Research Paper

URBAN PARAMETERS ANALYSIS AND VISUALIZATION

A Support to planning decisions
for the definition of urban surface usages

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Abstract

Several mitigation and adaptation strategies are proposed to tackle the environmental issues associated to massive urbanization and climate change. All these solutions are highly related to the utilization of urban surfaces (i.e. building envelopes, streets, public spaces, etc.). However, the existing trends demonstrate the lack of a systemic approach able to integrate multiple possible functions and avoid sub-optimal solutions. In this context, urban planning can play an essential role in managing conflicts among different surface uses and ensuring their integration. This involves making spatially explicit decisions about the types of surface use allowable, and their extent and location. The decision-making process needs to be supported by accurate and detailed knowledge about the spatial distribution of a variety of parameters that influence the surface uses in cities.

This study presents a systematic framework to support planning decisions based on accurate, diverse and spatially explicit information, and discusses its application in a residential district located in Bolzano (Italy). The proposed method implies the assembly of a multivariate spatial database of significant morphological and environmental parameters acquired through environmental simulation techniques and on-site data collection. The three-dimensional visualization of this database represents a solid base to relate urban planning decisions on surface uses to their effects in terms of microclimatic conditions, thermal comfort, and on-site renewable energy production.

Keywords

Urban surface use, urban microclimate, urban morphology, spatial information, data visualization

1. Introduction

Massive urbanization and rapid growth of urban population worldwide are exposing cities to several stressors, many of which are largely driven and intensified by global climate change. More than half of the world population and the majority of the economic activities are located in urban areas (World Bank, 2018); this makes cities among the major contributors to climate change as well as particularly vulnerable to its impacts, facing major weather and environment-related challenges (Baklanov et al., 2018). Therefore, it is becoming essential for cities to develop strategies for controlling local climatic and biophysical conditions, protecting inhabitants and infrastructures from extreme weather events, and using their resources

efficiently. In this context, city planning is emerging as a key practice to contribute to the well-being of the urban environment. Hence, one of the most effective ways to address the challenges posed by urban development and climate change is to include responsive resilience strategies into the current planning processes. This arises the need for sets of data and information able to support urban planners and decision makers in implementing effective measures to address the most critical issues and vulnerabilities (Giordano *et al.*, 2019).

Climatic conditions in cities constitute a relevant issue for urban design, as they affect human thermal comfort, impact the energy consumption for heating and cooling, and influence the use of open and public spaces. These conditions are determined by the physical and morphological features of each urban areas, such as the distribution and density of the buildings, the materials characterizing their surfaces, the presence of vegetation, etc. Hence, the analysis and understanding of this environmental and geometrical attributes is an important step to identify responsive solutions at the urban and building scale during the design process (Silva *et al.*, 2018). In this scenario, urban design and urban planning play a key role. However, despite the development of numerous studies and scientific techniques, current city planning processes does not thoroughly make use of the knowledge generated by the available research on the field. Furthermore, current policies, such as those aimed at the reduction of urban heat island (UHI), are often applied uniformly to all the areas of a city, neglecting the spatial variation of climatic conditions in relation to the urban form (Danahy *et al.*, 2015). To address this lack of awareness, there is the need for going beyond both abstract analyses on single physical and atmospheric processes, and studies on single urban areas, by implementing an interdisciplinary approach to consider the interrelation of climate, city structure, and thermal comfort (Eliasson, 2000; Martinelli and Matzarakis, 2017). Two- and three-dimensional (3D) visualization processes can increase awareness of the role of urban and environmental features and their spatial variability. Moreover, they can support urban decision makers in investigating the local effects of general policies, in comparing several strategies, and in communicating the different options to the involved stakeholders and to the citizens (Danahy *et al.*, 2015).

This work proposes an approach to reduce the gap between scientific research and the real challenges of its integration into practice at urban scale by setting a framework to inform urban planners and decision makers about the relevant characteristics of each area, and the impact of their decisions on microclimate, human thermal comfort, and on-site renewable energy production.

