INTEGRATING UI GREENMETRIC AND WALKABILITY STANDARDS: A FACTOR ANALYSIS OF PEDESTRIAN-FRIENDLY SIDEWALK DESIGN IN A TROPICAL CAMPUS ENVIRONMENT

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Resume

Background: The decline in walking interest on campus is an unresolved issue. Through this study, factors that influence walking intention by integrating the Walkability Index and UI GreenMetric standards are identified. Methodology: The measuring instrument for data collection in the form of a questionnaire was distributed to 110 respondents at Padang State University. The data were analyzed using Exploratory Factor Analysis (EFA) and PCA with Varimax Rotation. Results: As a result, 5 factors were identified with their eigenvalues for pedestrian-friendly sidewalk design, namely: comfort (6.867), technical suitability (2.200), accessibility (1.662), safety (1.156), and sidewalk dimensions (1.142), with a KMO value of 0.823. Conclusion: Comfort is the most dominant factor that infrastructure planners can prioritize by focusing on elements that enhance it, such as the availability of supporting facilities, minimizing mode conflicts, and path cleanliness.

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1 Introduction

Sustainable transportation infrastructure is a key element in green campus planning to reduce carbon emissions and promote active mobility. In university environments, sidewalks are not just physical facilities, but also social spaces that determine user comfort and safety [1-3]. Although sustainability indicators, such as UI GreenMetric have emphasized the importance of non-motorized transportation, many campuses in developing countries, including Padang State University (UNP), still face infrastructure challenges such as damaged road surfaces, inadequate lighting, and poor accessibility for people with disabilities [3].

Previous studies on campus walkability have generally been limited to geometric compliance or partial technical safety thresholds [4]. There is a significant literature gap in integrating Indonesian national technical standards, the Global Walkability Index, and UI GreenMetric transportation indicators into a comprehensive user perception framework [5-6]. Consequently, policymakers often struggle to prioritize infrastructure improvements due to a lack of data on which latent dimensions most influence walking intentions in tropical climates [7].

This study aim was to fill this gap by answering a crucial question: Which latent factors most dominantly influence pedestrian perceptions of sidewalk quality, and how can these factors guide targeted infrastructure investments? Using an Exploratory Factor Analysis (EFA) approach, this study identifies the structure of user perceptions by synergizing three frameworks: technical standards, walkability indices, and institutional sustainability indicators.

Figure 1 *Condition of sidewalk at UNP campus*

Practically, this research provides a foundation for university policymakers in allocating limited budgets efficiently. By understanding key latent factors, for example, if thermal comfort proves to be the largest determinant budget investments should be prioritized on providing shade and vegetation rather than simply on surface aesthetics. This is crucial for encouraging a modal shift from motorized vehicles to walking, which will ultimately resolve the last-mile connectivity issues and enable the conversion of parking areas into multifunctional green spaces. Therefore, this study aim was to determine the key factors for pedestrian-friendly sidewalk design at UNP as a pilot project through the integration of walkability concepts, national technical standards, and UI GreenMetric indicators.

2. Materials and methods

2.1 Research design

In this study was adopted a quantitative research design to assess the condition of pedestrian sidewalks and to explore the underlying factors that shape pedestrian-friendly sidewalk design within a university campus setting. The quantitative approach was chosen to allow objective measurement of users' perceptions and physical sidewalk characteristics, as well as to facilitate multivariate statistical analysis. The research framework integrates walkability concepts, national technical standards for pedestrian facilities, and sustainability indicators derived from the UI GreenMetric framework.

2.2 Study area

The research was carried out at the main campus of Universitas Negeri Padang (UNP) in Padang City, West Sumatra, Indonesia. This campus represents a high-intensity pedestrian setting, as most daily academic activities are undertaken on foot. The observation was focused on the primary internal campus roads that are provided with sidewalks connecting academic buildings, administrative offices, and supporting facilities. For systematic assessment and analysis, the sidewalks were divided into several segments.

2.3 Existing sidewalk conditions

The condition of sidewalks varies considerably across campus segments. Sidewalks located in central academic areas generally exhibit better physical conditions compared to those in peripheral zones. However, even in central areas, several segments still show deficiencies related to continuity, accessibility, and lighting. The condition of the sidewalks in the research area can be seen in Figure 1.

