SPN: Smart Pedestrian Net

A Smart Approach to Evaluate Built Environment Attributes and their Influence on Walkability; Fundamentals, Assessment and Application

The Project

SPN - Smart Pedestrian Net. SPN is a European research project funded by the ERA NET Cofund Smart Urban Futures/JPI Urban Europe (ENSUF/0004/2016). The goal of SPN is to plan a smart pedestrian network and to create a pedestrian navigation system.

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ISBN: 978-989-8793-11-9

Co-Funding

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PROLOGUE

Walking is the oldest and simplest form of human mobility. Everyone is a pedestrian and people walk for many reasons. Many people walk to public transport, some walk directly to local destinations, to go shopping and do other business, while many people walk just for recreation. Whatever the type of trip, walking is usually the first and last mode used, providing an important link between land use and motorised transport modes. Therefore, walking as a principal or a secondary mode of transport is an essential part of mobility.

Over the last 100 years, urban environments have been designed for vehicle traffic flow. As the urban population increased, cities built sophisticated road systems to facilitate traffic flow for millions of vehicles. However, walking has been ignored and excluded to a certain extent from urban planning. Only recently have walking policies appeared on the agenda in European cities. Many local authorities have undertaken a range of activities to stimulate walking as a daily transport mode due to potential environmental and health benefits.

Creating walkable environments starts with the built environment. However, many questions need to be effectively addressed by planners and decision-makers. Specifically, how to assess the conditions provided to pedestrians? How to provide high-quality walking facilities? How to develop effective walking policies? What will the best approach be in a specific city?

This book summarises part of the work developed within the context of the research project **SPN – Smart Pedestrian Net**. Specifically, this book provides a comprehensive approach for evaluating 23 built environment and streetscape attributes that influence the decision to walk and the satisfaction one gets from walking. The proposed SPN approach offers a clear and systematic framework to help planners and decision-makers in evaluating pedestrian conditions and in developing walking policies. The guidelines provided in this book were developed considering the cities of Porto and Bologna but can serve as a reference for evaluating pedestrian conditions in other similar medium-sized European cities.

The assessment guide is accompanied by a practical implementation of the walkable conditions in Porto and Bologna. The goal was to provide more detailed and technical information on how to objectively evaluate a selection of built environment and streetscape attributes. The guidance offered in this book is meant to be of real practical use to local authorities and researchers in assessing pedestrian environments and in helping planners to design policies to improve walkability. Furthermore, the book could be of use to developers of new standards in aspects of urban development.

This book should be considered as work in progress with the potential to encourage debates. Based on received feedback, further revision and refinement is planned for future work.

1. INTRODUCTION

1.1. Why should we walk?

Improving the level of walkability in a city brings a wide range of collective and individual benefits in multiple areas, such as in the environmental and socio-economic domains.

Walking can replace many short car trips, which heavily contribute to urban pollution and congestion. In Europe, 30% of urban car trips are shorter than 3 km and 50% are shorter than 5 km (Hooftman et al., 2018). Walking can be an alternative mode of transport for short urban trips of around 1 km (just a 10-minute walk). More walking means decreasing harmful vehicle emissions, traffic noise, traffic congestion, and the consumption of non-renewable resources. Thus, walking more and reducing driving will contribute to more sustainable and liveable cities.

Walking is a form of physical activity that helps to prevent several physiological and mental diseases associated with sedentary lifestyles, such as obesity, diabetes and depression. For this purpose, the World Health Organization (WHO) recommends 10,000 steps per day to increase physical activity among adults.

Walking is also the cheapest form of transport for all people. When compared to cars, walking cuts down on fuel costs, car maintenance and parking spaces and additionally avoids wasting time in traffic jams or looking for parking spaces. Walking is also good for business as studies show that people who walk in commercial streets spend more time and money than those who access streets by car (Bushell et al., 2013). Moreover, houses in walkable areas tend to be more attractive and expensive than those in less pedestrian-friendly areas.

Furthermore, walking solves many social and economic problems through social interaction. As walking can be a very interactive activity, it enhances social cohesion. Walkable streets tend to attract more people, which increases wellness and the level of security. Walkable cities are, therefore, more liveable, attractive and healthy urban spaces.

Considering the above benefits, walking is very important for sustainable transport policies. Developing walkable cities is a way of creating affordable and equitable transport systems for the entire urban community. However, walkability is difficult to evaluate and quantify, because of the multiple built environment attributes and subjective factors, which are related to human behaviour (Papageorgiou and Demetriou, 2019) and influence the choice of a transport mode to arrive at a destination.

Owing to this, new approaches to measure walkability are necessary. As highlighted by Keyvanfar et al. (2018), as well as Wang and Yang (2019), a list of comprehensive criteria and sub-criteria to objectively assess the influence of the built environment on walking is missing. The aim of this book is also to fulfil this gap detected in the literature.

1.2. What makes a city walkable?

Several factors and attributes affect walkability. Understanding these factors and their relationships is essential for implementing pedestrian-friendly policies. According to recent studies on walkability (Garcia and Lara, 2015; Moura et al., 2017), a walkable city generally needs to address the following seven aspects:

i) Coherence

Coherence is related to the spatial legibility and arrangement of the walkable spaces. Sidewalks should be organised in an understandable manner, easy to follow, be continuous and connected, consistent in terms of width, surface condition, etc., provide information to pedestrians and have clean lines of sight.

ii) Continuity

The continuity of pedestrian infrastructures reflects the existence of uninterrupted walking routes (sidewalks, footpaths). Continuous sidewalks providing good conditions increase the satisfaction and comfort of walking and prevents safety risks, namely those resulting from pedestrians walking on carriageways.

iii) Safety

Factors affecting the perception of safety are critical in making a walkable environment and are a primary consideration in walkability. Safety reflects the ability to feel safe from traffic and from crime and includes factors such as intersection design, traffic speed, lightning, etc. Measures to protect pedestrians from traffic and from crime are highly valuable for creating safer and more attractive walkable environments.

iv) Comfort

Comfort refers to the extent to which walking accommodates capabilities and skills for all pedestrians. Comfort involves a large number of highly diverse attributes that in conjunction define a comfortable walking environment: characteristics of sidewalks, slopes, safety and weather conditions, among others.

v) Accessibility

Accessibility defines the opportunity for all individuals to utilise the pedestrian environment to reach a destination. Accessibility is expressed by contextual features such as proximity to public transport stations, distance to nearby activities and easy access for pedestrians.

vi) Attractiveness

Attractive environments for walking are those that provide clean and well-maintained sidewalks, as well as several supporting pedestrian facilities, such as street furniture, street trees and greenery, streetlights, etc., with adjacent storefronts and cultural activities that provide sidewalk interest.

vii) Convenience

Convenience refers to the extent to which walking is possible and is able to compete with other modes of transport, especially by considering travel time and travel cost.

1.3. Concepts and fundaments

If we want to develop walking as a daily urban transport mode, cities need to be pedestrian-friendly. A safe and accessible pedestrian network is essential to provide an equitable and sustainable urban mobility system so that walking could be a competitive alternative mode of transport to the car in short urban trips.

A pedestrian network consists of a set of links, nodes, and their attributes that represent real streets. In an urban space, practically all streets should be walkable offering to pedestrians' great freedom of movement. In the literature, pedestrian networks are often based on the street network. According to this, pedestrians can move through the network just like cars, regardless of the presence of sidewalks and intersections and the location of specific destinations on either side of the street. However, pedestrian networks can be significantly different from motorised street networks as they should incorporate both formal and informal paths (the "real pedestrian network"), consisting of a variety of footpath segments, footbridges and tunnels, among others (Ellis et al., 2016).

The extent to which the built environment is pedestrian-friendly and enables walking is broadly defined as "walkability" (Habibian and Hosseinzadeh, 2018). Walkability is often evaluated by considering specific built environment attributes and measures to assess how walkable an urban area is. Walkability is a relative composite measure of several built environment and streetscape attributes that reflect pedestrian-friendliness and ease of travel (Frank et al., 2010).

The built environment can be broadly defined as the distribution of buildings and designed spaces that support all urban activities, services and infrastructure (Salvo et al., 2018). It is generally recognised that compact urban environments provide better conditions for pedestrians. In compact cities, destinations are closer to each other, they usually have higher public transport densities and mixed land use areas that people can easily access on foot or by wheelchair.

Built environment features can be controlled through suitable planning policies and consequently actions to improve walkability are often encouraged by enhancing the quality of the built environment. Therefore, the quality of the walking environment has become an essential element of urban planning and design (Wang and Yang, 2019).

Streetscape is a term used to express the pedestrian environment at the sidewalk level. Streetscape includes visual and design elements, including the characteristics and condition of sidewalks, adjacent building frontage, trees, street furniture, open spaces, etc. These micro-level aspects also have a significant impact on the walking experience.

Attributes are variables or criteria that reflect specific features of the built environment, such as land-use mix, access to amenities, sidewalk characteristics, slopes, etc. There is an extensive list of built environment attributes to assess walkability, but there is no consensus on how to measure and analyse these variables (Ruiz-Padillo et al., 2018).

1.4. Methods, measures and data

Studies on walkability usually consist of classifying urban environments as high or low walkable and identifying the features of the built environment that can support or hinder walking (Moura et al., 2017). Built environment and streetscape attributes have been measured and analysed by using different methods and tools, different scales of analysis and different types of data.

Objective methods consist of quantitative measurements of the built environment attributes. These include ratios, indexes and composite measures to describe walkability. Such methods are based on objective data (number of intersections, densities, floor areas, etc.) and have smaller measurement errors. They can be compared across studies and can be easily translated into planning policies and be replicated in other cities (Mayne et al., 2013).

Subjective methods have been supported by qualitative assessments based on stated preferences and individual perceptions usually collected through questionnaires, surveys or by consulting expert panels. It is recognised that subjective methods can assess variables usually not included in objective assessments, namely those related to design and security (Kerr et al., 2014). These measures can be used for correlating walking preferences and behaviours to various personal characteristics, including age, gender, income and health. However, they always reflect individual opinions.

Empirical methods correspond to audits implemented to record and evaluate the presence/absence of specific attributes, usually at the streetscape level. As observations can be subjective and inconsistent, this method requires trained observers (Yin, 2017). Audits are performed through fieldwork or by using Web processing tools, such as Google Street View (Larranaga et al., 2018).

Regarding the scale of analysis, studies have been predominantly focused at the neighbourhood level. These approaches try to assess the impact that urban form, street configuration, land-use mix and other features may have on walking. Such approaches rely on widely replicated mesoscale indexes (Frank et al., 2005, 2010) and on the availability of georeferenced data.

Mesoscale approaches do not capture street-level attributes, such as the condition of sidewalks and streetscape design. As these micro variables play an essential role in walking (Moran et al., 2018), microscale analysis has recently gained popularity in walkability (Yin, 2017; Galpern et al., 2018). However, working at a high-disaggregated level poses some problems, namely the lack and difficulty of obtaining objective data, which usually requires street audits.

Many tools have been adopted to assess the correlation between attributes of the built environment and walking. In a recent literature review, Wang and Yang (2019) argue that the Geographical Information System (GIS) is one of the most popular tools for examining walkability due to its capabilities of processing objective data and geocoding the location of built environment data, which can be presented spatially and visually. Other tools adopted include multi-criteria analysis, Walk Score, agent-based models, among others.

2. BUILT ENVIRONMENT AND STREETSCAPE ATTRIBUTES

This section describes the built environment and streetscape attributes adopted in the Smart Pedestrian Net (SPN) in order to assess the level of walkability in Porto and Bologna. In this book, we describe how the attributes were selected, clustered and analysed to assess walkability.

The first stage of the work consisted of selecting the attributes with considerable influence on walking. The selection was supported by an electronic literature search on the Scopus database. The search was limited to peer-reviewed documents written in English, published until the end of 2018 as journal articles, conference papers and book chapters. A total of 219 documents were retrieved in the search. Then, in the second filter, a total of 23 attributes (some divided into several sub-criteria) were selected and clustered into six pedestrian determinants (main factors). As shown in Figure 1, these attributes cover several variables clustered into the following determinants: accessibility, land use density, diversity and design, street connectivity, pedestrian facilities and safety/security.

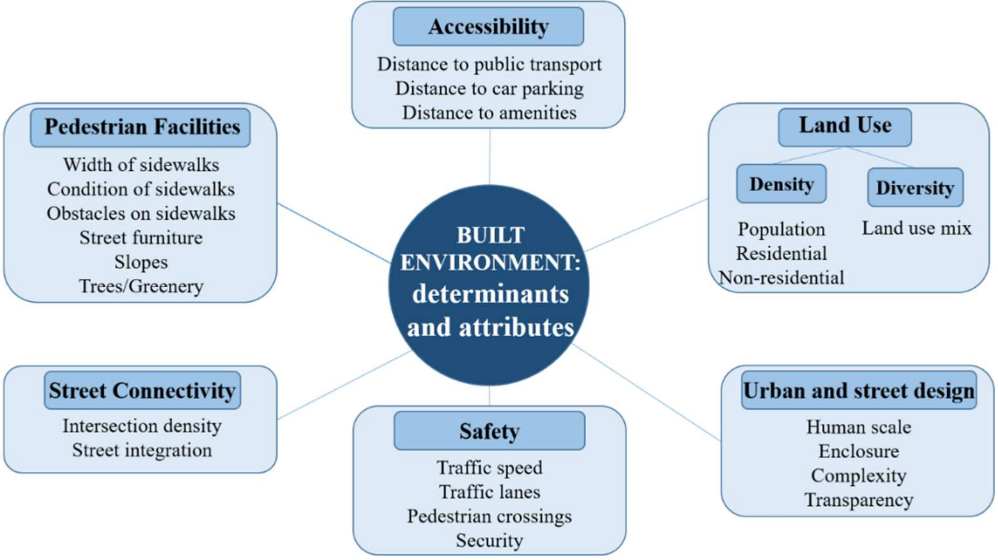

Figure 1: Attributes and determinants used for assessing walkability in SPN.