1.1. Urban surface use definition: the role of urban planning

In the current scenario of urbanization, growth of urban population, and global climate change, several strategies are being proposed to tackle the correlated environmental issues. All these solutions are highly related to the utilization of urban surfaces, which are considered as key element in our approach. The term “urban surfaces” identifies all the surfaces that characterize physically and morphologically the three dimensions of the built environment, including the horizontal and vertical surfaces of the ground and of the building envelopes (Croce, Vettorato and Paparella, 2019). Ground surfaces comprise the road network and the urban open spaces, while building envelopes’ surfaces include façades and rooftops. Urban surfaces can be characterized by different materials and can host several functions. With “urban surface usage” we define the way a surface is deployed to address urban resiliency - protection of people and infrastructures from extreme climate events - and sustainability - efficient use of resources - objectives. The term encompasses all the materials and solutions

that can built-up the different surfaces or be applied on them. The main solutions, clustered in five main categories, are schematized in Figure 1.

Figure 1. Overview of the main categories of urban surface uses.

Once being seen only as a cost, due to their maintenance (Becchio *et al.*, 2011; Augeri, Greco and Nicolosi, 2019), urban surfaces are becoming a key opportunity for cities in latest years. Their exploitation offers the opportunity to increase resource efficiency, to exploit renewable energy sources, and to reduce the overall environmental impact (Kellett, 2011; Sadineni, Madala and Boehm, 2011; Toboso-Chavero *et al.*, 2018). However, the common approaches to urban surface use definition are still mainly focused on single solutions (e.g. urban vegetation, use of reflective materials, etc.), and on pursuing single objectives. Furthermore, these approaches are often bi-dimensional, still strongly connected to the concept of land use (Davoudi, Crawford and Mehmood, 2009; Yiannakou and Salata, 2017), disregarding the three-dimensional complexity of the build-environment.

The existing trends demonstrate the lack of a systemic process able to integrate multiple possible solutions, and to avoid sub-optimal solutions. For example, in cities, conflicts are arising between the surface uses for renewable energy production, urban agriculture, and green solutions (Penaranda Moren and Korjenic, 2017). Urban planning is essential to manage conflicts among different surface uses and ensure their integration in the process toward resilient and sustainable cities (Kellett, 2011). This involves making spatially explicit decisions about the types of surface use allowable, and the extent and location of these. This decision-making process needs to be supported by accurate and detailed information about the spatial distribution of a set of parameters. Indeed, many environmental and morphological features influence the distribution of surface uses in cities and affect the priorities for their definition. These parameters not only include the morphological and geometrical features of the urban areas, which can be easily assessed and are already part of traditional urban design processes, but also a variety of environmental and microclimatic parameters. Hence, a clear understanding of the physical interaction between the built environment and the climate boundary conditions is crucial to determine truly responsive strategies.

2. Morphological and environmental parameters

This study presents a systematic framework to support planning decisions about the mix of surface uses and their spatial arrangement in the urban environment, based on accurate,

diverse and spatially explicit information. The method implies the assembly of a multivariate spatial database of significant morphological and environmental parameters, obtained from environmental simulation techniques and on-site data collection. The three-dimensional visualization of this database represents a solid base to relate urban planning decisions on surface uses and their effects, e.g. in terms of microclimatic conditions enhancement and on-site renewable energy production. Furthermore, it provides an easily understandable way to recognize specific elements of the urban environment and orient the design process. This section presents an overview of the main parameters, their role, and characteristics.

2.1. Morphological parameters

Several studies have demonstrated that the urban spatial configuration can influence the local climate (Pisello *et al.*, 2018; Shooshtarian, Rajagopalan and Sagoo, 2018). Indeed, the replacement of natural, permeable surfaces, with mineral materials is the main responsible of both UHI and surface storm-water runoff problems. The low albedo of materials applied on the majority of the urban surfaces is cause of the increase of solar radiation absorption and consequent high surface temperatures. Furthermore, the territorial expansion produced by the urbanization increases the land consumption and causes relevant changes in the land use. Consequently, the reduction of green spaces due to the territorial expansion produces a serious environmental degradation with the loss of urbanecosystems. The increase of buildings heights and urban density is responsible for low induced wind velocities, which impede suitable heat removal rates. Therefore, the proper understanding of the site geometry and urban surfaces features is crucial.