2.4 Data collection

Data were collected through the two primary methods: field observations and a questionnaire survey in June to early August 2025. In general, the period from June, July, to August 2025 is the peak of the dry season in most areas of Padang City, where the UNP Campus is located. Field observations were conducted using a structured checklist to evaluate the physical characteristics of sidewalks, including width, surface quality, continuity, lighting, accessibility features, and supporting facilities. The observation indicators were developed based on the technical guidelines for pedestrian facilities issued by the Indonesian Ministry of Public Works and Housing, the Global Walkability Index parameters, and transportation indicators from the UI GreenMetric framework. In the questionnaire, respondents' answers were scored for quantitative analysis, which can be seen in Table 1. The table is a quantitative research tool used to measure respondent perceptions for 20 indicators of pedestrian facilities. The indicators are from the Global Walkability Index (GWI)

Table 1 *Research Instrument Combination of the Walkability Index, UI Greenmetric, with Likert Scale*

Item	Indicators	Likert Scale				
		1	2	3	4	5
P1	Sidewalk height according to condition categories					
P2	Minimum sidewalk width (1.85 m)					
P3	Longitudinal and transverse slopes of the sidewalk					
P4	Availability of appropriate sidewalk construction					
P5	Sidewalk provisions in bridge areas					
P6	Management of vehicle entry and exit access					
P7	Availability and safety of pedestrian crossings					
P8	Availability of curbs or separators between the sidewalk and roadway					
P9	Safety from crime (Security)					
P10	Driver/Motorist behavior					
P11	Supporting facilities, such as street lighting					
P12	Network connectivity					
P13	Disability-friendly infrastructure					
P14	Sidewalk accessibility					
P15	Integration of green corridors (shade trees or ornamental plants)					
P16	Supporting amenities, such as seating/street furniture					
P17	Drainage system					
P18	Provision of segregated waste bins					
P19	Information boards regarding green open spaces					
P20	Obstacles or physical barriers					

and UI GreenMetric, as well as the Technical Planning Guidelines for Pedestrian Facilities No. 07/P/BM/2023, shown in Table 1, and were given to the sample [6].

In parallel, a questionnaire survey was administered to campus users, mainly students, who regularly use the campus sidewalks. The questionnaire employed a five-point Likert scale to capture respondents' perceptions of sidewalk conditions and their influence on walking comfort, safety, and accessibility. The survey items covered aspects related to comfort, technical compliance, accessibility, safety, and dimensional adequacy.

2.5 Population and sample

The population of this study involved students at Padang State University who use campus sidewalks for daily mobility. Sampling focused on students within this population who had direct experience and were familiar with the existing sidewalks. This sampling provided deeper insights compared to other groups who used them less frequently.

To ensure sample adequacy for Exploratory Factor Analysis (EFA), the sample size (N) was determined based on the N:p ratio (subject-to-item ratio). Although various researchers suggest ratios ranging from 5:1 to 20:1 [8-9], this study adopted a baseline approach of targeting a minimum of 100 respondents to increase statistical stability and minimize standard error [10].

A total of N = 110 samples were administered validated questionnaires for analysis. The resulting ratio exceeded the minimum requirement of five respondents per observed variable. To test the robustness of the factor structure, the Kaiser-Meyer-Olkin (KMO) sampling adequacy measure and Bartlett's sphericity test were conducted before extraction to ensure that the data matrix was suitable for factor analysis. This sample size was deemed sufficient for an exploratory study aimed at identifying the underlying dimensions of pedestrian satisfaction in a specific campus context.

3 Results and discussions

3.1. Instrument validity and reliability

Prior to the main analysis, the questionnaire instrument was subjected to validity and reliability testing. Construct validity was examined using Pearson correlation analysis to ensure that each item measured the intended construct. The recapitulation of the validity and reliability testing procedures is presented in Table 2.

Table 2 explains that reliability was assessed using Cronbach's alpha coefficient, with values exceeding the acceptable threshold of 0.70, indicating internal consistency of the measurement instrument. The Cronbach's alpha value listed in the table is positive

***Table 2** The Recapitulation of the Validity and Reliability Test*

Item-Total Statistics				
	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected item-Total Correlation	Cronbach's Alpha if Item Deleted
P1	67.16	141.006	0.553	0.932
P2	67.42	138.118	0.526	0.933
P3	67.32	140.826	0.544	0.932
P4	67.97	136.699	0.631	0.931
P5	68.00	138.933	0.493	0.934
P6	67.74	142.265	0.469	0.933
P7	68.06	136.529	0.659	0.930
P8	67.71	136.280	0.611	0.931
P9	67.35	139.703	0.591	0.931
P10	67.61	139.178	0.555	0.932
P11	67.45	141.256	0.572	0.932
P12	67.45	137.456	0.643	0.930
P13	67.52	140.658	0.586	0.932
P14	67.65	136.503	0.791	0.928
P15	67.26	135.398	0.726	0.929
P16	68.23	131.047	0.753	0.928
P17	68.00	133.933	0.767	0.928
P18	67.87	135.583	0.843	0.927
P19	68.55	134.723	0.545	0.934
P20	67.58	136.985	0.735	0.929

because it is in the acceptable category above the median.