2.1. Accessibility

Accessibility is one of the dimensions that make cities walkable. Accessibility is described as the ability to reach desired goods, services, activities and destinations (Habibian and Hosseinzadeh, 2018). Accessibility can also be described as the distance to public transport and key amenities.

Distance is widely known as an important barrier to walking. For utilitarian trips, a widely accepted walking distance is 0.8 km (half a mile) or 10-minutes' walk (Bejleri et al., 2011; Kang et al., 2017). As walking is a slow mode of transport, it is not viable for long trips due to travelling times and the high physical effort required. In this case, walking can be combined with other modes of transport, namely with public transport and private vehicle travel. In this case, trips start by walking to a public transport station or to the place where the car is parked and ends again by walking between the station/car parking and the final destination. The walking distance to public transport stations and car parking influence the decision of combined modes of transport.

2.1.1. Distance to public transport

Walking is the most widely used mode of transport to access public transport. Access to public transportation means that public transport stations/stops should be near enough to be reached by walking. People choose public transport more often when they find that the travelling time, including the time spent walking to a stop, is shorter than travelling by car. Cities with high public transport densities, intensive land use mix and low detour factors for walking are more attractive for using combined modes of transport (public transport plus walking).

Figure 2: [A] São Bento train station, Porto. Photo by Fernando Fonseca, CTAC.
[B] Bologna central station. Photo by Danijela Prijovic, Unsplash.

Scientific evidence shows that the shorter the distance to a stop, the higher the walking activity (Moeinaddini et al., 2015; Sung et al., 2015). However, how far would pedestrians walk to access a public transport stop? The answer depends on several variables, including the type of public transport.

In North American and European cities, it is widely recognised that in daily utilitarian trips, people are usually willing to walk about 400 m to get to a bus stop (Millward et al., 2013; Boulange et al., 2018; Jabbari et al., 2018).

In turn, people are often available for walking more to access light rail and train stations. The light rail and in particular the train are distinguished for providing different levels of service, and for having greater spacing between the stations. While the bus is mainly used for short urban trips, the light rail and trains are used for longer trips. In the literature, a distance of 800 m has been the referential walking distance adopted to analyse access to train and light rail stations (El-Geneidy et al., 2014; Boulange et al., 2018; Jabbari et al., 2018).

Figure 3: Bus stops in Porto. Photos by Fernando Fonseca, CTAC.

2.1.2. Distance to car parking

Car parking policies have a direct impact on travel behaviour and the overall mobility as they may stimulate or discourage private car trips, namely in specific urban areas, such as city centres. There is evidence that cities providing many free car parking spaces encourages the daily use of cars in urban trips (Ferrer et al., 2015; Moeinaddini et al., 2015).

Figure 4: Car parking at the centre of Porto (Praça Gomes Teixeira).
Photo by Fernando Fonseca, CTAC.

Almost all car trips start and end in a parking space and involve walking activity from the chosen parking lot to the final destination. Besides the costs of driving and parking a car, the distance that drivers need to walk between car park and the final destination is the main variable for choosing a specific car park and for deciding to drive or not. The distance that drivers are predisposed to walk from the car park also depends on the purpose of the trip. For example, Waerden et al. (2017) demonstrate that drivers prefer to walk less (50 meters) when they go to work, they accept to walk more (100 meters) to go shopping and they are available to walk even more for non-weekly activities (500 meters or more). Nonetheless, there is no consensus in the literature about the distance that drivers usually walk to/from a car parking place. Variables such as the purpose of the trip, city size, car parking policies, public transport service and individual preferences have a direct influence on that decision. However, some studies indicate that the median walking distance between the car parking place and the final destination is about 500 meters (Hayashi and Morisugi, 2000).

2.1.3. Distance to amenities

Accessing amenities and services provides an opportunity to walk, especially if they are intermingled amongst one another and in areas with intensive land use mix. Thus, people may be more predisposed to walk if amenities are close and have good pedestrian accessibility. There is a wide range of amenities with different levels of service for pedestrians. Walking to school, urban parks and shopping have been studied extensively.

Figure 5: Faculty of Law located in the city centre of Porto (Rua dos Bragas).
Photo by Fernando Fonseca, CTAC.

Walking to school is an active mode of transport that reduces the risk of childhood obesity, increases children's independent mobility and fosters social engagement (Mitra, 2013). Among other factors, distance is a recognised barrier for walking to school. Significant distances decrease the likelihood of walking to school and increases the predisposition of using other modes, including motorised transport (Hatamzadeh et al., 2018). However, the so-called "acceptable" walking distance differs across countries due to both cultural and physical environmental factors.

Nonetheless and depending on the type of school, and therefore the age of the students, distances ranging from 800 to 1000 meters are considered a threshold-walking distance to schools (Pojani and Boussauw, 2014; Waygood and Susilo, 2015).

Urban parks are important spaces that perform high valuable environmental and social functions in urban areas. Urban parks often provide pleasant and healthy spaces for walking, but they are mostly accessed for recreational and leisure purposes. Distance is also a barrier for walking to urban parks, but the walking distance and walking time are not as restrictive as those for accessing other amenities. The European Environment Agency recommends that people should have access to a green space within 15 minutes walking, roughly about 900 to 1000 meters. This distance can be considered a referential distance for accessing urban parks, which is confirmed by some studies carried out in European cities (Rioux et al., 2016).

Figure 6: Palácio de Cristal, Porto. Photos by Fernando Fonseca, CTAC.

Commercial stores and shops, such as restaurants, bars, grocery stores and shopping centres, can generate a high volume of pedestrian trips as they act as places for work, entertainment and services, fulfilling the daily needs of many people. It has been demonstrated that commercial areas and streets can satisfy people's needs more effectively and encourage them to walk rather than drive (Peiravian et al., 2014). For short urban trips, walking is more competitive in terms of time and cost than other motorised transport modes. Walking for shopping usually involves more time than other trip purposes as people stop to look in shop windows and to buy things. It also involves carrying bags and pushing trolleys, which can work as a barrier for walking because it requires more physical effort and more space (wider sidewalks). For these reasons, walking for shopping generally involves short distances ranging from 600 to 800 meters (Larsen et al., 2010; Yang and Diez-Roux, 2012; Millward et al., 2013).

Figure 7: Example of a commercial street in Porto (Rua de Cedofeita).
Photo by Fernando Fonseca, CTAC.

Cultural amenities, such as museums, libraries and theatres, generally create considerable pedestrian activity. A walking distance of 400 meters (10 minutes walking) is generally seen as acceptable for accessing these type of amenities (Vaughan, 2007; Abass and Tucker, 2018). In relation to religious temples, some research shows that people tend to walk if the temple is located at a distance shorter than 500 meters (Lovasi et al. 2008; Abdullah et al., 2013). Regarding health amenities, 800 meters is an acceptable distance to health centres and hospitals (Reshadat et al., 2015; Meeder et al., 2017). However, it should be highlighted that the pedestrian access to these amenities has been much less analysed than walking to schools, urban parks and shopping purposes.

Figure 8: Two cultural amenities in Porto: Casa da Música [A] and Teatro Nacional S. João [B].
Photos by Fernando Fonseca, CTAC.

2.2. Pedestrian facilities

Pedestrian facilities are infrastructures necessary to enhance the quality of the pedestrian environment. Sidewalks are the basic unit of mobility within any overall transport system. Sidewalks are usually in pairs and provide a safe path for pedestrians to walk along. As they are separated from motorised traffic, sidewalks restrict the interaction between pedestrian-vehicle and improve pedestrian safety. The characteristics and the condition of sidewalks are attributes that make walking more attractive, convenient and safe (Wang et al., 2016). Sidewalks should be designed to meet the needs of all users: people of different ages, people with bags and strollers, people using wheelchairs and other assistive devices. The lack of sidewalks or sidewalks that do not meet pedestrian needs encourage people to travel by motorised transport modes. Other facilities that influence walking are street furniture, the presence of trees and slopes.

2.2.1. Width of sidewalks

The sidewalk width is an attribute that plays a significant role in the pedestrian experience and in choosing a specific route. Sidewalks should never be less than 1.5 meters, which is the minimum width required for people using a guide dog, crutches, and wheelchairs. Sidewalks with a width of less than 1.5 meters do not provide enough space for two people to walk at the same time and, therefore, they do not support a strong volume of pedestrians. Thus, narrow sidewalks may cause excessive congestion of pedestrians due to slower movement and may encourage them to walk on roadways. Wheelchair users need sidewalks with at least 1.5 meters to turn around and 1.8 meters to pass other wheelchairs. In areas with high pedestrian volume, such as nearby schools, urban parks, shopping areas, and downtown areas, sidewalks should be wider than in residential areas. In these cases, sidewalks should be at least 1.8 to 4.5 meters wide (NACTO, 2019) to meet the desired level of pedestrian service. Sidewalks should be free of obstructions that reduce the available space for walking and can be hazardous to pedestrians, particularly for pedestrians with vision impairments.

Figure 9: [A] A very narrow sidewalk (Street Rainha Dona Estefânia) and [B] a wide sidewalk (Praça Carlos Alberto) in Porto. Photos by Fernando Fonseca, CTAC.

2.2.2. Condition of sidewalks

The characteristics of sidewalks also have a significant impact on the pedestrian comfort, safety and overall experience of walking (Corazza et al., 2016). Walking on uneven sidewalks, having surfaces with bumps, cracks, holes, deformations due to roots and depressions, create difficulties in controlling balance and increase the risk of slipping and falling. This problem is particularly significant for people that have difficulty in controlling their balance, such as elderly and disabled pedestrians. Therefore, a sidewalk surface should be firm, stable, slip-resistant, and sloped for drainage. Sidewalks should also have a low cross slope. Severe cross slopes require wheelchair users and pedestrians to work against the effects of gravity to maintain their lateral balance and can encourage them to move to the roadway. It is recognised that cross slopes should be lower than 2%.

Unsuitable sidewalks can also result from the lack of or carrying out regular maintenance and cleaning operations to restore evenness aftershock damage, weather phenomena, and installation of equipment. The use of low-quality materials on the sidewalk surface can contribute to accelerating the deterioration caused by the daily use and by shock damage. Inappropriate maintenance can not only put pedestrians off but also reduce the walkable surface and encourage pedestrians to walk on the roadways. Thus, inappropriately maintained sidewalks are not safe, nor comfortable and not attractive (Corazza et al., 2016).

Figure 10: Sidewalks in Porto with various types of deformations.
Photos by Fernando Fonseca, CTAC.

2.2.3. Obstacles on sidewalks

Physical obstacles on sidewalks such as parked cars, light poles, bollards, bar terraces, bus stops, lampposts, furniture, trees, among others, reduce the area available for walking, create unpleasant routes and cause discomfort to pedestrians (Ferrer et al., 2015). The usable width of a sidewalk is determined by reducing the space occupied by all types of obstructions. Thus, when a sidewalk should have at least 1.5 meters, this width should be free of obstructions.

Obstacles on sidewalks deters all pedestrians, mainly the elderly, people with reduced mobility and people with strollers. Obstacles are particularly dangerous for people with vision impairment. Blind pedestrians may not detect obstacles on sidewalks and collide with them. Thus, it is recognised that when necessary, objects mounted on the wall, post, or side of a building, should not protrude more than 0.1 meters into the sidewalk corridor.

Figure 11: Sidewalks in Porto obstructed by cars, by bus stops and by pedestrian barriers due to construction. Photos by Fernando Fonseca, CTAC.

2.2.4. Street furniture

Street furniture is a supportive sidewalk infrastructure that serves to create a more pleasant and attractive environment for pedestrians (Bushell et al., 2013). Street furniture also contributes to giving human scale and complexity of street scenes. Benches, toilets, water fountains, bus shelters, kiosks, litterbins, parking meters, public art, streetlamps and signs are just a few examples of street furniture elements. Streets with furniture provide settings for resting, sitting and eating and for social encounters with others. Such settings may be of great importance to the elderly, people with limited mobility and adults with small children (Yücel, 2013). Some studies demonstrate that streets with suitable furniture have more pedestrian volume than other streets (Sung et al., 2015).

Furniture should be properly planned and placed by considering the urban design and planning decisions such as the layout of streets and the interaction with other elements of the local environment. According to Yücel (2013), planning and placing street furniture should follow five main aspects: i) function (how necessary an object is and serves it purpose); ii) placing (where the object will be installed); iii) form and appearance (object design and their insertion in the remaining space); iv) durability (expected usage); and v) cost. More specifically, street furniture should be available in proportion to the intensity of activity in a street and carefully placed to create unobstructed paths for pedestrians.

Figure 12: Benches are essential to provide resting areas for pedestrians. Piazza Aldrovandi, Bologna. Photo by Alice Panciroli, UNIBO.

2.2.5. Slopes

Slopes (or grades) refer to the tangent of the angle (º) of a surface to the horizontal but can also be expressed as the percent (%) change in a surface over a certain distance. The slope is an attribute having a significant influence on walking and on choosing a route as it affects the walking speed and time, the comfort and safety of walking, as well as the energy and effort required for walking (Koh and Wong, 2013; Taleai and Yameqani, 2018). Sloped sidewalks also increase the risk of pedestrian slipping and falling, mainly with rainy and snowy conditions. Sloped sidewalks are universally not very attractive for pedestrians. Meeder et al. (2017) reported a reduction of 10% in the pedestrian attractiveness by each 1% increase of grade. However, slopes are always very difficult to control in the sidewalk environment because sidewalks follow the path of the street that, in turn, is shaped by the overall topography of the area.

Slopes are especially important for aged and impaired pedestrians, namely for people using wheelchairs. According to North American and European guidelines, sidewalk slope ideally should not exceed 5 % (PQN, 2010). This is also valid for Portugal where, according to the Decree-Law 163/2006, sidewalks should have a slope lower than 5%. This grade (5%) is considered the maximum recommended for wheelchairs, while some European countries also allow a maximum of 6% (PQN, 2010). Sidewalks with a slope greater than 5% are considered ramps, which should not have a grade greater than 8%. Where the sidewalk slope approaches or exceeds the maximum defined for a ramp, it is good practice to provide level resting areas including some furniture, such as benches and drinking fountains. Identically to high slopes, stairs are often described as an impediment by those experiencing mobility limitations.