Among the main parameters used to characterise the urban structure there are the building height, total height-to-floor area ratio, building volume density, the aspect ratio and the sky view factor (Oke, 1990). The aspect ratio (H/W) defines ratio of the mean building height (H) to road width (W). The larger is the H/W , the denser is the urban area. The sky view factor (SVF) is defined as the portion of sky visible from a specific point inside the urban area. Its values ranges from 0 to 1, which refer respectively to a completely obstructed and unobstructed sky. SVF has an important role in determining the receipt and loss of radiation in the built environment. During the day, a low SVF will result in less incoming solar radiation in the urban canyon, affecting the ground surface as well as the air temperature. While during nighttime, it reduces the loss of long-wave radiation to the sky and the turbulent heat transfer in the canyon air.

The urban built environment is constituted by a variety of surfaces, whose properties play a key role. The most relevant thermal and radiative properties of urban mineral surfaces include the type of material, its albedo, emissivity, and thermal conductivity. Albedo plays an important role in the surface energy balance; it is defined as the ratio of solar radiation reflected to the amount of radiation absorbed by a surface (Kotharkar, Bagade and Ramesh, 2019). With regard to natural, permeable surfaces, soil type, and vegetation type and species influence the variability in local urban climate (Vuckovic, Kiesel and Mahdavi, 2017).

2.2. Environmental parameters

Environmental parameters include the main physical quantities characterising the microclimatic conditions in an urban area, i.e. air temperature (T_{air}), surface temperature (T_s), mean radiant temperature (T_{mrt}), global shortwave solar radiation (Irr_{SW}), and wind speed (W_s) and direction (W_{dir}). These variables are also used to calculate the thermal environment by means of suitable indexes, such as the Universal Thermal Climate Index (UTCI), which

evaluates the human thermal perception and the correlated grade of physiological stress (Jendritzky, de Dear and Havenith, 2012; Pappenberger *et al.*, 2015).

2.3. Data sources

Access to spatialized data at the appropriate resolutions is important to correctly represent the distribution of morphological and environmental features, and to characterise urban phenomena, such as the microclimatic conditions. Figure 2 presents an overview of the main parameters and the main data sources.

Figure 2. Parameters influencing the definition of urban surface uses, and main data sources.

A variety of data is suitable for the creation of the 3D model of an urban area. Aerial images and photos taken on-site are used to define the geometrical characteristics of the buildings, the finishing materials of the urban surfaces, and the presence and typology of the vegetation. Based on this, different methods and techniques are available to analyse urban morphological parameters, ranging from spatial metrics to the use of satellite images.

The local climate conditions can be assessed by measuring the main microclimatic parameters in-situ, with the use of weather stations (Pyrgou *et al.*, 2017), extensive sensor networks (Tong *et al.*, 2018), or mobile meteorological stations (Chokhachian *et al.*, 2018). However, setting up and maintaining an in-situ monitoring network is resource and time consuming, and not always feasible due to technical reasons. However, the interactions between the built environment and the climate boundary conditions can also be modelled and evaluated by means of numerical simulations. Several models and tools allow to conduct environmental analyses. Depending on the selected tool, it is possible to calculate single variables, such as the incoming solar radiation, or complex atmospheric process, such as wind flow, turbulence, processes of heat and vapour exchange at urban surfaces, and exchanges of energy and mass between the vegetation and its surroundings (Lobaccaro *et al.*, 2018). In this study, different tools have been chosen depending on the aims of each investigation; an overview is presented in Table 1.

Table 1. Main typologies of environmental analyses, aims, and tools used.

