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Pedestrian Perception of the Built Environment and Walkability in Joinville, Santa Catarina

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A Percepção do Pedestre em Relação ao Ambiente Construído e à Caminhabilidade em Joinville-SC

RESUMO

Objetivo - Identificar os locais de maior probabilidade de concentração de atropelamentos (hot spots) e a correlação entre a caminhabilidade do local.

Metodologia - A metodologia aplicada utilizou os registros de sinistros de trânsito (2015-2019) e o instrumento estatístico Getis-Ord Gi* e as ferramentas SIG disponibilizados pelo software Esri ArcGis 10.3.

Originalidade/relevância - A relevância está na abordagem quantitativa e qualitativa para análise de um *hot spot* de atropelamento.

Resultados - O método identificou que a região central é a área que apresenta maior concentração de hot spots. Para verificação das variáveis do ambiente construído foi aplicado o indicador de caminhabilidade Active Design em seis trechos dentro de um hot spot, permitindo a análise quantitativa e qualitativa do espaço sob a ótica do pedestre.

Os resultados demonstram a influência do uso do solo; do tempo semafórico no comportamento de travessia dos pedestres; do fluxo de veículos e das velocidades para veículos, incompatíveis com a quantidade de pedestres presentes no hot spot. Ao vivenciar o local de estudo sente-se as percepções de angústias e inseguranças dos pedestres durante seu deslocamento e permanência.

Contribuições sociais e ambientais – A contribuição desta pesquisa está na soma das análises quantitativa e qualitativa, as quais se mostraram importantes para a compreensão do ambiente construído no *hot spot* de atropelamentos, onde a quantitativa aponta o local e a qualitativa vivência o ambiente a partir do usuário.

PALAVRAS-CHAVE: Mobilidade. Active Design. Atropelamentos. Uso do Solo.

Pedestrian Perception of the Built Environment and Walkability in Joinville, SC

ABSTRACT

Objective - To identify locations with the highest probability of pedestrian accidents (hot spots) and the correlation between walkability and accident rates.

Methodology - The methodology applied used traffic accident records (2015-2019) and the Getis-Ord Gi* statistical tool and GIS tools provided by Esri ArcGis 10.3 software.

Originality/relevance - The relevance lies in the quantitative and qualitative approach to analyzing a pedestrian accident hot spot.

Results - The method identified that the central region is the area with the highest concentration of hot spots. To verify the variables of the built environment, the Active Design walkability indicator was applied to six sections within a hot spot, allowing for quantitative and qualitative analysis of the space from the pedestrian's perspective.

The results demonstrate the influence of land use; traffic light timing on pedestrian crossing behavior; vehicle flow and vehicle speeds, which are incompatible with the number of pedestrians present in the hot spot. When experiencing the study site, one senses the anxiety and insecurity of pedestrians during their travel and stay.

Social and environmental contributions – The contribution of this research lies in the sum of the quantitative and qualitative analyses, which proved important for understanding the built environment at the hot spot for pedestrian accidents, where the quantitative analysis points to the location and the qualitative analysis experiences the environment from the user's perspective.

KEYWORDS: Mobility. Active Design. Pedestrian accidents. Land use.

La percepción del peatón en relación con el entorno construido y la transitabilidad en Joinville-SC

RESUMEN

Objetivo: Identificar los lugares con mayor probabilidad de atropellos (puntos críticos) y la correlación entre la transitabilidad del lugar.