Figure 13: [A] Street in Porto with a high slope (Rua do Corpo da Guarda) and [B] street in Porto with stairs (Escadas da Vitória). Photos by Mona Jabbari, CTAC.

2.2.6. Trees/greenery

Street trees enhance urban environments both functionally and aesthetically. Street trees are part of the urban green structure and provide many environmental benefits: shade to pedestrians and homes, and consequently a cooling effect on the pedestrian environment and UV protection. Street trees also help to reduce traffic speeds, especially when placed on a curb extension in line with on-street parking and to separate motorised traffic from pedestrians. Both functions have an important role in enhancing pedestrian safety.

Figure 14: A wide sidewalk lined with trees providing shade (Praça da Liberdade, Porto). Photo by Mona Jabbari, CTAC.

Trees also perform a well-documented aesthetic function. Studies conducted in the field of landscape architecture and environmental psychology confirm that people have positive aesthetic, emotional, and physiological responses to nature (PQN, 2010). Street trees frame the street and the sidewalk as discrete public realms, enriching them with a sense of rhythm and human scale. Rows of trees on both sides of a street can humanise the height-to-width ratio and can help to enclose the pedestrian environment.

However, street trees may bring some problems. They are one of the most common causes of sidewalk cracks and changes on the surface level. Trees can also reduce the sidewalk width and obstruct pedestrian movements. Low hanging branches (lower than 2 m) can be a safety hazard mainly for pedestrians with vision impairments. In some circumstances, street trees can also block the line of sight and enclose the space more than the desired. Therefore, street trees should be carefully selected, placed and maintained to provide a comfortable and safer environment for pedestrians and remaining street users.

2.3. Safety

In the context of walkability, safety refers to both traffic safety and public security. Traffic safety means that pedestrians should be protected from motorised traffic (Williams et al., 2018). In 2017, about 5300 pedestrians were killed on EU roads/streets. Pedestrians are vulnerable road users due to their small mass and lack of protection in the event of a collision with a vehicle. In turn, public security is an attribute associated with the risk of crime and the occurrence of incivilities on the street/public spaces (Larranaga et al., 2018). Safety is particularly important for schoolchildren and seniors. Active transportation to school is strongly influenced by safety issues (Giles-Corti et al., 2011; Habibian and Hosseinzadeh, 2018), while elderly pedestrians are disadvantaged regarding their ability to move safely and independently (Galanis et al., 2017). Traffic safety and public security are influenced by streetscape and built environment features (configuration of streets, lack of street lighting), individual aspects (pedestrian and driver behaviour), social aspects, as well as by transport policies and traffic rules. The attributes with more influence on safety are traffic speed, the number of traffic lanes, the conditions found at the pedestrian crossings and public security.

2.3.1. Traffic speed

Traffic speed refers to the average speed of vehicles passing a point. Speed is critical to pedestrian safety. It is recognised that high average traffic speed represents greater traffic risk, increases the likelihood of a pedestrian being struck by a car and leads to high injury severity (Chen and Zhou, 2016; Galanis et al., 2017). Traffic speed has a direct influence on whether or not pedestrians feel safe and comfortable and, therefore, influences the streets chosen by pedestrians to walk along (Garcia and Lara, 2015). According to some studies, pedestrians prefer quiet streets than car-oriented streets, with high traffic speed and volume (Ferrer et al., 2015). Thus, reducing traffic speed is critical for providing safe and comfortable pedestrian environments.

Traffic speed can be controlled and reduced by formal speed limit changes or by introducing physical traffic calming measures. Traffic calming covers a range of self-enforcing measures including physical crossing aids, priority/time separated facilities and segregated facilities. Physical crossing aids, such as crossing islands and curb extensions, reduce the crossing distance and provide a safe refuge for pedestrians crossing two-way traffic. Priority facilities mostly consist of marked crossings and signs. Crossings are facilities where pedestrians have the right of way and vehicles are expected to stop. Different types of traffic signs and lights can be used for guiding and regulating traffic and for reducing conflicts between pedestrians and traffic. Segregated facilities mainly consist of overpasses and underpasses (bridges and tunnels), designed to help pedestrians in crossing major barriers safely, such as bypasses and railways. They completely separate pedestrians from vehicles but result in longer walking journeys and in a minor perception of security, which may reduce the convenience of walking.

2.3.2. Traffic lanes

Streets with many traffic lanes reflect the focus given to motorised transport modes in detriment to active modes of transport. Streets with many lanes are usually characterised by higher traffic speeds and volumes (Rankavat and Tiwari, 2016). Streets with multiple lanes are also associated with higher pedestrian-vehicle crashes and fatal collisions (Ukkusuri et al., 2012; Aziz et al., 2013). They are generally more difficult and require more time to be crossed by pedestrians (Gori et al., 2014). In turn, streets with few lanes increase the pedestrian perception of safety (Kadali and Vedagiri, 2015). It has been shown that pedestrians prefer to cross roads with no more than two lanes (Zhang et al., 2017).

Figure 15: A street with multiple lanes in Bologna (Viale G. Gozzadini, Bologna).
Photo by Paula Saavedra Rosas, UNIBO.

The adoption of physical traffic calming measures helps pedestrians to cross streets with multiple traffic lanes. Crossing islands allow pedestrians to deal with only one lane at a time, and enable pedestrians to stop partway across the street and wait for an adequate gap in traffic before crossing the second lane. Traffic signs are the only full-time at-grade crossing control option where there are more than two lanes of traffic to be crossed. Reducing the width of lanes available to cars helps slow vehicles down and makes crossings safer for pedestrians. For arterial roads, with multiple lanes and a high volume of traffic, where the implementation of traffic calming measures is more limited, the provision of overpasses and underpasses is the only option for crossing these barriers.

2.3.3. Pedestrian crossings

Pedestrians are exposed to considerable safety risks when crossing a road. Pedestrian crossings are places where pedestrians have the right to cross and vehicles are expected to stop. Thus, they correspond to conflict points where pedestrians and vehicles are in interaction. Pedestrian crossings are usually installed at intersections, but also at midblock locations. Streets that facilitate safe and comfortable crossings are more attractive and vibrant for pedestrians.

A wide variety of marking patterns exist, such as solid, parallel and zebra lines, to warn drivers to expect a pedestrian crossing ahead and to indicate its location. Good quality road crossings reduce the occurrence of crashes, often severe, involving pedestrians and vehicles. However, pedestrian crashes at crossings are quite frequent (Aziz et al., 2013). To improve pedestrian safety, pedestrian crossings are usually complemented with other pedestrian facilities and traffic calming measures.

Figure 16: [A] A crossing with pedestrian traffic signals (Praça Carlos Alberto, Porto) and [B] a zebra crossing (Rua Campo Alegre, Porto). Photos by Fernando Fonseca, CTAC.

Several variables influence the level of safety at crossings, such as the width of roads, the number of lanes, the presence of signs, and the distance from the curb. For example, crossing large multi-lane avenues and roundabouts can be a deterrent for walking due to long waiting times and to more conflicts with cars. Moreover, the number of crossings encountered along the route may cause delays in the journey. At intersections regulated by traffic lights, pedestrians sometimes need to wait long intervals before crossing. Long crossing waiting times is unpleasant for walking (Ferrer et al., 2015). The Highway Capacity Manual 2010 (TRB, 2010) recommends a waiting time no longer than 30 seconds to avoid the propensity of pedestrians disobeying traffic signs.

2.3.4. Security

Security is associated with the perception and risk of crime (Ruiz-Padillo et al., 2018). The fear of crime is a strong deterrent for walking (Foster et al., 2013; Ferrer et al., 2015). There is evidence that security is affected by design and planning aspects such as the configuration of streets and spaces, the types of land uses, the presence of street lighting, the maintenance of public spaces, among other aspects (Lee et al., 2016). For instance, Foster et al. (2013) showed that graffiti, closed shops, the presence of vagrants, and vacant lots increase the feeling of insecurity. The perception of security is also conditioned by social aspects such as the presence of other people along the walking route (Ghasrodashti et al., 2018), the occurrence of undesirable activities like drug dealers and bullies (Bejleri et al., 2011) and the presence of policing (Ruiz-Padillo et al., 2018).

In cities characterised by urban violence, security has been identified as the most critical deterrent for walking (Larranaga et al., 2018; Ruiz-Padillo et al., 2018). The feeling of insecurity tends to result in behavioural adaptations. Changing the pedestrian route and driving instead of walking are common behavioural changes adopted by pedestrians in cities with urban violence. Insecurity has also been found to be a barrier for using public transport, because people feel insecure mainly at transfer and waiting areas, especially after dark (PQN, 2010).

Figure 17: Example of graffiti under a portico in Bologna.
Photo by I.Sailko, CC BY-SA 3.0 Licence.

Street lighting recognisably enhances the feeling of security and increases pedestrian activity after dark (Aghaabbasi et al., 2018). The installation of surveillance systems on the streets also discourages crime and other undesired activities, increasing the perception of security (Aghaabbasi et al., 2018). Increasing the number of police officers has a positive effect on enhancing security levels (Larranaga et al., 2018). Regular maintenance of streets and public spaces also increase the sense of security. Streets and public spaces should be clean, free of graffiti, facades and buildings kept in good repair and vacant lots should be clear of weeds.

2.4. Street connectivity

Street connectivity can be understood as the directness and availability of alternative routes between destinations (Ellis et al., 2016). Street connectivity increases walkability in two ways. First, more interconnected streets provide more potential routes for walking and shorter distances to destinations (Jabbari et al., 2018; 2020). Second, more interconnected streets provide more destinations that are likely to be suitable for walking (Özbil et al., 2015). Street connectivity can be expressed in terms of measurable properties of the street network, but there is no accepted standard for assessing connectivity (Ellis et al., 2016). Various aspects of the street network have been used to describe street connectivity, including intersection density, block length/size, link-node ratio, route directness, and topological closeness, among others. However, it has been argued that a street network representing the car-oriented accessibility is not always the most reliable process because it may neglect the availability of sidewalks and the finer-grained footpaths (Ellis et al., 2016; Shashank and Schuurman, 2019).

2.4.1. Intersection density

Intersection density has been the most used attribute to describe street connectivity. Intersections are important because they show how space is organised and how many route choices are available for pedestrians. A higher density of intersections provides more direct paths between destinations. Intersection density was first included by Frank et al. (2005) in a walkability index developed for Atlanta, USA. They concluded that areas with ≥30 intersections per km^2 are more walkable than other areas. More recently, intersection density has been frequently analysed as the number of true intersections (three or more legs) per unit area (Frank et al., 2010; Boulange et al., 2018; Larranaga et al., 2018).

Intersection density has been positively associated with walking and physical activity (Erath et al., 2017). It has been described as a good indicator of walk-friendly neighbourhoods (Meeder and Weidmann, 2018) and as the best measure of street connectivity (Ellis et al., 2016). However, some studies also showed that areas with high street connectivity have more crossings, which are positively associated with pedestrian crash frequency and risk (Chen and Zhou (2016). Providing good pedestrian facilities and ensuring pedestrian safety is essential for minimising pedestrian crashes in areas with high street connectivity.

2.4.2. Block sizes

Blocks are the land area carved out by the street network. Block measures can both express the average length of city blocks as the average size in units of area. It is assumed that the shorter the block length or size, the greater the connectivity. Moreover, smaller block sizes tend to provide a more pleasant environment for pedestrians than larger block sizes (Peiravian et al., 2014).

2.4.3. Nodes

Nodes correspond to intersections, usually of three or more segments and are measured through the link-node ratio. It reflects the ratio of intersections to all nodes including cul-de-sacs (Habibian and Hosseinzadeh, 2018). The higher the ratio, the more connected the network is (Ellis et al., 2016).

2.4.4. Directness

Directness defines how pedestrian routes compare with a straight-line distance between two points. As route directness incorporates distances, it has a stronger correlation with trip duration. A directness ratio closer to one may represent a better-connected network and shorter walking distances (Bejleri et al., 2009).

2.4.5. Street density

Street density measures the linear distance of streets per square distance of land. Usually, only local and collector streets, which ensure internal traffic to neighbourhoods are considered in the calculation of street density (Faerstein et al., 2018).

2.4.6. Street integration

Integration shows how close the streets are to each other from a topological point of view. Higher integration denotes greater street connectivity (Sugiyama et al., 2019). Space syntax is a suitable method for measuring the level of integration of a street network.

2.5. Land use

Land use is an attribute of the built environment, reflecting the location, intensity and diversity of activities in a location. Land use has a significant influence on walking and on transport mode choice (Dhanani al., 2017). Land use is often operationalised using density, diversity and design measures. Cervero and Kockelman (1997) were the first authors that proposed these three attributes (“3Ds”) to assess the impact of the built environment in travel demand. They found that neighbourhoods with high population density, diverse land uses, and pedestrian-oriented design were more likely to facilitate walking. Later, Frank et al. (2005, 2010) developed two widely replicated walkability indexes, supported on diversity (land use mix and retail floor area) and residential density. Land use density, diversity and design are the most cited and used attributes in walkability.

2.5.1. Density

Density refers to the concentration of land uses within a specific area. Different types of land use densities have been included in walkability indexes, namely population density and residential density. Amenities and public transport densities have also been adopted but to a less extent.

Density brings “things” closer together. There is clear evidence that increasing density reduces the need to travel great distances for local needs and reduces the reliance on cars for transport (Wei et al., 2016). High dwelling and population densities also attract retailing and amenities that encourage walking by reducing the distance between origins and destinations. In turn, areas with low residential density were found to be less attractive for walking, because they are often less interconnected and mixed. Therefore, population density has been included in several walkability indexes by considering the number of inhabitants living in a specific unit area (Habibian and Hosseinzadeh, 2018).

