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Investigating and Improving Pedestrian Safety in an Urban Environment of a Low- or Middle-Income Country: A Case Study of Yaoundé, Cameroon

Steffel Ludivin Tezong Feudjio [1,*,†], Dimitri Tchaheu Tchaheu [2,†], Stephen Kome Fondzenyuy [1], Isaac Ndumbe Jackai II [3], Davide Shingo Usami [1] and Luca Persia [1]

1 Center of Research for Transport and Logistics, Sapienza University of Rome, Via Eudossiana 18, 00184 Rome, Italy; stephenkome.fondzenyuy@uniroma1.it (S.K.F.); davideshingo.usami@uniroma1.it (D.S.U.); luca.persia@uniroma1.it (L.P.)
2 Department of Transport Planning, National Advanced School of Public Works, Elig-Effa Street, Yaounde P.O. Box 510, Cameroon; dimitri.tchaheu@facsciences-uy1.cm
3 Department of Civil Engineering, National Advanced School of Public Works, Elig-Effa Street, Yaounde P.O. Box 510, Cameroon; i_ndumbe@yahoo.com
* Correspondence: steffelludivin.feudjiotezong@uniroma1.it
† These authors contributed equally to this work.

Abstract: In Yaoundé, Cameroon, where walking dominates transport modes, pedestrian safety remains an issue as pedestrians account for a fair share of road traffic casualties, partly due to the lack of walking policies and pedestrian facilities safety data, hindering targeted intervention. This study used a pedestrian safety index (PSI) and the Global Walkability Index (GWI) to investigate 12 road segments frequented by diverse pedestrian groups. Indexes were graded from E—lowest to A—highest and analyzed using description and rank correlation. Main safety issues included lack of adequate and accessible sidewalks, bollards, pedestrian crossings, signage, shade, and street lighting. Only one segment (R7) achieved grade C, while the remainder scored D or E, indicating poor pedestrian safety conditions and an unpleasant walking experience. The correlation coefficient (0.69) between the PSI and GWI at a 99% significance level validated the safety assessment, providing confidence in the results. A seven-year (2024–2030) safety strategy is proposed to improve all roads to grade B. This strategy contains several interventions, including engineering improvement, which have been proven effective. This study offers evidence for city officials to improve pedestrian safety and informs walking policies and the implementation of upcoming projects. Future research should quantify the recommendations' benefits and validate indexes with crash or conflict data.

Keywords: road safety; pedestrian safety; urban environment; LMICs; pedestrian safety index; global walkability index

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1. Introduction

Road traffic injuries are a major public health problem and a leading cause of death and injury around the world.

Each year, road traffic crashes result in over 1.19 million fatalities and 50 million injuries or disabilities worldwide, causing immense human suffering and significant economic losses, typically equating to 3% of a country's gross domestic product (GDP) [1]. Shockingly, despite possessing only 60% of the world's vehicles, low- and middle-income countries (LMICs) bear a disproportionate burden, accounting for a heart-wrenching 92% of these fatalities [1], which can represent up to 6% of their GDP [2]. Vulnerable road users (VRUs), including cyclists, motorcyclists, and pedestrians, are unfortunately the most affected, representing over 50% of global road traffic deaths [1].

1.1. Generality

According to the European Road Safety Observatory, a pedestrian road user is a "person on foot; person pushing or holding bicycle, person who uses a wheelchair, a pram or a pushchair, leading or herding an animal, riding a toy cycle on the footway, person on roller skates, skateboard, or skis. Does not include persons in the act of boarding or alighting from a vehicle" [3]. Pedestrians, lacking the protective gear of cyclists and motorcyclists [4], are highly vulnerable on roads due to their low position and absence of vehicular protection [5]. This puts them at significantly higher risk of injury or death in collisions, as they lack any external shielding to absorb impact [6]. This is because the kinetic forces resulting from differences in the mass and speed of various types of vehicles largely determine the severity of a road crash [7]. Pedestrian road crash fatalities represent an issue that has been highlighted by the World Health Organization (WHO) global assessment of road safety over the past decade. In 2013 and 2016, pedestrians accounted for 22% and 23% of all road crash fatalities, respectively [8,9]. In 2021, the proportion of pedestrians in global road traffic fatalities increased to 26%, corresponding to 309,400 deaths [1].

In Europe, 98% of fatalities in pedestrian-related crashes are pedestrians themselves, representing 20% of all road fatalities or 4628 deaths in 2019 [3] and 3608 deaths in 2021 [10]. In Australia, 12% of deaths from road traffic crashes in 2020 were pedestrians [4]. Similarly, the Center for Disease Control and Prevention revealed that 8000 pedestrians were killed in road traffic crashes in 2021 in the United Sates, accounting for 17% of the road traffic deaths in the country.

According to the World Health Organization (WHO), there are several risk factors that put pedestrians at risk of crashes with death and serious injuries as a potential result. These factors include speeding, alcohol impairment, inadequate visibility of pedestrians on roads, and lack of road infrastructure for pedestrians [11].

The speed at which a car travels influences both crash risk and crash consequences [12,13]. The higher the speed of a vehicle, the shorter the time a driver has to stop and avoid a crash, including hitting a pedestrian [14], the higher the energy released during the collision, and the higher the risk of death and injury for the pedestrian [7]. Research has shown that an adult pedestrian hit by a car moving at 30 km/h has 99% chance of survival and hit at 50 km/h has 80% chance of survival [15]. A meta-analysis of 20 studies assessing the risk of fatality for pedestrians revealed that for every 1 km/h of speed increase above 30 km/h, the chance of pedestrian death increases by 11% [16].

Alcohol consumption results in impairment, which also increases the likelihood of a crash because it produces poor judgement, increases reaction time, lowers vigilance, and decreases visual acuity, not only for vehicle drivers [17] but also for pedestrians [18]. In the United Sates, it is illegal to drive with a blood alcohol concentration (BAC) of 0.08 g per deciliter (g/dL) in all states except Utah, where the legally acceptable threshold is 0.05 g/dL) [19]. In 2021, 19% and 30% of crashes that resulted in pedestrian deaths involved a driver and a pedestrian with a blood alcohol concentration (BAC) of at least 0.08 g per deciliter (g/dL), respectively [19]. Similarly, in Australia, where the legally acceptable BAC threshold is 0.05 g/dL, approximately one-third of all adult pedestrians fatally injured between 1999–2001 were found to have a BAC exceeding 0.08 and up to 0.1 g/dL [20].

Inadequate visibility of pedestrians is equally associated with increased risk of pedestrian-related crashes [21,22]. Poor visibility of pedestrians arises from pedestrians sharing road space with fast-moving vehicles, using motor vehicles that are not equipped with lights, inadequate or lack of roadway lighting [23,24], and pedestrians not wearing reflective accessories or brightly colored clothes [25], especially at night where the risk is greater [26,27].

Several road parameters are also associated with increased pedestrian crash risk, including undivided roads with greater numbers of lanes [28], lack of protection from motor vehicles [29], lack of wide, grassy walkable areas [30], lack of buffers between the road and the sidewalk [31], intersections without marked pedestrian crosswalks, and locations lacking sidewalks or pedestrian pathways [32].

Despite the evidence on the risk factors associated with pedestrian road crashes, the phenomena continue to rise. Between 2013 and 2021, there was a measurable increase in the proportion of pedestrian-related fatalities in global road traffic, rising from 22% to 26%. This upward trend could be partly attributed to the lack of road design and land use planning providing infrastructure facilities and traffic control mechanisms to separate pedestrians from motor vehicles and enable pedestrians to cross the roads safely [11]. As a matter of fact, almost 80% of pedestrians globally travel along unsafe roads [1].

In Cameroon, as in numerous other LMICs, road traffic fatalities remain a major health issue, with speeding a major risk factor [33]. Current data shows Cameroon's traffic death rate at 11 per 100,000 population, despite the country having only 31,590 vehicles per 100,000 inhabitants [1]. Pedestrians are among the most exposed and this has been the case for a long time. In 2001, for instance, 29% of injuries and 26% of deaths from road traffic crashes in Cameroon were among pedestrians, mainly attributed to lacking or inadequate pedestrian facilities constraining pedestrians' navigation on the carriageway [34]. In 2016, almost 15 years later, 11% of road traffic deaths in Cameroon were pedestrians, according to World Bank estimates [35].

According to the World Health Organization, Cameroon does not have national technical standards for new roads that take account of all road users including pedestrians, nor do they align with relevant UN conventions and comply with regulations [1]. Roads in Cameroon do not always have pavements for pedestrians, let alone lanes for buses and/or taxis or cycle paths [36]. In fact, less than 0.5% of the urban road network (roads within cities with speed limited to 60 km/h) in Cameroon include adequate pedestrian facilities [37]. In most of the few roads that include pedestrian facilities, these are poorly maintained, unsafe at all times of the year [38], and clogged with obstacles like cars, bikes, and streets vendors [35–37]. Yaoundé is particularly affected since 18% of road users are pedestrians [39], generating almost 35% of all the daily trips in the city [40]. In 2007, 6234 injured people were admitted to the Central Hospital of Yaoundé's emergency ward during the year. Nearly 60% of the injuries were due to road traffic crashes, 46% of which involved pedestrians [41]. In 2014, in a hospital-based pilot surveillance study in Yaoundé, 34% of the 1,655 road traffic crash victims enrolled were pedestrian [42]. Some efforts to improve pedestrian safety in the city exist [36], but the issues still persist. In fact, analysis of 2021 law enforcement agency statistics show that Yaoundé accounts for most of the road traffic crashes in Cameroon, partly due to absence of sidewalks, poor geometric alignment of roads, lack of access control, absence of crosswalks, and lack of channelization at intersections [43]. Pedestrian deaths are potentially underestimated, as there is usually underreporting of pedestrian related crashes in law enforcement records [7].

Several engineering interventions to improve pedestrian safety have been proven effective when properly implemented on urban streets. These include road lighting [44], road narrowing with refuge islands [30], raised pedestrian crossings [30,45], and reducing speed with a 30 km/h posted speed limit [46] and traffic calming measures (speed hump, speed table, speed cushion, tight corner radii, etc.) [47–49]. Investing in road safety and in pedestrian facilities yields not only safety benefits, but also health, economic, and environmental benefits as a result of increased active mobility.

A review of 17 studies found that the use of walking or cycling to commute reduced all-cause mortality by 9% and cardiovascular mortality by 15% [50]. Walking also enhances mental health, brain function, sleep quality, self-esteem, and overall well-being [51–53]. A WHO study in Accra, Ghana, showed that investing in pedestrian and cycling infrastructure could prevent 33,000 deaths over 35 years and save USD 15 billion in healthcare costs, due to increased physical activity [54]. The economic benefits of walking are apparent in retail, as people who walk, or cycle spend up to 40% more over the course of a month that people who drive [55]. After New York City pedestrianized Times Square, the area saw a 22% increase in economic activity compared with a 9% increase across the rest of the city [56].

Walking is also viewed as a zero-carbon mode of transport and is associated with a decrease in emissions. For instance, the pedestrianization of New York's Times Square also led to a 60% decrease in nitrous oxide pollution levels and a 41% reduction in nitrogen dioxide [57]. The implementation of effective and targeted transport and urban planning strategies to promote pedestrian safety requires clear and detailed data, information, and evidence of the pedestrian safety issue in relation to the existing transport infrastructure [58].

The most used methods in the literature to investigate the safety of pedestrians in respect to the existing facilities include surveys and interviews of pedestrians, computation of walkability index, level of service of pedestrian facilities, and pedestrian safety index [59–68].

