet for social/personal parameters used during the undertaken field survey.

PERSONAL PARAMETERS								
Date								
Time	11 a.m. – 2 p.m.			**Atmospheric conditions**				
				Clean sky				
				Cloudy				
				Covered sky				
Starting hour				**Ending hour**				
0 Type of user	**0.1** A		**0.2** B	**0.3** C	**0.4** D		**0.5** E	**0.6** F
1 Age	**1.1** Child	**1.2.** Adolescent	**1.3.** 18-24	**1.4** 25-34	**1.5** 35-44	**1.6** 45-54	**1.7** 55-64	**1.8** >65
2 Gender	**2.1** Male				**2.2** Female			
3 Activity	**3.1** Sleeping	**3.2** Reclining	**3.3** Seated	**3.4** Standing	**3.5** Walking slow	**3.6** Walking moderate	**3.7** Walking fast	
4 Clothing level	**Male**			**Female**				
	4.1 Ensemble A_m Clo 0.31	**4.2 Ensemble B_m Clo 0.49**	**4.3 Ensemble C_m Clo 0.74**	**4.5 Ensemble A_f Clo 0.32**	**4.6 Ensemble B_f Clo 0.45**	**4.7 Ensemble C_f Clo 0.73**		
								
5 Position								
6 Food/drink consumption	**6.1** Cold drink	**6.2** Hot drink	**6.3** Food	**6.4** No consumption				
7 Company	**7.1** Alone	**7.2** With 1 person	**7.3** With more than 2 persons					
8 Exposure to sun	**8.1** Sun	Shade	**8.2** Building **8.3** Tree **8.4** Shading devise					

Annex B

FIELD SURVEY — CLOTHING ENSEMBLES

The social/personal observation datasheet considered during the field survey has valued two crucial issues: types of users and clothing level. The types of users were empirically defined by the observation exercise and the questionnaires. For clothing levels three clothing ensembles for man and women were considered having as reference the clothing insulation values (Clo) for typical ensembles presented in the ASHRAE Standard 55 (2010; 18). Simultaneously, the considered ensembles represent the three main types of clothing usually worn during summer in Porto.

CLOTHING ENSEMBLES CONSIDERED DURING THE FIELD SURVEY

Table B.1 – Clo values for the defined male ensembles. Adapted from ASHRAE Standard 55.

MALE		
Ensemble A_m		
Underwear	0.04	
Short-sleeved shirt	0.17	
Shorts	0.08	
Sandals	0.02	
Total	0.31	
Ensemble B_m		
Underwear	0.04	
Long-sleeved shirt	0.25	
Straight trousers (thin)	0.15	
Shoes and socks	0.05	
Total	0.49	
Ensemble C_m		
Underwear	0.04	
Long-sleeved shirt	0.25	
Long-sleeved sweater (thin)	0.25	
Straight trousers (thin)	0.15	
Shoes and socks	0.05	
Total	0.74	

Table B.2 – Clo values for the defined female ensembles. Adapted from ASHRAE Standard 55.

FEMALE		
Ensemble A$_f$		
Underwear	0.03	
Sleeveless blouse	0.13	
Shirt (thin)	0.14	
Sandals	0.02	
Total	0.32	
Ensemble B$_f$		
Underwear	0.03	
Long-sleeved shirt	0.25	
Jeans/long skirt	0.15	
Sandals	0.02	
Total	0.45	
Ensemble C$_f$		
Underwear	0.03	
Long-sleeved shirt	0.25	
Long-sleeved sweater (thin)	0.25	
Jeans/long skirt	0.15	
Shoes and socks	0.05	
Total	0.73	

Annex C

FIELD SURVEY — QUESTIONNAIRES

This annex presents the questionnaire prepared for the field survey. This questionnaire has as main reference the ISO 10551:2001 standard (Ergonomics of the thermal environment — Assessment of the influence of the thermal environment using subjective judgement scales). A short-answer and closed questions format was considered. In order to comply with ISO 10551 standard, attention was given to the terminology and wording. The questionnaire was structured in two parts: questions and pictures.

The first part of the questionnaire constituted the questionnaire itself and it was sub-divided into seven interrelated sections. The first five sections were based on the considerations of the ISO 10551 standard and refer to five different judgement scales. The sixth section consists of questions for evaluating the extent to which people could perceive the role facing materials and vegetation were playing in their thermal experience. Finally, the seventh section relates to general personal parameters, aimed at gathering additional information about the interviewees that could eventually help understanding their votes in depth. These two last sections were based in previous studies in the same research field, such as from Spagnolo and de Dear (2003), Nikolopoulou (2004), Nikolopoulou and Lykoudis (2006), or Oliveira and Andrade (2007).

QUESTIONNAIRE IN ENGLISH

Table C.1 – The undertaken questionnaire.

THERMAL SENSATION						
9 How are you feeling at this precise moment?						
9.1 Cold -3	**9.2** Cool -2	**9.3** Slightly cool -1	**9.4** Neutral 0	**9.5** Slightly warm +1	**9.6** Warm +2	**9.7** Hot +3
THERMAL EVALUATION						
10 Do you find this:						
10.1 Very uncomf. (cold) -3	**10.2** Uncomf. cool -2	**10.3** Slightly uncomf. cool -1	**10.4** Comfortable 0	**10.5** Slightly uncomf. warm 1	**10.6** Uncomf. warm 2	**10.7** Very uncomf. (hot) 3
11 Please chose the most unpleasant climatic variable to you at this moment:						
11.1 Temperature	**11.2** Humidity	**11.3** Sun	**11.4** Wind	**11.5** None		
THERMAL PREFERENCE						
12 Please state how you would prefer to be now						
12.1 Much cooler -3	**12.2** Cooler -2	**12.3** Slightly cooler -1	**12.4** Neither warmer or cooler 0	**12.5** A little warmer 1	**12.6** Warmer 2	**12.7** Much warmer 3
THERMAL ACCEPTABILITY						
13How do you judge this environment (local climate) on a personal level?						
13.1 Clearly acceptable 0	**13.2** Just acceptable 1	**13.3** Just unacceptable 2	**13.4** Clearly unacceptable 3			
THERMAL TOLERANCE						
14 Is it:						
14.1 Perfectly tolerable 0	**14.2** Slightly difficult to tolerate 1	**14.3** Fairly difficult to tolerate 2	**14.4** Very difficult to tolerate 3	**14.5** Intolerable 4		
ADDITIONAL PARAMETERS						
15 Why have you come here?						
15.1 Rest	**15.2** Sports	**15.3** Meeting	**15.4** Passage to another place	**15.5** Stroll		
16 For how long have you been in this space?						
16.1 - 5 min	**16.2** 5 to 15 min	**16.3** 15 to 30 min	**16.4** 30 to 60 minutes	**16.5** > 1 hour		
17 How often do you use this space?						
17.1 Daily	**17.2** Weekly	**17.3** Monthly	**17.4** Annually	**17.5** First time		
18 In summer you consider this space usually:						
18.1 Comfortable, so I feel motivated to use it	**18.2** Uncomfortable, so I don't feel motivated to use it					
19 Where were you before you came here?						
19.1 Indoor space	**19.2** At home	**19.3** Outdoor space	**19.4** Own car	**19.5** Public transport		
20 How do you feel regarding your health condition at this precise moment?						
20.1 Uncomfortable, disease manifestation	**20.2** Comfortable, no symptom					
MATERIALS & VEGETATION						
21 Do you think the paving materials of this space are:						
21.1 Too soft	**21.2** Soft	**21.3** Mixed [soft/hard]	**21.4** Hard	**21.5** Too hard		
22 Do you think the facing materials of the facades around this space are:						
22.1 Dark-coloured	**22.2** Mix-coloured[dark/light]	**22.3** Light-coloured				
23 Do you usually feel glare in this space						
23.1 Yes, by the ground	**23.2** Yes, by the buildings facades	**23.3** No glare				
24 Can you count on this space's vegetation to be more comfortable?						
24.1 Yes, because it protects me from sun and/or wind	**24.2** No, because it does not protect me at all from sun and/nor wind					
PICTURES						
25 Which of these spaces do you think it might be the more thermally comfortable?						
25.1 A	**25.2** B	**25.3** C				
26 Which of these spaces do you think it might be the less thermally comfortable?						
26.1 A	**26.2** B	**26.3** C				

QUESTIONNAIRE IN PORTUGUESE

Table C.2 – The undertaken questionnaire (Portuguese). The questionnaire in Portuguese language was, obviously, the considered version for undertaking the interviews.

PERCEPÇÃO TÉRMICA						
9 Como se está a sentir neste preciso momento?						
9.1 Frio -3	**9.2** Fresco -2	**9.3** Ligeiramente fresco -1	**9.4** Neutro 0	**9.5** Ligeiramente quente +1	**9.6** Quente +2	**9.7** Muito quente +3
AVALIAÇÃO TÉRMICA						
10 E acha essa sensação é:						
10.1 Muito desconfortável (frio) -3	**10.2** Fresco desconfortável -2	**10.3** Fresco lig. desconfortável -1	**10.4** Confortável 0	**10.5** Quente lig. desconfortável +1	**10.6** Quente desconfortável +2	**10.7** Muito desconfortável (quente) +3
11 Por favor escolha a variável climática que mais o incomoda neste momento:						
11.1 Temperatura	**11.2** Humidade	**11.3** Sol	**11.4** Vento	**11.5** Nenhum		
PREFERÊNCIA TÉRMICA						
12 Por favor refira como preferiria sentir-se neste momento						
12.1 Muito mais fresco -3	**12.2** Mais fresco -2	**12.3** Ligeiramente mais fresco -1	**12.4** Nem mais quente nem mais fresco 0	**12.5** Ligeiramente mais quente +1	**12.6** Mais quente +2	**12.7** Muito mais quente +3
ACEITABILIDADE						
13 Pessoalmente, como considera este ambiente?						
13.1 Claramente aceitável 0	**13.2** Aceitável 1	**13.3** Inaceitável 2	**13.4** Claramente inaceitável 3			
TOLERÂNCIA						
14 E considera-o:						
14.1 Perfeitamente tolerável 0	**14.2** Ligeiramente difícil de tolerar 1	**14.3** Francamente difícil de tolerar 2	**14.4** Muito difícil de tolerar 3	**14.5** Intolerável 4		
PARÂMETROS ADICIONAIS						
15 Porque razão veio aqui?						
15.1 Repousar/lazer	**15.2** Desporto	**15.3** Encontro	**15.4** De passagem	**15.5** Passeio		
16 Há quanto tempo aqui está?						
16.1 Menos de 5 min.	**16.2** 5 a 15 min.	**16.3** 15 a 30 min.	**16.4** 30 min. a 1 hora	**16.5** Mais de 1 hora		
17 Com que frequência aqui vem?						
17.1 Diariamente	**17.2** Semanalmente	**17.3** Mensalmente	**17.4** Anualmente	**17.5** Primeira vez		
18 No verão, acha que este espaço é geralmente:						
18.1 Confortável, pelo que se sente motivado a utilizá-lo	**18.2** Desconfortável, pelo que não se sente motivado a utilizá-lo					
19 Onde estava imediatamente antes de vir para aqui?						
19.1 Num espaço interior	**19.2** Em casa	**19.3** Num espaço exterior	**19.4** No seu carro	**19.5** Num transporte público		
20 Neste momento, como se sente em relação à sua saúde ao nível respiratório?						
20.1 Desconfortável, manifestação da doença	**20.2** Confortável, nenhum sintoma					
MATERIAIS DE REVESTIMENTO E VEGETAÇÃO						
21 Acha que os materiais de pavimento deste espaço são:						
21.1 Demasiado suaves	**21.2** Suaves	**21.3** Mistos [suaves/duros]	**21.4** Duros	**21.5** Demasiado duros		
22 Acha que os materiais de revestimento das fachadas em torno deste espaço são:						
22.1 Escuros	**22.2** Mistos [escuros/claros]	**22.3** Claros				
23 Costuma sentir-se encandeado neste espaço?						
23.1 Sim, pelos pavimentos	**23.2** Sim, pelas fachadas dos edifícios	**23.3** Não				
24 Sente que pode contar com a vegetação deste espaço para estar mais confortável?						
24.1 Sim, pois abriga-me do sol e do vento	**24.2** Não, pois não me abriga de todo					
IMAGENS						
25 Qual destes espaços acha que será o mais termicamente confortável?						
25.1 A	**25.2** B	**25.3** C				
26 Qual destes espaços acha que será o menos termicamente confortável?						
26.1 A	**26.2** B	**26.3** C				

IMAGES PRESENTED AT THE END OF THE QUESTIONNAIRE

The second part of the questionnaire was targeted at knowing people's capacity to associate given ensembles of materials and vegetation to the conditions offered for thermal comfort. This was made by means of three pictures of different public spaces with contrasting facing materials, amount of vegetation, and presence of water. Picture A represents a public space with mixed paving materials and water features but with medium-aged vegetation and a high sky view factor; picture B is about a public space with hard paving materials, no vegetation, no water, and no shading devices; and picture C shows a public space with mixed-paving materials, dense vegetation, water, and shading devices. This exercise was also aimed at assessing people's previous votes to the questionnaire.

Fig.C.1 – Picture A

Fig.C.2 – Picture B

Fig.C.3 – Picture C

No contextualisation or description was made for any picture. People were shown the pictures and asked, according to their experience, to select the potentially most pleasant and most unpleasant space in a typical summer day.

Fig.C.4 – Final part of the questionnaire: the process of showing (top) and selecting (bottom) pictures. Source: João Cortesão, 2011.

Annex D

FIELD SURVEY — QUESTIONNAIRE TO LOCAL BUSINESSES' OWNERS

Beyond the questionnaire to people found at or passing through the square, at a later stage, the owners of the businesses surrounding the square were also interviewed in order to know how the square was influencing their businesses. This *in loco* contact consisted of a short questionnaire and of presenting the same three pictures as for people found at the square.

QUESTIONNAIRE IN ENGLISH

Table D.1 – The questionnaire for local businesses' owners.

QUESTIONS		
1 How does the climate of the Square, during summer, influence your business?		
1.1 Positively	**1.2** It's irrelevant	**1.3** Negatively
2 Do you think that if the Square was cooler during summer that could positively influence your business?		
2.1 Yes	**2.2** It would be irrelevant	**2.3** No
Because:	**Because:**	**Because:**
IMAGES		
3 Which of these spaces is the potentially most comfortable during summer and, thus, that you would expect the Square to be like?		
3.1 A	**3.2** B	**3.3** C
4 Which of these spaces is the potentially less comfortable during summer and, thus, that you would not expect the Square to be like?		
4.1 A	**4.2** B	**4.3** C

QUESTIONNAIRE IN PORTUGUESE

Table D.2 – The questionnaire for local businesses' owners (Portuguese). The questionnaire in Portuguese language was, obviously, the considered version for undertaking the interviews.

QUESTÕES		
1 De que forma o clima da Praça, no verão, influencia o seu negócio?		
1.1 Positivamente	**1.2** É irrelevante	**1.3** Negativamente
2 Pensa que se a Praça fosse mais fresca durante o verão isso poderia positivamente influenciar o seu negócio?		
2.1 Sim, poderia melhorar	**2.2** Seria irrelevante	**2.3** Não, poderia prejudicar
Porque:	**Porque:**	**Porque:**
IMAGENS		
3 Qual destes espaços será o + termicamente confortável durante o verão e que, portanto, gostaria de ver aplicado na Praça?		
3.1 A	**3.2** B	**3.3** C
4 Qual destes espaços será o - termicamente confortável durante o verão e que, portanto, não gostaria de ver aplicado na Praça?		
4.1 A	**4.2** B	**4.3** C

Annex E

FIELD SURVEY — PORTABLE METEOROLOGICAL STATION

A portable meteorological station was used for the microclimatic monitoring of the analysed spaces. The ISO 7726 standard (Ergonomics of the thermal environment - Instruments for measuring physical quantities) was considered for the preparation of the microclimatic monitoring, namely the methodology and instruments for measuring the selected physical quantities. The climatic variables chosen to monitor were those related to the basic physical quantities that characterise an outdoor environment presented by the ISO 7726 standard: air temperature, relative humidity, direct solar radiation, wind speed, and mean radiant temperature.

PORTABLE METEOROLOGICAL STATION

Fig.E.1 – The used portable meteorological station. Source: João Cortesão, 2011.

The used portable meteorological station was made up of a thermometer, a hygrometer, a pyranometer, an anemometer, a black globe thermometer, and a data logger. Table E.1 lists the climatic variables monitored during the field survey with relation to the instruments composing the used portable meteorological station. All the equipment was kindly provided by the Building Physics Laboratory (LFC) of the Faculty of Engineering of Porto University.

Table E.1 – Monitored climatic variables and instruments composing the meteorological station.

Climatic variable	Instrument	Equipment
Air temperature (T_a)	Thermometer	Onset Computer Corporation Hobo H08-003-02 data logger, model RH/Temp. Onset Computer Corporation Solar Radiation Shield - RS1
Relative humidity (RH)	Hygrometer	
Solar shortwave radiation ($K\downarrow$)	Pyranometer	Kipp&Zonen SPLITE sn 064310
Wind speed (W)	Anemometer	Itise EE70-VT33C3 0408/P22508.4071
Mean radiant temperature (MRT)	Black globe thermometer	Metal black globe with a PT100 resistant sensor
	Data Logger	Technetics mikromec Logbox 16 channels MLbm1624n Vers 5.0 multisens
	Software [data readout and analysis]	
	Air temperature Relative humidity	Onset Computer Corporation's BoxCar 3.7 (for data logger Hobo H08-003-02)
	Solar radiation Wind speed Mean radiant temperature	Technetics' MMgrafix 7.0 (for data logger mikromec multisens)

Annex F

FIELD SURVEY — FUNCTIONAL AND MORPHOLOGIC CHARACTERISATION OF POVEIROS SQUARE AND SÃO LÁZARO GARDEN

This annex presents the detailed data gathered for the functional and morphologic analysis of Poveiros Square and São Lázaro Garden.

The functional analysis accounted with a brief characterisation, delimitation of the site, space typology, specific functional requirements, special activities, access and equality, vehicular access, parking places, drainage, water and power supply, night environment, highway systems, buses, taxis stands, coach and bicycle facilities, pedestrian facilities, and public facilities and services.

The morphologic analysis included the parameters area/size, topography, orientation, H/W ratio, Sky View Factor, number of edges, number of built edges, buildings' average heights, main colours, architectonic typologies, built heritage, effective function, effective surrounding buildings age and functions, influence of the built surrounding, lighting, street furniture, quality and position of sitting elements, ground level and buildings shading devices, facing materials, and vegetation.

