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Walkability Index for Elderly Health: A Proposal

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Abstract: Nowadays, the elderly tend to make more trips: Health benefits resulting from their daily walking routines are an important topic in the context of urban renewal processes. Many health organizations and researchers have demonstrated the influence of the urban environment on walkability levels. This article aims to design a multifactor Walkability Index for Elderly Health (WIEH), capable of associating both the adequacy level of public spaces to elderly walkability, and physical exercise benefits while walking. The methodological approach comprised two main parts: Firstly, a literature review of main reports, legislation, and scientific articles was conducted at the intersection of 'gerontology and physical exercise' with 'urban design and mobility', leading to the selection of four aging-related studies as main contributors to the design of the WIEH; and, secondly, the development of the WIEH was undertaken, based on two premises and designed according to four steps. The first premise defined three systematic areas (urban tissue, urban scene, and safety), variables, and criteria to classify the pedestrian network; and the second premise focused on slopes and stairs in public spaces. The WIEH is divided in four steps: (1) Analyzing public spaces and characterizing their quality for walking, (2) considering the existence of slopes and stairs, (3) calculating different routes for the elderly in their daily routines, or when going to points of interest, and (4) selecting the "heart-friendly route" for elderly people. Adequate walking paths for the elderly can be identified through this innovative approach, with the aim of achieving direct health benefits during their daily routines. Ultimately, the WIEH is capable of supporting decision makers and designers in creating inclusive and age-friendly spaces.

Keywords: age-friendly spaces; elderly health; physical activity; active aging; walkability combined index

1. Introduction

Nowadays, elderly people tend to travel more, for longer distances, and for various reasons [1–4]. Either as residents or as tourists, elderly people are more active, and health support has become more efficient, as have the different modes of transportation. Gradually, more policies have been taking into account the longevity of society and encouraging the autonomy and independence of older adults [5]. Thus, it is of upmost relevance to study their pedestrian mobility and how to adequately design urban spaces in order to respond to their needs. Pavement physical characteristics, gardens, sidewalks, squares, shops, and public buildings play a key role in pedestrian mobility, access to services, and elderly social involvement [6,7]. Consequently, pedestrian mobility is fundamental for active aging purposes and life quality, by enabling the elderly's social participation and autonomy. The integration of good mobility conditions and accessibility in urban public spaces is crucial in aging, so as to provide easy access to convenient services and facilitate favorable conditions for social interaction [8–10]. A lack of pedestrian mobility policies for the past decades, together with the existence of various barriers in public spaces, led to a continuous decrease of elderly people's independence. This situation seriously influences their quality of life, contributing to a diversity of issues: Depression, social isolation, reduced physical endurance, cardiovascular diseases, hypertension, musculoskeletal diseases, mental illness, blindness, and decreased vision; there is also an increased risk of falls. Together, these constitute the major causes of mortality among the elderly population [11–13]. However, personal decisions such as a change of lifestyle may delay the onset of certain diseases. Some empirical evidence shows that it is possible for health growth and positive trends to appear during the aging process [14]. Moreover, built-environment factors have been found to increase elderly walkability levels, as well as the frequency and the length of their physical activities; these factors can be as varied as high housing density, good sidewalk conditions, high intersection density, easy access to public transport, and high land-use mix. Residential neighborhoods with better walkability usually have higher levels of active commuting and physical activities, like walking and running [15,16], which lead to the mitigation of different problems (i.e., overweight, depression, alcohol and drug abuse) and contributes to increased sociability [17,18].

In recent years, due to a growing concern regarding these issues, there has been an increase in the number of studies on the quality of public space, and how it relates to elderly walkability and accessibility to services and activities. Nevertheless, no studies relate age-friendly pedestrian itineraries with the benefits of physical exercise through walking. The literature that presents the different relationships between objectively measured walkability and physical exercise among adults, and how these relate to data on common diseases, comes from the field of geriatrics and medicine [19]. Because the definitions of walkability vary, systematic literature reviews regarding the different aspects of walkability often present very mixed findings [20]. It is still rather difficult to determine a core of consensual common attributes in the study of walking [21]. Moreover, in available literature, no index combines the following three major convergent domains: Quality factors of the public space, elderly walkability characteristics, and the physical effort to attain optimal hearth rate in old age. In fact, most of the existing walkability indexes consider land mix use, accessibility (for example, number of destinations reachable on foot), street connectivity, and pedestrian infrastructure as the sole indicators of higher walkability [22]. Therefore, this study aimed to fill this research gap, by developing a multifactor Walkability Index for Elderly Health (WIEH), capable of measuring the adequacy level of public spaces for elderly walkability and connecting it to physical exercise benefits.

2. Methodological Approach

The methodology applied in this research comprised two main phases. In the first, a review (further presented in Sections 3 and 4) of main studies was conducted, including reports, legislation, and scientific papers on two main fields of knowledge: 'Gerontology and physical exercise' and 'urban design and mobility'. The second phase (in Section 5) corresponded to the development of the Walkability Index for Elderly Health (WIEH), here presented conceptually.

The literature review was conducted within three main domains: (1) Elderly walkability characteristics, (2) general qualifying factors of the public space, and (3) existing tools, selected from the literature review, which measure walkability and the quality of public spaces. Beyond the analysis of elderly walkability characteristics and the influence of related urban determinants of walkability, other factors that improve physical activity (and health) were also studied. Therefore, some walkability indicators were selected: Different gait speeds [23–25], the recommended distance between elderly people's dwellings and services [26], heart rate reference values [27,28], average step length [29,30], and average number of steps [30–32]. Nevertheless, some of these indicators—the average step length and the average number of steps—serve only as a basis for index construction, considering that they are also part of the average speed and the expected physical effort for each type of walk/activity. In what concerns public space, a set of quality indicators were selected due to their relevance in the literature review process [33–35], and subsequently aggregated into three sets of components: Urban Tissue, Urban Scene, and Safety (Table 1).

Table 1. Systematic areas and related urban variables.

	Systematic Areas	Set of Urban Variables
(1)	Urban Tissue	Pedestrian surface quality; sidewalk existence and width; traffic street intersections; existence of stairs; existence of obstacles; land mix use.
(2)	Urban Scene	Existence of trees/vegetation; existence of urban furniture.
(3)	Safety	Street lighting quality; diversity of information signs.

In order to avoid an eventual lack of objectivity when analyzing the physical urban factors that directly influence the walking patterns of elderly people, other variables lacking a consistent physical nature were not considered, such as noise, air pollution, sense of comfort/discomfort, and aesthetic issues. In fact, such variables can act as ephemeral agents in the urban environment, often depending on singular circumstances (celebrations, exhibitions, etc.); therefore, they fail to permanently influence citizens' walking patterns. It should also be mentioned that, in our study, access to public transportation was implicit in elderly people's daily routines, as was the access to public and private services, commerce, leisure areas, etc. Similarly, public transport stops and kiosks were integrated into the 'urban furniture' variable.

In the second phase, the conceptual design of the WIEH was presented based on two initial premises, and further developed in four sequential steps. The first premise included variables regarding the classification of the public space, and thus the quality of pedestrian network; the second considered the influence of slopes and existence of stairs in hindering the walking activity.

The first step—"Classifying the pedestrian network"—concerned the classification of the pedestrian network into four types, represented on a layer through the use of Geographic Information System software. The second step—"Integrating slopes and stairs"—corresponded to the classification of the pedestrian network, including the definition of criteria for slopes and stairs. The third step—"Calculating age-friendly routes"—aimed to position the elderly in relation to their most frequently attended places in their daily routines (e.g., supermarkets, churches, groceries, pharmacies, day-care centers, etc.). The fourth step—"Selecting the heart-friendly route"— which is also the most operational one, concerned the applicability of the Index in urban spaces.

As the WIEH is presented conceptually, the figures that accompany the various steps are only illustrative, simulating a real situation.

The WIEH can help decision makers and designers with finding better aging-friendly solutions for public spaces. It can also inform elderly people and social institutions on the most convenient and healthy itineraries available for the elderly's daily routines, something which it can achieve through several different means (technology devices, apps, cell phones, flyers, urban displays, screens, etc.).

To fully develop this methodology, it is important to first build an appropriate background for the issues under discussion. Therefore, the next section comprises the state of the art regarding the connection between walkability performance and elderly people's health.