Surveys and interviews consist of pedestrians self-reporting their attitudes to walking, their user experience of walking facilities, and their general satisfaction with land use and street type. They are particularly useful to gather data on the unique perspective of the pedestrians who are the center of all policies [67]. In the largest and most recent survey study, called ESRA (E-Survey of Road Users' Attitudes), an international online consultation of road users in 60 countries on six continents aims to gather data on road users' behavior, including pedestrians', and also their perception of safety with regards to walking, in order to provide evidence and make international comparisons. The first edition of the survey was launched in 2015, and the third in 2023 [69]. Surveys also allow researchers to analyze the potential contributing factors (socio-demographic, environmental, and infrastructure) affecting pedestrians' general satisfaction [70]. However, results from surveys are subjective, depend on each respondent's perspective, and do not provide a clear and objective representation of the state of pedestrian facilities [61].

The walkability index is an assessment method used in determining the environmental quality measures for walking activities [66]. It is a composite approach combining several components (urban life, land use, pedestrian facilities) identified as correlated to increased walking [71,72], in order to capture their co-occurrence, reduce multicollinearity, and create an actionable index for policy application compared with individual components [73,74]. There are various methods to compute the walkability index [75–78]. A pioneer index is the Global Walkability Index (GWI), comprising 14 indicators related to the state of pedestrian facilities, behavior of motorized vehicles, availability of funding, stands, guidelines, and regulations related to pedestrian safety. Developed by Krambeck in 2006, at the request of the World Bank, the index has been applied on location in Washington, Beijing, and New Delhi [79]. In Jakarta, Indonesia, Muhammad used a modified version of the GWI and found that walkability increased by 38.98% in the Sudirman–Thamrin central business district as a result of improvements in pedestrian facilities [59]. In an African context, the World Bank recently used a global walkability index composed of indicators related to urban life, pedestrian facilities, and safety to conduct a sidewalk safety assessment in Addis Ababa, Ethiopia and provided recommendations to improve pedestrian safety [80].

Pedestrian Level of Services (PLOS) is another indicator used to assess pedestrian facilities. In contrast to the walkability index, PLOS usually also considers the pedestrian flow and whether it is properly served by pedestrian facilities [62]. PLOS includes criteria such as security, convenience, comfort, and attractiveness and studies have focused on applying this approach at intersections, sidewalks [81,82], midblocks [83], stairways [84], and segments [85,86]. However, most of these LOS models have not focused on pedestrian safety [87–89]. To alleviate this, several studies have developed indexes focusing on pedestrian safety.

In 2012, during a pedestrian safety evaluation program, Tanaka developed a pedestrian safety index to evaluate the safety of pedestrians at intersections in the city of Ottawa [90]. Considering the exposure of pedestrians to motorized vehicles, some authors have also proposed a pedestrian risk index measuring the likelihood and severity of potential crashes resulting from vehicle–pedestrian conflicts [63,91]. Most of the pedestrian safety evaluation methods have overlooked roadway segments and have focused on intersections, crosswalks, and midblock crossing [92–94]. As an attempt to overcome this, Asadi-Shekari led a study in which they developed a Pedestrian Safety Index (PSI) that considered both roadway segments and intersections and evaluated the essential needs of pedestrians to ensure their safety while walking [95]. The PSI also considers the special demands of vulnerable pedestrians including older and disabled individuals. Prior to the PSI, there was no established approach existing for measuring pedestrian safety along streets (segments and intersections) and encompassing the various safety needs (infrastructure, furniture, etc.) of pedestrians of various ages and abilities. The PSI was successfully applied to a collector street in Singapore, to identify pedestrian safety issues and propose improvements [95].

In Cameroon, studies on pedestrian safety are scarce and typically focus on pedestrians' perceptions of safety through surveys rather than assessing the actual condition of pedestrian facilities. In Bamenda, in an interview-based study assessing the state of the road infrastructure, 68.1% of the respondents found the roads unsafe for pedestrians [96]. During the second edition of the ESRA survey in Cameroon, 98.5% of the respondent reported using walking as a mode of transport with a mitigated feeling of safety [97]. There is a notable gap in the research quantitatively assessing the safety of road infrastructure for pedestrians in Cameroon, which hampers evidence-based planning and interventions [98]. As a matter of fact, the UN-Habitat have reported that there are no walking and cycling policies in Cameroon and pedestrian safety remains a problem as pedestrians account for 22% of road traffic injuries every year [58], mainly due to the poor quality of road infrastructure [39]. In Yaoundé, where walking is the main mode of transport, unsafe pedestrian facilities and lack of sidewalks combined with chaotic traffic pose a major threat to pedestrians' safety, while pedestrians are responsible for almost 4 million trips every day [40,98]. It is thus important to investigate pedestrian safety in Yaoundé in order to unveil evidence of the issues necessary for targeted intervention, which is the intent of this work.

1.2. Aim

The objective of this study was to investigate the safety of pedestrians along selected streets in Yaoundé, using a robust methodology developed and applied in a comparable context, and to propose measures not only to improve pedestrian safety but also to enhance the overall walkability and livability of the city.

This work is sequenced as follows: introduction, research methodology, results, discussion, recommendations, and, lastly, conclusions and future research.

To the best of the authors' knowledge, this work is among the first to quantitatively investigate the safety of pedestrians along the streets of an urban area in Cameroon, from the facilities viewpoint.

Therefore, this study is expected to be a valuable contribution to the body of road safety research in this context, providing quantitative insights on issues of pedestrian safety, important for elaborating evidence-based intervention, using a method easily replicable in the other cities.

2. Site Characteristics and Research Methodology

2.1. Study Context

Yaoundé is the political capital of Cameroon, the second-largest city in the country after Douala, with a total population of 4,100,000 inhabitants and an annual growth rate of 3.5% [40]. It is monocentric, dominated by the tertiary sector (four out of every five jobs) and essentially the informal sector, with a low average income level. The city includes a road network estimated at 4762 km with only 300 km asphalted, composed of 64 km of primary roads and 236 km of secondary and tertiary roads. There are 8 million daily trips generated in the city by car (48.4%), pedestrians (35%), motorbikes (14.2%), and buses (2.4%). General traffic data for the whole city are missing. Traffic data from specific locations are not regularly collected, due to the lack of permanent traffic sensors. Nevertheless, during the elaboration of the city's sustainable urban mobility plan, several traffic counts were conducted at different road sections in the city, including at a major road section in the city center called "Boulevard du 20 Mai" where the daily traffic volume was found to be 85,110 vehicles (85% car, 5% truck, and 10% motorbike). The transport and mobility systems are not efficient, with a lack of public transport services, slow, irregular, and uncomfortable transport options, congestion, and pollution [40].

Safety is also a major issue for mobility in Yaoundé, where road traffic crashes cause around 1000 deaths and 5000 serious injuries per year [40]. Detailed police statistics on pedestrian road crash fatalities in the city are scarce; however, latest estimates from the World Bank Global Road Safety Facility suggest that around 11% of road traffic casualties in Cameroon are pedestrians [35]. Assuming this percentage applies to Yaoundé statistics, that would imply that every year, road traffic crashes kill 110 pedestrians and seriously injure 550 others in the city. Pedestrians are exposed to a higher risk of crashes partly thanks to the flaws of the road infrastructure in meeting their safety needs [40,98].

This study focuses on 12 road segments leading to two high-pedestrian (including student) areas in Yaoundé, namely Poste Centrale and the University of Yaoundé I. Some of the 12 road segments include Boulevard du 20 Mai, Avenue Monseigneur Vogt, Rue Elig Effa, and Rue Goker (See Section 2.4.1).

To investigate pedestrian safety in this study, the pedestrian safety index (PSI) [95] and the Global Walkability Index (GWI) [80] were used. These methods involved site observation to collect several road, traffic, and environment parameters including speed, road type, road width, median type, sidewalk presence, etc. (See Section 2.4.2).

The PSI was chosen as it is a comprehensive approach that covers both roadway segments and intersections, considers the safety needs of pedestrian of different categories including older and disabled people, uses the point system incorporating various safety factors, is based on numerous guidelines and research-based quality standards, and is transferable and easily applicable in areas with a similar context to Yaoundé [95].

The GWI developed by the World Bank was chosen to complement the assessment made using the PSI as it includes, in addition to pedestrian facilities, additional factors related to existing activities, urban life, urban furniture, etc., providing a different perspective of the walking friendliness of the streets. In addition, the Global Walkability Index is transferable, and has been successfully applied in Addis Ababa, Ethiopia, which is a similar context to Yaoundé [80].

2.2. Pedestrian Safety Index

The following description of the pedestrian safety index (*PSI*) is derived from [95]. The *PSI* considers 24 safety indicators carefully identified from over 19 guidelines developed in various countries. The *PSI* was computed using Equation (1):

$$PSI = \sum_{i=1}^{24} c_i \times SI_i \quad (1)$$

where:

- *PSI* = the pedestrian safety index
- *i* = the indicator number
- *c* = the coefficient of safety indicator
- *SI* = safety indicator score

The coefficient (c) associated with the safety indicators represents their effectiveness in determining the PSI. It indicates the importance and priority of each indicator within the evaluation. The coefficient is determined by assessing the significance of the indicator across different guidelines [99–108]. Some guidelines provide thorough descriptions and standards for indicators' implementation, while others offer only suggestions without detailed standards. Additionally, certain guidelines present indicators as more than suggestions but lack complete implementation standards.

If, for instance, guideline A has complete standards for street sidewalks, including type, dimension, materials, specificity for persons with disabilities (PwDs), etc., the depth of evaluation of the sidewalk indicator according to guideline A could be considered as complete (D = 3). If guideline B, for instance, suggests providing sidewalks on streets without further description, its depth of evaluation could be considered as incomplete (D = 1). If, on the contrary, guideline C suggests providing appropriate and well-designed sidewalks on both sides of streets, considering all types of road users including PwDs without providing further description, its depth of evaluation could be considered as semi-complete (D = 2)

Table 1 presents the numbers of guidelines (N) that evaluate the indicator "i" with the depth of evaluation "j" (how completely was the indicator addressed in the guidelines). Table 1 also contains the values of the coefficient of each safety indicator.

Table 1. Number (per depth level) of guidelines addressing each of the 24 safety indicators.

D [b]	Indicators [a]																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	7	3	3	4	3	3	6	7	3	2	0	1	2	5	11	4	6	2	2	4	4	4	3	5
2	0	9	1	6	7	10	1	3	7	5	0	1	3	7	2	7	2	0	4	0	2	4	2	2
3	10	6	4	4	5	5	8	3	5	1	13	2	5	4	3	0	8	1	7	1	3	1	6	6
Ci	37	39	17	28	32	38	32	22	32	15	39	9	23	31	24	18	34	5	31	7	17	15	25	27

[a] 1—Slower traffic speed, 2—buffer and barriers (curb and furnishing zone), 3—fewer traffic lanes, 4—shorter crossing distance (curb extension), 5—mid-block crossing, 6—landscape and trees, 7—footpath pavement, 8—marking (crosswalk), 9—pedestrian refuge and median, 10—splitter island, 11—sidewalk on both sides, 12—advance stop bar, 13—driveway,14—lighting, 15—signing, 16—bollard, 17—running slope, 18—lift, 19—curb ramp, 20—tactile pavement (guiding), 21—tactile pavement (warning), 22—ramp, 23—grade, 24—signal.
[b] D1 = 1 (incomplete), D2 = 2 (semi complete), D3 = 3 (complete).

In Table 1, column 15, the value of indicator 14 (lighting) indicates, for instance, that 16 guidelines (5 + 7 + 4 = 16) addressed street lighting, 5 incompletely, 7 semi-completely, and 4 completely.

The coefficient of each safety indicator was then computed using Equation (2):

$$C_i = \sum_{j=1}^{3} D_j \times N_{ij} \tag{2}$$

where:

- c = the coefficient of safety indicator
- i = the indicator number
- j = depth of the evaluation number
- D = depth of the evaluation
    - D_1 (incomplete)
    - D_2 (semi-complete)
    - D_3 (complete)

In the previous illustration, the coefficient of the safety indicators "lighting" has been computed as follows: $c_{14} = 1 \times 5 + 2 \times 7 + 3 \times 4 = 31$

With all the coefficient values obtained, only the SI_i is needed to achieve the PSI. A comparison of design standards of the combined guidelines (combined standards for each indicator) with the actual street conditions was used to calculate the SIi. This is to display the extent to which a street meets the universal pedestrian safety standards. The SI_i value lies between 0 and 1, representing, respectively, the lowest and highest compliance of the safety indicators with standards according to several points or conditions to be fulfilled. The standard values of the safety indicators were derived from [95] and from the National Association of City Transportation Officials (NACTO) guidelines, especially the urban street design guidelines [109] and the global street design guidelines [110].