Identically, it has been reported that areas with high residential density are significantly related to walking (Kerr et al., 2013). This attribute measures the number of residential units (dwellings) in a unit area or the average number of households per residential building along the route (Boulange et al., 2018; Ribeiro and Hoffimann, 2018).

Figure 18: In Porto, the residential blocks around the Mouzinho da Silveira and Bainharia streets (in the Figure) have high population densities. Photo by Fernando Fonseca, CTAC.

Amenities also act as destinations for various service-related trips. The higher the density of amenities, the more people's needs can be satisfied within a small area, encouraging them to walk rather than drive (Peiravian et al., 2014). Areas with a high density of public transport stops/stations are also more attractive for pedestrians because they spent less time walking than in areas characterised by a low density of stops (Todd et al., 2016).

2.5.2. Diversity

Diversity shows the degree to which there is a mix of land uses within an area (Conticelli et al., 2018). Areas with mixed land uses have been significantly associated to utilitarian walking and physical activity (Wei et al., 2016; Carlson et al., 2018). There is abundant evidence showing that compact and well-connected areas with mixed land used containing non-residential activities (shops, restaurants, offices, banks, etc.) provide conditions for more frequent and short walking trips (Maleki and Zain, 2011). Different measures have been proposed to measure diversity. Land use mix entropy indexes and retail floor areas are two of the most adopted measures for assessing diversity.

Land use mix entropy indexes result in 0 to 1 normalised scores, where 0 represents a homogeneous space having a single land use and 1 denotes a heterogeneous area comprising all possible combinations of land uses. Heterogeneous areas are those having high entropy scores (close to 1) and are usually associated with high walking levels and short walking trips. In turn, homogeneous areas with less land use diversity are less pedestrian-friendly. The five land-use types (residential, retail, entertainment, office and institutional) adopted by Frank et al. (2010) in their walkability index become referential and have been highly replicated (Tsiompras and Photis, 2017; Habibian and Hosseinzadeh, 2018; Ribeiro and Hoffimann, 2018).

Figure 19: In Porto, the residential blocks around the Bolhão and Santa Catarina streets (in the Figure) have high functional diversity. Photo by Fernando Fonseca, CTAC.

Frank et al. (2010) also introduced the retail floor area ratio (FAR) as a novel component in their walkability index to increase the sensitivity to retail use believed to stimulate pedestrian activity. This ratio is obtained by dividing the retail building floor area footprint by the retail land floor area footprint. A low ratio indicates a retail development likely to have substantial parking, which can encourage driving; in turn, a high ratio indicates smaller setbacks and less surface parking, which can encourage walking. The literature indicates that FAR is correlated to walkability (Ewing et al., 2015). However, the calculation of this ratio is difficult because it requires building data that is not always available.

2.6. Urban design and street design

Urban design is focused on the design and shape of the physical structure of cities. In this broader sense, urban design has the goal of making urban spaces more attractive and functional, namely for pedestrians. Improving walkability through better urban design requires careful thinking about how people are going to use a space. However, the design is also related to the impact of streetscape design qualities on walkability. At this microscale level, design refers to the process of designing and constructing attractive pedestrian facilities, such as sidewalks facilities and furniture that meet accepted standards and guidelines. In both cases, design indicates the aesthetic quality of the pedestrian space. Abundant research indicates that urban and street design features have a significant impact on walking (Ewing et al., 2015; Galpern et al., 2018; Werner et al., 2018). Measuring objectively design features is often difficult, due to the involvement of perceptual and subjective evaluations. What defines urban design is a matter of opinion. Nonetheless, some authors, such as Clemente et al. (2005), Ewing and Handy (2009) and Ewing et al. (2015) developed a comprehensive manual to guide field observation for streetscape design features, while Yin (2017) proposed GIS-based tools to objectively measure specific design attributes. In walkability, four of the most used design attributes are human scale, enclosure, complexity and transparency.

2.6.1. Human scale

Human scale reflects how the size and texture of built elements match the human size, the extension to walk and are adjusted to the walking speed (Yin, 2017). Creating a human scale environment means making sure that the objects that we interact with every day are of a size and shape that is reasonable for an average person to use. Tall buildings with large entrances, windows placed above a pedestrian's line of sight, blank walls, long sightlines, and ornamentation that is larger than a person make people feel smaller. Moreover, when a space is too large to understand or control make people feel smaller and unsafe. Scaling buildings to a person can enhance their feeling of size and safety.

Building details, pavement texture, street trees, and street furniture are all physical elements contributing to human scale. Appropriately scaling buildings to a human dimension can be done by providing a high proportion of openings in the building facade (windows and doors), as opposed to blank walls.

Planting trees and installing furniture on the streets also helps to rescale the built environment to a human scale, namely to moderate the scale of tall buildings and wide streets. Street widths should not be out of proportion with building heights. Cities with a compact design and urban structure are better than sprawled cities because they provide shorter distances among destinations.

Human scale is measured differently. The ratio of the building height to street width, sidewalk width, frequency and height of windows and entrances, the proportion of street furniture and trees on sidewalks are just some variables that have been used for measuring human scale (Clemente et al., 2005; Ewing and Handy, 2009; Yin, 2017).

Figure 20: Blank walls in Porto - Rua D.Pedro V [A] and Rua Jorge de Viterbo Ferreira [B]. Photos by Fernando Fonseca, CTAC.

2.6.2. Enclosure

Enclosure reflects how the built environment encapsulates the pedestrian environment and confines the urban space and more particularly how the streets are defined by vertical elements, such as buildings, walls and trees (Battista and Manaugh, 2019). A sense of enclosure is when lines of sight are so blocked that outdoor spaces seem to have fixed boundaries. A good sense of enclosure creates a space with a room-like quality. The presence of overhead planes such as building projections, arcades, canopies, trees and urban furniture can further contribute to an increased sense of enclosure.

Enclosure is a key aspect that helps to attract people. It is generally considered that people prefer to be located in enclosed spaces as they provide a greater sense of security (Ewing and Handy, 2009; Adkins et al., 2012). However, Singh (2016) argues that room-like spaces could be uncomfortable and claustrophobic for pedestrians. These contradictory findings highlight the personal perception associated to enclosed spaces.

It seems that people prefer to walk on areas not excessively open neither excessively bounded. As reported by Adkins et al. (2012:507) people like to walk in “open but bounded space”. Different variables have been used to measure and describe enclosure, such as the proportion between the ground-floor height and the sidewalk width. Singh (2016) argues that highly walkable streets have a height to width ratio ranging from 1.5 to 2 and that 1.4 is the threshold value for perceiving enclosure.

Figure 21: About 40 km of arcades cover the city centre of Bologna, giving a sense of enclosure and protecting pedestrians from adverse weather. Photos by Bianca Ackermann and by Maria Bobrova, Unsplash.

2.6.3. Complexity

Complexity refers to the visual richness of a place, which is defined by the variety of physical environment attributes, such as buildings shape, size, materials, colours, architecture, ornamentation (street furniture, trees, signs, etc.) and human activity. Streets with few colours, buildings and pedestrians are poor in complexity; streets with many different buildings, colours, ornamentation and pedestrians are visually complex. Streets with high complexity are globally more attractive for pedestrians because they provide many interesting things to look at. As pedestrians move slowly, they have more time and ability to analyse complex environments than, for instance, drivers that find complex environments chaotic. However, environments providing too much information may create sensory overload. As emphasised by Clemente et al. (2005), the information should be provided to pedestrians at a perceivable rate.

The perception of complexity is difficult to measure (Park et al., 2013). Complexity has been analysed by considering many different built environment features, which also highlights the subjective dimension of this design attribute. However, some authors measured complexity by counting the number of buildings, building colours, outdoor dining, pieces of public art and people walking on streets (Clemente et al., 2005; Ewing and Handy, 2009; Yin, 2017).

Figure 22: [A] Colourful building wall at Largo Moinho de Vento, Porto. Photo by Fernando Fonseca, CTAC. [B] Arcades with painted scenes at Via Farini, Bologna. Photo by Maria Bobrova, Unsplash.

2.6.4. Transparency

Transparency refers to the degree to which people can see or perceive what lies beyond the edge of a street or other public space, and more specifically, the degree to which people can see or perceive human activity beyond the edge of a street (Singh, 2016). According to Hamidi and Moazzeni (2019), transparency is a design quality that significantly and positively improves walkability. Physical elements that influence transparency include walls, windows, doors, fences, landscaping, and openings into midblock spaces. While blank walls and reflective glass restricts transparency, streets with many entryways and shopping displaying windows at the street level improve transparency. Streets with many windows at the street level and active building uses are attractive to pedestrians and improve the perception of security.

This attribute has often been operationalised in terms of windows as a percentage of ground floor facade. The greater the surface area of the first floor that is a window, the greater the transparency is. Other measures used to describe transparency include: i) the proportion of the street with buildings fronting the sidewalk having active uses (shops, restaurants, services, etc.) that generate pedestrian traffic; and ii) the proportion street wall, considering portions of the block that are occupied by continuous facades or walls adjacent (less than 3 m) to the sidewalk (Clemente et al., 2005).

3. CRITERIA APPLICATION TO BOLOGNA AND PORTO

In the previous chapter, we explained the main attributes of the built environment contributing to walkability. Such attributes were used to assess walkability within the project Smart Pedestrian Net. We explained the meaning of each attribute, how they influence pedestrian mobility and transport mode choice and how each attribute has been measured and analysed in walkability.

In this chapter we explain how the selected attributes were used for assessing walkability on SPN. The assessment was carried out in two case studies; one in Porto and another in Bologna. These were the two cities selected for implementing a prototype of SPN. The areas chosen in each city to apply the SPN are shown in Figure 23.

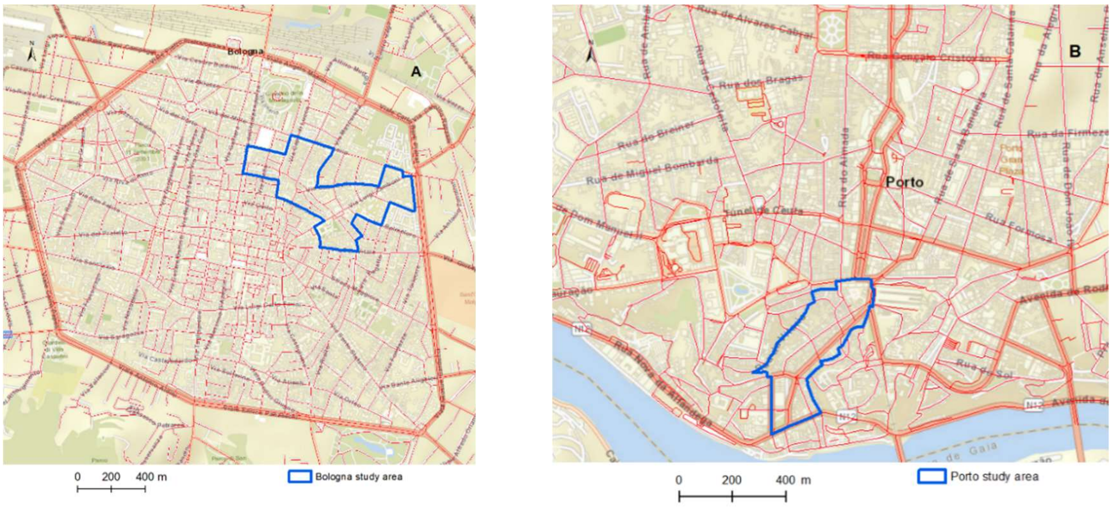

Figure 23: City centre of Bologna (A) and city centre of Porto (B).

Porto is the second largest city in Portugal and has a population of about 250 thousand inhabitants. Bologna is the capital of the Emilia-Romagna region in Italy and has about 390 thousand inhabitants. Both Porto and Bologna were walled cities with a long and rich history and culture. Based on the outstanding universal value of the urban fabric and its many historic buildings, the historical centre of Porto was classified by UNESCO as a World Heritage Site. Bologna is also an old city and contains an immense wealth of significant medieval, renaissance, and baroque artistic monuments. Bologna is particularly famous for its monuments and porticoes and arcades that covered the city centre.

The conditions provided to pedestrians in both cities are quite different, but both cities are engaged in improving walkability as part of a broader process of sustainable urban development. In this chapter, we describe how the selected built environment and streetscape attributes were assessed in Porto and Bologna. We present the attributes and the measures adopted for assessing the performance of the various criteria, the data required and the respective assessment methods. As part of the work was based on a GIS model, we provide maps and detailed figures to explain the assessment. The goal is to provide an overall guidance on how to objectively evaluate each attribute so that the process could be replicated in other cities with similar urban structures for assessing the overall conditions provided to pedestrians.

3.1. Assessment of accessibility attributes

Accessibility attributes are related to distances, namely to public transport stops car parking and specific amenities (public and private services) that can potentially attract a high number of pedestrians. In SPN, accessibility was measured considering the following amenities: schools, hospitals and health centres, cultural centres, such as museums, theatres and galleries, religious temples such as churches, urban parks and other public administrative services.

Methods and measures adopted

The method adopted was the Euclidian distance measured from stops/stations, car parking and specific amenities by adopting a changeable buffer from each dot (Table 1). Each buffer indicates how walkable an area is for accessing a public transport, a service or other amenity.

Data required

In SPN, buffers and distances were calculated in ArcGIS. This software uses digital vector storage format for storing geometric location and associated attribute information (*shapefiles*) for describing points, lines and polygons. The data required for the operation are: shapefiles (points or centroids) representing the location of public transport stops, car parking and the different types of amenities selected. A shapefile from the street network (lines) is also needed to check which streets are within the buffers.