3. Walkability and Elderly Physical Exercise and Health

Physical activity is important to improve the elderly's quality of life, specifically their health, function, and well-being, and, therefore, to prevent the onset of diseases [36–38]. Evidence shows that physical activity is associated with a number of positive health outcomes, such as increased longevity and decreased risks of cardiovascular disease, improved sleep quality, lower risk of hip fracture and increased bone density, reduced risk of dementia, depression, weight gain, stroke, some types of cancer (e.g., colon, breast, lung), and diabetes mellitus type 2 [37,39–44]. Due to the relevance of physical exercise on the elderly's well-being, different worldwide organizations and experts claim that an elderly person's walk should consist of approximately 30 min per day, or 150 min per week, of moderate-intensity physical activity; this is the necessary baseline to achieve the purpose of reducing chronic disease risks and improving overall health. Moreover, should chronic diseases occur, elderly people are expected to remain physically active to the extent that their clinical condition allows. This form of physical exercise can also alternate with 20 min per day of continuous, vigorous physical activity [28,31,32,42,43,45–51]. In addition, guidelines recommend 75 min per week of vigorous aerobic activity like running or playing tennis [42,48]. It is important to highlight that any physical exercise derived from daily chores (e.g., shopping, cooking, housework) is insufficient to increase heart rate [48] and achieve direct and visible health benefits; it can, nevertheless, contribute to the reduction of sedentary time [47].

Some studies have estimated the average elderly walking speed and its reduction with aging, as well as the average speed (and its reduction) by age group. In general, healthy elderly people walk on average 7000–10,000 steps per day, which is equivalent to 30 min per day of moderate to vigorous physical activity [31]. The group of older-age adults typically averages 100 steps per minute at a brisk pace (walk faster than normal) and can walk at the speed of 1.34 m/s (4.83 km/h) to 1.56 m/s (5.63 km/h) on flat paths [30,32]. The results found in existing literature are systematized in Table 2.

Table 2. Walking average speed by age group (adapted from [23–25,52].

Studies/Authors	Younger-Age Adults		Older-Age Adults	
	Age Groups	Estimated Walking Speed	Age Groups	Estimated Walking Speed
[52]	<30 30–39 40–49 50–59	1.34 m/s (4.82 km/h) 1.26 m/s (4.54 km/h) 1.26 m/s (4.54 km/h) 1.23 m/s (4.43 km/h)	Over 60	1.21 m/s (4.34 km/h)
[24]	25–34	1.25 m/s (4.5 km/h)	Over 65	0.95 m/s (3.42 km/h)
[25]	–	–	Over 65	0.80 m/s (2.88 km/h)
[23]	–	–	Over 65	0.60 m/s to 1.00 m/s (2.16 km/h to 3.6 km/h)

Table 2 shows a visible consensus between authors in what concerns the estimated walking speed for younger-age adults [24,52]. However, regarding the estimated walking speed of adults over 65, there is a discrepancy between authors, of 0.35m/s (1.26 km/h). This value excludes the study by Schimpl et al., [52], which stands apart due to their older-age threshold of 60 years of age, with an estimated value of 1.21 m/s (4.34 km/h). Yet, the aforementioned difference between the other three studies blurs when considering that Julius et al.'s (2012) estimated walking speed varied between 0.60 m/s (2.16 km/h) and 1.00 m/s (3.6 km/h). In fact, all values from the three studies fit well within this interim. Furthermore, the values presented by Schimpl et al. [52] for people over 60 are very close to those attributed by Silva, Cunha, and Silva [24] to their 25–34 age group. This discrepancy might be due to the interviewee sample obtained by Schimpl et al. [52], which possibly included very active older people.

Literature also shows that it is possible to classify the type of physical activity (moderate, vigorous) according to "heart rate" (HR) (Table 3). Moderate activities require an effort of 50 to 85% of the "heart rate maximum average" (HRMA), while vigorous activities require an effort corresponding to the maximum heart rate for that age [27,28].

From the analysis of the age limits (left column—65 years to 90 years), one can see that the expected maximum HR for people aged 65 (132 bpm) corresponds to 66% of their HRMA at moderate activity and to 77.5% of their HRMA at vigorous activity. Both values (66% and 77.5%) are well balanced regarding the correlation between the target HR zone and the HRMA (50–85% of HRMA). The same analysis can be applied to people aged 90, whose expected maximum HR corresponds to 65% of HRMA at moderate activity and to 77.5% of HRMA at vigorous activity.

Table 3. Heart rate references. Adapted from [28].

	Heart Rate (bpm)	
	Moderate Activity	**Vigorous Activity**
Age groups (years)	HR Target 50–85% of HRMA	HRMA (220 bpm-age)
65	78–132 bpm	155 bpm
70	75–128 bpm	150 bpm
75	73–123 bpm	145 bpm
80	70–119 bpm	140 bpm
85	68–115 bpm	135 bpm
90	65–111 bpm	130 bpm

(HR = heart rate; HRMA = heart rate maximum average; bpm = beat per minute).

Slope surfaces are one of the greatest challenges in walking studies for all age groups, but especially for the elderly. So far, few studies have investigated how walking on inclined surfaces influences the performance and changes the walking patterns of healthy elderly people [53–59]. Furthermore, these studies were more concerned with spatiotemporal gait parameters and energy expenditure when walking uphill and downhill [54,58] and less with direct benefits to elderly people's health. The influence of slopes and of altimetry differences on pedestrian performance is well described in the biomechanics field, starting as early as the 1960s [53]. Regarding the degree of walking difficulty, some studies refer to "oxygen consumption" as an objective indicator of the effort expended by the pedestrian while moving [60]. Other authors [61] mention "heart rate" as an indicator of walking exercise effort. In our study, this second indicator was adopted, in order to maintain the coherence between cross-sectional studies related to our objective. As for the relationship between physical effort (heart rate) and slopes in public spaces, literature also points out related values [61,62] that allow for some conclusions regarding suitable elderly walking paths. The authors analyzed the relation of the heart rate (beats per minute-bpm) with six selected types of slopes (Table 4).

Table 4. Relation between bpm and slope.

Slope—% Inclines	Heart Rate/bpm Average
5% slope * (uphill)	120 bpm
(0%) (ground flat)	105 bpm
−5% (downhill)	97 bpm
−10% (downhill)	96 bpm
−15% (downhill)	100 bpm
−20% (downhill)	105 bpm

* Maximum acceptable walking slope [62].

Downhill walking effort is, as expected, significantly less than walking upwards on a steep slope street. In the 1990s, Kawamura et al. (1991) concluded that at 12 degrees (21.2%), the product of step length and cadence (step/minute) decreased significantly for both upslope and downslope walking. Table 4 shows that between the maximum incline (5% slope uphill, corresponding to 2.86 degrees uphill) and the minimum incline (−20% downhill) there is a large difference in terms of heart beats per minute (15 bpm). Recent legislation and manuals of good practices present some recommendations regarding public space. Based on Portuguese legislation [63] and on the recommendations of the Portuguese Institute for Mobility and Land Transports [62,64], three types of walking inclines were adopted:

- <5%—Suitable
- 5% $< x <$ 8%—Acceptable
- >8%—Inappropriate

Up to 5% of inclination, elderly people are not expected to overly exert themselves. Their physical effort should, in fact, parallel a moderate activity (120 bpm, according to Table 3). Therefore, the 5% threshold represents the maximum incline that can be considered suitable not only for all-inclusive elderly walkability, but also for people of all age groups with reduced mobility. In addition, inclines between 5% and 8% can still be considered acceptable for elderly individuals. Inclines over 8% are considered steep slopes that require the highest level of physical effort and, consequently, a significant increase in heart rate and muscle fatigue. Also, on higher inclines, pedestrian security decreases. Evidence shows that, during inclined walking, a significant decrease occurs in mean step length, mean cadence, and mean normalized speed [54,58].

Public ramps and stairs are not an equivalent challenge for the elderly. Nevertheless, depending on their nature and maintenance conditions, they can be a good stimulating exercise even for the older-adult age groups, especially when associated with other motivators (urban landscape, views, historic itineraries, etc.). While the difficulty of inclined surfaces depends on their declivity degree, the same is not true for stairs. At a normal pace, stairs are rather taxing to the elderly; however, at a slow and steady pace, they can transform into a health asset. Opting for stairs or inclined surfaces should be encouraged when the elderly individual is capable of it, in cases where public space offers good physical and visual security conditions.

Concerning the elderly's stride, some authors have long been studying the importance of step length for walking performance [29,30,58,59]. Step length differs between women and men and naturally decreases with age and the type of walking pace. Öberg et al. [29] calculated step length by gender, age group, and type of walking speed (slow, normal, or fast gait) (Table 5).

Table 5. Step-length average by gender, age group, and gait.Adapted from [29].

