Simulating carbon dispersion in the outdoor built environment using urban building energy modeling and computational fluid dynamics

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Motivation

With climate-related hazards like heatwaves, fires, hurricanes, droughts, and floods becoming more frequent, reducing atmospheric carbon has become a priority. In cities, efforts to reduce atmospheric carbon have primarily focused on lowering building energy consumption. However, studies suggest that simply minimizing building energy consumption won't be enough to meet the Paris Agreement's targets [4]. To achieve these goals, new building materials and urban designs are being explored to transform cities into carbon sinks [1, 5].

Before evaluating carbon sink strategies' efficacy, we must assess the potential amount of carbon dispersed within the urban canopy from various anthropogenic sources, including buildings. For this reason, this study aims to simulate carbon dispersion within the urban canopy using urban building energy modeling (UBEM) and computational fluid dynamics (CFD). UBEM is employed to estimate carbon emissions from buildings at the neighborhood scale, while CFD simulates carbon dispersion through air movement within the urban canopy.

Methodology and preliminary results

Figure 1 shows the method to be implemented for studying carbon dispersion in the outdoor built environment using an Urban Building Energy Model (UBEM) and Computational Fluid Dynamics (CFD). The UBEM consists of various Building Energy Models (BEMs), which are generated from a 3D city model and a database as white-box, grey-box, or black-box models. The 3D city model defines the geometry, geolocation, and orientation of buildings, while the database contains information related to their materials, internal heat gains, and heating/cooling systems. Using City4CFD [3], the 3D city model can be expressed as an input for CFD-based simulations of the outdoor environment. The urbanmicroclimateFoam solver is intended to be used to assess outdoor conditions while being coupled with BEMs. In addition to wind motion, which is provided by most solvers accessible in OpenFOAM, urbanmicroclimateFoam estimates outdoor temperature and humidity, considering building materials and solar ray tracing [2]. Its features can easily be extended to incorporate carbon dioxide dispersion, as shown in Figure 2.

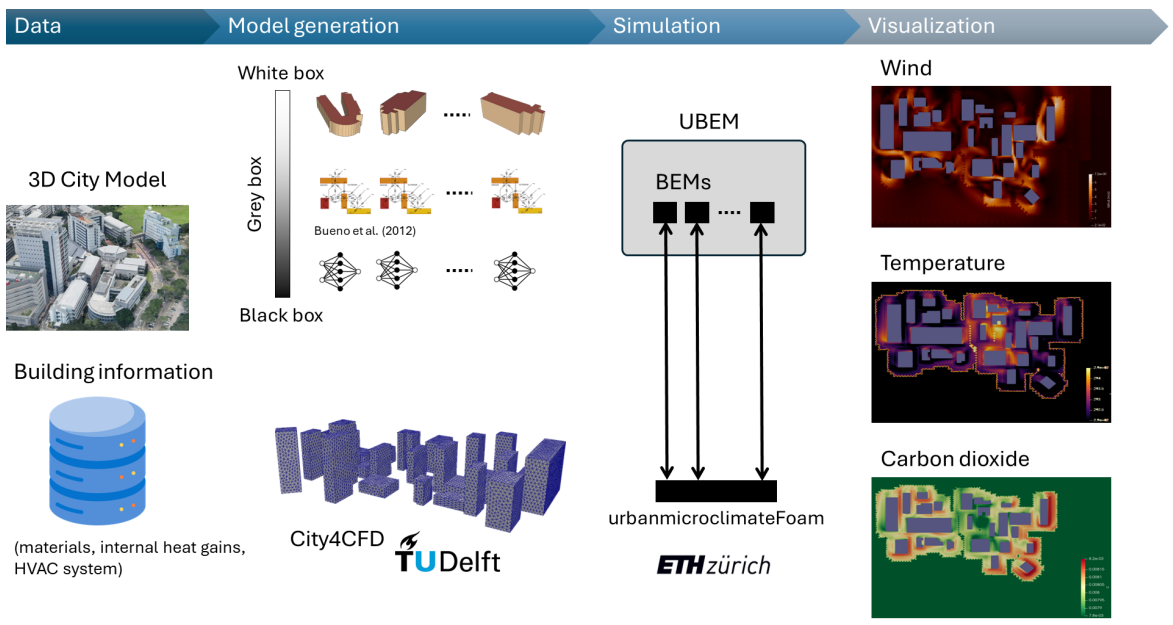

Figure: Proposed method to study carbon dispersion in the outdoor built environment

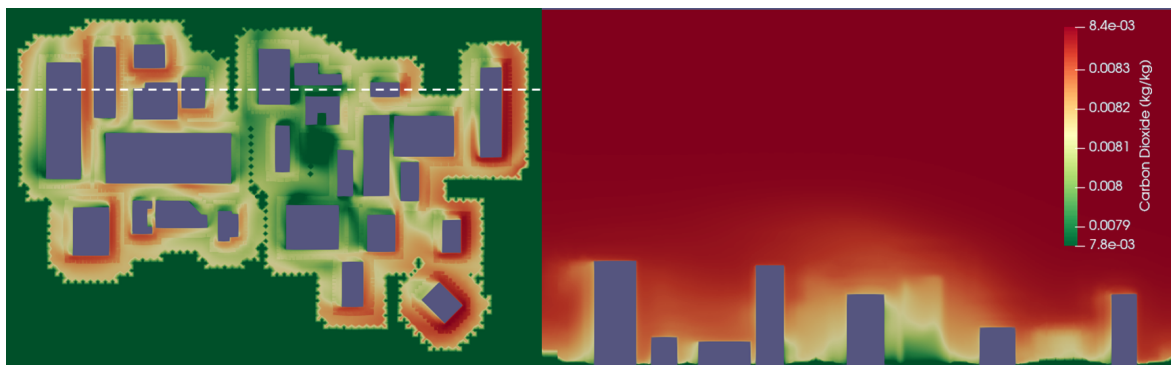

Figure: Carbon dioxide dispersion as assessed using the urbanmicroclimateFoam solver

City4CFD

The GitHub repository of the City4CFD project can be found using the following QR code:

urbanmicroclimateFoam

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References

[1] G. Churkina, A. Organschi, C. P. Reyer, A. Ruff, K. Vinke, Z. Liu, B. K. Reck, T. Graedel, and H. J. Schellnhuber. "Buildings as a global carbon sink". In: *Nature sustainability* 3.4 (2020), pp. 269–276.

[2] C. Nevers, J. Carmeliet, D. Strebel, S. Wood, A. Kubilay, and D. Derome. "Understanding cooling potential of urban trees in a typical North America neighborhood". In: *Building and Environment* (2025), p. 113303.

[3] I. Pađen, R. Peters, C. García-Sánchez, and H. Ledoux. "Automatic high-detailed building reconstruction workflow for urban microscale simulations". In: *Building and Environment* 265 (2024), p. 111978.

[4] J. Rockström, O. Gaffney, J. Rogelj, M. Meinshausen, N. Nakicenovic, and H. J. Schellnhuber. "A roadmap for rapid decarbonization". In: *Science* 355.6331 (2017), pp. 1269–1271.

[5] E. Velasco, M. Roth, L. Norford, and L. T. Molina. "Does urban vegetation enhance carbon sequestration?" In: *Landscape and urban planning* 148 (2016), pp. 99–107.

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