Analyses (<i>Parameters</i>)	Aims	Tools
Solar potential (Irr_{sw})	Identify the most irradiated areas and the surfaces most affected by overshadowing	<i>Rhinoceros, DIVA-for-Rhino, Honeybee for Grasshopper</i>
Microclimate (T_{air} , RH , T_{mrt} , T_s)	Define local microclimate conditions and verify impacts of specific modifications of surfaces uses	<i>ENVImet, Ladybug tools for Grasshopper, Rhino-2-ENVI</i>
Urban airflow (W_s , W_{dir})	Evaluate the natural ventilation and identify the prevalent winds in the district	<i>Butterfly for Grasshopper, OpenFoam</i>
Thermal comfort ($UTCI$)	Assess the human thermal comfort conditions	<i>ENVImet - BioMet, Rayman</i>

3. Data analysis and visualization for urban surface use definition

The traditional products of environmental simulation tools, abstract climate maps or descriptive texts can be confusing to non-experts, and lack the flexibility necessary for informing planning decisions in complex urban environments with competing demands. Relating urban form to local climate conditions plays an important role when facing several urban issues, such as urban heat island, energy resiliency, water availability, etc. Visualization can be used to guide an effective decision making process and to effectively represent the effects of surface use choices in a 3D model, making them more tangible. Figure 3 schematizes the structure of the proposed framework.

Figure 3. Scheme of the proposed process.

4. Application to a case study in Bolzano

In this section, the application of the proposed method is tested for the analysis of the current conditions and for the definition of suitable surface uses in an existing district in Bolzano.

The city of Bolzano (UTM 46°29'53.8" N, 11°21'17.1" E) is located in the north-east of Italy, at a height of 265 m above sea level; its climate is categorized as moist continental (i.e. "Dfb" Köppen-Geiger classification) and is characterized by strong seasonal fluctuations. The location of the city, which is situated in a basin surrounded by mountain ranges, often exacerbates high temperature and heat waves during summer, when T_{air} frequently exceeds 35 °C. In this context, the municipality of Bolzano is committed in mitigating the effects of climate change through several actions, such as the exploitation of RES, the energy retrofit of buildings, and the increase of urban vegetation by planting new trees and supporting the diffusion of green roofs.

The residential district selected as case study is one of the five areas in Bolzano taking part to the Smart Cities European project SINFONIA (SINFONIA, 2017); it includes two social housing blocks, being innovatively refurbished in the framework of the project, and the nearby buildings.

4.1. Characterization of the area under study

The area is characterized by the presence of five urban canyons: *Via Milano* and *Via Cagliari* from north to south; *Via Brescia*, *Garden*, and *Via Palermo* from west to east (Figure 4). *Via Palermo* is one of the main roads connecting the eastern and southern areas of Bolzano; due to its importance in the traffic network of the city, together with *Via Milano* and *Via Cagliari*, is considered as geometrical invariant. Therefore, the possible surface uses are restrained to the solely modification of the materials, while original geometrical and functional features are kept unvaried. On the contrary, *Via Brescia* and *Garden*, the central vegetated public area, are regarded as possible variants.

Figure 4. Aerial view, urban canyons, and morphological parameters in representative locations.

Being the mitigation of summer temperatures among the main objectives of Bolzano Municipality's planning actions, the environmental characteristics of the area have been assessed for a typical hot summer day. Figure 5 visualizes the main surface uses in the district, together with the spatial distribution of some representative microclimatic parameters that have a major influence in defining the thermal conditions in the districts, i.e. Irr_{SW} , T_s , and T_{air} . The data visualized in 3D have been obtained from environmental analyses.

Figure 5. Surface uses (a), and spatial distribution of microclimatic parameters in the district.

The characterization of microclimatic conditions in the district is not only conducted through the use of tools for environmental analyses. Hence, since July 2019, the area is subject to an in-situ monitoring campaign, which will last for one year and collect data relatively to all the main meteorological parameters. The monitoring network is constituted by two high resolution weather stations, installed on *Via Brescia* Sinfonia building roof, and in *Garden*, and 15 custom made sensor nodes, which are positioned at different height on the external surfaces of *Via Brescia* Sinfonia building. The configuration of the network and its main characteristics are shown in Figure 6.

