TÉCNICO LISBOA

Walkability Assessment for the Urban Environment

Lisbon Case Study

Luis Maria José de Mello

Thesis to obtain the Master of Science Degree in

Civil Engineering

Supervisor: Prof. Filipe Manuel Mercier Vilaça e Moura

Examination Committee

Chairperson: Prof. João Torres de Quinhones Levy

Supervisor: Prof. Filipe Manuel Mercier Vilaça e Moura

Member: Prof. Ana dos Santos Morais e Sá

September 2015

Acknowledgements

Foremost I wish to thank my parents and family for their unconditional support through my student path.

The IAAPE team, Prof. Filipe Moura, Prof. Alexandre Gonçalves, Paulo Cambra and Sérgio Correia were crucial for this dissertation by providing not only guidance but also help and to allow me to be part of the project. I also want to thank Carolina Figueiredo, Marcos Correia and Hugo Nunes for their time on the street auditing process.

ABSTRACT

Whether you live in a city or a small town, and whether you drive a car, take the bus or ride a train, at some point in the day, everyone is a pedestrian. Many factors are linked to what makes an environment pedestrian friendly: built environment, weather and even crime rate, to mention a few aspects. Walking also brings many benefits such as of health problems and the reduction of pollution. Turning cities into more walkable spaces and more pedestrian orientated is of very high importance.

Walkability assessment is a way to measure if an urban environment is pedestrian friendly. Many studies are addressing this concept, although it is not recent. A large number of experts consider that it is possible to assess walkability by analyzing built environment. This dissertation follows this approach.

As part of the IAAPE project (Indicators of accessibility and attractiveness of pedestrian environments), this dissertation aims to contribute to the GIS-based framework to assess walkability, by proposing a set of indicators and value functions to quantify all the dimensions of walkability. To do so, the main objective is to collect as much information regarding indicators related to walkability as possible, normalize their values and couple them in the IAAPE framework.

The main conclusions were that different pedestrian groups (adult, children, elderly, impaired) would chose different indicators for the several dimensions of walkability analyzed according to the 7 C's (connectivity, convenience, comfort, conviviality, conspicuousness, coexistence and commitment) and that these would be different depending on the type of trip motive, i.e., leisure or utilitarian. The choice and transformation of indicators is critical in the procedure, due to different aspects: availability of databases, possibility of street auditing, and possibility to calibrate the value functions for normalization.

The model was applied to a case study in Lisbon, Portugal. The chosen area was Arroios, where urban design features are diversified. The results suggest that this methodology is transferable but further research should be done to refine the model, for instance regarding the scales using for the indicators and the value functions for normalization.

Keywords: Walkability, pedestrians, multicriteria assessment, Delphi, indicators

Table of Contents

Figure Index

Table Index

1. Introduction

1.1 Motivation and research problem

As the U.S. Secretary of Transportation, Anthony Foxx, once said "*Whether you live in a city or a small town, and whether you drive a car, take the bus or ride a train, at some point in the day, everyone is a pedestrian*". Pedestrian walking quality should therefore be a top priority for governments.

Walking is also associated with a very large number of benefits not only to the active person but also to the community: it reduces pollution emissions, reduces obesity related health problems and creates more "livable communities" (Cambra, 2012; Coffee, Howard, Paquet, Hugo, & Daniel, 2013; Frank et al., 2006; Park, 2008). John Butcher, the founder of Walk 21, points out a number of advantages on walking: the streets become safer with the present of people, it's cheap, it develops trade and tourism and it's a great way of socializing and interacting with the urban environment.

Although Humans have started walking long before we started driving, there are currently more studies on how to assess motorized vehicles quality of circulation than pedestrians'. However in more recent years, a very large number of studies have been done on walkability. Walkability is simply how pedestrian friendly is the environment (Abley, Turner, & Singh, 2011). Although this concept has a relatively simple definition, measuring walkability is not short of a very complex problem. Most experts use built environment to assess and measure how pedestrian friendly the environment is. The motivation for this dissertation is to contribute to the development of such a model that can measure walkability.

This dissertation is part of the IAAPE project – Indicators of Accessibility and Attractiveness of the Pedestrian Environment (http://www.iaape.org). The concept behind the IAAPE project is to innovate the methodology for walkability assessment in urban environments by using an analytical framework based on GIS (Geographic Information Systems), making a further validation of the results obtained by analyzing case studies. This tool targets local authorities (Municipalities) as principal users that can analyze the impact of urban planning policies on the walkability performance of their cities. IAAPE builds upon the work by Cambra (2012).

1.2 Objectives

The main objective for this work is to contribute to IAAPE's GIS-based framework to assess walkability, by proposing a set of indicators and value functions to quantify all the dimensions of walkability. Pedestrians are divided into groups of citizens (adult, children, elderly and impaired) and travel motives (utilitarian and leisure). As such, the majority of users of the network are represented for the major two types of travel motives. In order to measure walkability, built environment will be assessed.

To do so, the challenging endeavor was to collect as much information regarding indicators related to walkability, as possible, normalize their values with value functions and couple them in the IAAPE framework.

1.3 Thesis Outline

In Chapter 2, an introduction to walkability is made. First, what it is and why is it important. The relevance of this concept is explained and defined. In section 2.2, the different concepts and methodologies are approached and presented. Then, literature review is performed to identify the indicators used to measure the pedestrian friendliness of the built environment. In subsection 2.3.1 main approaches to this problem are described and in subsection 2.3.2 several multicriteria analysis methods are presented.

Chapter 3 discusses and presents the different methods considered to assess walkability and which was chosen. The IAAPE project, of which this dissertation makes part, is also presented. The methodological approach is described throughout this chapter.

The IAAPE framework is described and explained in Chapter 4. This chapter presents the indicators used and discusses them, such as their value functions. A description of how the network vectorization is done is briefly explained. This topic is being explained in detail in a forthcoming dissertation by Hugo Sousa to be published as an MSc Thesis at the Instituto Superior Técnico (Sousa, 2015).

In Chapter 5, the model is applied to a case study. After a brief description of the area, the results are presented and discussed.

Finally, in Chapter 6 the overall work is summarized and leads for future research are suggested.

2. Literature Review

2.1 What is Walkability and why is it important

Walkability has been defined as "*the extent to which characteristics of the built environment and land use may or may not be conductive to residents in the area walking for either leisure, exercise or recreation, to access services, or to travel to work"* (Leslie et al., 2007). This measure is highly correlated to higher walking levels of the community in the area (Coffee et al., 2013).

Bradshaw (1993), cited by Cambra (2012) defined Walkability as "quality of place" with four characteristics:

- "*A "foot-friendly" man-made, physical micro-environment: wide. leveled sidewalks, small intersections, narrow streets, lots of litter containers, good lighting, and an absence of obstructions;*
- *A full range of useful, active destinations within walking distance: shops, services, employment, professional offices, recreation, libraries, etc.;*
- *A natural environment that moderates the extremes of weather- wind, rain, sunlight - while providing the refreshment of the absence of man's overuse. It has no excessive noise, air pollution, or the dirt, stains, and grime of motor traffic;*
- *A local culture that is social and diverse. This increases contact between people and the conditions for social and economic commerce."*

Abley, Turner, & Singh (2011) define walkability as "*the extent to which the built environment is walking friendly".* As Cambra (2012) this definition will be used in this paper as a reference.

Coffee et al., (2013) stated that health benefits of physical activity are well established and well documented by the scientific community. Also in this article it is demonstrated that in the case studies, walkability scores have a negative correlation with cardio metabolic risk.

A favorable environment to walking brings three types of benefits: social, economic and environmental benefits (Litman, 2003). By improving accessibility, the number of pedestrians is expected to increase. This decreases the transportation costs. With less automotive transport there are environmental benefits such as the reduction of the carbon emissions and the reduction of land use to build roads. According to Ariffin & Zahari (2013) walking increases neighborhood interaction and community cohesion. Moreover less roads help preserve a site's identity, adding to social benefits.

2.2 Measuring Walkability

2.2.1 Concepts and Methodologies

Although humans have started walking long before they started driving, there are currently a far superior number of studies on driving than walking. But Walkability has become one of the biggest concerns for town planners and is now the basis of a sustainable city (Ariffin & Zahari, 2013). Therefore the number of studies addressing this subject has been increasing in the past years. Despite the impressive developments in walkability measurement studies, some practical issues are found to remain unaddressed (Cambra, 2012):

• Dispersion of concepts and measurement methodologies,

• Scale of analysis,

• Urban context and origin of studies,

• Multiplicity of indicators used for assessment, and

• Model validation

Some authors consider different types of walking. Leslie (2007) considers that there are two types: walking as a mean of transport and walking for recreation. The latter incorporates walking for exercise, walking for tourism and walking as a leisure activity. According to Owen et al., (2007) different correlates of walking for transport and walking for leisure have been identified.

The goal of walking as a mean of transport is getting from an origin to a destination as quickly and as comfortably as possible. In our daily lives we do this often in journeys to work, to the supermarket or to an appointment. Walking as leisure is an activity in itself. The pedestrian's goal is not to reach a destination as quick as possible but to enjoy the trip.

Throughout the modernization of transport technology, where cars became more affordable and grew exponentially, pedestrian environment has been degraded. The built environment has been pointed out by experts such as Abley, Turner, & Singh (2011) and Leslie et al. (2007), as the main dimension to evaluate when looking to score walkability.

Owen et al., (2007) take into account social and demographic attributes when measuring walkability. According to their study, gender, age and socioeconomic status are linked to physical activity. Elderlies tend to be less active than younger demographic groups. Women have also been proven to do less high intensity physical activity compared to men. When focusing on socioeconomic status, people in higher social ranks tend to be more active in their leisure time but tend to walk less as a mode of transport due to having private vehicles. People that have more children or are overweight are more likely to perceive a walkable friendly environment as a low-walkable environment (Ariffin & Zahari, 2013).

Weather conditions have also shown to influence walking (Clark, Scott, & Yiannakoulias, 2014). This Canadian study suggests that in locations with lower temperatures, or high amounts of precipitation, it is more difficult to implement walking as a mean of transport. As seen in sub-section 2.2.2, comfort is one of the biggest concerns for pedestrians and adverse weather conditions are hard to overcome.

Doyle & Kelly-Schwartz (2006) suggest that crime rates are very repulsive to walking. In fact, neighborhoods with lower crime rates have more pedestrians. There are many studies that confirm this theory, where personal safety is correlated with pedestrian activity (Appleyard, 2003).

Cambra (2012) who had done a very extensive review of the literature defined four trends in terms of walkability:

- Quest for standardization: Action Cost 358 – Pedestrian Quality Needs (PQN)
- Quest for local methodologies: examples from South Africa, Greece and Spain
- Quest for real world applications: PERS, Walkscore
- Quest for walkable cities: Transport for London + Space Syntax

In the quest for standardization Cambra (2012) presents the PQN project with the following objectives (*Source: http://www.cost.eu/COST_Actions/tud/Actions/358 visited on 09-02-2015*):

"1. To improve the understanding of pedestrians' quality needs with regard to public space, the transport system and the social, legal and political context and their interrelations, thus developing an essential tool for the stakeholders (such as decision makers, politicians, planners as well as NGOs) that can implement better conditions for walking and pedestrians' quality of life.

2. Describe the state-of-the-art, identify an agreed set of requirements and develop a new paradigm (a coherent system of theories and models regarding adequate pedestrian facilities and qualities) that can be used by stakeholders for analyzing and improving reality.

3. Provide an accessible knowledge base and easy to use auditing scheme that enables authorities and possibly interest groups to tackle, prevent and priorities current and future problems regarding pedestrian mobility and presence in public space.

4. To stimulate partners to innovate tools and disseminate knowledge that helps in shedding new light on the issue and stimulates a new spirit in providing for safe mobility of the pedestrian.

5. To provide recommendations for further research."

This project corroborates with the concern of the governing authorities in transforming cities into more walkable environments and ultimately benefitting from its potential advantages. Also it aims to achieve the much-needed standardization in evaluating walkability.

Regarding the Quest for Local Methodologies three examples are presented: South Africa, Greece and Spain, although many other were developed each one with their own particularities. On this dissertation we will focus solely on the three examples. With pedestrian safety as the main driver for development, the Pedestrian Environment Assessment Tool has been developed by the University of Pretoria in South Africa (Albers, Wright, & Olwoch, 2010). The University of Thessaloniki in Greece has developed a model for the estimation of the pedestrian level of service for the Greek environment (Christopoulou & Pitsiava-Latinopoulou, 2012). The main contribution this project gives to the community is the different weights given to each evaluation factor. This has been done through a series of extensive questionnaires. Finally, in Spain a study by "*Centro de Estudios y Experimentacion de Obras Publicas"* (www.cedex.es), a local center for public studies has the objective of studying what influences pedestrians and to make recommendation guidelines for how to improve walking. This study involved a series of questionnaires to several age ranges of citizens. These local studies favor methodologies that are best applied to their case study and do not have the objective to standardize pedestrian analysis.

PERS, Walkscore and Walkanomics are real world applications of walkability evaluation. PERS has been developed by the Transport Research Laboratory in London and is software that enables users to determine walking scores. Indicators of walkability have different weights so it is more flexible and easier to apply to other cities (Kelly et al., 2011). It has been applied in the UK and in Australia. Walkscore and Walkanomics are both web-based applications. These apps have as an output "how walkable is the neighborhood you are looking at". While in Walkscore an algorithm is applied, in Walkanomics users score the streets according to the parameters provided.

Finally, in the Quest for Walkable Cities, the Mayor of London Boris Jonson commissioned the Transport for London committee to make London a pedestrian friendly city as much as possible, following its predecessor's goal. The scoring of walkable segments was done based on the Space Syntax methods. For further information refer to Bafna (2003) or the website: www.spacesyntax.net. The final output is a map with scoring of each segment.

When reviewing the literature a number of papers and studies were very frequently cited. These were the works of S. Abley and R. Ewing (Abley et al., 2010; Abley et al., 2011; Abley, 2006; Ewing & Handy, 2009; Ewing, 1999). Krambeck in 2006 submitted a work commissioned by the World Bank on Walkability that has great relevance to this dissertation. Krambeck has the goal of creating a method to rank cities across the World on their walkability. In order to do so, the method should be possible to apply to different cities. This is one of the goals of this dissertation. Also a dissertation by S. Park in 2008 is very much aligned with the subject of this project. The author ranks an urban area according to its walkability, this dissertation does it in a similar way.

Ewing & Handy (2009) attempt to measure the impact of the built environment on walking. A group of experts from professional practice and from academia was assembled to qualitatively define indicators to evaluate the streets. These indicators belong to five groups: imageability, enclosure, human scale, transparency and complexity. Each street is rated on these dimensions and a weighted sum is done in order to score streets. Authors were working on a validation in New York City.

Krambeck (2006) *"was retained by the World Bank to devise a walkability index, which would rank cities across the world based on the safety, security, and convenience of their pedestrian environments".* The author began by selecting a list of variables, with the help of experts, used to measure walkability. Krambeck created the *Global Walkability Index*, an index used to measure the walkability of the streets. Among the conclusions of the author were that walkability is of difficult comprehension and may lead to errors because of that, and that the field surveying is time consuming and may lead to great costs.

Park (2008) set out two main goals for his dissertation: operationalizing path walkablity by creating a tool that measures it and testing this tool and try to validate it. The author chose to evaluate four dimensions per sidewalk: "sidewalk amenities," "traffic impacts," "street scale and enclosure," and "landscaping elements". After measuring these scores a logit analysis was conducted. A survey was done in Mountain View, California to about 250 people. Park concluded that the survey confirmed that higher scores of walkability were consistent with walk friendly environments.

Abley et al. (2011) were commissioned by the New Zealand Transport Agency to undertake research into predicting walkability. Using the Community Street Review (CSR) method that consists on a group of pedestrians rating a footpath or crossing across a number of factors from 1 to 7, and the street survey developed by this author in 2006 (Abley, 2006), the footpaths and crossings were given walkability scores. *"A CSR is an assessment of the walkability of a route from the point of view of the people using the route. It focuses on peoples' perceptions regarding the road or crossing environment and how they feel when walking. It collects data on safety, functionality of the pedestrian space, ease of road crossings, effects of urban design and other walkability factors. CSRs thus include not only a qualitative consumer audit but also a quantitative rating. A CSR benefits both the immediate community (auditing) and provides practitioners with an asset management tool (rating) to prioritize potential walking schemes"* (S Abley et al., 2011). This method scored the criteria and then a weighted sum was made. Please observe the equation in Figure 1.

$$\text{Walkability}_{\text{Path Length}} = 4.426 + 0.561\,\text{footcon} + 0.300\,\text{green} - 0.378\,\text{vspeed} + 0.294\,\text{comfort} - 0.464\,\text{devi} + 0.415\,\text{pa+res} + 0.170\,\text{min ewidth} - 0.186\,\text{numhide} - 0.0034\,\text{Avg stepav} + 0.201\,\text{dese}$$

Figure 1 – Example of walkability of street used in Abley, 2006

2.2.2 Walkability Indicators

Although walking is the simplest form of transport, assessing and measuring walkability is a very complex problem. It is not consensual which indicators should be used to measure walkability. We have seen in sub-section 2.1.2 that the scientific community has different opinions on what affects this measure: some propose that the weather should be taken into account and others the crime rate, and so on. For the purpose of this dissertation we will focus on the built environment.

Methorst, Bort, Risser, & Sauter (2010), responsible for the Action Cost 358, propose that there are several ways of assessing an object and created Figure 2. It is defended that these methods have no hierarchy and should complement each other. However a number of specialists argue that objective measurements should be used as often as possible in order to reduce ambiguousness by evaluators (Duncan, Aldstadt, Whalen, & Melly, 2013; Keast, Carlson, Chapman, & Michael, n.d.; Leslie et al., 2005; Villanueva et al., 2014).

	"qualitative" results usually based on small numbers, approximations, judgments, descriptions (verbal data)	**"quantitative"** results usually based on larger (representative) figures
"subjective" results usually based on personal perceptions and opinions	*Example:* Community street audit *(How community members judge safety of a crossing)*	*Example:* Population survey about attitudes towards walking *(How safe people feel generally)*
"objective" results usually based on 'immediate reality' ('objectivated' judgments)	*Example:* Expert street audit based on norm checklist *(How well a street fulfills official safety requirements)*	*Example:* Counts and 'hard' data collection *(How many people got killed and seriously injured)*

Figure 2- Classification of Assessment Methods (Source: Action Cost 358)

There has been an effort from the scientific community to aggregate the factors that affect walking into dimensions or groups. Cervero & Kockelman (1997) proposed three dimensions: Density, Diversity and Design. Ewing & Connors (2013) proposed a revision of these three dimensions by adding two more: Destination Accessibility and Distance to Transit.

Transport for London (cit. Cost 358) has proposed that pedestrian needs and concerns should be aggregated in five groups or "Five Cs":

- "*Connected: The extent to which the pedestrian network links to key trip origins and destinations, as well as the extent of linkages between different routes on the network;*
- *Convivial: The extent to which walking is a pleasant activity, in terms of interaction with people, the built and natural environment, and other road users;*
- *Conspicuous: The extent to which walking routes and public spaces feel safe and inviting for pedestrians, in terms of clear and legible signing and information;*
- *Comfortable: The extent to which walking is accommodated to competences and abilities of all types of pedestrians;*
- *Convenient: The extent to which walking is possible and able to compete with other modes of transport in terms of efficiency (time, money and space)."* (Cambra, 2012)

Cambra (2012), after an extensive review of the literature proposed to add two more Cs: coexistence and commitment.

Lack of coexistence has been one of the main reasons people walk less. The presence of motorized vehicles affects safety and comfort. The priority set out in the past century to improve cars accessibility has degraded the pedestrian network and therefore discouraged people to walk.

Commitment by the policy maker and local communities is essential in a way that the authorities control and plan the built environment and local associations promote walking. As demonstrated previously, built environment has a great impact on walking activities. Moreover the policy maker could create incentives and programs to encourage walking. A number of programs have been organized in the US by the American Heart Association. The first promotes local events called “Heart Walks” that are the association’s premier fund-raising events (http://www.heart.org/). In Lisbon, Portugal the Mayor of Lisbon has ordered the construction of several cycle and walk paths through the city. These are aimed at promoting a healthier lifestyle (http://www.cm-lisboa.pt/).

In short, the present research focuses on the 7Cs of walkability proposed by Cambra (2012):

- Connectivity;
- Conviviality;
- Conspicuousness;
- Comfort;
- Convenience;
- Coexistence;
- Commitment.

One of the difficulties encountered at this stage were the lack of information on indicators given by the authors. Some only state the importance of a certain aspect for walking but do not suggest how it should be measured. On Chapter 3, this struggle will be further commented and it is shown how it was overcome.

A full list of indicators found in the literature can be found in Annex I.

2.3 Integrating Multiple Dimensions of Walkability

2.3.1 Multiple approaches

Walkability, as referred previously is influenced by a variety of factors. In this chapter, some methodologies will be presented and discussed.

Fruin (1971) was the first to introduce the concept of Level of Service (LOS) to pedestrians. The author scored the environment from LOS A (best) to LOS F (worst) according to pedestrian flow rates and densities. Fruin presented a formula to assess this problem according to each situation. This method is a qualitative method of evaluating the infrastructure.

The LOS method has been widely used to measure performances for motorized vehicles and also to assess pedestrian performance by the Transportation Research Board, on the Highway Capacity Manual (HCM-2000). The HCM is one of the most used set of methods to calculate performance for motorized vehicles. This Manual admits that environmental factors are the essential part of the pedestrian experience and should be taken into account when determining the LOS. This is a measure of comfort, convenience, security and economy.

Steve Abley (2006) considers there are three techniques available to assess the performance of the built environment: by reviewing existing situations, by auditing existing or proposed designs and by rating the facilities according to its walkability features. In this dissertation we will focus on the latter. Abley et al. (2011), used the Community Streets Reviews (CSR) method as well as physical and operational data collected using the Walkability Tools Research Manual (Abley, 2006). In order to select which variables to be used, a correlation between them was made and not all of them were included. Variables that had very high correlation among them were excluded in order to avoid skewing of the results. To assess all the variables would be unfeasible. In an attempt to exclude human behavior and subjective evaluation, a manipulation of the data was made: first an adjustment of participant mean ratings, then an addition of mean participant rating. "*This was done by calculating the average walkability score of the common participant for the given site, and adding the average walkability score of the common participant to the values obtained from Step 1"* (S Abley et al., 2011). This procedure was made to sidewalks and crossings separately. The final formula is presented in Figure 1.

Krambeck (2006) set out a very ambitious goal: to find a global walkability index for cities across the world. Without scoring, the author proposed a method on how to do it. Data should be gathered through surveys on public agencies and an area survey. For the public agency survey, it is asked to assign the responses, and then they are summed and normalized from all cities. The area survey is done with a LOS measurement according to the guidelines provided. The LOS are also normalized. A final average is calculated from the sum of the averages for ach survey area. Each average is weighted equally. This result is later added to the average from the public agency. A z-score is calculated from this result to avoid problems of scale when comparing countries. This final score is the Walkability Index. The author then questions weather if the averages should have different weights in order to reduce skewing from less important variables. It is concluded that it is a very complex problem and should require further investigation. The methodology proposed by Cambra (2012) and further developed in (Moura et al., 2014) aims to complete the weighing step and final validation step.

Park (2008) explored two ways of operationalizing micro-level walkability: inductive and deductive operationalization. The first method ignores the scientific literature and tries to find walkability components from his measurements. Walkability components are obtained through regression model of several walkability indicators. In Figure 3 a scheme is presented to understand the components.

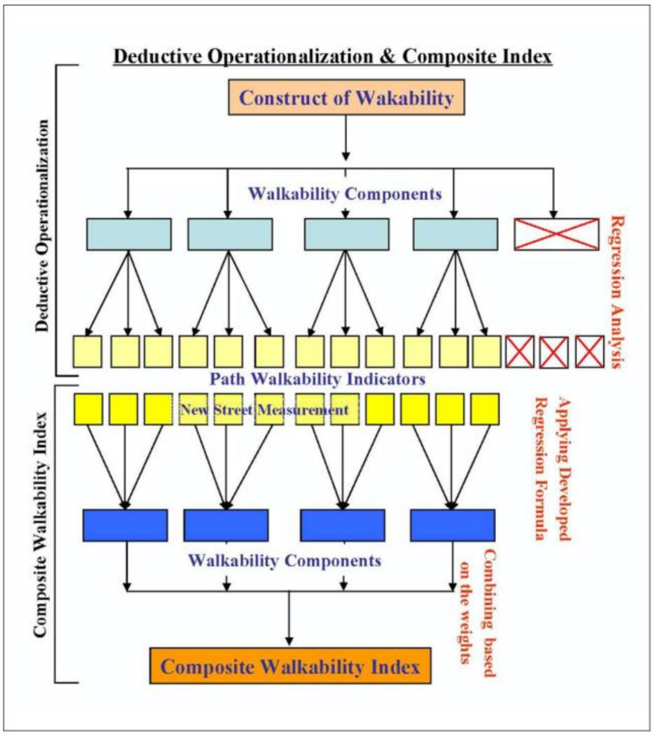


Figure 3-Creating a Composite Index (Park, 2008)

The second method is more relevant to this dissertation and was called the Composite Walkability Index. "*This composite walkability index will allow other researchers to calculate a walkability index directly from their own walkability measurements, and to compare the index of one street/route to another*" (Park, 2008).

Starting with 52 path walkability indicators, collected from the literature, Park eliminates those who, through a factor analysis, appear to have little or no correlation with pedestrian behavior. Factor analysis was proposed by Cervero & Kockelman in 1997 in order to reduce the number of variables and prevent multicollinearity. Park then applies a Developed Regression Formula, and obtains Walkability Components.

Finally, Park calculated the weight values from surveys made to users in his case study. The final walkability measurement is a weighted sum of walkability components.

Frank et al. (2006) measured street walkability using a "walkability index". This method consists on a composite measure of the built environment, and summing z-scores for net residential density, intersection density, land use mix and retail floor area for each census group. This method has been used in other papers (Owen et al., 2007; Saelens, Sallis, & Frank, 2003). In this case, street connectivity was given twice the weight as other values (a decision was made by the author). Moreover the criterion used has not been always the same: on previous works, retail floor area was not considered.

This far we have covered the most important, and most used, approaches to the multiple dimensions of walkability. As it was demonstrated, there is not a consensus on how to measure, how to score and which dimensions to use when assessing walkability. In the next chapter, we review some of the most relevant works on how to score the weights to measure walkability.

2.3.2 Multi criteria Assessment

Although there has been an increase in literature on walkability in the more recent years, methods to aggregate the several dimensions of walking are still not consensual amongst experts. Although some papers simplify the problem by assuming that all criterion evaluated should have the same weight, others try to take a step further. We will expose different methods of ranking importance of the criteria. Amongst others, the Analytical Hierarchy Process (AHP), the fuzzy set theory and the Analytical Network Process (ANP) are the most frequently used methods.

The AHP was developed by Saaty (1977) and is a multi-criteria decision making method to determine which alternative are most important relative to each other. This method allows using quantitative and qualitative methods which is a definite advantage when solving complex problems (Vidal, Marle, & Bocquet, 2011).

The AHP, like others, uses pairwise comparisons between two elements and creates a ratio scale. These are done by asking how more valuable for a criteria C is an alternative A compared to an alternative B. Saaty developed scales that transform these choices and results into numerical values. In Figure 4, the matrix exemplifies the pairwise comparisons and values that are comprised between 9 and 1/9. Diagonal values are 1. The element *ij* is the comparison between i and j regarding the considered criterion. Where *ji*=1/*ij*.

$$\begin{bmatrix} 1 & a_{12} & \dots & a_{1i} & \dots & a_{1j} & \dots & a_{1n} \\ 1/a_{12} & 1 & \dots & a_{2i} & \dots & a_{2j} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ 1/a_{1i} & 1/a_{2i} & \dots & 1 & \dots & a_{ij} & \dots & a_{in} \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ 1/a_{1j} & 1/a_{2j} & \dots & 1/a_{ij} & \dots & 1 & \dots & a_{jn} \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ 1/a_{1n} & 1/a_{2n} & \dots & 1/a_{in} & \dots & 1/a_{jn} & \dots & 1 \end{bmatrix}$$

Figure 4 - AHP pairwise positive comparison matrices (Vidal et al., 2011)

Behzadfar, Habibi, & Shahmoradi (2012) used the AHP combined with GIS to select which areas to implement urban regeneration work in Zanjan City, Iran. Seven causes and factors that affect pedestrians were chosen for this process. The AHP was then carried out and resulted in a selection of one part of the town that residents find more urgent to have requalification work. Although they concluded that the results were positive caution when using the AHP is advised: criterion can have “cross-feedback” and all factors may not have a hierarchical structure. “Cross-feedback” is usually referred to when criterion do not have a clear hierarchical structure and appear to give mixed results.

In the AHP method, the criteria are considered independent of one another. However, in the real World a very large number of decisions are dependent of the alternatives. In the ANP, it is not required to have independence from the criteria so it could be very advantageous to use on these cases.

As an example, consider the decision to purchase a house. As the criteria, the buyer believes that the most important factors for his decision are location, price, size and parking spaces. The AHP would consider that the three factors are independent but the ANP would evaluate this problem considering that the criteria could be interdependent: i.e. with a larger price, the buyer would get a larger home. Additionally, if all the hypothetical houses had parking spaces, this criteria’s importance could be reduced.

In the case that the criteria might be interdependent, the authors suggest that ANP and fuzzy methods may be used (Behzadfar et al., 2012).

AHP is often used alongside with the Delphi methodology. This process was developed in the 1950s (Okoli & Pawlowski, 2004) and is a very flexible and interactive tool that relies on an expert panel to reach a consensus. According to Okoli & Pawlowski (2004) direct confrontation of experts is avoided by keeping anonymity. Experts are chosen taking into account three criteria (Skulmoski, Hartman, & Krahn, 2007):

- Sufficient knowledge and experience about the survey issues,
- Capacity, willingness and time to participate,
- Good communication skills.

It has been proven over the years to be a very effective decision aid tool (Vidal et al., 2011).

Vidal et al., (2011) used an adapted AHP to evaluate the complexity of projects. The authors started by defining the “project complexity framework” i.e. the criteria that “make a project complex”. The team faced a challenge: the number of inputs was very extensive. According to Baker et al. (2002), criteria used in multi-criteria decision making methods should be:

- Able to discriminate among the alternatives and to support the comparison of the performance of the alternatives,
- Complete to include all goals,
- Operational and meaningful,
- Non-redundant,
- Few in number.

The decision was then made to utilize a Delphi method to reduce the number of variables. After selecting a panel of experts, the process was conducted through email. 18 Experts participated in the discussion. The number of criteria was significantly reduced (to 17, about a third of the initial number). The AHP was then taken into place. After finalizing the model, a case-study was made with a start-up company. It operates in the entertainment business. The model was then applied and tested with the several projects the company was analyzing. The results were confirmed by the executive board.

The ANP replaces the hierarchies used in the AHP by networks. This is particularly useful when interactions among elements that are being evaluated form a network (Wey & Chiu, 2013). While the AHP uses unidirectional hierarchical relationship among levels, ANP allows attributes to be taken into consideration in a more general form as this method allows interrelationships between several levels. The main difference is illustrated by Wey & Chiu (2013) in Figure 5.

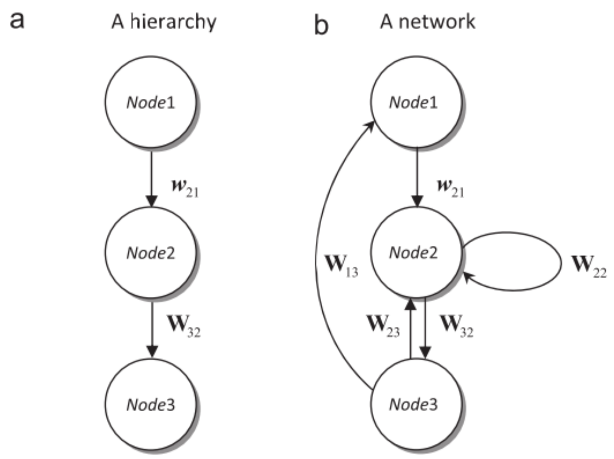


Figure 5- Linear hierarchy (a) and Nonlinear hierarchy (b) (Wey & Chiu, 2013)

The ANP generalizes the AHP by replacing hierarchies with networks (Saaty, 1977). The method has been widely used in multi criteria decision analysis in various fields such as environmental management, multi-dimensional fore- casting, strategic decision, project selection, alternative planning, and so on (Wey & Chiu, 2013).

The ANP is constructed as follows (Wey & Chiu, 2013):

Step 1. Model Construction and problem structuring

The model must be clearly defined and be presented in a rational system like a network that represents interdependence among the components.

Step 2. Pairwise comparisons matrices and priority vectors

Compare criteria in the same way as done in AHP.

Step 3. Supermatrix formation

A supermatrix is as presented in Figure 6. *"The components of a network system are Ck, k= 1,.., N, and each component k has nk elements, denoted by ek1;ek2;...;eknk. The influence of a set of elements belonging to a component on any element in another component can be represented as a priority matrix (Wij) by applying pairwise comparisons in the same way as in the AHP. Wij shows the influence of the elements in the ith component to the elements in the jth component, and vice versa. In addition, if there is no influence, then Wij=0"* (Wey & Chiu, 2013)

$$
\begin{array}{c}
\\ \\ \\
W =
\end{array}
\begin{array}{cc}
 & \\
C_1 & \begin{matrix} e_{11} \\ \vdots \\ e_{1n_1} \end{matrix} \\
\vdots & \vdots \\
C_k & \begin{matrix} e_{k1} \\ \vdots \\ e_{kn_k} \end{matrix} \\
\vdots & \vdots \\
C_N & \begin{matrix} e_{N1} \\ \vdots \\ e_{Nn_N} \end{matrix}
\end{array}
\overset{\begin{matrix} C_1 & \cdots & C_k & \cdots & C_N \\ e_{11}\cdots e_{1n_1} & \cdots & e_{k1}\cdots e_{kn_k} & \cdots & e_{N1}\cdots e_{Nn_N} \end{matrix}}{
\begin{bmatrix}
W_{11} & \cdots & W_{1k} & \cdots & W_{1N} \\
\vdots & & \vdots & \ddots & \vdots \\
W_{kl} & \cdots & W_{kk} & \cdots & W_{kN} \\
\vdots & & \vdots & \ddots & \vdots \\
W_{Nl} & \cdots & W_{Nk} & \cdots & W_{NN}
\end{bmatrix}}
$$

Figure 6- Supermatrix (Saaty, 1977)

Step 4. Selection of best alternatives

The best alternatives are present in the first column of the matrix.

This four step methodology has been extremely simplified as the whole process is very complex. Refer to (Saaty, 1977) for a complete explanation.

Wey & Chiu (2013) use an adapted form of the ANP combined with a technique named house of quality (HOQ) to assess the walkability of pedestrians. The HOQ has two inputs: 1) the citizen needs (CN) and 2) the alternative technical requirements (ATR). This paper employs ANP approach to incorporate CNs and ATRs systematically into the alternative design phase in order to assess customer satisfaction. Due to the complexity of the above method, it has not been used in this dissertation.

Mikaeil et al. (2013) tried to rank the sawability of an ornamental stone using Fuzzy Delphi and AHP methods combined (resulting in a FDAHP method). Just like walkability, sawability of an ornamental stone can be hard to define. The author defines it in terms of production rate of a sawn rock. This paper is very similar to the problem we faced when choosing which criteria would be more important when measuring walkability. This methodology is very similar to what was described on other papers that used AHP (Behzadfar et al., 2012; Vidal et al., 2011). A list of criteria was chosen as well as a panel of experts. These were chosen from several backgrounds relevant to this study. A normal AHP process was conducted. However, after obtaining the matrix, the fuzzy weights method was applied. The Fuzzy Delphi Method is a mathematical method that enables the number of surveys to be reduced and save time (Mikaeil et al., 2013). Although it enables time saving, it is a very complex method.

Another method used to assess multi criteria decision is the MACBETH approach. This is a computer program developed by Bana e Costa, De Corte and Vansnick (Bana E Costa & Vansnick, 1997). It is described in its official web page (http://www.m-macbeth.com/):

"MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique) is an interactive approach that requires only qualitative judgments about differences to help a decision maker or a decision-advising group quantify the relative attractiveness of options. It employs an initial, interactive, questioning procedure that compares two elements at a time, requesting only a qualitative preference judgment.

As judgments are entered into the software, it automatically verifies their consistency. A numerical scale is generated that is entirely consistent with all the decision maker's judgments. Through a similar process weights are generated for criteria."

This method has been extensively used and tested by Bana e Costa et al. (Bana E Costa, 1997). In his paper, the authors present two cases of multi criteria decision and use MACBETH to structure a decision. This method can be used to calculate value functions and to determine weights between criteria. On another paper (Bana e Costa & Oliveira, 2002), the authors were commissioned by the Lisbon Municipality to design a priority assignment model to support decision making on prioritizing interventions in the city. MACBETH was extensively used in an interactive and constructive process. Although weights cannot be disclosed by confidentiality reasons an overall look of the decision tree is presented. The work was then tested with the decision makers of the Lisbon Municipality and validation will come with extensive use of this tool.

1000minds is Internet based software that provides tools to help decision-making. It is of very simply usage. The decision-making tool is based on their award winning PAPRIKA software. This method is thoroughly explained in Hansen & Ombler (2008).

1000minds uses the following procedure:

- Determine and insert the criteria list you are trying to evaluate.
- Determine several levels for each criterion (for example if assessing the criteria "visibility" levels could be "good visibility" or "bad visibility"). More than two can be added.
- Answer the questions provided for the software.
- Get the weights for decision-making.

The questions asked users to compare alternatives between criteria. *"Each time you pairwise rank a pair of hypothetical alternatives ('projects', in the example above), PAPRIKA immediately identifies all other pairs of hypothetical alternatives that can be pairwise ranked by applying a logical property known as 'transitivity'. For example, if you rank hypothetical alternative X ahead of alternative Y and also Y ahead of alternative Z, then, logically (by transitivity), X must be ranked ahead of Z. PAPRIKA ranks this third pair implicitly, and any others similarly implied by transitivity, and eliminates them – so that you are not asked any questions pertaining to these implied rankings" (www.1000minds.com).* An example of a question used in the method is presented in Figure 7.

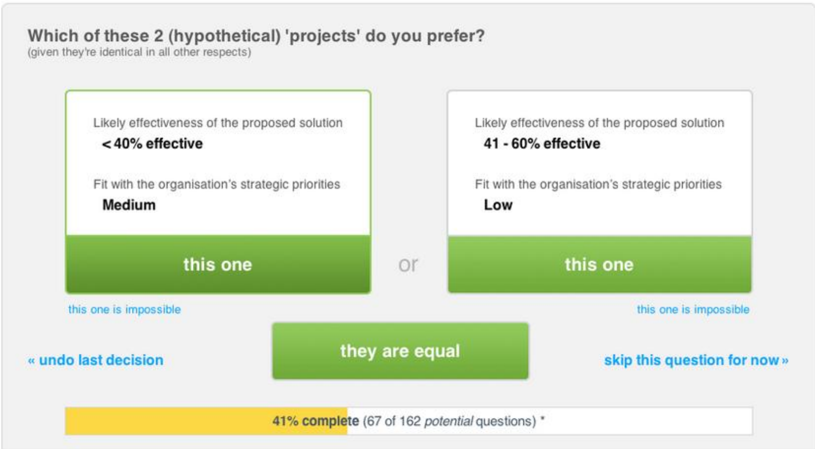


Figure 7- Example question of 1000minds. Source: www.1000minds.com

The software asks the user to choose between a series of alternatives and ranks the choices between each other, thus creating a hierarchy for the criteria. The main advantage of PAPRIKA is its easiness of use (www.1000minds.com). By choosing between two alternatives the process is therefore much simpler to the user. Comparing to the above explained AHP, the latter asks: on a scale from 1 to 9 how many more times is criterion A more important than B. 1000minds therefore presents a simpler solution and more user friendly.

Based on the previous literature review, we conclude that there has been a significant effort by the scientific community to study and develop walkability in order to foster the many advantages of a more pedestrian friendly environment. As referred before, it brings communities not only health benefits besides economical positive externalities (Litman, 2003).

As previously stated, an effort was done to gather the most information regarding walkability we could find. Although a lot of information is available, it is common to not find a description of indicators used and especially how the author measures them. This dissertation follows IAAPE's framework and does not have as main purpose to propose new methodologies. In Chapter 4, the process of choosing the indicators and the decision on how to evaluate them is presented.

This is one of the most significant contributions this paper brings to the scientific community: not only has it compiled important information from several authors but also proposes alternatives to measuring assess Walkability whenever the scientific literature does not advise on a method. Moreover this dissertation proposes a method to assess Walkability of the built environment that can be applied to other locations.

3. Methodology and Methods

3.1 Methodological Approach

3.1.1 The IAAPE Project

This dissertation is part of the IAAPE project ("Indicadores de Acessibilidade PEdonal" is translated to English as "Pedestrian accessibility indicators"). This acronym in Portuguese means "go by foot" or "walking".

IAAPE's research team is coordinated by Filipe Moura and gathers the following researchers: Alexandre Bacelar Gonçalves, Paulo Cambra, MEng, Sergio Nunes Correia, Luis Mello, Hugo Sousa and Carolina Figueiredo.

IAAE's mission is to innovate the methodologies used to measure walkability in urban environment using a GIS-base framework of assessment, with an application to selected case studies. This tool targets local authorities that can analyze potentially how built environment planning affects the walkability of their cities.

The project is divided into several steps:

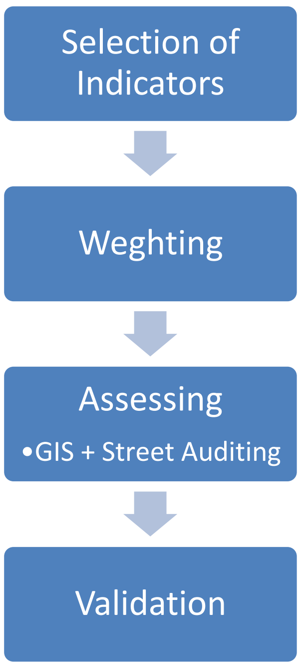


Figure 8 – Main steps of the IAAPE Framework

The present dissertation focuses mainly on the weighting and assessing of indicators, although the 1st structuring step is also described. Additional information can be found in the IAAPE's website: www.iaape.org .

3.1.2 Methodology

One of IAAPE's policies is to try to use as much of the available literature as possible as opposed to propose new sets of indicators. After a thorough research of the literature of walkability assessment, too much indicators were collected, of which many overlapped. As such, trimming this list was required. The number of variables was therefore reduced through guided interviews with experts who could determine which of the indicators were more relevant and suggest others that they felt were important and missing. In order to weight the indicators another session was held with several stakeholders using 1000minds. After one indicator was selected for each of the seven dimensions (the 7Cs of walkability), value functions and cut-offs were chosen according to the available literature. Each method used is described in section 3.2 and its use justified.

A very important part of the process was the Pedestrian Network Vectorization in order to use the pedestrian network and not the roads' centerline that pedestrians do not actually use. Furthermore, we could use GIS analysis tools and represent each link walkscores. The methodology used here is presented below in Figure 9 and it corresponds roughly to the structure of this dissertation.