Table 2, extracted from [95], shows how the SI_i is calculated for each safety indicator.

Table 2. Safety Indicator (SI_i) computation.

Indicator Evaluation Description	Illustration
(1) Slower traffic speed (speed) $\mathbf{SI_1} = \begin{cases} \mathbf{0 \text{ if } S>50} \\ \mathbf{1 \text{ is } S \leq 50} \end{cases}$ S = Average vehicle speed in street (km/h)	50 km/h average speed $SI_1 = 1$
(2) Buffer and barriers $SI_2 = (CI + FI)/2$ $CI = CL/N_1$ CL = Standard curb length (m) N_1 = Length of curb that street needs (m) $FI = C/N_2$ C = Area of furnishing zone adjacent to the curb (m^2) $\mathbf{N_2} = \begin{cases} \textbf{length of street} \times \mathbf{1.8 \text{ if } W < 1.80m} \\ \textbf{lenght of street} \times \mathbf{W \text{ if } W \geq 1.80} \end{cases}$ W = Width of furnishing zone adjacent to the curb (m) If W varies in different parts of street W_i = Width of furnishing zone adjacent to the curb in section i (m) $\mathbf{FI} = \left(\sum_{i=1}^{k} (\mathbf{FIC_i} \times \mathbf{L_i})\right)$/(length of street (both sides)—length of intersections) i = 1, 2, 3, . . ., k (different parts of street with various widths of the furnishing zone) $FIC_i = C_i/A_i$ C_i = Area of furnishing zone adjacent to the curb in section i (m^2) $\mathbf{A_i} = \begin{cases} \textbf{length of street (in section i)} \times \mathbf{1.8 \text{ if } Wi < 1.80m} \\ \textbf{length of street (in section i)} \times \mathbf{W \text{ if } Wi \geq 1.80m} \end{cases}$ L_i = Length of street in section i (m)	CL = 1367 m N_1 = 1367 m CI = 1 $W_1 = 5.5$ $W_2 = 1.3$ $C_1 = 280 \times 5.5 = 1540$ m^2 $C2 = 1087 \times 1.3 =$ 1413.1 m^2 $A_1 = 280 \times 5.5 = 1540$ m^2 $A_2 = 1087 \times 1.8 = 1956.6$ m^2 $FIC_1 = 1540/1540 = 1$ $FIC_2 = 1413.1/1956.6 = 0.72$ $L_1 = 280$ $L_2 = 1087$ $FI = (1 \times 280 + 0.72 \times 1087)/1367 = 0.78$ $SI_2 = (1 + 0.78)/2 = 0.89$
(3) Fewer traffic lane (number of travel lanes) $\mathbf{SI_3} = \begin{cases} \textbf{0 if Number of lanes>5} \\ \textbf{0.25 if Number of lanes = 5} \\ \textbf{0.5 if Number of lanes = 4} \\ \textbf{0.75 if Number of lanes = 3} \\ \textbf{1 if Number of lanes} \leq \mathbf{2} \end{cases}$	Number of lanes = 2 $SI_3 = 1$
(4) Shorter crossing distance (curb extension) $\mathbf{SI_4} = \begin{cases} \mathbf{1} \textbf{ if } \mathbf{P \geq 1} \textbf{ or there is no need for curb extension and there is sidewalk} \\ \mathbf{P} \textbf{ if } \mathbf{P < 1} \\ \textbf{0 if there is no need for curb extension and there is no sidewalk} \end{cases}$	There is no on street parking and there is sidewalk $SI_4 = 1$
(5) Shorter crossing distance (mid-block crossing) $\mathbf{SI_5} = \begin{cases} \sum \mathbf{P_i}/\textbf{lTotal number of sections that are more than 120 m} \\ \textbf{0 if total length of streets is less than 120 m and } \mathbf{C_i = 0} \end{cases}$ $\mathbf{P_i} = \begin{cases} \mathbf{1 \text{ if } Pci \geq 1} \\ \mathbf{Pci \text{ if } Pci < 1} \end{cases}$ $Pc_i = c_i/n_i$ i = 1, 2, 3, ..., k (different sections of street between intersections that are more than 120 m) c_i = Number of standard mid-block crossing in section i n_i = Length of street in section i/120	c1 = 1 c2 = 1 n1 = 256/120 = 2.13 n2 = 437/120 = 3.½ c1 = 1/2.13 = 0.47 P c2 = 1/3.6 = 0.28 P1 = 0.47 P2 = 0.28 SI5 = (0.47 + 0.28)/2 = 0.375
(6) Landscape and tree $SI_6 = (P_1 + P_2)/2$ $P_1 = F/N$ F = Length of street that has vertical clearance standard condition N = Length of street (both sides)-total length of intersections and their considered standard limitations (m) $P_2 = NI/I$ NI = Number of intersections with second standard condition I = Number of total intersections	F = 1242.20 N = 1325.20 P1 = 1242.20/1325.20 = 0.94 NI = 0 I = 3 $P_2 = 0/3 = 0$ $SI_6 = (0.94 + 0)/2 = 0.47$
(7) Footpath pavement $SI_7 = C/N$ C = Area of standard pavement (m^2) Li = length of intersections L = length of street (both sides) $\mathbf{N} = \begin{cases} (\mathbf{L}-\mathbf{Li}) \times \mathbf{1.8 \text{ if } W < 1.80m} \\ (\mathbf{L}-\mathbf{Li}) \times \mathbf{W \text{ if } W \geq 1.80m} \end{cases}$ W = Width of footpath (m) If W varies in different parts of street W_i = Width of footpath in section i $\mathbf{SI_7} = \left(\sum_{i=1}^{k} (\mathbf{PC_i} \times \mathbf{L_i})\right)$/(length of street (both sides)—length of intersections) i = 1, 2, 3, ..., k (different parts of street with various width of the footpath) $PC_i = C_i/N_i$ C_i = Area of standard pavement in section i (m^2) $\mathbf{N_i} = \begin{cases} \textbf{length of street (in section i)} \times \mathbf{1.8 \text{ if } Wi < 1.80m} \\ \textbf{length of street (in section i)} \times \mathbf{W \text{ if } Wi \geq 1.80m} \end{cases}$ L_i = Length of street in section i (m)	W = 1.5 $C = (1367 \times 1.5)$ -$(12 \times 1.5 \times 2) = 2014.5$ m^2 $N = 1367 \times 1.80 = 2460.6$ $SI_7 = 2014.5/2460.6 = 0.82$

Table 2. *Cont.*

Indicator Evaluation Description	Illustration
(8) Marking (crosswalk) $\mathbf{SI_8} = \begin{cases} \mathbf{1 \text{ if } P \geq 1} \\ \mathbf{P \text{ if } P < 1} \end{cases}$ P = C/N C = Number of standard crosswalk markings N = Number of crosswalks that street needs (mid-block and cross walk at intersections)	C = 25 N = 31 P = 25/31 = 0.81 SI_8 = 0.81
(9) Physical pedestrian refuge and median $\mathbf{SI_9} = \begin{cases} \mathbf{1 \text{ if } P \geq 1} \\ \mathbf{P \text{ if } P < 1} \end{cases}$ P = C/N C = Number of standard crosswalk markings N = Number of crosswalks that street needs (mid-block and cross walk at intersections)	C = 1 N = 4 P = 1/4 = 0.25 SI_9 = 0.25
(10) Splitter island SI_{10} = C/N C = Number of standard splitter island N = Total splitter island that street has SI_10 = 1 if there is no splitter island	C = 12 N = 12 SI_{10} = 1
(11) Sidewalk on both sides $SI_{11} = (a + m)/2$ $\mathbf{a} = \begin{cases} \mathbf{1 \text{ if } P_1 \geq 1} \\ \mathbf{P_1 \text{ if } P_1 < 1} \end{cases}$ $P1 = l1/N1$ l_1 = Length of sidewalk in one side (m) N_1 = Length of street—length of intersections in one side (m) $\mathbf{m} = \begin{cases} \mathbf{1 \text{ if } P_2 \geq 1} \\ \mathbf{P_2 \text{ if } P_2 < 1} \end{cases}$ $P2 = l2/N2$ l_2 = Length of sidewalk in opposite side (m) N_2 = Length of street—length of intersections in other side (m)	$l_1 = 250 + 430 = 680$ $N_1 = 680$ $P_1 = 680/680 = 1$ a = 1 $l_2 = 256 + 431 = 687$ $N_2 = 687$ $P_2 = 687/687 = 1 m = 1$ $SI_{11} = (1 + 1)/2 = 1$
(12) Advance stop bar $\mathbf{SI_{12}} = \begin{cases} \mathbf{1 \text{ if } P \geq 1 \text{ or no need for stop bar and there is enough crossing}} \\ \mathbf{P \text{ if } P < 1} \\ \mathbf{0 \text{ if no need for stop bar since there is not enough crossing}} \end{cases}$ P = C/N C = Number of standard advance stop bars N = Total advance stop bars that street needs	C = 26 N = 32 P = 26/32 = 0.81 SI_{12} = 0.81
(13) Driveway $SI_{13} = C/N$ C = Number of standard driveways N = Total driveways that street has SI_{13} = 1 if there is no driveway	There is no driveway SI_{13} = 1
(14) Lighting $\mathbf{SI_{14}} = \begin{cases} \mathbf{1 \text{ if } P \geq 1} \\ \mathbf{P \text{ if } \mathit{P} < 1} \end{cases}$ P = C/N LSL = Length of street with pedestrian lighting TLI = total length of intersections $\mathbf{C} = \begin{cases} \mathbf{((LSL - TLIi) \times 9)/D \text{ if } D > 9 \text{ m}} \\ \mathbf{LSL - TLI \text{ if } D \leq 9 \text{ m}} \end{cases}$ D= Distance between light poles (m) N = (length of street (both sides)—intersections length) (m) If D varies in different parts of street $\mathbf{SI_{14}} = \sum_{i=1}^{k} \mathbf{C_i} / \sum_{i=1}^{k} N_i$ i = 1, 2, 3, ... k (different parts of street with various distances between light poles) $\mathbf{C} = \begin{cases} \mathbf{((LSL \text{ in section } i) \times 9)/D \text{ if } D > 9 \text{ m}} \\ \mathbf{LSL \text{ in section } i \text{ if } D \leq 9 \text{ m}} \end{cases}$ N_i = length of street in section i (m)	C = 0 N = 680 + 687 = 1367 P = 0/1367 = 0 SI_{14} = 0
(15) Signing $SI_{15} = C/N$ C = Total crossing facilities that have signs N = Total crossing facilities that street needs	C = 25 N = 31 P = 25/31 = 0.81 SI_{15} = 0.81
(16) Buffer and barriers (bollard) $\mathbf{SI_{16}} = \begin{cases} \mathbf{1 \text{ if } P \geq 1} \\ \mathbf{P \text{ if } \mathit{P} < 1} \end{cases}$ P = C/N C = Number of standard bollards rows N = (total crosswalks + total median crosswalk sections that street needs) ×2	C = 0 $N = (31 + 4) \times 2 = 70$ P = 0/70 = 0 SI_{16} = 0

