Walkability Indexes: Fusing Environmental, Social, and Infrastructural Perceptions: A Fuzzy Logic-Based Index

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***Resumen*—In this study, the use of a fuzzy system allows us to consider a wide range of factors that influence the experience of walking along an urban route. By assessing aspects such as population density, safety, the presence of green areas, the quality of sidewalks, among others, we can obtain a more comprehensive picture of the walkability of a specific route. These walkability indices not only provide a quantitative evaluation but also offer qualitative information about the ease and comfort perceived when walking in a given urban environment. This can be invaluable for local authorities as it enables them to identify problematic areas and take specific measures to improve pedestrian infrastructure and promote physical activity. Ultimately, promoting more walkable urban environments benefits not only the health and well-being of residents but also contributes to reducing traffic congestion and improving overall urban sustainability.**

INTRODUCTION

Walkability has become a central concept in urban planning and the development of more livable and sustainable cities. A walkable city is one that has the physical and design conditions necessary for residents to move around on foot safely, comfortably, and efficiently.

Improving walkability in urban spaces brings multiple interrelated benefits for public health, the environment, the local economy, and quality of life. On the one hand, promoting walking has proven positive impacts on physical activity and reducing sedentary lifestyles, contributing to the prevention of diseases such as obesity, diabetes, and cardiovascular diseases. In turn, increasing the proportion of trips made by walking instead of private cars helps to reduce air and noise pollution, and mitigate climate change. It also contributes to a more equitable distribution of public space, prioritizing more inclusive modes of transportation.

From an economic and social point of view, walkable streets and neighborhoods favor the development of more dynamic commercial areas, increase citizen security by having more .eyes on the street", and foster community cohesion by creating spaces for meeting and interaction between neighbors. In short, making a city more walkable substantially improves the quality of life for residents. However, in order to implement effective public policies in this regard, it is necessary to be able to measure and monitor the walkability of the urban environment systematically.

The problem lies in the fact that cities generally seek to promote walkability through strategies or infrastructure developments that, while enriching pedestrian spaces, neglect the integral experience of the pedestrian in the city. This lack of assessment of the real needs of pedestrians can lead to inadequate planning of urban infrastructure, causing higher economic costs and hindering the potential of our cities as healthy and sustainable environments.

Thus, with the goal of constructing walkability indices that primarily capture pedestrian perceptions, it is important to design and conduct surveys that clearly capture these perceptions. Therefore, this article presents a detailed description of the survey to be conducted and the process for constructing a walkability index based on fuzzy logic. This approach will not only accurately measure walkability from the residents' perspective but also identify priority areas for urban interventions that improve the quality of life in cities. Additionally, the methodologies employed for data collection and analysis will be discussed, and recommendations will be presented for the implementation of public policies aimed at fostering more walkable and sustainable urban environments.

Fuzzy logic provides a powerful framework for addressing walkability assessment, as it allows for handling the multidimensional and subjective nature of this concept. By considering factors such as pedestrian safety, comfort of the built environment, connectivity of transportation networks, and accessibility to services, fuzzy logic enables us to capture the complexity of the pedestrian experience more accurately than traditional approaches. In this regard, the present study proposes the development of a walkability index based on fuzzy logic, which will integrate multiple input variables to provide a holistic and adaptable evaluation to different urban contexts.

LITERATURE REVIEW

The development of a walkability index for a city involves considering various aspects related to health, economy, and urban planning, such as the relationship between physical activity and health, age groups, regional differences, socioeconomic levels, air pollution, traffic, road conditions, among others. According to (Kahlmeier *et al.*, 2011) economic analyses showed positive benefit-cost ratios, with a median of 5.1 and values ranging from -0.4 to 32.5 , demonstrating the economic benefits of promoting walking and cycling as means of transportation. This project can benefit from tools like HEAT (Health Economic Assessment Tools) for walking and cycling (Kahlmeier *et al.*, 2011), which provide detailed methodological guidance and guidelines for assessing the economic effects on health derived from these activities. These tools have been developed by an international multidisciplinary group of experts and may be useful in addressing challenges associated with the economic evaluation of health impacts from cycling and walking in urban environments.