Table 1: Distance criteria for assessing accessibility

Attribute	Sub criteria	Threshold distance	Assessment
Public transport	Bus stop	400 m	≤400m = 1; >400m = 0
	Light rail station	800 m	≤800m = 1; >800m = 0
	Train station	800 m	≤800m = 1; >800m = 0
Car parking	-	500 m	≤500m =1; >500m = 0
Amenities	Educational	800 m	≤800m = 1; >800m = 0
	Health	750 m	≤750m = 1; >750m = 0
	Cultural	400 m	≤400m = 1; >400m = 0
	Public services	400 m	400m = 1; >400m = 0
	Religious	500 m	500m = 1; >500m = 0
	Urban parks	1000 m	1000m = 1; >1000m = 0

Example/Calculation

Figure 24 represents the public transport amenities located in part of the central area of Bologna, including bus stops, train stations and car parking. Figure 25 provides an example of the process used to estimate the streets near a bus stop located in the centre of Bologna (Via delle Moline). The green streets are those located within a distance ≤ 400 m. These streets are considered to be near enough to be reached by walking and scored 1. In turn, the red streets are at a greater distance (> 400 m) and, therefore, scored 0. The described process was adopted for calculating the distances to the train stations, car parking and remaining amenities considered

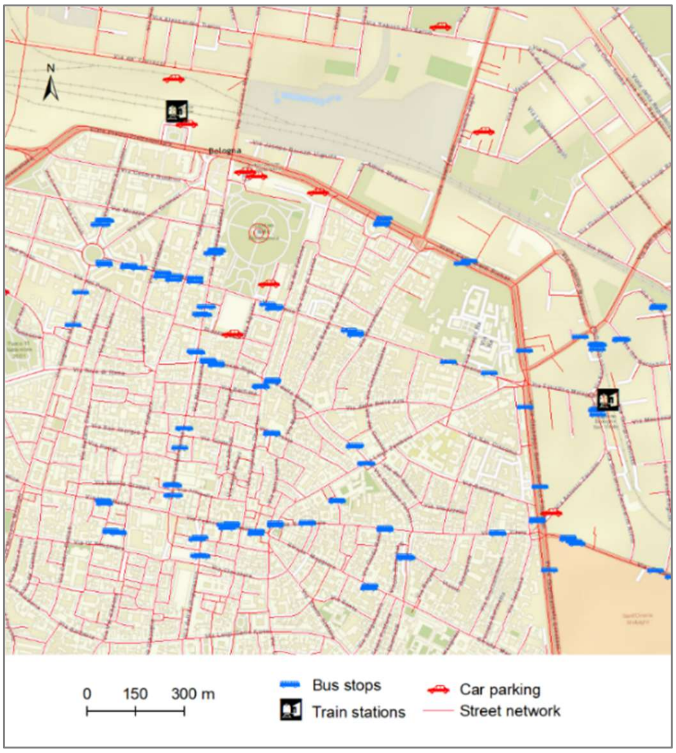

Figure 24: Public transport facilities and car parking in the city centre of Bologna.

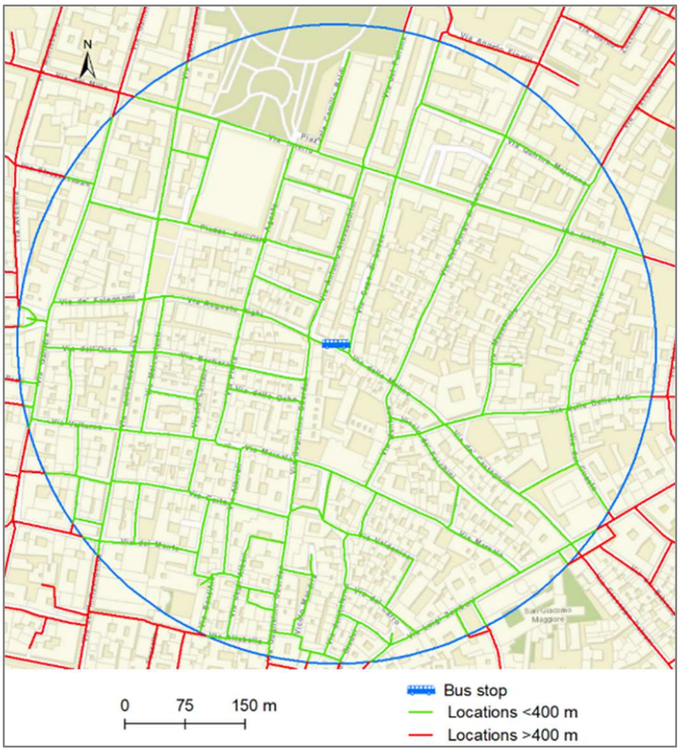

Figure 25: Estimation of distances to a bus stop in Bologna.

3.2. Assessment of pedestrian facilities

In SPN, pedestrian facilities are mainly defined by the characteristics of sidewalks, which contribute to the degree of safety, comfort and enjoyment of walking along a street. The attributes analysed were the width of sidewalks, condition of sidewalks, obstacles on sidewalks and street furniture on sidewalks. Slopes and trees/greenery were also included as attributes influencing the characteristics of sidewalks.

Sidewalks are the first-class members in a transport network. However, sidewalk features are not often included in geospatial databases. For example, online sites providing free geographic data, such as the OpenStreetMap do not provide data about sidewalks. The two municipalities that were researched (Bologna and Porto) do not have sidewalk GIS data. Therefore, online mapping services and streets audits were used to collect sidewalk data and to provide interactive panoramas along streets.

3.2.1. Width of sidewalks

Methods and measures adopted

The method adopted in the SPN was a dichotomous (0/1) evaluation according to the characteristics of sidewalks found in the prototype areas of Porto and Bologna. Streets with no sidewalks or sidewalks with less than 1.5 m scored 0 because they do not provide conditions and enough space for wheelchairs and for more than one person to walk at the same time. In turn, sidewalks wider than 1.5 m scored 1. The mentioned distances require sidewalks free from obstacles or obstructions.

Data required

The evaluation of this attribute only requires sidewalk data. More specifically, it is necessary to check the presence of sidewalks on streets and, if there are any, the respective width. Data was obtained through fieldwork (street audit) and by using online mapping services, such as Google Street View.

Example/Calculation

Figure 26A was depicted in Porto (Rua do Campo Alegre) and shows an example of what can be considered as a narrow sidewalk. This sidewalk has a width of 1 m, which is not enough for wheelchairs and for two people to walk at the same time. The example given is particularly serious because this area has high pedestrian volume generated by several faculties located in the surroundings. The presence of pedestrians walking on the road is very frequent. On the other hand, Figure 26B shows a wide and pedestrian-only street in Porto (Rua das Flores). This type of streets supports high pedestrian volumes and people free walking in both directions, without the safety concerns caused by motorised traffic on the roads.

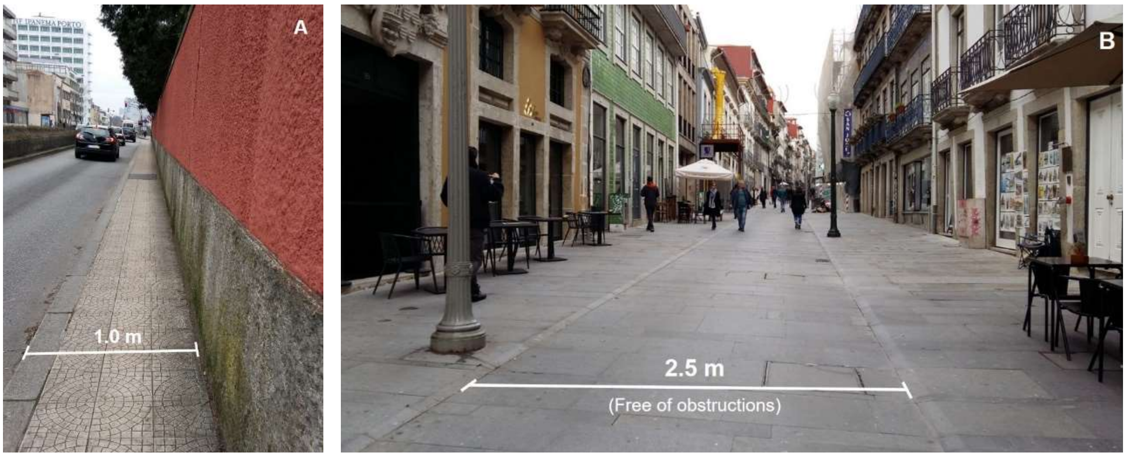

Figure 26: A narrow sidewalk in Rua Campo Alegre [A] and a wide sidewalk in Rua das Flores [B] in Porto. Photos by Fernando Fonseca, CTAC.

3.2.2. Condition of sidewalks

Methods and measures adopted

The condition of sidewalks is focused on the surface quality of sidewalks. The goal is to check if sidewalks have major gaps or deformities, such as cracks, holes and sections that either were depressed or raised. The method adopted was a dichotomous (0/1) evaluation according to the condition of sidewalks. Sidewalks with no obvious trip hazards and without major gaps or deformities scored 1. In turn, sidewalks showing surface defects and deformations (higher than 20 cm) that make them less walkable and safe scored 0.

Data required

The evaluation of this attribute requires detailed sidewalk data. As data for examining this attribute was not available, street audits in Porto and Bologna were performed to check the condition of sidewalks. The use of Google Street View could be inappropriate, as the interactive panoramas could not provide the necessary details for assessing this attribute.

Example/Calculation

Figure 27A shows an example of a sidewalk considered in good condition in Porto (Rua Magalhães Lemos). This sidewalk presents a continuous surface without deformities, such as cracks and holes. Thus, this sidewalk ensures a safe and comfortable walking experience. In turn, Figure 27B shows raised pavements caused by tree roots (Rua Campo Alegre). This type of deformation is very common due to the trees planted on the sidewalks. Raised pavements make walking difficult and cause a significant number of tripping hazards including falls and obstructions, especially to wheelchairs. They also accelerate other problems such as surface cracking.

Figure 27: [A] Pavement with no deformations (Rua Magalhães Lemos, Porto) and [B] pavement with deformations due to tree roots (Rua Campo Alegre, Porto).
Photos by Fernando Fonseca, CTAC.

3.2.3. Obstacles on sidewalks

Methods and measures adopted

The presence of obstacles on sidewalks, such as parked cars, furniture, posts and bus stops can create barriers for pedestrians and can significantly reduce the sidewalk width. The presence of obstacles on sidewalks was evaluated by considering three issues: i) the presence of cars parked on sidewalks; ii) the location (alignment to side) of street furniture and other elements such as trees; and iii) clear circulation (free of any obstacle or protruding objects) of at least 1.5 m. Score 1 was assigned to streets with no cars parked, with objects aligned to the side, providing a minimum width free of obstructions of 1.5 m. In the remaining cases, sidewalks scored 0.

Data required

The assessment of this attribute requires detailed sidewalk data. Data was collected through a street audit performed in Porto and Bologna. Using Google Street View to collect this type of data has some limitations, especially because imagery was not recent and new barriers were not detected.

Example/Calculation

Figure 28A shows an example of a sidewalk without any physical obstacles or barriers to pedestrians. There are no cars parked or other obstacles on sidewalks. The sidewalk provides a free width higher than 1.5 m. In turn, Figure 28B shows a common obstruction on sidewalks: a bus stop placed in the middle of the sidewalk, which narrows the area available for walking and causes a main obstruction to pedestrians.

Figure 28: [A] A sidewalk with no obstructions (Rua 31 de Janeiro, Porto). Photo by Fernando Fonseca, CTAC. [B] A sidewalk obstructed by a bus stop (Viale Giosuè Carducci, Bologna). Photo by Paula Saavedra Rosas, UNIBO.

3.2.4. Street furniture

Methods and measures adopted

Street furniture comprises a long list of facilities that can help to create more attractive, comfortable and safe pedestrian environments. However, it is not expected that each sidewalk provides all furnishings, as they should be suitably distributed around larger areas. In the SPN approach, street furniture was evaluated by considering the presence of four facilities: i) benches as they provide areas for resting; ii) streetlamps as they contribute to security; iii) litterbins as they help to keep sidewalks clean; iv) pedestrian signs as they are important for informing pedestrians. Streets with sidewalks providing benches, streetlamps, litterbins and pedestrian signs scored 1; otherwise, streets scored 0. In the evaluation of this attribute, the location and quality of the furnishings were not considered.

Data required

Detailed sidewalk data regarding the existing furniture (benches, streetlamps, litterbins and pedestrian signs) are needed to assess this attribute. Data was collected through a street audit performed in Porto and Bologna. Using Google Street View to collect this type of data has some limitations, especially because imagery does not provide the necessary details for assessing it.

Example/Calculation

Figure 29A shows an example of a sidewalk (Praça Carlos Alberto, Porto) providing the four selected facilities. In addition, furniture is well placed and do not obstruct sidewalks. In turn, Figure 29B presents an avenue (Viale Gozzadini) that does not provide furniture to pedestrians.

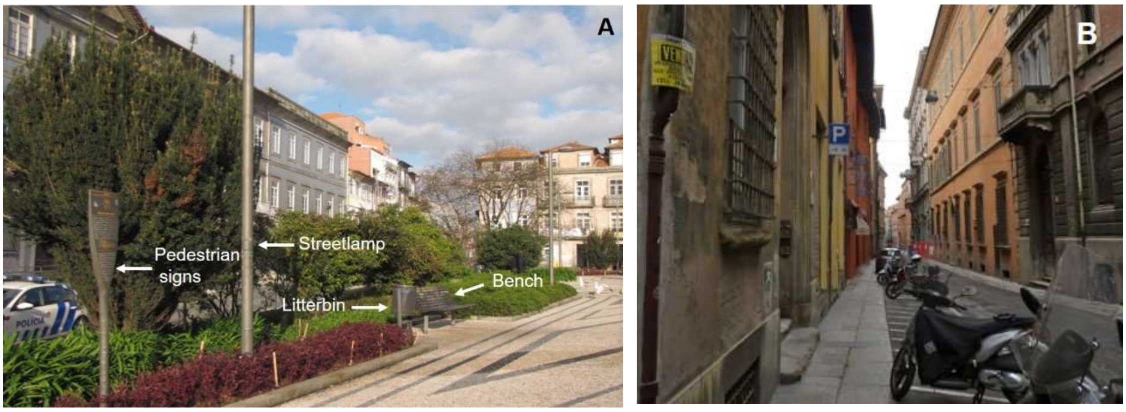

Figure 29: [A] A sidewalk providing benches, streetlamps, litterbins and pedestrian signs (Praça Carlos Alberto, Porto). Photo by Fernando Fonseca, CTAC. [B] A sidewalk with no furniture for pedestrians (Via Cesare Battisti, Bologna). Photo by Elisa Conticelli, UNIBO.