3.2 Data analysis

Data analysis was performed using descriptive statistics and Exploratory Factor Analysis (EFA). The descriptive analysis was applied to summarize the physical condition of sidewalks and respondent characteristics. The EFA was conducted to identify latent factors influencing pedestrian-friendly sidewalk design. The analysis employed Principal Component Analysis (PCA) as the extraction method, followed by varimax rotation to achieve clearer factor interpretation. The suitability of the data for factor analysis was verified using the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's Test of Sphericity. Factors with eigenvalues greater than 1.0 were retained, and variables with factor loadings of 0.50 or higher were considered significant contributors to each factor.

Exploratory Factor Analysis was selected instead of Confirmatory Factor Analysis since the integrated framework combining technical standards, walkability indicators, and sustainability metrics has not yet been empirically established as a unified measurement model. Given the exploratory nature of identifying latent dimensions underlying pedestrian perceptions in a green campus context, EFA was considered the most appropriate analytical approach to avoid imposing predefined factor structures displayed in Table 3.

The Cronbach's Alpha values in Table 3 show a high category ($\alpha > 0.9$) and explain that this instrument is not only reliable but very cohesive in measuring different aspects of pedestrian satisfaction, as well. Table 3 presents the results of EFA, which identifies the underlying structures within the 20 variables (P1-P20). It represents the correlation between an item and a component. Loadings above 0.5 (e.g., P18 at 0.787) indicated a strong relationship, signifying high construct validity. Additionally, the presence of a single item, such as P11, across multiple components in Table 3 suggests that comfort is often a factor. The 20 items have been successfully condensed into five unique thematic components. For instance, Component 1 is defined by a cluster of 6 items (P18, P20, P16, P19, P12, P17). In addition, Figure 2 can explain it.

The structural relationship between these variables is visualized through a three-dimensional component plot in a rotated space, which depicts the spatial distribution and clustering of items P1 to P20 across the primary extracted components. This visualization serves as a crucial tool for identifying the latent dimensions of sidewalk design, allowing researchers to observe how specific indicators, such as technical dimensions and environmental amenities, group together within the factor space.

Table 3 The Matrix of All Factors (P) for Pedestrian-Friendly Sidewalk Design

Rotated Component Matrix					
	Component				
	1	2	3	4	5
P1					0.862
P2					
P3				0.741	
P4		0.674			
P5		0.740			
P6		0.763			
P7	0.487				
P8	0.402	0.516			
P9				0.770	
P10	0.476			0.594	
P11	0.493	0.469			
P12	0.721				
P13			0.836		
P14			0.823		
P15			0.752		
P16	0.758				
P17	0.667				
P18	0.787				
P19					
P20					0.758

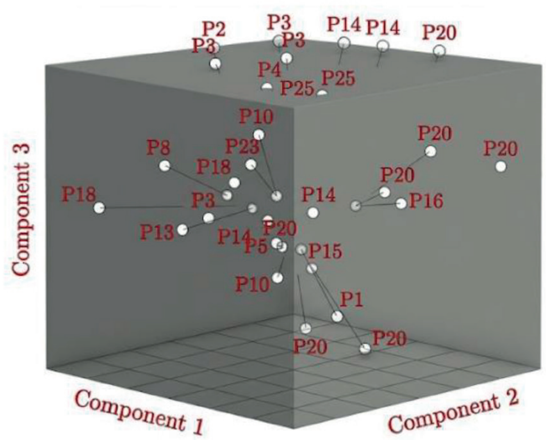

Figure 2 *The component matrix plot in rotated space*

The decision to assign these factors is statistically justified by the scree plot (Figure 3), which displays a clear inflection point (elbow) after the fifth component. The curve shows a sharp decrease in eigenvalues for the first few factors, followed by a gradual flattening, confirming that the five-factor structure is the most parsimonious model for explaining the fundamental dimensions of pedestrian-friendly sidewalk design without extracting excessive noise.