(Trolese *et al.*, 2023) developed a walkability index for access to transportation nodes. In this model, the factors with the greatest impact on walkability were classified into four groups, based on the reviewed literature. Regarding infrastructure, characteristics of the sidewalk were identified as a crucial variable, while in terms of attractions, pedestrian interests were highlighted. Concerning infrastructure, important variables included crosswalk, car lanes, and intersections. Lastly, in relation to the urban environment, variables such as population, green areas, building elevation, lighting, benches, and fountains were considered. It was found that the number of signalized intersections, the number of car lanes in the near proximity, and building elevation negatively impact pedestrians' willingness to walk. Conversely, the variables mentioned earlier act as incentives to encourage pedestrian activity. It is noteworthy that sidewalk width and the number of activities and points of interest are factors that have a more significant impact, making them crucial for the construction of the walkability index in this project.

As previously mentioned, factors that promote walking activity are often linked to specific characteristics of urban environments. However, the question arises of how to analyze these urban characteristics and their impact on walking behavior when there is a lack of sufficient geographic data. To address this challenge, (Koohsari *et al.*, 2016) has developed a methodology based on Space Syntax to construct indices of total walkability and walkability for access to transportation. These indices incorporate three fundamental components of urban structure: density, diversity, and design. In this way, the resulting index provides a perspective on how the concept of space syntax and its associated methods can be used to generate an easily calculated walkability indicator when the availability of geographic data is limited. Additionally, this project considers residents' perceptions of the urban environment and walking experience, offering an effective way to integrate the pedestrian perspective with the urban characterization.

METHODOLOGY

In general, the walkability index is given by:

$$WI_{ij} = \sum_i \beta_i X_{ij}$$

Where,

- j : Pedestrian link
- i : Attribute
- X : Enlace attributes
- β: Weights of subjective perceptions or attribute relevance

The coefficients of this walkability index can be built in various ways: through linear regressions when existing walkability indices are available, through the expertise of infrastructure experts, or through pedestrian perception (Trolese *et al.*, 2023). In this case, the index based on pedestrian perception will be developed. Therefore, survey design is essential for calculating these coefficients and subsequently the walkability index. This survey will cover the following factors:

- Population Density: Refers to how pedestrians perceive and experience the number of people living or moving in a specific area. This perception can influence their willingness to walk and their experience while doing so. Factors such as comfort level, sense of security, ease of socializing, and availability of suitable pedestrian services and infrastructure can all be influenced by population density.

- Intersection Density: The perception of the frequency and proximity of street and road crossings in a specific area. This can influence the feeling of monotony when walking through certain environments, the diversity in selecting alternative routes, reducing distances, congestion, among others.

- Safety: Perception of safety plays a pivotal role in assessing walkability in urban contexts. Pedestrians' perceptions of safety influence their willingness to walk and the quality of their walking experience. Factors such as well-lit streets, visibility, presence of surveillance, and absence of crime or hazards contribute to a sense of security. Additionally, infrastructure features like well-maintained sidewalks, designated crosswalks, and traffic calming measures enhance safety perceptions.

- Land Use: Refers to how different activities and functions are distributed and organized within an urban area. Land use influences the space available for walking, access to services, and other factors that affect the decision to walk.

- Green areas: The presence of green areas influences the motivation to walk, affecting aspects such as air quality, thermal comfort, and visual appeal. Additionally, it contributes to creating sustainable and pleasant environments for walking.

- Intersection Signaling: Signaling ensures the safety and efficiency of pedestrian and vehicular traffic, reducing the risk of accidents and facilitating pedestrian orientation by providing information on services, points of interest, and transportation routes.

