Walkability: Digital Parametric Process for Analyzing and Evaluating Walkability Criteria in Peripheral Central Regions of Belo Horizonte

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Abstract. According to one of the Sustainable Development Goals (UN, 2018), it is important for cities to be inclusive, safe, resilient, and sustainable. Therefore, it is necessary to value pedestrians and consequently active mobility, giving priority to the concepts of the Transportation Oriented Development (TOD) methodology. Although the Master Plan (BELO HORIZONTE, 2019) proposes that areas located in regional centralities are enhancing active mobility, can residents actually benefit from these resources at a walkable distance to access basic services? Thus, the aim of this research is to utilize digital technologies to visualize, analyze, and assess pedestrians' access conditions to commerce and basic services, identifying areas lacking infrastructure. The goal is for the model to serve as a reference for the development of public policies. To achieve this, metadata was used for parametric modeling to study walkability in the peripheral region of the city of Belo Horizonte.

Keywords: Walkability, Urban Data Analysis, Urban Design, Parametric Urbanism, Algorithmic Logic.

1 Introduction

Walkability is an important concept in sustainable urbanization that aims to promote walking as a means of transportation, rather than relying on cars. The current Master Plan of Belo Horizonte (2019) aims to implement urban planning actions based on the principles of Transportation Oriented Development (TOD) for central areas. In Paris, we have an example of a city that sought to embrace these walkability values. This strategy was adopted during a period of social isolation and had as its main objective to rethink how to include everyday activities that promote greater social connection and, consequently, a more ecological perspective. The proposal is defined as the "15-minute city," meaning its ultimate goal is for residents to have access to basic daily services within a maximum of a 15-minute walk, resulting in shorter commutes between their homes and workplaces, schools, restaurants, leisure spaces, hospitals, parks, squares, and more. However, walkability is even more crucial in peripheral regions that often lack adequate infrastructure and rely more on government actions to improve active mobility.

To develop an interactive model to assess walkability conditions in peripheral regions, this study adopted a methodology that included the collection of georeferenced layers from the "BH Maps" portal, the selection of the study area in the Vale do Jatobá region (characterized by its rugged topography and low Urban Development Index), and the use of metrics such as Walk Score and Physical Proximity Algorithm (APF) for analysis and evaluation.

Based on the collected metadata, it was possible to build an interactive model that allows micro and macro local analyses, using the Urban plugin through the Grasshopper plugin. The model enables measurement and classification of a route according to the access conditions from a specific residential lot to a particular facility. It also allows visualization, through heatmaps, of the walkability quality level in specific areas, such as access to the main bus station in the region. The analysis results will help identify areas lacking public facilities, shops, and services in the region, as well as evaluate critical points on roads that do not meet the necessary conditions for active mobility.

However, the construction of the model also brought us the perception of inherent contradictions that can arise between the importation of urban planning models and their possibilities for effective local actions. Therefore, we believe that this study can be especially useful for policymakers to develop active mobility-oriented intervention projects, taking into account specific contexts and optimizing resource allocation for the revitalization of peripheral centralities.

1.1 Urban Legislation

In the current Master Plan of Belo Horizonte, approved by Law 11.181/19, regional centrality areas were established, where one of the main principles of development is focused on active mobility. In these areas, the government aims to promote the use of non-motorized transportation and encourage walkability. However, do these demarcated regional centrality areas effectively provide suitable walkability conditions for pedestrians? Therefore, the objective of this research is to quantitatively and qualitatively assess the walkability conditions in these centrality areas.

1.2 Metrics for analysis and evaluation

For the quantitative analysis, a digital parametric method will be used for modeling and evaluating the existing conditions using two metrics. The first metric is called "Walkscore" (WALKSCORE, 2021), which, according to Carr et al. (2011), is an algorithm capable of generating scores based on distances from a given location, as well as the closest points of service and commerce to it. These points can be classified into five categories (education, commerce, entertainment, and recreation). These categories are then weighted equally and added together, resulting in a single index that can classify the walkability of the desired location.