3.2.5. Slopes

Methods and measures adopted

The slope is a physical attribute that shapes the attractiveness and comfort of a sidewalk. Slopes can be calculated differently. As digital elevation models were not available, we used the digital inclinometer (Bosch DNM 120L Professional) to directly obtain the gradient of the sidewalk slope in per cent. If the slope was equal or less than 5%, sidewalks scored with 1, which means they are suitable for walking, including for pedestrians with impairment and wheelchairs. If the slope was greater than 5%, sidewalks scored 0, meaning that they are less attractive and comfortable for walking.

Data required

Street slopes are the data required for assessing this attribute. In Porto and Bologna, as digital elevation models were not available, street slopes were manually obtained by using an inclinometer. Then, slope data was inserted into ArcGIS. If digital elevation models are available, slope maps can be easily created in GIS software by calculating the gradient of the slope in per cent. However, both methods are considered accurate for describing slopes.

Example/Calculation

Figure 30 exemplifies how slopes were evaluated by using the inclinometer. The example given (Rua Corpo da Guarda, Porto) has a high slope (11%) that works as a barrier for impaired pedestrians and poses difficulties to pedestrians due to the physical effort required for walking up the street. The values obtained with the inclinometer were then inserted into ArcGIS to evaluate the performance of the various streets.

Figure 30: Measuring the slope in a street in Porto (Rua Corpo da Guarda, Porto). Photos by Rui Ramos, CTAC.

3.2.6. Trees/greenery

Methods and measures adopted

Street trees and other plants adjacent to the sidewalk are a beneficial amenity for a variety of reasons, namely for shading and visual interest. In SPN, the presence of street trees was globally valued and considered positive. An average tree spacing of 8 meters (one side) was defined as the threshold value for distinguishing tree-lined from less tree-lined sidewalks. Therefore, sidewalks with at least one tree planted on both sides every 8 meters (or less) scored 1. In turn, sidewalks with no trees or with trees which had spacing greater than 8 meters scored 0. Additional factors related to trees planted on sidewalks (lateral distances, obstructions, sidewalks lifted by tree roots, tree maintenance, adequacy of the tree for the place, etc.) were not evaluated within this attribute.

Data required

Porto and Bologna do not have georeferenced street tree databases. The solution found was to make a street audit for checking the presence and counting the number of street trees by segments of 8 meters.

Example/Calculation

Figure 31 shows a street with a line of trees with a spacing of 8 m. In addition, in the case of this street (D. Pedro V), trees are well maintained and they do not reduce the sidewalk width to less than 1.5 m, they are not in conflict with adjacent infrastructure and they do not deform the sidewalk surface. Sidewalks with trees are globally more attractive for pedestrians.

Figure 31: Trees regularly planted and maintained on both sides of a street in Porto (D. Pedro V). Photos by Fernando Fonseca, CTAC.

3.3. Assessment of safety

Safety is a major barrier for walking and for choosing pedestrian routes. In the proposed SPN approach, safety refers to traffic safety and public security. Traffic safety is related to the risk of crashes with motorised vehicles and the barrier effect caused by the roads. The concept of “community severance” is also linked with this physical separation created by the roads that also produce other undesirable effects on pedestrians: delays for crossing the roads and visual effects of road infrastructures. Thus, the traffic safety attributes considered were: traffic speed, the number of traffic lanes and pedestrian crossings on roads.

In turn, public security is defined by the risk of crime, violence and incivilities on streets and public spaces. The fear and perception of crime are also described as deterrents for driving instead of walking. In SPN, public security was evaluated by considering three main attributes related to the built environment: the presence of street lighting, abandoned buildings and graffiti.

3.3.1. Traffic speed

Methods and measures adopted

It is recognised that the higher the driving speed, the higher the risk and the severity of pedestrian crashes. Low-speed limits enable pedestrians to feel a prior component of urban traffic and make them feel safe. The method adopted in SPN was an evaluation according to the legal maximum traffic speed. Streets having a 30 km/h limit scored 1 because they are safer for pedestrians, including for vulnerable groups (children, aged and disabled) and better for the environment (fewer emissions and noise). In turn, streets allowing higher speed limits scored 0, meaning that they represent higher risks for pedestrians.

Data required

The data required for assessing this attribute is the legal maximum speed allowed in each street. Basically, it is necessary to identify streets with low-speed limits (30 km/h) and streets allowing higher driving speeds (50 km/h or higher). In SPN, data was collected through a street audit and then included in ArcGIS.

Example/Calculation

Figure 32 shows a low-speed street in Bologna. In the case of this street, the sign with the speed limit was directly painted on the roadway.

Figure 32: A low-speed street in Bologna, San Lazzaro di Savena, Via Marzabotto.
Photo by Paula Saavedra Rosas, UNIBO.

3.3.2. Traffic lanes

Methods and measures adopted

Streets with several traffic lanes are associated with higher traffic volume and speeds that could be hazardous for pedestrians. Therefore, the number of traffic lanes in a corridor is an attribute that influences traffic safety, in terms of traffic speed, traffic volume, distance to cross, delaying time at crossings, etc. In SPN, streets with one or two traffic lanes scored 1, because they are easier to cross and involve fewer risks. In turn, streets with more than two traffic lanes scored 0 as they are associated with higher accident frequency levels, require more time and are more difficult to be crossed. They act as physical barriers namely for disabled and aged pedestrians.

Data required

The number of traffic lanes by corridor or street is the data required for assessing this attribute. In Porto, the number of traffic lanes was collected through fieldwork (street audit). The number of street lanes was checked and then introduced in ArcGIS. In the case of Bologna, data was downloaded from OpenStreetsMaps and directly imported to ArcGIS.

Example/Calculation

Figure 33A shows a street having one traffic lane (score 1) while Figure 33B represents a street with and multiple (5) two-way traffic lanes (score 0).

Figure 33: [A] A street with only one traffic lane (Mura di Porta Castiglione, Bologna). Photo by Paula Saavedra Rosas, UNIBO). [B] A multiple two-way traffic lane (Rua Júlio Dinis, Porto). Photo by Fernando Fonseca, CTAC.

3.3.3. Pedestrian crossings

Methods and measures adopted

Pedestrian crossings are an essential facility for helping pedestrians move safely, conveniently and predictably across roadways. However, pedestrian crossings do not fully ensure pedestrian safety, as many accidents occur in these locations. In SPN, crossings providing higher safety conditions were highly scored. Thus, crossings with central islands, hump crossings, signalized crossings and segregated crossings scored 1. Simply marked pedestrian crossings, such as zebra crossings, scored 0. Aspects such as the condition, usefulness, and visibility of pedestrian crossings were not considered within this criterion.

Data required

Detailed sidewalk data regarding the location and type of pedestrian crossings (zebra crossings, crossings with central islands, hump crossings, crossings controlled by signals, segregated crossings such as overpasses and underpasses) are needed for assessing this attribute. Data were collected through a street audit performed in Porto and Bologna. Using Google Street View for collecting this type of data has some limitations, especially because the imagery may not be recent.

Example/Calculation

Figure 34 shows an example of the geospatial process adopted for scoring the pedestrian crossings in Porto. Firstly, the crossings were mapped and described according to their attributes (zebra, signalized, segregated, etc.). Secondly, the streets were scored according to the predominant type of crossings found. In the example given, the street Mouzinho da Silveira scored 1 due to the predominance of signalized crossings, while the Largo S. Domingos scored 0 due to the prevalence of zebra crossings.

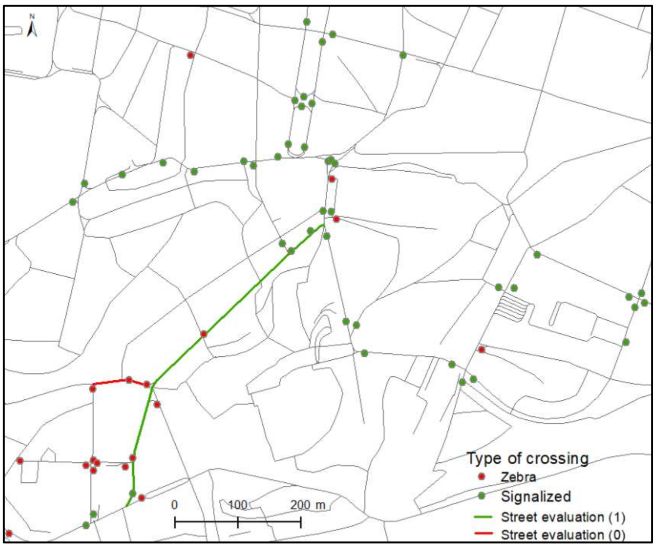

Figure 34: Type of crossings and street evaluation in the central area of Porto.

3.3.4. Security

Methods and measures adopted

Fear about personal security is one factor that influences both pedestrian route choice and mode choice. Many people do not walk because they are frightened about being attacked. In SPN, security was assessed as a composite attribute of three built environment features: street lighting, abandoned buildings and graffiti. Lighting is needed for both lateral movements of pedestrians and to facilitate their detection by motorists at crossings. Abandoned buildings, with broken windows and doors, are one of the highest symptoms of urban decay, strongly associated with illegal activities and outlaw behaviours. Graffiti is considered street art but it is also associated to decay, to communities out of control and, therefore, to perceptions of insecurity. The process adopted was: if streets have street lighting

and if the rate of abandonment and graffiti is less than about 20%, they were considered secure and scored 1; if streets have no lighting, or if more than 20% of the buildings are abandoned or have graffiti, they scored 0.

Data required

For analysing the three mentioned built environment variables, detailed street-level data is necessary regarding the existence of street lighting, abandoned buildings and graffiti. As this type of data was unavailable, a street audit was the method adopted for collecting the required data. Alternatively, Google Street View can be used to collect data if the imagery provided is recent.

Example/Calculation

Figure 35A shows an example of a street in Bologna with much graffiti on the buildings walls. In turn, Figure 35B shows an example of a street in Porto with many abandoned buildings. Both graffiti and abandoned buildings created a perception of insecurity.

Figure 35: [A] Graffiti in Via Belle Arti, Bologna. Photo by Carlo Benini, Creative Commons Attribution-Share Alike 4.0 International). [B] Abandoned buildings in Rua da Torrinha, Porto. Photo by Fernando Fonseca, CTAC.

3.4. Assessment of street connectivity

Street connectivity is an important variable of the built environment due to its implications on walkability and on human behaviour. Street connectivity analyses the characteristics of the street network but differs from other indicators, such as accessibility. Thus, connectivity provides a complementary and different approach of the street network, which is not supported on distances or proximity, but in the structure and spatial organization of the street network. As mentioned in Subsection 2.4, several measures have been proposed for measuring street connectivity. In SPN, street connectivity was assessed by considering two attributes: intersection density and street integration.

3.4.1. Intersection density

Methods and measures adopted

Intersection density measures the density of intersections in an area or over a specific length. It is one of the most adopted measures for analysing street connectivity. In SPN, intersection density was calculated as the number of intersections per unit area, a 200 m buffer around specific locations. It was decided to use small buffer areas (200 m or 5 minutes walking) to capture the different grid street patterns in both cities.

Data required

The data required for the calculation is a shapefile representing the street network. Street network data is often available at GIS municipal services or OpenStreetMap.

Example/Calculation

Figure 36A shows the density of intersections in the city centre of Bologna around the Piazza del Nettuno, while Figure 36B shows the density in a residential area of Bologna (Piazza Giovanni da Verrazzano). The intersection density in the city centre reaches 0.325 intersections/12.5 ha (buffer area), while in the selected residential area it only reaches 0.05 intersections for the same area. These examples show that the city centre has many more connections and provides more route options, while the residential area has a much lower street density and is less pedestrian-friendly.

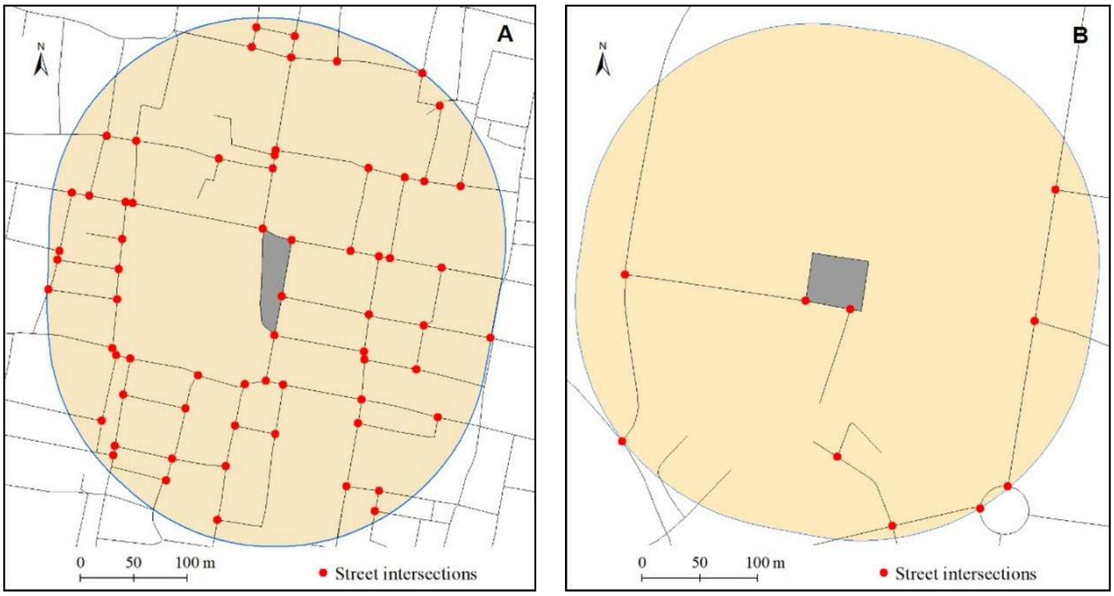

Figure 36: Street intersection density around the Piazza del Nettuno (A) and the Piazza Giovanni da Verrazzano (B), Bologna.