- Gradient: Refers to how pedestrians experience and evaluate the slope or unevenness of the terrain when walking. Urban infrastructure influences the feeling of fatigue, tiredness, and effort required to complete the journey.

- Sidewalks: Sidewalks provide a safe space for walking, with adequate widths and connectivity between them, ensuring the comfort and safety of pedestrians.

- Diversity: The perception of the diversity of services available along the route can significantly influence the decision to walk. If people perceive that there is a wide range of accessible services, such as shops, restaurants, parks, medical or educational facilities, they are more likely to view walking as an attractive and convenient option.

Subject to these factors, 13 fundamental questions are formulated to identify pedestrians perception regarding the aforementioned factors. These questions are evaluated using a Likert scale, which consists of 5 response options: Strongly agree, Agree, Neutral, Disagree, and Strongly disagree. The questions are as follows:

1. Along your route, do you feel that there are people around you who could support you in case of any problem?

2. Along your route, do you feel that there are many intersections that allow you to cross the streets safely?

3. Do you find your journey long and monotonous because you walk through areas with very large and boring blocks?

4. Along your route, is it possible to deviate at multiple points/intersections to change your route?

5. Along your route, can you take advantage of accessing multiple services and meeting diverse needs?

6. Along your route, do you feel that the comfort of your walk is influenced by the number of people and activities taking place on the sidewalk?

7. Along your route, do you encounter elements that make your walk interesting/less monotonous?

8. Along your route, do you feel that the type of vegetation provides shade and protection from the sun?

9. Along your route, do you feel that the presence and type of vegetation create a pleasant environment?

10. Along your route, do you consider that walking involved great physical effort due to the slope/incline?

11. Along your route, do you feel that the presence of sidewalks makes you perceive safety or tranquility in the presence of vehicles?

12. Along your route, do you feel that the comfort of your walk is influenced by the width of the sidewalks to avoid conflicts with other actors (e.g., other pedestrians, cyclists, vendors, etc.)?

13. Along your route, do you feel that the continuity of sidewalks allows you to walk comfortably?

Through the responses to these questions, the coefficients of the walkability index would be constructed. However, currently, we do not have the capacity to conduct surveys with the target audience or have access to this information. Therefore, the following methodology is presented for the construction of walkability indices based on fuzzy logic, which takes into account pedestrians' perceptions of each of the aforementioned factors. In the future, the results of surveys on pedestrians' perceptions could suggest significant improvements to this methodology.

Fuzzy Logic

Fuzzy logic, also known as fuzzy reasoning, is a mathematical paradigm that allows for the representation and processing of imprecise or uncertain reasoning. Unlike classical logic, where propositions are either true or false absolutely, in fuzzy logic, propositions can have degrees of truth ranging from completely true to completely false. This approach is especially useful in situations where the boundaries between categories are fuzzy or ambiguous, such as in control systems, decision making, artificial intelligence, and pattern recognition. Fuzzy logic is based on fuzzy sets, which allow for the representation of imprecision through membership functions that assign degrees of membership to a set. Here are some key concepts of fuzzy systems to understand the construction of the walkability index through fuzzy logic.

Key concepts of fuzzy logic

- Fuzzy sets: In fuzzy logic, a fuzzy set is a set whose elements have degrees of membership, rather than absolute or null membership. This allows representing the imprecision and vagueness in set descriptions.

- Membership functions: A membership function assigns a degree of membership to each element of a fuzzy set. This function describes how an element belongs to the fuzzy set, assigning values in the range [0, 1], where 0 indicates no membership and 1 indicates full membership.

- Fuzzy operations: Fuzzy operations are operations applied to fuzzy sets to obtain new fuzzy sets as a result. Some of the most common operations include fuzzy union, fuzzy intersection, and fuzzy negation.

- Fuzzy rules: Fuzzy rules are logical statements that relate fuzzy sets using fuzzy connectors such as ”and", ”or", and "not". These rules are used in fuzzy inference systems to combine fuzzy information and make decisions based on it.

