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Derivation of generic typologies for microscale urban airflow studies

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A B S T R A C T

Because of their structures, urban areas induce very complex airflow in the roughness sublayer while it notably impacts on urban microclimates, ventilation potential, pedestrian wind safety and comfort as well as building energy loads. Designing sustainable cities requires thus a pluridisciplinary approach. Therefore, this paper aims to support cooperation between urban designers and urban physicists/climatologists. After a review of air flow types in the urban canopy layer (UCL) in case of forced convection, this paper reviews qualitative and quantitative characterizations of urban structures used in urban airflow studies. Combining the morphological attributes identified as influential on airflow in the UCL with a morphological analysis of existing urban patterns in a transdisciplinary approach, generic typologies of isolated buildings and urban blocks suited for systematic environmental airflow studies are suggested. Within this framework, the complexity of the proposed types could be further increased towards realistic urban configurations.

1. Introduction

Urban buildings are mostly bluff bodies positioned close to each other, which shape airflow in the urban roughness sublayer (RSL) and more particularly, in the urban canopy layer (UCL). Resulting aerodynamic conditions strongly affect (1) pedestrian wind and thermal comfort (Blocken & Carmeliet, 2004; Chen & Ng, 2012; Ng, 2009; Stathopoulos, 2006) because of gusts or sheltered zones, turbulence and convective heat and mass transfers, (2) ventilation potential of urban spaces (Hu & Yoshie, 2013; Ramponi & Blocken, 2012; Steemers et al., 1997), which especially affect the urban heat island development and pollutant dispersion, and (3) building energy demand (Allegrini, Dorer, & Carmeliet, 2012; Bouyer, Inard, & Musy, 2011) because of convective heat transfers, natural ventilation processes and effects on renewable energy systems'efficiency. Considering the current context of climate change and urban development, the integrated – environmental – design of cities and buildings is one of the most effective means for ensuring the safety, health and comfort of citizens while reducing the environmental impact of cities. This is why some guidelines were proposed around the 2000s, helping designers to develop such an approach (Brown & DeKay, 2000; Givoni, 1998), part of which could be derived from vernacular urban design analysis. However, airflows in the RSL and more specifically in the UCL, are complex because of the complexity of urban structures, turbulence as well as the multiscale and multiphysic properties of urban atmospheric phenomena (see Arnfield, 2003; Barlow, 2014; Schlünzen, Grawe, Bohnenstengel, Schlüter, & Koppmann, 2011). To improve knowledge about these complex airflows, urban physicists/wind engineers/climatologists performed field or reduced-scale experiments as well as computational fluid dynamics studies (Barlow & Coceal, 2009; Blocken, 2013; Moonen, Defraeye, Dorer, Blocken, & Carmeliet, 2012) on more or less simplified configurations.

However, for this scientific knowledge to be more widely applied towards an integrated urban and architectural design, a framework that gather these applied science studies with urban morphology analysis appears valuable. Indeed, as shown in Ng (2009), coupling urban planning and wind engineering notions and skills may yield solutions for better urban wind environments. Urban morphology is currently understood in its environmental (bio-climatic) dimension (Lévy, 2005) as the 3D form of a group of buildings and the space they create (Steemers, Ramos, & Sinou, 2004),[1] i.e. as a material configuration composed of a relative arrangement of bluff bodies and unbuilt volumes. According to the classification of Fig. 1, urban morphology mostly refers to the three smallest scales of urban spatial analysis, i.e. the neighborhood, block and building scales. These scales correspond to the micrometeorological scale as usually considered in urban physics and climatology, and coincide with the scale of building wakes, i.e. airflow next to constructions.

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[1] Originally: "La forme tridimensionnelle d'un groupe de bâtiments ainsi que les espaces qu'ils créent."