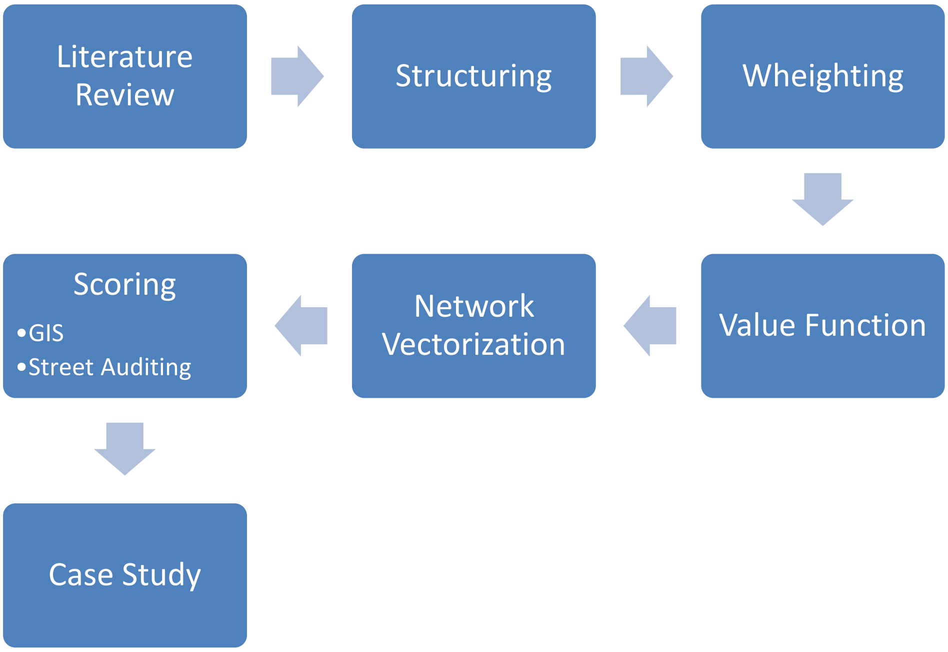


Figure 9 - Dissertation Methodology

3.2 Methods

3.2.1 Structuring

IAAPE's structuring stage is fundamental as it involves stakeholders in the making of the assessment procedure. From the extensive literature review, indicators are selected to address each of the 7 dimensions referred before. This approach is even more important as IAAPE's framework is for local authorities and respective decision makers to support their decisions on urban planning and design interventions.

As referred previously, a full list of the indicators found in the literature is presented in Annex I.

Indicators collected from the literature were grouped into seven dimensions (Cambra, 2012; Methorst et al., 2010). In PQN Cost 358, five dimensions of walkability were proposed and Cambra (2012) added two more. As proposed by Cambra (2010) walkability indicators for the built environment can be grouped as illustrated in Figure 10:

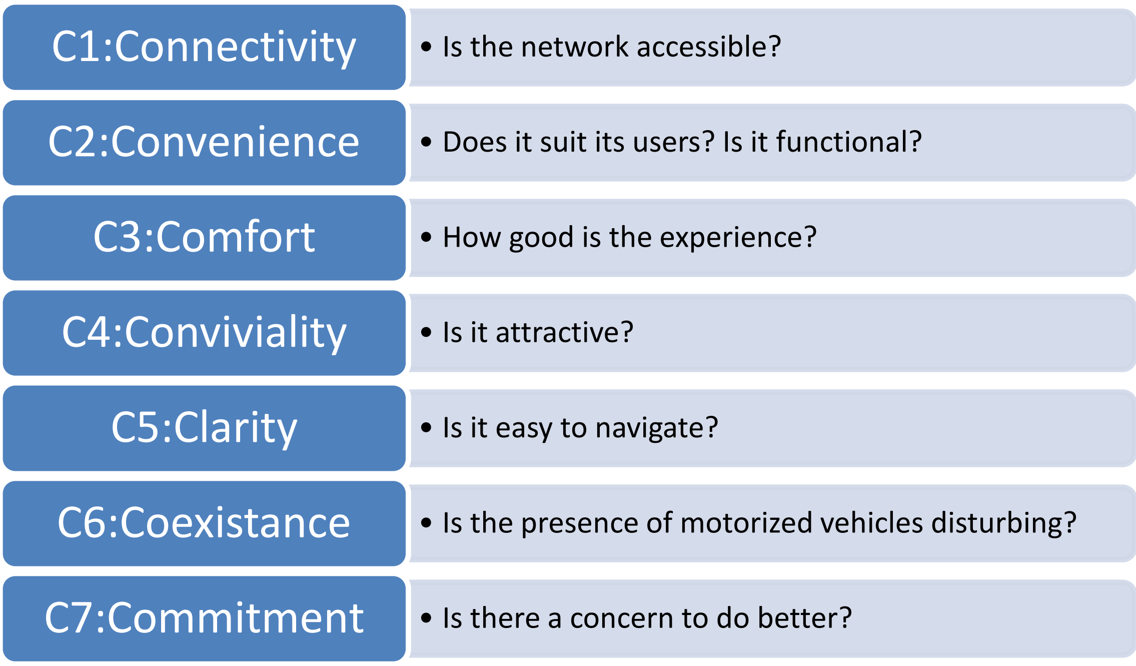


Figure 10 - 7C's of walkability

The list of indicators presented in Annex I is very extensive and sometimes redundant. This poses a problem because in order to apply multi criteria decision models indicators have to be few in number and non-redundant, among other qualities (Baker et al., 2002). In order to overcome this, guided interviews were conducted. This process was done by interviewing experts of several fields.

After the Delphi method, each dimension of walkability was left with the five most relevant indicators. The next step would be to evaluate which was the most important and how the importance of indicators varies from one dimension to another. In other words, to weigh the dimensions.

3.2.2 Weighting

In the scientific literature some authors divide the population in sectors (S Abley & Consultants, 2010; Owen et al., 2007). The rational for this division is that throughout the several stages of life, our perceptions of the built environment and our needs vary. For example, whilst an active adult may be looking for the quickest way to get to work or to get his or her daily tasks done as efficiently as possible, an elderly person may be more concerned about the location of public meeting places and the sidewalk quality.

Owen et al. (2007) differentiate walking for transport from walking for leisure. On one hand, walking for transport is when the user is trying to walk from A to B as fast as possible, taking into account the other dimensions of walkability. Everyday pedestrians walk for utilitarian purposes: going to work, going to school, to a health appointment, etc... On the other hand, walking for leisure is when a pedestrian walks as a recreational activity. It may be for exercise, tourism or other reasons. In this form of walking, the pedestrian's goal is to have an enjoyable journey. These very distinct goals have an impact on how the users view the pedestrian network and are therefore considered in this dissertation. The structure of the evaluation is presented in Figure 11.

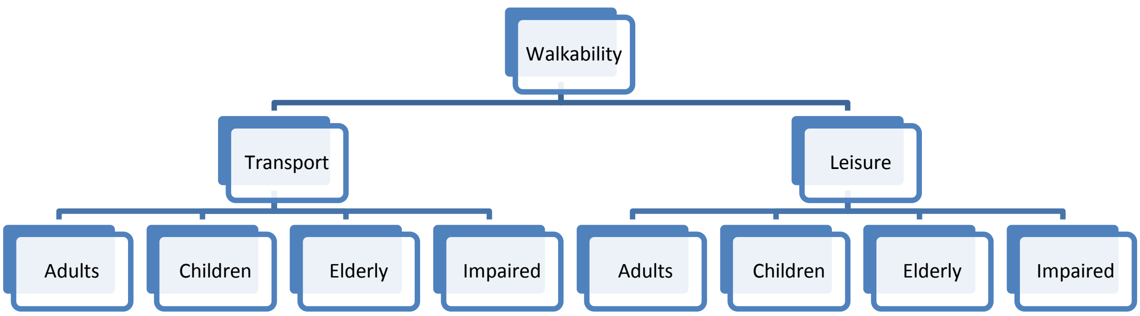


Figure 11 - Structure of population

After the experts' interviews and reducing the number of indicators of each dimension, the weighting of the indicators had to be made. Several methods were considered: AHP, ANP MACBETH, 1000minds or a combination of two or more of the methods above.

Mikaeil et al. (2013) had an objective very similar to what is proposed here, in this case, to compare two ornamental stones on their sawability, starting with a list of indicators. In the same way as walkability, sawability is not defined in the Oxford English Dictionary and is jargon mainly used by professionals. Mikaeil used AHP method combined with Fuzzy Delphi and also TOPSIS analysis. The process is quite complex and hard to understand.

In regards to the ANP, after a discussion with an expert in Multi Criteria decision, Prof. Rui Oliveira (see Bana e Costa & Oliveira, 2002; Bana E Costa, Oliveira, & Vieira, 2008), we were advised to utilize a more simple process. The utilization of MACBETH or a similar method was proposed.

By its easiness of use, and user friendly characteristics the 1000minds process was chosen. This method allows users to weigh indicators against each other by choosing between two alternatives given by the software. The questions are: What is preferable for pedestrians: Alternative A or Alternative B?

The 1000minds returns the weighted indicators so that each indicator can be evaluated and have a walkability score for the street segments evaluated.

3.2.3 Value Function and Cut-offs

The evaluation of the environment of which the pedestrian network is part can be evaluated by many methods such as surveys, inventories or extraction of data by GIS analysis. The measurements can be qualitative or quantitative (Figure 2) and indicators had to be defined for the Macro and Micro scale indicators, whether they refer to whole environment (e.g., several streets of a neighborhood) or if they refer to a single street.

Macro Scale indicators evaluate criteria for an area that includes more than one street or one neighborhood and can be quantitative or qualitative. Surveys to users about how the walking environment is perceived are an example of qualitative indicators. The “Neighborhood Environment Walkability Scale”, developed by Saelens et al. (2003), where pedestrians were asked about residential density, land use mix, access or connectivity is one example. The results obtained for various locations enabled comparing different neighborhoods and establish a benchmark. Quantitative indicators are obtained through the analysis of attributes of an area. These can be the Link-to-Node ratio as proposed by several authors (Dill, 2004) or the density of crossings for instance.

Micro scale indicators can also be quantitative or qualitative. These are applied to a street segment or crossing. They can be evaluated through street auditing or through data on GIS software (eg. street inclination). Street auditing is the most used technique of evaluation for micro scale indicators. The Level Of Service (LOS) indexes are very usual and have been developed by the Transportation Research Board.

Value functions for a specific criterion serves to establish the relationship between what is observed and a relative score (Bana e Costa et al., 2008). They can be created with MACBETH or other tools. In Figure 12 an example of value functions obtained through MACBETH is shown. The extreme values (objects that have an image of 1 or 0 in the value function) are sometimes given by either legislation or on scientific literature. These values can also be obtained through comparison of what is observed in the sample of evaluations. Saleans et al. (2003) determine value functions through comparison of different ratings observed in different areas.

These functions should be normalized in order to determine comparable weights and feed the additive model, which can then be used to assess the overall score.

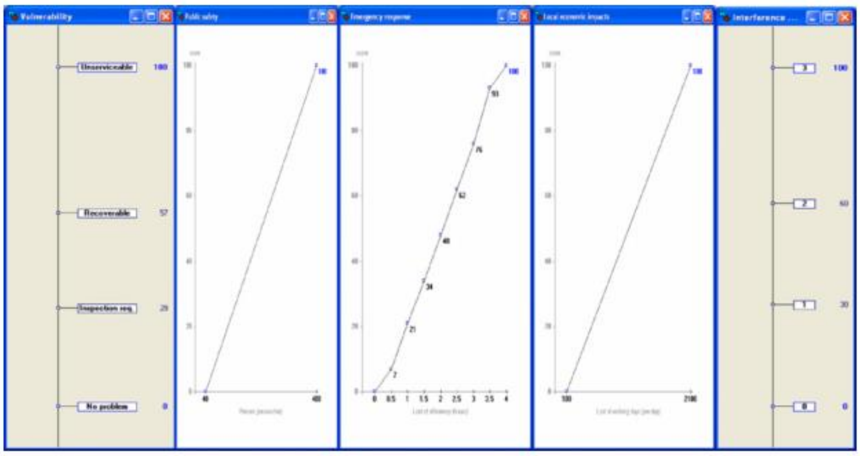


Figure 12 - Value functions determined by MACBETH (Bana e Costa et al., 2008)

In the same way as Park (2008), this dissertation follows a composite method. When building the value functions for the different indicators, scientific literature was reviewed, instead of defining new functions or indicators. Some papers do not publish the value functions used to measure their indicators. In case of lack of literature data, a linear value function was used by default. Clearly, some value functions could be non-linear (e.g., logarithmic), but to determine such specifications, we should perform more observations to evaluate the perception of each indicator by pedestrians. This is out of this dissertation scope.

Cut-offs are observations eliminate the segment evaluated from the network (i.e. virtually speaking). They can be, for example a sidewalk width that does not allow sufficient space for a wheelchair to pass. This sidewalk cannot be considered a possible route for the disabled group. Cut-offs are present in the scientific literature. Bana e Costa & Oliveira (2002), when assigning priorities for maintenance and repair of houses, determined that if the gravity of physical injuries was considered above a certain level, the house would be ranked as “Absolute urgency for acting”. This meant the house would not be evaluated through the model and receive a rating as the other houses would.

3.2.4 Network Vectorization

The network vectorization of the pedestrian network is a crucial step when assessing walkability. It defines the segments that are being evaluated as well as their type (see classifications below). The network is also used to evaluate some Macro indicators.

We used ARCGIS as a GIS tool to take advantage of available tools that are described in this section and on the indicator's description section. The description of the vectorization methodology used here is part of the IAAPE project and was developed mainly by Paulo Cambra, Alexandre Gonçalves and Sérgio Nunes (Gonçalves et al., 2015).

It is important to differentiate crossings from arcs. Arcs are elements that are used by pedestrians to walk: sidewalks, stairs, informal paths, etc. Crossings are elements such as zebra crossings, signalized crossings or lines of desired crossings. These lines are routes that pedestrians use but are not officially marked with the appropriate signalization. The full list of types used is specified in Table 1.

Table 1 - Types of segments used in the model

Pedestrian Network	Arcs				Crossings			
	Formal		Informal		Formal		Informal	
	Type	Name	Type	Name	Type	Name	Type	Name
1st Level - base network	0	Sidewalks	90	Informal path	10	Zebra crossings	20	Desire line type I
	1	Differenciated pavement	91	Open space (parking lot, garden)	11	Traffic light crossings	21	Desire line type II
	2	Local access streets (users tend to use the road)	99	Conector	12	Leveled crossings - aerial		
	3	30 Zone street or coexistence street			13	Leveled crossings - subterrainean		
	4	Shared Space street			14	Other type		
	5	Space exclusively pedestrian dedicated			15	Traffic separator/refuge		
	6	Staircase			16	Garage and other access		
Pedestrian Network	Arcs				Crossings			
	Formal		Informal		Formal		Informal	
	Type	Name	Type	Name	Type	Name	Type	Name
2nd Level - additional network	80	Paths in gardens and public spaces	92	Shortcut			22	Desire line type III
	81	Paths through buildings	93	Possible but not permitted paths				
	82	Paths through blocks						
	83	Elevators, mechanical aid equipments						
	88	Other						

The most common feature for the network is sidewalks (type 0). These are marked whenever a street has a sidewalk. In the vectorised model they appear as in Figure 13.

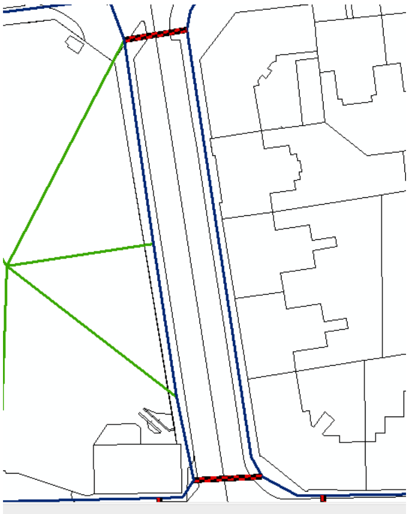


Figure 13- Sidewalks (Blue)

Lisbon is a particularly challenging city due to its historical characteristics. The Portuguese capital was planned hundreds of years ago and has been going through many transformations to cope with the new mobility patterns of more recent decades, and especially the private car. Therefore many of the streets are not prepared to host both pedestrians and vehicles. Where there is no sidewalk, streets were named local access streets. In GIS representation, the street is represented by only one element located on the axis of the road. These are also very common in other cities of Europe. London has a great amount of *Mews*, a local access road where pedestrians and vehicles share the same space.

Lisbon is also known as the city of the Seven Hills. Due to these characteristics, there is a significant amount of staircases. These should be considered differently as a normal pavement as they are not accessible to every pedestrian (note that it is very rare to see specialized equipment to enable disabled pedestrians to overcome this adversity).

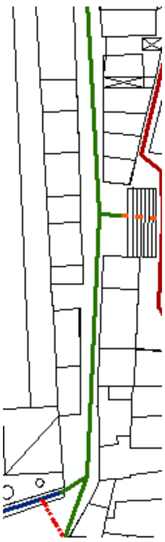


Figure 14 – Local access road (green) and staircase (dashed-orange)

Unlike motorized vehicles, pedestrians are not limited to certain paths (roads). People tend to take shortcuts and use routes that are not officially marked as such. These were called informal paths (Figure 18). They can be found mainly in large squares or gardens, where pedestrians usually take the most direct path (diagonally). An example of both is given below in Figure 15.

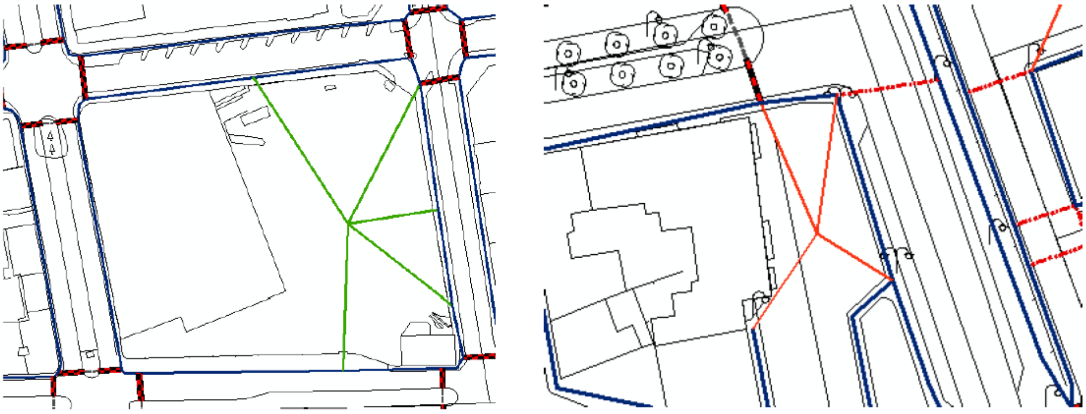


Figure 15- Direct paths used by pedestrians in a garden (right) and in a parking lot (left)

Crossings are a particularly challenging part of the network due to its complexity and diversity. Zebra marked crossings and signalized crossings for pedestrians were marked differently. However, there is a very large amount of non-signalized intersections. These have to be considered in the model but marked as different. The desired pathways and desired crossings are present throughout the city: in front of car parking garages, near gardens etc. In Figure 16 an example of an intersection between roads is presented. Signalized crossings are marked as dotted red and black. The desired paths are marked as red.

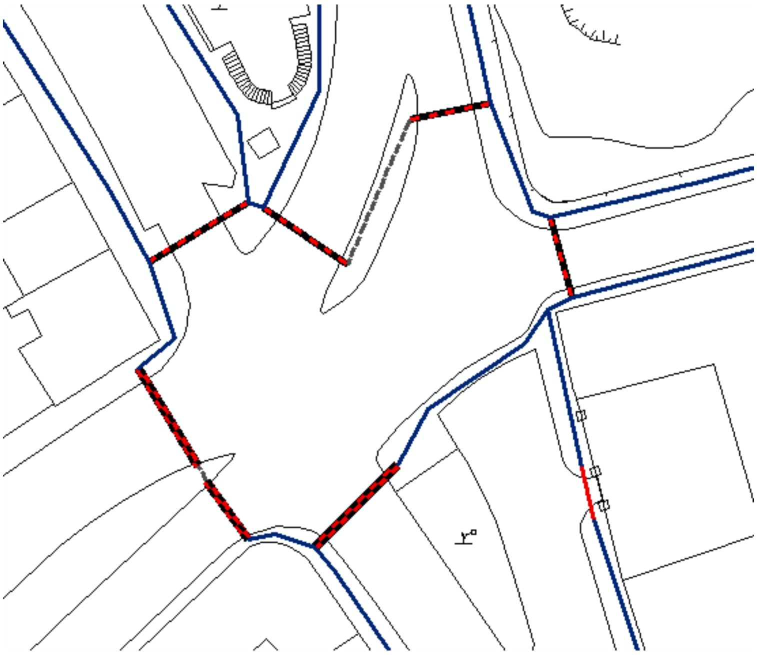


Figure 16 – Signalized crossings (black and red dotted) and desired crossings (full red)

In the upper part of Figure 16, a pedestrian refuge separates two roads. Although it is not a sidewalk, it is considered in order to guarantee a connection between the two crossings.

The most common types of pedestrian network links have now been addressed. These could be adapted to other cities and if needed, other types would be added to the database.

The process of network vectorization is time consuming. After a steep learning curve, the time to realize this task is estimated as 6 h/km^2 for an orthogonal urban pattern. For a more complex urban design the estimates are 8 h/km^2. In neighborhoods where it is difficult to identify where the sidewalks are located, the process is very slow and can reach 12 h/km^2.