- Fuzzy inference systems: A fuzzy inference system is a system that uses fuzzy rules and fuzzy logic to process imprecise information and make decisions. These systems are widely used in scenarios where solid databases are not available, having applications in process control, medical diagnostics, recommendation systems, among others.

Fuzzy logic provides a flexible and effective approach for creating walkability indices that accurately capture pedestrians' experience in urban environments. By considering aspects such as safety, comfort, and aesthetics, fuzzy logic can model pedestrians' subjective perception, surpassing the limitations of traditional methods based on binary or rigid numerical values.

Moreover, this methodology allows for the customization and adaptation of walkability indices to different contexts and population groups, making them more relevant to the specific needs of each urban community. This adaptive capacity is particularly useful in situations where there is uncertainty or lack of data, as commonly encountered in pedestrian perception studies. By enabling the management of uncertainty, fuzzy logic facilitates the construction of walkability indices even when available information is limited or imprecise.

FUZZY INFERENCE SYSTEM

In this section, the fuzzy inference system constructed for the development of the walkability index is presented.

Variables

This inference system is constructed using pedestrians' perceptions of the previously defined factors as input variables:

- Population Density Perception
- Intersection Density Perception
- Safety Perception
- Land Use Perception
- Green Areas Perception
- Intersection Signaling Perception
- Gradient Perception
- Sidewalks Perception

The output of this inference system is precisely the walkability index given by the input variables. Subject to the future survey, the Likert scale will be maintained with 5 response options, assuming in this case, numerical values between 1 and 5 for each scale, as follows:

- Strongly disagree (1)
- Disagree (2)
- Neutral (3)
- Agree (4)
- Strongly agree (5)

Therefore, the input variables will have values between 1 and 5, while the walkability index will have values between 0 and 1.

Linguistic Categories

For each input variable, we have chosen to use three classical linguistic categories. This decision is justified as these categories effectively cover a wide range of scenarios, avoiding redundancies and unnecessary complexities in the fuzzy system. Using three categories strikes an optimal balance between model simplicity and the ability to accurately represent the various situations that may arise for the mentioned variables. Although the survey uses the Likert scale with five response options: "Strongly agree”, ”Agree", "Neutral", "Disagree” and "Strongly disagree” it is simpler and more effective to use only three linguistic categories that equally capture pedestrians' perceptions of each factor. Therefore, the chosen linguistic categories are: "Good", "Neutral", and "Bad".

Thus, it can be said that the membership values of the Likert scale options "Strongly Agree” and ”Agree” belong to the fuzzy set "Good", "Neutral” belongs to the fuzzy set "Neutral", and finally, "Strongly Disagree” and "Disagree” belong to the fuzzy set "Bad."

For the output, specifically for the walkability index, five linguistic categories or fuzzy sets have been defined:"Very Low", "Low", "Medium", "High", and "Very High". This choice is suitable because it allows for a more detailed and precise differentiation of the walkability index. With five categories, the system can better capture the nuances and variations in walkability, providing a more granular assessment. This results in a greater ability to reflect the different conditions affecting walkability, from the least favorable to the optimal ones. Additionally, using five categories for the output ensures that the model can offer more specific and useful recommendations to improve walkability conditions in various areas.

Fuzzy Membership Function

The membership functions for each fuzzy set in this system are implemented using Gaussian and S-shaped functions. Each fuzzy set will employ one of these functions with variations in the parameter values, which will be detailed for each set later on.

