Programa Unificado de Bolsas de Estudos – PRG/USP 2018-2019

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## 1. Title

Generating urban canopy parameters for urban climate and environmental models: Sao Paulo as a testbed for an international collaboration project

## 2. Abstract

The WUDAPT (World Urban Database and Access Portal Tools, http://www.wudapt.org/) generates and provides information on urban form and function by and for a community-without borders. This activity builds upon a universal framework and commonly available input data so that urban surfaces for each city can be characterized and partitioned into unique Local Climate Zones (LCZs) endowed with sets of parameters used to describe the underlying physical, thermal and radiative properties. The particular collaboration between WUDAPT and PLEA (Passive and Low Energy Architecture, http://www.plea-arch.org/), coordinated by the supervisor of this proposal from the PLEA side,[1] intends to add further details and refinements based on an innovation approach that incorporates Architectural Typology (AT) framework in conjunction with employing crowdsourcing data gathering methods, and selected Sao Paulo as one of the testbeds for this new methodology. Recognizing that ATs vary between cites, regions and countries, hence the need for the expertise and experience of architectural community. Starting from the WUDAPT level 0 map (already done and published by this research group) the objective is to generate original maps of urban canopy parameters for urban climate and environmental models (WUDAPT level 1 and 2). This proposal is part of a series of ongoing studies in the same research group, at the Laboratory of Environment and Energy Studies – LABAUT/AUT/FAUUSP, broadening the scope of urban microclimate studies from the local to the city scale.

[1] This proposal is presented in English because it is part of an ongoing international collaboration project between WUDAPT and PLEA, coordinated by this supervisor from the PLEA side, detailed on item 9, describing relevant information for the evaluation process. The proposal has direct links with the research developed by the supervisor at FAUUSP in other projects financed by CNPq, Fapesp, Erasmus+ and TUM Global Fund, registered at the CV Lattes, Scopus, ORCID and Researchgate. The students enrolled must have intermediate English reading skills; besides the literature in this subject (mainly in English), they will interact with other partners involved, graduates and undergraduate students from different cities in the world.

## 3. Introduction and Justification

Cities occupy a unique position in climate science for a number of reasons. They occupy a small proportion of the planet's available land area yet house most of humanity and are the focus of resource use. Cities affect (and are impacted by) climate at a hierarchy of scales and the outcomes vary widely across the world depending on their geographic and topographic situation, their climate and weather regimes. The resulting model framework requires appropriate information on the underlying morphological features that impact the structure, dynamics and thermodynamics of the Urban Boundary Layer - UBL and human activities that generate wastes emitted into the atmosphere – however, for most cities in the world, including Sao Paulo, these data do not exist. Aiming to establish a fit-for-purpose modelling framework, a brief description of these parameters is presented. These urban parameters can be classified into five categories: land use, morphological, architectural, energy and uses, vegetation.

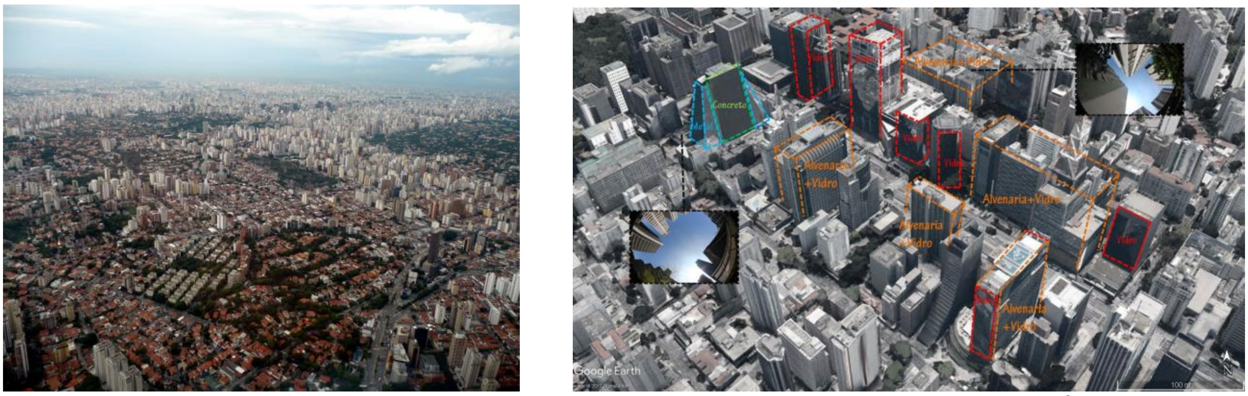


Figure 1 - Heterogeneous urban morphology in Sao Paulo. Urban geometry, building components and surface properties influencing urban climate.