FUNCTIONAL CHARACTERISATION

Table F.1 – Functional characterisation of Poveiros Square and São Lázaro Garden.

Parameter	Poveiros Square	São Lázaro Garden
Brief characterisation	The present scheme moved a former surface car parking to an underground level and, by doing so, has aimed recovering the site for pedestrian activities.	São Lázaro Garden is a typical Romantic garden conceived to promote a major link between people and nature in an urban context. This is the city's first public garden, opening to the public in 1834.
Delimitation of the site	*Rua de Santo Ildefonso* (north), *Rua de Passos Manuel* (north), *Rua do Campinho* (west) and *Passeio de São Lázaro* (south)	*Avenida Rodrigues de Freitas* (south), *Passeio de São Lázaro* (north) and *Rua de Dom João IV* (east).
Space typology / function	Square / Public space and underground car parking (2.358 m^2 x 3 floors)	Garden / Public space
Specific functional requirements	The square functions as a unity with no subspaces (exclusive of the cafe terrace in the northern edge)	The garden functions as a unity with no subspaces (exclusive of the area around the bandstand)
Special activities	Features encouraging spontaneous public meetings and gatherings have not been considered	Though there are no specific facilities encouraging spontaneous public meetings and gatherings, there is a strong sense of community in this space
Access and equality	The square was designed for safe, convenient and seamless use for pedestrians, removing the dominance of parked private vehicles and of barriers associated to this surface car parking	The garden was designed for safe, convenient and seamless particularly for pedestrians
Vehicular access	No alteration to the existing access to public roads was proposed	The contiguous Western street was recently pedestrianised
Parking places	284 new parking places (3 of which to disabled people) in the underground car parking, and 13 parking places at the surface	8 parking places at the northern border of the garden (*Passeio de São Lázaro*)
Drainage	Storm water is disposed of to existing mains, and foul water is disposed of to mains sewer	Storm water is disposed of to existing mains, and foul water is disposed of to mains sewer
Water supply	There is mains water supply to the site	There is mains water supply to the site
Power supply	No sockets available	No sockets available
Night environment	Not suitable for 24 hours use	Not suitable for 24 hours use
Highway systems	Traffic at site has become less disturbed by entering in or leaving out vehicles from the car parking	The surrounding area accommodates a considerable proportion of through traffic in the east-west and west-east directions
Buses	None	Bus stops exist around the garden
Taxis stand	None	None
Coach facilities	Long-term coach parking is not provided	Long-term coach parking is not provided
Bicycle facilities	No special attention was paid to bicycles	No special attention was paid to bicycles
Pedestrian facilities	The 3 crossing points connecting the square to the surrounding streets pavements are well-suited to the main desire movement lines	The 5 crossing points connecting the square to the surrounding streets pavements are well-suited to the main desire movement lines
Public facilities and services	Municipal Library, School of Fine-Arts, nursery and offices	Municipal Library, School of Fine-Arts, nursery and offices

MORPHOLOGIC CHARACTERISATION

Table F.2 – Morphologic characterisation of Poveiros Square and São Lázaro Garden.

Parameter		Poveiros Square	São Lázaro Garden
Area/size		2.050 m^2	4.500 m^2
Topography		Practically flat from east to west; slight slope (4.41 %) towards south	Flat
Orientation		East-west	East-west
H/W ratio		Low (0.34)	Low (0.16)
Sky View Factor		Sky does not present any obstruction	Sky is mainly obstructed by trees
Number of edges		4	4
Number of built edges		4	4
Buildings' average heights		3-5 floors	3-5 floors
Main colours		Equally mixed colours	Equally mixed colours
Architectonic typologies		Terrace buildings	Terrace buildings and 2 single public buildings
Built heritage		Within the area classified as World Heritage Site by UNESCO 2 listed buildings by the City Council Within an archaeological protection area	Within the area classified as World Heritage Site by UNESCO 4 listed buildings by the City Council 7 listed statues by the City Council 1 listed tree by the City Council Within an archaeological protection area
Effective function		Passage through	Resting
Effective surrounding buildings age and functions		Mid 19^{th} to early 20^{th} century Housing (upper floors) and commercial (ground floor) functions	18^{th}, 19^{th} and 20^{th} century Housing (upper floors) and commercial (ground floor) functions
Influence of the built surrounding	**Wind conduction**	Pleasant – the prevailing wind does not tend to be funnelled by any building or street	Pleasant – the prevailing wind does not tend to be funnelled by any building or street
	Access to sun	Unpleasant (excessive exposure to sun)	Pleasant (balanced exposure to sun/shadow)
	Crossings	Several, especially in the east-west direction (connecting downtown and centre eastern districts)	Several, especially in the east-west direction (connecting downtown and centre eastern districts)
Lighting		Unpleasant and trivial	Unpleasant and trivial
Street furniture		Limited (few different elements) No urban art elements	Limited (few different elements) 7 sculptures
Quality and position of sitting elements		Inadequate and limited amount of seating	Adequate, sufficient and randomly disposed units
Ground level shading devises		None (exclusive of few parasols at the two existing cafe terraces)	None (exclusive of trees)
Buildings shading devises		Awnings (only in ground floor levels with trade activities)	None
Facing materials			
Horizontal surface	**Facing materials**	Granite slabs, setts, kerbs benches and walls, and grass at the centre; asphalt at the traffic lanes	Bare soil (footpaths); green grass; seasonal flowers
	Materials' nature	Natural hard impervious	Natural soft permeable
	Main colours	Grey	Varied (soil, leaves, green grass, flowers)
	Permeable area	5 % (120 m^2 faced to the total 2.050m^2)	97 % (4.365 m^2 faced to total 4.500 m^2)
	Impermeable area	95 % (1.930 m^2 faced to the total 2.050m^2)	3 % (135 m^2 faced to the total 4.500 m^2)
	Water elements	One raised shallow pool with a fountain at the northern edge, contiguous to the raised flowerbed	One pool with a fountain at the centre of the garden
	Water elements area	2 % (40 m^2 faced to the total 2.050m^2)	1 % (58 m^2 faced to the total 4.500m^2)
Vertical surfaces	**Facing materials**	Granite applications; mix-coloured ceramic tiles; render painted in a wide range of colours	Granite applications; ceramic tiles with a wide range of colours; render (cement) painted in a wide range of colours

	Materials' nature	Mainly hard composite materials	Mainly hard composite materials
	Main colours	Light blue, light green, yellow, white, grey	Light blue, light green, yellow, white, grey
	Flexibility to changes	Low (patrimonial constraints)	Low (patrimonial constraints)
	Surface continuity	Continuous	Continuous
	Alignments	Straight	Straight
	Openings	Multiple openings mainly disposed in a regular rhythm	Multiple openings mainly disposed in a regular rhythm
Vegetation			
Green surface		5 % (120 m^2 faced to the total 2.050 m^2)	40 % (1.790 m^2 faced to total 4.500 m^2)
Non-green surface		95 % (1.930 m^2 faced to the total 2.050 m^2)	60 % (2.710 m^2 faced to total 4.500 m^2)
Green coverage		3 % (77 m^2 faced to the total 2.050 m^2)	77 % (3.485 m^2 faced to total 4.500 m^2)
Trees	**Planted species**	*Acer palmatum* (Japanese Maple)	*Acer palmatum* (Japanese Maple)
		Ligustrum lucidum (Glossy Privet)	*Cedrus libani* (Lebanon Cedar)
		Tilia platyphyllos Scop. (Largeleaf Linden)	*Magnolia grandiflora* (Southern Magnolia)
		Trachycarpus fortune (Windmill Palm Tree)	*Tilia platyphyllos Scop.* (Largeleaf Linden)
			Trachycarpus fortune (Windmill Palm Tree)
	Vegetative cycle	Evergreen and deciduous specimens	Evergreen (mainly)
	Maturity	Medium and adult	Adult
	Quantity	10	64
	Position	Concentrated in the raised flowerbed at the northern edge, and aligned along the eastern edge	Randomly throughout the garden
	Sizes (approx.)	*Tilia platyphyllos Scop*. – 9 m high and 3 m wide (young-medium); *Acer palmatum* – 6 m high and 4 m wide (adult); *Trachycarpus fortune* – 6 m high and 2.5 m wide (adult); *Ligustrum lucidum* – 6 m high and 3 m wide (medium)	*Acer palmatum* – 10 m high and 5 m wide; *Cedrus libani* – 30 m high and 20 m wide (crown base); *Magnolia grandiflora* – 30 m high and 10 m wide; *Tilia platyphyllos Scop.* – 30 m high and 10 m wide; *Trachycarpus fortune* – 20 m high and 2.5 m wide
	Shape	Various (natural, not trimmed) – *Tilia platyphyllos Scop*. – round; *Acer palmatum* – dense rounded, spreading branches; *Trachycarpus fortune* – upright; *Ligustrum lucidum* – vase shape	Various (natural, not trimmed) – *Acer palmatum* – dense rounded, spreading branches; *Camellia japonica* – round; *Cedrus libani* – pyramidal; *Magnolia grandiflora* – round; *Tilia platyphyllos Scop*. – round; *Trachycarpus fortune* – upright
Shrubs	**Planted species**	*Gardenia jasminoides* (Gardenia)	*Camellia japonica* (Japanese Camellia)
			Gardenia jasminoides (Gardenia)
			Hydrangea macrophylla (Hydrangea)
			Rhododendron simsii (Azalea)
	Vegetative cycle	Evergreen	*Gardenia jasminoides* — Evergreen; *Hydrangea macrophylla* and *Rhododendron simsii* — Deciduous
	Maturity	Adult	Adult
	Position	Aligned along the eastern edge flowerbed	Throughout the garden's flowerbeds
	Sizes	0.80 m	From 0.80 m to 4.00 m high
	Shapes	Geometric approximately rectangular trimmed shape	Natural
Herbs	**Planted species**	Turfgrass	Turfgrass
	Position	Throughout the raised flowerbed at the northern edge	Throughout the garden's flowerbeds

Annex G

THE PROPOSED METHODOLOGY

This annex presents the proposed methodology for the retrofitting of public spaces in compact urban areas based in programmes of ‘cool’ materials and vegetation and on a bioclimatic perspective. This methodology envisions the adaptation of the built environment to the substantial increase in temperature extremes brought by climate change. An overarching intervention methodology and a specific guide for help specifying programmes of ‘cool’ materials and vegetation, both built of bioclimatic urban design principles, are proposed.

