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Effects of modeling detail of 3D city models on CFD Urban microclimate assessment

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Summary

Urban microclimate study typically focuses on modern developments and developed parts of the world, leaving historic urban environments and urban forms in developing countries. Resource limitations in such contexts for modeling further create challenges. This research aims to explore the effect of the level of detail in modeling on urban microclimate Computational Fluid Dynamics (CFD) study. It will assess whether 3D models acquired from different resources, typically with limited detail, create different results compared to detailed models. Zanzibar City will be studied, with a focus area primarily on the UNESCO-registered Stone Town and Ng'ambo. CFD will be used to study microclimate variations in pedestrian wind, urban corridor ventilation, and convective heat exchange by simulating representative urban models with varying levels of detail in modeling. The research will contribute to the understanding of the effect of urban modeling level of detail on urban microclimate studies in developing countries and unexplored climates.

Keywords: *Microclimate, LoD, Pedestrian wind, Urban ventilation, Convective coefficient, CFD*

1 INTRODUCTION

The urban microclimate has a significant influence on various aspects of urban life, influencing urban comfort and impacting human well-being, while also shaping building performance and energy use patterns. The influence varies based on different shaping factors, such as urban forms, the impacts of which were shown to alter wind flow patterns that create multifaceted influences (Adamek et al. 2017). Several studies have highlighted the limitations of urban microclimate studies in developing parts of the world (Mills 2014; Barros and Bueno 2024). Besides this context and climate-related limitations, there exist gaps in Computational fluid dynamics (CFD) studies in terms of geometric modeling. Due to a lack of information and to reduce model complexity targeted at limiting experimental effort and computational costs, CFD models are usually oversimplified (Ricci et al. 2017; García-Sánchez et al. 2021), while the quality of the geometry model is crucial (Hågbo et al. 2021). Complex facade details, roof geometries, and other significant details are usually overlooked. Despite this trend, however, several studies have shown the significance of modeling on the accuracy of CFD results. Hgbo et al. (2021) identified that building footprint extruded models showed variations in pedestrian wind comfort compared to detailed models. Garcia-Sanchez et al. (2021) have shown that local wind conditions and pedestrian wind comfort are shaped by the varying level of detail and changes from flat roof models to simple shape roofs affect CFD simulation results. Other studies have similarly shown that simplified models created less accurate results compared to approximated and detailed models (Ricci et al. 2017). These studies are limited to contexts in the developed parts of the world and focus on assessing the impacts of modern development. Despite the significance of geometric modeling detail its impact and overall microclimate research are limited in developing and historic contexts.

This research will explore the effect of the level of detail in 3d city modeling on CFD results of different urban microclimate conditions using Zanzibar city in Africa as a case study, with an overall goal of contributing to the understanding of urban microclimates in developing countries and unexplored climates. The research aims to explore how changes in geometric details, mainly roof detail, and surface properties of significant structures affect microclimate variations. Unlike the focus of earlier studies on individual microclimate influences, this study will explore multiple urban microclimate variations.

2 METHODS AND MATERIALS

This research will assess urban forms in Zanzibar City, which has a history of over 800 years of development. The UNESCO-registered part of Zanzibar, Stone Town, is described as a representative Swahili coastal trading town in East Africa, with cultural elements from Africa, the Arab world, India, and Europe. Ng'ambo has part of the city, which is inscribed as a buffer zone for the Stone Town heritage site. For this research, four types of models will be used with details ranging from footprint extrusions to detailed 3D city models. For comparison, the selection considers historical influences and representativeness. Among the significant urban topologies identified are Bazaar street, Michenzani area, grid Swahili, and organic Swahili, and Karume new town. A wind blowing from the southeast-by-south direction is selected for this study.

Best practice guidelines (BPGs) (Franke and Baklanov 2007; Tominaga et al. 2008) along with pedestrian-level wind environment studies of similar city-level studies (Adamek et al. 2017) and geometric modeling detail effect studies (Ricci et al. 2017; Hågbo et al. 2021; García-Sánchez et al. 2021), were closely followed in setting up the simulation. In the case study area, a suburban area with roughness length of z_0 of 0.05 was considered to determine the inlet velocity profile. The pedestrian-level wind assessment focuses on the mechanical effects of wind on comfort, considering the velocity amplification factor to make comparisons across models. Reynolds Averaged Navier-Stokes (RANS) solutions are used in with a standard RANS-based technique in CFD, a widely used turbulence model (Shi et al. 2015) with k-ε turbulence model. Domain size and boundary conditions, with a box-shaped domain, are used in the study following BPGs. Similar urban-level pedestrian wind environment studies are also used as a reference (Adamek et al. 2017). A smaller maximum blockage of 3% recommendation was used to determine the lateral extension and height of the domain. Polyhedral meshes were used to discretize the computational domain, with three zones of varying meshing levels, and the highest grid resolution on building surfaces and the core area of study. Grid-sensitivity analysis was conducted with three base sizes, with a basic grid with a base size of 20 m identified as suitable for the study.

