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# A Comparative Analysis of Drivers Impacting Urban Densification for Cross Regional Scenarios in Brussels Metropolitan Area

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**Abstract:** Our research aims at unveiling the various drivers that can have an impact on urban densification. Unlike the usual logistic modelling techniques, our study considers multi-level built-up densities ranging from low to high built-up density. The commonly used dataset for a number of present studies is based on raster images. Our study uses vector-based cadastral data to create maps for the years 2000, 2010 and 2020 in order to better trace densification. Furthermore, our study addresses the situation of a metropolitan area, Brussels, that spreads over three different regions that are developing independent land-planning policies. Since the state reform of 1993, Belgium has undergone a significant political transformation with a decentralization of land-planning policies from the state level to regional authorities. This reform allowed a progressive divergence of planning policies between the three regions, i.e., Flanders, the Brussels Capital Region and Wallonia. According to our findings, all the controlling factors exhibit distinct variation over all their density classes for the three regions. This may be due to differences in socioeconomic, territorial, and regulatory factors. For Flanders and the Brussels Capital Region, slope and distance to roadways are the most significant drivers explaining densification, whereas densification in Wallonia is predominantly influenced by land-use policies, especially the zoning regime. These results highlight the impact of considering cross-regional divergences in the implementation of planning policies at the metropolitan level, especially in those metropolitan areas that are expanding into different regions with divergent planning policies.

**Keywords:** urban densification; land development; net land take; driving factors; multinomial logistic regression

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## 1. Introduction

A significant amount of the planet's land surface has been altered by land-use activities, including the conversion of natural landscapes for human use and the modification of land management methods. Nearly all economic activity requires land as a necessary capital for development [1]. The functions of the ecosystem are also supported by the land, which is resilient to anthropogenic and biophysical stressors [2]. Globally, land degradation has been escalating and getting worse since the 20th century as a result of the deteriorating ecological environment, increased food demand brought on by rapid population growth, the rapid development of urbanization and industrialization, and the unreasonable development and exploitation of land resources by people [3,4]. Future unpredictability necessitates improved scenario-based planning techniques as society, the environment, and technology change so quickly [5]. Understanding earlier land development methods can help planners better anticipate the long-term effects of different planning policies [6].

Growing urban sprawl (dispersed urban development) is a serious concern worldwide for a number of environmental and socioeconomic reasons. The increasing urban sprawl in Europe is causing land-use conflicts and is posing a major threat to sustainable land use [7]. Land take in urban areas of the EU increased by 3581 km$^2$ in the period between 2012 and 2018 [8]. Increasing land take and soil sealing make Europe's ecosystems less resilient, with negative impacts on biodiversity and weaker potential for climate change adaptation [9]. Such impacts can be expected to have a negative effect on the quality of life including people's well-being and health care along with increased social costs associated with the provision of public infrastructure in European cities [9]. Therefore, it is crucial that nations use cutting-edge land-use planning and steering strategies that are intended to reduce land take and enforce efficient growth within a cogent framework for sustainable land-use governance [10].

Without any alterations in policy, urban settlements will encompass 4–5% of the world's acreage by 2050 [11,12] and over 70% of inhabitants would dwell in urban areas [13,14]. The area used for national economies has increased significantly at the same time, as have the number of roads, parking lots, railroads, and other transportation-related infrastructure developments [15]. This expansion has frequently come at the price of agricultural land and may have detrimental effects on the environment, natural resources, and public health [16]. Urban sprawl is criticized as a concomitant result of urban expansion and declining city densities [17]. Density can be seen as a desired and advantageous substitute for the sprawl, which is said to be less ecologically friendly and economically productive. Urban densification, often known as infill development, is a crucial strategy for decreasing land take and reversing ongoing density decline in order to promote more effective land use (e.g., in terms of housing per unit of land area or utilization of urban infrastructure) [18]. Low-density development can also be considered as a direct consequence of land take. Consequently, urban densification can also be viewed as a strategy to set growth restrictions on potential land take. The European Commission has been fostering a no-net land take policy since the adoption of the 2011 action programme [19]. This policy has been progressively transposed by the different member states/regions into national law and planning policies. In Belgium, the Flanders region of Belgium has a goal of no-net land take, aiming to cut land take from 6 ha/day to 3 ha/day in 2025 to accomplish net zero land take by 2050. Similar objectives were adopted by the Walloon Region in 2019. Still this document has not been formally adopted and land-use policies keep being dominated by the zoning plan adopted before decentralization.

Densification policies are being introduced in numerous regions of the world to limit population expansion in constructed areas and to curtail suburbanization. It also encourages more effective usage of the amenities already in place, such as roads, schools, retail spaces, and public spaces, and it helps to support urban development by regenerating vacant land and/or brownfields within cities [20,21]. Repurposing urban spaces already present within the city is one way to achieve densification without encouraging urban sprawl [22]. Because social infrastructures are closer together, densification also improves access to services, but it also runs the risk of making local issues and discontent worse [23]. Even if there are many global factors, such as national and global market expansion and economic globalization that explain how cities are now evolving, local factors have an impact on urban densification in the form of specific attributes.

The focus of the present paper is to provide a framework to analyze the process of urban densification in the Brussels metropolitan area (BMA). Urban sprawl is historically viewed as the result of the post-socialist transformation of Belgium from a strongly central government-led urban planning system into a noticeably free form of development in a generally neo-liberal environment driven by individual families seeking to improve their housing standards. In formulating hypotheses, specific consideration is given to the Belgian system of regional zoning planning, which has allegedly had a significant and ongoing influence on the evolution of the built environment since its inception in the 1970s. Planning responsibilities were transferred from the federal government level of Belgium to the regional governments of Flanders, Wallonia, and Brussels in the 1980s, and these governments then began creating their own policy plans. Since 2015, the focus of the spatial policy of Belgium has moved towards social cohesion, sustainable development and urban regeneration. Planners and policymakers must comprehend the trends, characteristics, and drivers of sprawl in order to control the significant growth of medium- and high-density residential and commercial areas outside of the city limits, which exacerbates a number of issues related to densification. As the BMA is expanding over three different regions, i.e., the Brussels Capital Region, Wallonia, and Flanders, our study compares the impact of drivers on densification in these three regions so as to highlight the potential effects of different policies on land-use processes. We also examined the relationship between several built-up densities and other variables in order to identify the drivers of densification. We support our claims by using multinomial logistic regression (MLR) through the period of 2000–2020. The distribution of the studied variables was analyzed at a statistical level for socioeconomic, regional, and spatial planning characteristics.