The main difficulties felt with this process were the definition of where the pedestrian does walk i.e. defining sidewalks, crossings (signalized and unsignalized) and other walking elements. As previously stated, the productivity of the vectorization is very much related to the type of network that is being evaluated. Desired trajectories are also a challenge. The fact that there is not always a physical element present (e.g., sidewalk, zebra, etc.), forces the analyst to verify how pedestrians can foreseeably use the built environment, either through photography analysis (www.maps.google.com) or through on site analysis.

It is very important to verify that the endpoints of links and crossings are connected. During the network vectorization, some errors occurred and endpoints were not linked to other elements, thus creating a discontinuity of paths.

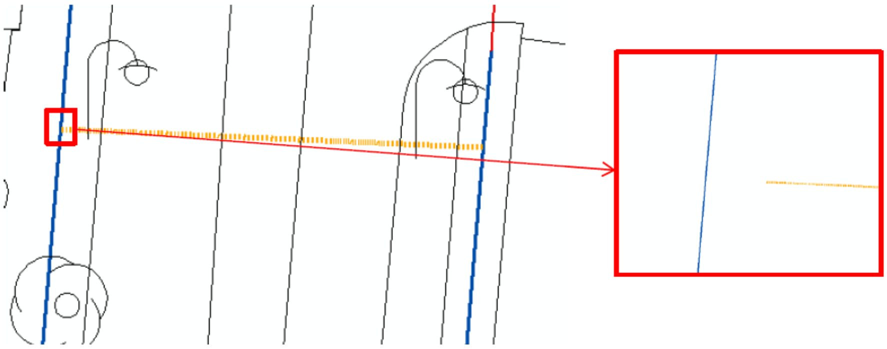


Figure 17 - Error in Network Vectorization

In Figure 17 an error in network vectorization is presented. The two segments should be connected and because of an error they are not. This creates problems as the software considers that the pedestrian cannot go from one to the other. These are very common. An easy and effective way to verify the data is to use the Network Analyst tool of ArcGIS. This error is detected by running this tool and elements appear disconnected. As the connection between the elements is zoomed, a slight gap between arcs is detected.

Figure 18 - Design vs. User Experience. Source: Twitter@usabilla

4. Walkability Indicators, Weighting and Integration into GIS

4.1 Selection of Indicators

The structuring and selection of indicators was a two-step process. The first step consisted in guided interviews with an expert panel and a session with stakeholder to determine the weights of the indicators.

Structuring the problem is considered by many authors as fundamental and of very high importance as it will influence the decisions made based on the model. Batista e Silva et al. (2013) refer to the structuring part of the process as a mixture of art and science.

The research of the scientific literature resulted in a very extensive list of indicators. After a primary filtering of redundancy and only keeping those referring to built environment, the number of indicators was still considerable (approximately 200). Multicriteria Decision Analysis (MCDA) literature considers that the indicators should be consensual, exhaustive, non-redundant and as concise as possible (Moura et al., 2014). It should be non-redundant to avoid double counting of results and therefore biasing the results, but also exhaustive enough to include all dimensions to be evaluated.

To choose which indicators fulfill the list of criteria stated above, guided interviews with a panel of experts were held. Experts have a deep understanding of walkability and or urban planning. They each come from a unique background that assures that all perspectives of the problem are covered. The panel is composed by engineers, architects and representatives of users of the pedestrian network. A list of experts is presented in Table 2.

Table 2- List of Experts

Expert	Institute
Carla Cachadinho	LNEC
Mariana F. Almeida	Instituto do Envelhecimento
Teresa Santos	Engimind
Prof. Jorge Silva	IST
Pedro Gouveia	CM Lisboa
Vera Paisana	ISPA
Francisco Costa	TiS
Prof. Pedro Brandão	IST
Prof. David Vale	FAUTL
Vasco Colaço	TiS
Nuno Raposo	Espaço & Desenvolvimento
Bernardo Campos Ferreira	BFJ Arquitectos

The extensive list of indicators was grouped according to the considered dimensions of walkability, the 7C's of walkability: Connectivity, Convenience, Comfort, Conviviality, Conspicuousness, Coexistence and Commitment. Each expert was then part of a guided interview to determine which indicators were the most important. Coming from different fields, each group member was able to represent at least one of the 4 pedestrian groups – adults, elderly, impaired or children.

The interviews were conducted face to face and had the following structure:

- Short presentation of the IAAPE project,
- Introduction to walkability,
- Dimension presentation,
- Choosing of indicators.

In the dimension presentation, the expert was given a brief presentation of each of the 7 dimensions of walkability considered in IAAPE methodology. Examples of cases were used as an example of good and bad results on that dimension (Figure 19). To the expert was then presented a list of the indicators for this dimension. The subject was then asked to choose the most important indicators to measure this dimension. The expert also had the option to add extra indicators, if needed.

Figure 19- Example of High and Low levels of Comfort

The fact that experts came from different backgrounds, and are from academia or are practitioners, contributed to clarify which indicators are best suited to evaluate each dimension. Additionally, different experts chose different indicators as the most important whereas a different expert considered that criteria not relevant. This is a sign that different user groups will have different user need and concerns. It is a confirmation that pedestrians' perceptions of the built environment for walking are not all the same.

Regarding the 7Cs layout, there was a general agreement, with a clear consensus on the addition of Coexistence and Commitment to the existing 5C layout (Moura et al., 2014). The experts agreed that all seven dimensions are relevant and different (non-redundant). The importance of an inclusive pedestrian network that can be used by everyone was several times reaffirmed. Moreover experts agreed that it is an issue of network connectivity rather than convenience.

A transversal analysis of the results enabled a shortlist of the indicators that are best used to measure each dimension of walkability. The experts were not consensual in finding the most important indicator for each C of walkability. This process resulted in a list of five indicators per dimension (Table 3).

Table 3 - List of the most important indicators chosen by Experts

Dimension	Indicators
C1: Connectivity	C11: Street density (alternative routes)
	C12: Continuity of walking path/sidewalk
	C13: Path directness
	C14: Existence of dedicated pedestrian infrastructure, accessible to all groups
	C15: Network integration in the urban fabric
C2: Convenience	C21: Land use diversity
	C22: Sidewalk available width
	C23: Obstacles (absence of)
	C24: Density of daily uses
	C25: Facilities for accessing steep streets (escalators, elevators, ramps)
C3: Comfort	C31: "Eyes on the street" - windows and facade transparency
	C32: Pavement surface quality
	C33: Amenities (trees, benches, lighting, etc.)
	C34: Climate protection (sun, rain)
	C35: Sensory quality of urban environment
C4: Conviviality	C41: Opportunities for meeting and sojourning (benches, tables, terraces)
	C42: Existence of "anchor sites" - squares, open-air markets, parks, etc.
	C43: Mixed uses and mixed working hours
	C44: "Active edges" - absence of blank walls, empty lots, dull facades
	C45: Population density
C5: Conspicousness	C51: Landmarks
	C52: Clear sightlines
	C53: Street names, signposting, waymarking
	C54: Architectural complexity
	C55: "Sense of place"
C6: Coexistence	C61: Traffic safety (at pedestrian crossings)

	C62: Pedestrian crossing location
	C63: Appropriate spatial segregation of transport means
	C64: Proportion of pedestrian friendly streets
	C65: Pedestrian space "invasion" - parked cars, running bicycles
C7: Commitment	C71: Enforcement of pedestrian regulations (as the recent disabilities act)
	C72: Street cleanliness
	C73: Means for public participation
	C74: Walking initiatives (walk to school, walk to work, senior walks, etc.)
	C75: Existence of design standards and planned public space interventions

The list of indicators was significantly reduced as seen on the above table. This will enable the application of a MCDA method.

As of this point, a consensual table of concerns used to measure walkability was found. The next step was to determine weights to the indicators. As demonstrated in Chapter 2, some experts ignore different weights and consider that all indicators are equally important. Others weigh indicators without a solid basis and justification.

This leads to the second stage of the structuring of the model: weighting the indicators. This phase consisted in a stakeholder session that had the objective of finding a consensus between the experts' opinion and the user's experience. A panel of 17 stakeholders was gathered with different backgrounds and experiences in order to cover all four groups considered. Representatives play active roles in urban planning, transport and social sciences.

In order to represent each group, each stakeholder was assigned a role and was to defend the interests of the group (adults, children, elderly or disabled). These roles were attributed taking into account the stakeholder's background.

The session had two parts: 1- Selection of indicators and 2 – Calibration of weights. Both steps took place in a room with seven posters (one for each dimension of the 7 Cs) with a description of the dimension and the indicators (i.e., shortlist from the experts presented in Table 3). Colored stickers were given to each stakeholder according to the group they belong to.

Figure 20 - Posters for Stakeholders Session

In a first round, each participant was given 6 stickers to use on each poster (Figure 20). Stakeholders were asked to rank the indicators in order of importance. This could be done by putting all of the stickers in just one indicator, distribute them equally or how the participant choses. The stakeholders were asked to split into random groups and face one of the posters. The decision not to divide people into the groups they represent was meant to avoid a biased opinion or participants reaching a consensus before voting. The stakeholders had limited time and had to rotate between all posters. At the end, the votes were counted and posters changed to a second round.

In this round stakeholders were given 28 markers to cast their votes chose without restrictions, i.e. ultimately, they could allocate all 28 stickers in one indicator or distribute them evenly along the 7 dimensions (if the stakeholder wished to do so). This round had the intention of verifying that the dimensions of walkability were not all equally important. This concludes the first part of the session and stakeholders were invited to take a small break while the IAAPE's team counted the votes.

The results of the first round of voting by stakeholder were used for the second step of the session. One indicator per dimension was chosen, which brought some concern as sometimes indicators that have been eliminated by during the stakeholders session, were previously selected by experts as the most important to evaluate the dimension. The results of both sessions can be found in Table 4.

These results clearly show that indicators have different degrees of importance for each group. It confirms the importance of weighting indicators when assessing walkability.

Table 4 - Results of first step of stakeholder session

		Pedestrian user group				**Round 1**	**Round 2**
Dimension	**Key-concerns**	**Adults**	**Seniors**	**Disabled**	**Children**	**aggregate**	**aggregate**
C1: Connectivity	C11: Street density (alternative routes)	0.13	0.07	0.13	0.06	0.014	0.017
	C12: Continuity of walking path/sidewalk	**0.27**	**0.37**	0.25	0.33	**0.043**	**0.084**

	C13: Path directness	0.27	0.17	0.04	**0.44**	0.031	0.036
	C14: Existence of dedicated pedestrian infrastructure, accessible to all groups	0.10	0.33	**0.50**	0.17	0.039	**0.059**
	C15: Network integration in the urban fabric	0.23	0.07	0.08	0.00	0.015	0.027
C2: Convenience	C21: Land use diversity	**0.27**	0.20	0.13	**0.28**	0.031	**0.044**
	C22: Sidewalk available width	0.23	0.07	**0.25**	0.22	0.026	0.013
	C23: Obstacles (absence of)	0.20	0.23	0.21	0.28	**0.032**	0.034
	C24: Density of daily uses	0.23	**0.33**	0.17	0.11	0.032	0.025
	C25: Facilities for accessing steep streets (escalators, elevators, ramps)	0.07	0.17	0.25	0.11	0.021	0.036
C3: Comfort	C31: "Eyes on the street" - windows and facade transparency	0.20	0.20	0.17	**0.39**	0.032	0.036
	C32: Pavement surface quality	**0.40**	**0.33**	**0.33**	0.22	**0.047**	**0.065**
	C33: Amenities (trees, benches, lighting, etc.)	0.10	0.23	0.29	0.17	0.028	0.027
	C34: Climate protection (sun, rain)	0.07	0.17	0.13	0.22	0.020	0.017
	C35: Sensory quality of urban environment	0.23	0.07	0.08	0.00	0.015	0.002
C4: Conviviality	C41: Opportunities for meeting and sojourning (benches, tables, terraces)	0.27	**0.33**	0.21	0.22	**0.038**	**0.055**
	C42: Existence of "anchor sites" - squares, open-air markets, parks, etc.	0.20	0.27	**0.29**	**0.33**	0.038	0.029
	C43: Mixed uses and mixed working hours	**0.33**	0.13	0.21	0.22	0.032	0.013
	C44: "Active edges" - absence of blank walls, empty lots, dull facades	0.03	0.17	0.17	0.22	0.020	0.023
	C45: Population density	0.17	0.10	0.13	0.00	0.015	0.015

C5: Conspicousness	C51: Landmarks	**0.43**	**0.37**	0.21	**0.50**	**0.053**	0.011
	C52: Clear sightlines	0.13	0.13	0.17	0.17	0.021	0.002
	C53: Street names, signposting, way marking	0.10	0.17	**0.46**	0.17	0.031	0.019
	C54: Architectural complexity	0.13	0.10	0.17	0.11	0.018	0.008
	C55: "Sense of place"	0.20	0.23	0.00	0.06	0.020	0.006
C6: Coexistence	C61: Traffic safety (at pedestrian crossings)	**0.37**	**0.43**	**0.33**	0.28	**0.052**	**0.076**
	C62: Pedestrian crossing location	0.17	0.07	0.33	**0.39**	0.031	0.042
	C63: Appropriate spatial segregation of transport means	0.13	0.20	0.00	0.17	0.018	0.008
	C64: Proportion of pedestrian friendly streets	0.10	0.03	0.00	0.00	0.006	0.017
	C65: Pedestrian space "invasion" - parked cars, running bicycles	0.23	0.27	0.33	0.17	0.036	**0.063**
C7: Commitment	C71: Enforcement of pedestrian regulations (as the recent disabilities act)	**0.30**	**0.33**	**0.33**	0.22	0.043	0.021
	C72: Street cleanliness	0.23	0.20	0.22	**0.39**	0.032	0.023
	C73: Means for public participation	0.17	0.03	0.07	0.00	0.011	0.019
	C74: Walking initiatives (walk to school, walk to work, senior walks, etc.)	0.03	0.13	0.04	0.17	0.013	0.008
	C75: Existence of design standards and planned public space interventions	0.27	0.30	0.33	0.22	**0.047**	0.017

The results obtained on this first step allow us to take a number of observations. The first, as was pointed out previously is the confirmation that in fact different groups of users have different perceptions of what is more important to them regarding the built environment. There are some common concerns but there is not a consensual decision on what should be considered more important. By analyzing the results, it can be observed that the most agreed dimension was **comfort** and the least was **convenience**.

Several methods can be found in scientific literature to determine weights of indicators in MCDA. After carefully analyzing the pros and cons of each other, 1000minds (www.1000minds.com) was chosen. This software is very user friendly and has been extensively tested. But if the user puts in a high number of criteria, the questionnaire's time for completion increases significantly and users tend to get tired and lose focus after 30min. Therefore the decision was to use one indicator per dimension. The indicator chosen was the most voted by each group for each dimension on phase 1. This can lead to bias results and should, in future researches, be looked into.

The stakeholders were then asked to group according to the pedestrians they were representing and answer a series of question from 1000minds. These had the structure described in Chapter 3. Two different sessions were held: one where the stakeholders were asked to judge their options while walking for utilitarian motives or leisure.

These two Delphi sessions produced different results as shown in Table 5. Each column sums 100%, translating the different weights that each population group attributes to the indicators selected from Phase 1, for the two types of trip motives considered: utilitarian and leisure.

Table 5 - Results 1000minds

1000 Minds Weight results		Utilitarian Trips				Leisure Trips			
Dimension	**Key-concerns**	**Adults**	**Seniors**	**Disabled**	**Children**	**Adults**	**Seniors**	**Disabled**	**Children**
C1: Connectivity	C12: Continuity of walking path/sidewalk	0.17	0.11	---	---	0.04	0.07	---	---
	C13: Path directness	---	---	---	0.19	---	---	---	0.09
	C14: Existence of dedicated pedestrian infrastructure, accessible to all groups	---	---	0.17	---	---	---	0.17	---
C2: Convenience	C21: Land use diversity	0.06	---	---	0.15	0.19	---	---	0.23
	C22: Sidewalk available width	---	---	0.17	---	---	---	0.17	---
	C24: Density of daily uses	---	0.16	---	---	---	0.27	---	---
C3: Comfort	C31: "Eyes on the street" - windows and facade transparency	---	---	---	0.19	---	---	---	0.18
	C32: Pavement surface quality	0.17	0.21	0.17	---	0.12	0.17	0.17	---

C4: Conviviality	C41: Opportunities for meeting and sojourning (benches, tables, terraces)	---	0.11	---	---	---	0.17	---	---
	C42: Existence of "anchor sites" - squares, open-air markets, parks, etc.	---	---	0.09	0.04	---	---	0.09	0.18
	C43: Mixed uses and mixed working hours	0.17	---	---	---	0.23	---	---	---
C5: Conspicousness	C51: Landmarks	0.11	0.05	---	0.12	0.19	0.03	---	0.14
	C53: Street names, signposting, way marking	---	---	0.04	---	---	---	0.04	---
C6: Coexistence	C61: Traffic safety (at pedestrian crossings)	0.22	0.21	0.22	---	0.15	0.17	0.22	---
	C62: Pedestrian crossing location	---	---	---	0.23	---	---	---	0.14
C7: Commitment	C71: Enforcement of pedestrian regulations (as the recent disabilities act)	0.11	0.16	0.13	---	0.08	0.13	0.13	---
	C72: Street cleanliness	---	---	---	0.08	---	---	---	0.05

Table 5 - Results 1000minds shows the results from the two Delphi sessions done using the 1000minds software. It can be observed that there is a clear difference in the weights attributed by the different groups, again confirming that in fact user groups should be separated. In addition, for each user group, the two types of journeys (utilitarian and leisure) produced different results, and should be considered separately as this dissertation proposes. When comparing results from different user groups, it can be observed that some users consider **connectivity** the most important dimension as opposed to others that consider **comfort**. In general, for utilitarian trips, **connectivity** played a bigger role than in leisure trips.

The Delphi session produced very interesting results as it confirmed some of the assumptions made in the IAAPE project and, as such, in this dissertation: to consider several pedestrian groups and several walking modes.

Despite believing that this was the most effective solution to assess the problem IAAPE proposes to solve, the Delphi method has some limitations. If one of the group members becomes a leader, the results of this analysis reflect his or her opinions rather than a consensus between the group. The stakeholders were chosen to represent a certain group that they are used to work with or are a part of. However, by only choosing representatives, scoring may not be representative of the group that is being tested. The validation of the model therefore plays a very important role and should be done in the future (not in the scope of this work).

17 different indicators have, to this point, been chosen by stakeholders to evaluate walkability and assess the built environment, by the 4 population segments and for utilitarian and leisure trips. As such, some indicators were selected for several combinations of trip motive vs. population group. The next challenge was to determine how to score these dimensions.

4.2 Scoring of Dimensions

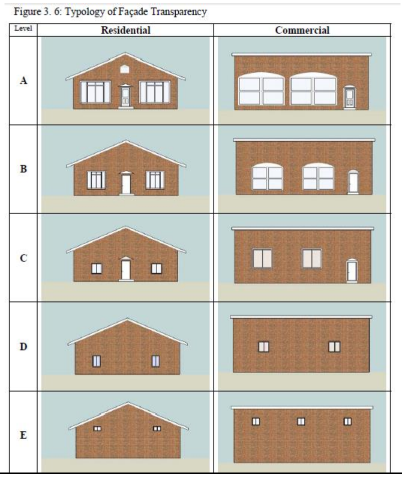
This dissertation has the intention of gathering as much information from the scientific literature as possible. When scoring the dimensions of walkability, other authors in the literature typically suggested new indicators and scoring methodologies. Here, we decided to use whenever possible, indicators and assessment procedures proposed by other authors. Table 6 presents the complete list of indicators used here, the methodology used to assess them as well as its justification. The scoring of dimensions is done on a Micro or Macro level, depending on what is considered more appropriated. Additionally, some indicators refer to crossings and others to links. It was intended, to facilitate the analysis that if possible, the scoring would be made through GIS analysis. This would reduce the time of evaluation considerably and therefore reduce the potential costs of hiring a team to do street auditing.

The table presents the walkability indicator, the groups that have considered this as the most relevant for the dimension, the segments that will be evaluated and how it was evaluated. Whenever appropriate, an alternative approach is proposed as sometimes it is not possible to use the most desired one.