Age Group	Female			Male		
	Slow Gait	Normal Gait	Fast Gait	Slow Gait	Normal Gait	Fast Gait
60–69	47.5 cm	55.3 cm	62.5 cm	56 cm	65 cm	73.6 cm
70–79	47.1 cm	54.2 cm	60.4 cm	52.7 cm	61.5 cm	71.5 cm

According to Hollman et al. [30], on a walkable flat surface, 57 cm is the average women's step length and 66 cm is the average men's step length [30]; these values do not deviate from Öberg et al.'s [29] report on normal gait. Given the purpose of our study—mapping friendly walking routes for elderly people that can be linked to their physical exercise—we only considered an average step length comprising both gender's averages, a more practical standard that is also of easier use for mapping interpretation. Therefore, the adopted average steps lengths are:

(1) Age group 60–69 = 51.8 cm—Slow gait; 60.2 cm—Normal gait; 68 cm—Fast gait.
(2) Age group 70–79 = 50.1 cm—Slow gait; 57.9 cm—Normal gait; 66 cm—Fast gait.

Another important factor that influences elderly daily walkability is the location of basic services (e.g., post offices, grocery stores, etc.) [65,66]. These services should be located within 400 m of elderly people's residences, which corresponds to a 5-min walking distance. Secondary services should be located within 800 m [65,66] or twice the walking distance when compared to the first group. A good understanding of travel patterns, needs, and factors that influence elderly mobility is necessary, so as to enable an active aging life and, consequently, to maintain an active economic and social participation.

Burton and Mitchell [26] argue that the maximum comfortable walking distance is 500 m, from the elderly person's house to available primary services, warning that elderly people can take twice the walking time when compared with younger adults. Based on the fact that elderly people also need to reach secondary services during their daily routines, which might be located further than the 800 m previously mentioned, distances above 800 m are also considered important in this study for investigating and mapping feasible distance-walking routes which favor 30 min of physical exercise.

In this context, four levels of physical exercise were defined: (1) Not Considered Physical Exercise, (2) Very Light Physical Activity, (3) Moderate Physical Activity, and (4) Vigorous Physical Activity. Also, four different types of speed were defined for elderly walking routines: (1) Low walking speed, (2) normal walking speed, (3) fast walking speed, and (4) running speed. These are presented in Figure 1, for a walking distance of 500 m.

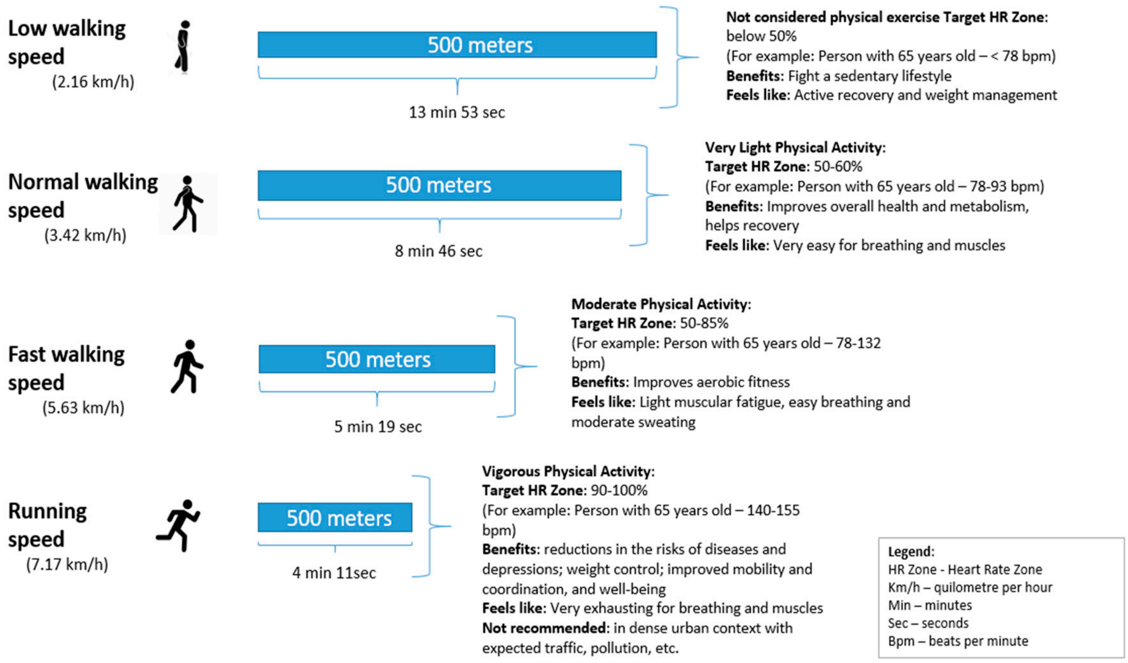


Figure 1. Correlation between different levels of physical exercise, walking speed, and 500-m walking time.

At low walking speed, for elderly people to walk 500 m at 0.60 m/s (2.16 km/h), approximately 13 min and 53 s will be necessary. In the literature, it is reported that this walking mode is not considered effective physical exercise, since it does induce an increase of the heartbeat. However, as mentioned in the "walkability and elderly health" section, this (more common) activity mode at least counters a sedentary lifestyle, helping in maintaining light activity and weight control. At normal walking speed, an elderly person walks at 0.95 m/s (3.42 km/h) on average and would take 8 min and 46 s to cover the same distance (500 m). This speed mode requires some physical effort and is expected to increase the heart rate of an elderly person, from 50% to 60% of the maximum heart rate, thus being considered light physical exercise. In addition to countering physical inactivity and weight control, this walking mode presents other benefits, allowing elderly people to achieve general improvements in their health status as well as a metabolic balance, and aiding specifically in physical recovery (especially regarding muscle damage). At a fast walking speed (accelerated pace), 5 min and 19 s are needed for an elderly person to walk 500 m at 1.56 m/s (5.63 km/h), on average. This walking mode is more accelerated than normal and not all elderly people can achieve it; it can even be considered a moderate-intensity form of exercise. This mode forces greater muscle fatigue and better breathing control, with elderly people being expected to reach 50% to 85% of their maximum heart rate. One major benefit of this type of exercise is that it can improve individuals' aerobic capacity and, consequently, burn fat tissue. Finally, only elderly people who remain active through a continuous and consistent physical exercise practice are expected to reach the level of effort needed for running speed, which is 1.99 m/s (7.17 km/h) on average. To travel this distance (500 m) at this speed, it would take about 4 min and 11 s, with the elderly person being expected to reach 90% to 100% of their maximum heart rate. Relevant benefits of running are related to aerobic resistance growth, the decrease of risk probability of diseases and mental illnesses (i.e., depression), weight control, better motor coordination, and well-being improvement.

It is urgent to rethink concepts of mobility and "specifically, planned and implemented in a more sustainable, inclusive and integrated manner than has been the case until now" [67] (p. 5). One of the reasons for the lack of inclusiveness (e.g., spaces that can be used by all age groups, genders, (dis)abilities, and ethnicities) is that mobility studies have always paid more attention to utilitarian walking than to recreational walking [68]. The elderly population has specific travel needs, and it is up to urban planners, transportation experts, and public health experts to assist and enable their active life. The importance of "walkable urban environments" must be reflected on these professionals' agendas, as planning for health is one of the growing concerns of the last decades [37,69–71]. Planners must consider opportunities for inclusiveness, such as the concept of promoting a pleasant extension of domestic sociability between neighboring families [70]. Walkable and age-friendly neighborhoods are critical factors of the active aging process, by way of allowing the integration of physical activity into daily routines and fostering social connections [7,72,73]. Therefore, green spaces, well-designed and safe streets and sidewalks, accessible walking paths, crosswalks, and cycle paths are fundamental for social interaction support and elderly people's health conditions' improvement.

In the following section, a selective synthesis of the literature review is presented, enhancing the results compiled from studies that refer to different walkability indexes, with a focus on the correspondence between walkability and elderly quality of life.

4. Walkability Indexes—A Literature Review

Literature reveals potential conflicts been forms of walkability [20]. According to this author, it is considered that walkability promotes liveliness, sustainable transport options, or exercise. Moreover, it is broadly considered to be centered on good urban design, either because it is multidimensional and measurable or a holistic solution to several human problems. For example, criticism of the walkable neighborhood often comes from those who see it as distracting from more urgent needs, especially affordable housing [74]. Originally based on the categorization of keywords of 45 referenced manuscripts, academics point out the "walking phenomenon" as a key element of Pedestrian Profile, Pedestrian Activity, and Pedestrian Environment—PLACE: Profile, Activity, and Environment [21]. According to Sing [75], evidence shows that face-to-face human interactions in a neighborhood are substantially relevant for supporting livability, economic development, safety and control, civic participation, and identity [76–79]. Other researchers focus their research on the observation of citizens in real-life situations, to determine how the built, urban environment impacts social wellness [80–83]. Consequently, the results of these studies have been leading designers and policy makers to rethink the impact of their plans upon their citizens' real life [75]. Direct observation of real-life situations was not an objective of this study, but its implementation is expected to be part of further works related to our study area.

