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Urban Morphology Extractor: A spatial tool for characterizing urban morphology

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ABSTRACT

Urban climate studies crucially depend on various urban morphological parameters. The availability of these parameters assists in understanding wind flow inside urban areas, Urban Heat Island (UHI) phenomenon and also aids in estimation of anthropogenic heat in Numerical Weather Prediction models for improved forecast. Of the two approaches used, micro-meteorological approach is un-suitable for urban applications due to various operational complexities. Morphometric approaches are more feasible to use in urban areas but their estimation requires automation. The paper presents a software suite which uses novel and existing algorithms to compute variety of urban morphometric parameters including frontal area, height-to-width ratio and sky view factor, which further can be used for the computation of aerodynamic parameters. The application is developed using open source technologies and each component is tested over a sample dataset. The estimated values were validated against manually calculated values and error percentage was found to be within 3% and then demonstrated on a real city database. The developed application can be effectively utilized for urban climate modeling studies, as it enables users to compute urban morphology parameters.

1. Background

Urbanization refers to the increasing number of people that live in urban areas. Urbanization which is closely associated with the modernization, industrialization and sociological advances is key concern for many developing nations. Indian cities and towns currently accommodate 300 million inhabitants and this is expected to rise by another 300 million in coming 20–25 years (Planning Commission of India, 12th Plan). To accommodate this huge population surge, high rise structures have taken the cities skyward which has led to a changed morphology in all three dimensions which impacts urban climate. Urban climate which is defined by the set of climatic conditions such as different levels of humidity, temperature and wind speed and direction that prevails in an urban area and most of the time differs from the climate of its rural surroundings. One of the most discussed and surveyed effect that urbanization leads to is Urban Heat Island (UHI) effect. UHI phenomenon, highly prevalent in cities, is hugely affected by the urban form and functions and it is defined as the affect that leads to substantial difference in the temperature of the urban area and the surrounding rural area. Urban areas are generally hotter as compared to their rural counterparts. This temperature difference is greatly due to the lot of anthropogenic activities, the material used for construction of three dimensional urban structures and the

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complexity of urban structures. The urban geometry also retards or channelizes the urban wind flow and significantly determines how the wind inside the urban area flows. Due to the high density of built up and impervious surfaces and the advent of high rise structures, wind flow is restrained and also the direction of wind flow is changed. Planned urbanization can lead to proper channelization of wind inside the urban area which will further ease the effect of UHI. Also, wind flow or proper ventilation inside the urban environment is effective to drain out the accumulated vehicular and anthropogenic emissions.

Urban canyon geometry/morphology, which varies with building's height, length, and spacing, has a significant impact on energy exchanges and the temperatures and wind profiles within urban areas (Grimmond et al., 2001). Roughness Length (z_0) and Zero-Plane Displacement Height (z_d) are two vital parameters that draw the concord between urban geometry and aerodynamic properties of an urban area. Plan Area Density (λp), Frontal Area Index (λ_f) (Grimmond and Oke, 1999; Burian et al., 2002; Wong et al., 2010), Frontal Area Density (Yuan et al., 2014), Depth of the Roughness Sub-layer (z_r) (Bottema, 1997; Grimmond and Oke, 1999) and the Effective Height (h_{eff}) (Matzarakis and Mayer, 2008) are some other key parameters that represent urban morphology. Other parameters such as Sky View Factor (SVF) and height-to-width ratio have a strong relation with the urban ambient temperatures. SVF is the ratio of the radiation received (or emitted) by the ground surface to the radiation emitted (or received) by the entire hemispheric environment (Watson and Johnson, 1987). SVF is the measure of sky openness and is being used to build relationship with urban ambient temperature (Nunez and Oke, 1976; Oke, 1987; Nichol, 1996; Chang and Goh, 1999). Recent studies (Scarano and Sobrino, 2015; Yang et al., 2015) establish the fact that there exist a positive relation between emissivity, land surface temperature and SVF. Height-to-width ratio is also being utilized to identify the urban areas with good and poor ventilation. Dispersion modeling that includes flow and dispersion of pollution at micro level or street level require height-to-width ratio as a main geometrical input to estimate flow (Nakamura and Oke, 1988; McHugh et al., 1997). A study conducted by Bakarman and Chang (2015) investigated role of Height-width ratio as an influential factor in the formation of UHI and results showed that UHI increases with the decrease in height-width ratio. However, estimation of frontal area, height-to-width ratio and SVF is difficult and complex for urban areas and the major challenge lies in the computation of these parameters.

