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Using morphological analysis to predict the potential for high wind speeds

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SUMMARY:
Winds are deeply affected by the urban morphology, changing from street to street depending on the building landscape. A clear example for this is when new high-rise buildings are constructed and winds speed up in the area. Therefore, wind environments are very important when we aim at designing cities that are safe, comfortable and resilient. However, to determine wind environments, engineers usually apply computational fluid dynamic simulations or wind tunnel measurements. Which means that when architects iterate over preliminary designs, the possibilities of evaluating the wind impact of each of those proposal designs is unattainable. This motivates our work that aims at using open data to compute morphological parameters in Rotterdam and derive their effects in what we named "potential for wind velocity". To achieve this, we first define a limited set of urban parameters, such as urban canyon, wind- or leeward facade, angle of attack and terrain roughness length, and then relate them to a scoring method. Then we compare our scores with two meteorological stations inside the area of interest, showing that both stations show higher mean wind velocity for higher scores. We finally compare the results with computational fluid dynamic simulations in the area.

Keywords: urban winds, morphological analysis, CFD

1. INTRODUCTION

Current developments in urban areas and climate change effects are highlighting the importance of urban wind patterns when we aim to design resilient, safe and comfortable cities. However, it is really costly to perform accurate analysis of wind for each proposal when designing urban landscapes. From this point of view, simpler morphological analysis becomes a really attractive approach to reduce the number of proposal designs towards the best choices that then can be fully studied with computational fluid dynamic (CFD) simulations or wind tunnel experiments. In this regard, various researchers have shown in the past the effects of urban structures in winds (Oke, 1988), and proved that wind structure and turbulence profiles can be addressed with morphological methodologies (Jiang et al., 2008). In this work, we develop a morphological analysis based on most predominant parameters found in literature and compare the results with wind measurements (Jongh, 2021a). Further work will include the comparison with CFD simulations for multiple wind directions.

2. METHODOLOGY

To compute the morphological parameters we use a set of open datasets such as the Basisregistratie Adressen en Gebouwen (BAG) for building footprints, the Centraal Bureau voor de Statistiek (CBS) for polygons of urban neighborhoods, the Algemeen Hoogtebestand Nederland (AHN) version 3 for building height information (point clouds) and the Basis Grootschalige Topografie (BGT) for classifying the non-built space typologies and materials (roughness length).

2.1. Morphological parameters

To define the morphological parameters, we explore the literature and analyze the importance of already identified parameters.

2.1.1. Tall buildings

It has been already shown that tall buildings have a relevant impact in the wind environment (Blocken and Carmeliet, 2004; Tsang et al., 2012). As previous studies mentioned, tall buildings speed up winds in their laterals at pedestrian level due to the downwash from the building's façade. Furthermore, there is a relation between the height of the building and the area and intensity of the lateral speed up in neutral boundary layers. To detect tall buildings, we built a query with a threshold value based on the building height histogram for the area of interest. In our case that threshold was set to 23 m (Jongh, 2021b).

2.1.2. Urban canyon: building heights, street widths and lengths

Urban canyon is a parameter widely used that relates building heights (H) and street's widths (W) and lengths (L). Their ratio describes the shape of the canyon. Several authors evaluated the urban canyon impact in wind flows, deriving different type of flows so-called: skimming flow, isolated roughness flow and wake interference flow (Oke, 1988; Soulhac, Perkins, et al., 2008). To define the urban canyon we used voronoi diagrams. A voronoi diagram partitions planes into regions (voronoi cells) that are close to a set of objects. We use this partition method throughout the research to show morphological attributes as a map (see figure 1).

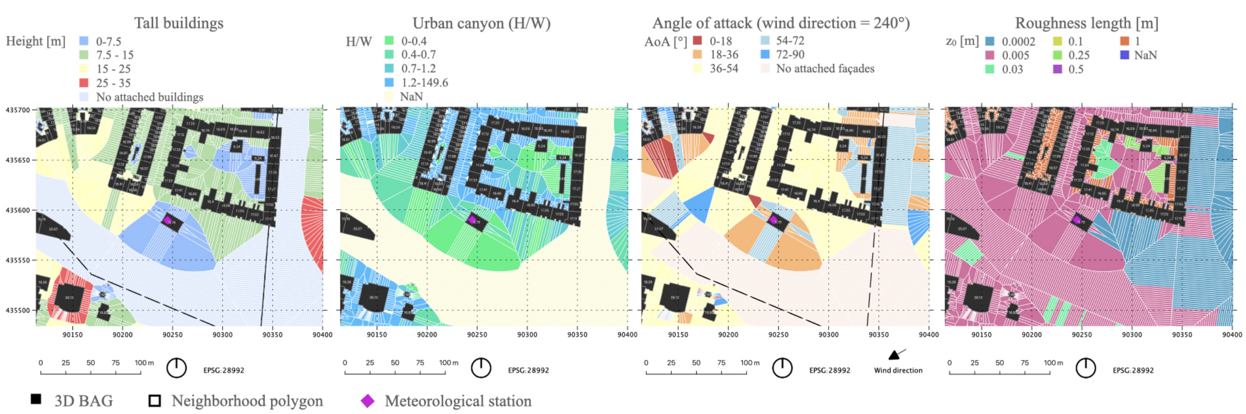

Figure 1. Maps showing the different parameters considered in the study area.