The remainder of paper is structured as follows. Section 2 explains the conceptual framework and previous research on densification. It also explains the concepts of compact cities, mid cities, and small towns. Section 3 describes the datasets used and reports on various drivers involved in the densification process. It also entails the research methodology used for the density profile using MLR for the three regions. Section 4 presents the results of regression analysis. It also evaluates and analyzes the results of the study area and compares the impact of drivers in the BMA by comparing the results of the three regions involved in the management of its territory. Section 5 offers conclusions in response to various land-use policies and identifies the kind of constraints that affect the potential of built-up developments to densify.

## 2. Conceptual Framework

### 2.1. Urbanization in European Cities

Gu [24] characterized urbanization as the process that rural residents go through as they adopt an urban lifestyle, the growth of built-up areas in cities, and the development of urban environments. In order to approach and comprehend it, one must take into account the unique geographical and historical context in which urban forms build cities. As a demographic process, it is at first, an increase in the proportion of the population living in all urban places; and second, the growing concentration of those people in larger urban settlements. Between 1950 and 2020, the world's urban population has grown by a factor of 5.8 [25] and urban economies have grown by a factor of 25. However, 36% of the urban population live in slums due to a lack of economic development and growth factors [26]. Urban sprawl is a word used to describe the phenomena of expanding urban areas occupying a larger percentage of the available land [9]. A city with a given population will have a smaller geographic footprint due to urban density [27]. Thus, expansion and densification might be viewed as partial alternatives.

In the context of the Global North, urban sprawl can be understood as an outward expansion of low-density areas [28,29] with increased car dependency [30]. In Europe, cities have traditionally been rather compact, having developed a dense historical core shaped before the emergence of modern transport systems. Since the mid-1950s, European cities have expanded on average by 78%, whereas the population has grown by only 33% [31]. Although there are several regions (e.g., East Germany) where the human population is not growing, the expansion of built-up areas has continued in most European regions, even where the population has declined [32]. Metropolitan regions in southern Europe have been found to be rather homogenous in their landscape structures and land-use composition and have emerged as particularly compact and dense in respect to cities in other European regions [33].

Belgian spatial planning is renowned for combining comprehensive and regulated planning elements [34]. The three Belgian regions of Wallonia, Flanders, and the Brussels Capital Region (BCR) have been developing independent spatial policies since decentralization occurred in 1984. The landscapes of Flanders have been significantly altered by ribbon-like development [35]. The Flemish countryside's fragmented nature was emphasized by a lack of strict spatial planning [36]. Wallonia is distinguished by a scattered urbanization, which leads to urban fragmentation [37]. The Brussels Capital Region stands out significantly from the other two regions because its territory is very limited compared to the other two regions. Most importantly, the territory of the BCR does not include all the metropolitan area that spreads over the other two regions [38]. The urban and rural portions of Belgium are closely intertwined, even more so than in other western European countries [39]. This "rural-urban" environment has been distinguished by a highly fragmented complex mosaic of varied land uses since the 1960s, when the population of the old city centres dropped in favor of the population of the outer urban fringe [39,40].

### *2.2. Densification and Sustainability*

Densification, often referred to as urban consolidation or redensification, has been advocated as an urbanization strategy that makes the most of small amounts of living space, intensifies the built environment, and builds compact cities as opposed to large ones. In planning literature, residential densification is presented as a means of developing more compact cities, stopping sprawl, and promoting urban sustainability [41,42]. The relationship between urban design and sustainability and densification are debated issues [28,43]. Due to these important benefits, densification is now "enshrined in land use planning policy in many countries" and is now a part of goal 11 (Indicator 11.3.1) of the Sustainable Development Goals of the United Nations [44].

Increasing urban density within existing urban areas is a critical step when it comes to sustainable development, according to several recent studies on sustainable city models, especially in the compact city [45]. Urban densification's main objective is to create denser urban forms—more buildings/people per hectare—between previously developed urban sections of the metropolis. Densification is viewed as a solution to help contain population growth inside built-up regions as it allows for a more effective use of already established urban spaces and aids in the preservation of agricultural and undeveloped land [46]. Forecast models have been used by urban planning agencies to look at sustainable futures [36] but usually fail to address densification [47]. In terms of society, density is associated with social justice and diversity because it promotes access to social infrastructures and fosters a more varied, inclusive, and livable urban environment by making chances for social interaction more readily available [48]. A minimum density is required economically for the effective use of urban resources and to lower the cost of infrastructure provision [46].

### *2.3. Concept of Compact Cities, Mid Cities and Small Towns*

Densification, also known as urban consolidation and urban intensification, is a process in which new structures are built (or renovated) at increasing densities [49]. As a result, a compact city may be recognized by its high-density, mixed-use development, effective transportation, and various commercial and social activities. In an effort to address environmental and social effects and limit urban development, the paradigm shift towards "compact cities" maintains that it is in the public interest to densify the existing footprints of cities [50]. The advantages of compact cities gradually erode as metropolitan areas grow [42]. The city centre, its residents, users, and the larger socioeconomic surroundings should all co-evolve in order to build a sustainable city, according to Neuman [43].

For the creation of sustainable urban development strategies, it might be crucial to comprehend the city's present and projected growth patterns as well as the factors influencing them [51]. Life satisfaction is significantly influenced by where a person lives, and it has been discovered that individuals who live in small towns are typically happier than those who live in larger cities [52]. Due to today's high travel demand and low population density, it may be challenging to build an effective public transportation system, which increases the need for private automobiles [53]. For example, New York is a city that spreads over cities and should include divergence regulation but also takes into account different policy regimes. A 15 min town is planned so that everyday tasks may be completed within 15 min of the dwelling, or around 1 km, by foot. Grocery stores, banks and ATMs, restaurants, sources of employment, facilities for sports and entertainment, as well as services for health, education, and culture should all be accessible by foot.

When paired with other physical design elements (architectural design, streets that foster urban life, public space, and mixed land use), a higher residential density encourages resident interaction and a sense of community [53]. The most important features of towns that promote wellbeing are livability, identity and control, access to opportunities, authenticity and meaning, community and public life, urban self-reliance, and an environment for all [54]. In the most current COVID-19 scenario, larger urban densities were linked to a higher likelihood of human contact, exposure, and interactions. The potential role of urban density in viral transmission has been hotly contested [55,56], but it has also been viewed as a crucial element during the pandemic because it significantly affects a number of other built environment features.

