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Object-oriented approach to urban canyon analysis and its applications in meteorological modeling

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ABSTRACT

The study applies object-oriented analysis to the extraction of urban canyons and introduces the concept of directed urban canyon which is then being experimentally applied in urban meteorological modeling. Summary of current approaches for describing urban canyon geometry is provided. Then a new theoretical approach to canyon delineation and three-level hierarchical classification is presented. The study discloses an original methodology based on triangular irregular network (TIN) designed to allow extraction of directed and undirected urban canyons from cartographic data and estimation of their geometric characteristics. Obtained geometric properties of canyons are coupled with land cover data into the database, which is then applied in micro-to-local scale temperature and wind modeling. Using URB_MOS model and the derived database we refined COSMO_RU modeling results which facilitated the decrease of the mean root square error of temperature forecast from 4.0 to 2.1 degrees. Estimation of possible wind accelerations along canyons using the derived database is also presented. Results and future perspectives are summarized in the concluding part.

1. Introduction

A theory of urban canyons has been originally developed by Oke (Nunez and Oke, 1977; Oke, 1987) in the second part of XX century. According to this theory, an urban canyon is a three-dimensional space between buildings with two boards (building walls) and a bottom (the road). The main canyon parameters are its height H and width W, which together define height/width ratio that is being widely used in urban climate modeling. In some cases, canyon length L of the canyon and its azimuthal direction (orientation) θ are also being used. Fig. 1 illustrates these characteristics.

Short-term dependencies between the meteorological regime of urban canyons and their characteristics are significantly less investigated than their climatic properties. Almost all the existing models of the urban boundary layer consider canyons as one of the numerous land cover types, like parks or water bodies (Kusaka et al., 2001; Martilli et al., 2002). Dynamic models such as WRF (Shamarock et al., 2008) include urban block that can assimilate one fixed direction of an urban canyon (Kusaka et al., 2001). However, this approach is suitable for the cities with regular built-up layout and one prevailing canyon direction only. Masson (2000) developed a reductive scheme of thermal balance calculation for urban areas with more chaotic structure by integrating all possible canyon directions. This scheme was implemented as urban block in COSMO_CLM

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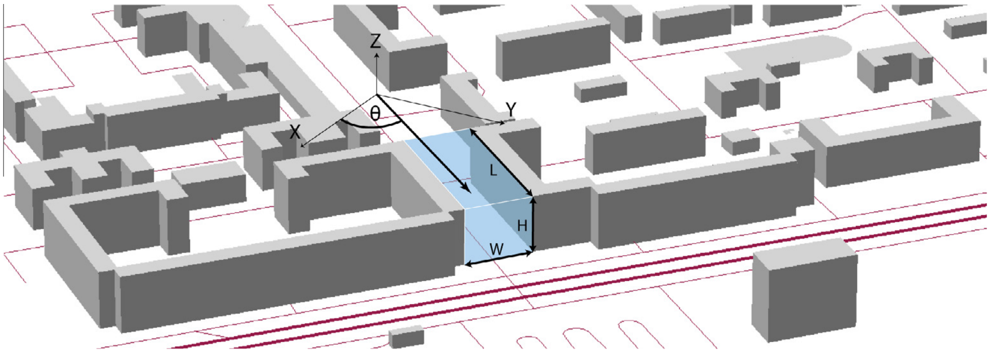

Fig. 1. Urban canyon and its parameters. W – width, H – height, L – length, θ – direction.

meteorological model (Trusilova et al., 2013). Inclusion of specialized urban module results in more detailed urban weather and climate forecasts. However, for some large cities like Moscow, Russia with radial-circular street layout prevailing, or Tokyo with its irregular street network, coarse canyon descriptions are correct for modeling average daily characteristics only and, consequently, for climatic predictions (Kislov and Konstantinov, 2011).

Short-term prediction of diurnal variation of meteorological parameters needs detailed description of urban environment. This description can be effectively derived from spatial data such as spatial databases (Lindberg, 2007; Gál and Unger, 2014) and remote sensing imagery (Moran, 2010; Peeters and Etzion, 2010; Pu et al., 2011). During the last two decades, significant progress has been achieved in development of supporting methods based on Geographical Information Systems (GIS). A wide array of urban geometric characteristics (Burian et al., 2002) can be derived and used in various tasks including meteorological modeling (Gál et al., 2008), architecture planning (Kropf, 1996) and even robots' navigation (Hrabar et al., 2005).

The main investigated geometric characteristics of an urban environment include canyon height/width ratio, sky view factor (percentage of visible sky from the point, abbreviated as SVF, see (Johnson and Watson, 1984)) and frontal area index (the ratio between area of the walls visible from a particular direction, to the area of the cell on which these buildings are located, see (Raupach, 1992)). Various algorithms are designed for calculation of these parameters, and results are used for urban climate investigations. Ratti et al. (2006) proposed a raster algorithm to estimate canyon height/width ratio. Unger (2009) revealed the connection between urban heat island and sky view factor using 3D Urban Database. Wong et al. (2011) calculated a frontal index and estimated urban ventilation from cartographic databases in various azimuthal directions. Chen and Ng (2011) used cartographic databases for SVF and frontal area density calculation, classified them to derive thermal load map and wind dynamic map respectively, and finally produced climatic map classes.

Urban geometry characteristics are usually calculated for *one point*, thus characterizing a particular location in urban space. A raster-based approach often helps to solve such tasks. If urban *digital elevation model* (DEM) is used for calculation, then height/width ratio or sky view factor are calculated for each raster cell using focal analysis (Ratti et al., 2006; Gál and Unger, 2014). The frontal area index, which is an integral value over some area, is also calculated by regular grid tessellation of the city (Wong et al., 2011).

At the same time, a large demand in characterization of an urban environment coming from architects, planners and meteorologists has lead to the emergence of such an interdisciplinary field as *urban morphology* (Moudon, 1997), which suggests the city to be described in terms of its physical form. In urban morphology approach the city is decomposed into three major elements: buildings, plots and streets, while four levels of detail are possible in investigation: building/plot, street level, city and regional levels. Various classifications are developed to decompose city structure (Kropf, 1996; Osmond, 2010; Oliveira, 2013). Kropf (1996) developed the concepts of specificity level, resolution level and outline/external form in urban morphology analysis. Böhm (1998) introduced the urban structural unit idea, which was lately evolved by Osmond (2010), who, in turn, introduced the hierarchy of inbuilt spaces such as parks. Recently Oliveira (2013) proposed the *morpho* approach to assess the urban form. His methodology considers only physical properties of an urban form and includes a limited number of characteristics that are used to estimate the degree of *urbanity*. It included estimation of accessibility, density and divergence of urban elements. One of the major parts of this study was related to the calculation of parameters of street networks and centerlines based on works of Hillier et al. (2010) and Turner (2007).

From this summary we can differentiate between two alternative approaches to investigation of urban environment. Urban climate researchers are interested in local or continuously distributed characteristics. Urban morphologists study the city as a structure of discrete geometric objects, each having its functional properties. The intersection of both approaches leads us naturally to the definition of urban canyon. This also gives raise to the urban canyon investigation from a new point of view, which is in between local point-wise calculations, and those averaged over some abstract area, representing the level of analysis of the canyon itself. Such investigations require a methodological framework to the definition, extraction and description of canyons as geometric elements of urban environment with the focus on meteorological applications. By using this integrated approach we will be able to make assumptions like "this particular canyon has high h/w