As an example, if the closest service in a specific category is located 400m away (approximately a five-minute walk) in a certain location, then the maximum points will be attributed to that category for that location. The score decreases as the proximity increases to 1.6 km (which is approximately a 30-minute walk), and thus no points are attributed to services located at that distance. All categories have equal weights, and their respective points are summed and then normalized to generate a score between 0-100, allowing the walkability of the desired location to be classified (see Table 1). The number of nearby and available services, as well as their respective distances to nearby residences, are the main parameters that contribute to optimized walkability.

Table 1. Walkscore Value Classification

90-100	*Walker's paradise*
	Daily routes do not require a car
70-89	*Very walkable*
	Most routes can be completed on foot
50-69	*Somewhat walkable*
	Some routes can be covered on foot
25-49	*Car-dependent*
	Most routes require a car

0-24	*Car -dependent*
	Almost all routes require a car

Source: Walkscore, 2014

The second metric used is the Physical Proximity Algorithm (APF), a tool that calculates routes with the shortest physical distances from different origins to specific destinations within a given location, taking into account the respective inclines of each route. Therefore, the APF considers the positioning of specific starting points (which could be lots within a neighborhood), street layout, as well as the positioning of desired points of interest. This allows for the calculation of physical proximity based on the calculation references presented in the "Walkscore."

For instance, if the starting point is located 400m away (a 5-minute walk) from its destination, a final value of 1 is attributed. As the distance between a starting point and its final destination starts to approach 1.6 km (a 20-minute walk), its score decreases. A value of 0 is assigned for distances where the nearest destination is equal to or greater than 1.6 km away (as shown in Table 2). The lowest value (0) results in the route being disregarded, while the highest value (1) indicates that the route has excellent quality.

Table 2. Reference values for calculating physical proximity measures.

Índex	*Meaning*
1	Excellent proximity - less than 5 minutes walk
0,5	Good proximity - 10 minutes walk
0	Proximity disregarded – more than 20 minutes walk

Source: LIMA, 2017'

Similarly, considering the influence that terrain inclinations have on walking routes (time and effort) during pedestrian travel, the APF allows for applying penalties to uphill routes. Thus, the steeper the incline of a certain segment, the greater the penalty applied to that route. For example, if we consider a flat route of 400m, it will be assigned the maximum index (1). However, if another route covers the same distance of 400m but has an incline of 10%, the final value assigned to that route will be 0.9. This is because the route will incur a penalty of 10%, corresponding to its slope. Therefore, the APF aims to measure and assess the walkability of a specific area by calculating routes with shorter distances to all targets within the same category. It takes into account their physical distances, inclinations, and applies respective penalties, allowing each category to receive a partial index. The total index is then obtained through the average calculated across these partial indices.

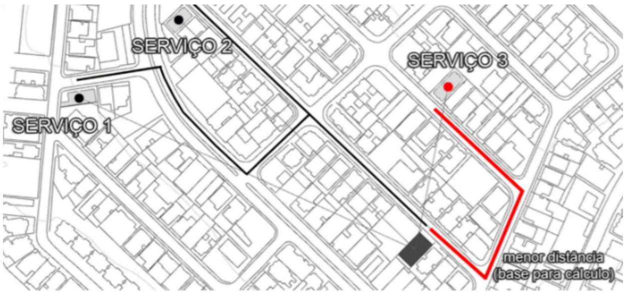

Figure 01. APF calculation logic Source: LIMA, 2017

Therefore, for different targets: the algorithm calculates the shortest physical routes to all targets (services) in the desired category, subsequently identifies the service with the shortest physical distance (highlighted in red), and measures its proximity to the origin based on this distance (including possible inclines and their respective penalties) as depicted in Figure 01.

To conduct a qualitative analysis as well, it will be necessary to focus on a specific context, a segment of the Macroplan of Jatobá in the Barreiro region. As a method for qualitative analysis, we propose the use of digital parametric modeling by designing algorithms for the analysis and evaluation of the established criteria. The unique aspect of implementing parametric systems in urban planning lies in their ability to "maintain the capacity for the model to change throughout the entire design process and to generate and test a large number of versions within a controlled design environment, based on simple changes in specific parameter values" (LIMA; CURY; RIPPER, 2015).

Furthermore, these systems also allow for the visualization of the entire project, which enables an understanding of how the proposed new interventions are being applied, as well as their functionality. With the achieved results, it will be possible to assist the parties responsible for spatial production in identifying the roads within the centralities that do not facilitate walkability, offering objective analyses for potential infrastructure interventions, or in revising areas designated for centralities that do not provide conditions for the effective implementation of active mobility. Such results could be used to guide urban restoration projects, considering that the financial resources have already been allocated for this purpose, established in the Master Plan through the creation of the Centralities Fund, where resources will be allocated for works in these designated areas.

2 Methodology

2.1 Choice of analysis area

The selected study area is within the Jatobá Macroplan in the Barreiro Region, encompassing the Barreiro neighborhood and extending to the Diamante Station and its surroundings, which is approximately 3.5 km away from the mentioned neighborhood. The Barreiro Region, where the study area is located, is characterized as a peripheral region of Belo Horizonte with around 280,000 inhabitants. It can be considered the second busiest region in the capital after the commercial center.

The challenges faced in this locality stem from the fact that the road system and public transportation offerings have not kept pace with the region's development and growth. Many residents work in the central area of the city and require easy access to public transportation and other services. There is a small extension beyond the Barreiro neighborhood selected for analysis, which directly connects to the Diamante Station. This is because it is the nearest station for the residents, making it challenging to connect with local neighborhoods, other bus stations, as well as the central region of Belo Horizonte.

Another recurring factor in the area is its topographical characteristics, with many hills. When combined with the limited availability of basic services and few public transportation options, this further hinders accessibility and active mobility for the residents.

2.2 Surrounding modeling

For the modeling of the location, metadata was collected from the "BH Map", geoportal of the city of Belo Horizonte based on GIS (Geographic Information System), is responsible for providing necessary information in accordance with categories that will be used for analysis and modeling of the area, including (1) Bus Stops, (2) Bus Stations, (3) Schools, (4) Hospitals, (5) Health Centers, (6) CTM Lots, (7) Road Slopes, and (8) Surrounding Buildings. After downloading each of these datasets, they were imported into the QGIS software to perform a more specific area cut. Following the cut, the shapefile files could then be imported into Grasshopper.

The shapefile files were introduced into Grasshopper through the urban plugin. This plugin allows for the reading of shapefile files using metadata, enabling the modeling of the surrounding area of the study as well as the desired analyses. For the modeling of the buildings, the urban plugin was utilized, making use of the building height metadata present in the shapefiles. This process enabled the generation of the volumetric surroundings of the study area cut.

2.3 **Application of walkability analysis criteria**

Subsequently, it was necessary to extract a list of data with the respective slopes of each road segment, enabling the application of a weighting formula to indicate the quality of the route. The formula utilized would consider the distance between a starting point and its final destination and apply a certain penalty value based on the slope of each segment. For instance, if the route is less than 400 meters, it would receive a score of "1" (suitable route); if it's between 400m and 1600m, the score would be "0.5" (less suitable route); and if it's over 1600m, it would receive a score of "0" (unsuitable route). Moreover, penalties would also be applied based on the slope of each segment. For instance, if a 400m route has a slope of 10%, a value of "-1" would be subtracted from its final score, resulting in an adjusted value of "-0.9". If the slope were 20%, then "-2" would be subtracted, and so on.

To facilitate the analysis, slope values were extracted for each route through a datalist. Furthermore, several categories were scored for analysis, including (1) Schools, (2) Bus Stops, (3) Bus Stations, (4) Metro Stations, (5) Hospitals, and (6) the starting point. The urban plugin was used to measure the distance between the starting point and the final destination, as it can generate routes and provide various access possibilities to the desired location. By moving points within the urban grid, it generates adaptable routes.

Finally, a color scheme from red (poor access quality) to green (good access quality) was used to visually represent the route's quality. Different forms were used according to each category of basic services and the starting point. Numerical values were assigned to identify the score for each location, making it easier to interpret the list.

3 Results

Based on the analyses conducted using the metrics applied to potential pedestrian routes in relation to the basic services in the region, generated by the urban plugin, it was concluded that, for the most part, the accesses become inadequate and unfeasible for pedestrians. In some cases, these results are not solely due to the long distances but are also greatly influenced by the steep terrain of the area. In Figure 02, we can observe the modeling of the surroundings based on the acquired metadata from the region. Currently, the modeling has a limitation regarding the local topography, as it is represented on a flat surface. This characteristic did not significantly impact the evaluation results, we chose to create a 3D model to better illustrate the analysis conducted. With the modeling of the surroundings, it becomes easier to understand and represent what is being analyzed. However, as the research progresses, there may be ways to enhance the representation to be more accurate, potentially incorporating the actual topography.

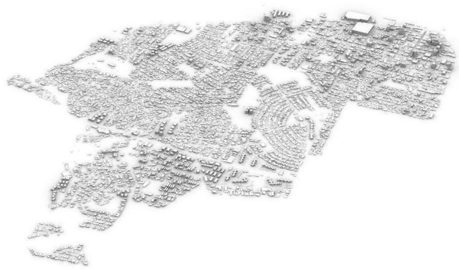

Figure 02. Modeling of the study area based on metadata. Source: Authors, 2023.

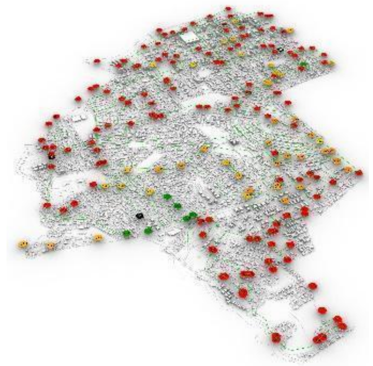

Figure 03. Quality of access to basic services in the region. Source: Authors, 2023.

The warmer colors highlight areas that are difficult for residents to access due to their distance being over 1.6 km, as well as due to the local slope influence. On the other hand, scores indicated by green colors indicate that these routes fall within the accessibility metrics, as shown in Figure 03. Parametric modeling also enables the generation of different routes within the urban grid, allowing paths to adapt according to the starting point. This provides a greater number of analysis possibilities. Below, routes generated and their corresponding results will be shown. The color gradient from red to green indicates the lowest (red) to most suitable (green) quality of access, with the black point representing the initial starting location.

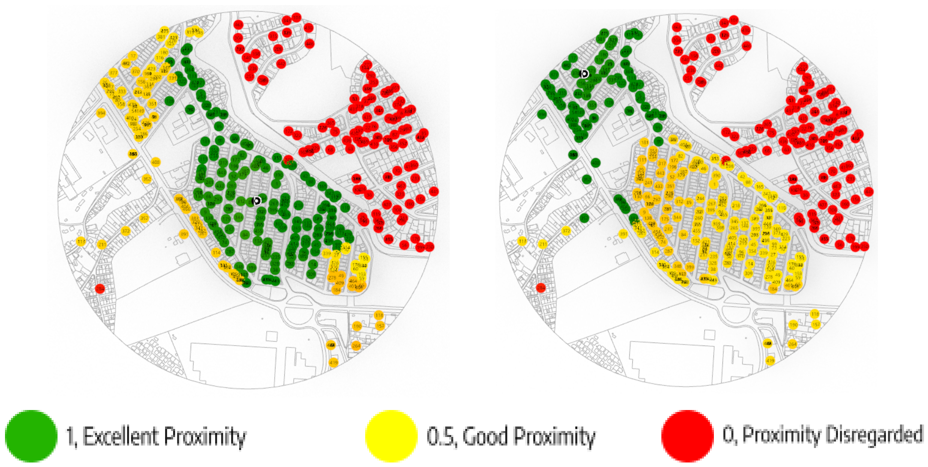

Figure 04. Representation of the parametric model assessing different routes in the urban network. Source: Authors, 2023.