Figure 6. Sinfonia in-situ outdoor monitoring network.

4.2. Definition of surface uses

Some main evidences emerge from the analysis of the environmental parameters' spatial distribution: (i) the area is affected by summer overheating and the hotspots are localized in the urban canyons due to high asphalt T_s , (ii) T_{air} is mitigated in the green areas, and (iii) several surfaces present suitable Irr_{SW} levels for the integration of solar active systems. Based on the existing conditions in the district, several configurations have been analysed in order to evaluate the effects of applying different solutions for surface uses (e.g. green solutions at building scale, water surfaces, solar active systems, etc.). The main objectives defined for the area are: (i) mitigation of high summer temperatures, (ii) energy production from RES, and (iii) increase of green areas in the district for environmental enhancement and community well-being. Based on these, and on the results of several environmental analyses, a possible final configuration of the urban surfaces has been defined as schematized in Table 2.

Table 2. Final configuration of urban surfaces in the case study area.

	Surface	Solution
Ground	Open areas	Increase of green areas of + 15%
	Road network	Water basin close to <i>Via Cagliari</i> hot spot Cool grey asphalt (albedo = 0.40)
Building envelope	Façade	Vertical greening on façades (i) exposed at south, (ii) along roads with high T_{air}
		BIPV on the surfaces with suitable solar potential
	Roof	PV panels on the most irradiated surfaces Cool paint on the remaining areas (albedo = 0.80)

The environmental analyses demonstrate the effectivity of this configuration. In terms of microclimate conditions, the air temperature is reduced in all the hot spots (Figure 7), with an average T_{air} decrement up to - 0.50 °C in *Via Cagliari* and *Via Milano*, and - 0.40 °C in *Via Palermo* and *Via Brescia*. Furthermore, the combination of increased relative humidity, and decreased surface and mean radiant temperature, produces an improvement of human thermal comfort. Hence, the UTCI is reduced on average of - 1.00 °C, decreasing the thermal stress from “very strong” to “strong” compared to the current configuration (Park, Tuller and Jo, 2014). Simultaneously, the production of renewable energy through solar active systems is guaranteed. The installation is possible on 6 500 m² of building envelope surfaces with suitable solar irradiation (i.e. $Irr_{SW} \geq 950$ kWh/m²), with a corresponding annual solar potential of 6 320 MWh/a.

Figure 7. Distribution of air temperature at pedestrian level at 15:00 in summer conditions - Current (a) and final configuration (b); Absolute temperature difference (c).

5. Conclusions

This study presented a systematic framework to support planning decisions based on accurate, diverse and spatially explicit information. The method implies the assembly of a multivariate spatial database of significant morphological and environmental parameters that influence the distribution of surface uses in cities and affect the priorities for their definition.

The application of the proposed method to a case study in Bolzano demonstrates the importance of understanding the distribution of urban parameters for taking spatially explicit decisions about the types of surface use allowable, and the extent and location of these. The three-dimensional visualization of the morphologic and environmental variables represents a solid base to relate urban planning decisions on surface uses and their effects in terms of microclimatic conditions, thermal comfort, and on-site renewable energy production. This is demonstrated by the results obtained in the final configuration, in which several uses have been systematically integrated on the urban surfaces of the district. With regard to high summer temperatures mitigation, the air temperature is reduced on average of -0.50°C , and the outdoor thermal comfort in the district is improved, with an average decrease of UTCI of -1.00°C . Simultaneously, the production of renewable energy through solar active systems is guaranteed, existing green areas are preserved, and $+15\%$ of new vegetation is added.

Future developments of the study will address the need for (i) a set of indicators and quantitative thresholds to identify the suitability of each surface to different uses, and (ii) more comprehensive criteria for the evaluation of the environmental effects of each use. Furthermore, the possibilities and potentialities for the inclusion in the current urban planning processes of the proposed framework and of indications on the surfaces uses will be investigated and tested in collaboration with the municipality.

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6. References

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