- Gaussian Fuzzy Membership ($gaussmf(x, \mu_x, \sigma)$)

$$\mu(x, \mu_x, \sigma) = e^{-\frac{(x-\mu_x)^2}{\sigma^2}} \quad (1)$$

- S-function fuzzy membership ($smf(x, a, b)$)

$$\mu(x, a, b) = \begin{cases} 0 & si \quad x \leq a \\ \frac{2(x-a)}{(b-a)^2} & si \quad a < x < \frac{a+b}{2} \\ 1 - \frac{2(x-b)}{(b-a)^2} & si \quad \frac{a+b}{2} < x < b \end{cases} \quad (2)$$

Since all input variables have the same linguistic categories and scales, they share the same fuzzy sets and, therefore, the same membership functions. For the fuzzy set "Bad" perception, an S-function given by $1 - smf(x,$ 1.5, 3) is used. For the "Neutral" perception set, a Gaussian function given by $gaussmf(x,$ 3, 0.3) is used. Finally, for the "Good" perception set, $smf(x,$ 3, 4.5) is used.

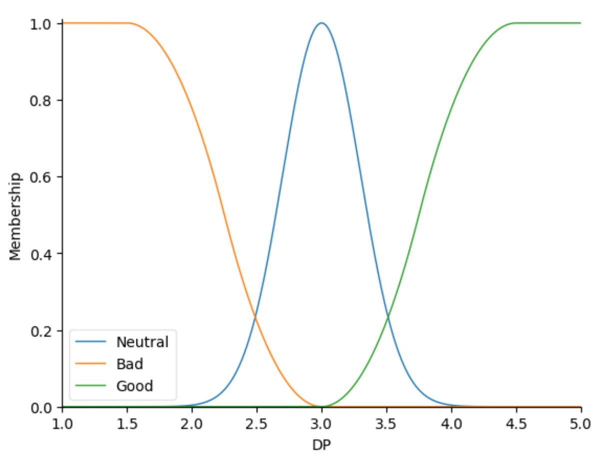

Figura 1: Membership Functions of Input variables

For the output variable, specifically the Walkability Index, the membership functions for each fuzzy set are defined as follows: 1 - smf(x, 0.08, 0.2) for the "Very Low" set, gaussmf(x, 0.25, 0.07) for the "Low" set, gaussmf(x, 0.5, 0.07) for the "Medium" set, gaussmf(x, 0.75, 0.07) for the "High" set, and smf(x, 0.8, 0.92) for the "Very High" set.

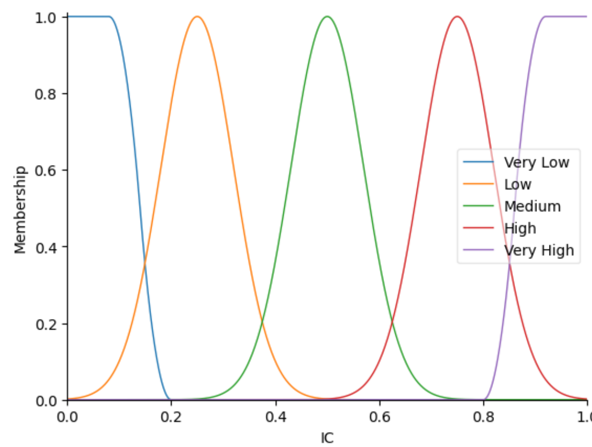

Figura 2: Membership Functions of Output variable (Walkability Index)

T and S Norms

Two S-norms and two T-norms are considered as logical operators.The T-norms will be used to perform the intersection between fuzzy sets, and the S-norm for the union. The norms to be used are presented below, and a comparison of results with respect to the norms will be presented in the results section.

- T-Norms
  - Product: $T(a, b) = ab$
  - Minimum: $T(a, b) = Min(a, b)$
- S-Norms
  - Maximum: $S(a, b) = Max(a, b)$
  - Minimum : $S(a, b) = Min(a + b, 1)$

Defuzzification

Defuzzification is the process of converting an output fuzzy set into a single, crisp value. In this case, we will use three defuzzification methods:

- Centroid:Calculates the center of mass of the output fuzzy set.

- Mean of Maxima (MOM): Calculates the mean of the values with the highest membership degree in the output fuzzy set.