(1) land use (and surface) fractions are parameters that describe the amount of surface that are in contact with the atmosphere. They are of primary importance, because the nature of each surface will strongly modify the energy exchanges with the atmosphere. For example, the impervious surfaces will favour sensible heat flux while permeable ones will favour evapotranspiration from soil and urban vegetation. The presence of walls will increase the surface of exchange with the atmosphere compared to a 2D flat surface, and this will tend to increase the storage heat flux, which is a major contribution of the energy balance in cities and drives the nocturnal urban heat island.

(2) morphological parameters are those that describe the 3D form of the urban fabric. Note that many indicators of these types exist, some may be retrieved by combination with other under certain hypotheses. One such hypothesis can be the urban canyon geometry approximation, which is often used in models. Canyon aspect ratio is then linked to sky view factor for example. Here are some of the indicators. Some of them are usually secondary parameters, retrieved from others. These include:

- building and road fraction (surface of buildings seen from above divided by the surface of the LCZ);

- surface of walls in contact with the atmosphere (or the ratio between this quantity and the surface of the LCZ). This parameter can eventually be deduced from road fraction and other morphologic parameters (such as the street/width canyon aspect ratio);
- impervious and pervious (distinguishing between vegetation and non-vegetated) surfaces fractions;
- mean building height. This is the key parameter, which is needed by all Urban Climate Models - UCM;
- building height standard deviation;
- roughness length. While this is fundamentally an aerodynamical parameter describing the air flow above a surface, it is classically estimated from the structure of the surface below. There are many ways to estimate the roughness length mathematically in cities;
- canyon aspect ratio (height/road width ratio) and sky view factor. These parameters give information on the pervious and compactness of the city, and its ability to trap the radiation and favour the storage heat flux;
- parameters that describe the arrangement between buildings, and can be used to define the roughness length.

(3) architectural parameters describe how buildings are built, and influence the radiative balance and the energy conduction between the building and the atmosphere. Hence, they can strongly modify the urban heat island. Many adaptation strategies are based on modifications of these characteristics, because they are relatively easy to implement, since this occurs at building scale. The architectural parameters that are directly used by the UCM are: depth, thermal conductivity, heat capacity (or thermal emissivity) of all wall or for each layer of wall (for example for the layer of structural material and for the insulation layer inside or outside) and for roofs.

(4) building's archetype (house, high-rise building, mid-rise building, industrial building). This is a parameter that allows to describe the typical individual building's structure within the LCZ. - the same for the inner floors and walls, if a Building Energy Module (BEM) is included in the UCM, as is the case for example ENVI-met (https://www.envi-met.com/) and Town Energy Budget – TEB (https://www.umr-cnrm.fr/isbadoc/projects/teb.html). Important parameters include: albedo and emissivity of walls and roofs, window wall ratio (WWR) e.g. the fraction of windows on the external facades (if a BEM exists), the thermal characteristics of the windows (if a BEM exists) and the presence of shelters on windows (if a BEM exists).

The main problem is that all these parameters depend on the materials used in the buildings, and this varies a lot in time and space. Furthermore, almost no generic information exists on these at large scale. However, an approximate approach is possible, which is to define, from experts in architecture or from crowdsourcing, an architecture database that will describe how, in each city, buildings are typically built, depending on:

- building's age;
- building's use (residential, commercial, offices, ...);
- building's type (single house detached, high-rise building, etc..., see morphological parameters above);
- geographic area (this can be the city or the neighbourhoods, the region, the country). This approach has been adopted in France, using an architect’s expertise approach to define how is built each type of building in each of the 95 administrative regions of France. This allows to describe a spatial variability between the different cities in France, but still not within each city.
- building's use and socioeconomic information, energy usage. Especially when BEM are implemented, the UCM require, for building related impacts evaluations, some information on the use of the buildings. Of course, all these information are likely to come from census (in very few countries), so are probably statistically grouped on larger surfaces than the LCZ. These information allow to compute the meteorologically-dependant anthropogenic heat fluxes, such as from domestic-heating and air-conditioning of buildings. If no BEM is implemented, a specification of the anthropogenic heat fluxes is also needed. In both situations, there is need for anthropogenic heat fluxes coming from the traffic and the industries releases.

