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# Modelling the effect of urban design on thermal comfort and air quality: The SMARTUrban Project

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## Abstract

More than half of the world population lives nowadays in urban areas and that's the reason why the quality of the urban environment has become a key issue for human health. In this context, it is important to estimate and document any action that contributes to improving thermal comfort and air quality. The aim of this paper is to present a system for the design of urban spaces developed in the framework of the SMARTUrban project. Such a system aims at giving a strategic tool to administrators and design professionals for sustainable management and urban planning. SMARTUrban is a prototype of an urban space design software that estimates the effect of design modification or of new design on thermal comfort, carbon sequestration and air pollutant removal.

## Keywords

urban planning,
thermal comfort,
carbon storage,
pollutants removal,
design software

## Article History

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## 1 Introduction

The continuous increase of population in cities inevitably leads to the rise of anthropic activities and different land use with repercussions for the urban microclimate (Akbari and Kolokotsa 2016; Kaloustian and Diab 2015; Mirzaei 2015) together with the accentuation of the differences in the temperature of urban areas with respect to the surrounding rural ones (Oke 1982).

The increase in population jointly with the increase in buildings affects weather variables such as temperature distribution and intensity. As stated by Grimmond (2007), cities make a strong contribution to local and global warming. One of the main reason is that urban materials (such as concrete, asphalt, etc.) modify soil permeability and contribute to storing energy and re-dispersing it in the form of heat, and are by themselves warmer (Dirmeyer et al. 2010). One of the main drivers of global warming is $CO_2$, and cities are known to be major sources of this gas. Indeed, a compensation of $CO_2$ emitted by human activities is achievable through sustainable urban planning. Urban greening, in particular, can contribute effectively to $CO_2$ atmospheric reduction by assimilation and storage, as $CO_2$ is converted into organic carbon by photosynthesis and then stored as woody biomass for the long term (Mori et al. 2016).

Another effect of urban population growth is the increase in air pollutant concentrations with a consequent rise in negative health impacts. An estimation to 2050 done by Lelieveld et al. (2015) of urban premature mortality states that mortality due to outdoor air pollution in 2010 is 2.0 million,

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but it is supposed to increase up to 4.3 million in 2050. In Italy, more than 34000 inhabitants died in 2010 because of exposure to transport-related pollution (Mori et al. 2015).

In this general context of ongoing urbanization, the number of people experiencing stressful urban environmental conditions is increasing. At our latitudes, the negative impact of urban climate on human health is stronger during the summer season. Among air pollutants, ozone reaches higher concentrations during summer, while other pollutants like particulate matter, nitrogen and sulphur oxides, peak during winter. Moreover, cities contribute to carbon dioxide emissions both locally and globally (Satterthwaite 2008).

Urban greening provides several benefits both in terms of pollution removal and temperature mitigation. On the one hand, trees and shrubs have the potential to remove large quantities of gaseous and solid (i.e. PM) pollutants, with plant leaf area and density, as well as leaf anatomical characteristics, playing a major role in determining the amount of pollutants sequestered (Mori et al. 2015). On the other hand trees and green areas contribute to mitigating the negative effects of the urban environment on both citizens' health and the environment (Petralli et al. 2014).

Hence, better knowledge about the urban environment and its peculiarities is the basis for future urban planning aimed at sustainable development, ensuring a better quality of life for citizens (Leyzerova 2016). Although there are many studies in the literature on the environmental dynamics of the urban environment, there is still a need to make this information easily accessible to urban planners and policymakers (Eliasson 2000; Roth et al. 2011; Massetti et al. 2014; Ugolini et al. 2015).

Numerical methods have become essential tools to analyze urban microclimate for engineers, architects, urban planners and policy makers for comparing urban design alternatives and providing guidelines (Toparlar et al. 2017). Two types of simulation approaches can be identified: energy balance based schemes like the Town Energy Budget (TEB) model (Masson 2000) and computational fluid dynamics based models like ENVI-met (Bruse and Fleer 1998). Initially these models were created to estimate meteorological conditions in large or small urban settings (e.g. air temperature, wind distribution, thermal properties in urban canyons). At the same time, specific models like *i-Tree* (Hirabayashi et al. 2012), were developed to estimate ecosystem services (e.g. carbon storage, air pollution removal) provided by urban forests. Currently, the tendency is towards the development of tools that are able to estimate thermal and air quality benefits of an urban design through a system that can be easily used and interpreted by urban designers and policymakers.

In this context the SMARTUrban project (Monitoring System and Territorial Urban Research) was conceived. The aim of the project is to develop a prototype user-friendly system for the design of urban spaces and for the estimation of their environmental impacts such as: human thermal comfort, air pollution, $CO_2$ storage and sequestration and sensible heat.

This paper presents the prototype of the software tool, realized within the SMARTUrban project, which aims to facilitate the estimation of the impact of an urban space design and to provide an easy-to-use interface for both the design and the estimation phases.

## 2 The software application

The SMARTUrban software has a graphic component for the design of urban spaces that are georeferenced through a GIS system and a database component implemented with a set of functions to calculate indices of environmental performances such as perceived temperature, energy balance, $CO_2$ storage and sequestration and pollutants removal. The graphic component is a proprietary software developed by Florinfo snc.

The database component was implemented using the spatial database PostGIS that is an extension for PostgreSQL object-relational database. It contains information about a large number of surface materials and plant species. Each material is characterised according to its thermal and radiative properties (albedo, heat capacity, conductivity and emissivity), and also by permeability (permeable or impermeable); tree species are clustered according to their similarity and characterized in terms of crown shape and size, leaf area index (LAI) and growth curves.

The software requires a dataset of the following meteorological parameters: solar radiation, air temperature, relative humidity, rainfall and wind speed. Thus, the user should upload a dataset that refers to a weather station near the working area.

The system calculates indices of thermal comfort and level of selected pollutants and $CO_2$ storage and sequestration, using a set of algorithms implemented in the procedural programming language PL/pgSQL (Procedural Language/PostgreSQL) supported by the PostgreSQL software.

The software involves 3 different phases:

1–DESIGN PHASE: the user can define his working area starting on a new empty layer or on the Google Maps plugin. After the area definition, the user can draw objects as surfaces, buildings, plants, defining them with their attributes such as type of surface, tree species, tree height, etc. (Fig. 1).

2–SIMULATION RUN: after the design phase and after having selected the indices needed as the final results, the simulation can be started. The project is transferred to the GIS engine that runs the mathematical model for the calculation of the environmental indices: