Urban Performance: Parametric Digital Process for Simulation and Analysis of Occupancy in Regional Centralities Areas of Belo Horizonte

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Abstract. The present study aims to explore the urgent issue of urban expansion and its impact on cities, with a specific focus on the regional centrality areas of Belo Horizonte. The main contribution of this work is the development of a parametric model to assess the environmental impact of intensive occupation in these areas and verify their compliance with sustainable development criteria. The study directly addresses the challenges arising from rapid urbanization, offering a digital approach to analyze and simulate the impact of intensive urban occupation in the regional centrality areas. As a methodology, we used georeferenced data, the Grasshopper parametric modeling software, and the Ladybug plugin for environmental simulations, effectively combining empirical information and computational tools to obtain significant results related to the impacts resulting from the proposed densification.

Keywords: Urban Data Analysis, Urban Design, Parametric Urbanism, Sustainability, Parametric Modeling.

1 Introduction

Urban expansion has been a common characteristic of the urbanization process in many cities, resulting in issues such as low connectivity, underdeveloped infrastructure, and socioeconomic inequality. On the other hand, the compact city is seen as a more sustainable and inclusive alternative. In this context, the Belo Horizonte Master Plan (2019) establishes regional centrality areas as priority zones for population increase and construction density, aiming for a more inclusive, safe, resilient, and sustainable city (UN, 2018). However, it's necessary to assess the environmental impact of this intensive occupation in centrality areas, which justifies the present research. Thus, the objective of this work was to build a parametric model for environmental analysis of Belo Horizonte's regional centrality areas, in order to evaluate the environmental impact of intensive occupation in these areas. Parametric tools are instruments that are not commonly used to aid decision making in urban planning. These have great potential for analyzing important factors such as environmental and landscape impact, more quickly and assertively, making it possible to generate several models in a short period.

The methodology used in the research involved collecting georeferenced data from Belo Horizonte's regional centrality areas, available on the BHMaps portal. This data was imported into the parametric modeling software Grasshopper through the Urban plugin, which enables reading shapefile format files. The Ladybug plugin was used to conduct temperature and relative humidity simulations based on information from the EPW climate file. Sky View Factor (SVF) analyses were also performed to assess the amount of visible sky due to verticalization. Based on the simulation results, it was possible to generate comparative graphs between the current occupation scenario and the scenario proposed by the master plan.

With the obtained results, it was possible to critically evaluate the environmental impact of intensive occupation in these areas quantitatively and qualitatively, as well as to determine if the urban density parameters proposed by law meet measurable criteria of sustainable development. Additionally, the research sought to explore how new information design technologies can assist stakeholders in decision-making processes in urban planning.

2 Guidelines for Regional Centrality Areas

The current Master Plan approved for the city of Belo Horizonte (2019) through Municipal Law 11181/19 classifies as Regional Centrality Areas those portions of the territory where greater construction and population density are intended, promoting mixed use and concentration of economic activities. In addition to infrastructure requalification, the plan's intention is that interventions to be carried out in these areas represent opportunities for transforming the forms of appropriation, uses, and actions of centralities through interventions that express global objectives for a more inclusive, safe, resilient, and sustainable city (UN, 2018).

The idea of decentralization aims to shift from the formation of a monocentric city to the reconfiguration of a polycentric city, reducing dependence on the central area and the need for population displacement. Associated with urban and environmental improvement, the priority is to promote density and concentration of activities in areas with support capacity so that the largest number of people benefit from the actions resulting from redevelopment projects. According to Calthorpe (2001), the emergence of a new polycentric regional structure is a step towards reducing the increasing economic and social resource gaps between communities in metropolitan regions.

However, considering that very tall buildings can have negative effects such as distancing activities from street level and alterations in microclimate (SANCHES, 2020), it's necessary to analyze the occupancy patterns that will be generated by urban parameters with increased floor area ratio. It's also crucial to analyze how the distribution of green areas can contribute to improving density and verticalization conditions, as well as the direct effects on urban drainage metrics.

As guidelines to promote urban improvement and sustainability in these centrality areas, among others, the stimulation of socio-environmental solutions is established, foreseeing measures that seek to mitigate polluting events and encourage ecological solutions. Therefore, the main guidelines focus on promoting active mobility, expanding the availability of green public spaces, addressing lighting and public safety, encouraging cultural events and activities, and adhering to the principles of the smart city concept.

In this context, the Master Plan establishes that technology should be proposed as a "tool for the development of actions and agency among people who experience the daily life of the area, as well as for engagement and conscious use of public space" (BELO HORIZONTE MUNICIPALITY, 2021).

3 Technology and Urban Planning

The way we understand our cities is being transformed by georeferenced mapping. However, the way we design them is also influenced by the possibilities brought about by emerging digital tools. As layers of data and digital information cover urban space, new approaches to studying and analyzing the built environment emerge.

The relationship between cities and the use of digital technologies relates to the widely spread concept of smart cities, which emerged in the early 21st century due to the advancement of various digital tools in information and communication technology applied to urban management and planning. However, despite the term's prevalence in both mass media and specialized literature, there are several contradictions and ambiguities associated with what has been produced.

The technocratic view of the smart city focuses solely on controlling the urban organism, highly strategic and data-driven, resulting in a limited impact confined to administrative processes. Therefore, new perspectives of democratization, connected with data availability, can mature the concept to harness the potential of algorithmic and parametric digital tools to assist in decision-making processes in urban design.

In digital practice, parametric processes combined with visualization and simulation capabilities have influenced architectural development since the 1950s. The development of experimental design systems based on systems theory and the possibilities brought by electronic computers has become primary tools for facilitating problem-solving logic and decision-making.

The possibility of interacting with the model through parameter manipulation allows for simulation and evaluation of various scenarios. This gives stakeholders the opportunity to mediate and interfere with the planning and urban management model. These tools support the idea, as stated by Ratti and Claudel (2015), that in the contemporary digital paradigm, the architect's role lies between top-down and bottom-up, with a focus less on designing objects and more on constructing and orchestrating user-oriented processes.

While this theme is still in its early stages in academic research and governmental practice, some experiences are being conducted in various national and international academic and professional contexts.

In the academic sphere, we can mention the work carried out by the MIT (Massachusetts Institute of Technology) SENSEable City Lab, which aims to promote "urban imagination and social innovation" through design and science. The lab's mission is to anticipate city transformations through technology and study them critically.

On the professional level, the commercial project City Zenith (2015) involves creating a platform based on gaming logic to assist various agents (architects, urban planners, governments, entrepreneurs, builders, among others) in decision-making through visualization and simulation of master plans, urban restructuring plans, and infrastructure projects. The work of the French firm Reperáge Urbain, which created the Carticipe platform (2013), is also centered around a participatory cartographic device designed by sociologists and urban geographers to foster debates and citizen consultations about a city or territory. The platform's goal is to systematically implement a local "participatory ecosystem," offering methodological and human support to users.

Another reference project is the 3DEXPERIENCity platform (2013), which provides a 3D view of the city and ongoing processes. Through various simulation and analysis tools, all stakeholders in urban design processes can understand and visualize the impact of possible decisions. This platform aims to transcend governmental departmental boundaries to facilitate holistic and cooperative territorial planning.

4 Methodology

Thus, within the scope of the developed research, the construction of a parametric model was proposed to carry out the analysis and evaluation of the impacts of verticalization and urban intensification proposed in the Master Plan (BELO HORIZONTE, 2019) in the Regional Centrality Areas, in such a way that it provides a methodological innovation in urban planning, taking into account environmental factors that may have previously been neglected.

To achieve this, the model aimed to provide a three-dimensional visualization of the effects of the proposed occupation in the centrality areas and measure the performance of these areas from the perspective of metrics used to define sustainability criteria. To accomplish this, the research procedures were organized as follows:

- Selection of the analysis area and collection of open data from selected layers in BHMaps;
- Algorithmic modeling of occupation parameters for the Regional Centrality Areas in Rhinoceros software and Grasshopper plugin, with metadata transposed to the Urbano plugin;
- Visualization of occupation parameters, analysis, and evaluation of environmental performance resulting from proposed intensification using the Ladybug add-on.