The proposed methodology assumes the form of a group of tables, each addressing an indicative projectual stage. These tables should be regarded as desktop notes to support the development of a public space proposal. The methodology is herewith presented as it was conceived for being visualised and used.

METHODOLOGY FOR THE THERMAL RETROFITTING OF PUBLIC SPACES IN COMPACT URBAN AREAS

PROGRAMMES OF 'COOL' MATERIALS AND VEGETATION

STRUCTURE

PREPARATION		
APPRAISAL	Client's intentions Functional characterisation Morphological characterisation Social characterisation Microclimatic characterisation Projectual constraints	
FUNDAMENTALS FOR THE INTERVENTION	Statement of need Attraction of investment Management & maintenance policy Community engagement policy	
DESIGN		
DESIGN POLICY	Premises	
SPECIFICATION OF PROGRAMMES OF 'COOL' MATERIALS AND VEGETATION	Specification of programmes of 'cool' materials and vegetation. Guide available at www.budsum.com [GUIDELINES - selection of materials and vegetation] Concept design Virtual simulation Discussion of alternatives	
SPATIAL DESIGN	Robustness Ease of movement Relevance & legibility Maintenance requirements	Guide for the specification of programmes of 'cool' materials and vegetation available at www.budsum.com [GUIDELINES - spatial design]
CONSTRUCTION		
PRE-CONSTRUCTION ORGANISATION	Team Planning the impacts of site operations	
SITE OPERATIONS	Build quality Construction management Impacts of site operations	
USE		
EVALUATION & FEEDBACK	Monitoring policy Post-completion review Post-occupancy review	

1. PREPARATION STAGE

APPRAISAL

Topic	**Principles**
Client's intentions	▪ Identification of the client's needs and objectives.
Functional characterisation	▪ Analysis of the space's functioning irrespective the initially planned function.
Morphological characterisation	▪ Analysis of the space's morphology in global and microclimate terms.
Social characterisation	▪ Identification of types of users; ▪ Knowing users' thermal comfort evaluations and personal parameters eventually influencing these; ▪ Identification of people's wishes and expectations for the site.
Microclimatic characterisation	▪ Collection of data about the climatic variables at the microclimatic scale by alternatively: o using a portable meteorological station; o running a microscale climate model (e.g. ENVI-met); o using the proposed guide, available at www.budsum.com (for an empirical assessment which can be correlated to people's thermal comfort evaluations).
Projectual constraints	▪ Identification of eventual projectual constraints (e.g. physical and regulative constraints, ownership).

FUNDAMENTALS FOR THE INTERVENTION

Topic	**Principles**
Statement of need	▪ Stating and justifying why is it worth improving the space's microclimate.
Attraction of investment	▪ Showing how the thermal retrofitting intervention can benefit people's welfare and bring revenues from the initial investment.
Management & maintenance policy	▪ Definition of activities and their distribution throughout the space; ▪ Definition of maintenance policy suitable to the intervention vision; ▪ Definition of who is going to manage and maintain the space and through which means.
Community engagement policy	▪ Definition of the extent to which community will be involved; ▪ Conciliation of the client's and users' expectations.

2. DESIGN STAGE

DESIGN POLICY

Topic	Principles
Premises	▪ Integration of all issues relevant to site and project defined in the Preparation stage; ▪ Definition of the general vision for the intervention and how it meets the client's expectations; ▪ Definition of whether or not facing materials and vegetation will have the same importance; ▪ Definition of which surfaces will be acted upon (ground and/or facades) and to which extent (%); ▪ The fit between the retrofitting strategy and the activities planned at the fundamentals for the intervention.

SPECIFICATION OF PROGRAMMES OF 'COOL' MATERIALS AND VEGETATION

Topic	Principles
Selection of materials and vegetation	▪ Using the guide for the specification of programmes of 'cool' materials and vegetation available at www.budsum.com [GUIDELINES - selection of materials and vegetation] ▪ Collection of technical information about the physical, moisture-related and optical parameters of materials and biophysical parameters of vegetation.
Concept design	▪ Development of planning drawings providing outline sizes, quantities, layout, and design, paying attention to the optimisation of the amount of materials and vegetation required; ▪ Definition of suitable alternatives.
Virtual simulation	▪ Running a microscale climate model (e.g. ENVI-met) for simulating the expected microclimate of the concept design and of alternatives.
Discussion of alternatives	▪ Choosing the solution presenting the best correlation between potential for microclimatic improvement and cost.

SPATIAL DESIGN

Topic	Principles	
Robustness	▪ Addressing appearance and ensuring relaxation, people's active involvement, people's passive involvement, exploration, fruition, adaptability, safety and security.	Guide for the specification of programmes of 'cool' materials and vegetation available at www.budsum.com [GUIDELINES - spatial design]
Ease of movement	▪ Ensuring access and fitting movement patterns.	
Relevance & legibility	▪ Ensuring visual/spatial relevance and legibility.	
Maintenance requirements	▪ Addressing the maintenance requirements of materials, vegetation and water drainage.	

3. CONSTRUCTION STAGE

PRE-CONSTRUCTION ORGANISATION

Topic	Principles
Team	▪ Letting the building contract, appointing the contractor; ▪ Issuing information about the proposal to the contractor; ▪ Ensuring the quality of construction by promoters before contracts are signed; ▪ Handing over the site to the contractor.
Planning the impacts of site operations	▪ Phasing site operations carefully, bringing its duration down to a minimum; ▪ Anticipating the likely impacts of site operations.

SITE OPERATIONS

Topic	Principles
Build quality	▪ Accurate installation of all material layers in order to ensure good mechanical resistance, durability, visual aspect, and contribution to the space's microclimate; ▪ Proper planting of vegetation complying with all culture specificities; ▪ Tight delimitation between areas of hard and loose pavings; ▪ Proper tightness of water features, preventing leaks.
Construction management	▪ Incorporation of best-practices at all times; ▪ Ensuring that the workforce is skilled enough to undertake installation with technical accuracy; ▪ Ensuring that the workforce is well informed about the aims of the intervention; ▪ Restricting working hours and deliveries; ▪ Ensuring that there is not a supply exceeding the predicted quantities; ▪ Optimisation of the use of natural, human and capital resources; ▪ Minimisation of equipment renting and transportation of people and/or components; ▪ Definition of a robust waste, energy and water management during site operations.
Impacts of site operations	▪ Reducing the amount of physical and visual barriers; ▪ Reducing the production of noise, smoke, dust, vibrations and so on.

4. USE STAGE

EVALUATION & FEEDBACK

Topic	Principles
Monitoring policy	▪ Definition of the parameters to be monitored and associated key-performance indicators; ▪ Definition of who is going to monitor; ▪ Definition of how will the monitoring results be collected and reported, and to whom; ▪ Definition of the periodicity of monitoring; ▪ Definition of the source of funding for the monitoring system; ▪ Elaboration of design status schedules, progress reports or annual monitoring reports.
Post-completion review	▪ Robustness of the built physical layout; ▪ Effectiveness and appropriateness of the specified materials and vegetation; ▪ Effectiveness and appropriateness of additional bioclimatic urban design principles and elements; ▪ Technical accuracy of the construction details; ▪ Suitability of the chosen consultants and contractor; ▪ Compliance with cost and time targets; ▪ Identification of elements leading to eventual ulterior failures.
Post-occupancy review	▪ Analysis of the space's functioning; ▪ Analysis of the space's morphology in global and microclimate terms; ▪ Identification of users' thermal comfort evaluations; ▪ Assessment of the capacity of the space to attract and retain pedestrian activities; ▪ Compliance with the client's goals and the initially stated business goals; ▪ Efficiency of the management and maintenance policy; ▪ Identification of eventual failures.

Annex H

SPECIFICATION OF PROGRAMMES OF ‘COOL’ MATERIALS AND VEGETATION FOR POVEIROS SQUARE

After settling the general vision for the improvement of Poveiros Square, preliminary possible alternatives for programmes of ‘cool’ materials and vegetation were developed for this space. These alternatives were defined taking into consideration the client’s objectives, the results from the undertaken field survey, the square’s functions, and the principles presented at the guide proposed within the methodology. Each alternative was further subjected to a virtual simulation with ENVI-met. Once selected the materials and vegetation integrating these programmes, technical information about their physical, moisture-related and optical parameters, and biophysical parameters, respectively, was collected. Following the principles of the proposed guide, environmental costs are added to these parameters.

