AN AGENT-BASED SIMULATION APPROACH TO URBAN MORPHOLOGY ANALYSIS

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ABSTRACT: The analysis of urban morphology and its impact on ventilation is a critical task in urban planning. Accurate urban-scale computational fluid dynamics models (CFD) are sometimes too expensive for rough estimations. Effective and convenient computer tools that could depict the pattern of the urban roughness are in great need. This paper presents a simulation approach which is grounded in the agent-based modeling (ABM) paradigm. A multi-agent simulation system is implemented which treats air particles as intelligent individuals that avoid obstacles and look for outlets based on 3-D building database. Path finding algorithms are developed to locate potential air paths and assess the ventilation condition. Various parametric models are built for a qualitative analysis of the model. A preliminary quantitative comparison with data obtained from a CFD model is also carried out in real world context. The comparison shows reasonable agreement between the present method and the traditional CFD method, suggesting that the ABM simulation approach can provide new perspectives to the wind engineering domain.

***Keywords**: Urban Morphology Analysis, Multi-agent System, Way-finding*

1. INTRODUCTION

The analysis of urban morphology and its impact on ventilation is a critical task in urban planning. Environmental modeling tools have been increasingly widely applied in this domain, as they allow design scenarios to be tested with a lower cost compared to physical models. Urban-scale *computational fluid dynamics* models (CFD) have been commonly used to fulfill this task, because they can provide accurate estimations of the aerodynamic conditions owing to the urban structure. A problem with CFDs is that they are normally expensive both in economic and computational terms therefore may impose limitations on their applicability.

The objective of this study is to evaluate urban morphology from a "layman's" perspective, i.e., to find an alternative of the traditional aerodynamic approach. A multi-agent simulation system is implemented which treats air particles as intelligent individuals that avoid obstacles and look for outlets based on 3D building database. Way-finding algorithms are developed to locate potential air paths and assess the ventilation condition. Both parametric model and real-world case studies are carried out to test the effectiveness of the proposed approach.

2. BACKGROUND

To characterize urban form from computational perspectives is not a novel idea. For example, Ratti and Richens [1] have shown that how image processing techniques can be applied in urban texture analysis. Burian et al. [2] have used 3D building database to analyze the urban morphology. Similar examinations are also conducted by [3-5]. These studies, despite their different focuses and implementational approaches, all aim to describe the urban morphology by indicators and quantifiers which can be evidently derived in the digitalized reconstruction of the urban environment. The urban-scale investigations make them practically applicable in environmental modeling and assessment, and therefore able to provide useful implications in urban planning and design.

As apposed to the aforementioned top-down methods which model the urban environment from the aggregated scale, the agent-base modeling (ABM) [6] approach is a promising modeling paradigm that describes the system by investigating the collective dynamics of its composing units. ABM is particularly suitable for characterizing spatially explicit processes or relationships, and has found its most common applications in traffic simulation [7], social simulation [8] and geographical studies [9].

ABM's accounting for the individual building blocks of a group naturally lends itself to the presentation of air particles. This paper presents a preliminary attempt along this line of research.

3. METHODOLOGY

The basic idea of the present study is to treat air particles as individual units looking for outlets. The concept of *way-finding* in artificial intelligence research is employed to study the blockage of buildings and find potential ventilation paths. Surface roughness of the urban environment is used to evaluate path cost.

3.1 Way-finding model

Way-finding in artificial intelligence generally refers to the determination of the "best" route between two points through a searching approach. The definition of "best" varies depending on different criteria of the route: shortest distance, least cost, etc. Our primitive motivation of this study is to find a path traversing the urban area along the wind direction. The cost of the path can be used as an indicator of the blockage effect of buildings on the approaching wind. Figure 1 gives an illustration of the way-finding concept based on two 2D pseudo urban settings. The wind is assumed to come from the north.

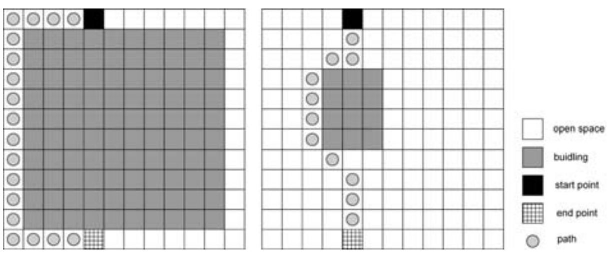


Fig. 1 Way-finding in two pseudo urban settings.

One thing to be noted is that, how the path is diverted from the start point can reflect how the buildings block the wind. This forms the basis for the definition of the *Traverse Cost*, which is the weighted length of a selected path traversing the urban area. Path diverted farther from the start point is "punished" by assigning a larger weight when calculating the cost. Dijikstra's famous *A* algorithm* [10] is used for the path selection process. A program provided by Lester [11] is modified for the Traverse Cost calculation.

