Housing Development Optimization: A Generalizable Framework with Case Studies for Toronto, Houston, and Perth

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Problem

Balancing the numerous impacts of housing development often requires mathematical methods, but existing approaches have two main problems: (a) They are handcrafted for one particular city and can't be easily applied to the thousands of other cities around the world that are also trying to find ways to build more housing, and (b) they divide cities up into a grid, or into neighbourhood-level "blocks", and use these shapes as their fundamental planning units (Figure 1). The shape and scale of these means that they don't accurately capture the existing urban form.

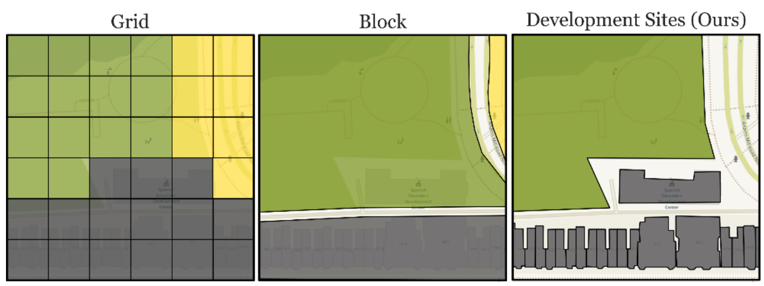

Figure 1. Modelling a city as a collection of development sites (e.g., individual buildings) results in a more representative optimization problem

Solution

This research develops an adaptable tool for optimizing housing form and location. It uses globally available datasets on building footprints/height to solve the problem at extremely high resolution (Figure 1, right). Our approach allows users to define what "optimal" means for them, which, together with the global data sources, helps make it adaptable to cities worldwide.

Case Studies

We demonstrate the effectiveness of our approach by demonstrating development optimization for three cities: Toronto (Canada), Houston (USA), and Perth (Australia) – each among the fastest-growing cities in their respective countries. We focus on answering the question:

> *How can we meet housing needs using only gentle-density developments while minimizing embodied carbon emissions?*

For our purposes, "gentle-density development" means either basement suites, vertical splits (converting an existing single-family house into multiple flats), tearing down a bungalow and replacing it with a 3-storey multiplex, accessory dwelling units (ADUs) or 4-storey low-rise apartment buildings.

Key Takeaways

1) New geospatial datasets make it possible to optimize housing development at the resolution of individual buildings, and advances in optimization methods allow for solving such problems across entire cities.
2) Toronto, Houston, and Perth can meet their 2050 housing needs using only gentle-density development, but this will incur a minimum of 3.0, 12.4, and 15.7 Mt CO_2-eq of embodied carbon emissions from the structural and architectural materials used in that housing (total embodied GHG will be higher).
3) The minimum embodied carbon emissions increase by up to 50% under simulated NIMBY scenarios, and up to 183% if we constrain how many single-family homes can be renovated.
4) Jointly optimizing for accessibility (Toronto), flood risk (Houston), and climate damage risk (Perth) increases the embodied GHG emissions by 166%, 18%, and 15% respectively.

Figure 2. Optimal housing development plans in Toronto, Canada under base case and NIMBY scenarios. In the NIMBY constraints, populations of the top 30% of neighbourhoods by household income were only allowed to increase by a maximum of 10%.

Figure 3. The trade-off between embodied carbon emissions and flood risk in the optimal housing development plans for the city of Houston.