SELECTED MATERIALS AND VEGETATION

Table H.1 – Technical information about the selected materials and vegetation.

MATERIALS

Material	Durability	Albedo	Emissivity	Impermeability Degree	Environmental cost
Granite cubes with mortar joints	Very high	0.40	0.90	1.00	High - high PEC, easily reusable and/or recyclable, outcoming from reasonable natural stocks but extraction may have serious environmental impacts, some entailed pollution and toxicity (dust).
Limestone cubes	Very high	0.45	0.93	1.00	High - high PEC, easily reusable and/or recyclable, outcoming from reasonable natural stocks but extraction has profound environmental impacts, some entailed pollution and toxicity (dust).
Gravel (bound)	High	0.72 (light grey)	0.28	0.40	Medium – high PEC (lower if recycled), easily reusable and/or recyclable, outcoming from reasonable natural stocks but extraction may have serious environmental impacts (except when recycled), some entailed pollution and toxicity (dust).
Asphalt	Short	0.20 (aged)	0.90	1.00	Very high – high PEC, reusable and/or recyclable, outcoming from an extremely limited resource, high entailed pollution and toxicity (fumes).

VEGETATION

Species	Category	Vegetative cycle	Growth rate	Maximum height	Shape	Root system	Resistance
Acer palmatum (pre-existent)	Tree	Deciduous	Slow to medium	5 m to 8 m	Dense rounded, spreading branches	Fibrous, shallow and not invasive	Resistant to breakage, pests and diseases
Ligustrum lucidum (pre-existent)	Tree	Evergreen	Medium	8 m to 10 m	Vase shape	Woody, shallow and not invasive	Resistant to breakage, pests and diseases
Betula papyrifera	Tree	Deciduous	Medium	15 m to 20 m	Oval (9.14m wide)	Woody, shallow and wide spreading	Resistant to breakage but vulnerable to pests and diseases
Lantana camara	Shrub	Evergreen	Fast	0.91 m to 1.22 m	Spreading	Woody, shallow and wide spreading	Low tolerance to cold but regrowing quickly. It may be affected by pests and diseases
Hydrangea macrophylla	Shrub	Deciduous	Fast	1.50 m to 2.50 m	Round	Fibrous, thin, densely woven and shallow	Very resistant to pests and diseases

Annex I

VIRTUAL SCENARIOS OF IMPROVEMENT FOR POVEIROS SQUARE — COSTS FOR PORTO CITY HALL [VAT 6 %]

The cost values presented in this annex refer to the common prices and associated taxation (VAT 6 %) applied to Porto City Hall, the project's 'client'. These prices relate to 2013, include capital cost and workforce, and encompass four generic topics: building site, demolitions, installation, and green areas.

CONCEPT DESIGN / SCENARIO 1

Table I.1 – Cost estimation for the concept design / scenario 1 (VAT 6 %).

STAGE	COST+VAT 6 %	QUANTITY	FINAL COST [for Porto City Hall]
BUILDING SITE			
Assembly and disassembly of building site structures + maintenance of safety conditions (fencing)	2120€	1 unit	2.120€
Work identification sign	424€	1 unit	424€
SUBTOTAL			**2.544€**
DEMOLITIONS			
Removal of granite cubes	5.30€/m^2	106.83m^2	566.20€
Removal of granite slabs	8.48€/m^2	17.25m^2	146.28€
Demolition of concrete walls + transportation of waste to landfill	74.20€/m^3	1.82m^3	135€
Removal of earth	5.30€/m^2	0.64m^2	3.39€
Earthwork with selected soils [tout-venant]	5.30€/m^2	0.64m^2	3.39€
Tree transplantation [pre-existent *Tilia platyphyllos Scop.*]	530€	1 unit	530€
SUBTOTAL			**1.384.26€**
INSTALLATION			
Granite cubes	29.68€/m^2	0.86m^2	25.52€
Concrete walls [0.15m]	636€/m^3	14.97m^3	9.520.92€
Waterproofing with anti-root asphalt felt	15.90€/m^2	124.26m^2	1.975.70€
Drain [diam. 0.63m]	8.48€/m	65.68m	556.97€
Gravel [0.15m] laid on geotextile	5.30€/m^2	38.81m^2	205.69€
Trench opening and paving replacement	21.20€/m^2	38.81m^2	822.77€
Connection to gutter	106€	3 units	318€
SUBTOTAL			**13.425.57€**
GREEN AREAS			
Humus	21.20€/m^2	105.31m^2	2.232.57€
Betula papyrifera [5 m high]	47.39€	8 units	379.12€
Lantana camara [0.30 m high]	1.90€	52 units	98.80€
Hydrangea macrophylla [0.40 m high]	4.31€	29 units	124.99€
granite kerbs [0.15 m] + foundation	37.10€/m	5.94m	220.37€
SUBTOTAL			**3.055.85€**
TOTAL			**20.409.68€**

SCENARIO 2

Table I.2 – Cost estimation for scenario 2 (VAT 6 %).

STAGE	COST+VAT 6 %	QUANTITY	FINAL COST [for Porto City Hall]
BUILDING SITE			
Assembly and disassembly of building site structures + maintenance of safety conditions (fencing)	2120€	1 unit	2.120€
Work identification sign	424€	1 unit	424€
SUBTOTAL			**2.544€**
DEMOLITIONS			
Removal of granite cubes	5.30€/m^2	1143m^2	6.057.90€
Removal of granite slabs	8.48€/m^2	17.25m^2	146.28€
Demolition of concrete walls + transportation of waste to landfill	74.20€/m^3	1.82m^3	135€
Removal of earth	5.30€/m^2	0.64m^2	3.39€
Earthwork with selected soils [tout-venant]	5.30€/m^2	0.64m^2	3.39€
Tree transplantation [pre-existent *Tilia platyphyllos Scop.*]	530€	1 unit	530€
SUBTOTAL			**6.875.96€**
INSTALLATION			
Limestone cubes	34.98€/m^2	1143m^2	3.9982.14€
Concrete walls [0.15m]	636€/m^3	14.97m^3	9.520.92€
Waterproofing with anti-root asphalt felt	15.90€/m^2	124.26m^2	1.975.70€
Drain [diam. 0.63m]	8.48€/m	65.68m	556.97€
Gravel [0.15m] laid on geotextile	5.30€/m^2	38.81m^2	205.69€
Trench opening and paving replacement	21.20€/m^2	38.81m^2	822.77€
Connection to gutter	106€	3 units	318€
SUBTOTAL			**53.382.19€**
GREEN AREAS			
Humus	21.20€/m^2	105.31m^2	2.232.57€
Betula papyrifera [5 m high]	47.39€	8 units	379.12€
Lantana camara [0.30 m high]	1.90€	52 units	98.80€
Hydrangea macrophylla [0.40 m high]	4.31€	29 units	124.99€
granite kerbs [0.15 m] + foundation	37.10€/m	5.94m	220.37€
SUBTOTAL			**3.055.85€**
TOTAL			**65.858.00€**

SCENARIO 3

Table I.3 – Cost estimation for scenario 3 (VAT 6 %).

STAGE	COST+VAT 6 %	QUANTITY	FINAL COST [for Porto City Hall]
BUILDING SITE			
Assembly and disassembly of building site structures + maintenance of safety conditions (fencing)	2120€	1 unit	2.120€
Work identification sign	424€	1 unit	424€
SUBTOTAL			**2.544€**
DEMOLITIONS			
Removal of granite cubes	5.30€/m^2	1143m^2	6.057.90€
Removal of granite slabs	8.48€/m^2	17.25m^2	146.28€
Demolition of concrete walls + transportation of waste to landfill	74.20€/m^3	1.82m^3	135€
Removal of earth	5.30€/m^2	0.64m^2	3.39€
Earthwork with selected soils [tout-venant]	5.30€/m^2	0.64m^2	3.39€
Tree transplantation [pre-existent *Tilia platyphyllos Scop.*]	530€	1 unit	530€
SUBTOTAL			**6.875.96€**
INSTALLATION			
Bounded gravel	42.40€/m^2	1143m^2	48.463.20€
Concrete walls [0.15m]	636€/m^3	14.97m^3	9.520.92€
Waterproofing with anti-root asphalt felt	15.90€/m^2	124.26m^2	1.975.70€
Drain [diam. 0.63m]	8.48€/m	65.68m	556.97€
Gravel [0.15m] laid on geotextile	5.30€/m^2	38.81m^2	205.69€
Trench opening and paving replacement	21.20€/m^2	38.81m^2	822.77€
Connection to gutter	106€	3 units	318€
SUBTOTAL			**61.863.25€**
GREEN AREAS			
Humus	21.20€/m^2	105.31m^2	2.232.57€
Betula papyrifera [5 m high]	47.39€	8 units	379.12€
Lantana camara [0.30 m high]	1.90€	52 units	98.80€
Hydrangea macrophylla [0.40 m high]	4.31€	29 units	124.99€
granite kerbs [0.15 m] + foundation	37.10€/m	5.94m	220.37€
SUBTOTAL			**3.055.85€**
TOTAL			**74.339.06€**

SCENARIO 4

Table I.4 – Cost estimation for scenario 4 (VAT 6 %).