3.2 Surface roughness simulation

The way-finding model introduced in the previous section considers the urban space as homogenous terrain with two states, i.e., building and open space, and does not concern variations in surface roughness. However, in real-world cases, differences in building height and density will have significant influence on wind environment, as has been extensively discussed in [12]. In this sense, the morphological feature of the urban structure, describe by the indicator of *frontal area density* (FAD) [2] is simulated using 3D building database. FAD is a measure of the frontal area per unit horizontal area per unit height increment, and is defined as follows:

$$a_f(z, \theta) = A(\theta)_{proj(\Delta Z)} / A_T \Delta z \qquad \text{Eq. 1}$$

where $A(\theta)_{proj(\Delta Z)}$ is the area of building surfaces projected into the plane normal to the approaching wind direction for a specified height increment Δz; θ is the wind direction angle; and A_T is the total plan area of the study site. For a specified wind direction, the integral of *af(z)* over the canopy height equals the roughness length.

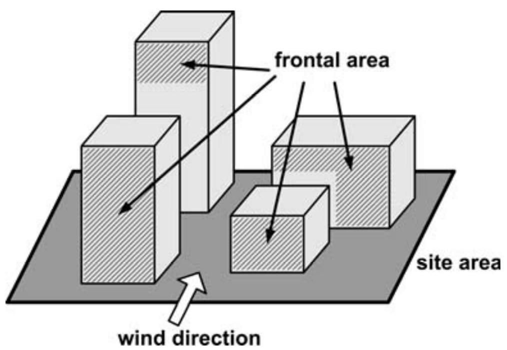


Fig. 2 Illustration of the spatial layout for the calculation of FAD.

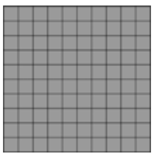
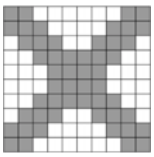
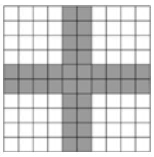
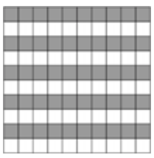
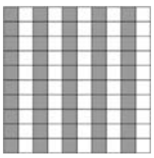
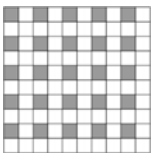
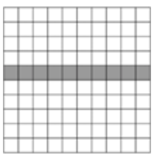
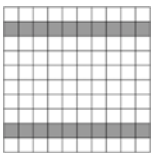
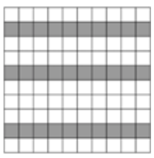
As its definition implies, higher FAD will indicate larger blockage of wind. Therefore FAD is integrated in the path evaluation in the way-finding model as the path weight.

4. CASE STUDY

4.1 Parametric study

A number of parametric models are built to test the effectiveness of the Traverse Cost. The studied pseudo urban environment is 10 × 10 in size with each gird as building area, which is unwalkable or open space, which is walkable. The wind is assumed to come from the north. Ten agents are placed at the top of the domain and assigned an initial speed to move top-down, simulating the air particles. The total Traverse Cost of each agent after traversing the model is calculated. Table 1 shows the result of the analysis. Dark grids indicate building and white grids indicate open space.

Table 1 Parametric model and Traverse Cost analysis.

 1: Σ = 440	 2: Σ = 336	 3: Σ = 202
 4: Σ = 410	 5: Σ = 60	 6: Σ = 55
 7: Σ = 170	 8: Σ = 342	 9: Σ = 380

*Σ is the total Traverse Cost.

The result of the parametric study is consistent with the common wisdom, which is that blockage perpendicular to wind direction will have greater influence on the ventilation condition, as is indicated by the larger Traverse Cost in Model 4, whereas blockage parallel with the wind direction will have a much less impact, as indicated by the case of Model 5. Also, displacement between buildings will substantially increase the ventilation, as illustrated by the case of Model 6.

4.2 Real-world case study

In this section, a preliminary comparison between the ABM approach and CFD simulation for a real urban area is presented.

The study site is a coastal area with flat terrain and similar land use, i.e., commercial buildings. For most of the time in a year, the prevailing wind comes from the east. A dataset obtained from an earlier CFD study [13] is used. The index of Wind Velocity Ratio (VR) is adapted to describe the wind environment, with larger VR indicating larger wind speed and therefore better ventilation. Figure 3 shows a map of the CFD result.