- Bisector: Divides the area under the curve of the fuzzy set into two equal areas, and the output corresponds to the value that divides the areas.

Scikit Fuzzy - Python

The fuzzy inference model was implemented in Python using the scikit-fuzzy (skfuzzy) library skfuzzy development team (s.a.). This powerful library provides a wide variety of functions that simplify the construction of models based on fuzzy logic. It is important to note that, by default, Skfuzzy uses a Mamdani inference system and the Max-Min composition rule.

During the model construction process, essential membership functions were created, such as smf, and gaussmf, which are fundamental for defining the fuzzy relationships between the variables involved. These functions allow for modeling the uncertainty and imprecision of the system's inputs and outputs.

In terms of structure, the fuzzy system was configured as a ControlSystem, in which the variables were specified as control variables, including antecedents and consequents. When defining the Walkability Index variable as a consequent, the defuzzification method that would determine the system output was also detailed. This output corresponds to the Walkability Index.

Fuzzy rules

For this fuzzy system, a set of around 80 logical rules was constructed. To avoid delving into exhaustive detail and to better grasp the system's functionality, here are some of these rules. When writing these rules, the following abbreviations are used: Population Density (PD), Intersection Density (ID), Safety (S), Land Use (LU), Green Areas (GA), Diverisity (D), Intersection Signaling (IS), Gradient (G), Sidewalks (SW), and Walkability Index (WI). (Note: When we say PD is "Good" it means that the perception of population density is Good.)

- **IF** (PD is Bad) & (ID is Bad) & (LU is Bad) & (S is Bad) & (GA is Bad) & (D is Bad) & (IS is Bad) & (G is Bad) & (SW is Bad) **THEN** (WI is Very Low)

- IF (PD is Good) & (ID is Good) & (LU is Good) & (S is Good) & (GA is Good) & (D is Good) & (IS is Good) & (G is Good) & (SW is Good) **THEN** (WI is Very High)

- **IF** (PD is Neutral) & (ID is Neutral) & (LU is Neutral) & (S is Neutral) & (GA is Neutral) & (D is Neutral) & (IS is Neutral) & (G is Neutral) & (SW is Neutral) **THEN** (WI is Medium)

- **IF** (PD is Bad) & (ID is Bad) & (LU is Good) & (S is Bad) & (GA is Neutral) & (D is Neutral) & (IS is Bad) & (G is Bad) & (SW is Bad) **THEN** (WI is Very Low)

- **IF**(PD is Neutral) & (ID is Neutral) & (LU is Bad) & (S is Neutral) & (GA is Bad) & (D is Bad) & (IS is Neutral) & (G is Neutral) & (SW is Bad) **THEN** (WI is Low)

- **IF** (PD is Bad) & (ID is Good) & (LU is Good) & (S is Bad) & (GA is Bad) & (D is Bad) & (IS is Good) & (G is Good) & (SW is Good) **THEN** (WI is Medium)

- **IF** (PD is Good) & (ID is Good) & (LU is Good) & (S is Good) & (IS is Good) & (G is Good) & (SW is Good) & [(GA is Bad) or (GA is Neutral) or (GA is Good) or (D is Bad) or (D is Neutral) or (D is Good))] **THEN** (WI is High)

- **IF** (PD is Good) & (ID is Good) & (LU is Neutral) & (S is Good) & (GA is Good) & (D is Neutral) & (IS is Good) & (G is Good) & (SW is Good) **THEN** (WI is Very High)

There may be a large fuzzy rule base; however, the model will consider only some relevant rules that represent more probable scenarios.

RESULTS

Through a brief survey exploring the perceptions of some students about the aforementioned factors in their daily walking routes, three specific cases were identified, which will be outlined in this section.