(5) anthropogenic heat fluxes (traffic, industries, eventually buildings if no BEM is used). Information to generate this may be computed from knowledge of: fraction of each use in the building (e.g. to describe complex patterns as commercial in first floor, then offices and residential apartments above); information on internal thermal loads (how much energy per square meter comes from electric apparatus, cooking and so on); information on the domestic heating target temperatures (day/night); type of domestic heating; information on the occupancy or not of the building during daytime/nighttime/holidays; and information on air conditioning use and, if any, target temperature.

(6) vegetation parameters which is highly variable from one model to another, so no general rule or lists of parameters should be included here. This description also depends on the way urban vegetation is modelled, as none could be present in most models, while other models do include urban vegetation (low and high vegetation in the canyon, green roofs, for example). A list of vegetation related parameters include: height of trees, type of trees, leaf area index, etc.

WUDAPT is organized in three levels. The lowest level of detail (L0) consists of decomposing urban (and surrounding landscapes) into common Local Climate Zone (LCZ) types using local expertise, Landsat remote sensing data and software tools (Figure 3). The net result is an LCZ map of an urban region where each LCZ type is associated with a universal range of values that describe aspects of urban form and function. Currently, L0 data are available for more than 120 city regions across all continents. For Sao Paulo, an updated L0 map was generated and published by this group (FERREIRA et al., 2017). L0 data can be used as a sampling framework to gather more detailed information on cities (L1 data). Level 2 (L2) data provide complete coverage of the urban landscape and include information on individual urban elements (buildings, trees, etc.). In the WUDAPT scheme, the distinction between L1 and L2 data is not definitive but based mainly on precision and completeness. L1 data is to be generated by sampling the urban landscape using the L0 data as a sampling framework to provide a more precise estimate of the UCP values in each cell replacing the requirement of some arbitrary selection criteria dependency from the range of values based on the LCZ lookup tables. The methodology is based on a pragmatic approach based on a paradigm that incorporates regionally based building typology archetypes, with crowdsourced sampling approaches. Another benefits of Level 1 outcomes are the regeneration of the range of values in the table lookup of Level 0 as distributions for the LCZ by city. For the prototype, the quality assurance of this methodology include independent verification approaches compared using independently generated data including UCP data based on testbed cities that have baseline data such as available in Hong Kong, Dublin and many French cities, and also Sky View Factor (SVF) maps. In this phase, data generation methodology for several cities including Toulouse, Hong Kong, Vienna, Victoria and Sao Paolo will be raised. All results will be available via the WUDAPT Portal.

## 4. Objectives

Starting from the WUDAPT level 0 map (already done and published by this research group) the objective is to generate original maps of urban canopy parameters of Sao Paulo for urban climate and environmental models (WUDAPT level 1 and 2), as part of the WUDAPT/PLEA collaboration project. This proposal is part of a series of ongoing studies in the same research group, at the Laboratory of Environment and Energy Studies – LABAUT/AUT/FAUUSP, broadening the scope of urban microclimate studies from the local to the city scale.