## 3. Materials and Methods

### *3.1. Study Area*

Belgium is one of Europe's most urbanized nations, where 98.12% of the total population stays in or near urban cores. That exceeds the urban population of many countries including Sweden, Singapore and also the entire United Arab Emirates. It comprises three main provinces of Flanders, the Brussels Capital Region and Wallonia accounting for a total population of over 11.5 million [57]. The country has established its own regional policies to ensure livability and strong social cohesion and to support economic development. Along with proliferated urban population, Belgium constitutes one of the greatest hubs of urban sprawl with an urban permeation unit value of more than six [58]. Hence, our study area covers includes the Brussels Capital Region, Flemish Brabant and Walloon Brabant covering 11% of the total area of the country.

Belgium (Figure 1) has a mixed landscape of dense urban cores such as the Brussels Capital Region and cities like Antwerp (508,000 inhabitants), Ghent (249,000 inhabitants), Charleroi (204,000 inhabitants) and Liège (196,000 inhabitants), whereas Wallonia and the north of Flanders have strong rural landscape structures with fragmented urban growth. As stated by De Smet and Teller [59], in this situation, densification methods are crucial to limiting further land consumption and improving the structure of existing peri-urban areas while taking into account their unique characteristics.

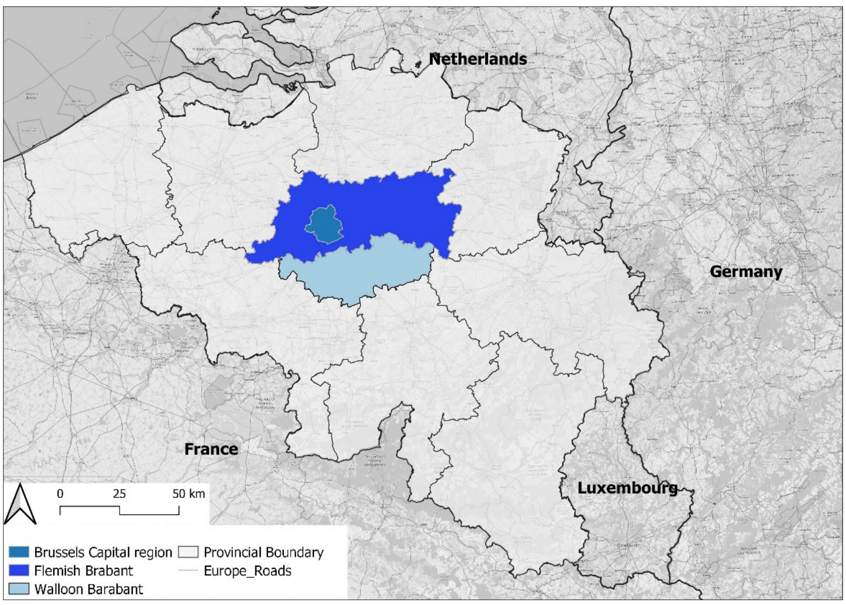


**Figure 1.** Area of interest showing the Brussels Capital Region, Flemish Brabant and Walloon Brabant.

### 3.2. Database Preparation

The spatial repository of our model includes two main entities which consist of (1.) dependent variables and (2.) independent variables. The dependent variables are represented by the Belgian cadastral data. The Belgian cadastral data is vector-based data provided by the land registry consisting of building footprint information at a two-dimensional level. This data is generally useful for statistical sector level studies due to its reliability and plot and parcel level information. The data have been used to create built-up density maps for the years 2000, 2010 and 2020 [60]. These cadastral maps were rasterized at a very fine resolution of $2 * 2$ m cells in order to avoid any erroneous differences during conversion. At such resolution the computation time is stretched and, as a result of which, the $2 * 2$ m images were aggregated to a $100 * 100$ m resolution.

The density index is performed at a grid of $100 * 100$ m square; this is also because it is commonly used in urban studies for regional land-use modelling [37,61–63]. A geometric classification technique has been adapted in order to classify the maps under different density levels as this particular classification method is useful for highly skewed data [64,65] and helps to normalize the data inculcating more variation to the data at a constant geometric interval. Thus, the density maps are classified under three main classes: (a.) low density; (b.) medium density and, (c.) high density built up. A threshold value of 25 m$^2$ exhibits a minimum density value for a cell to be considered as built up, which also corresponds to an average-sized Belgian residential building [65,66]. The methodology is aimed at identifying the driving factors of transitions from low- and medium-density classes to medium- and high-density classes in order to understand the process of densification and perform a comparative analysis using a cross-regional study in Belgium. Table 1 shows the percentage of $2 * 2$ m cells in each of the 100 m$^2$ images.

**Table 1.** Number of $2 * 2$ m cells in 100 m$^2$ image (represented in %).

| Class | Minimum | Maximum | Percentage |
|---|---|---|---|
| Class 0 (Non-Urban) | 0 | 24 | 1% |
| Class 1 (Low Density) | 25 | 117 | 5% |
| Class 2 (Medium Density) | 118 | 541 | 22% |
| Class 3 (High Density) | 542 | 2500 | 100% |

### 3.3. Modelling Urban Densification

In this study we used multinomial logistic regression (MLR) as an empirical modelling technique because (1.) it helps us to understand the relationship between muti-class dependent variables by using a set of explanatory variables; (2.) it predicts single categorical variables with a nominal outcome variable; and (3.) it yields a set of coefficients representing an odds ratio for each variable. Furthermore, it is important to understand the complexity of each region when the driver is modelled to analyze its impact. The modelling is performed by comparing three different regions of Belgium for the years 2000–2010 and 2010–2020 in order to understand the spatio-temporal significance of the impact of drivers.

Logistic regression models can be of two types: ordered where the drivers are classified in sequential order and non-ordered where the drivers have multi-class outcomes. In order to validate the most suitable model, a proportional odds assumption test was conducted [66]. The test violated the assumptions of the data being in order as the significance of chi-square in the test was <0.001. This is why a multinomial logistic regression model has been used. A set of variables were selected according to data availability and knowledge of geographical suitability [36]. These are known as "drivers of densification". Using the following equations, the logistic function determines the likelihood of urban growth for each observational unit (cell):

$$\log(k_1) = \alpha_{k_1} + \beta_{k_1^1}\ X_1 + \beta_{k_1^2}\ X_2 + \ldots + \beta_{k_1^v}\ X_v$$

$$\log(k_n) = \alpha_{k_n} + \beta_{k_n^1} X_1 + \beta_{k_n^2} X_2 + \ldots + \beta_{k_n^v} X_v \quad (1)$$

where $X$ s a set of explanatory variables ($X_1$, $X_2 \ldots$ , $X_v$), $\alpha_{k_n}$ is the intercept term for class $k_n$ against the reference class, and $\beta$ is the slopes for the classes (the coefficient vector).