Case 1

- Population Density perception = 4
- Intersection Density perception = 4
- Land Use perception = 5
- Safety perception = 4
- Green Areas perception = 1
- Gradient perception = 4
- Intersection Signaling perception = 3
- Diversity perception = 1
- Sidewalks perception = 5

The student assesses his route as follows: he notes that he passes through a busy area at certain times of the day, where there are security cameras and sometimes police presence, which gives him a sense of safety. He also highlights the width of the sidewalks on his route, reducing the risk of accidents with vehicles. Although the route is generally downhill, he feels the slope does not require significant physical effort and could consider walking uphill. He acknowledges the presence of numerous services along the route, mainly supermarkets, which have been helpful in times of need, although he notes that the diversity of these services is limited. Additionally, he points out that the supermarkets are conveniently located without obstructing pedestrian space.

However, he mentions that green areas along the route do not provide enough shade or are far from pedestrian areas, limiting their usefulness during the walk. He also finds it challenging and risky to cross some streets due to the lack of traffic lights at some pedestrian crossings.

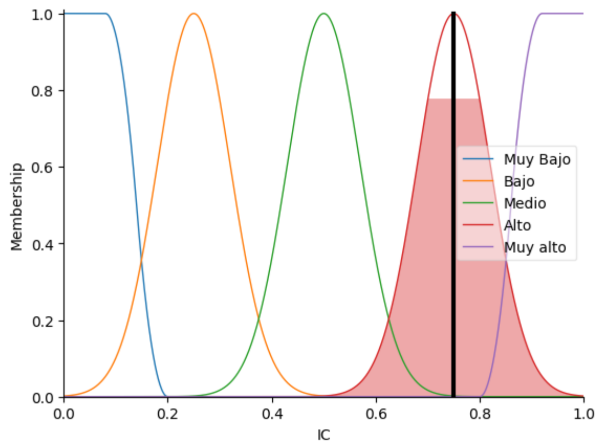

Figura 3: Case 1 - Walkability Index: 0.749948

In this case, using the norms: T norm: Minimum and S norm: Maximum, and the Centroid defuzzification method. According to the fuzzy rules, this scenario belongs to the "High" fuzzy set, therefore, the walkability index for this scenario is calculated as 0.749948. Although this walkability index is high, the perceptions of green areas, diversity of services, and intersection signaling are relatively low, which according to this result significantly impacts the decision to walk, indicating that, for example, the installation of traffic lights and green areas that provide more shade could further incentivize walking.

Case 2

- Population Density perception = 3
- Intersection Density perception = 2
- Land Use perception = 4
- Safety perception = 3
- Green Areas perception = 2
- Gradient perception = 2
- Intersection Signaling perception = 4
- Diversity perception = 3
- Sidewalks perception = 4

The student highlights that the population density and intersection density in his area are moderate, indicating that this population density depends very much on the time of day, and he is aware that there are usually not many people in the area at the time he travels through it. He has a good perception of land use, as he states that the activities that take place along his route do not obstruct his journey. He also considers that the diversity of services or facilities in the area is somewhat limited, but sufficient to meet some needs.

He states that there are very few green areas on his route, and that the little shade there is is due to the roofs of some houses. He positively highlights the signage at intersections, which facilitates his safe passage through the streets, and the sidewalks, as he states that they are quite wide and not affected by land use. Using the norms: T norm:

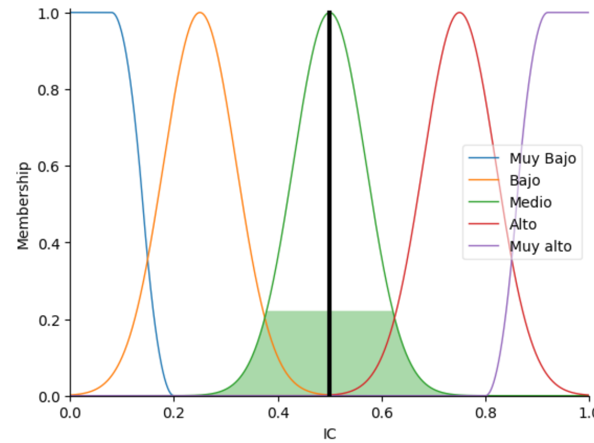

Figura 4: Case 2 - Walkability Index: 0.5

Product and S norm: Maximum, and the defuzzification method: MoM, the resulting walkability index of 0.5 suggests a moderate assessment in terms of the comfort and ease of walking along the specified route. While some perceptions, such as land use and intersection signaling, indicate favorable conditions for walking, others, such as population density, intersection density, and the presence of green areas, suggest potential areas for improvement to encourage pedestrian trips in this area.