## 5. Materials and Methods

Besides technical research support from Seção Técnica de Geoinformação e Produção de Bases Digitais - CESAD/FAUUSP (http://www.fau.usp.br/apoio/cesad/), on mapping, geographical information system, remote sensing, urban legislation, aerial pictures, statistical data, etc., and maps develop by QUAPÁ laboratory (http://quapa.fau.usp.br/wordpress/), also from FAUUSP, materials include original maps recently produced by this research group (unavailable by the public administration) encompassing:

- WUDAPT level 0 map for São Paulo, developed by this research group, presented and published in PLEA 2017 proceedings (FERREIRA et al., 2017);
- vegetation maps for São Paulo metropolitan area developed by a PhD candidate Fapesp 2015/17360-5; floor area ratio map, built volume map, sky view factor map for Sao Paulo city, developed by an undergraduate TT1

FAPESP 2017/12816-6, all of them part of an ongoing research project Fapesp 2016/02825-5, coordinated by this supervisor;

- previous data gathering resultant from the other ongoing and concluded research in the Laboratory of Environment and Energy Studies – LABAUT/FAUUSP, coordinated by this supervisor.

Starting from WUDAPT Level 0 map (already available), Level 1 methodology is based on building and architectural typology. In urban areas, the challenge is to organize the crowdsourcing activities with sampling strategies that account for the inherent and myriad of distributions of canopy building and vegetation entities creating spatial heterogeneities in the urban environment and which achieves the further requirement for meeting sufficient fit-for-purpose modeling applications levels of precision and details of both building data and their distributions and their UCPs. The building archetypes are based on four inputs: (1) urban types (LCZs, provided by the WUDAPT level 0 methodology), (2) information on geographical location (the city or country under consideration), and two other inputs, which are variable within each city; (3) date of construction of the building and (4) building use.

The gathering of the necessary information is not trivial. Two approaches are under development by WUDAPT. In the first, typical building characteristics can be evaluated in a region by experts. This is the methodology that was followed in France within the MApUCE project (http://www.agence-nationale-recherche.fr/Project-ANR-13-VBDU-0004). A collaboration with the international association Passive and Low Energy Architecture (PLEA) was started during the PLEA2017 conference in Edinburgh in July 2017. A group of architects, coordinated by the supervisor of this proposal, from the School of Architecture and Urbanism at the University of Sao Paulo - FAUUSP, is taking forward this important collaboration between WUDAPT and the architectural community. The second approach is to gather information using crowdsourcing APPs (CSAPPS), which complements the first approach (and will also be used by the PLEA community). The CSAPP questionnaire contained within a mobile application has been developed by another partner at WUDAPT, Dr. Linda See, from the International Institute for Applied Systems Analysis (IIASA) to allow people to provide information on individual buildings (which is an urban object and at a scale that is easy to apprehend). The questionnaire focuses on: 1) building function; 2) building age; 3) building material; 4) whether the buildings are painted (and the color if so); 5) window coverage; 6) existence of heating or air conditioning systems; 7) roofing materials; and 8) building height (number of floors). Even if all buildings are not described, a sampling approach to collect data across all of the different LCZs represented in a city will allow the spatial variability of the buildings to be approximated and provides input to customize the generic DSC. This general approach will be presented and evaluated for a number of cities around the world.

Many cities have Google StreetView images that can be retrieved in a web-based application via the Google StreetView API. Users can then identify the type of LCZ or the 4 to 6 building types from the MApUCE if validation is a primary concern, or answers to the previously identified questions can be collected such as the building function; the age of the building; the building material; whether the buildings are painted (and the color if so); the window coverage; the existence of heating or air conditioning systems; the roofing materials; and the building height (number of floors).

For WUDAPT, a survey-based mobile app has been built using ESRI's Survey123. The advantage of using this platform is that it is easy to use, freely available and works on both Android and iPhones. Concerning sampling strategies, the reason for sampling is to gain better estimates of UCPs (where level 2 data are not available) but also to obtain some indication in the variability of UCPs across LCZs or architectural types from MApUCE. The first approach is to create a systematic sample across a city. The advantage of such an approach is that you can approach level 2 data if the grid spacing is sufficiently fine. The disadvantage is that Google StreetView imagery may not be available at all locations and ground-based data collection may not be feasible (i.e. too many locations to visit or unreachable locations).

Targeting crowdsourcing strategies, experts in each city or region should devise a strategy for collecting the data. For example, they might recruit local experts in the city who are willing to contribute and/or they may involve a team of students as part of the curriculum. Data collection campaigns could also be aimed at broader citizen participation in the city but this would require incentives or ways of tapping into interested citizen groups, e.g. those concerned about the impacts of climate change.