Prior to factor extraction, the dataset was tested to ensure its suitability for Exploratory Factor Analysis. The Kaiser-Meyer-Olkin (KMO) measure exceeded the minimum acceptable threshold of 0.60, indicating adequate sampling adequacy. The Bartlett's Test of Sphericity produced a statistically significant result ($p < 0.05$), confirming sufficient correlations among variables. The results of the data feasibility test are presented in Table 4.

***Table 4** KMO and Bartlett's Test Results*

Statistical Test	Result	Standard
KMO Measure	0.823	> 0.70
Bartlett's Test (Sig.)	0.000	

***Table 5** Total Variance Explained*

Factor	Interpretation	Score and Category of Relative Contribution
1	Comfort	6.867 (Highest)
2	Technical suitability	2.200 (Moderate)
3	Accessibility	1.662 (Moderate)
4	Safety	1.156 (Lower)
5	Sidewalk dimension	1.142 (Lowest)

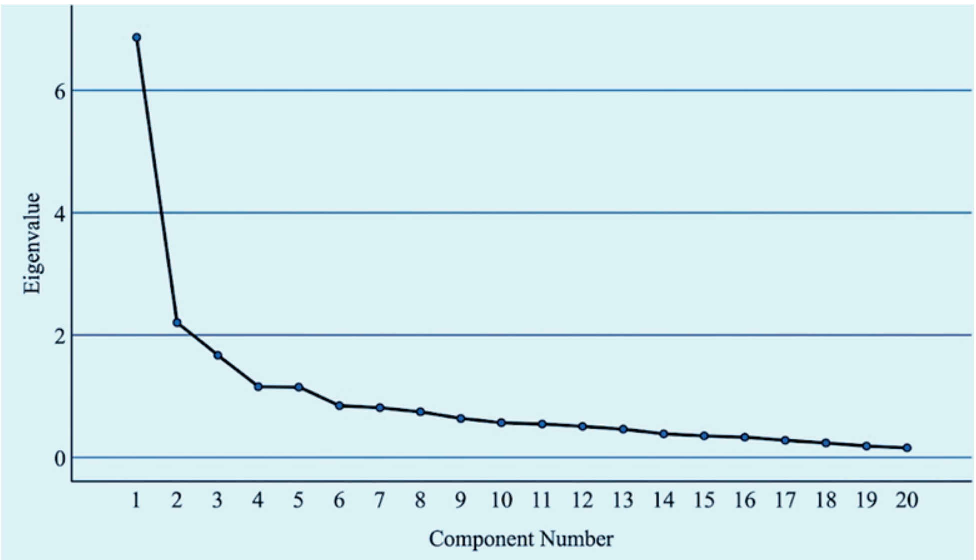

***Figure 3** Scree plot of exploratory factor analysis*

The analysis results in Table 4 demonstrate sample suitability with a KMO value of 0.823, exceeding the minimum threshold of 0.70. Furthermore, Table 5 shows a significant dominant trend in the Comfort factor, which contributes the largest amount of variance compared to the other four factors. This statistically proves that user perceptions of pedestrian facilities on campus are more influenced by the spatial experience (comfort) than simply meeting technical standards or physical dimensions.

Exploratory Factor Analysis was conducted using the Principal Component Analysis (PCA) with varimax rotation. The analysis extracted five factors with eigenvalues greater than 1.0, indicating that these factors represent meaningful latent dimensions influencing pedestrian-friendly sidewalk design. The five extracted factors collectively explain a substantial proportion of the total variance. The relative contribution of each factor is summarized in Table 5.

The results of the analysis show that the comfort factor is the main determinant of pedestrian satisfaction, with a dominant variance of 34.33%, where the high loading factor value on indicator P18 (0.787) confirms that the cleanliness aspect, especially the provision of trash cans, is a core pillar of the definition of comfort for students. Meanwhile, the eigenvalue values on the safety factor and sidewalk dimensions, which are only close to 1.0, indicate that these two aspects tend to be considered as basic standards (baselines) that should be met so that their contribution in explaining satisfaction is not as superior as the quality of the spatial experience offered by the comfort factor. The factor retention decision is visually supported by the scree plot, which shows a clear inflection point after the fifth factor, as presented in Figure 3.

The rotated component matrix reveals a clear clustering of observed variables into five interpretable factors. Variables with factor loadings ≥ 0.50 were considered significant contributors and were used to label each factor. A simplified summary of dominant variable loadings is presented in Table 6, adapted from the rotated component matrix explained before.