4.1 Selection of the Analysis Area and Data Collection

The selected Centrality Area is located in the Pampulha Region, in front of the UFMG Campus, intersected by Antônio Carlos Avenue and near Pampulha Airport. This area has significant development potential due to its proximity to the university, making it a regional centrality that is expected to experience greater construction and population density in the near future.

First, open data was collected from the selected layers in BHMaps for the chosen regional centrality, and this data was transposed to the QGIS software. The collected data primarily included layers related to city blocks and buildings along with their respective heights, considering that the analysis would primarily focus on the impact of the buildings. To enhance the analysis, it was necessary to perform a geographic boundary selection in QGIS before exporting.

Subsequently, the data was imported into the Grasshopper parametric modeling plugin through the Urbano plugin's component, which allows the reading of shapefile metadata. Reading the metadata enabled the generation of the selected city block within a controlled environment, making it possible to analyze and assess the area's environmental performance and heat island formation using the Ladybug plugin. This plugin enables the reading of EPW climate files.

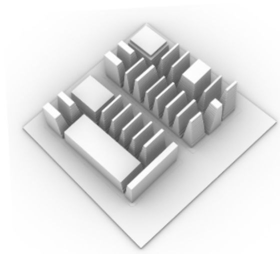
4.2 **Parametric Modeling**

Parametric modeling software enables the construction of interactive models that allow for a dynamic assessment of urban areas under study and proposed interventions. Beyond visualization possibilities, parametric and algorithmic models enable the creation of a metasystem capable of simulating complex dynamic processes, making it a fundamental tool for studying the complexity of the contemporary city and the overlapping diversity of parameters.

For the analysis of the selected area, the modeling process began by representing the city blocks in their current state. Subsequently, models were created for a potential future scenario resulting from the proposed intensification outlined in the new master plan, as well as a scenario without the utilization of the H-rule according to the new master plan of Belo Horizonte. The H-rule involves a formula for calculating lateral and rear setbacks for buildings exceeding 12m in height, where the setback equals 2.3 + (H-12.0)/B (for regional centralities, B=8). One of the primary reasons for this rule's existence is due to the Sky View Factor (SVF) between buildings and on streets, given that very tall buildings tend to impact it. Thus, using the Ladybug add-on again, within a controlled environment, the plugin can simulate scenarios using temperature and relative humidity information from the EPW climate file, generating comparative graphs that reveal potential climate changes resulting from alterations in the urban setting.

Additionally, the Ladybug plugin also facilitates Sky View Factor analysis. Using a three-dimensional model, the component generates visual graphs enabling the analysis and comparison of various scenarios. In this case, three different scenarios were analyzed (Table 1):

Table 1. Different city modeling scenarios.

Current scenario of regional centrality	Possible scenario with maximum CA (5.0) and the H rule	Possible scenario with maximum CA (5.0) without H rule using 2.3 m distance.
		

Source: Authors, 2023.

5 Results

The results obtained through the environmental analysis using the Ladybug add-on demonstrated that with the intensification of buildings, the climate of the region would indeed undergo temperature changes, leading to heat islands. In the case of the H-rule, it is possible to identify, through color-coded graphs analysis, a plausible justification, as the rule achieves one of its objectives by not negatively impacting the Sky View Factor (SVF), unlike the scenario where the rule is not applied. As a result, we can observe that the parameters of the new master plan have both positive and negative aspects regarding sustainability.

1.1 Climate Analysis

For the climate analysis, we conducted a comparison between the impacts of the existing buildings on the region's climate and the potential impacts of a future scenario with buildings at their maximum plot ratio (CA) using the EPW file extracted by the Ladybug add-on. This process generated two comparative graphs (Fig. 1), one for normal temperature and altered temperature, and another for normal relative humidity and altered relative humidity, for both scenarios over a one-year interval.

Based on these analyses generated by the Ladybug plugin, it became evident that there is an increase of at least 1°C in temperature for a significant part of the year, and a decrease in relative humidity in a potential future scenario under the influence of the new master plan. Consequently, it can be concluded that intensification does not contribute to environmental sustainability and aids in the formation of heat islands.