Table 6- Scoring of Dimensions

Walkability Indicator	Groups Affected	Segments Evaluated (Arcs or Crossings)	Scale	Method of Evaluation	Theoretical Foundation	Criteria Evaluated	Alternative approach
C12: Continuity of Path	Elderly and Adults	All	Macro	Evaluated through GIS analysis	Ewing 1996: Link to Node Ratio	Link-Node Ratio is an index of connectivity equal to the number of links divided by the number of nodes within in a study area. Links are defined as roadway segments between two nodes. Nodes are intersections or the end of a cul-de-sac. A perfect grid has a ratio of 2.5. Ewing (1996) suggests that a link-node ratio of 1.4, about halfway between extremes, is a good target for network planning purposes. At least three cities have adopted the link-node ratio as a standard, with values of 1.2 and 1.4 (Handy et al., 2003). Calculate the Link to Node Ratio. This should be referring to the center of roads. Sidewalks were not used because in the scientific literature, limits have not been proposed. Some authors consider that ends of cul-de-sac should not be considered (Dill, 2004). In this dissertation they have been counted as nodes.	Connected Node Ratio
C13: Condition to Take the Most Direct Path	Children	Arcs	Macro (applied for each individual block)	Evaluated through GIS analysis	Soltani & ALLAN, (n.d.) propose the Walking Permeability Distance Index (WPDI)	WPDI is an indicator used to measure how directly can pedestrians reach destinations. It is a ratio of the Euclidean distance between a trip's origin and destination to the actual distance. This ratio can be influenced by the choices of origin-destination pairs. In order to reduce subjectivity, this analysis was made using as origin destination, centers of gravity of blocks. Each center of gravity was analyzed for all destinations.	Block Size, Block Length (Handy, Boarnet, Ewing, & Killingsworth, 2002), Pedestrian Route Directness (many authors)

C14: Existence of Infrastructure for Disabled Access	Disabled	All	Micro	Evaluated through GIS and on-site analysis	Minimum walking width: 1.2m (DL163/2006) however, this value was not used as it would mean most of the footpaths would not comply. 0.8m from HCM were used as benchmark; Presence of steps higher than 0.15m (DL163/2006); Longitudinal gradient: 10% (DL163/2006) and (www.levelofservice.com)	Gradient will be evaluated by GIS and the gradient used for the arc will be the steepest of the segment. The other criteria will be evaluated on site. The crossing will be evaluated only on the height of sidewalk curb. If a segment does not fulfill these conditions, it is cut-off and the segment is not considered. If the arcs have a disabled accessible alternative for the steps, it is not considered a cut-off. The effective walking width does not consider temporary objects in the pavement as an impediment: cars temporarily parked, trash cans and objects such as shopping carts are not considered on the analysis.	
C21: Land Use Mix	Children and Adults	Arcs	Micro	Evaluated through on site analysis	There is not a simple way of assessing this indicator in the literature. Some propose the use of ratios of built areas.	Is there Commercial land use? Is there residential land use? Are there services/offices? For each yes, add one point to the maximum of 3. Arcs with 0 points get the lowest grade.	
C22: Footway Width	Disabled	Arcs	Micro	Evaluated through on site analysis	According to Evans 2009 the following will be used: Narrow<1,5m; Absolute 1,5m to 1,8m; Accepted 1,8m to 2m; Desired >2m	The width will be measured in the same way as C14	

C24: Everyday Use Commercial Activities' Density	Elderly	Arcs	Micro	Evaluated through on site analysis	Hoener et al. 2005 defines this as nonresidential destinations, including those related to restaurants, grocery stores, schools, retail, service, automobile, employment, government, civic organizations, entertainment, religious and health services (in a 400m radius from respondent's home)	The radius of 400m was considered to be of extremely high proportions and would not reflect user experience (walking 400m to go to a daily activity can be too much for an elderly person). The solution was to consider everyday destinations for elderly (small grocery shops, cafes, newspaper stands) and count them for the segment.	
C31: "Vigilance Effect": To see and be Seen	Children	Arcs	Micro	Evaluated through on site analysis	Park 2008	What type of façade is dominant in the segment? Using Park's design 	

C32: Pavement Quality	Disabled , Elderly and Adults	Arcs	Micro	Evaluated through on site analysis	Adapted from Abley 2011 that considers tripping hazards and pavement quality as inputs important to pavement quality.	-To measure pavement quality: 0: A large number of bumps, cracks, holes, weeds or overgrown vegetation e.g. tree roots protruding through surface or creating bumps, loose cobblestones, significant weeds and or significant potholes. Presence of a significant hole in the segment. 1: pavement between 0 and 2 2: Some bumps, cracks, holes weeds or overgrown vegetation e.g. some elements of a bad footpath but not many. 3: pavement between 2 and 4 4: Very few bumps, cracks, holes, weeds or overgrown vegetation e.g. generally smooth, no missing cobblestones, no potholes. -To measure tripping Hazard: Answer the question: In adverse conditions (wet and presence of leaves) is this pavement very slippery? Binary evaluation. -If the pavement quality is very bad there is a cut-off for disabled.	
C41: Existence of Public Meeting Places	Elderly	Arcs	Micro	Evaluated through on site analysis	A great number of authors consider the presence of esplanades and street furniture very appealing to pedestrians	Three levels: 0- There is not is an esplanade or street furniture in the arc, nor one is visible; 1-There is not is an esplanade or street furniture in the arc, but it is visible; 2- There is an esplanade or street furniture in the arc	
C42: Existence of Attractor Destinations	Children and Disabled	Arcs	Micro	Evaluated through on site analysis	Attractor destinations are: sporting facilities (Evans 2009); gardens and theatres (Maghehal 2010), retail centres (local supermarkets and grocery stores) (Soltani & Allan 2005), Schools and post office (Maghelal 2010), metro station	Evaluated in a similar manner as C24	
C43: Land Use Mix and Service	Adults	Arcs	Micro	Evaluated through on site analysis	A significant number of authors agree that Land Use mix increases walkability. No objective way of measuring this indicator has been found on the literature	0: There is very little land use mix; 1: There is good land use mix but the service hours are only during the night/day; 2: There is good land use mix and service hours are extended	

<table>
<tr>
<td>C51: Sense of Place and Reference Elements</td>
<td>Children, Elderly and Adults</td>
<td>Arcs</td>
<td>Micro</td>
<td>Evaluated through on site analysis</td>
<td>Kevin Lynch defined landmarks as readily identifiable objects which serve as external reference points.</td>
<td>Presence/visibility or not, from the majority of the segment, of landmarks which are: monuments, retail shops and restaurants of recognizable brands, religious buildings and large squares or plazas. Arcs are rated from 0 to 2 (0- cannot see any landmarks on the arc; 1- can see a landmark from the majority of the arc; 2- There is a landmark on the arc)</td>
<td></td>
</tr>
<tr>
<td>C53: Availability of Signals Adapted to Pedestrians</td>
<td>Disabled</td>
<td>All</td>
<td>Micro</td>
<td>Evaluated through on site analysis</td>
<td>Abley 2011</td>
<td>Evaluated using the following criteria:
<table>
<tr><td colspan="5">Availability of Signals: Are there pedestrian oriented finding signs, such as maps, or street names?</td></tr>
<tr>
<td>Nil (0): There was no directional information provided</td>
<td>Very Poor (1): The signs were pointing in the wrong direction and were not legible</td>
<td>Poor (2): The signs only included street names or were vague and not specific. Enough information on the arc is provided for the pedestrian to locate himself</td>
<td>Good (3): Adding to street names, the signs included directions to community services and areas of interest</td>
<td>Very Good (4): The signs provided a detailed map of where I was in relation to other community services and areas of interest areas including travel times.</td>
</tr>
</table>
</td>
<td></td>
</tr>
<tr>
<td>C61: Safety on Road Crossings</td>
<td>Disabled , Elderly and Adults</td>
<td>Crossings</td>
<td>Micro</td>
<td>Evaluated through on site analysis</td>
<td>Krambeck 2006: There are 3 key factors when evaluating how safe it is to cross the street: exposure to other modes; exposure time and at signalized intersections, the degree to which sufficient time is allocated for pedestrians</td>
<td>
<table>
<tr><td colspan="2" rowspan="2">Evaluated using the following criteria:</td><td colspan="3">Visibility</td></tr>
<tr><td>Low</td><td>Average</td><td>High</td></tr>
<tr><td rowspan="3">Exposure/Speed of traffic</td><td>Low</td><td>0</td><td>1</td><td>2</td></tr>
<tr><td>Average</td><td>1</td><td>2</td><td>3</td></tr>
<tr><td>High</td><td>2</td><td>3</td><td>4</td></tr>
</table>
</td>
<td></td>
</tr>
</table>

C62: Availability of Crossing in the Most desired Trajectory	Children	Crossings	Micro	GIS	No relevant way of assessing this indicator was found on scientific literature	Desire lines were placed in the network vectorization. This indicator is the ratio of formal crossings (signalized and zebra crossings) to the sum of desired crossings and formal crossings.	
C71: Enforcement of Legislation	Disabled , Elderly and Adults	All	Macro			This is a hard indicator to assess. The legislation is very extensive and virtually no streets comply with the full legislation. This was calculated as the ratio of non-cutoffs to total segments. Cutoffs are defined in C14.	
C72: Standardization of Interventions and Solutions	Children	Arcs	Micro			The standardization of solutions is quite difficult to assess. A solution was to consider whether the criteria for indicators C22, C32 and C61 were fulfilled. These indicators are not used for children and therefore are independent from this group of pedestrians.	

As previously stated, this dissertation intends to aggregate as much information available in the literature as possible as opposed to propose new methodologies. However in some cases that was not possible, either due to lack of information or because authors did not disclose their methodologies. Below is a description and justification for the use of each indicator.

C12: Continuity of Path

The Link-to-Node ratio is a very commonly used method to measure the continuity of path for vehicles. It is very simple to apply when using GIS tools such as ArcGIS. Ewing (1996) uses this method to evaluate the continuity of the network for pedestrians. However, limits and reference values for the value functions when applying the method to sidewalks have not been disclosed. Therefore, a decision was made to use the center of roads (paths for vehicles as opposed to paths for pedestrians). This enabled to score the areas to an approximate value.

One of the constraints of this simplification is that some roads do not have sidewalks or, some pedestrian paths are not parallel to roads (e.g. paths in gardens). These are not being taken into account. Some distortion of the results may occur.

C13: Condition to take the most direct path

The WPDI proposed by Soltani & Allan was used to measure this indicator. In order to adapt the method to the case study, divisions established by the municipality were used to determine each center of gravity. The more centers of gravity used, the most accurate result is expected to be obtained.

All in all, this method is very simple to be applied and the results obtained reflect the quality of the indicator being analyzed in the case study. Having access to ArcGIS tools is definitely advantageous.

C14: Existence of Infrastructure for Disabled Access

The impaired pedestrian group is the one with the most restrictions regarding the use of the network. Because of that, municipalities should plan their pedestrian networks so that they can be used by everyone. It was decided to evaluate several aspects of the infrastructure so that it is guaranteed that if the link is pedestrian accessible; it can be used by every user.

Criteria have been sourced from different locations such as scientific literature of local legislation. The fact that several aspects are being evaluated, reduces the possibility of a mismatch between the model and reality (i.e. ranking an arc as walkable when in reality, the impaired group cannot access it).

C21: Land Use Mix

This indicator is a complex one to evaluate. However it is a very relevant one. The majority of authors consider the Land Use Mix as a relevant criterion to evaluate. It was decided to add one point for each land use present in the arc. Although it was chosen because it seems to be an appropriate method to evaluate the indicator, it was proposed due to not having a clear method in the literature.

C22: Footway width

Footway width is an essential criterion to be evaluated as some users have minimum width restrictions, such as users in wheel chairs. However the definition of limits is not consensual among the authors found in the literature. Several possibilities of limits could be used: the Highway Capacity Manual or the local legislation are examples of sources to possibly use as they each define minimum widths for sidewalks. It was decided to use Evans (2009) as a source because the author defines limits for bad or good and this was then use to calibrate the value function.

C24: Everyday use of commercial activities' density

In this case, methodology to measure this indicator was found in the literature. However after careful examination of the method, it was decided not to use. 400m seems to be a large distance for some of the users such as the impaired or the elderly groups. Moreover, due to the large presence of local grocery stores, all the study case would rank as the top score, therefore skewing the results.

The solution adopted enables to differentiate the links and score them individually and the scoring is relative to one another, as the scoring is normalized from the observed scores. This is thought to be an appropriate solution and possible to implement in other locations.

C31: Vigilance effect: to see and be seen

The table proposed by Park (2008) was used to measure the vigilance effect. The fact that the scorer has a model that can use, in this case the images provided by the author, will reduce skewness of results. Moreover, the fact that Park used the method in California, USA, and was now used in Lisbon, Portugal, proves that it is transferrable to other locations.

C32: Pavement quality

The pavement quality is one of the most noticeable features of the built infrastructure for users. The vast majority of authors reference this as one of the most relevant aspects to evaluate. Abley (2011) proposes to measure the depth of irregularities of the pavement. This does not seem sustainable to do when evaluating about 250km of arcs. Therefore the methodology used was proposed using what the literature considers important i.e. pavement quality and tripping hazards. In order to reduce subjectivity, examples of the scores are presented in the Manual (refer to Annex). This should be adapted to other locations as Lisbon's sidewalks are in a majority paved with cobblestones.

C41: Existence of public meeting places

A clear methodology to evaluate this indicator was not found in the literature. However, some authors consider that the presence of esplanades or street furniture is perceived by users as meeting places. This methodology was then proposed. It seems to evaluate correctly the arc and is easily applied.

C42: Existence of attractor destinations

Just as **C24: Everyday Use Commercial Activities' Density,** the 400m distance seem to be very high. In a similar way, the same method was applied to C42, using different locations. In this case, the locations evaluated were proposed by authors found in the literature. It is an easy way to evaluate this criterion and possible to be applicable in other locations.

C43: Land use mix and Service hours

Like other indicators, there was no method to measure this in the literature. Although considered relevant, a method had to be proposed. This is measure in a similar way as C41, although with different criteria. It is easy to apply and could be transferred to other locations or case studies. Land use mix and service hours are evaluated together to provide a scoring of the arc.

C51: Sense of place and reference elements

This evaluation method is proposed, based on existent literature. It takes into account several aspects and considers reference elements as memorable locations. These could be recognizable brand locations, large squares or plazas or religious buildings. This follows the lines of Kevin Lynch that would consider any memorable element as a reference element. The scoring is made in a similar way as C41.

C53: Availability of signals adapted to pedestrians

The availability of signals adapted to pedestrians is an essential aspect when walking in an unknown area. The methodology used was adapted from Abley (2011) so that is suits the signs present in Lisbon. The methodology is easy to use and can be transferrable to other locations. In a similar way as it was done for this case, some adjustments may have to be done on the criteria evaluated.

C61: Safety on road crossings

Safety on road crossings proved to be one of the most difficult aspects to evaluate. Krambeck (2006) suggested there are three factors that should be evaluated when analyzing crossings: speed of traffic, exposure and visibility. However the author does not provide a way to score these factors.

In an attempt to reach a simple method to evaluate safety on crossings, a method was proposed. Each arc may have several adjacent crossings, and for the sake of being conservative, it was decided that each arc would get the lowest score of its adjacent crossings for C61.

The evaluation was done by scoring two dimensions: visibility and exposure/speed of traffic. In order to reduce subjectivity of evaluators, examples of crossings were given in the Manual (refer to Annex). The evaluator should mark the appropriate cell in the table. The value is the score.

This solution was implemented but we are aware that improvements on this method could be made, not only to simplify the method but to make it even less subjective.

C62: Availability of crossings in the most desired trajectory

To evaluate this indicator a method was proposed. No relevant way to score this dimension was found in the literature. The method is easily applied in other locations. It considers the ratio between informal and total crossings (formal + informal).

C71: Enforcement of Legislation

This is a difficult indicator to evaluate. If the full length of the legislation was to be followed, very few arcs would be considered according to the legislation. An alternative methodology would be to consider the percentage of arcs that are not considered cut-offs in C14. This indicator uses part of the legislation and would simplify the process.

C72: Standardization of intervention of solutions

No method to evaluate the Standardization of intervention of solutions was found in the literature. This method was proposed as a simple way to evaluate this indicator.

These methods used to evaluate the respective indicators seem to be the most efficient and accurate found or proposed. This contribution brought by this dissertation will definitely be helpful for further research done in this field. Not only does the dissertation aggregates a vast list of papers and extracts the most relevant information but also contributes when there are no methods available. When proposing new methods several aspects were taken in consideration. On one hand the method should be simple and practical enough to be applied, but also be a good way to evaluate the given indicator. On the other hand this method should be possible to be applied in other locations.

4.3 Value Functions of Indicators

After the definition of how to measure the indicators, value functions have to be determined. These are part of the MCDA. It converts the observations recorded into normalized values. This enables to sum the indicators to obtain a rating for the segment being evaluated. In this section the value function of each indicator will be specified. Although there are sophisticated methods to determine value functions such as MACBETH, this dissertation is a first approach to measuring walkability. Therefore the value functions are linear. However, the assessment of value functions should be studied in the future.

C12: Continuity of Path

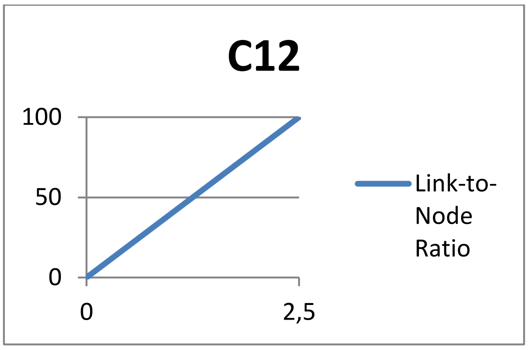


Figure 21 - Value Function of C12

As seen on the above figure, the values vary between 0 and 2.5. The value 2.5 (perfect grid) is proposed by Dill (2004). In the scientific literature there is no reference to base values so the value 0 was adopted. Ewing & Handy (2009) suggest that a value of 1.4 is a good target for network planning purposes. In this case, 1.4 would be equivalent to a ~56 score. It is considered a good score but not very high. Therefore this function is in line with the literature.

C13: Condition to take the most direct path

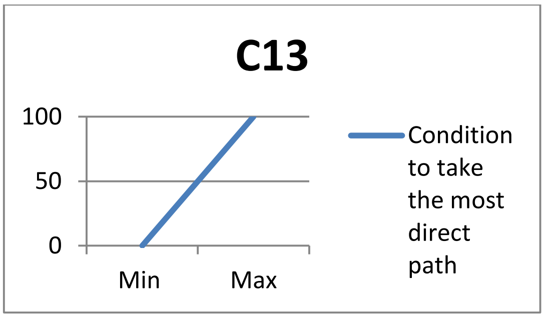


Figure 22- Value Function of C13

Due to the lack of data present in scientific literature the value function of this binary indicator varies between the Min and Max of the sample gathered. This leads to results that can be difficult to judge as there is no term of comparison. However this methodology of using the extreme values as 0 and 100 is widely used in the literature when assessing walkability. Further applications of this method will enable the creation of benchmarks.

C14: Existence of Infrastructure for Disabled Access

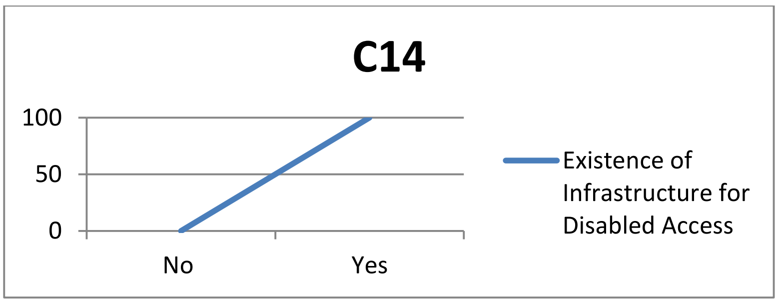


Figure 23 - Value function for C14

This value function acts as binary. The rational for this decision is that either there is an accessible network or there is not.

C21: Land Use Mix

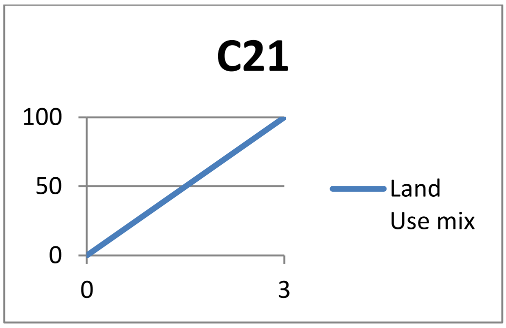


Figure 24 - Value Function for C21

This function varies between 0 and 3. The function is proposed by us. An arc with 0 is a segment where there is no Land Use, i.e. a street where there are no doors. An arc with a score of 100 should have the 3 types of land use: commercial, residential and offices. Other values are 33% (for one land use) or 67% (for arcs with two land uses).

C22: Footway width

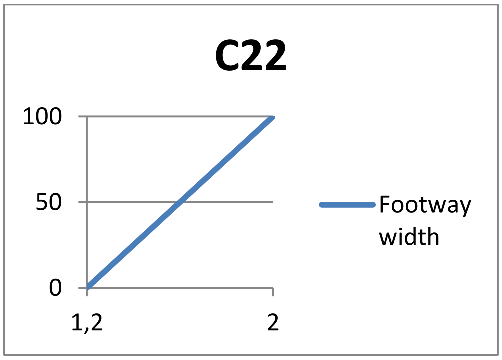


Figure 25 - Value Function for C22

The values 1.2m and 2m of effective footway width were proposed by Evans (2009) and used here. This value function indicates that the fact of having wider walkways does not improve its scoring for this dimension.

C24: Everyday use of commercial activities' density

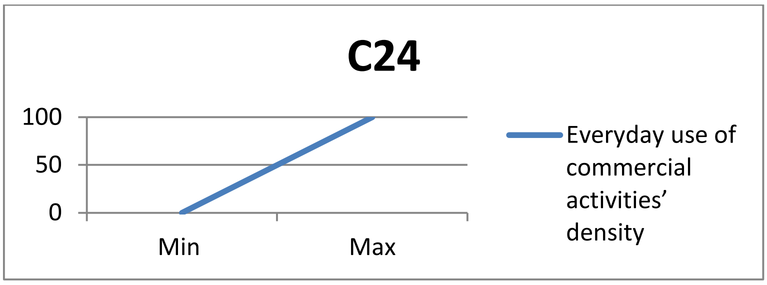


Figure 26 - Function value for C24

As there are no references to benchmarks for densities, this value function is proposed. The minimum and maximum are the values observed. This can create defective values in case of an outlier. Because of this, this function should be further looked into in future research.