STAGE	COST+VAT 6 %	QUANTITY	FINAL COST [for Porto City Hall]
BUILDING SITE			
Assembly and disassembly of building site structures + maintenance of safety conditions (fencing)	2120€	1 unit	2.120€
Work identification sign	424€	1 unit	424€
SUBTOTAL			**2.544€**
DEMOLITIONS			
Removal of granite cubes	5.30€/m^2	1143m^2	6.057.90€
Removal of granite slabs	8.48€/m^2	17.25m^2	146.28€
Demolition of concrete walls + transportation of waste to landfill	74.20€/m^3	1.82m^3	135€
Removal of earth	5.30€/m^2	0.64m^2	3.39€
Earthwork with selected soils [tout-venant]	5.30€/m^2	0.64m^2	3.39€
Tree transplantation [pre-existent *Tilia platyphyllos Scop.*]	530€	1 unit	530€
SUBTOTAL			**6.875.96€**
INSTALLATION			
Asphalt	21.20€/m^2	1143m^2	24.231.60€
Concrete walls [0.15m]	636€/m^3	14.97m^3	9.520.92€
Waterproofing with anti-root asphalt felt	15.90€/m^2	124.26m^2	1.975.70€
Drain [diam. 0.63m]	8.48€/m	65.68m	556.97€
Gravel [0.15m] laid on geotextile	5.30€/m^2	38.81m^2	205.69€
Trench opening and paving replacement	21.20€/m^2	38.81m^2	822.77€
Connection to gutter	106€	3 units	318€
SUBTOTAL			**37.631.65€**
GREEN AREAS			
Humus	21.20€/m^2	105.31m^2	2.232.57€
Betula papyrifera [5 m high]	47.39€	8 units	379.12€
Lantana camara [0.30 m high]	1.90€	52 units	98.80€
Hydrangea macrophylla [0.40 m high]	4.31€	29 units	124.99€
granite kerbs [0.15 m] + foundation	37.10€/m	5.94m	220.37€
SUBTOTAL			**3.055.85€**
TOTAL			**50.107.46€**

FINAL SCENARIO

Table I.5 – Cost estimation for the final scenario (VAT 6 %).

STAGE	COST+VAT 6 %	QUANTITY	FINAL COST [for Porto City Hall]
BUILDING SITE			
Assembly and disassembly of building site structures + maintenance of safety conditions (fencing)	2120€	1 unit	2.120€
Work identification sign	424€	1 unit	424€
SUBTOTAL			**2.544€**
DEMOLITIONS			
Removal of granite cubes	5.30€/m^2	116.50m^2	617.45€
Removal of granite slabs	8.48€/m^2	17.25m^2	146.28€
Demolition of concrete walls + transportation of waste to landfill	74.20€/m^3	1.82m^3	135€
Removal of earth	5.30€/m^2	0.64m^2	3.39€
Earthwork with selected soils [tout-venant]	5.30€/m^2	0.64m^2	3.39€
Tee transplantation [pre-existent *Tilia platyphyllos Scop* and *Gardenia jasminoides*]	530€	1 unit	530€
SUBTOTAL			**1.435.51€**
INSTALLATION			
Granite cubes	29.68€/m^2	0.86m^2	25.52€
Loose gravel [0.05m]	3.18€/m^2	30.40m^2	96.67€
Concrete walls [0.15m]	636€/m^3	17.72m^3	11.269.92€
Waterproofing with anti-root asphalt felt	15.90€/m^2	124.26m^2	1.975.70€
Drain [diam. 0.63m]	8.48€/m	65.68m	556.97€
Gravel [0.15m] laid on geotextile	5.30€/m^2	38.81m^2	205.69€
Trench opening and paving replacement	21.20€/m^2	38.81m^2	822.77€
Connection to gutter	106€	3 units	318€
Lamp post	170€	7 units	1.190€
SUBTOTAL			**16.461.24€**
GREEN AREAS			
Humus	21.20€/m^2	117m^2	2.480.40€
Betula papyrifera [5 m high]	47.39€	8 units	379.12€
Lantana camara [0.30 m high]	1.90€	52 units	98.80€
Hydrangea macrophylla [0.40 m high]	4.31€	29 units	124.99€
granite kerbs [0.15 m] + foundation	37.10€/m	5.94m	220.37€
SUBTOTAL			**3.303.68€**
TOTAL			**23.744.43€**

Annex J

VIRTUAL SCENARIOS FOR THE IMPROVEMENT OF POVEIROS SQUARE — COSTS FOR A COMMON PRIVATE CLIENT [VAT 23 %]

The cost values presented in this annex therefore refer to the common market prices and associated taxation — VAT 23 %. These prices relate to 2013, include capital cost and workforce, and encompass four generic topics: building site, demolitions, installation, and green areas.

CONCEPT DESIGN / SCENARIO 1

Table J.1 – Cost estimation for the concept design / scenario 1 (VAT 23 %).

STAGE	COST+VAT 23 %	QUANTITY	FINAL COST [for common client]
BUILDING SITE			
Assembly and disassembly of building site structures + maintenance of safety conditions (fencing)	2.460€	1 unit	2.460€
Work identification sign	492€	1 unit	492€
SUBTOTAL			**2.952€**
DEMOLITIONS			
Removal of granite cubes	6.15€/m^2	106.83m^2	657€
Removal of granite slabs	9.84€/m^2	17.25m^2	169.74€
Demolition of concrete walls + transportation of waste to landfill	86.10€/m^3	1.82m^3	156.70€
Removal of earth	6.15€/m^2	0.64m^2	3.94€
Earthwork with selected soils [tout-venant]	6.15€/m^2	0.64m^2	3.94€
Tree transplantation [pre-existent *Tilia platyphyllos Scop.*]	615€	1 unit	615€
SUBTOTAL			**1.606.32€**
INSTALLATION			
Granite cubes	34.44€/m^2	0.86m^2	29.62€
Concrete walls [0.15m]	738€/m^3	14.97m^3	11.047.86€
Waterproofing with anti-root asphalt felt	18.45€/m^2	124.26m^2	2.292.60€
Drain [diam. 0.63m]	9.84€/m	65.68m	646.29€
Gravel [0.15m] laid on geotextile	6.15€/m^2	38.81m^2	238.68€
Trench opening and paving replacement	24.60€/m^2	38.81m^2	954.73€
Connection to gutter	123€	3 units	369€
SUBTOTAL			**15.578.78€**
GREEN AREAS			
Humus	24.60€/m^2	105.31m^2	2.590.62€
Betula papyrifera [5 m high]	55€	8 units	440€
Lantana camara [0.30 m high]	2.20€	52 units	114.40€
Hydrangea macrophylla [0.40 m high]	5€	29 units	145€
granite kerbs [0.15 m] + foundation	43.05€/m	5.94m	255.72€
SUBTOTAL			**3.780.52€**
TOTAL			**23.917.62€**

SCENARIO 2

Table J.2 – Cost estimation for scenario 2 (VAT 23 %).

STAGE	COST+VAT 23 %	QUANTITY	FINAL COST [for common client]
BUILDING SITE			
Assembly and disassembly of building site structures + maintenance of safety conditions (fencing)	2.460€	1 unit	2.460€
Work identification sign	492€	1 unit	492€
SUBTOTAL			**2.952€**
DEMOLITIONS			
Removal of granite cubes	6.15€/m^2	1143m^2	7.029.45€
Removal of granite slabs	9.84€/m^2	17.25m^2	169.74€
Demolition of concrete walls + transportation of waste to landfill	86.10€/m^3	1.82m^3	156.70€
Removal of earth	6.15€/m^2	0.64m^2	3.94€
Earthwork with selected soils [tout-venant]	6.15€/m^2	0.64m^2	3.94€
Tree transplantation [pre-existent *Tilia platyphyllos Scop.*]	615€	1 unit	615€
SUBTOTAL			**7.978.77€**
INSTALLATION			
Limestone cubes	40.59€/m^2	1143m^2	46.394.37€
Concrete walls [0.15m]	738€/m^3	14.97m^3	11.047.86€
Waterproofing with anti-root asphalt felt	18.45€/m^2	124.26m^2	2.292.60€
Drain [diam. 0.63m]	9.84€/m	65.68m	646.29€
Gravel [0.15m] laid on geotextile	6.15€/m^2	38.81m^2	238.68€
Trench opening and paving replacement	24.60€/m^2	38.81m^2	954.73€
Connection to gutter	123€	3 units	369€
SUBTOTAL			**61.943.53€**
GREEN AREAS			
Humus	24.60€/m^2	105.31m^2	2.590.62€
Betula papyrifera [5 m high]	55€	8 units	440€
Lantana camara [0.30 m high]	2.20€	52 units	114.40€
Hydrangea macrophylla [0.40 m high]	5€	29 units	145€
granite kerbs [0.15 m] + foundation	43.05€/m	5.94m	255.72€
SUBTOTAL			**3.780.52€**
TOTAL			**76.654.82€**

SCENARIO 3

Table J.3 – Cost estimation for scenario 3 (VAT 23 %).