Table 6 *Dominant Factors and Their Indicators*

Name of Factors	Code	Indicators
Comfort	P7	Availability and safety of pedestrian crossings
	P11	Supporting facilities, such as street lighting
	P12	Network connectivity
	P16	Supporting amenities, such as seating/street furniture
	P17	Drainage system
	P18	Provision of segregated waste bins
	P19	Information boards regarding green open spaces
	P20	Obstacles or physical barriers
Technical Suitability	P4	Availability of appropriate sidewalk construction
	P5	Sidewalk provisions in bridge areas
	P6	Management of vehicle entry and exit access
	P8	Availability of curbs or separators between the sidewalk and roadway
Accessibility	P13	Disability-friendly infrastructure
	P14	Sidewalk accessibility
	P15	Integration of green corridors (shade trees or ornamental plants
Safety	P3	Longitudinal and transverse slopes of the sidewalk
	P9	Safety from crime (Security)
	P10	Driver/Motorist behavior
Sidewalk Dimension	P1	Sidewalk height according to condition categories

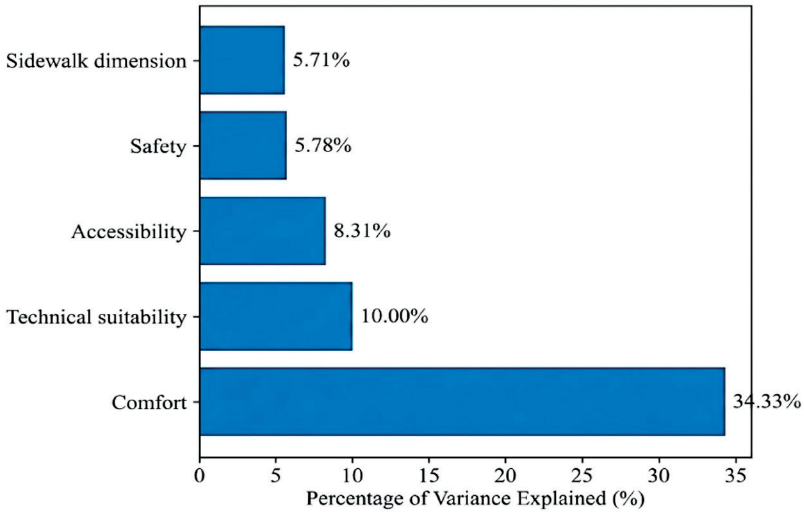

Figure 4 *Relative contribution of extracted factors to total variance*

Table 6 explains that each factor represents a previously analyzed indicator. The comfort factor has eight components and is the most numerous.

To enhance interpretability, the relative contribution of each extracted factor to the total explained variance is illustrated in Figure 4. The diagram highlights the dominant influence of the comfort factor compared to other factors. Comfort is the most important factor in planning pedestrian paths on campus since it directly shapes pedestrian readiness to walk by integrating fundamental aspects such as temperature, shade, surface quality, and perceived safety into a single dimension of experience. In campus environments, especially those in tropical or densely populated areas, exposure to heat, humidity, and rainfall increases the importance of providing physically and mentally comfortable paths, making comfort more important than purely technical or aesthetic considerations. The student sample in this study has provided their perceptions regarding this through their experiences.

Overall, the results indicate that pedestrians' perceptions of sidewalk quality are shaped by several latent factors, with comfort emerging as the most influential determinant within the campus setting. This finding confirms that pedestrian-friendly sidewalk design on university campuses is not governed by a single attribute, but rather by the interaction of experiential, technical, and contextual dimensions [11].

The prominence of the comfort-related attributes supports empirical evidence suggesting that pedestrian satisfaction and walking decisions are largely driven by experiential qualities, such as surface smoothness, path continuity, shading, and microclimatic comfort, rather than by dimensional or regulatory compliance alone [11-12]. This observation is consistent with studies highlighting the gap between the perceived walkability and objectively measured built-environment indicators, where users' subjective evaluations play a decisive role in shaping both perceived quality and willingness to walk [13]. In campus environments, where walking forms an integral part of a daily academic life, comfort therefore becomes a critical factor influencing pedestrian perceptions and behavior [14].

Technical suitability was identified as the second most influential factor, reflecting the importance of construction quality, material condition, and adherence to basic technical standards. While the technical compliance is necessary to ensure functionality and durability, previous studies indicate that compliance alone does not automatically lead to positive pedestrian experiences [15]. Evidence from walkability intervention research further suggests that technical improvements tend to affect walking behavior mainly when they contribute to enhanced comfort and experiential quality, rather than merely fulfilling regulatory requirements [16]. In this sense, technical suitability acts as a foundational condition that supports walkability rather than as a primary driver of pedestrian satisfaction.