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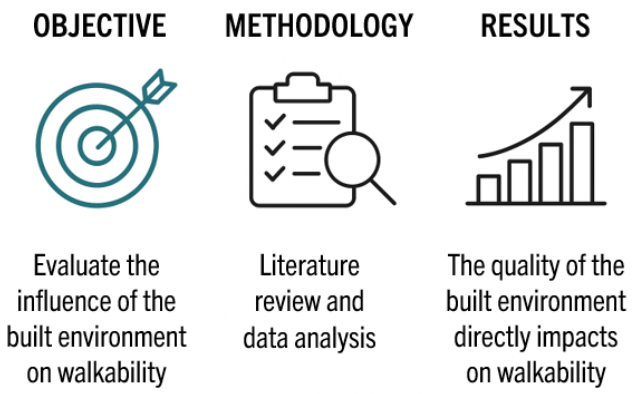
Metodología: La metodología aplicada utilizó los registros de accidentes de tráfico (2015-2019) y el instrumento estadístico Getis-Ord Gi* y las herramientas SIG disponibles en el software Esri ArcGis 10.3.
Originalidad/relevancia: La relevancia radica en el enfoque cuantitativo y cualitativo para el análisis de un punto caliente de atropellos.
Resultados: El método identificó que la región central es la zona con mayor concentración de puntos críticos. Para verificar las variables del entorno construido, se aplicó el indicador de transitabilidad Active Design en seis tramos dentro de un punto crítico, lo que permitió el análisis cuantitativo y cualitativo del espacio desde la perspectiva del peatón.
Los resultados demuestran la influencia del uso del suelo; del tiempo semafórico en el comportamiento de los peatones al cruzar; del flujo de vehículos y de las velocidades de los vehículos, incompatibles con la cantidad de peatones presentes en el punto crítico. Al experimentar el lugar de estudio, se perciben la angustia y la inseguridad de los peatones durante su desplazamiento y permanencia.
Contribuciones sociales y ambientales: la contribución de esta investigación radica en la suma de los análisis cuantitativos y cualitativos, que han demostrado ser importantes para comprender el entorno construido en el punto caliente de atropellos, donde el análisis cuantitativo señala el lugar y el cualitativo experimenta el entorno desde la perspectiva del usuario.

PALABRAS CLAVE: Movilidad. Diseño activo. Atropellos. Uso del suelo.

RESUMO GRÁFICO



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1 INTRODUCTION

The growing motorization of individual means of transport increases negative externalities such as noise and air pollution, and traffic accidents, impacting walking and cycling. Aiming to accommodate car traffic, urban planning promotes the construction of long blocks and the addition of parking lots to comply with the speed and needs of cars.

According to Gehl (2013), feeling safe is essential for people to take ownership of space and, consequently, for cities to become "alive." The insecurity pedestrians face is partly reflected in the data on traffic fatalities in Brazil. In 2023, 16.23% of victims were run over by cars (Bastos; Euleterio, 2025).

Road safety studies analyze the locations where traffic accidents occur, identifying areas with a high concentration of accidents, known as critical points (Ziakopoulos; Yannis, 2020). In Brazil, in 2021, the National Plan for the Reduction of Traffic Deaths and Injuries - PNATRANS -2021-2030 was launched, established by Law No. 13,614 of 2018, with the goal of reducing the number of traffic deaths by 50% by 2030. As part of this strategy to reduce deaths, the identification and treatment of critical points are priorities highlighted in the "Safe Roads" framework (BRAZIL, 2023).

Understanding the role of the built environment (BE) and urban land use are highlights in road safety research (Rahman; Jamal; Al-Ahmadi, 2020). Miranda Moreno, Morency, and El-Geneidy (2011) reveal that this relationship between the BE and pedestrian accidents is mediated by pedestrian activity, i.e., there is no linear relationship between the BE and the frequency of pedestrian accidents, which in turn depends on the interaction between environmental variables (Ding; Chen; Jiao, 2018), which may be related to the frequency, presence, and risk of pedestrian accidents. High-density and mixed-use locations encourage walking, while urban design influences the perception of road safety (Lee; Zegras; Ben-Joseph, 2013), which increases according to the quality of infrastructure, reflected in the segregation of sidewalks and their condition (Kim et al., 2024). Sidewalks with trees or flower beds increase this sense of safety, as does familiarity with the space (Yao; Wang; Wu, 2025).

A walkable city gives people a sense of protection from accidents with cars, to the point that they choose to walk. In this regard, walking safely becomes a right for everyone (Speck, 2017; IPPUJ, 2016b).

Walkability indexes propose ways to measure the attributes of urban space that reflect the physical and perceived quality of the network geared toward walking (Rodrigues et al, 2014; Speck, 2017; Veloso, França, and Santos Neto, 2023). The variables change according to scale and individual perception, that is, they are objective and subjective, seeking to cover the entirety of what occurs in urban space. The attributes of the built environment influence the choice to walk, as do personal and cognitive issues.

The UN established the Decade of Action for Road Safety between 2011 and 2020 with the goal of reducing the number of deaths worldwide by 50% and extended it between 2021 and 2030 as the second decade of road safety, continuing with the reduction goals (WHO – WORLD HEALTH ORGANIZATION, 2021).

In order to improve mobility and reduce negative externalities, Brazil enacted Law 12.587/12, known as the National Policy for Urban Mobility, which has as one of its premises

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the prioritization of Active Transportation. The municipality of Joinville, located in Santa Catarina, with an estimated population of 654,888 inhabitants (IBGE, 2024), developed the Joinville-SC Mobility Plan - PlanMob (IPPUJ, 2016a) and established the Active Transport Master Plan - PDTA (IPPUJ, 2016b), which aims to improve the quality of life of the population through non-motorized transport. To monitor the effectiveness of the actions taken, it was proposed the monitoring of traffic accidents and the use of indexes such as the walkability one.

2 OBJECTIVES

This article aims to study the relationship between traffic accidents, the built environment (BE), and walkability in the municipality of Joinville, Santa Catarina, Brazil. Its specific objectives are: a) to use a geostatistical index through spatial analysis to identify the regions with the highest concentration of pedestrian accidents in Joinville; b) to identify elements of the built environment that contribute to traffic accidents; c) to evaluate the variables of the built environment based on a walkability index; and d) to understand the interaction of the variables of the built environment based on the pedestrians' perception.

3 METHODOLOGY

Two methodological approaches were used: quantitative, using a statistical method to indicate the location with the highest concentration of pedestrian accidents; and qualitative, applying a walkability index to verify the variables of the built environment.

The Getis-Ord Gi* statistic establishes whether or not there is a concentration referring to the sum of values associated with a variable X, determined by the researcher, in each study area (Getis; Ord, 1995). From the application of the statistic, values called z-scores are generated, and the higher the z-score value, the greater the probability of occurrence of clusters of high values (hot spots), and the lower the z-score value, the greater the probability of occurrence of clusters of low values (cold spots), so that both extremes express a lack of randomness, reflecting in clusters (ITDP, 2019).

To apply the Getis-Ord Gi* statistic, the ArcGis 10.1 program was used. The field of analysis must consist of a variable attribute, which can be the number of traffic accidents at a given point, the accident severity ranking, or the number of victims. Therefore, for specific incidents, the data must be aggregated.

As traffic accidents in Joinville/SC are represented by incidents, where each mapped point represents an accident, it was necessary to adopt measures aimed at aggregating information to determine grouping patterns, thus assessing whether the mapped traffic accidents actually consist of hot spots or are merely random. Thus, a combination of the Integrate and Collect Events tools was used, allowing the transformation of isolated points into clusters of locations.

By integrating traffic accidents that occurred within a certain distance, set at a standard value of 200m, traffic accidents were aggregated, minimizing those described with