A number of different driving forces for land-use change have been considered in the literature. These include accessibility, socioeconomics, geophysical factors and land-use policies. However, most research takes geophysical and accessibility aspects into account [67–69]. Zoning regulations are frequently seen as one of the factors that could influence urban growth. In Belgium, contemporary spatial planning dates back to the 1960s. Because the new legislation gave landowners legal certainty and made sure that the spatial claims of the various policy areas and interest groups (land developers, farmers, nature associations, industry, etc.) were enshrined in land-use plans, the 1962 Belgian Planning Act established a strong legal status for the discipline that was based on broad social support [70]. From an economic, social, and aesthetic point of view, the 1962 planning system was designed to specify plans for the country, planning region, sub-region, and municipalities as well as to protect the country's landscape [71]. Urban sprawl, however, had already become a spatial aspect of land use in Belgium by this point; therefore, these measures were unable to stop it. The Flemish Structure Plan (RSV), a conceptual plan that aims at a "deconcentrated clustering" of residences and employment in the existing urban centres while protecting the remaining open space in the countryside, was put into effect by policymakers in 1995 [72–74]. The Walloon government adopted its Regional Development Schema in 1989. The evolution of planning policies helped to implement a number of new plans at the municipal level in recent years, each of which mandates a deliberate and participative implementation style.

By identifying the zones where urban growth is prohibited (code 0) and the zones that are designated for urban development (code 1), a zoning map was created. It is based on existing policies and plans in the three regions. The harmonization of data from the three regional policies was facilitated by the fact that all three were derived from a common root originating in the 1962 zoning regulations adopted when Belgium was still a unitary state.

According to a literature review [75–78] of common factors included in urban/built-up expansion models, the built-up causative elements were chosen. The spatial distribution and densification of urban areas are frequently attributed to geo-physical factors. A digital elevation model (DEM) was acquired from ALOS at a resolution of 30 m which was aggregated to 100 m in order to standardize with the resolution of the independent variables. This was further used to calculate the slope in percentage for each cell for the three regions.

Urban development models frequently contain accessibility indicators through the use of straightforward metrics, including distance to cities and distance to the road system [79,80]. The Euclidean distance of a cell to five categories of highways and significant Belgian cities was used to gauge accessibility in this study. The vector datasets from Belgium atlas and Open Street Maps (OSM) were used to identify roads and were further catalogued as (a.) highways or motorways; (b.) primary roads; (c.) secondary roads; (d.) residential and (e.) local roads and railways stations. For each region, cities with inhabitants of more than 30,000 were considered to develop a map of distance to cities. The cities of Tienen, and Waterloo were envisaged for the Brabant of Wallonia whereas, in case of Brabant of Flanders, the city of Leuven was used. This study also selected a few environmental factors. From a sustainable point of view, Euclidean distances from parks and natural reserves were included. It has been established that having access to public green spaces or green infrastructure, such as urban parks, is related to people's participation in physical activity [81]. Additionally, living close to an urban park improves the lives of city dwellers and raises their quality of life [82,83].

The official Belgian statistics gave information on the total demographic structure such as the total number of populations, population density, the number of households, jobs (employment rate), mean size of house (average useful floorspace), and income per household (total income of a household). These were mapped onto a raster grid of 100 m at a municipal and statistical level. For each municipality, the gross population density was determined by dividing the total population by the km$^2$ of the municipality. Variables were available at both the statistical level and the municipality level. In land-use studies, combining data from several resolutions is quite typical [84], especially those which are census dependent and can be acquired only for a definite timeline.

### *3.4. Multicollinearity Analysis*

It is important to select accurate drivers for efficient modelling. It is often possible to have two drivers with different information that are highly correlated to each other. Though it is evident that the response(s) and predictor(s) of a model can be highly correlated to each other, a problem arises if predictors are highly correlated [85]. This tends to produce a biased result, which could make the model statistically insignificant [86]. In order to avoid such discrepancies, different techniques can be used such as R2, sum of squares, regression weight and zero-order correlations [87].

In our study, variation inflation factor (VIF) was conducted to test multicollinearity. The test exhibits a value for each driver considered and ideally a variable with a VIF value of less than 4 is taken into consideration for modelling. Many authors considered 10 as a severe limit for correlation while others use 4 as their threshold value [88]. So, the variables considered in our study satisfy both criteria. A value exceeding 4 or 10 depicts that there is high correlation between the drivers. Our test was conducted for two consecutive runs. During first test run there was a high correlation between housing and household with values of 63.24 and 66.25, respectively. This is due to the fact that earlier household and housing data were treated the same, and their X matrix holds a linear constraint. Because our work involves urban densification, the number of households was chosen as it has a significance in terms of floor area ratio and infill development [89]. Figure 2 shows the final list of drivers that were concluded post exclusion of the data and after the second run.