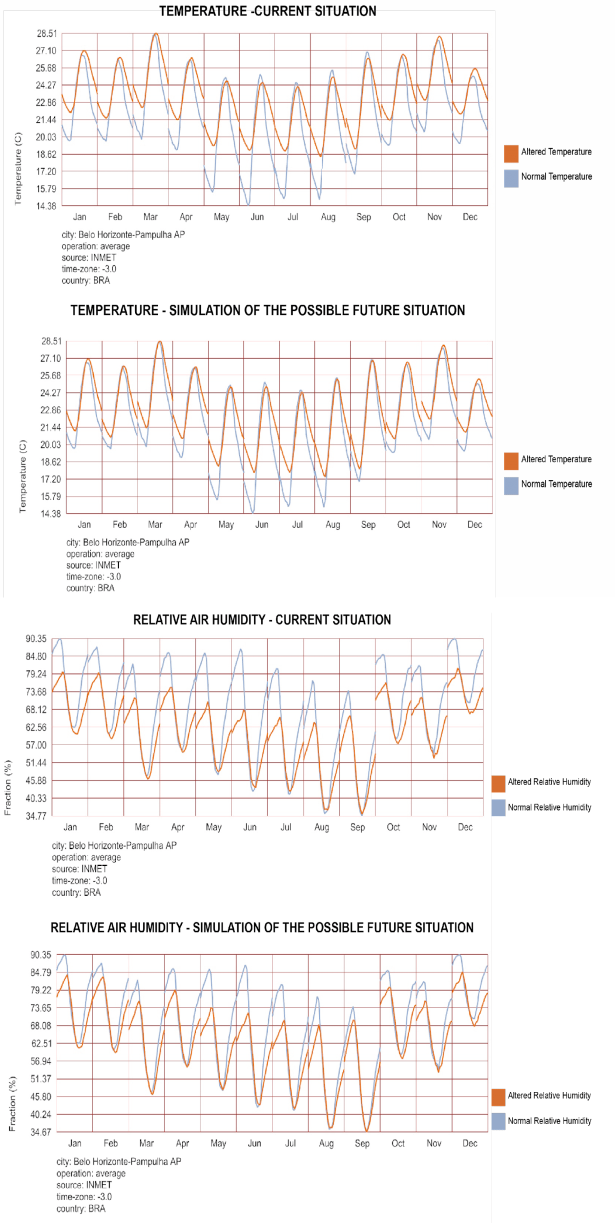


Figure 1. Graphics of simulations of temperature and relative air humidity.
Source: Authors, 2023.

1.2 Sky View Factor Analysis

The Sky View Factor (SVF) analysis refers to an evaluation aiming to determine the amount of visible sky from a given location. It is commonly used in studies related to urban lighting, the impact of light pollution, and the assessment of night sky quality. A high percentage of SVF indicates good visibility of the night sky, while a low percentage suggests less visible sky.

The SVF is associated with various urban environmental processes, as it is a primary cause of heat island formation. This occurs because the cooling of the earth's surface is proportional to the visible sky area. Thus, the SVF percentage represents the fraction of available sky for heat exchange (SOUZA, 2010).

To analyze the sky view factor using the Ladybug add-on (Fig. 2), it was first necessary to model the buildings in the scenarios under analysis: the current scenario, a potential future scenario with the H-rule, and a possible future scenario without the H-rule using a setback of 2.3m. Once the building geometries were modeled and imported, the plugin generated color-coded graphs that visualized the SVF percentages and the impacts caused by building heights. In these graphs, the color pink represents the lowest percentage, green signifies a medium percentage, and blue indicates the highest percentage.