C31: Vigilance effect: to see and be seen

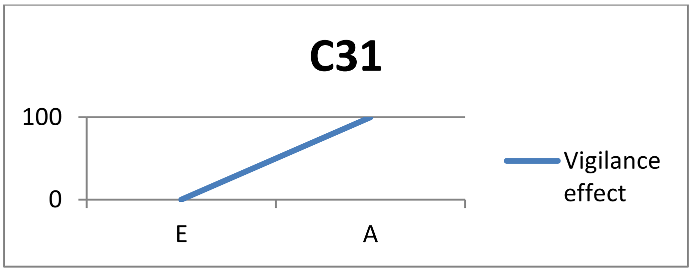


Figure 27 - Function value for C31

This value function is as proposed by Park 2008. It follows the author's methodology and scoring. An arc with a score of 0 is considered to be a segment where one would struggle to be seen in case something would happen. This does not take into account the pedestrian traffic but the facades of buildings in the arc. This was done because it is assumed (although not 100% accurate) that segments with more doors/shops would attract more pedestrians. An arc with the score of 100 would be a very busy arc and where a user would be seen very easily.

C32: Pavement quality

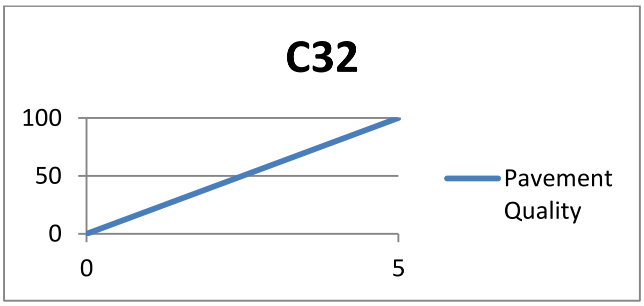


Figure 28 - Function value for C32

This function is an equally weighted average between pavement quality and tripping hazards. This enables taking into consideration several aspects that experts consider relevant in pavement quality.

However this value function enables compensating a bad pavement quality with the lack of tripping hazard (good).

C41: Existence of public meeting places

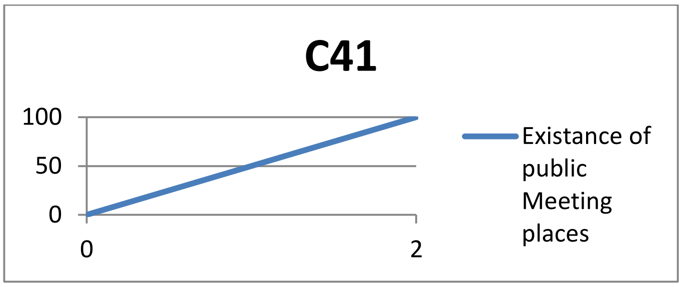


Figure 29 - Function value for C41

This value function varies between 0 and 2. This represents the worst and best values. For an arc with a 100 score, there is a meeting place, for 50 a meeting place can be seen and for 0 there is not nor can be seen a public meeting space.

C42: Existence of attractor destinations

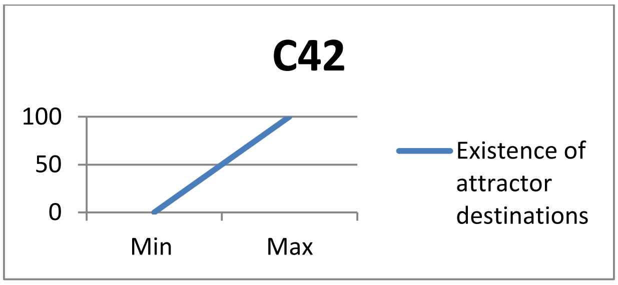


Figure 30 - Value function for C42

This is evaluated in a similar way as C24. It is a normalized function between the extreme values observed in the case study. This means that the function depends on what scores the area has. Extreme values may skew the scoring.

C43: Land use mix and Service hours

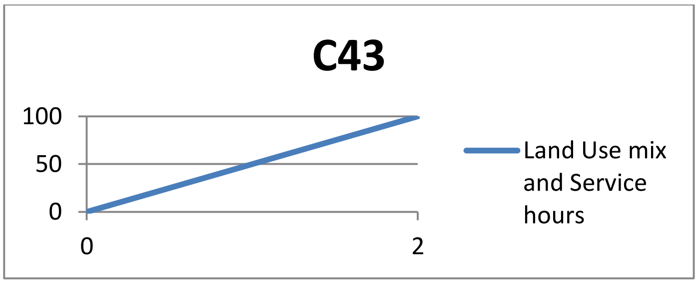


Figure 31 - Value function for C43

C43 is evaluated similarly to C41. For a segment with scores for C41 of 0 or 33%, the arc should have a 0 score for C43 as there is no land use mix. For an arc with land use mix but where service hours are very limited, a score of 50 should be given. Maximum score is attributed to arcs with land use mix and good service hours (i.e. there are establishments open to later than the average of places, 6pm. was considered for Lisbon).

C51: Sense of place and reference elements

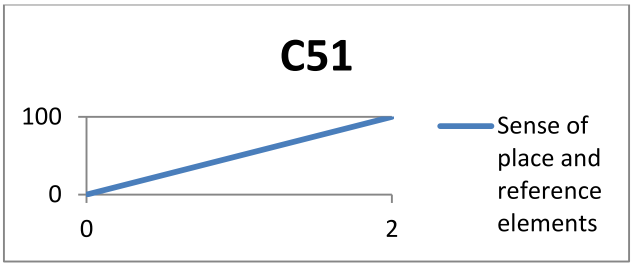


Figure 32 - Value function for C51

Evaluated in a similar way as C43 but with different criteria. An arc with a score of 100 should be very simple to identify as it has a reference element present. This element would serve as a reference when, for example, trying to explain someone where the pedestrian is.

C53: Availability of signals adapted to pedestrians

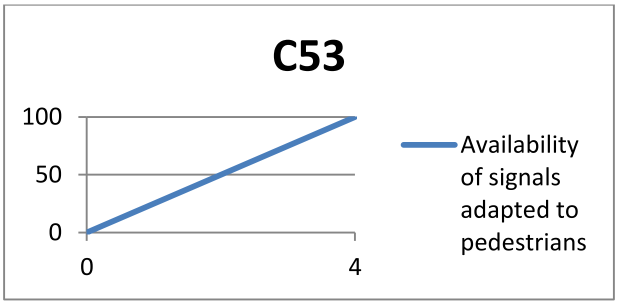


Figure 33 - Value function for C53

This indicator is evaluated as proposed by Abley (2011). The author did not specify the value function but in this dissertation it is assumed to be linear.

C61: Safety on road crossings

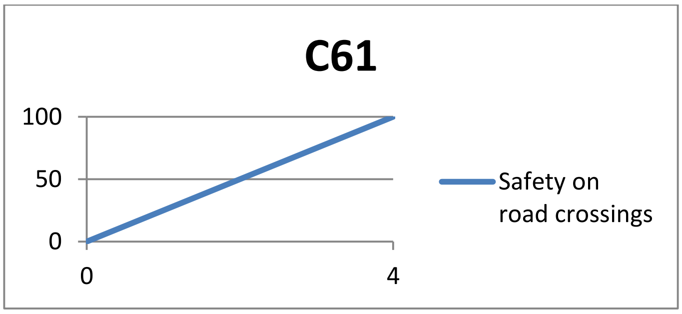


Figure 34 - Value function for C61

The input value is obtained through a sum of the score for exposure/speed of traffic and visibility. Both are rated 0-2, and the indicator has a maximum of 4. The inputs are obtained from the table presented previously in the description of the indicators.

C62: Availability of crossings in the most desired trajectory

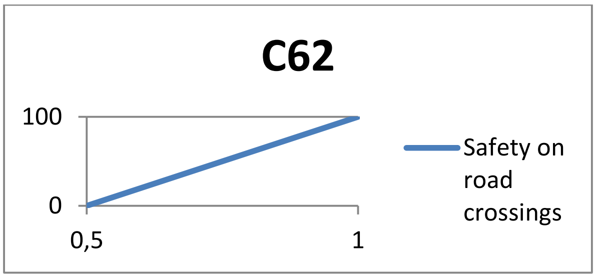


Figure 35- Value function for C62

This indicator was evaluated as a ratio between formal and al crossings (forma+ informal). Having no other reference on how the result of the ratio is considered good or bad, it was assumed that when only half of the crossings are signalized or zebra, it is a very bad and therefore have a value of 0. This should be reconsidered when further results are available through analysis of other regions.

C71: Enforcement of Legislation

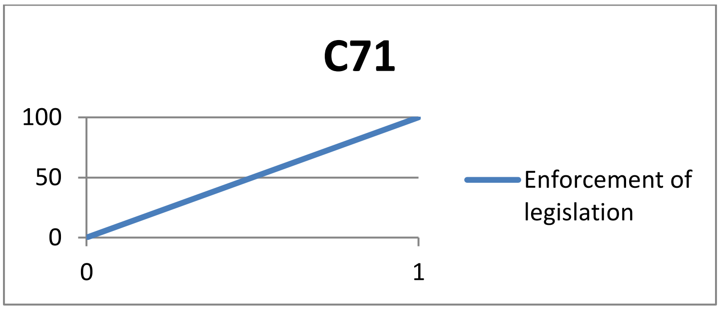


Figure 36- Value function for C71

This value function is a linear function but should be investigated. Is 0 the actual 0 or should the value function return 0 for a higher observed number, such as 0.5? i.e. does a 50% enforcement of the legislation correspond to a scoring of 0 to the case study. This should be further investigated.

C72: Standardization of intervention of solutions

This is a binary function: either there is standardization or there is not.

The value functions have been defined as described above. These were used in this dissertation but deserve a research paper of their own, due to the high complexity of the problem that is being faced. In fact, this is one of the points where most of the scientific papers disagree: standardization for how to measure walkability.

4.4 Model of evaluation of walkability

Having defined the weights and the value functions, it is now possible to measure walkability of streets and areas for the several user groups and modes.

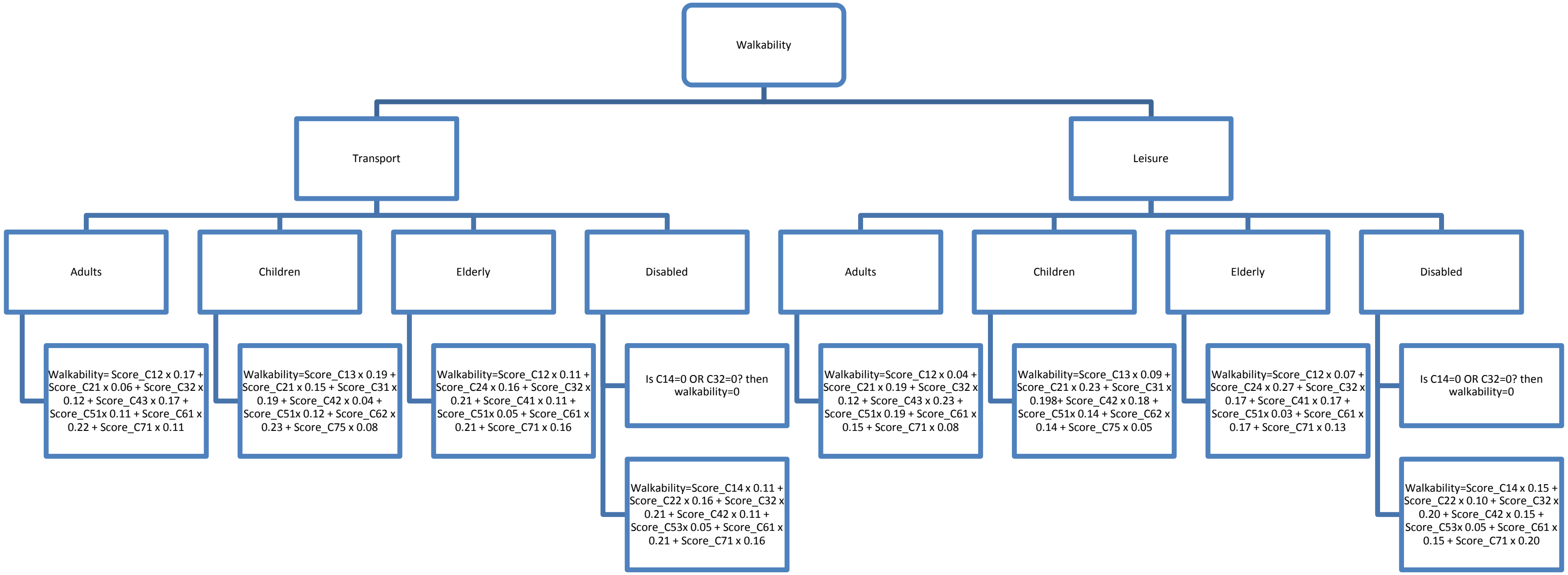


Figure 37 - Model of evaluation of walkability

Figure 37 illustrates how the measurement of walkability should be assessed, after the street auditing and GIS analysis for the criteria. As shown, there are two types of walking considered (leisure and utilitarian) and the pedestrians are divided in four groups. Walkability score is then determined as a weighted average of the indicators of each group. The method of determining which indicators are relevant has been explained previously.

When assessing walkability for the disabled group, the cut-offs should be considered. This is the only group with said cut-offs because it was considered that for other pedestrians with less constraints on mobility, obstacles are a negative factor but can be overcome. As an example, if a sidewalk is blocked a pedestrian from the Adult group can easily overcome it by changing sidewalks. For a pedestrian of the disabled group this obstacle would block the passage. It is difficult for a wheelchair to overcome steps and therefore this creates a discontinuity of the pedestrian network. Cut-offs are:

- Insufficient effective width (considered at 0,8m according to HCM)
- Steep longitudinal inclination (over 10% according to Decreto-Lei n.º 163/2006 de 8 de Agosto)
- Presence of steps (Decreto-Lei n.º 163/2006 de 8 de Agosto)
- Very bad pavement quality (proposed by this dissertation but considered relevant by the scientific community)

If a street segment does not comply with the cut-offs, the score of walkability is 0 and the street will not be considered for the macro criteria. This means that when assessing connectivity, ArcGIS does not consider that path as an option to go from A to B.

Crossings are not evaluated on walkability but are used to evaluate adjacent arches. For C61, each arch receives the evaluation of the worst evaluated adjacent crossing. This was decided due to the difficulty of evaluation for this criterion. If a street scores very poorly on all criteria and has a crossing with maximum score, the arch may have a higher walkability score than others that may be better for walking, therefore skewing the results. This should be further looked in in future research as it is a very complex problem.

C71 and C72 are two indicators that are being evaluated with a proposed method. This is a decent method of evaluation but should be further assessed.

This model has been designed as a first approach for measuring walkability using the above methodology. A first application of the model has been made and its results discussed on chapter 5.

5. Application to the Case Study of Arroios, Lisbon

5.1 Presentation of Arroios, Lisbon

As this dissertation is integrated in the IAAPE project, the Municipality of Lisbon proposed a case study location. A safety assessment for several schools in the city of Lisbon is currently being done. The schools chosen for this case study were *Escola Secundária Dona Luisa Gusmão* and *Escola Básica Natália Correia*. These are located as shown below.

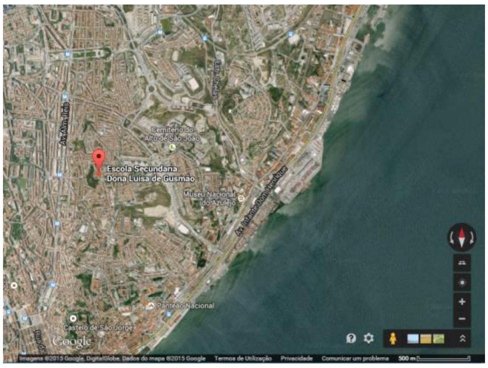


Figure 38 - Location of Esc. Sec. D. Luisa Gusmão

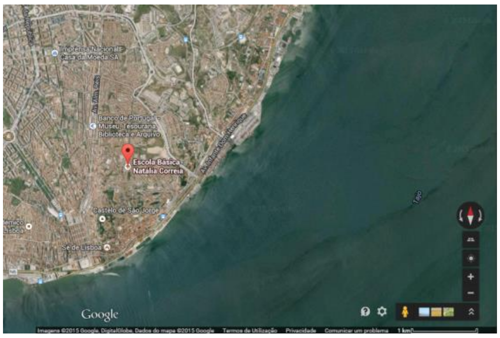


Figure 39 - Location of E.B. Natália Correia

These two schools are located in Lisbon, in a neighborhood called Arroios (Figure 40). Lisbon is divided into parishes (in Portuguese "*freguesias*"), and each one has responsibilities and some autonomy for decision making. Arroios is located in the center of Lisbon and is one of the oldest. It has about 31600 habitants (http://www.pordata.pt/) and an area of over 2 km^2. It is mainly a residential area but has some of the most emblematic touristic venues of Lisbon such as the Miradouro da Graça.

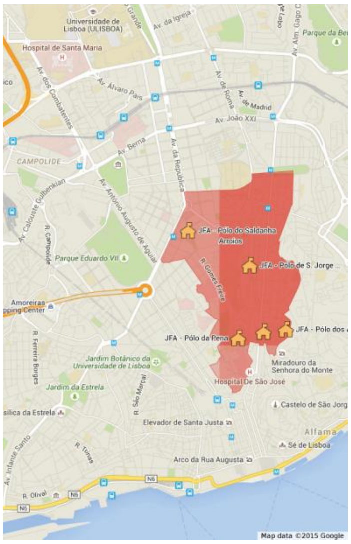


Figure 40 - Location of Arroios, Lisbon (source: Google Maps)

The study area is defined by two circumferences of 400m radius with centers in each school. This study area encompasses several different kinds of streets and neighborhoods. On the West, *Avenida Almirante Reis* is one of the most important 4-lane avenues of Lisbon. The *Anjos* neighborhood is a more traditional and residential one. Overall this case study will provide enough diversity so that differences in evaluations can be observed.

5.2 Street Auditing

In order to ensure that street auditing would not be affected by subjectivity of the evaluator, a street auditing guide was created. This 10-page document was created so that it would be as easy and objective as possible for the auditor to score the dimensions of walkability. After a brief introduction to what is being evaluated, the indicators are presented and how to evaluate them. Pictures of examples were given in order to ensure easiness of evaluation. The Street guide is presented in Annex II.

The auditor was then asked to complete the tables that were given to him/her. Each link was to be assessed as well as each crossing. In the case of crossings, it was required to determine which links are affected. An explanation is presented in the introduction of Annex II. The street tables for links and crossings are presented in Table 7 and Table 8, respectively.

Table 7 - Street auditing evaluation for arches

Arc Table			C53	C32		C14 and C22		C21	C41	C31	C43	C51	C24	C42
Segment Code	Street	From door - to door	Availability of Signals (0-4)	Pavement Quality (0-4)	Tripping hazard (0-1)	Steps (0-1)	Effective Width (m)	Land Use Mix (1-3)	Existence of public meeting places (0-2)	Vigilance effect (E-A)	Land use mix and service hours (0-2)	Sense of place and reference elements (0-2)	Commercial Activities	Existence of Attractor Destinations

Table 8 - Street auditing evaluation for crossings

Crossing Table			C14	C61	
Arc affected	Number of closet door No.	Segment Code	Steps and tactile aid (0-2)	Crossing safety (0-2)	Exposure/ Speed of traffic (0-2)

This street auditing guide and tables were created specifically for the city of Lisbon. This study case may differ from other cities in the sense that it was planned/built a very long time ago and has the tradition of cobblestones sidewalks. Moreover the streets in older neighborhoods can be very narrow and be very steep. When applying this model to other cities, a revision of which and how the indicators are assessed is mandatory.

The street auditing for the whole area took two working days, with 7 auditors. The process is gets faster as the evaluator gets more familiar with the criteria.

5.3 Calculating the Walkability Scores

After the whole case study area was evaluated, the data was then transferred manually to digital format. The process took two people one working day. Having the data, it was then passed into ArcGIS and the remaining scores of indicators were calculated through GIS analysis. A Microsoft Excel spreadsheet has been created with formulae that return final scores for the different walking modes and pedestrian groups.

The methodology used was described in previous chapters and the results are presented in the next section.

5.4 Indicators of Walkability at Arroios

The different indicators were measured and assessed and a summary for the results is presented in Table 9.

Table 9 - Measurements of Indicators for case study

	Code	Average/result[1]	Median	25% quartile	75% quartile
Continuity of Path[1]	C12	33.21			
Condition to Take the Most Direct Path	C13	21.66	18.46	14.95	23.48
Existence of Infrastructure for Disabled Access	C14	12.78			
Land Use Mix	C21	43.04	33.33	33.33	66.67
Footway Width	C22	27.42	0.00	0.00	40.50
Everyday Use Commercial Activities' Density	C24	4.41	0.00	0.00	0.00
"Vigilance Effect": To see and be Seen	C31	51.70	50.00	25.00	75.00
Pavement Quality	C32	69.35	75.00	62.50	87.50
Existence of Public Meeting Places	C41	15.09	0.00	0.00	0.00
Existence of Attractor Destinations	C42	1.23	0.00	0.00	0.00
Land Use Mix and Service	C43	10.67	0.00	0.00	0.00
Sense of Place and Reference Elements	C51	21.08	0.00	0.00	0.00
Availability of Signals Adapted to Pedestrians	C53	41.67	50.00	50.00	50.00
Safety on Road Crossings	C61	40.58	0.00	0.00	100.00
Availability of Crossing in the Most desired Trajectory[1]	C62	36.38			
Enforcement of Legislation[1]	C71	53.49			
Standardization of Interventions and Solutions	C75	20.42	0.00	0.00	0.00

Some indicators are presented as a classification because they are assessed on a Macro scale basis (C12, C62, and C71). C14 was evaluated as a binary: either the link has the maximum score or it is awarded 0. The score therefore indicates the percentage of evaluated links that scored 1, i.e. it is possible to conclude that only 12,78% of all segments evaluated have what was considered to be an existing

[1] Due to the method used, these are Macro scale indicators and therefore, all links are awarded the same score

infrastructure for disabled access. This is a clear sign that the area that is being studied should be analyzed by competent authorities to provide access to every pedestrian.