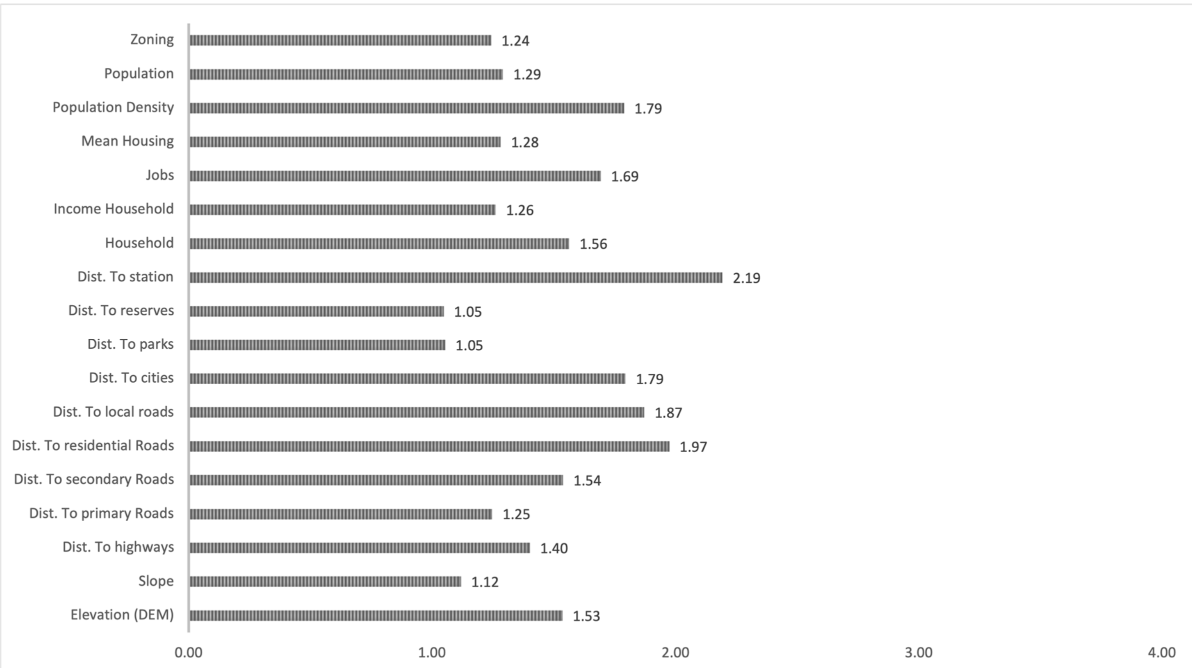


**Figure 2.** List of selected variables for models after second VIF test run.

## 4. Results

This section examines the built-up pattern that emerged from the classification of CAD data, results obtained from modelling, its analysis, and model validation. The multinomial logistic regression model produces a set of values represented as the odds ratio (OR) which equals to coefficient values equals to exp(β). This is calculated for each built-up density level, namely, from the low- to medium- (1–2) density class and the medium- to high- (2–3) density class. Because built-up class 0 to 1 corresponds to changes from non-built up to built up (expansion) it has been excluded from the result. An OR > 1 (coefficients greater than 0) indicates a positive effect, meaning that with an increase in the OR value the probability for new development due to those particular drivers increases whereas an OR value < 1 (coefficients less than 0) indicates a negative effect for new development potential. The absence of a major contribution to the development process is indicated by an OR equal to 1 (coefficients of 0).

Europe's most urbanized country is Belgium. Both the federal government and the three regions have created their own urban approaches, each of which has unique traits and frequently works in conjunction with the others. Since 2015, the focus of the spatial policy of Belgium has moved towards social cohesion, sustainable development, and urban regeneration [46]. A similar-sized area that was previously to be urbanized must be downzoned to a non-urban zone to offset the definition of a new zone to be urbanized in the regional zoning plan.

In this paper, calibration of the model parameters was based on the vector data which were converted to raster maps from 2000 and 2020. The three provinces showed a drastic growth in built-up density, which was the result of an urgent need for housing and communities. As regards the MLR model, all the standardized explanatory variables' VIF test scores (<2.19) indicate that the MNL model can accommodate all of the X variables. Thus, a random sample of 7450 cells, which constitutes around 2.6% of the study area, was used in the MLR model.

### 4.1. Model Assessment

Mostly the urban core and metropolitan city centres of Brussels and Leuven in Flanders experienced a high-density built-up concentration as shown in Figure 3. However, though comparatively less, cities like Waterloo and Tienen also showed a progressive shift towards infill development.

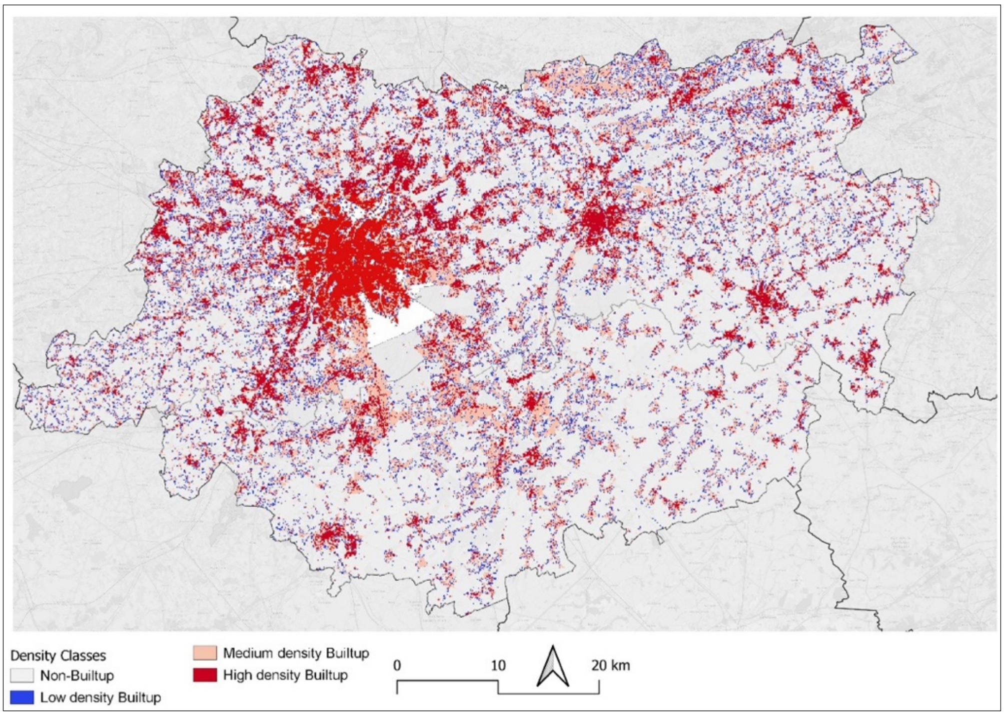


**Figure 3.** Urban built-up density classes at a square grid of 100 ∗ 100 m.

In Table 2, it can be seen that zoning has a substantial impact on densification in both Brussels and Flemish Brabant. An OR value > 1 indicates that the probability of new development is high in places that are designated particularly for urban development units. This is because, though the spatial planning act of 1962 was introduced for the whole national territory, Brussels reviewed its planning system in 1991 and the Flemish region reviewed its planning system around 1996 [71]. Flanders' spatial plan places special emphasis on sustainable development, particularly in the urban areas, whereas Brussels follows a two-tier system with the key priority of striking a balance between the socioeconomic, demographic and accessibility aspects of the region. On the contrary, zoning with an OR value < 1 loosely impacts the scenario of densification in the peri-urban region of Walloon Brabant because of the relative availability of land allowed by spatial planning regulations in this part of the region and the reluctance to densification observed in low-density areas. The resistance to densification in low-density areas appears to increase over time, which is the opposite to what is observed in Flanders and the BCR. As the findings of [21,64,90] demonstrate, distance to different types of roads plays a significant role in explaining urban densification for every density class. The road layout plays a part in the spatial pattern of ribbon development, which is a distinctive characteristic of Brussels and Flanders. These kinds of developments are highly influenced by transportation and accessibility. This can be observed from the OR values for distance to highways and primary and secondary roads, which imply that new built-up land is mainly developed in the immediate surroundings. Distance to high-speed roads (highways, primary roads, and secondary roads) negatively contributes towards densification in medium and high densities in the case of Walloon Brabant and Flemish Brabant. On the other hand, the Brussels Capital Region shows a positive impact, which contributed to the densification of high-density areas in 2000–2010. This is due to the fact that number of urban cores are directly accessible via roads in these regions. Other distance-related factors for high-speed roads have no impact in Walloon Brabant. The majority of newly developed areas in Brussels and Flemish Brabant are located next to or close to municipal and national roadways. This is in line with our research findings where distance to highways and primary roads showed a positive impact toward high density in Brussels and Flanders in 2010–2020.