3 RESULTS

Preliminary CFD simulations were first conducted with a simple footprint extrusion 3D city model. Figure 1 shows velocity amplification factors (VAF) values for pedestrian wind comfort assessment, urban ventilation potential residence time plots, and convective heat coefficients. The results show the Michenzani area exhibited high wind flow activity and the highest values of VAF. The case also has a significantly higher percentage of areas with compromised urban ventilation potential, particularly associated with the Michenzani blocks. The blocks also significantly influence the convective heat coefficient value distribution. The case study of Darajani, exhibited lower VAF and less wind activity, some areas with limited urban ventilation potential, and higher convective heat coefficients on multistory buildings. Wind activities were also identified to be lower between single-story Swahili houses. The next phase of this research will consider a comparison of these results with other simulation results using models with different levels of detail. The comparison will assess whether the addition of details for roof structures and facade details of multi-story buildings will significantly influence CFD simulation results. Particularly, mean VAF values, urban corridor ventilation potentials, and convective heat coefficient values will be compared to identify the influence of modeling decisions.

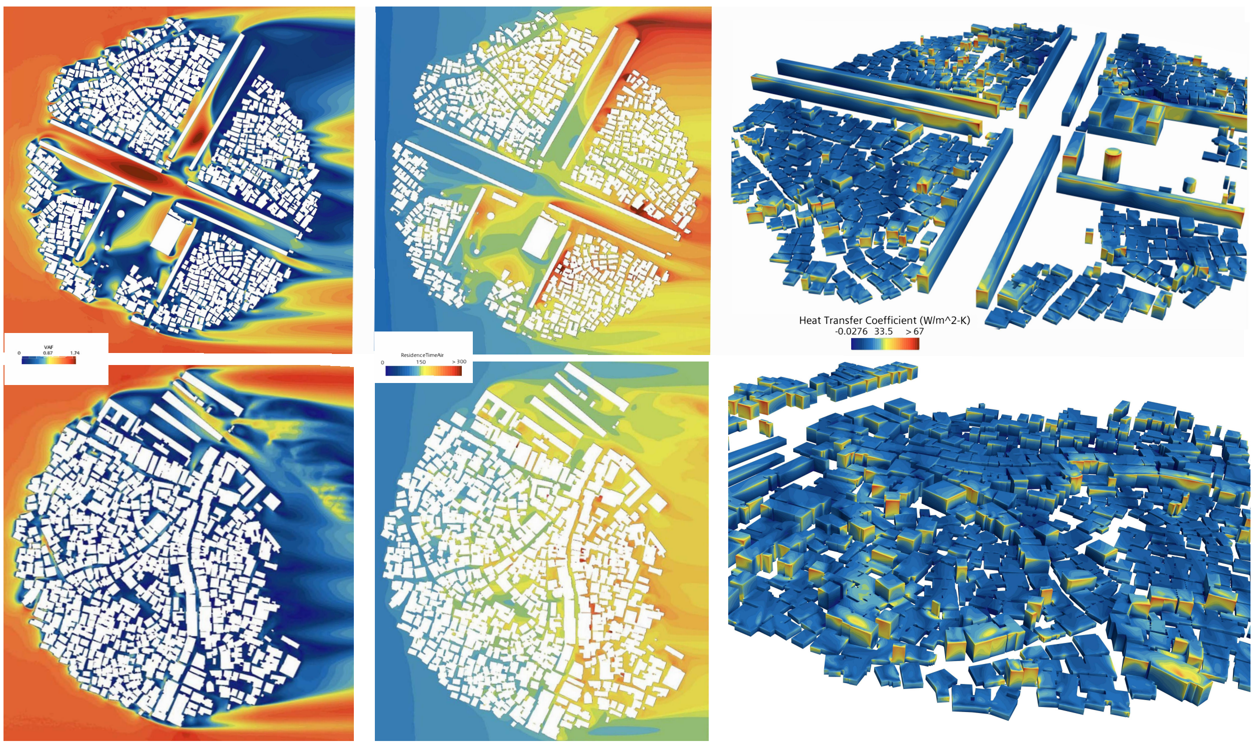

Figure 1: Microclimate variations, Case 1 Michenzani area (top) and Case 2 Darajani area (bottom)

4 DISCUSSION

Preliminary assessment of results shows that variation in urban form influenced the microclimate. It can thus be understood that the microclimate of cities, the comfort of its inhabitants, and the performance of buildings are associated with historical and contemporary urban planning and design influences. An important exploration in the next phase of this research is to understand the influence of modeling in understanding this association. The addition of roof detail and facade detail is expected to significantly alter CFD results. Comparison of the different models that will be used in this research is expected to exhibit varying levels of influence in different urban forms studied. Areas with predominantly single-story Swahili residences were identified to have low values of VAF, which correlates with earlier studies that show low wind speed associated with uniform building height and narrow streets (Hanqing and Frank, 2012). This research will assess how these patterns of low VAF values could potentially change with the consideration of roof and facade details.

5 CONCLUSIONS

Considering the urban microclimate research gap in developing parts of the world, along with resource limitations, this research proposes to explore the influence of the level of detail in 3D city modeling on urban microclimate CFD study. Based on preliminary results, which show variation in pedestrian level wind environment, urban ventilation potential, and convective heat coefficient of buildings, a comparison between four types of models will be used, with details ranging from footprint extrusions to detailed 3D city models. Results from the preliminary assessment presented, such as areas of low VAF values in single-story Swahili residences and areas of low urban ventilation potential associated with multi-story buildings, will be compared to assess their level of variation as the model level of detail varies. The research is intended to contribute towards the development of best practice guidelines in CFD study in developing parts of the world, and identify suitable modeling approaches to identify urban microclimate variations in different urban forms.

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