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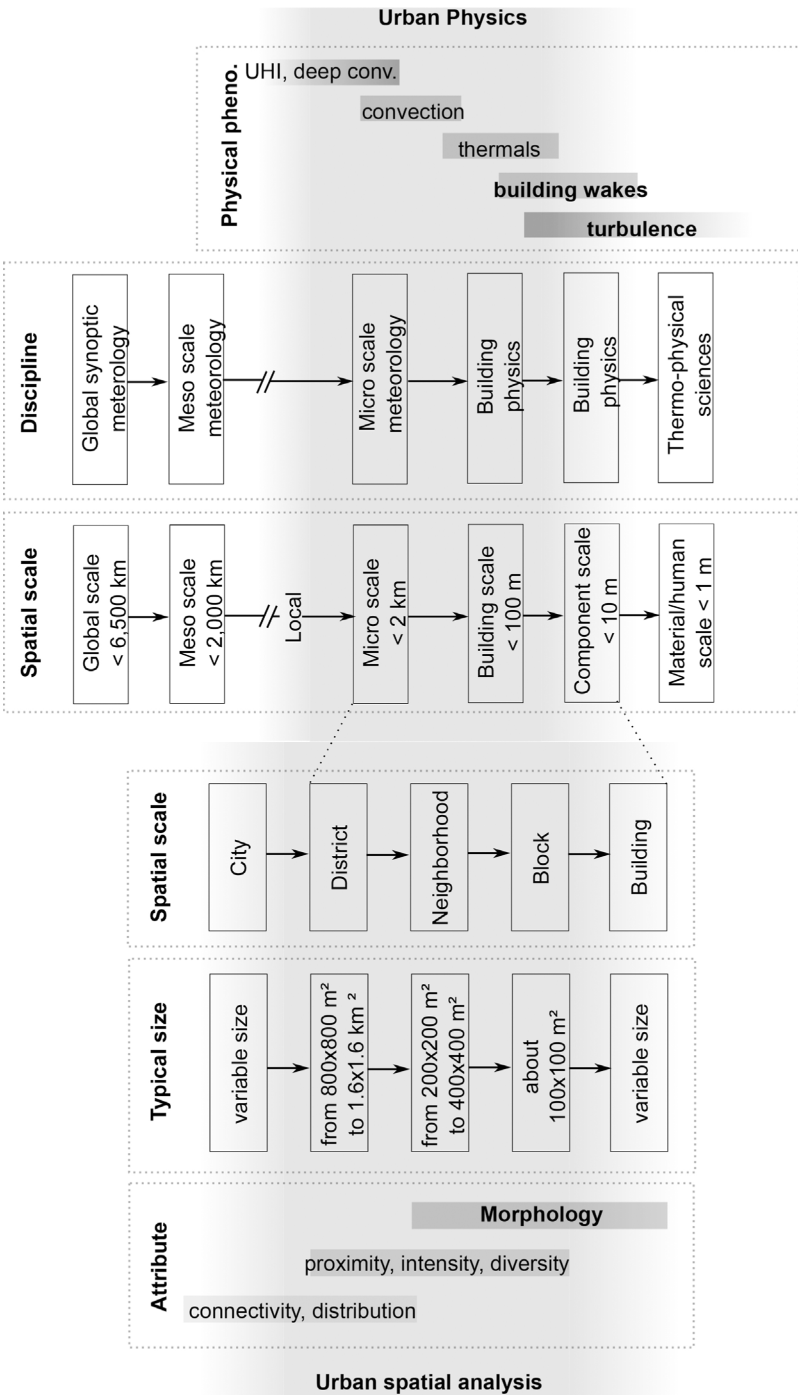

Fig. 1. Spatial scales related to urban physics and urban morphology analysis. (Based on Blocken, 2013; Blocken, 2015; Mirzaei, 2015; Salat, 2011; Schlünzen et al., 2011.)

Hence, aiming to support cooperation between urban designers and urban physicists, this paper develops a multidisciplinary approach that aims at (1) synthesizing the basic links between urban morphology and airflow types in the UCL in case of forced convection and (2) deriving representative generic typologies of building and urban block forms suited for systematic microscale airflow studies.

To develop this approach, Section 2 synthesizes airflow types developing in the UCL and details how urban forms are generally characterized from an aerodynamic point of view. Then, Section 3 combines the analysis of the literature review with urban morphology analysis concepts in order to derive the generic typologies. Finally, Section 4 summarizes the approach and open perspectives.

2. Airflow in the UCL and related characterizations of urban structures

2.1. Airflow types in the UCL

This section synthesizes basic airflow types that can be found in the UCL, around idealized and realistic urban forms. More extensive reviews can be found in Fernando et al. (2001), Britter and Hanna (2003), Ahmad, Khare, and Chaudhry (2005) and Barlow and Coceal (2009).

2.1.1. Airflow types around idealized urban structures

Focusing on a simple isolated bluff body, like an idealized building standing perpendicular to the incident flow without thermal effects,