Another very common impacting driver is distance to stations because it provides a means of transport for both inter-regional and international travel. The extension of high-density built-up areas is statistically significantly correlated with distance to train stations, indicating that parcels near train stations are desirable for future dense constructions. In the case of high-density developments, it is evident from our results that the BCR experienced a negative impact on development along the stations, whereas Flemish Brabant and Walloon Brabant still encourage development.

Furthermore, infill densification typically takes place close to the big cities and on levelled or flat terrain. In Wallonia and Brussels, both medium- and high-density classes show an OR > 1 for elevation. The scope of development is high in already existing built-up areas because they are mostly situated in already suitable places. Especially in Walloon Brabant which includes the range of the Ardennes that contains highly elevated areas. Hence, the inundation of slope and elevation plays an important role for new developments. In Walloon Brabant, elevation is a positive determinant for medium and high density, whereas slope has a remarkably negative impact on medium density. In Brussels, both elevation and slope have a positive impact that is suggestive of densification towards steep and elevated areas, whereas the opposite is true in the case of Flemish Brabant.

Analyzing population density also aids in understanding the dynamics of the city's various neighborhoods. The interpretation of population density is most tangibly understood in terms of the multiplicative effects of odds. The model coefficient ranges from 0.021 to 0.381, which implies that a one-unit increase in population density can multiply the odds by exp (0.381) = 1.463. The dense population in Flanders and Brussels contributes to one of the busiest crossings in the city, the strategic location of the European Union. In Walloon Brabant, there are more of these types of crossings such as the foundation, connecting the major Walloon cities.

**Table 2.** Coefficients derived for variables using multinomial logistic regression (reference class: 1).

| Factor | Coefficients β (Odds Ratio) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2000–2010 | | | | | | 2010–2020 | | | | | |
| | Brussels | | Flemish Brabant | | Walloon Brabant | | Brussels | | Flemish Brabant | | Walloon Brabant | |
| | Class-2 | Class-3 | Class-2 | Class-3 | Class-2 | Class-3 | Class-2 | Class-3 | Class-2 | Class-3 | Class-2 | Class-3 |
| DEM | 0.089 (1.094) | 0.215 (1.240) | −0.026 (0.975) | −0.026 (0.975) | 0.135 (1.145) | 0.370 (1.448) | 0.066 (1.068) | −0.119 (0.888) | −0.104 (0.901) | −0.245 (0.783) | 0.060 (1.062) | 0.136 (1.146) |
| Slope | −0.103 (0.902) | 0.165 (1.180) | −0.122 (0.885) | −0.571 (0.565) | −0.081 (0.922) | 0.218 (1.244) | −0.056 (0.945) | 0.150 (1.161) | −0.055 (0.946) | 0.246 (1.279) | −0.171 (0.842) | −0.935 (0.393) |
| Dist. to highways | −0.292 (0.746) | 0.060 (1.062) | −0.066 (0.936) | −0.433 (0.649) | −0.215 (0.807) | 0.231 (1.260) | −0.271 (0.763) | 0.085 (1.089) | 0.005 (1.005) | 0.055 (1.057) | −0.286 (0.752) | −0.338 (0.713) |
| Dist. To primary roads | 0.006 (1.006) | 0.307 (1.360) | −0.005 (0.995) | −0.544 (0.580) | −0.114 (0.892) | −0.892 (0.410) | 0.027 (1.028) | −0.183 (0.833) | −0.100 (0.905) | 0.115 (1.122) | −0.115 (0.891) | −0.129 (0.879) |
| Dist. To secondary roads | 0.029 (1.030) | 0.298 (1.347) | −0.029 (0.972) | 0.036 (1.036) | −0.120 (0.887) | −0.212 (0.809) | −0.019 (0.981) | −0.206 (0.814) | 0.012 (1.012) | −0.273 (0.761) | 0.028 (1.028) | −0.732 (0.481) |
| Dist. To residential roads | 0.344 (1.411) | 0.478 (1.613) | 0.055 (1.056) | 0.586 (1.797) | 0.059 (1.061) | 0.525 (1.691) | 0.308 (1.361) | 0.660 (1.934) | 0.030 (1.031) | 0.309 (1.362) | −0.202 (0.817) | 0.601 (1.823) |
| Dist. To local roads | −0.036 (0.965) | −0.062 (0.940) | −0.036 (0.965) | 0.045 (1.046) | −0.025 (0.976) | 0.549 (1.731) | 0.172 (1.188) | −0.151 (0.860) | −0.023 (0.977) | 0.001 (1.001) | 0.252 (1.286) | 0.525 (1.691) |
| Dist. To cities | −0.369 (0.691) | −0.536 (0.585) | −0.006 (0.994) | −0.131 (0.877) | −0.155 (0.857) | −0.480 (0.619) | −0.313 (0.732) | −0.144 (0.866) | 0.025 (1.025) | −0.115 (0.891) | −0.022 (0.978) | −0.165 (0.848) |
| Dist. To parks | −0.049 (0.953) | −0.173 (0.842) | 0.014 (1.014) | 0.230 (1.258) | −0.012 (0.988) | −0.235 (0.790) | −0.032 (0.969) | −0.168 (0.845) | −0.052 (0.950) | 0.183 (1.201) | 0.065 (1.068) | 0.575 (1.778) |
| Dist. To reserves | −0.137 (0.872) | −0.114 (0.892) | 0.139 (1.149) | −0.410 (0.664) | −0.015 (0.985) | −0.464 (0.629) | −0.140 (0.869) | −0.092 (0.912) | 0.170 (1.185) | 0.175 (1.191) | 0.089 (1.093) | −0.144 (0.866) |
| Dist. To stations | −0.049 (0.952) | −0.032 (0.969) | 0.008 (1.008) | −0.347 (0.706) | −0.012 (0.988) | 0.101 (1.106) | −0.263 (0.769) | 0.053 (1.054) | 0.032 (1.033) | −0.094 (0.910) | −0.067 (0.935) | −1.322 (0.267) |
| Total number of Household | −0.086 (0.917) | −0.326 (0.722) | −0.049 (0.952) | −0.458 (0.633) | −0.025 (0.975) | −0.543 (0.581) | −0.072 (0.930) | 0.065 (1.067) | −0.033 (0.967) | −0.132 (0.876) | −0.197 (0.821) | −0.345 (0.708) |
| Household Income | −0.093 (0.911) | −0.200 (0.819) | −0.067 (0.935) | −0.200 (0.819) | −0.032 (0.969) | −0.101 (0.904) | −0.213 (0.808) | −0.134 (0.874) | −0.155 (0.857) | 0.282 (1.325) | −0.128 (0.880) | −0.019 (0.982) |