For the development of this study, investigating whether available literature already possesses some aging-related indexes or tools was a priority, specifically in what concerns the relationship between walking and elderly health. Table 6 presents a selection of the most incisive publications on walkability issues and on older adults' health, aggregated into three major multi-factor domains: "Accessibility", "Urban Design/Walkability", and "Physical Activity and Well-being/Health".

In what concerns the quality of urban public space, four articles refer indexes/tools [15,33–35] that are similar to the Walkability Index for Elderly Health proposed in this study. These four articles highlight key factors, such as walkability and accessibility, that constitute important quality indicators for public spaces. The first one, the Walkability Index (WAI) applied by Reyer et al. [15], was developed by Frank et al. [84] in order to calculate walkability in the context of the International Physical Activity and the Environment Network (IPEN). The WAI is the result of a combination of multiple criteria that measure aspects of walkability, such as the "connectivity index" (also known as intersection density—the index measures the number of walkable road intersections per square kilometer) and "Shannon's entropy index" (a well-known diversity index from ecological literature, originally proposed by Claude Shannon to quantify uncertainty—entropy or degree of surprise—but that quantifies the level of mixed land uses within an area instead). It explains that for a higher mix of land uses, more destinations can be reached by foot, thus making the area more walkable. In its structure, the WAI incorporates two indicators/indexes, the "floor area ratio" and the "household density index". The floor area ratio relates to the intensity of shopping opportunities in a specific area, not only in terms of commercial land use, but also in terms of available retail floor area. If there are high levels of retail floor space in a commercial zone, more pedestrian-friendly shopping opportunities can be expected. The household density index divides the number of households by "living", a land-use category. Higher density values are assumed to be more pedestrian-friendly than lower density values [15]. The WAI final score is a simple aggregation of these indicators, with a double weighting for the connectivity index. However, authors consider that the WAI produces plausible results in terms of the variation of high and low walkability levels throughout the city, and successfully captures variations of the urban form seemingly relevant to walkability. Nevertheless, this methodological approach reveals some weaknesses in its generalization of land-use classes for the land-use mix, as measured by Shannon's entropy index [15] Due to this WAI difficulty, authors used another tool to measure walking friendliness, based on the proximity of important daily life amenities to specific addresses—the Walk Score. This digital platform, composed of two modalities, website and mobile application, can be used for USA, Canada, Australia, and New Zealand addresses [15,85]. The Walk Score app measures the walkability on a scale from 0–100, based on walking routes to destinations [85]. A range of different data products and information are available when accessing and using Walk Score services (e.g., pedestrian-friendliness routes, transit score, bike score, etc.). Data collected by the Walk Score platform can be tracked over time to measure historical trends; for example, it is able to track the percentage of residents in a city area who can walk to the grocery store in 5 min [85]. Thus, it allows us to evaluate residents' behavior and to think of strategic ways to mitigate eventual public space barriers, which can lead to citizens' reduced mobility.

Another instrument specifically focused on the relation between the urban built environment and adult physical activity was developed in 2014, by Su et al., [33] the China Urban Built Environment Scan Tool (CUBEST). This tool was designed based on a review of existing reliable instruments: Analytic Audit Tool, Active Neighborhood Checklist, Systematic Social Observation (SSO), PIN3 (Pregnancy, Infection and Nutrition) from Neighborhood Audit Tool, Irvine—Minnesota Inventory, Neighborhood Active Living Potential (NALP), Environment in Asian Scan Tool – Hong Kong (EAST_HK), Systematic Pedestrian and Cycling Environment Scan (SPACES), Pedestrian Environment Data Scan (PEDS), Walking/Bicycling Suitability Assessment Form (WABSA), Sidewalk Assessment Tool, and Physical Activity Resource Assessment Instrument (PARA). Furthermore, the CUBEST contemplates six combined factors: (1) Residential density, (2) street connectivity, (3) accessibility (land-use mix), (4) sidewalk quality, (5) bike-lane quality, and (6) aesthetic. Although the CUBEST was designed to analyze a Hangzhou case study, with suitable modifications it can be applied to the study of other worldwide cities.

Table 6. Review of three major multi-factor domains and related results.

Domains	Reference	Subject	Results
Accessibility	[86]	Accessibility to certain facilities, through the construction of two indicators: the percentage of citizens living in the surrounding facilities/services and the percentage of buildings that exist in these areas. Case study: Faro (Portugal)	The results indicate a trend towards an effective urbanism of proximity that can be boosted at the future location of new services. Available indicators also provide an important contribution to municipal management, through the definition of structural pedestrian infrastructures in the city.
	[87]	Review of the quantitative and qualitative aspects relevant for accessibility metrics and empirical studies addressing these aspects in relation to health. No case studies	Studies comparing different types of green space indicators suggest that cumulative opportunity indicators are more consistently and positively related to health than residential proximity ones. In contrast to residential proximity indicators, cumulative opportunity indicators take all the green space within a certain distance into account.
	Higgs, C., Badland, H., Simons, K., [88]	Combination of policy-relevant liveability indicators associated with health into a spatial Urban Liveability Index (ULI), examining its association with adult travel behaviours. Case study: Melbourne (Australia)	Urban Liveability Index (ULI) scores were positively associated with active transport behaviour: for each unit increase in the ULI score the estimated adjusted odds ratio for: walking increased by 12%; cycling increased by 10%; public transport increased by 15%; and private vehicle transport decreased by 12%.
Urban Design/Walkability	[20]	Review of English-language literature on walkability—from research, practice, and popular discussions. The review highlights potential conflicts between forms of walkability. The term is used to refer to significantly different kinds of phenomena. It clarifies different types of walkability, focusing on the implications of these definitions for urban design and planning.	Significant conclusions derived from a better definition of walkability: (i) walkable environments are not all the same; (ii) biases and assumptions undermine some popular definitions of walkability; (iii) walkable environments for transportation and recreation purposes sometimes overlap, but often do not; (iv) while walkability can be defined in multiple ways, it is broadly considered to be about good design.
	[81,82]	Observation of people in real-life situations, to determine how the built environment impacts social wellness.	Important principles to help guide designers in rethinking the impact of their plans on real life.
	[21]	Extensive literature review on the contribution of walking to sustainable urban development.	Identification of the walking phenomenon as a key-element of Pedestrian Profile, Pedestrian Activity, and Pedestrian Environment - PLACE.
	[89]	Comprehensive and objective measurement of the subjective qualities of the urban street environment.	Urban design can explain variation in walking behaviour that urban form cannot. Observational measures are used to validate digital measures, which make it possible to study the relationship between urban design and physical activity.
	[15]	Verification of whether the methods used in the US to measure the suitability of built environments for walking and cycling can be applied in a European context. Case study: Stuttgart (Germany)	A noticeable relationship between walkability and active transportation was found – the more walkable an area was, the more active residents were.
	[90]	Definition of a city's walkability assessment framework capable of highlighting points of strength and weakness in its urban environment. Case study: Milan (Italy)	Design recommendations to make specific evidence-based choices, and to understand what aspects of the urban environment must be improved or implemented to promote a walkable city.

Table 6. *Cont.*

Domains	Reference	Subject	Results
	[22]	Discrepancies within the use of survey data on pedestrian behaviour; a variety of GIS–derived land use and built environment measures of neighbourhoods; and socioeconomic characteristics obtained from the 2011 National Household Survey. Case study: Montreal (Quebec, Canada).	Some neighbourhoods with higher walking rates are characterized by a lower presence of parking lots and setbacks, and a greater proportion of on-street tree canopy. Linear regressions predicting walking rates confirm these associations, after adjusting for Walk Score and neighbourhood socioeconomic characteristics.
	[42]	Cross-sectional associations between neighbourhood walkability, crime and physical activity, depending on age and sex of residents. Case study: Hill District and Homewood (Pittsburgh, USA)	Neighbourhood walkability may play a stronger role in Moderate-Vigorous Physical Activity than accessible greenspace or crime in low-income urban communities. Walkability may differentially impact residents depending on their age and sex, which suggests tailoring public health policy design and implementation according to neighbourhood demographics to improve activity for all.
	[91]	Review of Australian state-level planning policies and standards for public open spaces, including policy-specific spatial measures generated in GIS. Case study: Australia context	Findings support existing literature, indicating that neighbourhoods with greater access to public open spaces (within 400 meters) are associated with higher odds of physical activity.
	[92]	Examination of associations of policy-derived urban design and empirical measures of POS proximity and density with walking and depression. Case study: Australia context	There are complexities in devising and delivering policies that promote health and wellbeing. However, the findings highlight the importance of identifying and testing spatial measures for public open spaces that are associated with health behaviours and outcomes in different contexts. This type of evidence is required to refine and strengthen implementation science related to (re)designing public open spaces, to better support population health outcomes.
	[38]	Use of an online participatory mapping method and a novel modelling of individual activity spaces to study the associations between both environmental and individual features and older adults' walking, in environments where older adults move. Case study: Helsinki Metropolitan Area	Walkway density, residential density, connectivity, and the density of recreational sport places within respondents' home ranges had an independent effect on older adults' walking. Residential and public transit stop density affects the motivation of the elderly to walk. Well-connected streets/different destinations may encourage the walking behaviour, even among those who are not very interest in physical activities. Personal goals related to physical activity also had a direct positive effect on walking. Additionally, an indirect effect of gender and of perceived health on walking was found.
	[44]	Exploration of three hypotheses: (1) trip purpose as an independent correlate of utilitarian walking; (2) associations between environmental attributes surrounding participants' destinations and walking; (3) association between the distance travelled and walking. Case study: Luxembourg	Trip purposes based on free-time activities – including visits to family and friends, and restaurants and cafés – seem to be less influenced by the barrier effect of distance on walking.

