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## Morphological parameters for urban dispersion models

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## Abstract

A method to calculate geometrical input parameters for urban dispersion models is presented. Two cases are considered according to the relative size of the pollutant plume compared to the building size. Applying image processing techniques to urban Digital Elevation Models (DEMs, 3-D urban databases), simple geometrical parameters over extensive urban areas are calculated. Some preliminary results are shown for a case-study in central London. It is envisaged that the technique will be developed to support urban designers and planners to assess the performance of different urban developments in terms of pollutant dispersion.

## INTRODUCTION

Because of increasing concern about air quality in cities, the dispersion of pollutants over and through urban areas is an increasingly important research area. Several operational dispersion models exist which require the input of geometrical parameters for the detailed description of the flow field and dispersion characteristics in the urban environment. Up to date no structured methods to calculate those geometrical parameters within urban areas have been used. As a result of recent advances in digital photogrammetry and remote sensing, databases of the actual 3D geometry of city centre areas are becoming more easily available at low cost. The aim of the present work is to show a method of extracting, from this large amount of data the input parameters for dispersion models.

## RELATION BETWEEN URBAN MORPHOLOGICAL PARAMETERS AND POLLUTANT DISPERSION.

Considering a pollutant plume travelling over a dense urban area, two cases are differentiated according to the relative depth of the pollutant cloud ( $h_p$ ) with respect to the height of the buildings ( $H$ ).

When  $h_p/H \gg 1$ , the relevant dispersion parameters are the aerodynamic roughness length  $z_0$  which is related to the aerodynamic drag coefficient of the buildings and to a lesser extent the displacement height  $d$  which correspond to the zero Reynolds stress plane [1]. A recently published method (among many others) for calculating  $z_0$  and  $d$  argues that these parameters can be calculated using the plan area ratio:

$$\lambda_p = \frac{\text{plan area of the building}}{\text{total lot area}} = \frac{A_r}{A_p} \quad (1)$$

Given this definition, expressions for the roughness length and displacement height are:

$$z_0 = \left( C_1 + \sum_{j=2}^{10} C_j (\lambda_p)^{j-1} \right) H \quad (2)$$

and

$$d = [1.4352\lambda_p - 0.0463]H \quad (3)$$

where the  $C_j$  are prescribed coefficients [2].

A correct estimation of  $z_0$  has direct consequences for the calculation of the pollutant concentration and the growth of the dimensions of the pollutant plume. In fact, dilution of the plume depends on the turbulent velocity fluctuations which are proportional to the friction velocity  $u^*$ . The latter, given a fixed reference wind velocity, is dependent on the parameter  $z_0$ . Differences in  $z_0$  values result in differences in the pollutant concentrations. For example the vertical standard deviation of the distribution of pollutant concentration varies as  $z_0^p$  with  $p$  between 0.10 and 0.25 [4]. Furthermore, comparing the dispersion of a plume on a rural environment and on an urban environment, the roughness lengths are about 2 orders of magnitude different [3], and consequently the urban plume height is about 3-4 times larger than its rural counterpart [4]. As a consequence if Equation 2 is used for  $z_0$ , the ability to calculate  $\lambda_p$  is essential.

When  $h_p/H \leq 1$ , the situation is far less well understood and is still unclear what the relevant parameters for dispersion models are. Indeed, the dispersion problem is very likely to depend on the category of flow type as a function of the height to width aspect ratio of the street [5]. Further, it has been shown that the height over length ratio of the street canyons is also of importance, as well as, obviously, the wind direction. Hence, we believe that the relevant geometrical parameters for dispersion models should include the along-wind and the cross-wind street canyon aspect ratios histograms for any given wind direction.

## CALCULUS OF MORPHOLOGICAL PARAMETERS IN URBAN AREAS

In both cases described above,  $h_p/H \gg 1$  and  $h_p/H \leq 1$ , a question arises: how to derive the morphological parameters related to pollutants dispersal over extensive urban areas? Only a few years ago, this problem would have been almost unsolvable, because of the difficulties of finding extensive 3-D urban databases and the time required to process them.