For the indicators C12, C62 and C7 it is difficult to provide any comments as there is no benchmark and its analysis should come after other areas are evaluated.

The data for C24 and C42 is highly conditioned by the presence of an outlier. A market street on the evaluated area has 10 commercial stores and therefore all the other streets have very low scores. This is a concern and should be assessed in future analyses.

Except for Comfort (C3), all dimensions have low scores. This indicates that both quality of pavement and vigilance effect are good in the Arroios area of Lisbon.

The dimension with the lowest scores is Conviviality (C4). Although these results are affected by the presence of an outlier, it was expected as it is an area with few zones that provide a physical space for citizens to interact.

A very large concern prior to the analysis was that indicators couldn't be correlated in order to use an MCDA method. As it is visible in Annex III – Correlation Matrix, there are no indicators with high correlation, except for C41 and C51 with an r=0,569. This can be explained because often where there are landmarks, there are also anchor spaces with attractive characteristics, such as esplanades.

It is also interesting that there are very few indicators with negative correlation. This indicates that if a street scores bad in one dimension, it is likely to have a very low score and the same would happen with high scores.

The scores for the arches are shown in Figure 41 and Figure 42. The red segments have low scores and bright green higher scores of walkability.

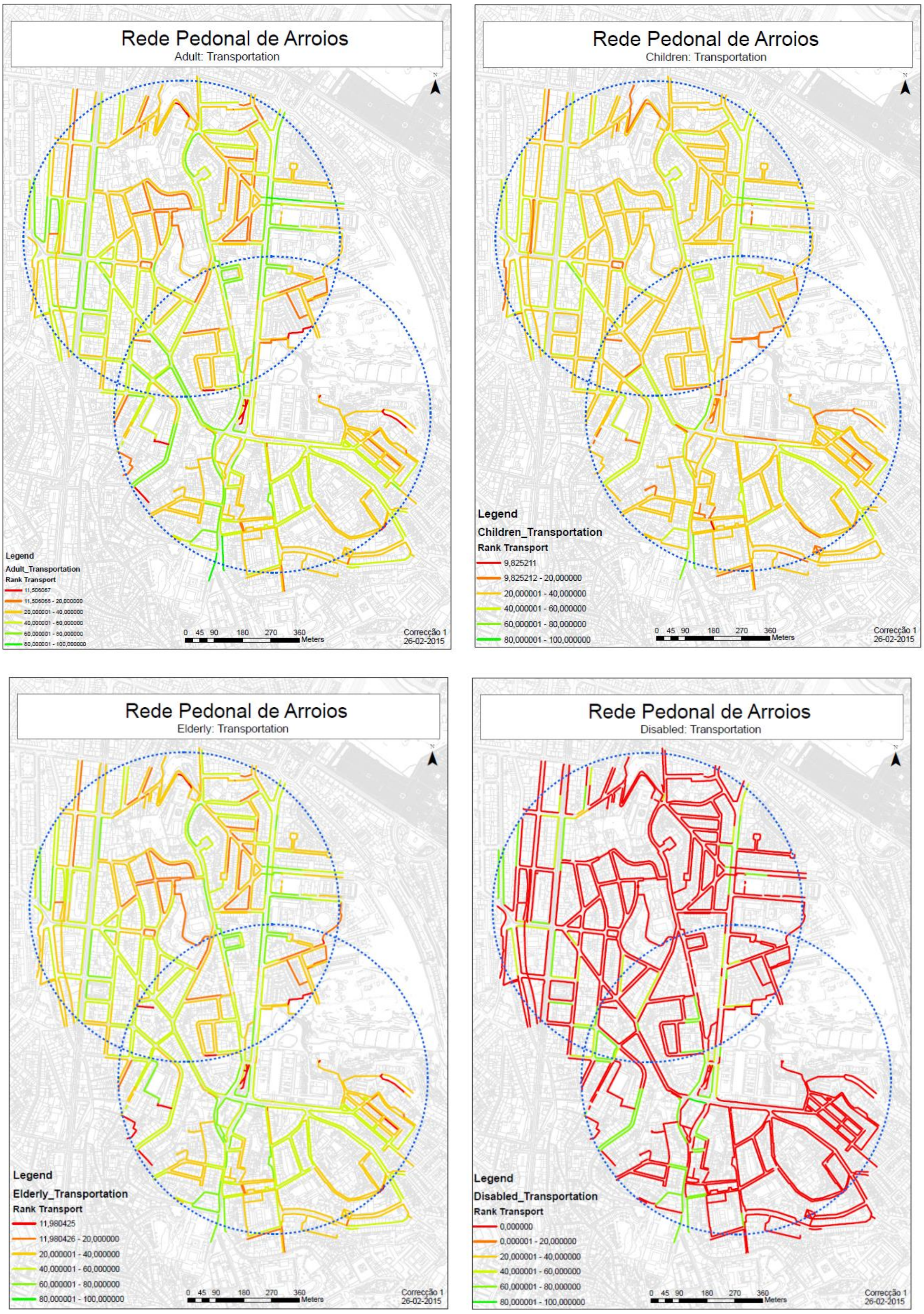


Figure 41 - Walkability evaluation for utilitarian trips and each population group

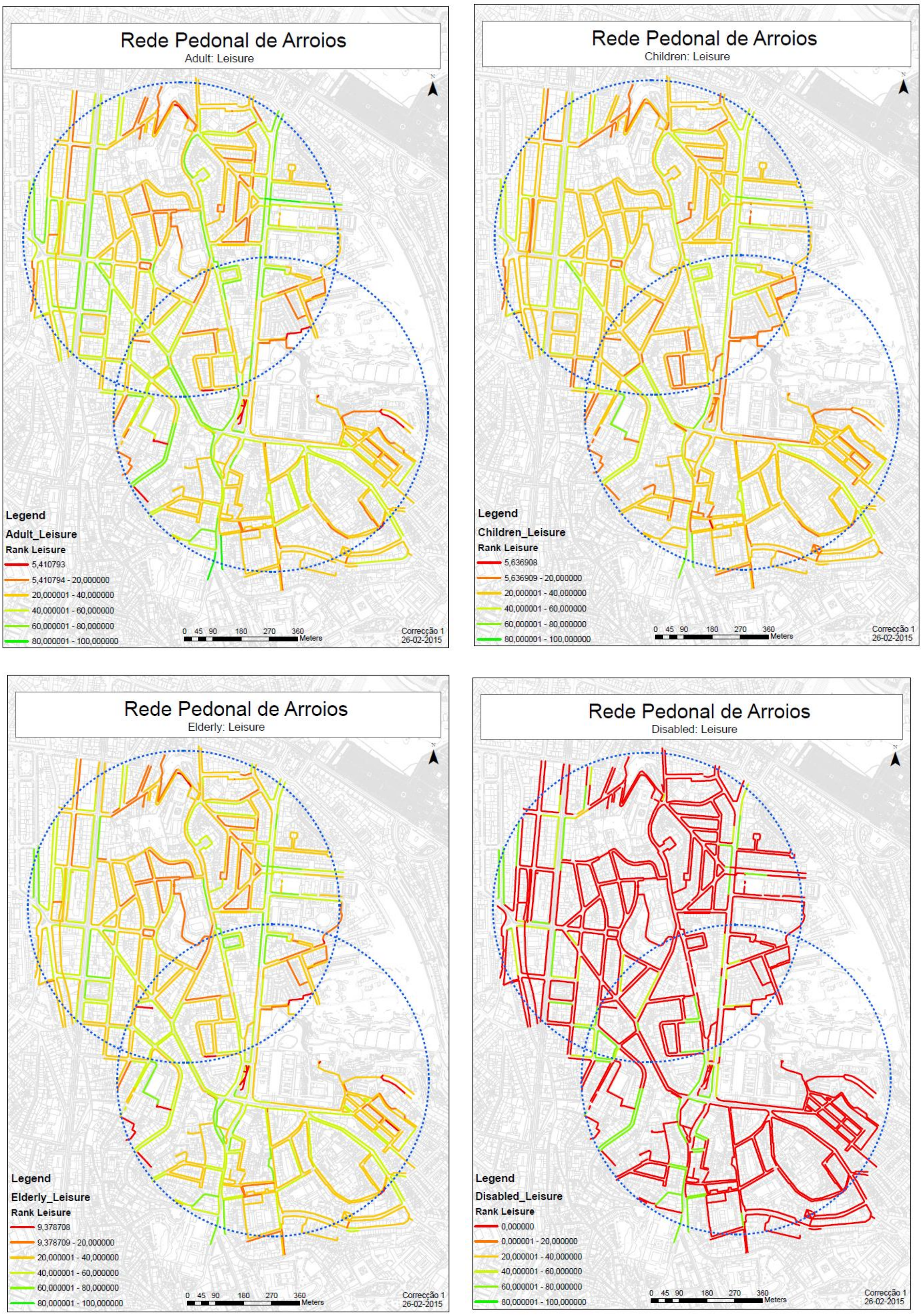


Figure 42 -Walkability evaluation for leisure trips and each population group

When analyzing the results, some differences are immediately observed. It is possible to confirm that in fact, different groups of pedestrians perceive the network differently. Moreover, the walking modes also have an influence on the results.

The adult and the disabled groups are the least influenced by the trip mode. In the latter group, this can be explained by the amount of cut-offs present in this case study. Additionally, the weights are not very different for the two trip modes. On the contrary, in the adults group, it was not expected as the weights are very different for the two modes. This can be explained by one of the methods used in this dissertation. Compensatory analysis was used: this is one of the Multi Criteria analysis techniques where the total score is a weighted average of the scores for the indicators. One of the weaknesses is that a bad score in one parameter can be overcome by a good score in another (Baltussen & Niessen, 2006). The effects on this were not addressed.

When comparing different groups of pedestrians, the differences are remarkable. Arroios scores very high for utilitarian trips for the Adults, while it scores very poorly for leisure trips made by impaired pedestrians.

The amount of cut-offs for the disabled group was expected. Lisbon is an old city and was not planned for all pedestrians when it was built nor when it was transformed over time. Although significant efforts are being made by the Municipality, sidewalk width remains a major concern. This can explain most of the cut-offs.

Elderly and Children groups generally scored average results (between 40 and 60). In order to compare and further provide comments on these results, other case studies should be analyzed.

It is also possible to observe that Avenida Almirante Reis is one of the avenues with the best score. This is located on the upper left corner of the study case area. This street has large sidewalks, a very large amount of appealing locations (shops, commercial activities etc...) and the crossings are all signalized. Also, the streets near Largo da Graça (southwest) have very high scores. This is a tourist attraction and has also a significant amount of commerce.

On more residential blocks, scores are lower due to the lack of land use mix.

6. Conclusions

6.1 Summary and Answering the Research Question

This dissertation had as main objective to contribute to the IAAPE evaluation procedure by defining a method to select indicators for the 7 walkability dimensions, weigh the selected indicators for different population groups and trip motives, and finally, transform these indicators into a single walkscore for each link of the pedestrian network. This was done using as much as possible the existing literature. It was achieved, but there are some points that still need work.

The model built was tested in the case study and in fact it was possible to measure walkability for the area. The results for this assessment were satisfying but a cautious optimism is needed at this point. In order to confirm these results reflect the users' perception of the built environment, a validation should be made.

17 different indicators were used to measure walkability for four pedestrian groups on two travel modes each. This was achieved through a weighted average of the scores. This is a concern: can a very bad result from one of the indicators be compensated by a good one in another? This is a question that is left unanswered in this dissertation. We can however discuss the hypothetical answers. Park (2008) also ended his dissertation with this concern. If we answer "Yes, a bad result in one indicator can be compensated by an excellent result in another", we are assuming that independently of how bad one of the features scored is, if another indicator scores very high, the pedestrian will chose this path (with the exception of the cut-offs for the impaired users of thee network). As an example of a path A that takes pedestrians from one origin to a destination very directly compared with the alternative link B. A, however is missing its pavement and is full of potholes. B is very nicely paved and very pleasant to walk, however the distance is double of A. Every day we encounter similar situations and take route A, simply for reducing our journey's time, especially when in a utilitarian trip.

On the other hand, one can argue that "no, if one of the indicators scores very low, this route should not be used". This is also a valid statement as some users would take the longer and more comfortable route. Also some pedestrians may not consider that A is a possible alternative for reaching their destination. A third answer for the previous question could be "well, it depends". This should pose a more complex problem. For answers "No" and "it depends" the method used in this dissertation should be reviewed and use a Non-compensatory Multicriteria method. This method enables the analyst to overcome this problem. This falls outside of the scope of this dissertation.

Moreover, some indicators are very difficult to evaluate. In Portugal the data is often not available; this can make things more difficult. For the land-use mix indicators, some experts use the built areas of each land use (commercial, residential and services) to get to an aggregate result. The Lisbon

Municipality does not have this data and therefore a different method was suggested. The method of adding one point per land use mix is a simple solution to a complex problem the team was facing.

The method suggested for C24 - Everyday Use Commercial Activities' Density - and C42 - Existence of Attractor Destinations - has he problem of the outliers, as was seen on Chapter 5. If one street has a lot of commercial destinations, the results for the entire area will be distorted by this outlier. Additionally, let us consider a zone with a very big concentration of commercial activities: either 6 or 7 on all streets. The segments with 6 will score 0 and the segments with 7 will score 100. The results depend on what is observed on the area and this should be further assessed.

Crossings are also a main concern for this model. It is very difficult to evaluate a segment with crossings. After the results were analyzed it was observed that a very large number of observations were the same. This can be explained because the architecture of crossings in the Arroios zone is quite similar. But if a street scores very low on all other indicators and has a very good crossing at one end, is it legitimate that it scores well above other that, a priori were considered more walkable? This is again part of the problem described earlier.

The literature was reviewed and the methodology used for this dissertation is thought to be the best for this situation. However some adaptations may need to be done when applying this method to other locations: how to evaluate the indicators and their weights should be adjusted accordingly by contacting with the stakeholders of those locations. The methodology however can be used globally. Creating a methodology that can be used globally is a very big and difficult task according to Krambeck (2006).

This dissertation brings a significant contribution to the community. It brings together a long list of papers and proposes a methodology that could be applied to other locations. From the selection of the most relevant indicators to scoring of dimensions this dissertation addresses the complete scope of evaluating Walkability. In the selection of indicators the methodology is easy to implement by selecting local stakeholders, the indicators evaluated have been described and could be replicated to some extent. Others should be adjusted to local conditions. Finally, this dissertation proposes a set of value functions to score the dimensions.

The methodology presented in the scope of this dissertation could be marketed to its target, the Municipalities, as a product to aid the decision making on where to act in order to improve the walkability. By acting as consultants, the analysts applying the method will help improve walkability for the users and benefit from the numerous advantages described in this report. By creating a tool that could be applied to several locations by undergoing minor adjustments, this dissertation proves to be an efficient way to evaluate walkability and reach as many locations as possible. In a sum, we have created a product that fulfills a need for the decision makers to transform their cities into more walkable and "green" spaces, and that could very efficiently applied to different locations.

6.2 Leads for Future Research

The main issues with the model presented are with the indicators, more specifically, how to measure and evaluate them. It can be very difficult to measure some of these variables as it was discussed. Further investigation should be done on this matter.

The methodology presented was successfully applied to a case study. But are the results true? I.e. are the streets with the highest scores considered by pedestrians as the more user friendly? This leads to validation, another very complex problem. IAAPE is currently working on a validation methodology that can bring further light to these questions.

References

Abley, S. (2006). WALKABILITY TOOLS RESEARCH Variables Collection Methodology.

Abley, S., & Consultants, A. (2010). Measuring accessibility and providing transport choice. *Australian Institute of Transportation …*. Retrieved from http://www.livingstreets.org.nz/sites/livingstreets.org.nz/files/1555 Steve Abley - Accessibility - Abstract and Paper.pdf

Abley, S., Turner, S., & Singh, R. (2011). Predicting walkability. Retrieved from http://www.hardingconsultants.co.nz/ipenz2011/downloads/Abley__Steve.pdf

Albers, P., Wright, C., & Olwoch, J. (2010). Developing a South African pedestrian environment assessment tool: Tshwane case study. *South African Journal of …*. Retrieved from http://reference.sabinet.co.za/sa_epublication_article/sajsci_v106_n9_10_a12

Appleyard, B. (2003). Planning Safe Routes to School. *Planning*. Retrieved from http://eric.ed.gov/?id=EJ671585

Ariffin, R. N. R., & Zahari, R. K. (2013). Perceptions of the Urban Walking Environments. *Procedia - Social and Behavioral Sciences*, *105*, 589–597. doi:10.1016/j.sbspro.2013.11.062

Bafna, S. (2003). Space Syntax: A Brief Introduction to Its Logic and Analytical Techniques. *Environment & Behavior*, *35*(1), 17–29. doi:10.1177/0013916502238863

Baker, D., Bridges, D., Hunter, R., & Johnson, G. (2002). Guidebook to decision-making methods. *Department of Energy, USA*. Retrieved from https://scholar.google.pt/scholar?hl=pt-PT&q=Guidebook+to+decision-making+methods+&btnG=&lr=#0

Baltussen, R., & Niessen, L. (2006). Priority setting of health interventions: the need for multi-criteria decision analysis. *Cost Effectiveness and Resource Allocation : C/E*, *4*(1), 14. doi:10.1186/1478-7547-4-14

Bana e Costa, C. A., & Oliveira, R. C. (2002). Assigning priorities for maintenance, repair and refurbishment in managing a municipal housing stock. *European Journal of Operational Research*, *138*(2), 380–391. doi:10.1016/S0377-2217(01)00253-3

Bana e Costa, C. A., Oliveira, & Vieira. (2008). Prioritization of bridges and tunnels in earthquake risk mitigation using multicriteria decision analysis: Application to Lisbon☆. *Omega*, *36*(3), 442–450. doi:10.1016/j.omega.2006.05.008

Bana e Costa, C. A., & Vansnick, J.-C. (1997). Applications of the MACBETH Approach in the Framework of an Additive Aggregation Model. *Journal of Multi-Criteria Decision Analysis*, *6*(2), 107–114. doi:10.1002/(SICI)1099-1360(199703)6:2<107::AID-MCDA147>3.0.CO;2-1

Batista e Silva, J., da Graça Saraiva, M., Loupa Ramos, I., & Bernardo, F. (2013). Improving Visual Attractiveness to Enhance City–River Integration—A Methodological Approach for Ongoing Evaluation. *Planning Practice and Research*, *28*(2), 163–185. doi:10.1080/02697459.2012.704734

Behzadfar, M., Habibi, K., & Shahmoradi, B. (2012). Feasibility Study of GIS and AHP Techniques in Site Selection for Pedestranization towards Urban Regeneration. *… Architecture & Urban …*, *4*(8), 83–91. Retrieved from http://198.55.49.74/en/VEWSSID/J_pdf/1026720120808.pdf

Bradshaw, C. (1993). Creating—and Using—a Rating System for Neighborhood Walkability: Towards an Agenda for “Local Heroes.” *14th Intl Pedestrian Conf*. Retrieved from https://scholar.google.pt/scholar?q=walkability+autor%3Abradshaw&btnG=&hl=pt-PT&as_sdt=0%2C5&as_yhi=2004#0

Cambra, P. (2012). *Pedestrian Accessibility and Attractiveness Indicators for Walkability Assessment*. Retrieved from https://fenix.tecnico.ulisboa.pt/downloadFile/395144992898/Dissertacao.pdf

Cervero, R., & Kockelman, K. (1997). Travel demand and the 3Ds: Density, diversity, and design. *Transportation Research Part D: Transport and Environment*, *2*(3), 199–219. doi:10.1016/S1361-9209(97)00009-6

Christopoulou, P., & Pitsiava-Latinopoulou, M. (2012). Development of a model for the estimation of pedestrian level of service in Greek urban areas. *Procedia-Social and Behavioral …*. Retrieved from http://www.sciencedirect.com/science/article/pii/S187704281202887X

Clark, A., Scott, D., & Yiannakoulias, N. (2014). Examining the relationship between active travel, weather, and the built environment: a multilevel approach using a GPS-enhanced dataset. *Transportation*. Retrieved from http://link.springer.com/article/10.1007/s11116-013-9476-3

Coffee, N. T., Howard, N., Paquet, C., Hugo, G., & Daniel, M. (2013). Is walkability associated with a lower cardiometabolic risk? *Health & Place*, *21*, 163–9. doi:10.1016/j.healthplace.2013.01.009

Dill, J. (2004). Measuring network connectivity for bicycling and walking. *83rd Annual Meeting of the Transportation …*. Retrieved from http://reconnectingamerica.org/assets/Uploads/TRB2004-001550.pdf

Doyle, S., & Kelly-Schwartz, A. (2006). Active community environments and health: the relationship of walkable and safe communities to individual health. *Journal of the …*. Retrieved from http://www.tandfonline.com/doi/abs/10.1080/01944360608976721

Dulmin, R., & Mininno, V. (2003). Supplier selection using a multi-criteria decision aid method. *Journal of Purchasing and Supply Management*, *9*(4), 177–187. doi:10.1016/S1478-4092(03)00032-3

Duncan, D., Aldstadt, J., Whalen, J., & Melly, S. (2013). Validation of Walk Scores and Transit Scores for estimating neighborhood walkability and transit availability: a small-area analysis. *GeoJournal*. Retrieved from http://link.springer.com/article/10.1007/s10708-011-9444-4

Evans, G. (2009). Accessibility and urban design - Knowledge matters. Birmingham City University Publication. Retrieved from http://bura.brunel.ac.uk/handle/2438/6442

Ewing, R. (1999). *Pedestrian-and transit-friendly design: a primer for smart growth*. Retrieved from http://epa.gov/livability/pdf/ptfd_primer.pdf

Ewing, R., & Connors, M. (2013). Validating Urban Design Measures. *… Research Board 92nd …*. Retrieved from http://trid.trb.org/view.aspx?id=1241107

Ewing, R., & Handy, S. (2009). Measuring the unmeasurable: urban design qualities related to walkability. *Journal of Urban Design*. Retrieved from http://www.tandfonline.com/doi/abs/10.1080/13574800802451155

Frank, L. D., Sallis, J. F., Conway, T. L., Chapman, J. E., Saelens, B. E., & Bachman, W. (2006). Many Pathways from Land Use to Health: Associations between Neighborhood Walkability and Active Transportation, Body Mass Index, and Air Quality. *Journal of the American Planning Association*, *72*(1), 75–87. doi:10.1080/01944360608976725

Fruin, J. (1971). *Pedestrian planning and design*. Retrieved from http://trid.trb.org/view.aspx?id=114653

Gonçalves, A., Sousa, H., Moura, F., & Nunes, S. (2015). The importance of digitizing a detailed pedestrian network for walkability assessment: the case of elderlies and impaired mobility. In *TRANSED 2015 conference, Lisbon, 29-31 July.* Lisbon.

