City Planning Dynamics: A Theoretical Framework of Urban Development Scenario of Belgium Provinces Using Logit Based Cellular Automata

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***Abstract*— The idea of compact city encourages a sustainable future in urban planning. Haphazard urban development affects the agricultural landscape of a country, degrades environmental qualities or leads to habitat fragmentation. Urban densification or development in already existing built up areas can help control such adversities. Addressing these challenges through the lens of compact city principles presents an intriguing avenue for sustainable urban development. Our study presents a theoretical framework as a solution to understand, analyze and implement urban densification in three provinces of Belgium: Brussels, Flemish Brabant, and Wallonia Brabant. Additionally, it talks about the future work based on regional planning scenarios for efficient land take. We use urban built up maps for three years 2000, 2010, and 2020 and then classified them into three density classes of 1 (low density built up), 2 (medium density built up), and 3 (high density built up). Using a genetic algorithm well known for its advanced single objective functionality, we optimized the neighborhood parameters for each density class built up. These are used in modelling urban densification from classes 1-2 and classes 2-3, using a multinomial logistic based cellular automata. Our findings show that while Brussels experiences high density with 80% of the region covered with residential built up, Wallonia still undergoes fragmented growth or urban expansion. Thus, our study can help the urban planners, researchers and stakeholders propagate an idea of smart solutions towards city planning.**

Keywords- urban densification; genetic algorithm; cellular automata; city planning; scenario modelling.

I. INTRODUCTION

One of the defining characteristics of the twenty-first century is the rapid urbanization that offers perspectives on sustainable development, as well as challenges [1], [2]. Urban growth frequently results in strained resources, degraded natural habitats, and encroachment into agricultural land, all of which calls for creative approaches to urban planning. Compact cities, which prioritize densification inside already existing urban areas, are becoming popular as a strategy to deal with these issues and to advance sustainable urban development [3].

Belgium, with its unique blend of urban and rural landscapes, serves as an ideal context for exploring the potential of urban densification strategies. A significant majority of Europeans reside in urban areas, with Belgium boasting an exceptionally high urbanization rate of 98% [4]. Particularly in the Wallonia region, located in the southern part of Belgium, urbanization proceeds at a rapid pace, expanding by approximately 17 km^2 annually [5]. This growth is anticipated to continue, fueled by demographic forecasts indicating a projected rise of 200,000 households from 2011 to 2026 [6]. Consequently, this trend is expected to lead to a further expansion of impermeable surfaces in the region.

The motivation behind this research stems from the pressing need to reconcile urban growth with environmental conservation, accessibility and socio-economic development [7], [8]. We aim to address the following key objectives:

- Mapping the spatio-temporal trend of demand for urban built up areas.
- Simulating futuristic urban densification scenarios.
- Analyzing the idea of densification as a pragmatic solution for 2050 no net land take.

Hence, we present a theoretical framework of approaching these objectives, and help planners and regional administration better understand the evolution of land use pattern and design policies for a smart and sustainable city planning. While our theoretical framework provides insights into urban densification, its real-world implementation may face challenges related to political, economical and social factors that influence decision making in urban planning. It is important to consider this as a limitation when formulating policies based on our findings.

Following the introduction, the rest of the paper proceeds to briefly explain the ideated methodology of the current ongoing research. In Section II, the area of interest is delineated, providing the rationale for our study area. Section III outlines the framework of the data and methodology used. Section IV includes the conclusion, summary of the main findings of the study and the highlights of its contributions to the field. Finally, Section V outlines avenues for future research, suggesting potential directions for further investigation, thus encapsulating the comprehensive narrative of the research endeavor.

II. AREA OF INTEREST

Belgium, as shown in Figure 1, is the 6th most urbanized country in Europe and the 22nd most densely populated country in the world, with 381 inhabitants per km^2 [9] The country is governed by three different federal bodies, making it a crucial area for studying the intricacies of different planning and policies.

On the other hand, there has been a growth of 17% in buildings for Flemish and Wallonia region. The growth in number of dwellings - to accommodate the growing population, has been alarming since 1995, at a rate of 31% in Flemish region and 29% in Wallonia. To address these challenges, policies and strategies aligned with the principles of "No Net Land Take" have gained prominence[10]Using this concept, the cross-border provincial region of Brabant can mitigate the adverse effects of urbanization by 2050. Furthermore, by identifying and strengthening centralities, urban planners and policymakers can foster compact, vibrant and well-connected urban environments.

Figure 1. Study Area

III. METHODS

A. Data framework

Though, many studies used Land Use Land Cover (LULC) maps, the quality of data and geometric error can lead to erroneous processing and results. In our study, we use cadastral data provided by Belgium's land registry. This is a vector-based data which contains useful information like "construction year". Since vector data is highly computationally inefficient, we rasterize it for big data processing. Similarly, we prepare the factors impacting the built up development under geophysical, accessibility and socio-economic category, as shown in Table 1. All of these maps are rasterized at 100 × 100m or 1 hectare as it is a commonly used scale for LULC studies. The model was calibrated using 2000-2010 data and was then validated using 2020.