2.1.3. Wind- and leeward façades

Wind direction has been shown to be very important for urban winds (García-Sánchez et al., 2014). The Angle of Attack (AoA) of the wind with respect to the urban morphology leads to different urban wind patterns. For example, winds within streets aligned with wind direction will conserve on average the same wind speed, but cross-aligned streets will have lower speeds inside (Oke et al., 2017; Soulhac, Garbero, et al., 2009). To quantify this parameter, we analyze buildings and façades with the corresponding wind direction, leading to the AoA.

2.1.4. Roughness length for non-built areas

Roughness length (z_0) is one of the variables within the logarithmic profile for wind velocity in neutral boundary layers. The roughness length represents the material and terrain properties, determining accordingly the shape of the wind profile over it. Larger values of roughness lead to greater intensity of turbulence, while lower values lead to higher wind speeds at pedestrian level (Wieringa, 1986). To set the roughness length parameter in the non-built area, we use land use maps and interpolate them to our voronoi diagram.

2.2. Meteorological stations

For this work we focus on one area of Rotterdam of about 9.2 km^2, where different typologies of urban environments are included, such as industrial zone, high-rise buildings and waterways. For the purpose of this publication, we focus on the Delfshaven area results, although more areas are deeply addressed in (Jongh, 2021b).

We use two types of meteorological stations. First, for comparison and validation, we use two meteorological stations available through the RainGain project from Delft University of Technology (RainGain, 2021). Second, as reference stations we use two meteorological stations located outside of Rotterdam, one in the Rotterdam/The Hague airport and the other in Oude Leden (KNMI, 2021).

(a) (b)

Figure 2. (a) Delfshaven meteorological station; (b) location and tall buildings around it.

2.3. Scoring of the voronoi cells

In order to determine if a specific voronoi cell of the area has the potential for wind velocity, we use a scoring method based on the summation of 5 parameters scores shown in table 1:

3. PRELIMINARY RESULTS

Figure 3 (a) show the scores for potential wind speed in Delfshaven area. We can see fairly low scores around the area, which get lower inside building patios and higher for more exposed areas. From all the wind directions studied, we can observe in figure 3 (b) that actually 240° wind direction represents the case with minimum potential wind velocity around the measurement station.

Table 1. Different thresholds used for the variables based on literature and area of interest.

score	5	4	3	2	1
Height(H) [m]	H >= 23	15.7 <= H <23	13.34 <= H < 15.7	10.3 <= H < 13.34	H < 10.3
H/W ratio	H/W <= 0.05	0.05 <H/W <= 0.4	0.4 <H/W <= 0.65	0.65 <H/W <= 0.1	H/W > 0.1
W/L ratio			W/L >= 0.07	0.07 < W/L <= 0.56	W/L > 0.56
L/H ratio			L/H >= 3.69	1.42 <= L/H < 3.69	L/H < 1.42
AoA [°]	AoA < 18	18 < AoA < 36	36 < AoA < 54	54 < AoA < 72	72 < AoA < 90
windward				Yes	No
z_0 [m]	0.0002	0.005	0.03	0.1	z_0 >= 0.25

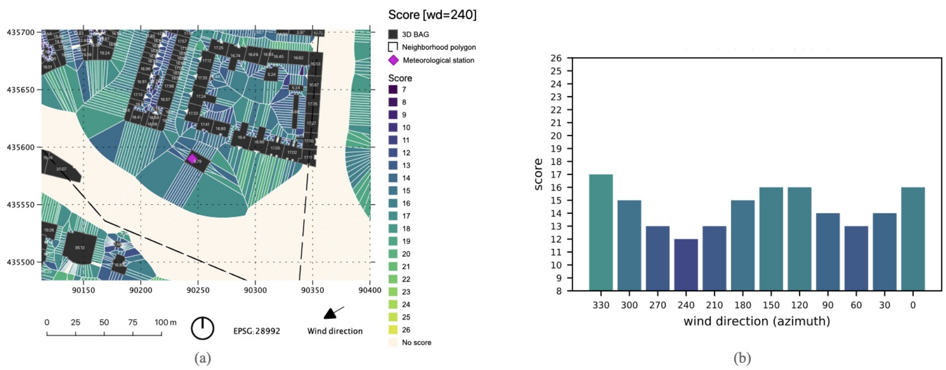

Figure 3. (a) Delfshaven scores for potential wind velocity; (b) Average score at the measurement station location.

4. FUTURE WORK

Currently, we are performing simulations in the Delfshaven area for multiple wind directions. The aim is to further support previous results shown in this work, but comparing the different wind speeds retrieved depending on the wind direction.

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