Figure 4 represents the practical route assessment index. Here, we have the three categories clearly specified according to their colors and respective categories. The green color indicates that these are basic services that fall within an excellent proximity, meaning pedestrians can access each of them within a maximum of 5 minutes, taking into account the local slope. In the yellow color, the routes that provide access to services with good proximity are highlighted, allowing pedestrians to access these services in approximately 20 minutes, similarly considering the local slope. Finally, there are the routes that have a disregarded proximity, as accessing each of these services would require pedestrians to walk for more than 20 minutes.In Figure 4, there are two examples of route assessments, starting from different points within the urban network, which is why the colors vary from one image to another. This allows for a better understanding of which areas have more advantages in terms of local basic services when compared to other areas in proximity.

A brief analysis reveals that the most viable points are those near the starting point, while the majority of others are largely unfeasible. Figure 04 presents a color gradient that highlights the quality of access to the final destination. Green lines depict the possible routes for each destination (generated with shortest walk) within each category (bus stops, health centers, and schools). These routes are updated automatically as the starting point is adjusted within the urban grid, generating different options and evaluations.

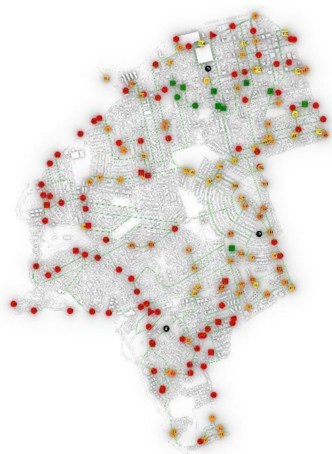

Figure 05. Route Quality. Source: Authors, 2023.

The same walkability analysis method was also applied in another area during a workshop taught by the authors at Digital Futures 2023, involving students from various parts of Brazil. This was done to understand its performance in different locations. The chosen location was in a region in the center of São Paulo, and it can be stated that the obtained results were satisfactory. Using the color gradient, it became possible to comprehend the most accessible services and those that do not fit within this category, thus facilitating the understanding of the pedestrian's relationship with the distribution of services in the area. In Figure 06 (leisure offer), there is an analysis in a central region within São Paulo. The model generated a color gradient that demonstrates the degree of accessibility, similar to the model used in the research, and similarly suggested shorter routes to each of these locations within the urban grid.

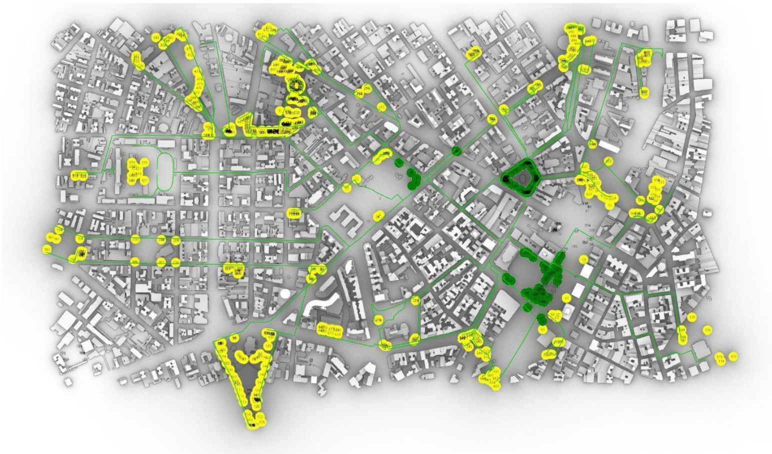

Figure 06. Analysis of leisure offers. Source: Authors, 2023.

4 Discussion

Based on the data obtained from the BH Maps regarding the study area and its parameters that enhance active mobility, it becomes possible to analyze the quality of walkability in the area. This analysis can lead to the conclusion that residents' access to basic services in the region is not providing means that encourage their comfort, necessitating the use of individual or collective transportation in most cases for them to access what they need. This is because these locations are at a considerable distance from their homes and/or have steep inclines, which poses a significant obstacle for individuals as not everyone can complete the journey due to their limitations.

Consequently, the information gathered from these analyses can also contribute to city sidewalk planning, offering pedestrian-friendly routes that grant better access to basic services, thus creating more sustainable cities as envisioned in the United Nations Sustainable Development Goals and Transportation Oriented Development principles.

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