Table 2. *Cont.*

Indicator Evaluation Description	Illustration
(17) Running slope (in the longitudinal direction of the street) $SI_{17} = C/N$ C = Area of sidewalk with the standard slope (m^2) L = length of street (both sides) LI = length of intersections $\mathbf{N} = \begin{cases} (\mathbf{L}-\mathbf{Li}) \times \mathbf{1.8 \text{ if } W < 1.80m} \\ (\mathbf{L}-\mathbf{Li}) \times \mathbf{W \text{ if } W \geq 1.80m} \end{cases}$ W = Width of the sidewalk (m) If W varies at different parts of street: W_i = Width of sidewalk (m) in section i $\mathbf{SI_{17}} = \sum_{i=1}^{k} (\mathbf{DIC_i} \times L_i)/(\mathbf{L}-\mathbf{LI})$ i = 1, 2, 3, ..., k (different parts of street with various width of the sidewalk) $DIC_i = C_i/N_i$ C_i = Area of the sidewalk with the standard slope in section i (m^2) $\mathbf{N_i} = \begin{cases} \textbf{length of street (in section i)} \times \textbf{1.8 if Wi < 1.80m} \\ \textbf{length of street (in section i)} \times \textbf{W if Wi} \geq \textbf{1.80m} \end{cases}$ L_i = Length of street in section i (m)	W = 1.5 $C = (1367 \times 1.5)-(12 \times 1.5 \times 2) = 2014.5$ m^2 $N = 1367 \times 1.80 = 2460.6$ $SI_{17} = 2014.5/2460.6 = 0.82$
(18) Lift $SI_{18} = C/N$ C = Number of standard lifts N = Number of lifts that street needs $\mathbf{N} = \begin{cases} \textbf{1 if street does not need lift and there are enough crossing facilities} \\ \textbf{0 if street does not need lift and there are not enough crossing facilities} \end{cases}$	C = 0 N = 2 $SI_{18} = 0/2 = 0$
(19) Curb ramp $\mathbf{SI_{19}} = \begin{cases} \textbf{1 if P} \geq \textbf{1 or no need for stop bar and there are enough crossing} \\ \textbf{P if P < 1} \\ \textbf{0 if no need for stop bar since there are not enough crossing} \end{cases}$ P = C/N C = Number of standard curb ramps N = Total number of curb ramps the street needs	C = 58 N = 70 P = 58/70 = 0.83 $SI_{19} = 0.83$
(20) Tactile pavement (guiding tile) $\mathbf{SI_{20}} = \begin{cases} \textbf{1 if P} \geq \textbf{1} \\ \textbf{P if } P < \textbf{1} \end{cases}$ P = C/N C = Length of standard guiding tactile pavement (m) N = Length of guiding tactile pavement that street needs (m)	C = 0 N = 1367 P = 0/1367 = 0 $SI_{20} = 0$
(21) Warning tile $\mathbf{SI_{21}} = \begin{cases} \textbf{1 if P} \geq \textbf{1} \\ \textbf{P if } P < \textbf{1} \end{cases}$ P = C/N C = Number of standard warning tactile pavement rows N = Number of warning tactile pavement rows that street needs	C = 0 N = 1367 P = 0/1367 = 0 $SI_{20} = 0$
(22) Ramp $\mathbf{SI_{22}} = \begin{cases} \textbf{1 if P} \geq \textbf{1} \\ \textbf{P if } P < \textbf{1} \end{cases}$ P = C/N C = Number of standard ramps N = Number of ramps that street needs	C = 6 N = 6 P = 6/6 = 1 $SI_{22} = 1$
(23) Grade $SI_{23} = C/N$ C = Area of sidewalk with the standard grade (m^2) L = length of street (both sides) LI = length of intersections $\mathbf{N} = \begin{cases} (\mathbf{L}-\mathbf{Li}) \times \mathbf{1.8 \text{ if } W < 1.80m} \\ (\mathbf{L}-\mathbf{Li}) \times \mathbf{W \text{ if } W \geq 1.80m} \end{cases}$ W = Width of the sidewalk (m) If W varies at different parts of street: W_i = Width of sidewalk (m) in section i $\mathbf{SI_{23}} = \sum_{i=1}^{k} (\mathbf{DIC_i} \times L_i)/(\mathbf{L}-\mathbf{LI})$ i = 1, 2, 3, ..., k (different parts of street with various width of the sidewalk) $DIC_i = C_i/N_i$ C_i = Area of the sidewalk with the standard slope in section i (m^2) $\mathbf{N_i} = \begin{cases} \textbf{length of street (in section i)} \times \textbf{1.8 if Wi < 1.80m} \\ \textbf{length of street (in section i)} \times \textbf{W if Wi} \geq \textbf{1.80m} \end{cases}$ L_i = Length of street in section i (m)	W = 1.5 $C = (1367 \times 1.5)-(12 \times 1.5 \times 2) = 2014.5$ m^2 $N = 1367 \times 1.80 = 2460.6$ $SI_{23} = 2014.5/2460.6 = 0.82$

Table 2. *Cont.*

Indicator Evaluation Description	Illustration
(24) Signal $SI_{24} = (SPI + CPI + WPI + API)/4$ $\mathbf{SPI} = \begin{cases} \mathbf{1} \text{ if } \mathbf{P_1} \geq \mathbf{1} \\ \mathbf{P_1} \text{ if } \mathbf{P_1} < \mathbf{1} \end{cases}$ $\mathbf{P_1 = SP/N}$ SP = Signals with first, second and third standards N = Total number of signals that street needs $\mathbf{CPI} = \begin{cases} \mathbf{1} \text{ if } \mathbf{P_2} \geq \mathbf{1} \\ \mathbf{P_2} \text{ if } \mathbf{P_2} < \mathbf{1} \end{cases}$ $\mathbf{P_2 = C/N}$ C = Signals with fourth condition $\mathbf{WPI} = \begin{cases} \mathbf{1} \text{ if } \mathbf{P_3} \geq \mathbf{1} \\ \mathbf{P_3} \text{ if } \mathbf{P_3} < \mathbf{1} \end{cases}$ $\mathbf{P_3 = W/N}$ W = Signals with fifth condition $\mathbf{API} = \begin{cases} \mathbf{1} \text{ if } \mathbf{P_4} \geq \mathbf{1} \\ \mathbf{P_4} \text{ if } \mathbf{P_4} < \mathbf{1} \end{cases}$ $\mathbf{P_4 = A/N}$ A = Signals with sixth condition $SI_{24} = 0$ if there is no signal	SP = 14 N = 32 $P_1 = 14/32 = 0.44$ $SPI = 0.44$ C = 14 $P_2 = 14/32 = 0.44$ CPI = 0.44 W = 14 $P_3 = 14/32 = 0.44$ WPI = 0.44 A = 14 $P_4 = 14/32 = 0.44$ API = 0.44 $SI_{24} = (0.44 + 0.44 + 0.44 + 0.44)/4 = 0.44$

To facilitate the understanding of the PSI value in a special rating system, the PSI% was defined. The PSI% value is the PSI rating, meaning the percentage of the existing PSI relative to the ideal PSI. The ideal PSI is when compliance with the standards occurs for all indicators (All SI_i are equal to 1). In this scenario, the ideal PSI is the maximum PSI value, or the sum of all the coefficient of safety indicators.

For the road segment R1 for instance, once the value of PSI1 has been computed, PSI1% corresponds to the proportion of PSI1 with respect to the ideal PSI.

The PSI% was computed with Equation (3):

$$PSI\% = 100 \times \left(\frac{PSI}{\sum_{i=1}^{24} c_i}\right) \tag{3}$$

where:

- $PSI\%$ = percentage of pedestrian safety index;
- PSI = pedestrian safety index;
- I = the indicator number;
- c = the coefficient of safety indicator;

Table 3 shows various classifications for the PSI rating and their interpretations.

Table 3. PSI rating (PSI%) interpretation.

PSI Rating (PSI%)	Value Range	Interpretation
A	80–100	Highest quality (very pleasant), many important pedestrian safety facilities present
B	60–79	High quality (acceptable), some important pedestrian safety facilities present
C	40–59	Average quality (rarely acceptable), pedestrian safety facilities present but room for improvement
D	20–39	Low quality (uncomfortable), minimal pedestrian safety facilities
E	0–19	Lowest quality (unpleasant), no pedestrian safety facilities

As an illustration, using data from Tables 1–3: PSI = (37 × 1) + (39 × 0.89) + (17 × 0.5) + (28 × 1) + (32 × 0.4) + (38 × 0.47) + (32 × 0.82) + (22 × 0.81) + (32 × 0.25) + (15 × 1) + (39 × 1) + (9 × 0.81) + (23 × 1) + (31 × 0) + (24 × 0.81) + (18 × 0) + (34 × 0.82) + (5 × 0) + (31 × 0.83) + (7 × 0) + (17 × 0.76) + (15 × 1) + (25 × 0.82) + (27 × 0.44) = 408.57.

PSI% = 100 × (408.57/597) = 68; thus, the PSI grade for this street (Canberra Road in Singapore) is B.

Further details on the PSI formulation, the definition of each safety indicator, the standards values for each of the indicators, the criteria to assess them depending on the road type (arterial, collector, local, access), the computation of the coefficient of the safety indicator, the computation of the safety indicator score, and the pedestrian safety index can be found in the literature [95].

2.3. Walkability Index

The Global Walkability Index (GWI), developed by the World Bank, was adopted from a similar index constructed by the Institute for Transportation and Development Policy (ITDP) [80]. The index quantifies sidewalk walkability based on nine variables related to the urban inventory, notably, the urban life and sidewalk conditions (permeable fronts, access to public transport systems, sidewalk dimensions, and pavement conditions), the urban furniture (trees, benches, lighting, and obstacles), and, finally, pedestrian crossings, universal accessibility, and safety perception.

The GWI was computed using Equation (4):

$$\mathrm{GWI} = \sum_{i=1}^{9} Y_i \times V_i \tag{4}$$

where:

- GWI = quantification of the Global Walkability Index
- i = the variable number
- V = score of the variable
- Y = weight of the variable

The weight values of each variable defined by the World Bank study were drawn from the "pedestrian first tools for a walkable city" study by ITDP. The weighting consisted of assigning a numerical value to the importance of each variable to the global walkability based on expert consultation and previous applications. Importantly, the weighting system was customized to consider particular situations such as school zones, where the prioritization of features like crossing accessibility is guided by the needs of young students. This distinction recognizes the necessity for safer and more accessible walking environments for young students, influencing the assessment of the overall global walkability in the school's vicinity compared with other areas.

Table 4 specifies the value of the weight of each of the nine variables extracted from the World Bank study [80].

Table 4. Weigh value of each variable.

ID	Variable	General Weight Factor Y1	School Area Weight Factor Y2
V1	Permeable fronts	0.08	0.06
V2	Sidewalk dimensions	0.18	0.2
V3	Pavement conditions	0.18	0.18
V4	Seating infrastructure	0.09	0.08
V5	Street lighting	0.09	0.06
V6	Obstacles	0.05	0.05
V7	Crossing accessibility	0.14	0.2
V8	Improper crossing	0.05	0.05
V9	Trees	0.14	0.12

The method to compute the value of the score V of each variable is illustrated in Table 5. The method is derived from [80,95] and incorporates the standard values of each variable. The urban street design guidelines [109] and the global street design guidelines [110] were also consulted to ensure that the values were coherent with international safety guidelines.

Table 5. Score of each variable of the global walkability index.