Table 6. *Cont.*

Domains	Reference	Subject	Results
	[35]	Development of the Walkability City Tool, in response to a need stemming from the lack of compiled, precise, objective information on the walkable network for making strategic urban decisions that affect pedestrian mobility. Case study: Financial District of Panama City	Walkability City Tool examines the studied factors via five topics: Modal Distribution - division of space between the different means of transportation; Urban Grid - characteristics of the sidewalks; Urban Scene - information on the environment around us as we walk; Safety - perception of safety when walking; and Environment - factors that influence walkers.
	[16]	Investigation of the influence of street greenery and walkability on body mass index. Case study: Cleveland (Ohio, USA)	The study found that associations between body mass index (BMI), Walk Score (WS) and Green View Index (GVI) vary among different age-gender groups. WS has a more significant association with decreased BMI for males over females. GVI has a more significant association with decreased BMI for females than males (in middle-aged and retiree groups). Urban greenery has a stronger correlation with BMI for females rather than males.
	[33]	Development of an urban built environment evaluation tool, with necessary reliability and validity tests being conducted. Case study: Hangzhou (China)	CUBEST was developed: a reliable and valid instrument that can be used to assess the physical activity-related built environment in Hangzhou, and potentially other cities in China.
	[34]	Development of an alternative walking index, the Quality of Pedestrian Level of Service (Q-PLOS) method. Case study: Metropolitan Area of Granada (Spain)	The Q-PLOS enabled a more detailed identification of characteristics related to pedestrian mobility, showing that they can be improved through mobility strategies of urban design, such as pedestrian continuity and connectivity of green spaces.
Physical Activity and Well-being/Health	[93]	Assessment of both the quantity and quality of street greenery, associating them with the recreational physical activity occurring in green outdoor environments, for 1390 participants in 24 housing units. Case study: Hong Kong (China)	There was a demonstration of the benefit of using Google Street View for health and physical activity studies. The study provides findings to recognize the impacts of environmental factors on residents' physical activity, hence contributing to targeted intervention strategies for creating activity-friendly urban design.
	[71]	Lessons on how the neighbourhood built environment may affect one aspect – specifically, happiness – of residents' wellbeing. No case studies	The authors draw lessons from a cross-disciplinary set of studies to reveal how the neighbourhood built environment may affect one aspect of residents' wellbeing: happiness. Providing residents with access to open, natural, and green spaces may directly increase their happiness. Incorporating design features that allow for social interaction and safety may also promote residents' happiness.
	[94]	Visitors' perceptions and activities in protected areas. Case study: Barcelona (Spain)	The majority of surveyed park visitors reported that physical health was an important motivation for visiting parks; a perceived improvement in their physical health was reported. The most physically-active recreation activities were more practiced by younger people. Nearby residents and visitors reported high levels of perceived physical health, motivation for visiting, and impact of that visit.
	[95]	In-depth characterization of a neighbourhood's social and physical environment, in relation to cardiovascular health. Case study: Madrid (Spain)	This experience led to the testing and refining of measurement tools, drawn from epidemiology, geography, sociology, and anthropology, in order to better understand the urban environment in relation to cardiovascular health.

Talavera-Garcia and Soria-Lara [34] developed the Quality of Pedestrian Level of Service (Q. PLOS) method, which aims to evaluate the quality of urban design for pedestrians and its relationship with walking needs. It is used to evaluate three parameters: (1) Pedestrian environments, through the use of urban design indicators related to walking needs, (2) a simple comparison between different case studies, through the definition of quality thresholds, and (3) an output that can be simultaneously presented as an aggregated result and as separate factors. According to walking needs, the authors selected pedestrian factors based on their literature review, namely, accessibility, security, comfort, and attractiveness. Also, five urban design indicators were chosen: Connectivity, pavement width, traffic speed, tree density, and commercial density. The concept of "thresholds" was defined, based on academic references from urban design handbooks and good practice guidelines [34]. The last of the previously mentioned parameters—the output that is simultaneously presented as an aggregated result and as separate factors—addresses the aggregation of quality values obtained in the previous stage for each urban design factor. While the results of each indicator can be shown through separate quality levels, the aggregation of these results into one image pertaining to quality level could provide a global perspective, in order to better compare different mobility environments [34].

Finally, Aranoa et al. [35] used sidewalks as a working base to develop the Walkability City Tool (WCT) and divided the information into five thematic areas: Modal distribution, urban tissue, urban scene, safety, and environment. Cumulatively, the authors also analyzed crosswalks, according to three different perspectives: Delay (the time a person takes to cross a sidewalk), safety, and accessibility. Based on their fieldwork, the authors assigned a classification value to each stretch of sidewalk. Later, by using a geographic information system whose base was developed by the Massachusetts Institute of Technology and applying its calculations to the flow between nodes, the authors undertook a range of different analyses, such as heat maps to assess streets, dysfunctions in the network, and black spots.

Based on these four articles, a list of public space-quality factors to analyze different research areas was built. The next section presents this list and explains the index construction method, step by step.

5. The Conceptual Design of the WIEH

The conceptual design of the Index comprised two initial premises. The first included variables regarding the classification of the public space and, consequently, the pedestrian network; the second focused on the influence that slopes and stairs exert on the walking activity. The WIEH builds on these premises, as shown in Figure 2.

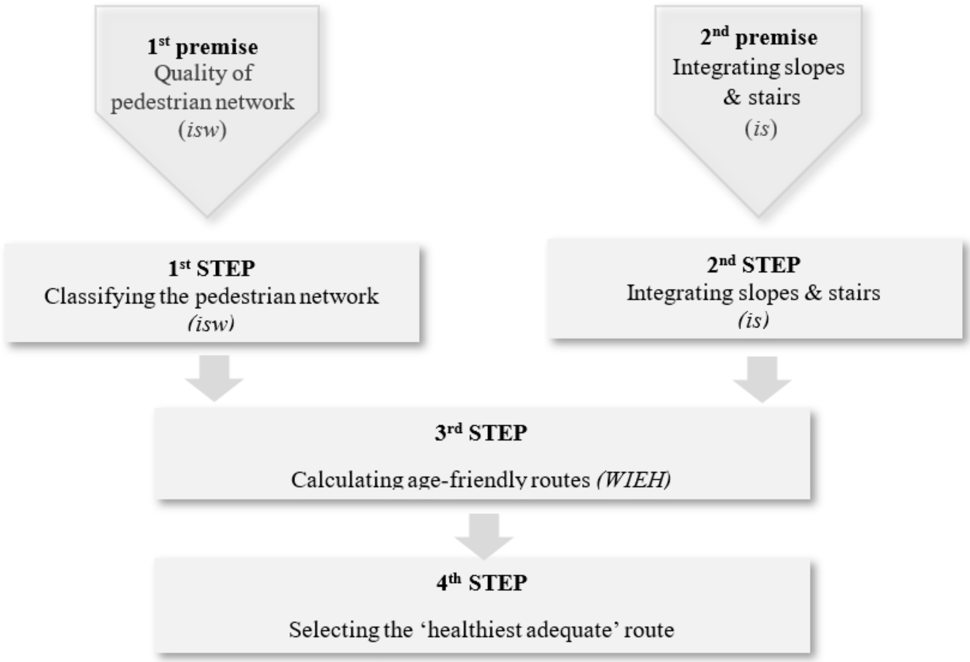


Figure 2. WIEH conceptual design.