3.4.2. Street integration

Methods and measures adopted

Street connectivity was also assessed by considering street integration measured in space syntax. When compared to more simple street connectivity measures, space syntax has some advantages as it shows how topologically close a street is to all other streets within a specified street network, reflecting more suitably movements in network-configured human settlements. A more integrated street network requires fewer turns to reach a destination from other streets. In SPN, street integration was calculated by using the DepthmapX software.

Data required

The data required for analysing street integration on DepthmapX is a Cad file representing the street network. DepthmapX is an open-source software, while street Cad files are often available at GIS municipal services or can be easily converted from a *shapefile* containing the street network.

Example/Calculation

Figure 37A shows the result of the spatial network analysis performed with the DepthmapX software for the central area of Porto. Figure 37B shows the spatial analysis and the street ranking obtained according to the level of connectivity. Higher space syntax values correspond to streets with many connections (nodes) and vice versa.

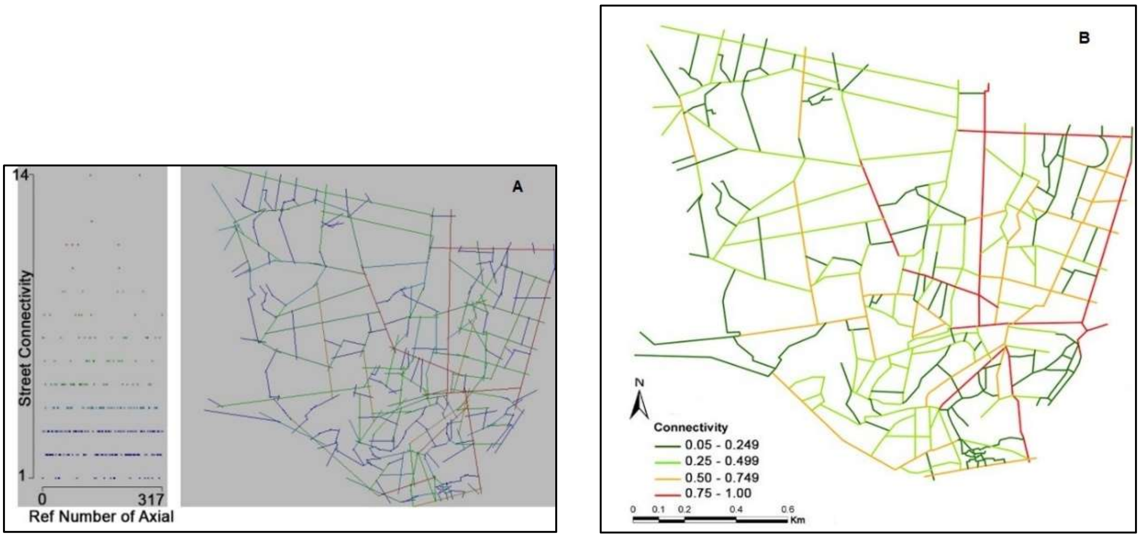

Figure 37: Street connectivity of the Porto central area calculated in the DepthmapX (A) and analysed in GIS (B).

3.5. Land use

Land use is one of the most important walkability determinants due to its broader impacts on walkability in terms of distances to destinations, street connectivity safety and pedestrian facilities. Land use planning is a basic process for planning, organising and managing regulations to control the existing and future land uses according to various purposes. Thus, land use planning could have a direct impact on walking by protecting the existing conditions of a street, promoting certain uses in a given area, restricting the use of cars, promoting the use of public transport, creating green corridors and green areas and by adopting various processes towards more active and sustainable urban environments. It is recognised that neighbourhoods with high population density and mixed land uses are globally more pedestrian-oriented. In SPN, land use was evaluated by considering population density, residential density, non-residential density and land use mix.

3.5.1. Population density

Methods and measures adopted

High population density areas have more pedestrian demand and often have more pedestrian movement. In SPN, the population density was calculated based on the most recent and disaggregated statistical data available – the 2011 Census tracts. The calculation consisted of dividing the population that was living in each tract by the respective area of the tract (inhabitants/ha). The average population density was used as the threshold value to distinguish areas with higher densities from areas with lower population densities. Therefore, the streets in areas with densities above the average scored 1 while streets in lower densities scored 0.

Data required

Statistical tracts were downloaded from the 2011 Census data provided by the Portuguese and Italian National Institutes of Statistics. Statistical tracts can be downloaded in a georeferenced format, containing GIS (tract polygon) and statistical data.

Example/Calculation

Figure 38 shows the population density in Porto at the finest disaggregation - the statistical tracts subdivision. According to the Census of 2011, the city had a population of 237,591 inhabitants and a density of 57.4 inhabitants/ha. The map represents the tracts that had a density above and below the average population density. The described process can be replicated in smaller parts of the cities.

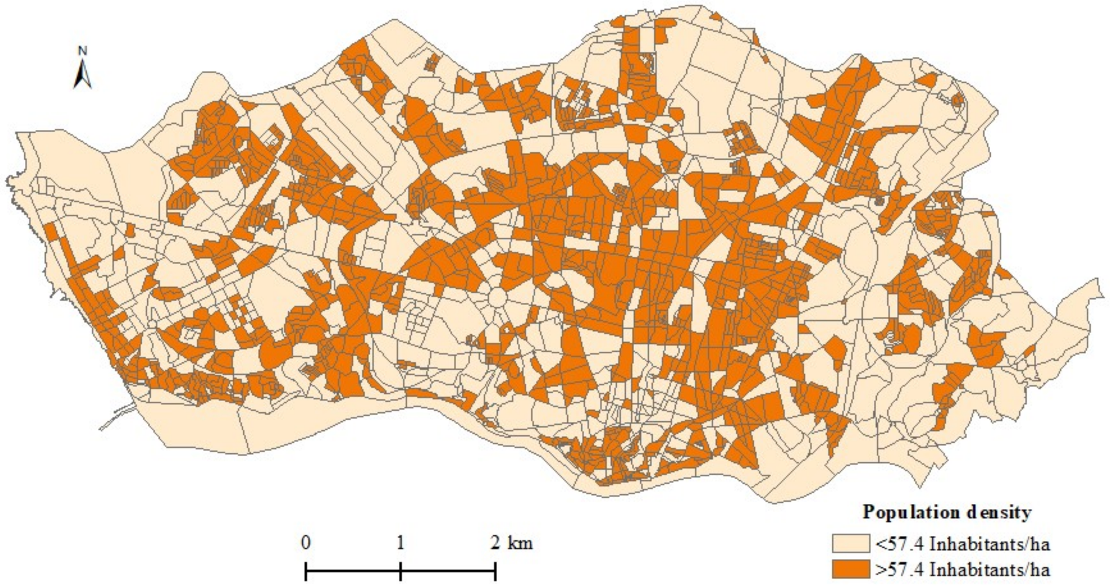

Figure 38: Population density in Porto.

3.5.2. Residential density

Methods and measures adopted

People dwelling in low residential density areas were found to walk less (and drive more) than people dwelling in the high residential density areas, due to the fact that high-density areas are usually more mixed and interconnected. Thus, many GIS-based walkability indices include residential density measures. In SPN, residential density was evaluated as the number of dwellings per unit area (ha). The method adopted was to use the density average to distinguish areas with higher densities from areas with lower residential densities. Streets in areas with densities above the average scored 1 while streets in lower residential densities areas scored 0.

Data required

The number of residential units was obtained from the 2011 Census data provided by the Portuguese and Italian National Institutes of Statistics. Data was downloaded at the most disaggregated level (statistical tract) in a GIS format. All spatial operations and calculations were performed on ArcGIS.

Example/Calculation

Figure 39 shows the residential density in Porto at the finest disaggregation - the statistical tract subdivision. According to the Census of 2011, the city had 137,371 dwellings and a density of 33.17 dwelling/ha. Figure 39 represents the tracts that had a density above and below the average population density. The described process can be replicated in smaller parts of the cities.

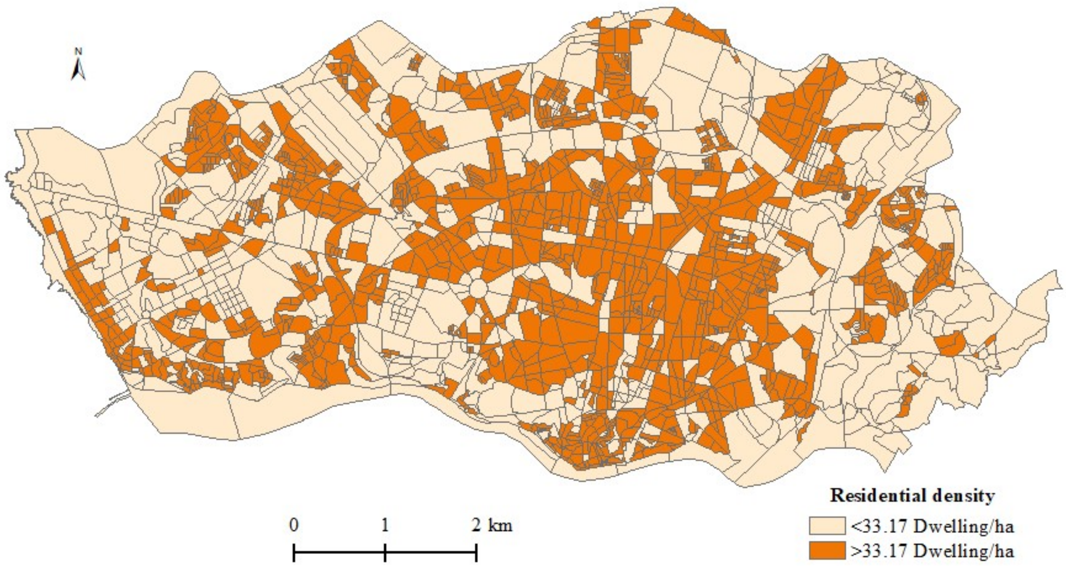

Figure 39: Residential density in Porto.

3.5.3. Non-residential building density

Methods and measures adopted

There are many non-residential uses in urban spaces, such as offices, shops, recreational spaces, urban parks, etc. These non-residential areas globally have low residential densities. Nonetheless, the density of services, shops, cultural/educational, and physical activity facilities had significant positive relationships with walking. In SPN, the density of non-residential land use was measured as the total non-residential building divided by the total land area of the statistical tracts. The average number of non-residential buildings in a given study area was then used for distinguishing the higher from the lower non-residential densities. The streets in areas with densities above the average were scored with 1, while streets in lower densities scored 0. The floor area of the non-residential buildings was not available, which enabled the calculation of the Floor Area Ratio (FAR).

Data required

The number of non-residential buildings was obtained from the 2011 Census data provided by the Portuguese and Italian National Institutes of Statistics. Data were downloaded at the most disaggregated level (statistical tract) in a GIS format. All spatial operations and calculations were performed on ArcGIS.

Example/Calculation

Figure 40 shows the non-residential density in Porto at the statistical tract subdivision. According to the Census of 2011, the city had 657 non-residential buildings and a density of 0.16 building/ha. Figure 40 represents the areas having non-residential buildings above and below the average. Many of the residential buildings are located in the city centre, which corresponds to the area with the highest concentration of shops, offices, hotels, etc.

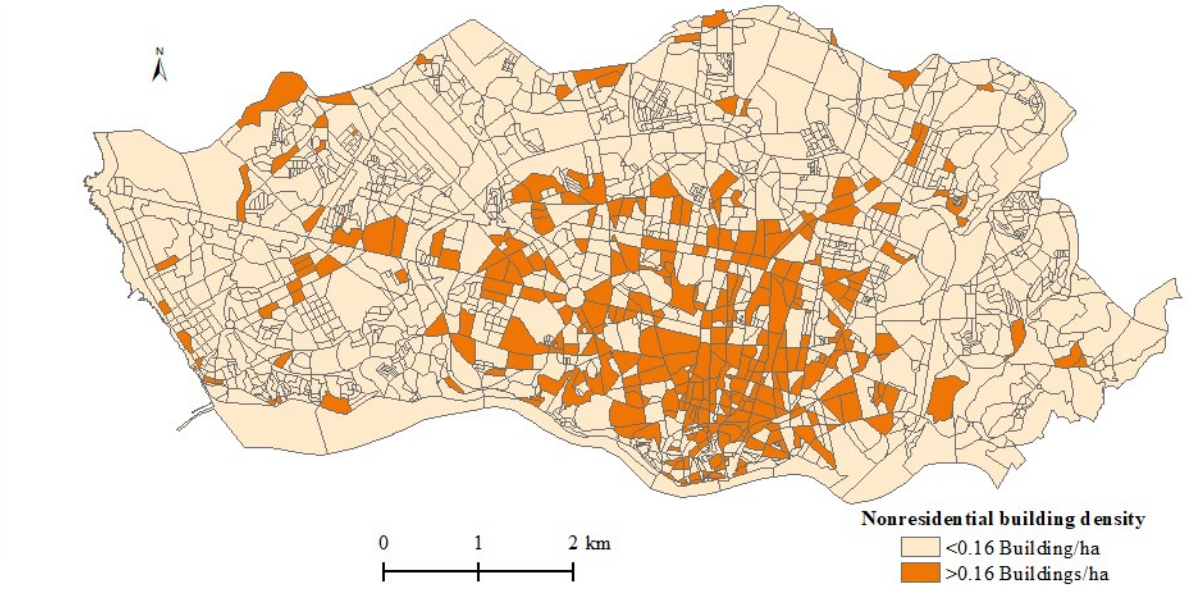

Figure 40: Non-residential building density in Porto.