Indicator Evaluation Description	Illustration (R1)
(1) (Permeable fronts $\mathbf{P} = \begin{cases} \mathbf{0 \text{ if there are no activities along street}} \\ \frac{NP\_G}{NA} \mathbf{\text{ else}} \end{cases}$ NP_G is the number of activities with fair or good permeable front. NA is the number of activities. $\mathbf{Q} = \begin{cases} \mathbf{0 \text{ if there are no bus stop along street}} \\ \frac{NB\_G}{NB} \mathbf{\text{ else}} \end{cases}$ NB_G is the number of activities with fair or good permeable front. NA is the number of bus stops. $\boldsymbol{M} = \frac{P+Q}{2}$ $\mathbf{V1} = \begin{cases} P \textit{ if there are activities an no bus stop} \\ \mathbf{Q \text{ if there are bus stop and no activities}} \\ \mathbf{M \text{ if there are both}} \end{cases}$	There is no bus stop $P = 1/5 = 0.2$ $V1 = P = 0.2$
(2) Sidewalk Dimensions $\mathbf{V2} = \begin{cases} \frac{\mathbf{W}}{\mathbf{2.5}} \textit{ if } \mathbf{W < 2.5\ 0 \text{ if there are no bus stop along street}} \\ \mathbf{1} \textit{ if } \mathbf{W \geq 2.5} \end{cases}$ W = Average width of a street If W varies at different parts of street: W_i = Width of sidewalk (m) in section i i = 1, 2, 3, ..., k (different parts of street with various width of the sidewalk) $\mathbf{W} = \frac{\sum_{i=1}^{k} W_i}{\mathbf{k}}$	W = 1.5 m $\text{V2} = \frac{1.5}{2.5} = 0.6$
(3) Pavement Conditions $\boldsymbol{V3} = \frac{C_7 \times SI_7 + C_{20} \times SI_{20} + C_{21} \times SI_{21}}{C_7 + C_{20} + C_{21}}$ SI_7 = the seventh safety index for pedestrian safety index SI_{20} = the twentieth safety index for pedestrian safety index SI_{21} = the twenty-first safety index for pedestrian safety index c_7, c_{20}, c_{21} are the respective coefficients of SI_7, SI_{20}, SI_{21}	$SI_7 = 0.8$ $SI_{20} = 0$ $SI_{21} = 0$ $\text{V3} = \frac{0.8 \times 32 + 0 \times 7 + 0 \times 17}{32 + 7 + 17} = 0.46$
(4) Seating Infrastructure $\boldsymbol{P} = \frac{NS\_G}{NS}$ $\mathbf{V4} = \begin{cases} P \textit{ if } \mathbf{P < 1 \text{ if there are no bus stop along street}} \\ \mathbf{1} \textit{ if } P \geq \mathbf{1} \end{cases}$ NS_G is the number of seating infrastructure which are in fair or good condition. NS is the number of seating infrastructure that street need.	There is no seating infrastructure $V_4 = 0$
(5) Street Lighting $V5 = SI14$ SI_{14} fourteenth safety index for pedestrian safety index	$SI_{14} = 0.6$ $V5 = SI14 = 0.6$
(6) Obstacle V6 = C/N C = Area of sidewalk street without obstacles (m^2) Li = length of intersections L = length of street (both sides) $\mathbf{N} = \begin{cases} (\mathbf{L}-\mathbf{Li}) \times \mathbf{1.8 \text{ if } W < 1.80m} \\ (\mathbf{L}-\mathbf{Li}) \times \mathbf{W \text{ if } W \geq 1.80m} \end{cases}$ W = Width of footpath (m) If W varies in different parts of street W_i = Width of footpath in section i $\mathbf{SI_7} = (\sum_{i=1}^{k} (\mathbf{PC_i} \times \mathbf{L_i}))$/(length of street (both sides)—length of intersections) i = 1, 2, 3, ..., k (different parts of street with various width of the footpath) $PC_i = C_i/N_i$ C_i = Area of sidewalk street without obstacles in section i (m^2) $\mathbf{N_i} = \begin{cases} \mathbf{\text{length of street (in section i)} \times 1.8 \text{ if } Wi < 1.80m} \\ \mathbf{\text{length of street (in section i)} \times W \text{ if } Wi \geq 1.80m} \end{cases}$ L_i = Length of street in section i (m)	$W - 1.5$ $C = (700 \times 1.5) - (25 \times 1.5 \times 2) = 975\ m^2$ $N = 673 \times 1.80 = 1211.4\ m^2$ $V6 = 975/1211.4 = 0.80$

Table 5. *Cont.*

Indicator Evaluation Description	Illustration (R1)
(7) Accessible crossing **V7 =** $\frac{\mathbf{C_8 \times SI_8 + C_9 \times SI_9 + C_{12} \times SI_{12}}}{\mathbf{C_8 + C_9 + C_{12}}}$ SI_8 = the eighth safety index for pedestrian safety index SI_9 = the ninth safety index for pedestrian safety index SI_{12} = the twelfth safety index for pedestrian safety index c_8, c_9, c_{12} are the respective coefficients of SI_8, SI_9, SI_{12}	$SI_8 = 0.8$ $SI_9 = 0$ $SI_{12} = 0$ $V7 = \frac{0\times22+0\times32+0\times9}{22+32+9} = 0$
(8) Improper crossings $\boldsymbol{P = \frac{NPC}{N}}$ NPC is the number of people crossing using the pedestrian crossing during a given period. N is the number of people crossing the street during given period **V8 =** $\begin{cases} \mathbf{0}\ \textbf{\textit{if there is no crossing section}} \\ \textbf{\textit{P if else}} \end{cases}$	There is no crossing section. V8 = 0
(9) Trees $\boldsymbol{P = \frac{NT}{N}}$ NT is the number of well-placed trees along the road, meaning trees placed outside the sidewalk or the path of travel of pedestrians along the road. N is number of trees that the road needs. **V9 =** $\begin{cases} \mathbf{P\ if\ P < 1} \\ \mathbf{1}\ \boldsymbol{if\ P \geq 1} \end{cases}$	$P = \frac{0}{19}$ V9 = 0

Just like the PSI, the GWI% was also defined and the same classification level (Class E to A) was used. The GWI% was computed with Equation (5):

$$GWI\% = 100 \times \left(\frac{GWI}{\sum_{i=1}^{9} Y_i} \right) \tag{5}$$

where:

- $GWI\%$ = percentage of Global Walkability Index, the rating value
- GWI = Global Walkability Index
- i = the variable number
- Y = weight of the variable

Further details on the Global Walkability Index can be found in the literature [80]

2.4. Data Collection

2.4.1. Site Selection and Timing

The study area was composed of two zones, selected via prioritizing high pedestrian activity and considering diverse profiles, especially students who are particularly exposed as they principally rely on walking due to its affordability. The first zone was around the Poste Centrale quarter, and the second zone was around the University of Yaoundé I (See Figure 1).

The choice of the first zone was made because Yaoundé is monocentric and "Poste Centrale" is considered as the city center, the principal heart of the city, and the main attraction, with most of the administration, the commercial center, most of the services such banks and insurance companies, and formal and informal commerce activities [111].

The choice of the second zone was made because it is considered the University Area, with the largest concentration of the most renowned and largest institutions in the city. As the capital of Cameroon, Yaoundé is home to a large share of the schools in the country, from the primary level up to the advanced level. With respect to the latter, the University of Yaoundé I (UYI) is not only considered the best public university in the city [112], but also the second largest by number of students enrolled [113]. In addition, the university area is home to the Faculty of Medicine and Biomedical Sciences (FMSB), the National Advanced School of Engineering (ENSP), and the National Advanced School of Public

Works (ENSTP), which are, respectively, the leading and largest medical and engineering schools in the city. The area also includes the National Institute of Youth and Sports (INJS), the Institute of Demographic Training and Research (IFORD) and the Inter-Army Military School (EMIA).

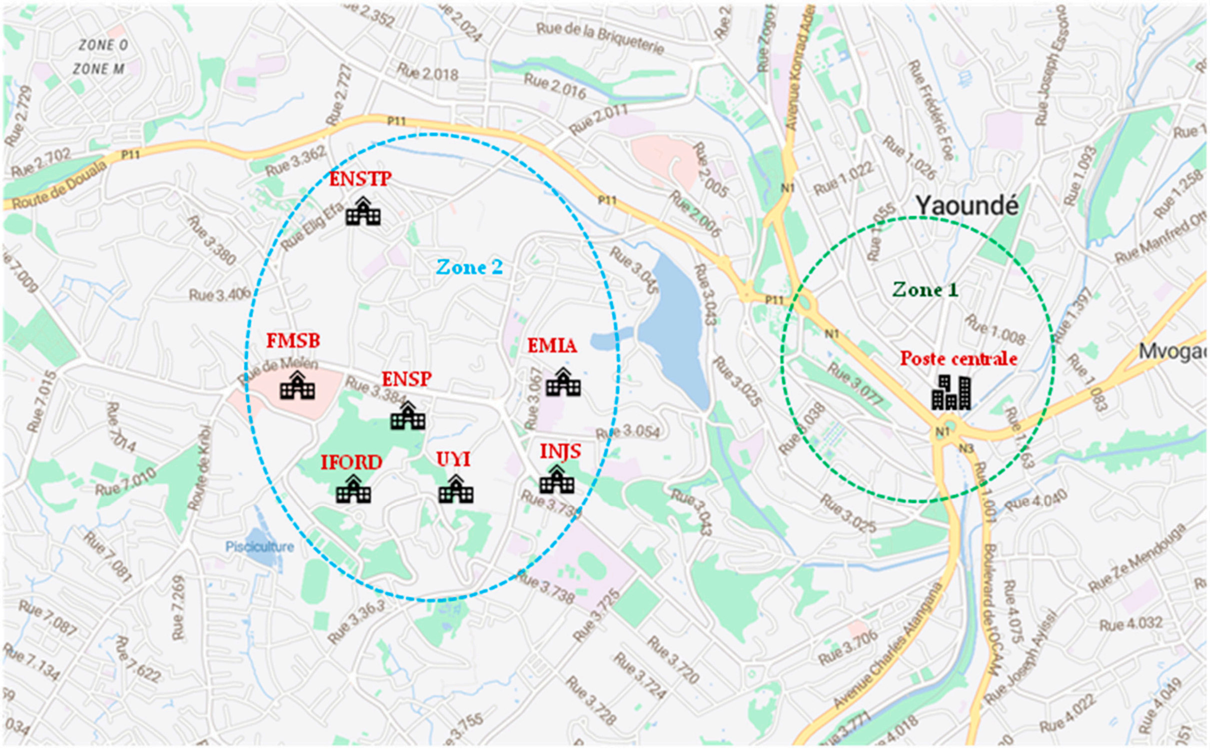

Figure 1. Illustration of the two zones in the area of study.

In total, 12 road segments were selected (see Table 6), essentially the main arteries to the two identified zones.

Table 6. List of Road segments investigated.

Zone	Road ID	Name	Start Latitude; Longitude	End Latitude; Longitude	Length	Type; Lane Width (L)	Median Type	Sidewalk Average Width	Pedestrian Crossing
1st	R1	Avenue Monseigneur Vogt	3.862448; 11.520995	3.865283; 11.522058	350 m	Undivided 1 × 1 (1 lane/way) L < 2.75 m	Centre line	1.5 m	No
	R2	Avenue de l'Independance 1	3.865392; 11.5219	3.866437; 11.52064	190 m	Undivided 1 × 1 L < 2.75 m	Centre line	1 m	No
	R3	Rue de Narvik	3.866020; 11.520468	3.863182; 11.520002	350 m	Undivided 1 × 1 L < 2.75 m	Centre line	1.5 m	No
	R4	Avenue Ahidjo	3.862918; 11.520542	3.866200; 11.517093	550 m	Divided 2 × 2 (2 lanes/way) L < 2.75 m	Central hatching	1.5 m	No
	R5	Avenue de l'Independance 2	3.867472; 11.517860	3.867080; 11.520097	350 m	Undivided 1 × 1 L < 2.75 m	Centre line	1.5 m	Yes

Table 6. *Cont.*

Zone	Road ID	Name	Start Latitude; Longitude	End Latitude; Longitude	Length	Type; Lane Width (L)	Median Type	Sidewalk Average Width	Pedestrian Crossing
	R6	Rue Goker	3.866222; 11.520272	3.864765; 11.518820	230 m	Undivided 1 × 1 L < 2.75 m	Centre line	1.5 m	No
	R7	Boulevard du 20 Mai	3.861663; 11.520118	3.865794; 11.515625	700 m	Divided 2 × 2 (2 lane/way) L < 2.75 m	Central hatching	2.5 m	Yes
2nd	R8	Carrefour GP—Carrefour EMIA	3.862886; 11.494085	3.862244; 11.503976	1200 m	Divided 1 × 1 L < 2.75 m	Physical median less than 1 m	2 m	No
	R9	Rue Elig Effa	3.864023; 11.496598	3.867354; 11.495855	1200 m	Undivided 1 × 1 L < 2.75 m	Centre line	1 m	No
	R10	Mini Ferme–Chapelle Elig Effa	3.867354; 11.495855	3.869919; 11.498435	400 m	Undivided 1 × 1 L < 2.75 m	Centre line	1 m	No
	R11	Carrefour EMIA–Chateau	3.862295; 11.504052	3.856377; 11.503734	750 m	Undivided 1 × 1 L < 2.75 m	Centre line	1 m;	No
	R12	Chateau–Cradat	3.856377; 11.503734	3.852437; 11.498658	800 m	Undivided 1 × 1 L < 2.75 m	Centre line	1 m One side	No

2.4.2. Data of Interest and Measurement Procedure

The data collection was carried out unobtrusively and while respecting the safety regulations. The observers were equipped with clipboards, pen, stopwatch, data collection sheet, and the necessary authorization.