Knowledge of aerodynamic parameters is required to gain insights of wind profile (Lyles and Allison, 1979), as inputs for urban dispersion models (Ratti et al., 2005), urban climate and air quality applications (Ching, 2013) and determination of ventilation pathways in urban areas (Gal and Unger, 2009). Mainly two approaches are being used for computation of urban morphometric parameters categorized as micrometeorological approach and morphometric methods. Micrometeorological method depends on extensive in-situ data which includes observations of wind direction and speed at different heights. Afterwards measured in-situ data is used for computations of parameters using log-law. An exhaustive site preparation as per the guidelines for installation of towers is required to take measurements at different heights. The urban areas are often not considered suitable for installing towers as per the site guidelines. Besides, the installation of large number of towers is not practically feasible in urban areas to capture the high micro-climatic variability within urban canopy layer. Hence, the application of these methods for estimation of roughness values for an urban area is limited. Computation of urban morphometric parameters using micrometeorological measurements considered to be quite accurate however due to the constraints of execution and site requirements, this method has less feasibility in urban areas.

The morphometric approach uses shape, size, density and height of urban roughness elements to estimate urban roughness length (z_0) and zero plane displacement height (z_d). Besides, Morphometric methods have opportunity of incorporation of satellite data and urban 3D databases which are nowadays abundantly available and can be used for 3D profiling of urban areas. These methods are also highly compatible with GIS technologies where remote sensing derived databases can be integrated for automatic and swift computation of roughness parameters. As urban areas span over a large geographical extent, hence automatic computation is must for capturing the vital morphometric parameters. Various past studies (Wong et al., 2010; Burian et al., 2002; Grimmond, 1998, Yuan et al., 2014) have efficiently used computer programs and GIS for automating morphometric parameter calculation for their respective study areas. Wong et al. (2010) and Yuan et al. (2014) used a computer program written in ESRI ArcGIS™ 9.2 software to compute frontal area index, Burian et al. (2002) used a 3D building database and an avenue script in ArcView™ GIS to automate calculation of various urban morphological parameters and Grimmond (1998) used GIS database to estimate urban morphometric parameters.

It is also established by some studies (Millward-Hopkins et al., 2011; Kanda et al., 2013) that a significant relationship exist between morphometric methods and anemometric methods, which consider height variability introduces a significant amount of drag in the skimming wind flow regime. Millward-Hopkins et al. (2011) observation was based on two vital parameters, surface area density and building height variability. Kanda et al. (2013) remodeled wind flow based on new parametrizations and illustrated wind flow over simplified array of buildings and arrays with height variations and estimated the displacement height. It was observed that there existed significant difference of 20–25% in the displacement height calculated over regular array and array with height variations.

The bottleneck however is the estimation of input parameters, as it is complex and tiresome, thus automation is usually preferred. However, most of the automation done (Gal and Unger, 2009; Wong et al., 2011) so far has limited scope and applicability, as it is majorly specific to the concerned study. There is still unavailability of a generic platform which can be used as a fully operational software suite, capable of computing all required morphological parameters and aid future studies.

With this point of view, this paper presents a standalone tool, named as Urban Morphology Extractor (UME), developed using open source technologies (such as Python, Numpy, GDAL/OGR etc.) designed to estimate frontal area by simulating wind in 8 directions, to estimate height-to-width ratio and to compute SVF, is presented. The UME intends to aid future studies in estimating input urban morphological parameters and thus, help researchers to invest more of their time in modeling parameters.