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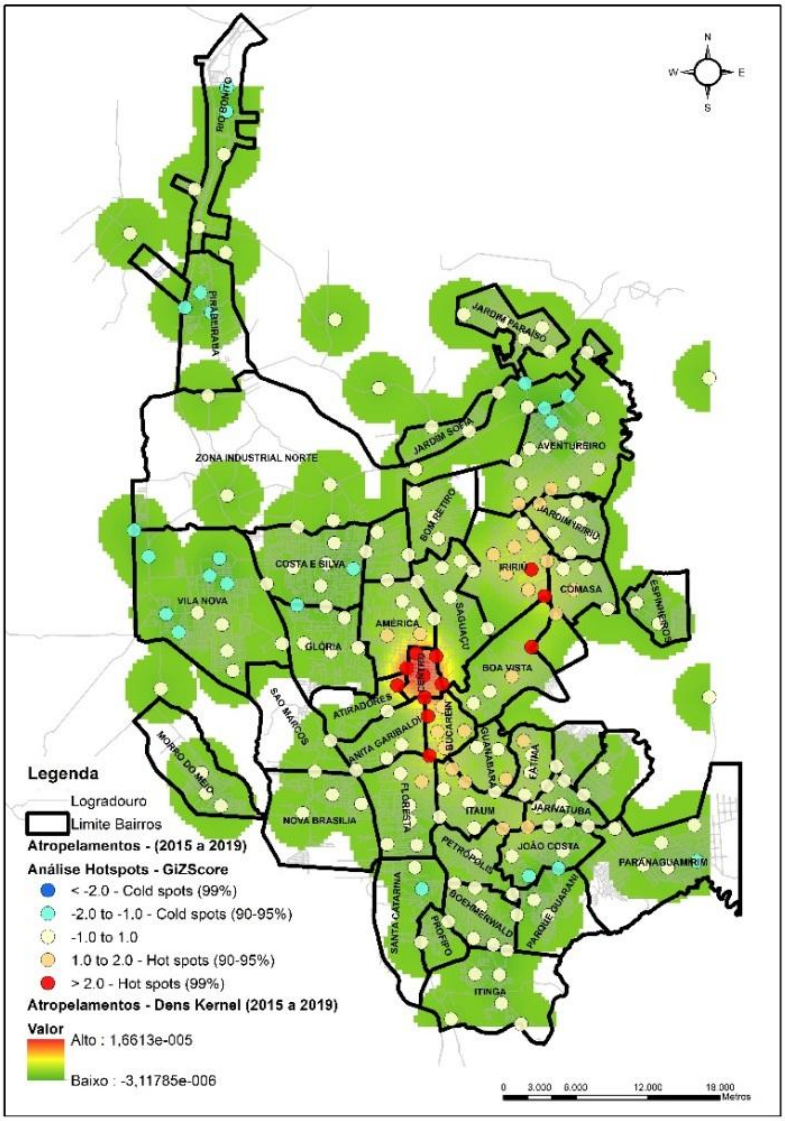
the approximate location of the reference point. Next, the Collect Events tool was applied, and the integrated data was accounted for, assigning the necessary variation for the application of the Getis-Ord Gi* statistic.

The compiled values were used to verify the existence of data clusters with the Hot Spot Analysis tool (Getis-Ord Gi*) (Spatial Statistics), establishing a fixed distance of 1000m, indicating the location of hot spots and cold spots (Figure 1).

Finally, the Kernel Density tool (Spatial Analyst) was applied, with a parameter of 1000 m, considering the GZ score values generated in the previous step, thus illustrating the locations with the highest density of traffic accident hot spots or the highest clustering of pedestrian accidents (Figure 1).

Figure 1 – Overlay map of the Hot Spot Analysis and Kernel Density tools – pedestrian accidents in Joinville-SC 2015-2019.



Source: The Author (2021).

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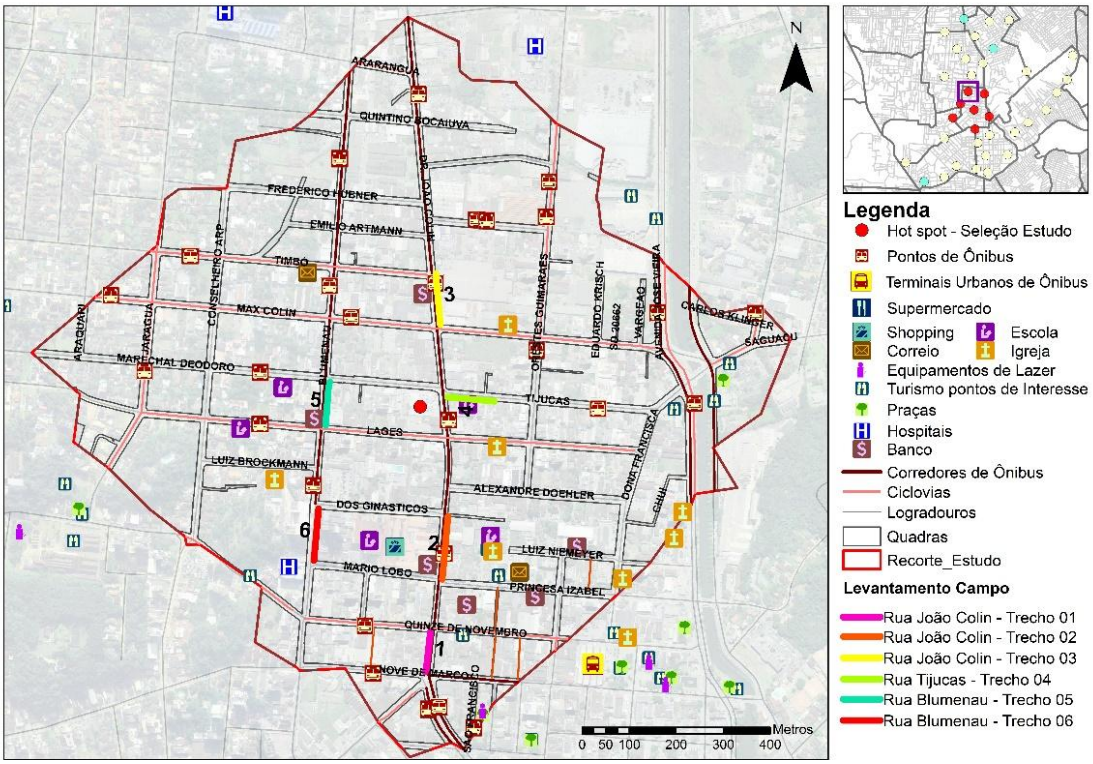
The downtown area has the highest concentration of hot spots of accidents involving pedestrians and cars (Figure 1), and one hot spot was selected for field verification of the built environment variables that may influence the occurrence of collisions with pedestrians. The Active Design method was used as an aid for this qualitative verification, based on a field survey of user perceptions.

From a field questionnaire adapted by the Cidade Ativa group, the methodology was applied on three scales of analysis: hot spot context, street context, and street scale, indicating from excellent to very poor, according to the score indicated by the methodology. In the hot spot context (Figure 2), within a linear distance of a 10-minute walk from the hot spot's centroid, information was collected on the road network, type of road, main roads, land use, land use density, population density, infrastructure for modes of transport, and main urban facilities.

Figure 2 – Hot spot map of pedestrian accidents and main facilities, means of transport, and selected sections.



Source: The Author (2021).

In the context of the street, three roads were selected, Rua Dr. João Colin, Av. Blumenau, and Rua Tijucas, collecting information on typology, uses, and facilities in the surrounding area. On the road scale, six sections were selected (Figure 2) to analyze six concepts: connectivity, accessibility, safety, diversity, pedestrian scale/complexity, sustainability/climate resilience, and the four sidewalk planes were analyzed: road plane, building plane, floor plane, and roof plane.

4 RESULTS

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Based on the analysis of the hot spot context, it was identified that the topography is flat, with a straight and connected urban grid. The area has structural roads—north/south axis—Av. Blumenau, Rua Dr. João Colin, Av. José Vieira, and east/west axis—Rua XV de Novembro and Rua Max Colin, which have a significant volume of traffic, collector roads, and local roads. Within this route, large facilities were identified, notably a hospital, public transport terminal, financial institutions, shopping center, fast food restaurant, and supermarket (Figure 2), making it a location that attracts pedestrians, with a topography that is conducive to walking, but with a high flow of vehicles and speeds that are incompatible with the presence of pedestrians.

The area has residential, mixed, commercial, and service land use, mainly with healthcare services. In the eastern and western portions, there is a higher residential density, while in the south, there is a higher density of mixed use and commercial density along Dr. João Colin Street.

The population density of the area is low, with medium density in the eastern part, where there are some multi-family buildings. The infrastructure is attractive to pedestrians, but shows a low population density, which means that the walkability potential of the area is underutilized due to the lack of people living in the region.

Dr. João Colin Street, an arterial road with a speed limit of 60 km/h, south/northbound, has an exclusive lane for public transportation, large-scale uses such as a shopping center, financial institution, and supermarket, and is close to the public transportation terminal and bicycle path. Tijucas Street, despite being a local road with a speed limit of 30 km/h, west-east, acts as a collector road, with residential and service uses and parking on both sides of the road. Blumenau Avenue, an arterial road with a speed limit of 60 km/h that connects the municipality's north to its south, has an exclusive lane for public transport. Health services are offered along the road, notably a hospital.

The overall assessment of the sidewalks in the hot spot was considered fair, since the area is heterogeneous, with no continuity in the attributes assessed (Table 1).

Table 1: Sidewalk experience.

	Dr. João Colin Street			**Tijucas Street**	**Blumenau Street**	
	Section 1	**Section 2**	**Section 3**	**Section 4**	**Section 5**	**Section 6**
Connectivity	Excellent	Good	Good	Excellent	Excellent	Good
Accessibility	Good	Poor	Fair	Poor	Fair	Fair
Safety	Good	Good	Fair	Fair	Fair	Good
Diversity	Fair	Fair	Poor	Fair	Poor	Poor
Pedestrian scale / Complexity	Good	Excellent	Fair	Good	Poor	Good
Sustainability / Climate Resilience	Very poor	Very poor	Fair	Good	Fair	Fair
Sidewalk Plans						
Building Plan	Good	Good	Fair	Good	Fair	Fair
Road surface	Poor	Fair	Fair	Fair	Poor	Poor
Coverage Plan	Fair	Poor	Very poor	Good	Poor	Poor
Floor Plan	Good	Poor	Good	Good	Good	Fair
Total sections	Good	Fair	Fair	Good	Fair	Fair
Overall			**Fair**			

Source: the Author (2021).

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Regarding concepts, connectivity was rated between good and excellent due to the proximity to major urban facilities, transport options (bike lanes and public transport), and connections between sidewalks, giving the feeling of choice and having everything within reach. Accessibility was considered fair due to the heterogeneity and discontinuity of the pavement, tactile paving, lack of lowered curbs, and, when present, lack of maintenance, making walking unpleasant as attention is focused on the ground in an attempt to avoid falling.

The perceived sense of personal safety varies according to the time of the day and day of the week. During the day, at business hours, the assessment was good due to the movement of people and open stores, which makes the street lively and keeps an eye on it. On weekends, because the buildings are closed and there is no pedestrian traffic, walking becomes unsafe, and at night there is a lack of lighting (Figure 3a).

Figure 3 – Sense of Safety and Diversity.

a) Section 6 – Blumenau Avenue on the weekend

b) Section 2 – Dr. João Colin Street – commercial buildings constructed along the front alignment, presence of a bus stop, and diversity of people.

Source: the Author (2021)

Regarding diversity, the assessment was between fair and poor. Diversity in the area is mainly due to the presence of pedestrians attracted by the shops located mainly at the beginning of Dr. João Colin Street, which has multiple access points, thus dictating the pace of walking. However, in the other sections, the sidewalks were built only for circulation or connection to public transportation, with no use for stops or leisure, resulting in an assessment between fair and poor (Figure 3b).

The pedestrian scale/complexity is compatible, with good block dimensions, buildings constructed along the building alignment and without lateral setbacks, with frontages of up to 15 meters and building heights of up to 12 meters, giving pedestrians the feeling of being enveloped and integrated into the space. This scale begins to be lost in section 3 of Dr. João Colin Street and section 5 of Blumenau Avenue, where the setbacks are larger, approximately 15 meters, and the frontages of the lots have an average length of 50 meters, thus presenting a scale closer to the needs of motor vehicles (Figure 3b).

The floor plan experience was rated between fair and good, due to the presence of damaged flooring (Figure 4a) and heterogeneous paving, discontinuous or non-existent tactile

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flooring, service network inspection accesses, lack of lowered curbs for accessibility, and existing curbs that lack maintenance or do not comply with standards (Figure 4b). The bus stop in the middle of the pedestrian crossing becomes an obstacle, as the furniture is incompatible with the width of the sidewalk, which means that pedestrians have to go into the street to continue their journey, thus increasing the risk of being run over.

In places where shops have 100% lowered curbs for motor vehicles to enter and exit, the risk of being hit by a car increases. This is the feeling, as cars often maneuver on the sidewalk, often ignoring the presence of pedestrians and damaging the sidewalk. At the same time, the area has a good size pedestrian crossing lane and visual continuity of the path to be traveled, except when there is a bus stop (Figure 5).

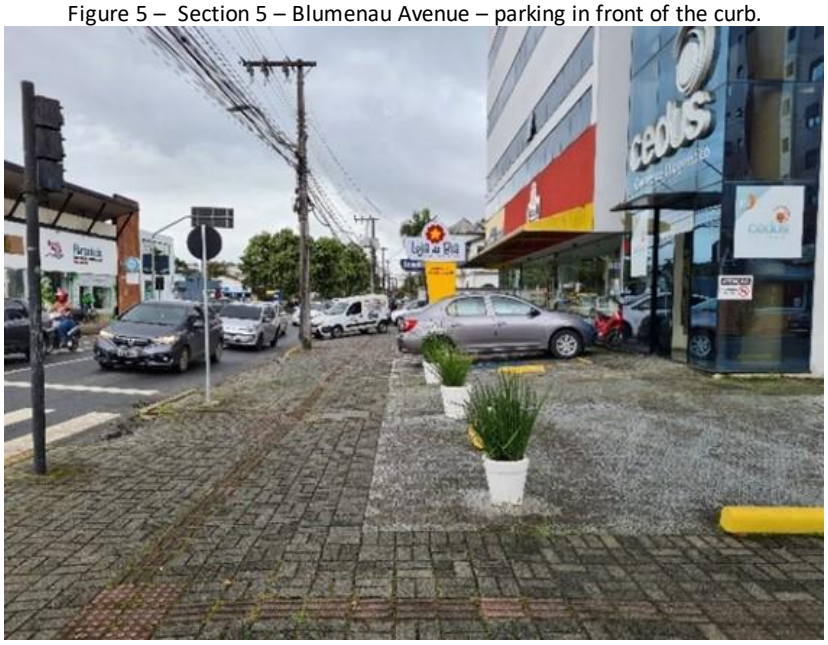
Figure 4 – Sustainability/climate resilience of the space and floor plan.

a) Section 4 – Tijucas Street – Lack of trash cans to accommodate common trash

b) Section 2 – Rua Dr. João Colin – lowered curb with lack of maintenance, forcing wheelchair users to wait on the road to allow time to cross

Source: the author (2021).

Figure 5 – Section 5 – Blumenau Avenue – parking in front of the curb.



Source: the Author (2021).

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With regard to the building plan, in places where the construction is aligned with the front build-to line, there is a greater connection with pedestrians, which is lost as the current front setback is expanded (Figure 6). The façade with shop windows and access that lend dynamism to the walk, and walls and gates in some sections, do not present continuity and convey a sense of distance between the public and private spheres, resulting in an area rated between fair and good.

In terms of the road plan, the perception was between poor and fair. At the edges of roads where there is parking and/or tree-lined medians, walking becomes safer with the intense flow of vehicles separated from the pedestrian traffic lane. In places where the edge of the sidewalk is close to the lane for motor vehicles, the noise is intense, which makes conversation difficult, and the feeling of insecurity increases with the proximity and speed of cars.

Figure 6 – Section 3 – Rua Dr. João Colin – setback and frontage of approximately 15 and 50 meters, respectively.

Fonte: the author (2021).

The same happens in places with an exclusive bus lane, where vehicles pass close to the sidewalk at a speed of 60 km/h, making it possible to feel the air displacement. The edge of the sidewalk generally includes signage and electricity poles, and in a small section there are flower beds, trees, and urban furniture for pedestrians (pay phones), thus revealing the functionality of the space (Figure 7).

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Figure 7 – Section 2 – Rua Dr. João Colin – presence of an exclusive lane for public transport, presence of signage for vehicles, and electricity poles.

Source: the author (2021).

The experience with the roof plan was poor, as the sections with awnings have varying heights and discontinuity in the structure. Some sections, mainly in front of residential buildings, have trees, and the other sections have electrical wiring, thus revealing a lack of consideration for pedestrians, since walking becomes unpleasant on sunny or rainy days.

The quality of the space reveals the lack of priority given to walking in public policies. The characteristics of the space are discontinuous, and the infrastructure was designed only for circulation, without any possibility for stops and contemplation, but mainly for the ease and priority of movement that private vehicles have in the area, reversing the priority on the sidewalk, when the front setback of the lots is used for parking, and these become maneuvering areas.

5 CONCLUSIONS

The application of the Getis Ord Gi* statistic proved valid in identifying hot spots for accidents involving pedestrians and vehicles, identifying locations with the highest concentration of statistically significant accidents. The number of points used and sensitivity in the distances adopted, in smaller sections, may be a limitation of this method.

The data used on these pedestrian accidents lack information such as the severity of traffic accidents, which could result in a different scenario and contribute to the development of public policies for road safety. The result of applying the method indicated the central

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region of the municipality as the location with the highest concentration of pedestrian accident hot spots, and the field research based on the Active Design questionnaire exemplified some variables that may influence the occurrence of collisions between cars and pedestrians.

The obvious variable was land use, with mixed and commercial use, particularly supermarkets, shopping centers, and hospitals, which are concentrated in the hot spot and attract a significant number of pedestrians. The presence of arterial roads, heavy traffic flow, and high speeds proved incompatible with pedestrian traffic. It was noted that traffic light timing influences pedestrians crossing in the middle of the block, which increases the possibility of accidents due to the speed of traffic.

Based on this scenario, public authorities can gain a focused view of some situations that may contribute to accidents and can establish partnerships to develop detailed studies and measures for the location, which can serve as a guide for proposing measures in the municipality.

It would be interesting to apply Active Design with a larger group of people of different ages, genders, and needs to gain a comprehensive understanding of the location, since the method focuses on the user experience.

The two approaches used in this research, quantitative and qualitative, proved to be important for understanding the hot spot, since the quantitative approach discovers the location, while the qualitative approach allows one to experience the sensations of the built environment from the user's perception.

Public policies aimed at encouraging walking, which use field surveys of variables and the quality of the built environment, should consider the sensory and personal perception of the environment, which generates people's identification with the place and a sense of safety, comfort, and individual and collective protection.

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DECLARATION OF CONFLICTS OF INTEREST

We, ISABELLE COSTA LUÍS AND ANDRÉA HOLZ PFÜTZENREUTER, declare that the manuscript entitled "**THE PERCEPTION OF PEDESTRIANS IN RELATION TO THE BUILT ENVIRONMENT AND WALKABILITY IN JOINVILLE-SC**":

1. **Financial ties**: We have no financial ties that could influence the results or interpretation of the work.
2. **Professional Relationships**: There are no professional relationships that could impact on the analysis, interpretation, or presentation of the results.
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