The data of interest were essentially related to road, traffic, and environmental parameters related to the 24 indicators (see Tables 1 and 2) of the pedestrian safety index and the nine variables of the Global Walkability Index (See Tables 4 and 5). A dedicated sheet was prepared for the researchers to collect all these parameters in addition to the road section attributes (road type, carriage way width, median type, lane number, lane width, sidewalk presence, sidewalk width, paved shoulder width). The length between intersections was measured using the measuring distance option on Google Maps, with the known coordinates of each starting and ending point.

The only traffic parameter collected was speed, via video recording of the vehicles and subsequently using the application Speed Xpert to compute the average speed. The traffic video was recorded during free-flowing traffic. The vehicles of interest were motorized four-wheelers, which were essentially passenger cars and a few light goods vehicles. The camera was unobtrusively placed on a lightweight metallic tripod at the roadside, in order not to alter drivers' normal speed and behavior. To validate the results from the application, a pilot test was conducted at one location. Typically, the stopwatch method was conducted to collect the speed data while the traffic was recorded. The speed results from the stopwatch method and Speed Xpert were consistent. The minimum road section length covered by each video was 15 m, which was the value used for the speed evaluation. The speed metric computed was the time mean speed, which was the average value of the individual speed of each vehicle passing the road section length during the observation period. To ensure that the average speed values were actual representations of the attitudes to speed in the location, the video recording of the traffic was long enough to ensure at least 250 vehicles were recorded, corresponding to a sufficient sample size for calculation of speed metrics in this traffic environment [114]. On road segments with pedestrian crossings, pedestrians were observed during the time of the video recording, in order to count those crossing the road within and outside the crosswalk. The data collection took place between December 2023 and January 2024, for 14 days spread over four weeks at a rate of 1 day per road segment, except for roads R8 and R9, which each required two days. Data collection was conducted for 8 h daily, from 08:00 AM to 04:00 PM, with speed data specifically gathered during off-peak hours, from 10:00 AM to 03:00 PM. This approach ensured observation of vehicles under conditions of free-flowing traffic, minimizing the impact of congestion prevalent during peak hours. The general drawback of this approach is that it might overestimate the average speed of vehicles when compared with a 24 h period, which does not apply to this study where the aim was to have free flow speed, corresponding to greater severity of injury for pedestrians in case of crashes.

2.5. Data Analysis

After the data collection, the physical sheets were reproduced in a Microsoft Office Excel spreadsheet for easier manipulation. During this process, quality control and data cleaning were conducted to ensure the data were consistent and in the proper format for analysis. The speed values were extracted from Speed Xpert and added to the Excel dataset. The main computations were the pedestrian safety index (PSI) and the Global Walkability Index, using the formulas presented in Sections 2.2 and 2.3, respectively. To automate the computation, a custom Visual Basic for Applications (VBA) program was developed and integrated into Excel. To ensure the accuracy and reliability of the program, the data from the article originally developing the PSI were used to compute the PSI for that study, and the program was able to generate the same values.

3. Results and Discussion

3.1. Pedestrian Safety Index

Table 7 shows the global results of the 24 safety indicators, the 12 PSI values, the 12 PSI% values, and the 12 grades for all the 12 road segments investigated.

Table 7. General results of the PSI.

	R7	**R3**	**R8**	**R4**	**R6**	**R10**	**R2**	**R11**	**R5**	**R1**	**R9**	**R12**
SI1	0	1	1	1	1	1	1	1	1	1	1	1
SI2	0	0	0	0	0	0	0	0	0	0	0	0
SI3	1	1	1	1	1	1	1	1	1	1	1	1
SI4	0	0	0	0	0	0	0	0	0	0	0	0
SI5	0.92	0	0	0	0	0	0	0	0	0	0	0
SI6	0	0	0	0	0	0	0	0	0	0	0	0
SI7	0.99	0.86	0.96	0.72	0.8	0.28	0.56	0.58	0.82	0.8	0.28	0.16
SI8	0.5	0	0	0	0	0	0	0	0.14	0	0	0
SI9	0	0	0.25	0	0	0	0	0	0	0	0	0
SI10	0	0	0	0	0	0	0	0	0	0	0	0
SI11	0.99	0.96	0.96	0.87	0.95	0.75	1	0.89	0.98	0.89	0.25	0.29
SI12	0	0	0	0	0	0	0	0	0	0	0	0
SI13	1	1	0.67	1	1	1	1	0.5	0	0	1	0
SI14	0.6	0.6	0.45	0.6	0.6	0.15	0.29	0.29	0.6	0.6	0.15	0.3
SI15	0.25	0	0	0	0	0	0	0	0	0	0	0
SI16	0	0	0	0	0	0	0	0	0	0	0	0
SI17	1	0.84	0.39	0.24	0	0.56	0	0.21	0	0	0.56	0.08
SI18	0	0	0	0	0	0	0	0	0	0	0	0
SI19	0	0	0	0	0	0	0	0	0	0	0	0
SI20	0	0	0	0	0	0	0	0	0	0	0	0
SI21	0	0	0	0	0	0	0	0	0	0	0	0
SI22	0.5	0	0	0	0	0	0	0	0	0	0	0
SI23	1	0.86	0.39	0.21	0	0.56	0	0.21	0	0	0.56	0.08
SI24	0	0	0	0	0	0	0	0	0	0	0	0
PSI	241.6	210.6	185.53	165.7	158.3	152.6	142.6	139.7	137.8	133.1	133.1	84.5
PSI%	40.5	35.3	30.6	27.8	26.5	25.6	23.9	23.4	23.1	22.3	22.3	14.2
Grade	C	D	D	D	D	D	D	D	D	D	D	E
Rank	1	2	3	4	5	6	7	8	9	10	11	12

- SI1: Slower traffic speed

The average speeds on all the road segments were lower than 50 km/h, except for road segment R7 "Boulevard du 20 Mai" where the averages speed value was almost 80 km/h. This is certainly because the road is wider (2 × 2 road, meaning two lanes in each direction) and in better pavement condition. As a result, except for R7 (SI1 = 0), all the road segments had safety indicator values of 1, indicating that their lower average speed made them safer for pedestrians compared with R7 [12,13].

- SI3: Fewer travel lanes

Except for R7 (2 × 2 road) and R4 (2 × 2 road), the number of lanes per travel direction for all road sections was one (1 × 1 road, meaning one lane in each direction). However, both values being lower or equal than 2, this safety indicator for all road segments was found to be 1, as fewer travel lanes mean shorter crossing distance for pedestrians, limited exposure time to motorized vehicles, and increased safety for pedestrians [28].

- SI5: Shorter crossing distance (mid-block crossing)

Among all road segments, only road segment R7 had a mid-block crossing. Consequently, this safety indicator value was zero for all the road segments except for R7 (SI5 = 0.92).

- SI7: Footpath Pavement

All the road segments had some sort of sidewalk. R7 "Boulevard du 20 Mai" (SI7 = 0.99) and R8 "Carrefour GP–Carrefour EMIA" (SI7 = 0.96) had the highest values for this safety indicator as their sidewalks were almost the total length of the road segment and in relatively good condition (pavement surface). On the other hand, R9 "Rue Elig Effa" (SI7 = 0.28), R10 "Mini Ferme–Chapelle Elig Effa" (SI7 = 0.28), and R12 "Chateau–Cradat" (SI7 = 0.16) had the lowest proportion of sidewalk, mostly in bad condition, increasing the risk of crashes for pedestrians [32].

- SI8: Marking (crosswalk)

Only R7 and R5 had crosswalks for pedestrians. However, the markings were not always clearly visible and clear for pedestrians, which is why this safety indicator for R7 had a medium value (SI8 = 0.5) and that for R5 an even lower value (SI8 = 0.14). These values were still greater than those for all the other road segments, which had no marked crosswalks for pedestrians.

- SI9: Physical pedestrian refuge and median

Among all road segments, only R8 "Carrefour GP–Carrefour EMIA" had a physical median in the middle of the road for pedestrians to mark a stop while crossing the roads. However, the design of the median was not adequate (e.g., width less than 1 m). Consequently, this safety indicator was only 0.25, which was still greater than for all the other road segments (SI9 = 0).

- SI11: Sidewalk on both sides

Similarly to SI7, R7 (SI11 = 0.99) and R8 (SI11 = 0.96) had high values for this safety indicator as their sidewalks were not only in better condition (pavement) but also on both sides of the roads. In contrast to SI7, for which the value was 0.56 (average condition of sidewalk pavement), the safety indicator for R2 "Avenue de Independence 1" was 1 as sidewalks were present on both sides on the total road length. This safety indicator was high for most of the roads, except only R9 "Rue Elig Effa" (SI11 = 0.25) and R12 "Chateau–Cradat" (SI11 = 0.29), which had the lowest proportions of sidewalk on both sides.

- SI13: Driveway

This safety indicator for most (7 out of 12) of the road segments was 1 as there were no driveways on these road segments, limiting the exposure of pedestrians walking on the sidewalk to motorized traffic coming in/out of driveways. However, there were some driveways in road sections R1 (SI13 = 0), R5 (SI13 = 0), R12 (SI13 = 0), R8 (SI13 = 0.68), and R11 (SI13 = 0.5), explaining the lower values of their safety indicators.

- SI14: Lighting

In general, the lighting was not adequate on any of the 12 road segments, increasing the risk of crashes for pedestrians, especially at night [23,24]. The lighting condition was better on R1, R3, R4, R5, R6, and R7, with a safety indicator of 0.6, compared with the remaining road sections. This was due to the fact that they had the highest proposition of road length covered by pedestrian lighting.

- SI15: Signing

As previously seen, only road segments R7 and R5 had crossings for pedestrians to cross the road, even though the markings were not always visible. In addition, there was a general lack of signage signaling the presence of the crosswalk to pedestrians and especially motorized vehicles, especially on road segment R5. Consequently, this safety indicator for R7 and R5 was 0.25 and 0, respectively. This safety indicator for all the other road segments was 0 for the obvious reason of there being no crosswalk.

- SI17: Running slope (in the longitudinal direction of the street)

The road segments R7 "Boulevard du 20 Mai" (SI17 = 1) and R3 "Rue de Narvik" (SI17 = 0.84) stood out with the highest values of this safety indicator, due to the fact that the slope of the sidewalk on these roads was adequate (less than 2%) in almost all of the length. The proportion of sidewalks with adequate slope was lower for road segments R9 "Rue Elig Effa (SI17 = 0.56) "and R10 "Mini Ferme–Chapelle Elig Effa" (SI17 = 0.56) but relatively acceptable. For the reaming road segments, the proportion of sidewalks with adequate slope was very low, indicating the low-safety experience of pedestrians using these sidewalks (loss of stability, risk of falling, etc.).