**Table 2.** *Cont.*

| Factor | Coefficients β (Odds Ratio) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2000–2010 | | | | | | 2010–2020 | | | | | |
| | Brussels | | Flemish Brabant | | Walloon Brabant | | Brussels | | Flemish Brabant | | Walloon Brabant | |
| | Class-2 | Class-3 | Class-2 | Class-3 | Class-2 | Class-3 | Class-2 | Class-3 | Class-2 | Class-3 | Class-2 | Class-3 |
| Jobs | −0.029 (0.972) | −0.057 (0.944) | 0.037 (1.037) | −0.038 (0.962) | 0.021 (1.021) | 0.195 (1.215) | −0.097 (0.908) | 0.204 (1.227) | 0.033 (1.034) | −0.141 (0.869) | −0.063 (0.939) | 0.249 (1.282) |
| Mean Housing | −0.504 (0.604) | −0.376 (0.687) | −0.137 (0.872) | −0.586 (0.557) | −0.160 (0.852) | −0.191 (0.826) | 0.298 (1.348) | 0.352 (1.422) | 0.020 (1.020) | −0.146 (0.865) | −0.275 (0.760) | −0.267 (0.766) |
| Population Density | 0.077 (1.080) | 0.075 (1.077) | 0.025 (1.025) | 0.051 (1.052) | 0.020 (1.021) | 0.381 (1.463) | −0.054 (0.948) | −0.034 (0.966) | 0.085 (1.089) | 0.089 (1.093) | 0.069 (1.072) | 0.102 (1.109) |
| Population | −0.088 (0.915) | −0.148 (0.862) | −0.027 (0.973) | −0.009 (0.991) | 0.020 (1.021) | 0.175 (1.191) | −0.102 (0.903) | −0.101 (0.904) | 0.007 (1.007) | 0.044 (1.045) | 0.065 (1.068) | 0.419 (1.520) |
| Zoning | −0.058 (0.943) | 0.076 (1.079) | 0.103 (1.109) | 0.225 (1.253) | −0.063 (0.939) | −0.151 (0.860) | −0.015 (0.986) | 0.312 (1.366) | 0.064 (1.066) | 0.112 (1.118) | 0.083 (1.087) | 0.135 (1.145) |

One of the focal points of our study, that can be found to be excluded in several other studies, is the consideration of the total number of households and total household income. These two are somewhat counterparts of each other because the socioeconomic condition of a household is the determinant of household income. However, though the OR is <1 for both household and household income, it could be an interesting fact to note that high-income households have a tendency to move outside the city centres thus encouraging urban sprawl, whereas people with low-income households mostly stimulate densification in areas like the Brussels Capital Region. This results in an escalation in rent–income ratio, especially in the private rental sector. Although Walloon Brabant was formerly a prosperous province with many heavy industries and job prospects, resulting in high-income takeaway, it has seen serious decline in recent decades resulting in very low income [91].

Although most development happens near to central business districts (CBDs) or around the periphery of city centres for better access to facilities, it can be observed that the OR value for distance from parks has an influence on development, especially in medium to higher built-up classes, which clearly depicts a progressive shift in development where a perfect balance between access to resources and facilities is required along with demand for ample environmental consciousness and recreational nearness. This is more apparent in Walloon Brabant where the shift in OR from 0.98 to 1.60 can be clearly seen in the period 2000–2020.

### *4.2. Model Validation*

The model's performance was assessed by evaluating the probability maps computed by different modelling approaches using ROC. ROC statistics were calculated for Flanders, Brussels, and Wallonia. The ROC statistic is derived from two-by-two contingency tables, each of which corresponds to a different simulated scenario of the predicted probability maps. When comparing the logistic regression models for the three provinces based on the ROC, there is not much variability between the performances of models. The ROC statistics calculated for Brussels and Flanders show that ROC values were higher in Brussels when compared to Flanders. In the Brussels Capital Region, the logistic regression model produced a probability map with a ROC of 84.6%. Estimation of the potential urban densification process produced many false positives for Wallonia, which ranged from 0.718–0.752. In both Flanders and the Brussels area, zoning status, slope, and distance to roadways are the most important variables to include in logistic regression. However, looking at Brabant Walloon, it is remarkably influenced by land-use policies.

## 5. Discussion

Spatial planning played a prominent role in the construction of road networks in Belgium, which was different to the neighboring country of Netherlands [92]. In Brussels, the highways are designed in a circumferential ring [93] which is not only linked to core urban areas but is also well connected to interstate roads probing right into the centre of the city. Furthermore, these roads are conceived as local service roads running parallel to the main lanes. It should be stressed that this development pattern is similar to Boston's Route 128, which suggests that peripheral highways have become the favored location of business facilities. The Flemish region also has a circumferential highway, much like the Brussels highway ring which acts as an alternative to provide full access to business parks and industrial zones [94]. Our findings suggests that distance to residential roads has a notable impact due to the same reason. In Walloon Brabant, it should be emphasized that most of the high-speed roads are linked to urban centres.

Thus, in line with Mustafa's [21] work, development occurs along most of the railway lines that include both residential and commercial sectors. In order to evaluate the 3D urban growth process from 1985 to 2006, Shi et al. [95] used Shanghai as an example and looked into the socioeconomic factors that influenced spatial expansion. Their research revealed that Shanghai's dominance in spatial expansion changed from vertical to horizontal. Similarly, Al shalabi et al. [96] predicted and forecasted the growth pattern in Yemen from the years 2000 to 2004 using an integrated model of CA and SLEUTH. They came to the conclusion that the greatest expansion took place around unplanned regions outside of municipal limits and in agricultural areas where there was no infrastructure system in place. Hu and Lo's [97] earlier research used logistic regression to simulate urban growth in Georgia's Atlanta Metropolitan Area in a GIS setting and to ascertain the connection between urban growth and the driving forces. They utilized logistic regression modelling to determine the most likely locations for urban expansion in Atlanta and to better understand the demographic, economic, and biophysical variables that have fuelled urban growth. They discovered that the impact of population density and the distance to city business districts (CBDs) on urban growth varied. Poelmans and Van Rompaey [63] assessed the performance of various modelling approaches for simulating spatial patterns of urban expansion in Flanders and Brussels during the years 1988–2000 based on the complexity of three scenarios: (i) logistic regression, (ii) CA transition rules, and (iii) a hybrid model, combining both approaches. The most significant factor influencing the spatial pattern of urban expansion in Flanders and Brussels, according to sensitivity analysis, was the zoning status. They also pointed out that the validity of a model cannot only be stated on the basis of one goodness-of-fit measure.