5.1. First Premise: Definition of Variables and Criteria to Classify the Pedestrian Network

As referred in the previous section, the qualifying factors of public space, obtained from the literature review, were divided into three systematic areas: Urban tissue, urban scene, and safety. Considering that the target was the analysis of space-walkability conditions, the selection of these three systematic areas sustains a complete and effective public-space analysis, through the evaluation of the corresponding variables. For each of the three systematic areas, a set of variables were defined for analysis. Then, a range of values (0–3) was assigned to these variables (Table 7).

Using the table above, the construction of a preliminary index exclusively assigned to public-space conditions was possible: The "isw"—"index of space suitability for walking". The weight distribution took into consideration the levels of importance of the different variables regarding walkable suitability of public space. For instance, the shadow of trees can play an important role when walking during hot days, but their absence does not imply a *decrease* of walking security. The next formula explains the index calculation:

$$\text{isw} = \text{Urban tissue variables} \times 60\% + \text{Urban scene variables} \times 16\% + \text{Safety variables} \times 24\%$$

$$\text{isw} = (\text{PQS} \times 0.08 + \text{SE} \times 0.06 + \text{SW} \times 0.06 + \text{TSI} \times 0{,}12 + \text{EoS} \times 0.08 + \text{EoO} \times 0.12 + \text{LUM} \times 0.08) + (\text{ETV} + \text{EUP}) \times 0.08 + (\text{SLQ} + \text{DIS}) \times 0.12)$$

Table 7. Systematic areas, corresponding variables, and criteria to classify the pedestrian network.

<table>
<tr><th rowspan="2">Systematic Areas</th><th rowspan="2" colspan="2">Variables</th><th colspan="3">Weight (%)</th><th rowspan="2">Criteria to Classify the Pedestrian Network</th></tr>
<tr><th colspan="2">Partial Weight</th><th>Total Weight</th></tr>
<tr><td rowspan="7">1. Urban Tissue</td><td colspan="2">Pedestrian surface quality (PSQ)</td><td colspan="2">8</td><td rowspan="7">60</td><td>1 = bad
2 = acceptable
3 = good</td></tr>
<tr><td rowspan="2">Sidewalks existence and width (SEW) (Average of SE and SW)</td><td>Sidewalks existence (SE)</td><td>6</td><td rowspan="2">12</td><td>1 = none
1.5 = one side partial or both sides partial
2 = one side continuous
2.5 = one side continuous and one side partial
3 = both sides continuous</td></tr>
<tr><td>Sidewalks width (SW)</td><td>6</td><td>1—SW < 0.90 m
1.5—0.90 m ≤ SW < 1.20 m
2—1.20 m ≤ SW < 1.50 m
2.5—1.50 m ≤ SW < 1.80 m
3 - SW ≥ 1.80 m</td></tr>
<tr><td colspan="2">Traffic street intersections (TSI)</td><td colspan="2">12</td><td>1—>3
2—1 or 2
3—no intersections</td></tr>
<tr><td colspan="2">Existence of stairs (EoS) (note: stairs are only considered when there are more than 3 steps)</td><td colspan="2">8</td><td>1—>3 stairs
2—1 or 2 stairs
3—no stairs</td></tr>
<tr><td colspan="2">Existence of obstacles (EoO)</td><td colspan="2">12</td><td>1 = systematically affects walking
2 = occasionally affects walking
3 = no obstacles</td></tr>
<tr><td colspan="2">Land use mix (LUM)</td><td colspan="2">8</td><td>1 = no land use mix
2 = medium land use mix (at least 2 different uses)
3 = high land use mix (3 or more different uses)</td></tr>
<tr><td rowspan="2">2. Urban Scene</td><td colspan="2">Existence of trees/vegetation (ETV)</td><td colspan="2">8</td><td rowspan="2">16</td><td>1 = no trees/vegetation
2 = moderate existence of trees/vegetation
3 = strong existence of trees/vegetation</td></tr>
<tr><td colspan="2">Existence of urban furniture (EUF)</td><td colspan="2">8</td><td>1 = no urban furniture
2 = moderate existence of urban furniture
3 = strong existence of urban furniture</td></tr>
<tr><td rowspan="2">3. Safety</td><td colspan="2">Street lighting quality (SLQ)</td><td colspan="2">12</td><td rowspan="2">24</td><td>1 = bad
2 = acceptable
3 = good</td></tr>
<tr><td colspan="2">Diversity of information signs (DIS)</td><td colspan="2">12</td><td>1 = low
2 = medium
3 = high</td></tr>
</table>

Thus, isw varies between 1 and 3; for each range of index values, an easy-to-interpret color is assigned in Table 8:

Table 8. Index results of the index of space suitability for walking (isw).

Index Values (isw)	Result
1–1.5	not suitable
1.5–2	less suitable
2–2.5	suitable
2.5–3	most suitable

Therefore, the results of the index calculation will vary between "1"/"not suitable for walking" (the worst case, generally assigned to neglected public spaces, with low quality and no security) and "3"/"most suitable for walking" (the best case, pertaining to public spaces with the best walkability conditions for elderly people, e.g., the best pedestrian networks).

5.2. Second Premise: Integrating Slopes and Stairs

Based on Table 4 [61,62], it is possible to establish a connection between inclines and the type of physical effort (data presented for the elderly's heart rate indicator) needed to cover them (premise 2), therefore providing us with detailed information regarding the elderly's path choices. Considering the three types of inclined walking surfaces adopted in our methodology [62–64], it was possible to attribute a heart rate average to different sets of slopes.

(1) "Suitable slopes" (≤5%): HR of 120 bpm, representing 55% of the recommended HRMA; this fits the moderate activity classification, as the value is within 50–85% of HRMA (Table 3).
(2) "Acceptable slopes" (>5% and ≤8%): It is expected that the HR will always remain under 85% (the maximum recommended percentage of the HRMA), even with this minor increase, from 5% to 8%. Thus, these slopes induce a moderate level of activity. Moreover, as mentioned before, evidence shows that the product of step length and cadence starts decreasing significantly between 15.8% and 21.2% inclines, in both upwards and downwards walking [59]. As our "suitable slopes" remain under these percentages, all the HR averages are expected to match the recommended values. Subsequent studies did not contradict Kawamura's findings [53,58].
(3) "Steep slopes" (>8%): These slopes are not recommended for elderly walking.

As mentioned in the "Walkability and elderly health" section, stairs are part of the analysis of spaces, but are not necessarily considered an obstacle to walking. Thus, the three classes of slopes are combined with the (in)existence of stairs in order to calculate "is", index of slopes & stairs.

Should the "is" equal 4 for a certain route, then said route should be excluded from the walking network.

5.3. Calculating WIEH—Walkability Index for Elderly Health

Based on the three premises developed until this point, it is possible to present a final formula to calculate the WIEH:

$$\text{WIEH} = \frac{\text{isw}}{\text{is}}$$

with "is" being the slope level (%) attributed to each space (street, square, other) and varying from "1" (flat ground) to "4" (inclines over 8%). It should be noted that stairs are not considered inclined spaces. In fact, the WIEH starts from the preliminary index (the isw-space suitability index for walking), but at this stage it also integrates the classification of existing slopes, thus allowing us to define a final classification of the suitability of walking paths.

The methodological procedure to apply the WIEH includes four main steps, based on both mentioned premises, as described below.

5.4. First Step—Classifying the Pedestrian Network

The quality factors of the public space mentioned in the first premise were used, in this step, to classify a pedestrian network into four types (see Table 8) and then represented on a layer through the use of GIS software. The values vary between 1 (the worst case, not suitable for elderly walkability) and 3 (the best case, presenting the most suitable conditions for elderly walkability). For the sake of clarity, an abstract urban grid was used (Figures 3–5). The four levels allowed us to understand the adequacy of the public space for elderly walkability.