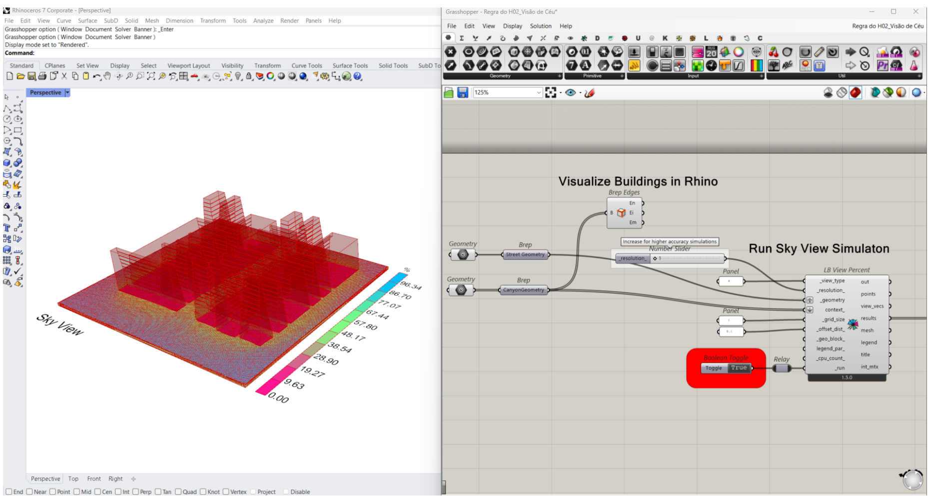


Figure 2. Capture of Sky View Simulation in Grasshopper with Ladybug add-on.
Source: Authors, 2023.

With this, from the analysis of the sky view factor in three different scenarios, it was possible to observe that the increase in the coefficient significantly affects visibility, especially on the streets (Fig. 3).

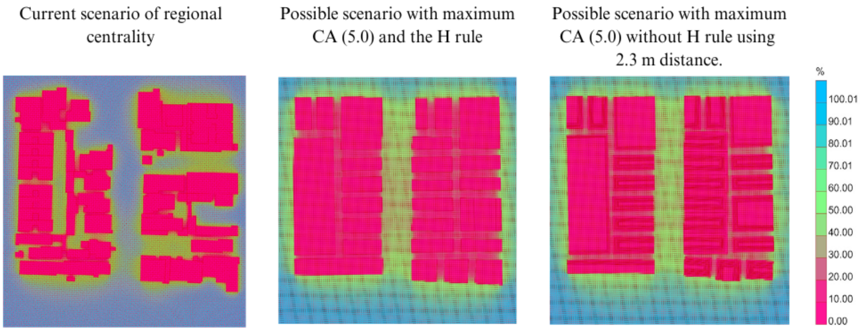


Figure 3. Sky View Simulation with Ladybug. Source: Authors, 2023.

6 Discussion

Contemporary cartography produced through digital mapping can be considered an infrastructure of public administration, as it provides a system for regulating space on a large scale. However, it can also open possibilities for data interpretation and visualization of intentions for urban planning. According to Picon (2015), the smart city is both an ideal and a process; this dual aspect allows this concept to escape mere urban utopias that are often laden with ambiguity. As a process, there are challenges that are simultaneously technological, environmental, social, and cultural, requiring dialogical approaches.

In this way, the availability of open data and the possibilities brought by emerging digital tools for the construction of performative parametric models can serve as devices to pragmatically test the relationship between urban parameters established by law and their contribution to sustainable urban development.

The tools used for urban performance analysis have the potential to predict possible climate changes resulting from changes in the urban scenario. The incorporation of these tools into urban planning could be crucial in avoiding future environmental damage. As demonstrated in the results of the analyses, the increase in the plot ratio can lead to changes in temperature and relative humidity, confirming the hypothesis that the increase in the coefficient does not contribute to environmental sustainability.

Furthermore, the results related to the sky view factor demonstrate that the H-rule does not necessarily contribute significantly to the visible sky area when buildings are at their maximum potential. Therefore, it can be concluded that the increase in the plot ratio is the factor that most negatively influences both environmental sustainability and the sky view factor.

Due to the high degree of flexibility and adaptability of the parametric model, we believe that the study can also serve for future research and complementary investigations, offering a tool for simulation and performance analysis not only of the relationship between morphological and environmental aspects but also of the impacts of socioeconomic dynamics resulting from urban intensification, converting the range of produced data into value of space use.

This research is expected to contribute to identifying challenges, strategies, and planning and urban design guidelines for Regional Centrality areas, as well as to cooperate in aligning urbanization processes with the principles of the compact city and environmental sustainability objectives. The hope is to contribute to more dynamic, participatory, and responsive processes, aiming for a more resilient and sustainable future for our cities.

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