Recent densification nearby railway hubs is much more important in Flanders than in RBC, which may be due to the fact that the vicinity of railway stations is already very dense in RBC, which was not the case in Flanders in the early 2000s. By contrast, one does not observe densification around railway hubs in Walloon Brabant. The implementation of transit-oriented development policies appears to be far more advanced in Flanders and RBC than in Walloon Brabant. The population of the three regions is unequally distributed with 1.14 million in Flanders in the north, 0.45 million in Walloon Brabant in the south and 1.22 million in Brussels. It is crucial to emphasize that the Flemish Region completely envelops and connects Brussels, making it more than just a crossroads of Europe. As a result, the demand for new infrastructure and housing units has increased, adding to the difficulty of demographic growth.

Although Walloon Brabant was formerly a prosperous province with many heavy industries and job prospects, resulting in high-income takeaway, it has seen serious decline in recent decades, resulting in very low incomes [91]. On the other hand, though Brussels and Flanders are economically prosperous, they have an unequal distribution of housing costs among different income groups. This shows that though people prefer to reside in the countryside rather than the city centres, the infill development which results in new development in city centres is mostly privately owned rather than socially owned and largely belongs to high-income households.

The year 2019 saw an approximately 10-point regional variation in unemployment rates in Belgium, with the Flemish region's rate falling to 3.3% and the Brussels Capital Region's rate rising to 12.8% [98]. A key feature of infill development is not only that it is happening faster than before, but that it is also happening in medium-density areas where job opportunities are relatively low. Accessibility to cities and road networks have increased job search efficiency and intensity in Flanders and Brussels. The ease of access to the labour market is a small but significant controlling factor in the Flemish province: new built-up land is primarily developing in the areas with a higher employment potential in the vicinity of the city of Leuven and in the west of the study area close to the employment centres in the Brussels area. Jobs in Wallonia have a big attraction effect on the high-density area. As expected, it is generally rising from medium- to high-density areas due to an influx of opportunity, particularly in city centres such as Tienen, Liege etc.

## 6. Conclusions

Although Belgium and the Netherlands are two of the most densely populated nations in Europe, they have diverse land ownership laws and varied urban growth patterns [99]. According to the European Environment Agency [7], Belgium was found to have the greatest level of urban sprawl in Europe at a country level. The Spatial Act of 1962 established a cogent spatial framework for economic prosperity and demographic growth, which led to a restructuring of the territory between housing and economic activities [100]. In the 1980s, planning policies were decentralized to the three regions, the Brussels Capital Region, the Flemish Region, and the Walloon Region. Furthermore, urban development of the north of Wallonia is greatly influenced by the presence of Brussels [15,101] resulting in a fragmented landscape. Urban development in Brussels and Flanders exhibits a relatively dispersed urbanization pattern that is the result of a pre-industrial settlement pattern. In this situation, densification methods are especially decisive to prevent future land consumption and to better systematize already existing peri-urban regions according to their unique characteristics [59].

Using a multinomial logistic regression model, this paper has reflected on and compared the factors typically used as driving forces behind urban densification in the three regions of Belgium as it allows us to better comprehend how human forces influence urban patterns. Because it requires fewer computational resources, multi-scale calibration is conceivable. This research has also demonstrated that the built-up development process is heterogeneous, with links between density and the impact of different built-up development causative factors. Overall, results show that the effect of driving factors used varies across regions. It has considered the three classes of built-up densities of low, medium, and high density. In this study, a total of 18 drivers were selected and processed from four sets of driving forces including socioeconomic, political, and geophysical factors. The built-up densities for Brussels, Wallonia, and Flanders for the years 2000, 2010 and 2020 were gathered. The influence of the factors driving the growth of the city is important in drafting regulations that involve spatial planning of areas for future development.

Our findings indicated that there are certain variables, as highlighted in Table 3, which show convergence or similar influence over time. On the other hand, it can be observed that temporal divergence exists in some variables. Our results reveal that zoning policies have been a constant influence in all densities except for the high-density class. This indicates that expansion or development in low- and medium-density classes still depends on spatial policies, whereas infill development is not majorly controlled by zoning policies. Our study also suggests that in terms of accessibility factors, distance to highways has a positive impact for both Brussels and Vlaams Brabant as it serves as a commuter corridor for people; whereas, in Walloon Brabant, there was no significant impact of highways on infill development. Contrary to these findings, in Vlaams Brabant and Walloon Brabant distance to railway stations had a higher impact on new development, whereas Brussels did not encourage new development along the railway line or in its periphery. Household income is an important driver in our research that had a comparatively mixed impact on all the three regions. Regions like Brussels and Flanders showed a negative impact of income household on development showing that people with high income prefer staying outside the centres, whereas densification is mostly a common phenomenon in areas with low-income households. This also reflects a direct relationship to the total number of households. Additionally, parks and distance to green spaces had a positive impact in Walloon Brabant, which is characterized by a peri-urban setup, but the negative impact of parks as a representation of green space shows that the local authority or municipality requires initiative to plan for green space management in the city.

Hence, through the conclusion, it is recommended that the government step up its direction and implement specific countermeasures based on scientific design of local traffic networks and spatial planning policies in order to support sustainable urban densification. The most effective strategy to date is to use multi-density statistics to handle the multi-scale characteristics of built-up land, allowing the driving forces to function from both the bottom-up (micro behavior) and top-down (such as regional planning regulations) perspectives. It can also be recommended that the concept of a 15 min city can aid in limiting land take adversities by addressing demands at the national level. In addition, a methodical gathering and integration of contextual knowledge at the regional level will help planners to streamline land policies as per the regional requirements.

**Table 3.** Summary of selected significant drivers with their impact on densification over time and region.

| | Brussels Capital Region | | Flanders Brabant | | Wallon Brabant | |
|---|---|---|---|---|---|---|
| | 2000–2010 | 2010–2020 | 2000–2010 | 2010–2020 | 2000–2010 | 2010–2020 |
| Dist. to highways | − | + | − | + | + | ? |
| Dist. To secondary roads | + | − | ? | ? | − | + |
| Dist. To residential roads | + | + | + | + | + | ? |
| Dist. To parks | − | − | ? | ? | − | ? |
| Dist. To stations | − | + | + | − | + | ? |
| Income household | − | − | − | + | − | − |
| Mean Housing | − | + | ? | ? | ? | − |
| Zoning | + | + | + | + | − | + |

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