Hereto preparing the dataset, it is observed that our dataset comprises of static and dynamic factors. But, the most dynamic variable which needed to be calibrated for scenario modelling was "Neighborhood". This will be discussed in the below sub-section.

TABLE 1. LIST OF EXPLANATORY VARIABLES

Factors	Name
X1	Elevation (DEM)
X2	Slope
X3	Distance to highways
X4	Distance to primary roads
X5	Distance to secondary roads
X6	Distance to residential roads
X7	Distance to railway stations
X8	Distance to large-sized cities
X9	Distance to med-sized cities
X10	Employment rate
X11	Population
X12	Zoning

B. Modelling framework

We propose a hybrid modelling framework, where the independent variables are calibrated using MultiNomial Logistic (MNL) regression model [8], [11], [12]. On the other hand, the Cellular Automata (CA) model has been used to calibrate the neighborhood interaction based on a push-pull effect. This means the probability of a cell transitioning to a particular land use depends on its weightage and its distance from the cell of interest (where the weights are optimized using genetic algorithms). This technique was chosen because of its ability to incorporate both - the explicit and implicit nature of urban development. While similar models have been used to study land use land cover changes, there have been few applications that take into account different built up density. Additionally, the genetic algorithm has been proven to simulate futuristic scenarios more precisely than other commonly used models [13]. Our results are expected to produce three scenario conditions based on the planning policy of regional development authorities.

- In the first scenario, we will simulate a futuristic scenario until 2050 based on the historic trends of urban built up derived from calibration. The calibration was done based on years 2000 and 2010, to simulate the year 2020 and was validated with the observed built up map of 2020.
- In the second scenario, we will simulate a futuristic scenario until 2050 for development across different density class of low-density built up to medium

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density built up, and medium density built up to high density built up. This is based on the idea of promoting gradual decrease in expansion to avoid overwhelming effect on land take.

- In the third scenario, we will simulate a futuristic scenario until 2050 using the centralities of a city as a promoting factor, while still a controlled part of the growth will be encouraged in the periphery of the city to maintain a balance between the economy and environment.

These studies are based on planning ideas of Belgium as a country and should be adapted contextually. However, it can aid to the foundation of "smart" planning especially for countries of global south, where unplanned growth is still prevalent.

IV. Results and Discussion

Urban development in Belgium presents complex challenges that require innovative approaches to city planning and management[6]. This research presents a theoretical framework for modelling urban growth scenarios by utilizing the power of MNL based CA modelling. Three scenarios present divergent ideas for the cross-border scenario of Brabant's future development: BAU, Stop au béton (STOP), and Centralities. BAU anticipates urban growth as a continuum of the past pattern of growth. In our results, BAU shows that urban expansion continues to grow rapidly, especially in Wallonia, which predominantly experienced the same over the years. On the other hand, STOP assumes that new urban development should be stopped beyond 2050, which means the growing population should accommodate the need for housing in existing built areas. Drawing inspiration from a centrality-focused approach, the third scenario aims to promote compact, integrated urban centers by 2040 and reduce a considerable amount of growth outside of these central zones. The implementation of these scenarios underscores the need for proactive and strategic land use policies tailored to the unique characteristics across borders. The STOP scenario highlights how critical it is to prioritize densification in order to stop urban sprawl and protect parks, green areas, and historical sites. On the other hand, in order to improve connection, accessibility, and livability for citizens and companies, the scenario of centralities emphasizes the possible advantages of supporting functioning urban areas and centralities.

In order to ensure that the model and its scenarios remain relevant and successful in guiding land use policy and urban planning activities in Belgium, a further study and collaboration are needed. The incorporation of both simulated and actual built up density maps into risk models facilitates the development of targeted policies, improved resource allocation, and a greater ability for policymakers and stakeholders to prioritize mitigation actions related to urban growth[11], [13], [14]. Stakeholders may collaborate to build prosperous, inclusive, and sustainable communities that improve everyone's quality of life by utilizing data-driven insights and proactive tactics.

V. Conclusion and Future Work

In this paper, we propose a framework for a modelling approach to understand and analyze the built up development type and its implications to the policy of no net land take. We have considered three scenarios for evaluating this. While BAU scenario shows that urban expansion still exists, STOP scenario assumes that this new development should be replaced by "rethinking" built up development in the form of densification, consequently slowly bringing it to zero land take. However, to address the complexity of planning and policy, the scenarios of centralities will still allow a 75-25 ratio of growth in central part of cities to its outskirts.

This study can lay a foundation for sustainable urban planning, although uncertainties are a part of futuristic simulation. This is why it is important to take into account the challenges of modelling perturbation, and to understand the difference between "What it is" and "What it should be". This will drive our futuristic research in a more realistic and accurate direction.

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