- SI22: Ramp

All road segments except R7 had a safety indicator value of 0, as there was no ramp provided for persons with disabilities (PwDs) along these road segments. R7 "Boulevard du 20 Mai" stood out with a safety indicator of 0.5 as there were a few ramps provided in some sections of the road segment. While not at the highest level, this suggests that this road segment was the most PwD-friendly, especially for pedestrians with mobility impairments or using wheeled devices [115].

- Other safety indicators

The remaining safety indicators had values of zero across all the 12 road segments. This can be explained by the fact that on the 12 road segments, there were no buffers with barriers (SI2 = 0), no curb extension (SI4 = 0), no trees (SI6 = 0), no splitter islands (SI10 = 0), no advance stop bar (SI12 = 0), no bollards along the road segments (SI16 = 0), no pedestrian lift (SI18 = 0), no curb ramp (SI19 = 0), no tactile pavement or guiding tiles for pedestrians with visual impairment (SI20 = 0), no warning tiles along the road segments (SI21 = 0), and no accessible (to all users including PwDs) and adequate pedestrian signalling (SI24 = 0).

- Overall observation

The road segment R7 "Boulevard du 20 Mai" was the safest road segment for pedestrians, with a PSI of 241.56, representing approximately 40.5% of the maximum PSI achievable. This PSI value corresponds to a grade of C, indicating low to average quality requiring attention for improvement. Similarly, road segments R3, R8, R4, R6, R10, R2, R11, R5, R1, and R9 obtained PSI values ranging from 210.6 (PSI rating of 35.3%) to 133.1 (PSI rating of 22.3%), falling into grade D, which signifies low safety consideration for pedestrians and low quality requiring considerable improvement. Road segment 12 had the lowest PSI value of 84.54, corresponding to 14.2% of the maximum PSI, resulting in a grade of E, indicating the lowest quality with unpleasant conditions requiring considerable improvement.

In comparison to the Canberra road in Singapore whose grade was B [95], all the road segments investigated felt into or below grade C, indicating the low levels of pedestrian safety in these road segments, calling for urgent and considerable improvement.

3.2. Global Walkability Index

Table 8 shows the results of the 12 Global Walkability Index (GWI) variables, the 12 GWI ratings (GWI%), and the 12 grades for all the 12 roads segments inspected.

Table 8. General results of the GWI.

	R7	**R5**	**R3**	**R4**	**R8**	**R6**	**R1**	**R11**	**R10**	**R9**	**R2**	**R12**
V1	0.77	0.63	0.83	0.94	0.32	0.77	0.2	0.6	0.4	0.087	0.2	0.6
V2	1	0.6	0.6	0.6	0.8	0.6	0.6	0.6	0.4	0.4	0.4	0.2
V3	0.56	0.47	0.49	0.41	0.55	0.45	0.46	0.33	0.16	0.16	0.32	0.091
V4	0	0	0	0	0	0	0	0	0	0	0	0
V5	0.6	0.6	0.6	0.6	0.45	0.6	0.6	0.29	0.15	0.15	0.29	0.3
V6	0.99	0.82	0.86	0.72	0.6	0.8	0.8	0.57	0.28	0.28	0.56	0.16
V7	0.17	0.048	0	0	0	0	0	0	0	0	0	0
V8	0.7	0.5	0	0	0	0	0	0	0	0	0	0
V9	0	0	0	0	0,1	0	0	0	0	0	0	0
GWI	0.5056	0.37	0.3605	0.347	0.346	0.345	0.301	0.261	0.155	0.137	0.199	0.118
GWI%	50.56	36.9	36.05	34.7	34.6	34.5	30.1	26.1	15.5	13.7	19.9	11.8
Grade	C	D	D	D	D	D	D	D	E	E	E	E
Rank	1	2	3	4	5	6	7	8	9	10	11	12

With respect to the nine variables of the Global Walkability Index, the conclusions are similar to the safety indicators of the PSI in terms of inadequacy of sidewalk (V2), poor pavement condition of footpath (V3), lack of street lighting (V5), lack of features for PwDs making crossing inaccessible and non-inclusive (V7), lack of crosswalks, average visibility of crosswalk markings, lack of crosswalk signage (V8), and lack of trees (V9), in addition to average access to activities along streets, lack of bus stops (V1), lack of urban furniture (V4), and obstruction of sidewalk by vendors or illegal parking (V6).

With respect to V8, only two road segments (R7 and R5) had a pedestrian crosswalk. Thus, pedestrian crossing within and outside the crosswalks were counted on these segments for 45 min and 30 min, respectively. On R7, 85 pedestrians were observed crossing the road (60 within crosswalk, 25 outside crosswalk). On R5, 73 pedestrians were observed (38 within crosswalk, 35 outside crosswalk).

Similar to the results from the PSI, the road segment R7 "Boulevard du 20 Mai" was the most walkable for pedestrians, with a GWI of 0.5056 representing 50.56% of the maximum walkability achievable. This GWI value corresponds to a grade C, indicating average walkability. The road segments R5, R3, R4, R8, R6, R1, and R11 obtained GWI values ranging from 0.369 (GWI rating of 36.9%) to 0.261 (GWI rating of 26.1%), falling into grade D, which signifies low quality and an uncomfortable walking experience. Road segments R10, R9, R2, and R12 had the lowest GWI values ranging from 0.155 (GWI rating of 15.5%) to 0.118 (GWI rating of 11.8%), resulting in a grade of E, indicating the lowest quality with poor walkability and an unpleasant walking experience.

In comparison to results from Addis Ababa [80], all the road segments investigated fell at or below grade C, indicating a low walkability index and an unsafe, poor, and uncomfortable walking experience for pedestrians along these roads, calling for significant improvement.

In Table 4, Y1 (general area) values have been used to compute GWI for R1 to R7, and Y2 (school area) values for R8 to R12.

3.3. Comparison of Indicators

The objective of this comparison was to relatively validate the PSI and GWI, the assumption being that if the two indexes are valid, they should generate similar and coherent results not only qualitatively in terms of the general description of pedestrian facilities (as previously seen) but also quantitatively in terms of the ranking of the 12 road segments according to their PSI and GWI values (see Table 9).

Table 9. Ranking of the 12 road segments per PSI and GWI values.

	R7	R5	R3	R4	R8	R6	R1	R11	R10	R9	R2	R12
GWI	0.5056	0.369	0.3605	0.347	0.346	0.345	0.301	0.261	0.155	0.137	0.199	0.118
GWI%	50.56	36.9	36.05	34.7	34.6	34.5	30.1	26.1	15.5	13.7	19.9	11.8
Grade	C	D	D	D	D	D	D	D	E	E	E	E
Rank	1	2	3	4	5	6	7	8	9	10	11	12
PSI	241.6	137.8	210.6	165.7	182.53	158.3	133.1	139.7	152.6	133.1	142.6	84.5
PSI%	40.5	23.1	35.3	27.8	30.6	26.5	22.3	23.4	25.6	22.3	23.9	14.2
Grade	C	D	D	D	D	D	D	D	D	D	D	E
Rank	1	9	2	4	3	5	10	8	6	11	7	12

The Spearman's rank correlation was used to determine the level of agreement between the rankings obtained using the two indicators. The correlation coefficient was calculated from the two vectors of ranks for the samples: let {Xi; i = 1. . .n} and {Yi; i = 1. . .n} be the vectors of ranks for sample 1 and sample 2, respectively. The coefficient was computed using Equation (6) [116]:

$$p_s = 1 - \frac{6 \times \sum_{i=1}^{n} {d_i}^2}{n^3 - n} \quad (6)$$

where:

- P_s = Spearman's rank-correlation coefficient (between −1 and 1);
- d_i = differences between ranks;
- n = number of paired data sets.

A score of 1.0 represents perfect correlation and a score of zero indicates no correlation. The t-approximation for this statistic, T, is valid for samples of eight upwards, and was calculated using Equation (7) [116]:

$$T = p_s \times \sqrt{\frac{n-2}{1-{p_s}^2}} \quad (7)$$

It has approximately a t-distribution with n-2 degrees of freedom and can be used for a test of the null hypothesis of independence between samples (Ps = 0). From Table 9, it can be seen that for 9 out of 12 road segments (R7, R5, R3, R4, R8, R6, R1, R11, and R12), the grade value was the same for both indexes, with a similarity coefficient of 75% (100 × 9/12). This means that with respect to the grade, the two indexes are quite coherent, indicating a relative validity. Figure 2 and Table 10 display the results of the Spearman's rank-correlation analysis. A clear tendency can be seen from Figure 2 in terms of similarity of the ranking between the two indexes for the 12 road segments. The value of the Spearman's coefficient (0.69) indicates a strong positive correlation between PSI and GWI. Furthermore, rankings from the PWI and GWI agree at the 99% significance level, providing further relative validation for the PSI and the GWI.

Table 10. Relative validation results.

	Ps	T	*p*-Value
GWI ranking vs. PSI ranking	0.69	3.015	<0.01

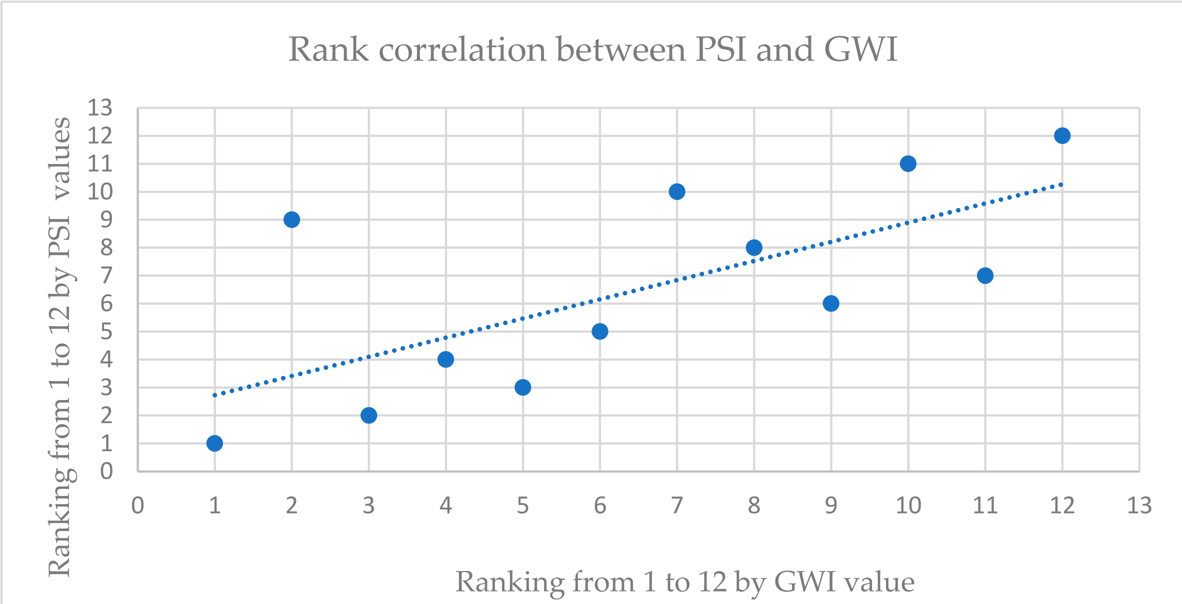

Figure 2. Rank correlation of the 12 road segments.

Road segments with similar results did not exhibit particular specificity, meaning that the performance of the indicator might have been independent of types of roads and solely reliant on in-built characteristics related to the safety of pedestrians. In addition, the positive significant correlation between the two indicators across all the road segment types implies that these indicators might perform similarly, irrespective of the road type, as long as they are properly applied.