Accessibility emerged as a separate factor, underscoring the relevance of inclusive design elements such as ramps and tactile paving. However, its moderate contribution implies that accessibility features may not yet be perceived as fully continuous or well-integrated across the campus. This aligns with inclusive design literature, which emphasizes that accessibility infrastructure becomes meaningful only when implemented as a coherent and connected network rather than as isolated provisions [17]. Systematic reviews of pedestrian infrastructure on university campuses further stress the need for multidimensional evaluation frameworks that combine physical conditions with user perceptions to adequately capture pedestrian experience [7].

The relatively lower contribution of safety and sidewalk dimension factors suggests that these attributes function more as baseline expectations than as distinguishing features. Pedestrians often take safety-related elements for granted unless they are seriously compromised [18]. Similarly, sidewalk width and other geometric characteristics tend to influence perceptions mainly when they fall below minimum acceptable levels, after which their marginal effects decrease. This reflects a threshold-based perception commonly reported in road safety and pedestrian design literature [19].

The dominance of comfort as the primary determinant indicates that the pedestrian perceptions within the campus are shaped more by experiential qualities than by geometric or regulatory compliance alone. In the Indonesian campus context, technical and geometric attributes, such as sidewalk width and separation from vehicular traffic, tend to serve as basic expectations. These features become perceptually salient only when they drop below acceptable thresholds, whereas the comfort-related aspects continuously influence walking experiences.

This pattern contrasts with findings from studies in developed countries, where geometric design and safety features often emerge as the key determinants of walkability. The difference may be explained by contextual factors, including tropical climatic conditions that intensify exposure to heat and rainfall, as well as socio-cultural walking practices in which pedestrians place greater emphasis on shade, surface quality, and path continuity. Consequently, in tropical campus environments, improvements in comfort-related attributes are likely to yield greater perceived benefits than interventions focused solely on geometric expansion or technical compliance.

Empirical studies conducted in hot and tropical climates have shown that pedestrians' walking behavior is strongly influenced by thermal perception and environmental heat exposure, as individuals tend to adjust their movement to minimize thermal discomfort [20]. This reinforces the importance of comfort-oriented design strategies in campus walkability planning [20, 22]. Moreover, exposure to vehicular traffic has been found to affect pedestrian experience primarily through the perceived environmental stress rather than through geometric configuration alone, further supporting the emphasis on experiential quality over purely technical design [12, 22].

A key contribution of this study lies in integrating Exploratory Factor Analysis with UI GreenMetric transportation indicators to provide a multidimensional understanding of pedestrian infrastructure within a green campus framework. By revealing the latent structure underlying pedestrian perceptions, this research demonstrates how sustainability-oriented assessment frameworks can be operationalized through empirical factor analysis in higher education environments [23].

From a planning and policy perspective, the findings suggest that efforts to enhance campus sustainability and improve UI GreenMetric performance should prioritize interventions that directly improve pedestrian comfort, such as upgrading surface conditions, ensuring path continuity, and providing adequate shading. Such strategies are more likely to generate meaningful improvements in perceived walkability than approaches focused solely on geometric expansion or technical compliance, thereby supporting sustainable transportation objectives in tropical campus settings.

The goals can enhance mobility within academic environments and also reinforce broader objectives for sustainable cities and communities, even when planning efforts are framed not only in normal conditions but also in disaster mitigation contexts as well [24-25].

4 Conclusions

In this study is concluded that pedestrian-friendly sidewalk design in a green campus environment is largely determined by experiential spatial experiences, where comfort is a key pillar over formal technical standards. Unlike urban contexts in non-tropical regions, where safety from traffic congestion may be a priority, in this study is shown that in a tropical campus context, thermal comfort and environmental cleanliness are key drivers of walking interest. As a concrete step, campus authorities are advised to prioritize interventions on the "Comfort" factor by providing shade elements and more intensive management of sanitation facilities on the most congested sidewalk segments. Measurable targets, such as increasing vegetation coverage by 30-40% along main paths, are recommended to stabilize the microenvironmental temperature for pedestrians. While providing in-depth insights into the green campus context, this study was limited to a student population in a tropical climate. Future studies should conduct cross-validation tests in more heterogeneous urban contexts or regions with extreme seasonal differences to test the stability of this model. Further research is also recommended to explore the specific needs of disability groups to ensure inclusivity and equity of outcomes in a sustainable campus transportation system.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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