Because of advances in digital photogrammetry and remote sensing, high-resolution urban Digital Elevation Models (DEMs) are now becoming increasingly common. DEMs are regularly spaced grids of elevation values and can be viewed as greyscale maps, where the level of grey is proportional to the height of the urban surface. An example is given in Figure 1, which represents an urban portion in central London. Due to their elementary data format DEMs are susceptible to a series of simple measurement techniques. In particular, we have developed a number of image processing algorithms, which are particularly fast and do not depend on geometrical complexity. These allow the derivation of the following parameters:

- The planar area ratio; the total lot area is calculated using the Sobel filters as described in [6];
- The width to height aspect ratio in the streets for a given wind direction and the relative distribution, as described in [7].

It is not possible here, due to the lack of space, to entail in a detailed description of the derivation of the algorithms. Results are presented in figures 2 to 4, while an introduction to the techniques can be found in [6].

### CONCLUSIONS AND FUTURE WORK

This paper reports on the calculation of plausible urban morphological parameters that are needed as input parameters for urban dispersion models. Histograms for the street canyon aspect ratios are also provided.

The next step is the development of the range of parameters, the study of their derivation on DEMs and the validation of results by comparison with numerical simulation and case-study measurements. The final aim of the work is to provide urban planners and designers with a tool that allows them to compare different development options in terms of pollutant dispersal properties.

### ACKNOWLEDGEMENTS

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### REFERENCES

1. J. C. Kaimal and J. J. Finnigan, *Atmospheric Boundary Layer Flows*, Oxford University Press, 1994.
2. C. S. B. Grimmond, T. Oke, *Aerodynamic properties of urban areas derived from analysis of surface form*, J. Appl. Meteorol., 38, 1261-1292, 1999.
3. J. Wieringa, *Updating the Davenport roughness classification*, J. Wind Eng. Ind. Aerodyn. 41, 357-368, 1992.
4. S. R. Hanna, G. A. Briggs, R. P. Hosker, *Handbook on Atmospheric Diffusion*, Technical Information Centre, U.S. Department of Energy, 1982.
5. T. R. Oke, *Boundary Layer Climates*, J. Wiley & Sons, 1978.
6. C. Ratti, P. Richens, *Urban texture analysis with image processing techniques*, Proceedings of the CAADFutures99 Conference, Atlanta, June 1999.

7. N. Baker, C. Ratti, *Simplified urban climate models from medium-scale morphological parameters*, Proceedings of the International Conference in Urban Climatology, ICUC '99, Sydney, November 1999.

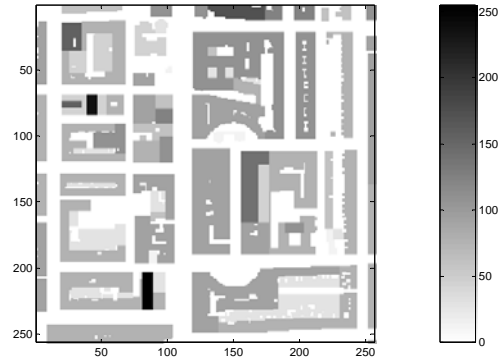


Figure 1 - Digital Elevation Model (DEM) of central London

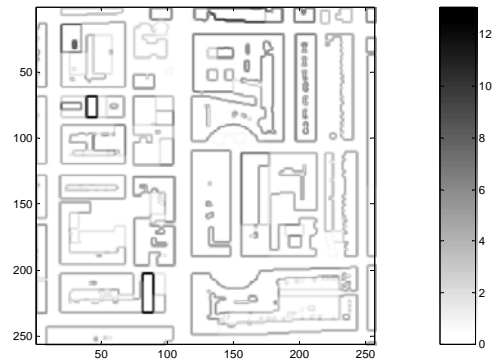


Figure 2 - Filtering the DEM with the Sobel edge detectors allows the determination the total lot area



Figure 3 - Height to width ratio in the North/South (azimuth=0) direction on the DEM; values in the streets range between 0 and 7

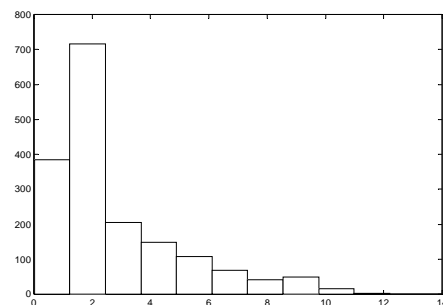


Figure 4 - Cross-wind summed histogram of the aspect ratio of street canyon calculated for the North/South (azimuth=0) direction