4. Recommendation

The UN-Habitat have reported that there are no walking and cycling policies in Cameroon. In Yaoundé, some efforts have been made to improve pedestrian safety, mainly led by city officials [36], but the issues still pertain. All the 12 road segments were found to be of grade C or lower both using both the PSI and the GWI, indicating low levels of safety and walkability. Although the study was limited to these 12 road segments, the same conclusion can be made for many other parts of the city. In fact, simple trips around the city by car or while walking allow one to observe the absence of pedestrian facilities in many areas and the inadequacy or poor condition of the few existing ones. The states of the pedestrian facilities observed during the data collection (see Figure 3) provide a real picture of the necessity of taking measures. This will require consolidated efforts from various actors, centered around the city officials. To this end, a pedestrian safety strategy for the city of Yaoundé is proposed. The strategy covers seven years (2024–2030) with the goal of improving the PSI and GWI along all the streets to a grade B minimum, and along streets with 75% of the pedestrian flow to grade A. The strategy is not limited to engineering action (pedestrian facilities improvement) but also includes legislation/enforcement, policy, land use, training, education, and awareness campaigning, which have been found effective in improving pedestrian safety [30,44–49,117]. The strategy draws from the experience of similar strategies developed for Austin, Texas, and Connecticut in the USA [117–119]. For each dimension of the strategy, practical actions are proposed along with potential participating organizations, degree of effectiveness (with respect to pedestrian safety improvement), the timeline for the implementation and the potential barriers [118]. The complete strategy could not be included here, to keep the length reasonable, but Figure 4 shows a picture of some engineering action recommended at the road segment R9 to improve its pedestrian safety level from grade E to grade A. The standard values are taken from two guidelines for pedestrian safety facilities design in African cities [120,121]. Beyond the proposed recommendations, it is important to highlight that programming the intervention within a period of time will require complete understanding of the available budget, the cost of interventions, and the potential constraints that might hinder the success of the intervention. City officials will be leading the implementation of the intervention, which will potentially help overcome political or administrative constraints.

Figure 3. Predominant existing sidewalk condition on the road segments investigated: (**a**) existing sidewalk already in poor condition obstructed by cars and vendors; (**b**) total absence of sidewalk; (**c**) existing sidewalk obstructed by motorcycles and vendors. (**d**) lack of adequate sidewalk and obstruction of informal sidewalk (available space as well drainage).

Funding is critical to road safety management [122] and the recent increase in the road funding budget, from 1.5% to 4%, testifies commendable commitment to bolstering road safety measures in Cameroon [36]. A comprehensive analysis of the available budget and the cost implications of the proposed interventions will be needed to ensure optimal resource allocation. By conducting a detailed cost breakdown of each intervention, including initial procurement and ongoing maintenance expenses, it will be possible to ascertain their economic feasibility and prioritize those with the highest cost-effectiveness and potential impact on safety. Moreover, to overcome potential resource constraints, city officials could explore additional funding avenues, such as international aid, and engage with stakeholders to align interventions with community needs and maximize their effectiveness. Furthermore, long-term financial planning strategies will be essential to sustain these interventions beyond the current budget cycle, necessitating adaptability and ongoing feedback mechanisms to adjust recommendations based on budgetary realities and operational requirements. Through a meticulous examination of the budgetary landscape and prudent financial planning, the successful implementation of road safety interventions can be achieved, contributing to the overarching goal of enhancing pedestrian safety in the city.

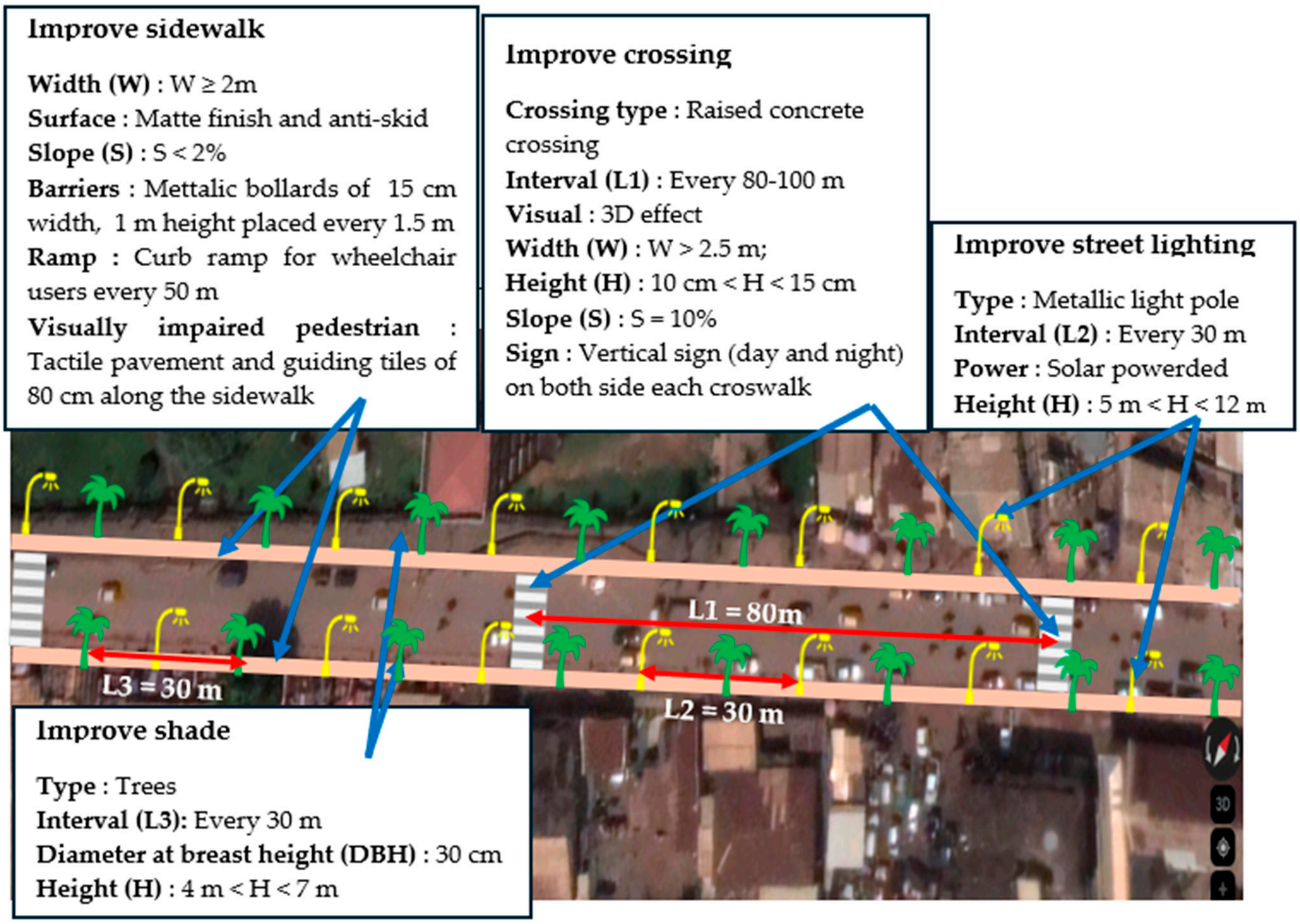

Figure 4. Engineering intervention at road segment R9 to improve its pedestrian safety grade from E to A.

5. Conclusions

Pedestrian safety is a major issue in Cameroon, as pedestrians account for almost 11% of road traffic deaths, and 22% of road traffic injuries every year. In Yaoundé, which accounts for most road traffic deaths in the country, walking is the main mode of transport and is responsible for almost 35% of daily trips. However, unsafe pedestrian facilities and a lack of sidewalks combined with chaotic traffic pose a major threat to pedestrians' safety. There are still no walking and cycling polices or a comprehensive pedestrian safety strategy, and the existing efforts seem not to be sufficient. In addition, the lack of studies assessing the safety of road infrastructure for pedestrians hinders the opportunity for the city to gather evidence of the issue and to develop and implement data-driven intervention. This study aimed to address this issue by investigating the safety of pedestrians in the city of Yaoundé and providing measures to improve their safety and walking experience.

The study used two sound and proven approaches, a pedestrian safety index, and the Global Walkability Index, both applicable in Yaoundé and any other cities of similar context. Road infrastructure, environmental, and traffic data were collected to generate the 24 safety indicators (sidewalk, street lighting, crossing, signing, ramp, etc.) of the PSI and the 9 variables of the GWI (urban furniture, sidewalk, shade, street lighting, etc.). The data were collected during on-field investigation for one month at 12 road segments representing the main arteries to two zones (Poste Centrale and University of Yaoundé I), with high numbers of pedestrians of diverse groups, especially students. The PSI and GWI were computed and normalized to a percentage to facilitate the understanding of the value in a special rating system from grade E (lowest) to A (highest). Descriptive statistics were used to unveil the insights from the PSI and GWI across the different safety indicators considered for all the road segments and to rank the road segments from the safest to the least safe. In addition, Spearman's rank correlation was performed to determine the level of agreement between the road segments' rankings obtained using the two indexes.

Overall, for both the PSI and GWI, only one road segment (R7) had a grade of C (average quality, rarely acceptable), making it the safest among all road segments. The remaining road segments had grades of D or E, indicating the lowest quality (uncomfortable) and minimal pedestrian safety facilities. In fact, most of these road segments were characterized by the lack of adequate sidewalk, poor condition of the existing sidewalk, lack of bollards, inaccessibility of the sidewalk to PwDs (mobile and visual impairment), lack of a pedestrian crossing, lack of signage for the few crossings, lack of shade, and lack of street lighting, to mention only a few. A correlation was found between the two indexes for the ranking of the 12 road segments. The value of the Spearman's coefficient (0.69) indicated a strong positive correlation between PSI and GWI. Furthermore, rankings from the PWI and GWI did agree at the 99% significance level, providing further relative validation for the PSI and the GWI.

To improve pedestrian safety in Yaoundé, based on these findings, a pedestrian safety strategy for the city of Yaoundé is proposed, covering seven years (2024–2030) with the goal of improving the PSI and WKI along all the streets to a minimum grade B and along streets with 75% of the pedestrian flow to grade A. The strategy includes engineering action, legislation/enforcement, policy, land use, training and education, and an awareness campaign, which have been found effective in improving pedestrian safety.

This study, which to the best of the authors' knowledge is one the few on the topic in Yaoundé, provides clear evidence of the safety level of pedestrian facilities, using robust and transferable methods.

The findings from this study and the pedestrian safety strategy proposed could help city officials to implement targeted intervention to improve pedestrian safety in Yaoundé, not only to save lives but to generate health, economic, and environmental benefits associated with increased active mobility in the city. The findings could also help city officials to develop or adopt walking and cycling polices which are currently lacking. Finally, the study can also help city officials in the implementation of upcoming projects in the city which all have components relating to pedestrian safety, notably, the city's sustainable urban mobility plan, the project Yaoundé Coeur de Ville, and the MoVe project to mention a few.

This study also has several limitations. Firstly, the indicators used are transferable, context free, and applicable in different environments and were applied as initially developed without modification. However, in order to consider the specificity of Yaoundé, Cameroon, it could be interesting in future research to investigate the possibility of fine tuning the indicators according to local peculiarities. Secondly, this study focused on assessment of pedestrian facilities and did not include surveys/interviews of pedestrian in the study area, which could have provided additional information with respect to the walking experience and pedestrians' perception of their safety. Future research should consider using surveys/interviews of pedestrian and performing comparative studies between different methods to determine whether the findings are coherent or whether there exists correlation between the safety results and the specific characteristics of road segments or the demographics of road users participating to the survey. Thirdly, although the validity of the two indexes was proven for this case study, it was a relative validity and not an absolute validity. Further research could explore more absolute validity, for instance, using crash data if available. Finally, this study did not quantify the benefits of the proposed engineering measures in terms of reduction in pedestrian fatalities. Future research should consider using safety performance function and crash modification factors derived from the proposed countermeasure to predict the reduction in pedestrian fatalities.

Despite these areas of potential amelioration, the current study represents a huge and significant contribution to enhancing pedestrian safety in the city of Yaoundé, with potential transferability to other cities in Cameroon.

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