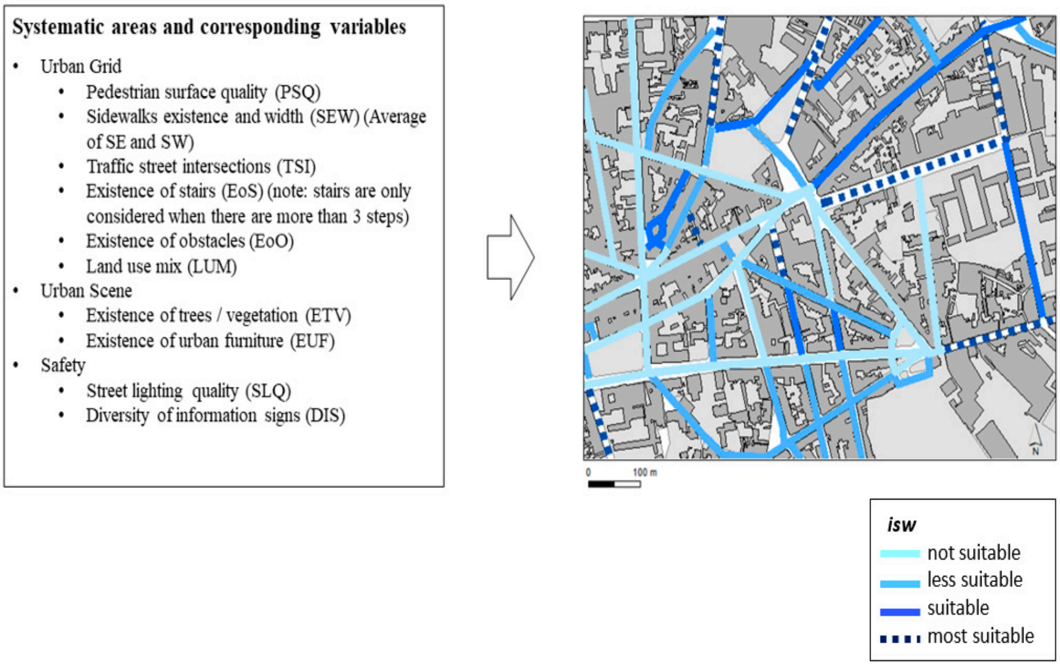


Figure 3. Pedestrian characterization according to the quality factors of public space.

However, keeping in mind that steep slopes and large numbers of steps are not recommended, all sections with ***is*** equal to 4 were excluded from the final map.

This step allowed us to exclude segments of the pedestrian network with no quality and adequacy for the elderly. In other words, those whose value equaled 1. Thus, the main output of this step was to classify the suitability of the pedestrian network for elderly walking.

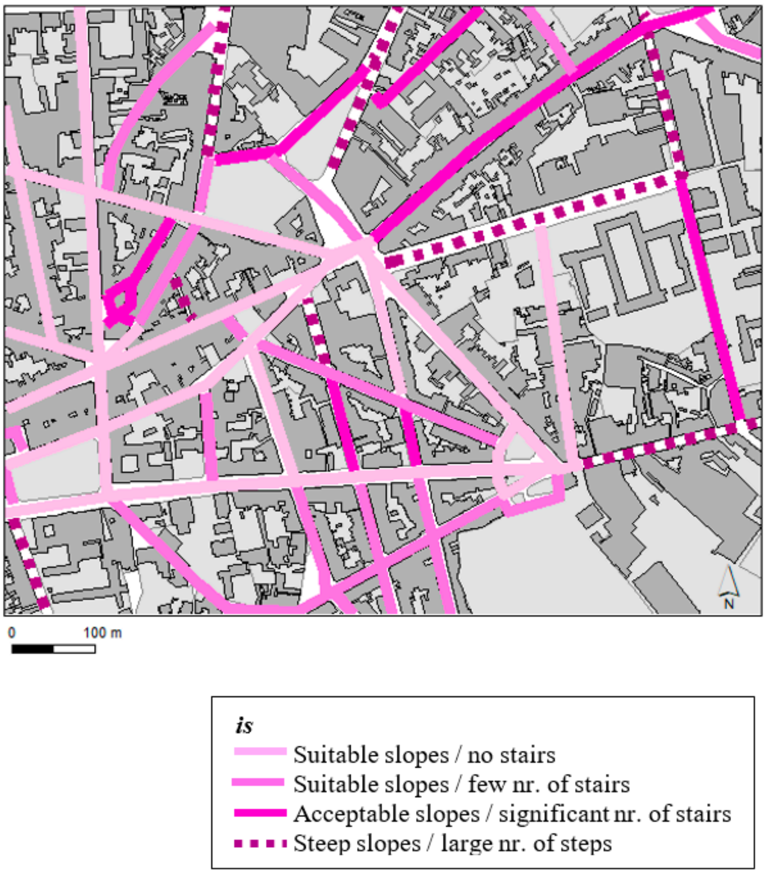
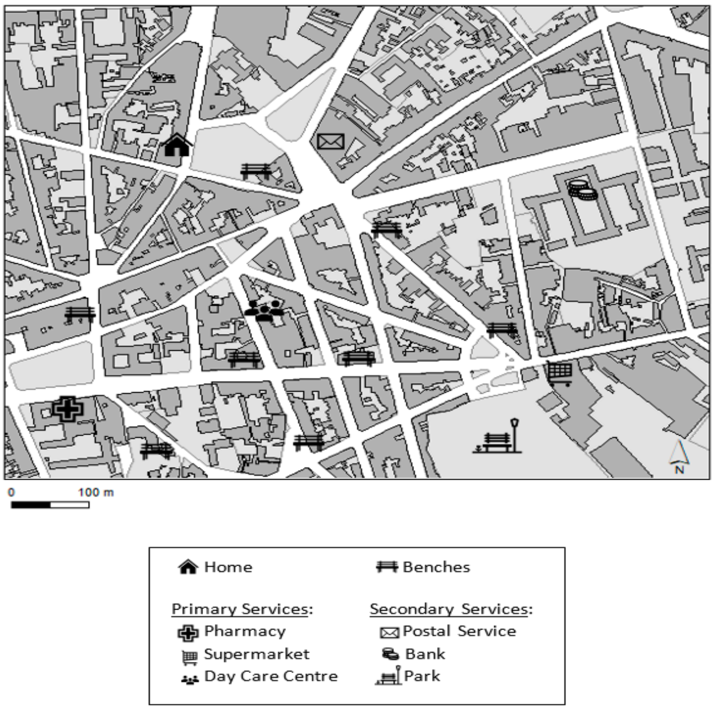
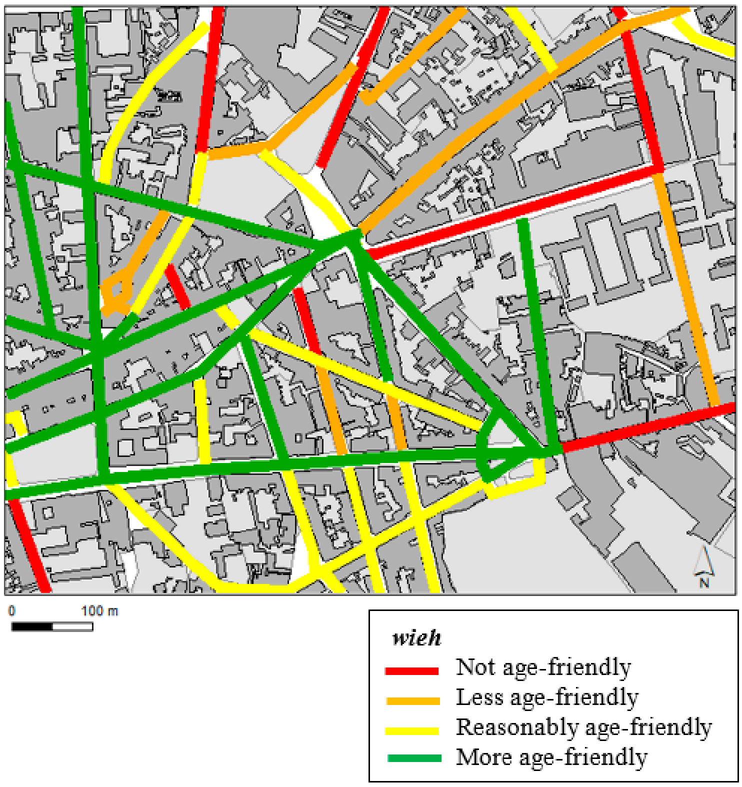


Figure 4. Pedestrian characterization according to slopes and existence of stairs.

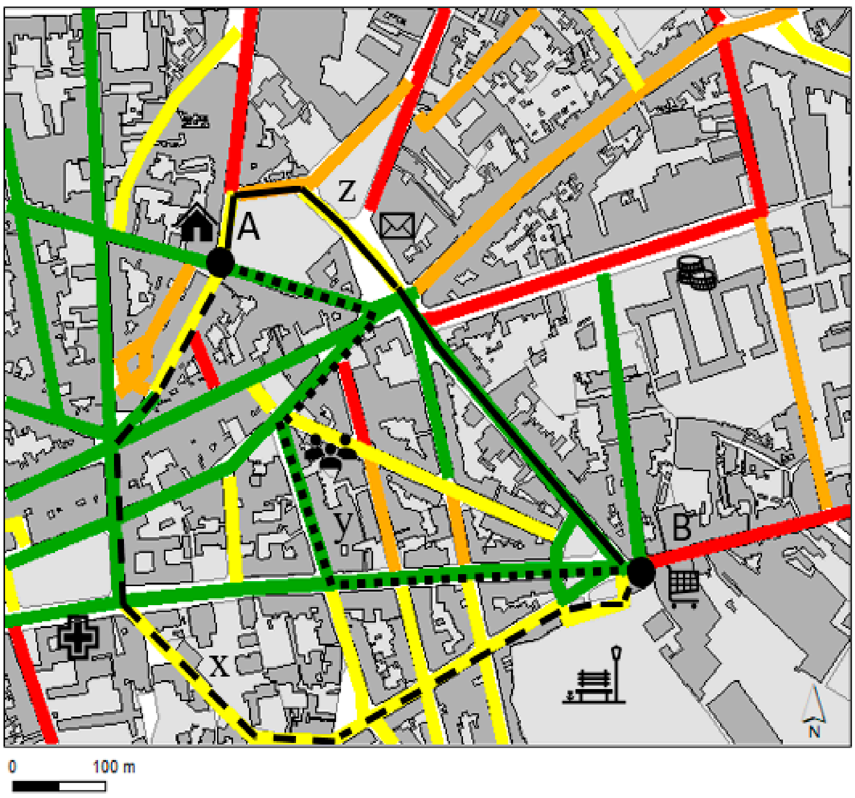


(**a**)

Figure 5. *Cont.*



(**b**)



(**c**)

Figure 5. (**a**) Identifying destinations, (**b**) calculating the WIEH, (**c**) mapping alternative routes from origin A (home) to destination B (e.g., supermarket).