STAGE	COST+VAT 23 %	QUANTITY	FINAL COST [for common client]
BUILDING SITE			
Assembly and disassembly of building site structures + maintenance of safety conditions (fencing)	2.460€	1 unit	2.460€
Work identification sign	492€	1 unit	492€
SUBTOTAL			**2.952€**
DEMOLITIONS			
Removal of granite cubes	6.15€/m^2	1143m^2	7.029.45€
Removal of granite slabs	9.84€/m^2	17.25m^2	169.74€
Demolition of concrete walls + transportation of waste to landfill	86.10€/m^3	1.82m^3	156.70€
Removal of earth	6.15€/m^2	0.64m^2	3.94€
Earthwork with selected soils [tout-venant]	6.15€/m^2	0.64m^2	3.94€
Tree transplantation [pre-existent *Tilia platyphyllos Scop.*]	615€	1 unit	615€
SUBTOTAL			**7978.77€**
INSTALLATION			
Bounded gravel	49.20€/m^2	1143m^2	56.235.60€
Concrete walls [0.15m]	738€/m^3	14.97m^3	11.047.86€
Waterproofing with anti-root asphalt felt	18.45€/m^2	124.26m^2	2.292.60€
Drain [diam. 0.63m]	9.84€/m	65.68m	646.29€
Gravel [0.15m] laid on geotextile	6.15€/m^2	38.81m^2	238.68€
Trench opening and paving replacement	24.60€/m^2	38.81m^2	954.73€
Connection to gutter	123€	3 units	369€
SUBTOTAL			**71.784.76€**
GREEN AREAS			
Humus	24.60€/m^2	105.31m^2	2.590.62€
Betula papyrifera [5 m high]	55€	8 units	440€
Lantana camara [0.30 m high]	2.20€	52 units	114.40€
Hydrangea macrophylla [0.40 m high]	5€	29 units	145€
granite kerbs [0.15 m] + foundation	43.05€/m	5.94m	255.72€
SUBTOTAL			**3.780.52€**
TOTAL			**86.496.05€**

SCENARIO 4

Table J.4 – Cost estimation for scenario 4 (VAT 23 %).

STAGE	COST+VAT 23 %	QUANTITY	FINAL COST [for common client]
BUILDING SITE			
Assembly and disassembly of building site structures + maintenance of safety conditions (fencing)	2.460€	1 unit	2.460€
Work identification sign	492€	1 unit	492€
SUBTOTAL			**2.952€**
DEMOLITIONS			
Removal of granite cubes	6.15€/m^2	1143m^2	7.029.45€
Removal of granite slabs	9.84€/m^2	17.25m^2	169.74€
Demolition of concrete walls + transportation of waste to landfill	86.10€/m^3	1.82m^3	156.70€
Removal of earth	6.15€/m^2	0.64m^2	3.94€
Earthwork with selected soils [tout-venant]	6.15€/m^2	0.64m^2	3.94€
Tree transplantation [pre-existent *Tilia platyphyllos Scop.*]	615€	1 unit	615€
SUBTOTAL			**7.978.77€**
INSTALLATION			
Asphalt	24.60€/m^2	1143m^2	28.117.80€
Concrete walls [0.15m]	738€/m^3	14.97m^3	11.047.86€
Waterproofing with anti-root asphalt felt	18.45€/m^2	124.26m^2	2.292.60€
Drain [diam. 0.63m]	9.84€/m	65.68m	646.29€
Gravel [0.15m] laid on geotextile	6.15€/m^2	38.81m^2	238.68€
Trench opening and paving replacement	24.60€/m^2	38.81m^2	954.73€
Connection to gutter	123€	3 units	369€
SUBTOTAL			**43.666.96€**
GREEN AREAS			
Humus	24.60€/m^2	105.31m^2	2.590.62€
Betula papyrifera [5 m high]	55€	8 units	440€
Lantana camara [0.30 m high]	2.20€	52 units	114.40€
Hydrangea macrophylla [0.40 m high]	5€	29 units	145€
granite kerbs [0.15 m] + foundation	43.05€/m	5.94m	255.72€
SUBTOTAL			**3.780.52€**
TOTAL			**58.378.25€**

FINAL SCENARIO

Table J.5 – Cost estimation for the final scenario (VAT 23 %).

STAGE	COST+VAT 23 %	QUANTITY	FINAL COST [for common client]
BUILDING SITE			
Assembly and disassembly of building site structures + maintenance of safety conditions (fencing)	2.460€	1 unit	2.460€
Work identification sign	492€	1 unit	492€
SUBTOTAL			**2.952€**
DEMOLITIONS			
Removal of granite cubes	6.15€/m^2	116.50m^2	716.48€
Removal of granite slabs	9.84€/m^2	17.25m^2	169.74€
Demolition of concrete walls + transportation of waste to landfill	86.10€/m^3	1.82m^3	156.70€
Removal of earth	6.15€/m^2	0.64m^2	3.94€
Earthwork with selected soils [tout-venant]	6.15€/m^2	0.64m^2	3.94€
Tee transplantation [pre-existent *Tilia platyphyllos Scop.*]	615€	1 unit	615€
SUBTOTAL			**1.665.80€**
INSTALLATION			
Granite cubes	34.44€/m^2	0.86m^2	29.62€
Loose gravel [0.05m]	3.69€/m^2	30.40m^2	112.18€
Concrete walls [0.15m]	738€/m^3	17.72m^3	12.634.56€
Waterproofing with anti-root asphalt felt	18.45€/m^2	124.26m^2	2.292.60€
Drain [diam. 0.63m]	9.84€/m	65.68m	646.29€
Gravel [0.15m] laid on geotextile	6.15€/m^2	38.81m^2	238.68€
Trench opening and paving replacement	24.60€/m^2	38.81m^2	954.73€
Connection to gutter	123€	3 units	369€
Lamp post	200€	7 units	1.400€
SUBTOTAL			**18.677.66€**
GREEN AREAS			
Humus	24.60€/m^2	117m^2	2.878.20€
Betula papyrifera [5 m high]	55€	8 units	440€
Lantana camara [0.30 m high]	2.20€	52 units	114.40€
Hydrangea macrophylla [0.40 m high]	5€	29 units	145€
granite kerbs [0.15 m] + foundation	43.05€/m	5.94m	255.72€
SUBTOTAL			**3.833.32€**
TOTAL			**27.128.78€**

Annex K

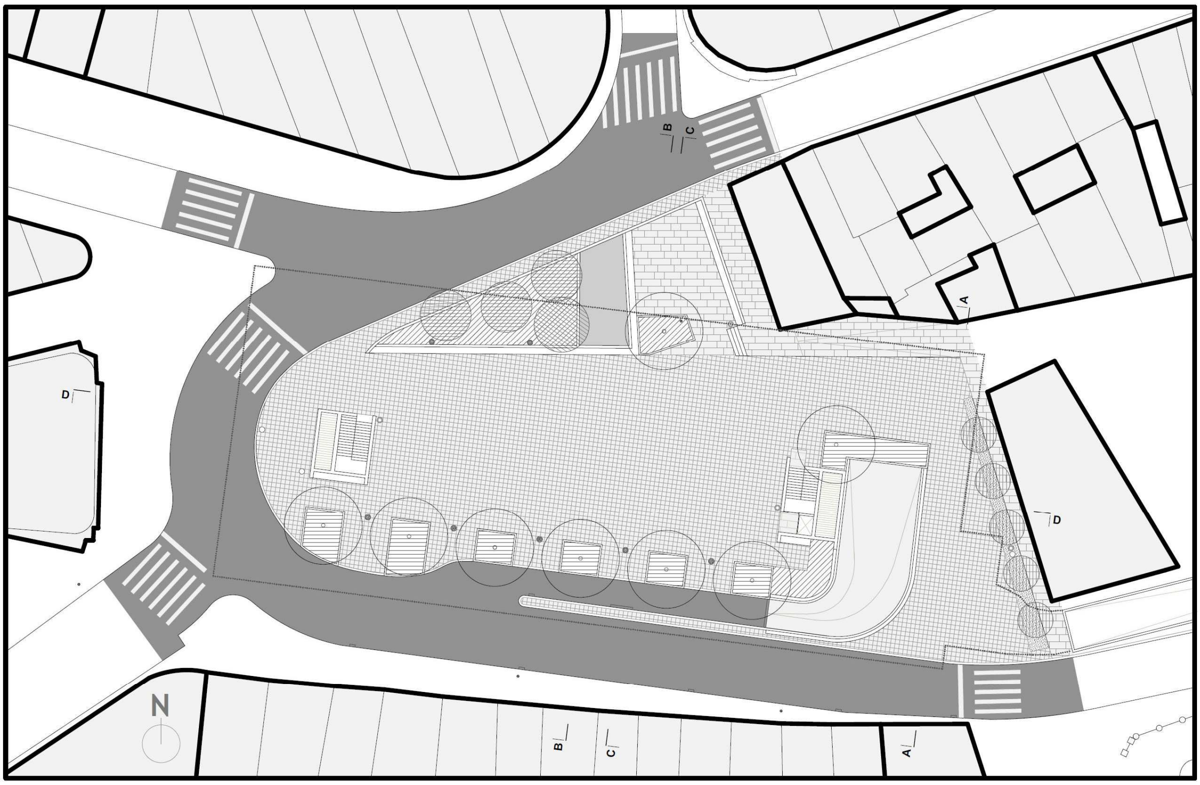
FINAL SCENARIO OF IMPROVEMENT FOR POVEIROS SQUARE — DRAWINGS

The final proposal for the thermal retrofitting of Poveiros Square presents, amongst the tested scenarios, the best correlation between microclimatic improvement, cost, and time required for installation. Based on scenario 1, on a bioclimatic perspective the final scenario of improvement of Poveiros Square accounts with:

- the preservation of the pre-existent granite cubes and slabs;
- the planting of a row of 6 *Betula papyrifera* (White Birch) on raised flowerbeds at the square's southern edge;
- the creation of a raised flowerbed at the northern edge of the underground car parking eastern staircase;
- the creation of a flowerbed at the eastern end of the southern row of raised flowerbeds, planted with 5 *Hydrangea macrophylla (Hydrangea)*;
- at the pre-existent raised flowerbed at the square's northern edge, the replacement of grass by 20 *Hydrangea macrophylla (Hydrangea*);
- the removal of the pre-existent *Tilia platyphyllos Scop.* (Largeleaf Linden);
- the creation of a raised flowerbed in the continuity of the pre-existent northern edge flowerbed where 1 *Betula papyrifera* and 4 *Hydrangea macrophylla (Hydrangea*) are planted.

