Simulating Social-Ecological Outcomes of Urban Greening Initiatives: A Cellular Automata Case Study in Montreal

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Abstract:

This study employs a Land Use Land Cover Change (LULCC) Cellular Automata (CA) model to examine the cumulative effects of various greening initiatives on urban Green Infrastructure (GI) in a Montreal neighbourhood. Utilizing NetLogo for simulation and QGIS for pre- and post-processing, the model simulates dynamics driving land cover changes over a decade, exploring pessimistic, standard, and optimistic future scenarios to assess how strategic urban planning can enhance green coverage, ecological connectivity, and human accessibility.

Figure 1. The case study area in Montreal, QC, Canada (green=park, grey=residential, white=street, red=vacant, beige=industrial).

Six key LULCC processes are analysed: street and alley tree planting, urban tree loss, public projects (a park and a bus station), parking lot policy reforms, and the conversion of vacant lots into green spaces. These processes incorporate both deterministic and stochastic elements to reflect urban landscape heterogeneity and land-use uncertainty. Results indicate significant variations in green coverage and accessibility across scenarios. Strategies focusing on large-scale public projects and revised parking policies offer the greatest potential to increase urban green cover and improve access to Urban Green Space (UGS), especially in areas with significant legacy industrial use. Initiatives like street and alley planting yield social and ecological benefits, including enhanced accessibility and expanded habitats for species such as the red-backed salamander.

To balance explanatory power and comprehensiveness, the model was designed with an adequate level of resolution (Grimm et al., 2005), avoiding the pitfalls of overly simplistic or excessively complex models. Following the guidance of Batty and Torrens (2005), the CA model serves as a tool for exploring "what-if" scenarios rather than predicting exact urban dynamics, providing practical insights for landscape management practices.

Several necessary simplifications define the model's limitations and suggest avenues for future research. Classifying patches as either green or non-green emphasizes spatial distribution but overlooks differences in vegetation types. Incorporating data on vegetation structure—distinguishing between ground-level greening and tree planting—could enhance ecological insights. Additionally, limiting each LULCC process to a single flow simplifies the model but may reduce representational accuracy. Figure 1 describes the central links between the modelled LULCC initiatives, related to each other through the internally defined variables used as proxies for the greenness, population density and land value within a certain radius; Future work could include more detailed process flows or interactions.

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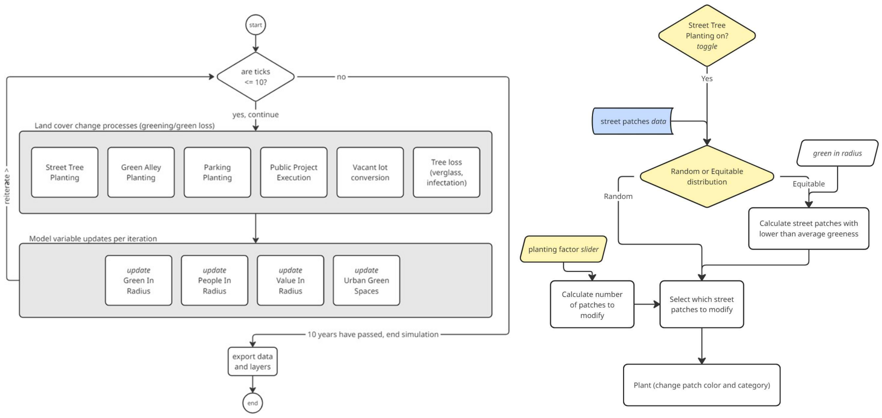

Figure 2. The flowchart on the right describes the model's logic overview. The flowchart on the left describes Street Tree Planting, one of the six sub-models for land cover change processes.

Figure 3. Standard simulation results. The image on the left is a simulated canopy cover for 2031 (white = vegetation, black = no vegetation). The image on the centre, the simulated Urban Green Spaces for 2031 (white = UGS, black = not UGS). The image on the right, the red-back salamander potential habitat map for 2031 (green = potential habitat, red = not a potential habitat), modelled based on species' minimum Patch size and Gap crossing distance habitat characterization (Oehri et al., 2024).

Outcome selection involved trade-offs. Focusing on UGS accessibility and greenness within a certain radius reflects deliberate scope limitations to facilitate actionable results, even if it may seem reductive to some urban ecologists. Future studies could integrate more complex, multidimensional outcome measures, drawing on advances in urban and landscape ecology. The study area—a 2 km × 2 km neighbourhood—provides an accessible case but may limit scalability to larger governance levels. Expanding the model to encompass larger scales, such as entire boroughs, could improve alignment with municipal governance structures and policy targets. Incorporating variable decision-making periods and engaging stakeholders more extensively could better reflect real-world planning cycles and refine LULCC process calibrations.

Overall, the research highlights the value of a complexity-based approach to urban planning that integrates multiple initiatives and assesses their landscape-level impacts. By linking ecological and social outcomes, the model acts as a decision-support tool, offering insights into the long-term implications of green infrastructure initiatives. The findings emphasize the importance of innovative policies in developing sustainable, accessible, and resilient urban environments. Addressing the identified limitations presents valuable directions for future research to enhance the model's utility in urban sustainability planning.

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