3.5.4 Land use mix

Methods and measures adopted

Land use mix is one of the most used attributes in walkability studies and indexes. Mixed land uses typically result in shorter distances between origins and destinations, which encourages walking. The method adopted for measuring this attribute was a modified version of the Shannon land-use diversity index. The equation for calculating the entropy was the following:

$$LUM = -1(\sum_{i=1}^{n} pi * \ln(pi))/\ln(n)$$

Where:
LUM is the land-use mix score
pi is the proportion of the neighbourhood covered by the land use
i against the summed area for land-use categories of interest
n is the number of land-use categories of interest.

SPN adopted a changed version of the equation because, due to the lack of data, land use was replaced by the land use occupied exclusively by residential buildings, by non-residential buildings and by mixed buildings (both residential and non-residential). Thus, the number of categories analysed was three. A land-use mix score 0 indicates the area containing a single building use type, while a score of 1 indicates the highest possible mix.

Data required
The assessment of this attribute required disaggregated georeferenced data regarding the type of building (residential, non-residential and mixed). Data were extracted from the 2011 Census database provided by the Portuguese and Italian National Institutes of Statistics.

Example/Calculation
The land use mix map obtained for Porto is presented in Figure 41. It can be concluded that the level of mixed land use is globally low, mainly in the areas which are more distant from the city centre, where the residential use prevails. In turn, the highest level of mixed land use was found in the centre (0.6), where there is more commercial and tourist activity, offices, restaurants, etc.

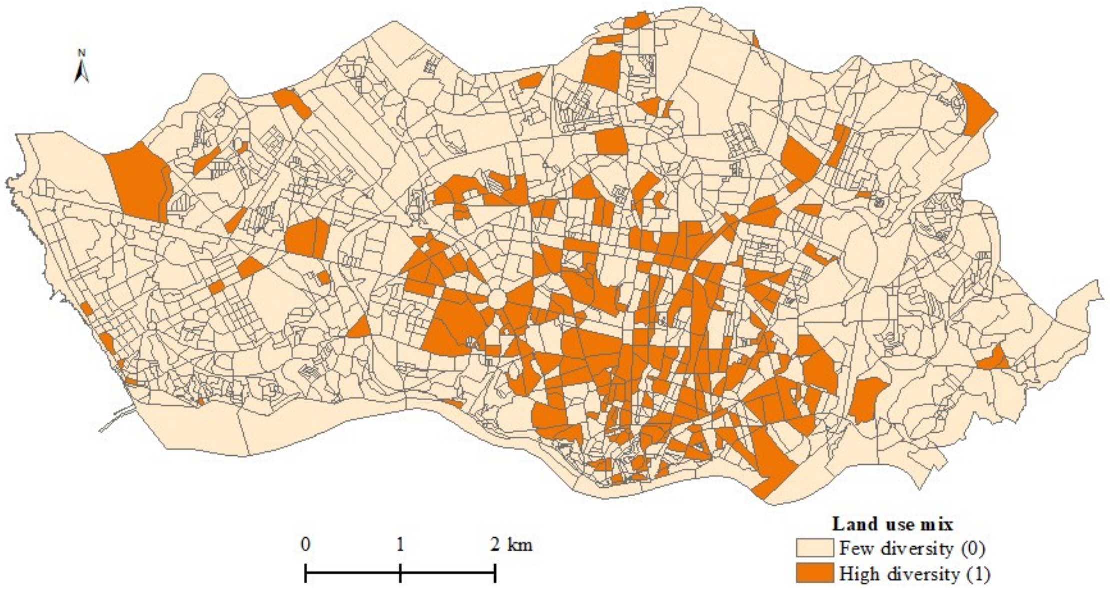

Figure 41: Land use mix in Porto.

3.6. Assessment of urban and street design

Design attributes are broadly defined as perceptual qualities known to contribute to the experience and satisfaction of walking. Design features are determined by aspects related to urban structure and land use, but also by aspects related to the streetscape level. The design attributes evaluated in SPN were mostly related to streetscape level: human scale, enclosure, complexity and transparency.

3.6.1. Human scale and enclosure

Methods and measures adopted

The ratio building height to the street width (H/W) was used to measure human scale and enclosure. The H/W is a three-dimensional ratio that relates the average building height to the street width and, therefore, evaluates various aspects that mostly define the human scale and the sense of enclosure: tall buildings and adjacent available space. In SPN, an H/W ratio changing from 0.5 to 2.5 was defined as providing adequate human scale and enclosure levels. Thus, if the H/W ratio was lower than 0.5, streets scored 0 as spaces are too large and may provide long sightlines into the distance. If the H/W ratio was greater than 2.5, streets also scored 0 as spaces create an excessive sense of enclosure. In turn, if the H/W ratio was between 0.5 and 2.5, streets scored 1, meaning that the buildings' height and street width are proportionally designed.

Data required

The data required for calculating the ratio is the building height and the street width. These building and street attributes were provided in a GIS format by the municipalities for the study areas.

Example/Calculation

Figure 42A shows an example of a street with an H/W ratio higher than 1.6, while Figure 42B shows a street providing an adequate human scale (0.6).

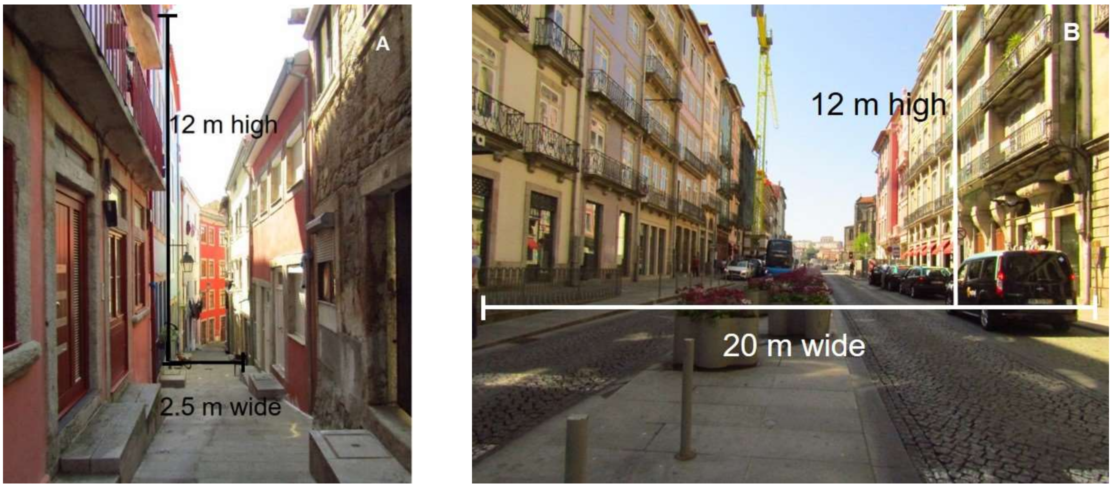

Figure 42: [A] Rua dos Pelames and [B] Rua do Infante, Porto. Photos by Mona Jabbari, CTAC.

3.6.2. Complexity

Methods and measures adopted

Complexity is one of the most difficult design qualities to be measured. The complexity of a place depends on various physical environment features and activities. In SPN, the diversity of building colours, the presence of outdoor dining and public art on the streets were the features selected for analysing complexity. They correspond to the three complexity features highly scored by Clemente et al. (2005). The evaluation was performed through a composite measure by multiplying partial scores (also adapted from Clemente et al., 2005) to the occurrences of design features on streets. The partial scores were as follows: building colours (0.245), outdoor dining (0.446) and public art (0.309). If the final value of this composite measure is greater than 3, streets are high in complexity, and therefore scored 1. If the composite measure has a value lesser than 3, streets are low in complexity and scored 0.

Data required

The analysis of the three mentioned design features requires very detailed street data regarding the diversity of building colours, the presence of outdoor dining and public art. The required data were collected in a street audit in Porto and Bologna. Online services, such as Google Street View, also have some potential to collect data for evaluating complexity.

Example/Calculation

Figure 43 shows two examples of complex public spaces. Both cases present visual richness, streets where there are places to dine, street art, many historical buildings and colour variation.

Figure 43: Street scenes with high complexity: Praça da Liberdade, Porto [A] (photo by Fernando Fonseca, CTAC) and Via degli Orefici, Bologna [B] (photo by Bianca Ackermann, Unsplash).

3.6.3. Transparency

Methods and measures adopted

Building walls namely from storefronts should provide medium to high levels of transparency, allowing a direct visual connection between pedestrians on sidewalks and the activities occurring indoors. At night, transparency is also a secondary source of lighting. In SPN, transparency was assessed by considering the proportion of windows at street level. This was the feature highly scored by Clemente et al. (2005) for measuring transparency. The proportion of windows at street level was recorded as a decimal. Blank walls and frontages with reflective glass were considered low transparent. Frontages with transparent windows/doors were considered as promoting high transparency. If the ratio of transparency had a proportion equal or greater than 50%, the street was considered transparent and scored 1. If the ratio was lower than 50%, the street was classified as low transparent, and therefore was scored 0.

Data required

The analysis of this design attribute needs disaggregated spatial data regarding the proportion of street windows along with ground floor levels. In SPN, data was collected by promoting fieldwork (a street audit). Online map services, such as Google Street View, can also be useful for collecting this type of data.

Example/Calculation

Figure 44 exemplifies the process of measuring transparency in a street in Porto (Rua de Cedofeita). This is a commercial street that has an estimated proportion of street windows along with the sidewalk level of 70%. Usually, residential streets provide lower transparency levels than commercial streets due to privacy and security reasons.

Figure 44: A street with a high transparency level (Rua de Cedofeita, Porto).
Photo by Fernando Fonseca, CTAC.

4. CONCLUSIONS

The concept of walkability has gained enormous popularity over the last years due to its potential to promote more sustainable urban environments and lifestyles. Walkability has been widely used to show how an urban area is pedestrian-friendly. The walkability concept has been described in terms of various built environment and streetscape attributes that can be used to designate if an area is walkable or not. In this context, the Smart Pedestrian Net (SPN) approach is proposed, aiming at developing a holistic and integrated method for assessing and improving the conditions provided to pedestrians. This book describes the approach adopted for SPN to assess walkability in two areas of Porto and Bologna. The approach is supported by 23 built environment and streetscape attributes that have a significant impact on the decision to walk, as well as on the satisfaction one gets from walking.

This book explained how the various walkability attributes were selected and evaluated. Insight is provided on the data required to assess each attribute and on the methods used for making the evaluation. In order to illustrate the application of SPN, various pictures and maps were depicted from the evaluation made in Porto and Bologna. This book shows that some limitations found in walkability indexes can be overcome by assessing a higher number of built environment attributes and by assessing both mesoscale and microscale attributes.

The steps for assessing the streets in an urban area were fully provided and described. To develop such an assessment method, it is necessary to have: i) the street network and desirably the pedestrian network of the area to be assessed; ii) data for describing and assessing each attribute through street audits (fieldwork), online map services, city and other georeferenced databases; iii) assigned scores according to the presence/absence and the condition of each score; iv) a GIS model for making a spatial analysis and developing the multi-criteria analysis; v) thematic maps in GIS software, representing the performance of each criterion.

The contents presented in this book correspond to the first work packages of the SPN project, which attempt to determine the standards of a pedestrian network and define a global comprehensive assessment method for walkability. The findings obtained were vital for developing the next steps of the project, especially to involve pedestrians from the two cities in defining the relative importance of each attribute and to define policies to improve walkability.

The work presented in this book shows the following:

- There are many factors and attributes affecting walkability. Moreover, obtaining data for objectively assessing walkability could be a difficult and time-consuming process. This was particularly true in the case of the streetscape and design features. Disaggregate data for evaluating these attributes was not available which required fieldwork and careful inspections carried out by a team of experts.

- Even though a large number of attributes were used within SPN, many were not included, due to the difficulty in obtaining data, in making objective assessments or because they are considered less relevant.

- The methods selected for making the evaluation are globally simple, functional, objective and replicable.

Nonetheless, some aspects can be rethought or reconsidered in future applications of the proposed SPN assessment. Firstly, the assessment was based on a 0 to 1 scoring process according to the presence and performance of each attribute. It is recognised that a larger scale (for instance 0 to 2) could be more suitable for evaluating attributes that require a greater degree of detail. This could be also applied to the threshold values used in some attributes to distinguish a “good” from a “poor” performance. For instance, places located at 50 m or 399 m from a bus stop were equally scored (1). Intermediate values could be useful for providing a finer evaluation, for instance, according to buffer distances of 100 or 200 m.

Secondly, the use of the real pedestrian network instead of the street network will provide a much more accurate assessment. A street network does not include pedestrian walkways, footpaths, crossings, stairs, pedestrian tunnels and bridges that are used by pedestrians in their daily trips. As the municipalities of Porto and Bologna do not have the “real pedestrian network” georeferenced, the solution adopted was to use the street network, which does not entirely correspond to the pedestrian environment.

Thirdly, distances were evaluated considering aerial distances from specific dots, such as bus stops. A buffer based on Euclidian distances does not rigorously reflect the real walkable distance that is often shorter than that given by the buffer. Using the real distance (street network) instead of the air distance will provide finer results, but such network analysis also required the real pedestrian network in GIS support. As mentioned above, the real pedestrian network, including footpaths and off-street pedestrian connections, was not available. This also has impacts on street connectivity that could be assessed by including footpaths (directness).

Fourthly, some attributes, such as traffic volume and floor area ratio, were not evaluated due to the lack of data. As highlighted in some pedestrian studies, the lack of available and consistent street and parcel-level data has been described as the main barrier for evaluating this type of attributes.

Besides the mentioned limitations, this book exemplifies how a significant list of interconnected attributes can be used to evaluate walkability in a multiscale (meso and micro) approach. The authors believe that this work can be helpful not only for researchers in improving knowledge on walkability but also for urban planners, designers and policymakers in identifying areas where walkability needs to be improved and to understand where the most critical situations exist. Furthermore, the book could be used as a starting point to develop new European and international standards in aspects of urban sustainability.

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