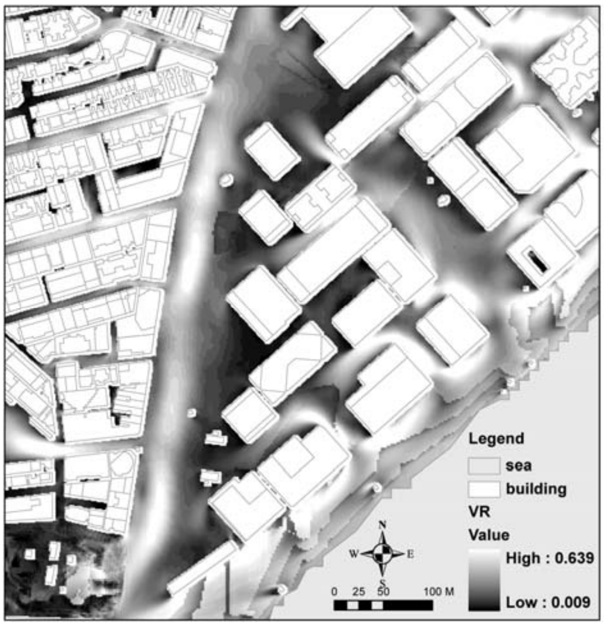


Fig. 3 CFD result of the study site.

The urban environment is divided into cells of size 100 m × 100 m. The mean VR of each unit is calculated. Each cell is further divided into 100 × 100 units and 100 agents are generated to traverse the cell unit from the right to the left, simulating the prevailing east wind. FAD for each cell is calculated and used in the way-finding process. The total Traverse Cost of the agent traversing a cell is calculated and assigned to that cell as an evaluation of the local ventilation condition.

As an initial study, only the cells along the sea front are analyzed because the local wind environment is relatively simple, i.e., with less turbulence such as downwash effect due to the irregular buildings. In practice, the Traverse Cost for 9 cells is calculated, as indicated by the rectangles in Figure 4. The average VR is also shown for reference.

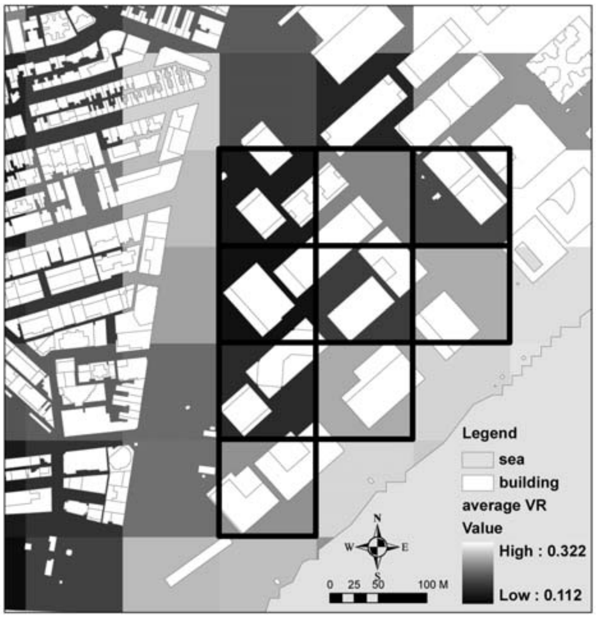


Fig. 4 A map showing the cells used in the analysis.

A linear regression analysis is carried out. The result is shown in Figure 5. The correlation in intra-urban area, as predicted, is scattered and therefore is not shown here. There result shows that Traverse Cost is reversely proportional to VR with reasonable explanatory power (R^2 ~ 0.74), suggesting that it can be used to describe wind blockage to a substantial extent.

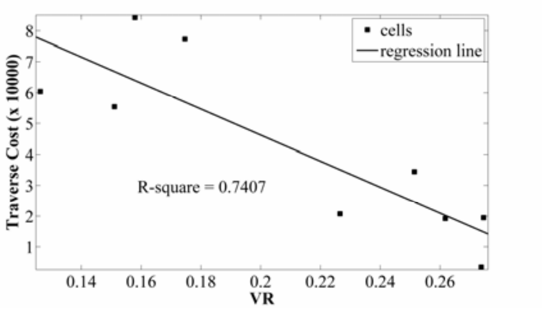


Fig. 5 Correlation between Traverse Cost and VR.

5. CONCLUSION

The present study demonstrates a proof of concept of how the bottom-up modeling approach could be applied in urban morphology analysis. A novel method is introduced, which is to evaluate the "cost" of a path traversing the urban area based on surface roughness. Multi-agent simulation is implemented to account for air particles in investigating the local ventilation condition. Through a primitive analysis, it is shown that way-finding principles in computer science domain can be used, at least partially in morphological analysis as an alternative to the conventional aerodynamic techniques.

It has to be noted that it is not the objective of this paper to build a model to describe the characteristics of urban form accurately, e.g., to calibrate the model to correlate well with other aerodynamic approaches. Rather, it aims to reveal how local features can be analyzed to imply global pattern in environment modeling and assessment. Theoretical frameworks and implementational paradigms in complexity study are highly related to this line of research, and are expected to bring new perspectives into this domain.

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