Case 3

- Population Density perception = 5
- Intersection Density perception = 1
- Land Use perception = 2
- Safety perception = 2
- Green Areas perception = 1
- Gradient perception = 3
- Intersection Signaling perception = 2
- Diversity perception = 2
- Sidewalks perception = 5

Considering a hypothetical scenario where there is a favorable perception of population density and ample sidewalk space, but with a mediocre perception regarding the route's slope and very negative perceptions in other factors, an extraordinarily low walkability index of 0.0828 is obtained. This result clearly suggests the need for significant improvements in the area.

Although there is a positive perception in two key

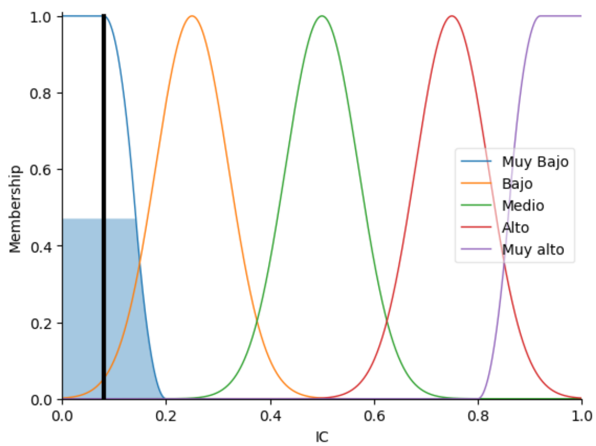

Figura 5: Case 3 - Walkability Index: 0.0828

aspects, such as population density and sidewalk width, these aspects alone are not sufficient to offset the deficiencies in other important aspects of walkability. The regular perception of the route's slope suggests that there might be some degree of comfort while walking, but the very negative perceptions in other factors, such as safety, presence of green areas, signaling, and others, indicate an environment that is not conducive to walking.

A walkability index as low as reflected in the value of 0.0828 indicates a critical situation that can significantly deter walking in that area. The presence of multiple aspects in need of urgent improvement, such as safety, environmental quality, and accessibility, underscores the importance of interventions to make the area more welcoming and safe for pedestrians. This assessment highlights the need for policies and actions that address the various aspects influencing the walking experience, aiming to promote pedestrian mobility and enhance the quality of life in the area.

Conclusion

Through the use of a fuzzy system and the assessment of various factors, including population density, intersection density, safety, presence of green areas, sidewalk quality, land use, street gradient, and intersection signaling, we can derive an index that reflects the comfort and ease of walking along a specific route. These analysis results can be instrumental in pinpointing areas for improvement in the urban environment, such as installing traffic lights, creating more green spaces, or enhancing intersection signage. By addressing these problematic areas, local authorities can foster urban environments more conducive to walking, potentially leading to increased physical activity, improved quality of life, and greater urban sustainability overall.

The results obtained from the three analyzed cases provide reasonable insights, suggesting that this approach is a viable option for quantifying walkability indices. As it is a generalized model, it could be applied across various areas, nationally and internationally, with the ability to adjust and reassess certain logical rules as needed. The planned survey will be invaluable as it will allow for the exploration of multiple perceptions of the same route and the establishment of a walkability index based on these perceptions. Furthermore, it could significantly contribute to the analysis of scenarios addressed in current logical rules, identifying those that have not yet been considered.

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