**6. Detailing of activities to be developed by the scholarship holders**

1. Literature review on the following themes: urban modelling for architecture and microclimate purposes, urban energy balance, urban geometry and urban materials related to urban climate, climate amenities in urban areas, WUDAPT methodology, basic GIS techniques for modelling, basic remote sensing techniques for modelling (all scholarship holders).

2. Data raising of available 2D and 3D urban maps, data bases and other complementary data, specially holding information about: a) urban geometry: building height, height/width ratio (H/W); urban floor area ratio, site coverage, built volume, building setbacks, sky view factor (scholarship holder 1); b) building geometry, building components, materials and external colors, building energy consumption (scholarship holder 2): c) green infrastructure: parks, street trees, intra blocks vegetation, etc (scholarship holder 3).

3. Check and update those maps, as far as possible, to make them compatible in date, scale, etc. (all scholarship holders);
4. Define areas of interest for a pilot data collection using the APP Survey123 adopted by WUDAPT methodology and data gathering (all scholarship holders);
5. Check the methodology flow and refine the necessary steps (also due to the Sao Paulo city complexity and urban heterogeneity) for Level 1 data collection (all scholarship holders);
6. Analysis of results (all scholarship holders);
7. Conclusions and final considerations (all scholarship holders);
8. Writing of the final report (all scholarship holders).

## 7. Expected Results

After data gathering and methodology flow refinements, also due to the Sao Paulo city complexity and urban heterogeneity, the aim is to complete and make available the São Paulo WUDAPT Level 1 map, generating urban canopy parameters for urban climate and environmental models, as well as initial samples of WUDAPT Level 2 map for a next phase.

## 8. Execution schedule

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## 9. Other relevant information for the evaluation process

This proposal is part of a series of ongoing studies in the same research group, at the Laboratory of Environment and Energy Studies – LABAUT/AUT/FAUUSP and broaden the scope of urban microclimate studies from the local to the city scale, generating original maps of urban canopy parameters for urban climate and environmental models. During PLEA conference 2017, held in Edinburgh, Scotland (https://plea2017.net/), the supervisor of this project, Dr. Denise Helena Silva Duarte, was nominated by the PLEA Board (I was one of PLEA directors in the period

2011-2017) as the representative from PLEA in the WUDAPT/PLEA Collaboration Project. Besides that, a PhD candidate from FAUUSP, Luciana Schwandner Ferreira, integrates the team. Other international participants include: Edward Ng and Chao Ren (Chinese University of Hong Kong), Evyatar Erell (Ben-Gurion University, Israel), Rohinton Emmanuel (Glasgow Caledonian University), Gerald Mills (University College Dublin), Jason Ching (University of North Carolina at Chapel Hill), Julia Hidalgo (French National Centre for Scientific Research), Valéry Masson (National Centre for Meteorological Research), Linda See (International Institute for Applied Systems Analysis (IIASA), among others.

In December 2018, at the annual PLEA Conference to be held in Hong Kong, a pre-PLEA-HK2018 WUDAPT Level 1&2 Workshop will focus on specific collaborative activities initiated at PLEA 2017 in Edinburgh. In this one-day workshop, we introduce and review the methodology of WUDAPT's form and function urban morphological data generation developments and ENVI-met model enabling application capabilities using WUDAPT. This is achieved based upon recognition and adoption of varying building and architecture typologies that reflect the unique characteristics of each urban area's varying local climate zones and also assurances of accuracy achieved with universal consistency.

PLEA expertise and collaborations in testbed activities further assures the generation of form and function modeling parameters are regionally customized. The L1 and L2 complement WUDAPT Level 0 encompassing cities worldwide with a common platform and protocol. Efforts to integrate the WUDAPT to the ENVI-met tool, the latter widely used by architectural communities are also discussed. The ENVI-met team, coordinate by Professor Michael Bruse, is working on a tool to integrate WUDAPT and ENVI-met. Applications of this tool are being tested in São Paulo and will be presented in PLEA2018. This integration with ENVI-met is of great interest for the architectural community, since ENVI-met is already used for many researchers in our area, and can boost the desired integration between WUDAPT and the architectural community.

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