5.5. Second Step—Integrating Slopes and Stairs

This second step comprised the classification of each section of the pedestrian network according to Table 9, which defines the criteria for slopes and stairs. This ranking index, "is", uses discrete values varying between 1 and 4.

Table 9. Index results for "is".

Index Values (*is*)	Slopes (sl)		Stairs	Result
1	Suitable slopes	<5%	No stairs	most recommended
2	Suitable slopes	<5%	Stairs/small number of steps	recommended
3	Acceptable slopes	5–8%	Stairs/significant number of steps	less recommended
4	Steep slopes	>8%	Stairs/large number of steps	not recommended

Table 10 combines the quality of pedestrian network with the index results for "is".

Table 10. Classification of the WIEH.

	WIEH	Routes Classification	Observations
1-4 A	≤0,5	Not age-friendly	Routes not at all recommended—No quality of pedestrian network and/or existence of steep slopes and/or large number of steps
1-4 B	>0.5 and ≤1	Less age-friendly	Routes that should be avoided—Unsuitable quality of pedestrian network and/or inexistence of acceptable slopes and/or significant number of steps
1-4 C	>1 and ≤2.5	Reasonably age-friendly	Routes that can be considered—Acceptable quality of pedestrian network, reasonably suitable slopes and stairs
1-4 D	>2.5 and ≤3	More age-friendly	Routes that are highly recommended—Good & suitable quality of pedestrian network, with reduced slopes and no stairs

5.6. Third Step—Calculating Age-Friendly Routes

This third step, illustrated in Figure 5a–c, aimed to position the elderly in relation to their most frequented spaces during their daily routines (e.g., supermarkets, churches, groceries, pharmacies, day-care centers, etc.).

First, the identification of potential destinations was undertaken and marked on the map layers, from among facilities, commerce, and other interest points for the elderly, either residents or tourists (Figure 5a).

Secondly, the WIEH for each section of the pedestrian network was calculated (Figure 5b).

Lastly, the elderly user was positioned at origin point A (potentially, their home) and different routes at an adequate distance for a pedestrian to walk were calculated toward destination point B (hypothetically, a supermarket) (Figure 5c); the walking distance considered adequate ranges from 400 m to 800 m [65,66].

For the next step, the selection of the best walking route is presented, combining walkability and health improvement.

5.7. Fourth Step—Selecting the "Heart-Friendly Route"

Based on a range of possible routes obtained through the previous step, and considering that paths with "is" value equal to 4 were removed from the final map, this fourth step focused on selecting the most recommended route for an elderly person, keeping in mind the intersection of space adequacy, walking distance, and walking time (Figure 6).

Figure 6. Selecting the "heart-friendly" route.

Considering an average step length of 68 cm (fast walking speed) to cover 1030 m (route x), an elderly person (age group 60–69) will take approximately 15 min to walk that distance. In order to travel 810 m (route y), it will take them about 11 min, and to travel 670 m (route z), it will take them about 9 min. Although route z represents the shortest distance, route x allows the user to walk the recommended time according to physical exercise baselines, extending into a walk of 30 min if we also take into account the return trip. This is, therefore, the "heart-friendly route".

Thus, when considering alternative paths from origin point A to destination point B, the selection is based on the following criteria:

– The route with the greatest number of sections best classified according to the WIEH (green-colored routes), and

– The route that allows the elderly to walk at a "fast walking speed" during a desirable time period of 30 min.

We emphasize that the main purpose was to select a route that allows the elderly to use public space as an "outdoor gymnasium". By following the "heart-friendly route", elderly people can exercise daily during their routine walk, receiving direct and quantifiable health benefits. As an example, in the given scenario (Figure 6), if an older-age adult chooses route *x* from home to the supermarket, this person will walk the distance of 1030 m twice, including the return trip; thus, they will be spending more than 30 min at a moderate walking speed. This person's heart rate will reach 78–132 bpm, corresponding to 50 to 85% of the "heart rate maximum average" (Table 3), which is considered a good interval to achieve direct health benefits, according to the literature presented in Section 2.

6. Concluding Remarks and Expected Outcomes of the WIEH

Most of the research on the adequacy of public spaces to the elderly focuses on identifying obstacles and problems around the city. Also, when looking at available literature on elderly health, studies present a bias toward particular aspects of health. Thus, there is a research gap in what concerns the connection between these two fields of knowledge.

This paper intended to fill this gap by proposing a conceptual framework to develop a Walkability Index for Elderly Health (WIEH), based on initial assumptions collected from each of the aforementioned areas of research. The WIEH is designed according to four sequential steps, starting by (1) analyzing public spaces and characterizing their quality for walking, then (2) considering the slopes and existence of stairs, (3) calculating different routes for the elderly in their daily routines or when walking to points of interest, and, lastly, (4) selecting the "heart-friendly route" for elderly people. It combines criteria for the most adequate route regarding the quality of public spaces (including variables from urban tissue, urban scenery, and safety) with recommended routes regarding slopes and existence of stairs. Ultimately, these factors are also combined with health issues linked to aging, with the objective of promoting direct benefits for the elderly's health during their daily routines. The Index is, thus, designed for the elderly, although it can be used by anyone from any age group or physical condition, based on the assumption that a good city for the elderly is a good city for anyone.

The presentation of the WIEH evidences its usefulness as a support tool for the elderly in their decisions to walk around the city, bringing together aspects related to the physical characteristics of the pedestrian network, combined with health issues. The main objective of this Index is to contribute to active and healthy aging, but also to provide end users (elderly or non-elderly, residents or non-residents) with a tool capable of assisting them in selecting more age-friendly routes. It also aims to help decision makers, urban planners, and designers to create better age-friendly spaces and walking itineraries (through maps, street signs, urban furniture, etc.). Moreover, it can provide useful walkability-related information to public or private elderly-service providers (day-care centers, nursing homes, and communities group associations, among others), thus allowing them to guide elderly people toward better walking places in the city or neighborhood.

There may be some limitations in applying this framework to real cases, due to contextual conditions: On one hand, an overall lack of quality of public spaces (e.g., historic centers easily present low standards of quality due to narrow streets, inadequate pavements, existence of stairs, etc.); on the other hand, there might be a lack in the provision of services, commerce, or points of interest around the elderly person's home. These limitations may hamper the selection of routes, decreasing the level of adequacy for the elderly.

Finally, the conceptual framework of the WIEH is expected to serve as the basis for the development of an interactive mobile app or web-based platform, by combining a way-finder tool with GIS maps and layers. In order to make the most use of these digital tools, they can be developed to be compatible with Google Maps or similar platforms. Nevertheless, on-site maps (placed on physical information boards) are also relevant, as most elderly people are not digitally savvy. The use of the WIEH tool, with its detailed classification of each section of path/street into levels, will support the elderly in making more conscious and informed decisions regarding their daily walking routes, promoting a healthier way of living by taking advantage of the public space as an "outdoor gymnasium". In a future testing phase, other urban qualitative aspects and perceptual qualities, such as those obtained through questionnaires, can be integrated into the WIEH design and implemented using a case-study approach. Direct observation of real-life situations was not an objective of this study. However, its future implementation in the study area, together with the integration of (other) urban qualitative dimensions (scale and variety, transparency, coherence, visual complexity, lighting, green areas, colors, pattern, softness, and street vitality, etc.), could provide interesting perspectives regarding further studies and debates. As to another future path, a partnership with city councils and other public and social institutions (day-care centers, seniors' residences, etc.) would also help strengthen the implementation of the WIEH and contribute to the success of the mobility tool.

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