On a global spatial design perspective, the specified programme of 'cool' materials and vegetation was refined with parameters related to current urban design: robustness, ease of movement, relevance & legibility, planting scheme, and maintenance requirements.

PLAN



KEY

SURFACE MATERIALS
- Asphalt
- Concrete
- Granite cubes
- Granite slabs
- Gravel
- Water

VEGETATION [pre-existent]
- ***Acer palmatum*** [Japanese Maple]
- ***Ligustrum lucidum*** [Glossy Privet]
- ***Trachycarpus fortune*** [Windmill Palm Tree]

VEGETATION [proposed]
- ***Betula papyrifera*** [White Birch]
- ***Lantana camara*** [Lantana]
- ***Hydrangea macrophylla*** [Hydrangea]

URBAN FURNITURE [pre-existent]
- Hidrant
- Litter bin
- Lamp post

URBAN FURNITURE [proposed]
- Lamp post

- Limit of underground car parking

Fig.K.1 – Plan of the final scenario/proposal of improvement for Poveiros Square. Do not scale drawing.

SECTIONS

SECTION A

Fig.K.2 – Final scenario/proposal of improvement for Poveiros Square. Section A. Do not scale drawing.

SECTION B

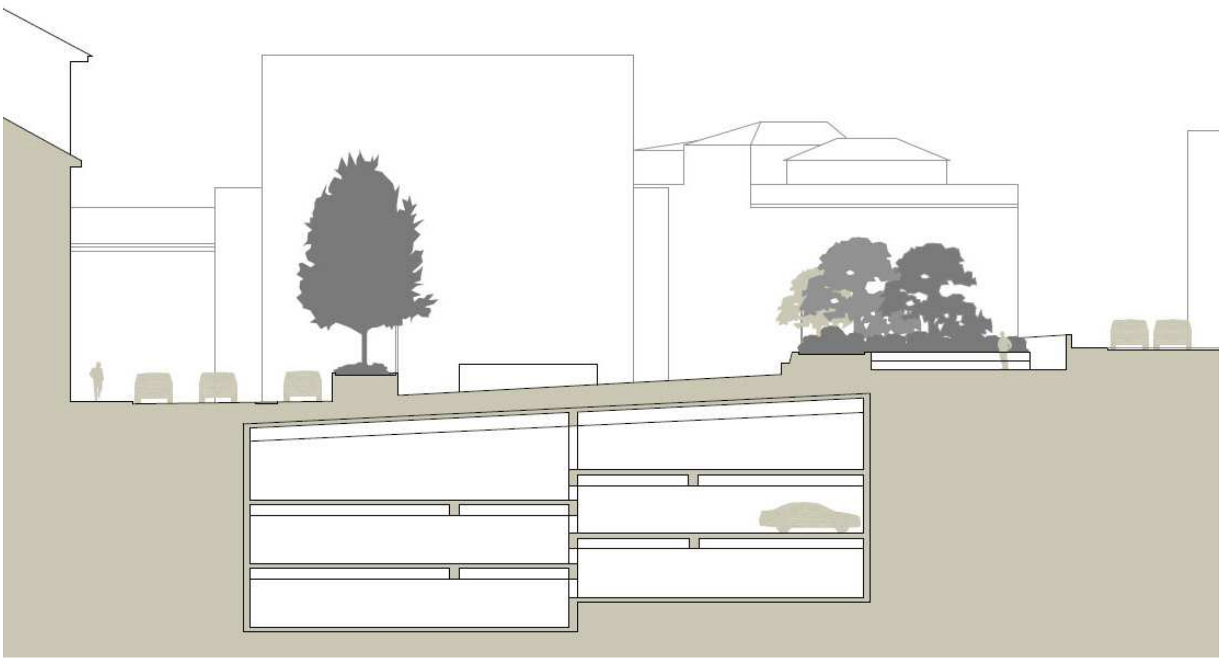


Fig.K.3 – Final scenario/proposal of improvement for Poveiros Square. Section B. Do not scale drawing.

SECTION C

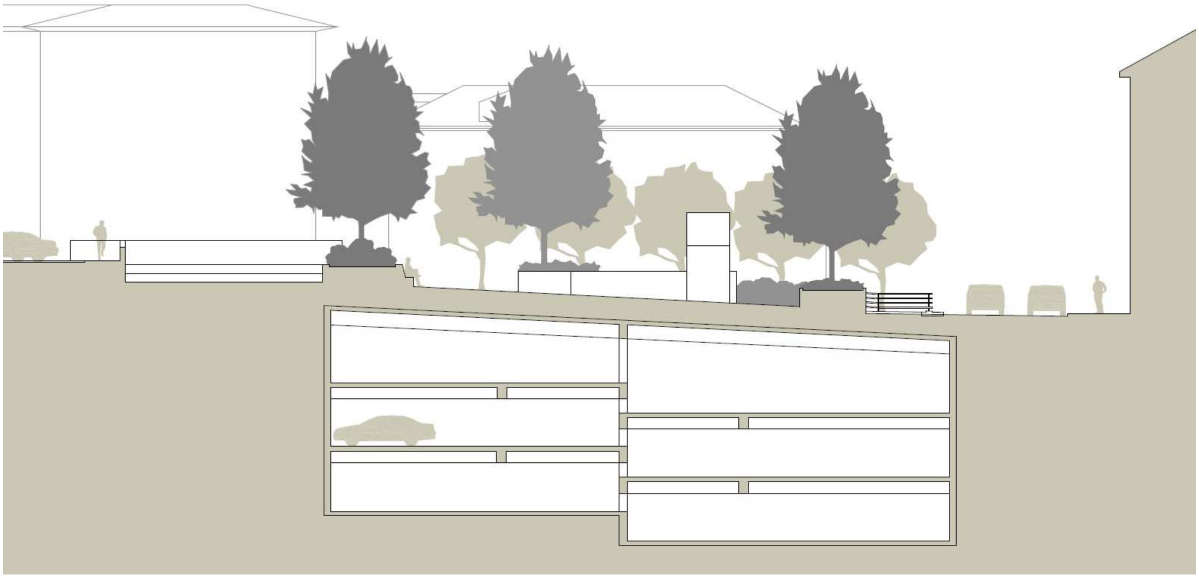
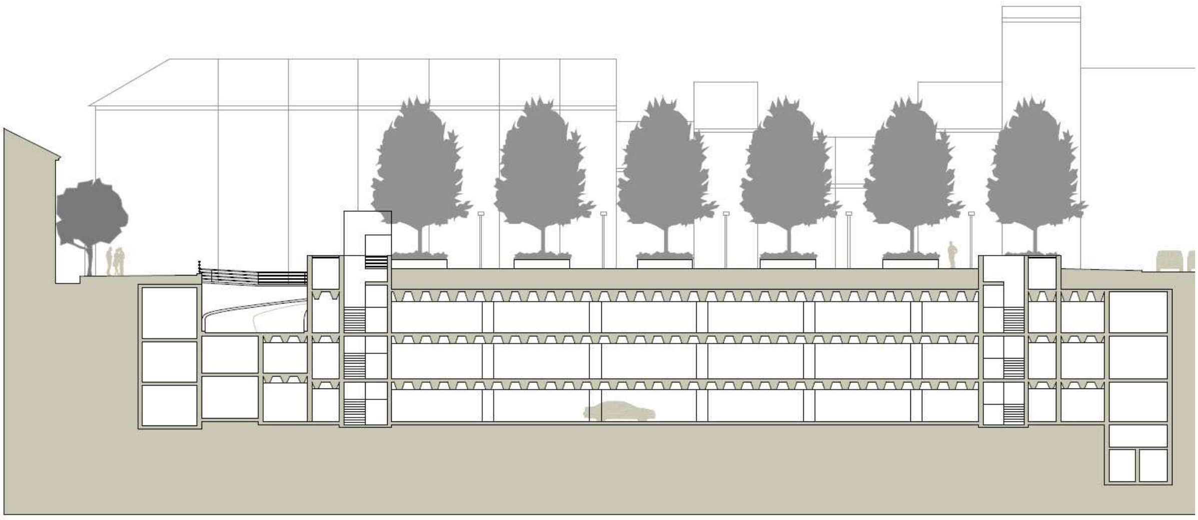


Fig.K.4 – Final scenario/proposal of improvement for Poveiros Square. Section C. Do not scale drawing.

SECTION D



SECTION D

Fig.K.5 – Final scenario/proposal of improvement for Poveiros Square. Section D. Do not scale drawing.