Handy, S. L., Boarnet, M. G., Ewing, R., & Killingsworth, R. E. (2002). How the built environment affects physical activity. *American Journal of Preventive Medicine*, *23*(2), 64–73. doi:10.1016/S0749-3797(02)00475-0

Hansen, P., & Ombler, F. (2008). A new method for scoring additive multi-attribute value models using pairwise rankings of alternatives. *Journal of Multi-Criteria Decision Analysis*, *15*(3-4), 87–107. doi:10.1002/mcda.428

Keast, E. M., Carlson, N. E., Chapman, N. J., & Michael, Y. L. (n.d.). Using built environmental observation tools: comparing two methods of creating a measure of the built environment. *American Journal of Health Promotion : AJHP*, *24*(5), 354–61. doi:10.4278/ajhp.080603-QUAN-81

Kelly, C. E., Tight, M. R., Hodgson, F. C., & Page, M. W. (2011). A comparison of three methods for assessing the walkability of the pedestrian environment. *Journal of Transport Geography*, *19*(6), 1500–1508. doi:10.1016/j.jtrangeo.2010.08.001

Krambeck, H. V. (2006). *The global walkability index*. Massachusetts Institute of Technology. Retrieved from http://dspace.mit.edu/handle/1721.1/34409

Leslie, E., Coffee, N., Frank, L., Owen, N., Bauman, A., & Hugo, G. (2007). Walkability of local communities: using geographic information systems to objectively assess relevant environmental attributes. *Health & Place*, *13*(1), 111–22. doi:10.1016/j.healthplace.2005.11.001

Leslie, E., Saelens, B., Frank, L., Owen, N., Bauman, A., Coffee, N., & Hugo, G. (2005). Residents' perceptions of walkability attributes in objectively different neighbourhoods: a pilot study. *Health & Place*, *11*(3), 227–36. doi:10.1016/j.healthplace.2004.05.005

Litman, T. A. (2003). Economic Value of Walkability - Transportation Research Record: Journal of the Transportation Research Board. *Transportation Research Record: Journal of the Transportation Research Board*, *Volume 182*(2003 Pedestrians and Bicycles 2003), 3–11. Retrieved from http://trb.metapress.com/content/m1573875u76t4223/

Methorst, R., Bort, H. M. i, Risser, R., & Sauter, D. (2010). *COST 358 – Pedestrians' Quality Needs Final Report* (UK: Walk21.). London, UK. Retrieved from http://www.cost.eu/media/publications/10-59-COST-358-Pedestrians-Quality-Needs-Final-Report

Mikaeil, R., Ozcelik, Y., Yousefi, R., Ataei, M., & Mehdi Hosseini, S. (2013). Ranking the sawability of ornamental stone using Fuzzy Delphi and multi-criteria decision-making techniques. *International Journal of Rock Mechanics and Mining Sciences*, *58*, 118–126. doi:10.1016/j.ijrmms.2012.09.002

Moura, F., Cambra, P., & Gonçalves, A. (2014). *IAAPE - Pedestrian accessibility and attractiveness assessment tool when planning for walkability*. *CITTA 7th Annual Conference*.

Okoli, C., & Pawlowski, S. D. (2004). The Delphi method as a research tool: an example, design considerations and applications. *Information & Management*, *42*(1), 15–29. doi:10.1016/j.im.2003.11.002

Owen, N., Cerin, E., Leslie, E., duToit, L., Coffee, N., Frank, L. D., … Sallis, J. F. (2007). Neighborhood walkability and the walking behavior of Australian adults. *American Journal of Preventive Medicine*, *33*(5), 387–95. doi:10.1016/j.amepre.2007.07.025

Park, S. (2008). *Defining, Measuring, and Evaluating Path Walkability, and Testing Its Impacts on Transit Users' Mode Choice and Walking Distance to the Station*. University of California.

Saaty, T. L. (1977). A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology*, *15*(3), 234–281. doi:10.1016/0022-2496(77)90033-5

Saelens, B. E., Sallis, J. F., & Frank, L. D. (2003). Environmental correlates of walking and cycling: Findings from the transportation, urban design, and planning literatures. *Annals of Behavioral Medicine*, *25*(2), 80–91. doi:10.1207/S15324796ABM2502_03

Skulmoski, G., Hartman, F., & Krahn, J. (2007). The Delphi Method for Graduate Research. *Journal of Information Technology Education: Research*, *6*(1), 1–21. Retrieved from http://www.editlib.org/p/111405/

Soltani, A., & ALLAN, A. (n.d.). *A COMPUTER METHODOLOGY FOR EVALUATING URBAN AREAS FOR WALKING, CYCLING AND TRANSIT SUITABILITY: FOUR CASE STUDIES FROM SUBURBAN ADELAIDE, AUSTRALIA*. University of South Australia. Retrieved from http://128.40.111.250/cupum/searchpapers/papers/paper272.pdf

Transportation Research Board. (2000). Highway Capacity Manual. *National Research Council, Washington, DC*. Retrieved from https://scholar.google.pt/scholar?q=highway+capacity+manual&btnG=&hl=pt-PT&as_sdt=0%2C5#1

Vidal, L.-A., Marle, F., & Bocquet, J.-C. (2011). Using a Delphi process and the Analytic Hierarchy Process (AHP) to evaluate the complexity of projects. *Expert Systems with Applications*, *38*(5), 5388–5405. doi:10.1016/j.eswa.2010.10.016

Villanueva, K., Knuiman, M., Nathan, A., Giles-Corti, B., Christian, H., Foster, S., & Bull, F. (2014). The impact of neighborhood walkability on walking: does it differ across adult life stage and does neighborhood buffer size matter? *Health & Place*, *25*, 43–6. doi:10.1016/j.healthplace.2013.10.005

Wey, W.-M., & Chiu, Y.-H. (2013). Assessing the walkability of pedestrian environment under the transit-oriented development. *Habitat International*, *38*, 106–118. doi:10.1016/j.habitatint.2012.05.004

ANNEXES

Annex I – Walkability Indicators

Dimension	Subgroup	Indicators	Type of Measure	Reference
N/A	N/A	Walking Path Modal Conflit	Subjective	Fabian et al 2011
N/A	N/A	Availability of walking Paths	Subjective	Fabian et al 2011
N/A	N/A	Availability of Crossings	Subjective	Fabian et al 2011
N/A	N/A	Grade Crossing Safety	Subjective	Fabian et al 2011
N/A	N/A	Motorist Behavior	Subjective	Fabian et al 2011
N/A	N/A	Amenities	Subjective	Fabian et al 2011
N/A	N/A	Disability Infrastructure	Subjective	Fabian et al 2011
N/A	N/A	Obstructions	Subjective	Fabian et al 2011
N/A	N/A	Security from crime	Subjective	Fabian et al 2011
N/A	N/A	Population Density	Objective	Grafova et al 2008
N/A	N/A	Alpha index of street connectivity	Objective	Grafova et al 2008
N/A	N/A	Pedestrian Danger	Objective	Grafova et al 2008
N/A	N/A	Crime Index	Objective	Grafova et al 2008
N/A	N/A	Count of nonresidential destinations	Objective	Hoehner et al 2005
N/A	N/A	Count of parks with facilities	Objective	Hoehner et al 2005
N/A	N/A	Sidewalks present	Objective	Hoehner et al 2005
N/A	N/A	Bikelane present	Objective	Hoehner et al 2005
N/A	N/A	Segments with a bus stop	Objective	Hoehner et al 2005
N/A	N/A	Street Safety Score	Objective	Hoehner et al 2005
N/A	N/A	Streets with attractive features	Objective	Hoehner et al 2005
N/A	N/A	Streets with amenities	Objective	Hoehner et al 2005
N/A	N/A	Streets with no garbage	Objective	Hoehner et al 2005
N/A	N/A	Physical Disorder Score	Objective	Hoehner et al 2005
N/A	N/A	Count of crime watch signs	Subjective	Hoehner et al 2005
N/A	N/A	Vehicular Traffic Exposure	Objective	Christiansen et al 2014
N/A	N/A	Road Connectivity	Objective	Christiansen et al 2014
N/A	N/A	Street Connectivity	Objective	Villanueva et al 2014
N/A	N/A	Residential Density	Objective	Villanueva et al 2014

Dimension	Subgroup	Indicators	Type of Measure	Reference
Connectivity	Sidewalk	Availability of sidewalk	Objective	Maghelal 2010
		Pedestrin Facility Provided		Dixon 1996
		Pedestrian Network Coverage	Objective	Steiner et al 2004
		Sidewalk Continuity	Objective	Maghelal 2010
		Sidewalk Density	Objective	Moudon 2006
	Intersection	Intersection Density (intersections by road length)	Objective	Maghelal 2010
		Intersection Density (intersection by square km)	Objective	Frank 2005
		Number of intersection	Objective	Steiner et al 2004
	Crossings	Availability of crossing along major roads	Subjective	Krambeck 2006
		Crossing oportunities		Gallin 2001
		Crosswalk lenght	Objective	Maghelal 2010
		Number of crosswalks per intersection	Objective	Maghelal 2010
		Number of mid-block crossings per 500ft block length	Objective	Park 2008
		Pedestrian crossing facility design index	Objective	Park 2008
	Urban Pattern	Average building widht		Park 2008
		Average parcel size	Objective	Maghelal 2010
		Block density	Objective	Steiner et al 2004
		Block isoperimetric ratio		Steiner et al 2004
		Block size		Moudon 2006
		Diversity in parcel size	Objective	Soltani & Allan 2005
		Length of origin/destination distance		Maghelal 2010
		Link-node ratio	Objective	Steiner et al 2004
		Link-node ratio		Ewing 1996
		median block area	Objective	Soltani & Allan 2005

		pedestrian route directness	Objective	Steiner et al 2004
		proportion of cul-de-sacs	Objective	Soltani & Allan 2005
		Street Connectivity		Gallin 2001
		Street connectivity indicator	Objective	Steiner et al 2004
		street density (km/km2)	Objective	Steiner et al 2004
		street pattern		Maghelal 2010
		street space allocation	Objective	Soltani & Allan 2005
		total length of road network	Objective	Maghelal 2010
		walking permeability time index	Objective	Allan 2001
	Gateways	multimodal facilities	Objective	Maghelal 2010
		public transport coverage	Objective	Soltani & Allan 2005

Dimension	Subgroup	Indicators	Type of Measure	Reference
Conspicuous		Availability of signals	Objective	Maghelal 2010
		Average building setbacks	Objective	Park 2008
		Average building to building distance	Objective	Park 2008
		Average skyline height (enclosure)	Objective	Park 2008
		Complexity		Park 2008
		Pedestrian Signal Coverage Rate	Objective	Park 2008
		Sense of place		Lo 2009
		Visual Interest		Lo 2009

Dimension	Subgroup	Indicators	Type of Measure	Reference
Convenience	Land use	Administrative (post office, banks,...)	Objective	Maghelal 2010
		Attractor destinations (grocery, restaurant, retail...)	Subjective	Moudon 2006
		Deterrent land uses (schools, offices...)		Moudon 2006
		Dwelling types	Subjective	Soltani & Alln 2005
		Educational (length of travel distance to school)	Objective	Maghelal 2010
		Employmennt density	Objective	Maghelal 2010
		Essential (stores, shopping centers,...)	Objective	Maghelal 2010

		Greenery (parks, public spaces, front garden...)	Subjective	Evans 2009
		Housing density	Objective	Maghelal 2010
		Land use mix (entropy level)		Frank 2005
		Net residential density		Maghelal 2010
		Number of stories per building	Objective	Evans 2009
		Open spaces uses (playground, sports pitch...)	Subjective	Evans 2009
		Population Density	Objective	Maghelal 2010
		Proximity to education centers	Objective	Soltani & Alln 2005
		Proximity to shopping complex	Objective	Soltani & Alln 2005
		Recreational (parks, theaters, cinema,...)	Objective	Maghelal 2010
		Residential gross density	Objective	Soltani & Alln 2005
		Shops at street level	Objective	Evans 2009
	Sidewalk	Access to buildings (level, ramp, step...)	Subjective	Evans 2009
		Average longitudinal gradient	Objective	Abley 2011
		Average width of walking zone	Objective	Park 2008
		Average, Maximum and Minimum width of the path		Abley 2011
		Deviation around obstacles	Subjective	Abley 2011
		Existence and quality of facilities for the blind and disables	Subjective	Krambeck 2006
		Footway accessibility		Space Syntax 2003
		Footway quality	Subjective	Space Syntax 2003
		Footway widht	Objective	Evans 2009
		Hazards (surface, tripping)	Subjective	Abley 2011
		Intersections with 4 curb cuts	Objective	Maghelal 2010
		Litter and detritus	Subjective	Abley 2011
		Maintenance		Dixon 1996
		Maintenance and cleanliness of walking path	Subjective	Krambeck 2006
		Number of curb cuts per intersection	Objective	Maghelal 2010
		Obstructions		Gallin 2001
		Path Widht		Gallin 2001
		Permanent and temporary	Subjective	Krambeck 2006

		obstacles in the walking path		
		Sidewalk slope	Objective	Maghelal 2010
		Sidewalk widht		Landis 2001
		Sidewalk with special pavement	Objective	Park 2008
		Street widht	Objective	Evans 2009
		Widht of outside lane	Objective	Landis 2001
		Width of shoulder or bike lane	Objective	Landis 2001

Dimension	Subgroup	Indicators	Type of Measure	Reference
Comfort	Sidewalk	Average length of pedestrian trail	Objective	Maghelal 2010
		Average length of off-road path	Objective	Maghelal 2010
		Average length of park trails	Objective	Maghelal 2010
		Average width of landscape trip	Objective	Park 2008
		Average width of on street parking	Objective	Park 2008
		Buffer width		Maghelal 2010
		Location of sidewalk (distance from edge of the road)		Landis 2001
		Surface quality		Gallin 2001
	Amenities	Amenities (benches, public toilets,...)	Subjective	Krambeck 2006
		Average number of intermediaries per 500ft sidewalk	Objective	Park 2008
		Average number of street furniture per 500ft sidewalk	Objective	Park 2008
		Average number of street trees per 500ft sidewalk	Objective	Park 2008
		Comfort features	Objective	Abley 2011
		Number of street trees	Objective	Maghelal 2010
		Street furnitures (seating, bollards,...)	Subjective	Evans 2009
		Support facilites		Gallin 2001
	Sense of Security	Alleyways	Objective	Evans 2009
		Average ground level luminosity after sunset	Subjective	Park 2008
		Average number of upper level windows per 500ft sidewalk	Objective	Park 2008
		Average skyline height	Objective	Park 2008
		Boarded up buildings, unused plots		Evans 2009
		Grafitty, vandalism, deriliction	Subjective	Evans 2009

		Lighting (number of street lights)	Objective	Maghelal 2010
		Perception of security from crime	Subjective	Krambeck 2006
		Personal security (number of burglary assaults and theft)	Objective	Maghelal 2010
		Windows	Subjective	Evans 2009
	Wheater /Climate	Average temperature (at closest reading stations)	Objective	Maghelal 2010
		Shade and rain cover (by tree canopy)	Objective	Maghelal 2010
		Wind, rain		Abley 2011

Dimension	Subgroup	Indicators	Type of Measure	Reference
Conviviality		Benches	Obbjective	Maghelal 2010
		Blank Wall		Evans 2009
		Building frontage, setbacks	Objective	Maghelal 2010
		Ethnic minority density	Objective	Maghelal 2010
		Fences		Evans 2009
		Mix of path users		Gallin 2001
		Pedestrian Density	Objective	Abley 2011
		Pedestrian Flow rate		Gallin 2001
		Pedestrian volume	Objective	Abley 2011
		Residential uses (%)	Objectives	Park 2008
		Stationary people (presence or absence)	Subjective	Space Syntax 2003
		Sidewalk lenght with fence (%)	Objective	Maghelal 2010

Dimension	Subgroup	Indicators	Type of Measure	Reference
Coexistence	Safety	Crossing safety	Subjective	Krambeck 2006
		Number of accidents per intersection	Objective	Maghelal 2010
		Number of vehicular and pedestrian accidents	Objective	Maghelal 2010
		Pedestrian fatalities	Objective	Krambeck 2006
		Quality of motorist behavior	Subjective	Krambeck 2006
	Traffic	Average number of cars per household	Objective	Maghelal 2010
		Average speed	Objective	Maghelal 2010

		Average traffic during a 15 min. Period		Landis 2001
		Average traffic volume	Objective	Maghelal 2010
		Average width of traffic zone	Objective	Park 2008
		Conflicts		Dixon 1996
		Motor vehicle LOS		Dixon 1996
		Noise	Objective	Abley 2011
		Number of accessways	Objective	Abley 2011
		Number of heavy-vehicles per hour	Objective	Abley 2011
		Number of traffic calming elements per 500ft block length	Objective	Park 2008
		Parking per household (on street and off street)	Objective	Maghelal 2010
		Potential for vehicle conflict		Gallin 2001
		Segment with on-street parking (%)	Objective	Abley 2011
		Total number of traffic lanes		Landis 2001
	Motorized Network	Average number of traffic lanes	Objective	Park 2008
		Average road width	Objective	Maghelal 2010
		Median length (% of 2way roads with median)	Objective	Maghelal 2010
		Number of through lanes	Objective	Maghelal 2010
		Road connectivity	Objective	Maghelal 2010
	Other Transportation	Average width of bike lane	Objective	Park 2008
		Bike commuters	Objective	Maghelal 2010
		Bike lane existence		Evans 2009
		Multimodal transit		Dixon 1996
		Path sharing		Gallin 2001
		Pedestrian commuters	Objective	Maghelal 2010
		Transit commuters	Objective	Maghelal 2010
		Walking path modal conflict	Subjective	Krambeck 2006

Dimension	Subgroup	Indicators	Type of Measure	Reference
Commitment		Existence/enforcement of pedestrian safety laws/regulations	Objective	Krambeck 2006
		Funding and resources devoted to pedestrian planning	Objective	Krambeck 2006
		New permits issued per unit area	Objective	Krambeck 2006
		Presence of relevant urban design guidelines	Objective	Krambeck 2006

Annex II – Street Auditing Guide

This guideline serves as a manual for how to assess and evaluate the descriptors used to measure Walkability.

Arcs and Crossings will be evaluated on different criteria. Each auditor will be given a map as the one as Figure 1.

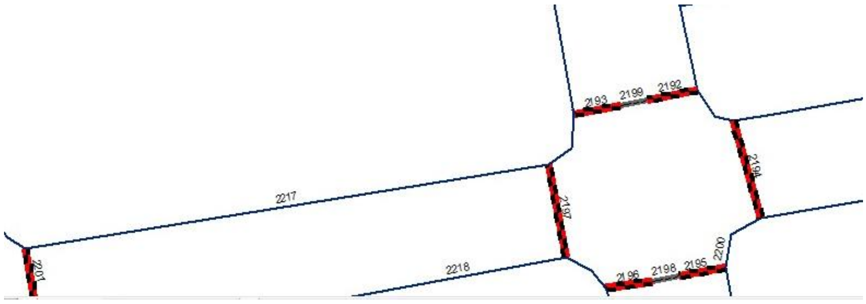


Figure 43 - Detail of study area

Segments in red are crossings and segments in blue are sidewalks. For each segment evaluated, specify its reference number on the table. The number is its unique code. Street and Door numbers are optional: please fill these if there is an error or the code numbers are not clear.

Elements should be evaluated in a specific order and on-site and through GIS analysis. In case of doubt between levels, use your best judgment.

The materials needed are: table, pencil and ruler and a map of the zone. Fill the criteria with abbreviations given on this manual and measurements. 0 always refer to the worst scenario and best can go up to 4.

Streets marked as mixed use or stairs should be evaluated once. For effective width define 3m or lower if measurements indicate as such.

1. Crossings

To complete the table start by defining which arc are you evaluating (column 1). Next, determine which crossings affect this segment on column 3. For example, in Figure 1, arc 2217 is affected by crossings 2193, 2197 and 2201. There is no need to evaluate each crossing twice, however the code should be specified in each arc it affects.

C61 – Crossing safety

Evaluate Safety of the crossings of the Arc on two criteria:

Exposure/Speed of traffic		
High (0)	Average (1)	Low (2)

Visibility		
Low (0)	Average (1)	High (2)

Evaluate both visibility and exposure to traffic in each crossing. “High visibility” is when it is possible for the pedestrian to see and be seen without any or with minor constraints. Please refer to Figure 2. In most crossings with vehicles performing left turns, Average visibility conditions apply (Figure 3). However some crossings with vehicles performing left turns may have high visibility. Low visibility conditions are when the pedestrian has difficulties on “seeing and being seen” by vehicles.

To evaluate Exposure/Speed of traffic, take in consideration the speed of which vehicles travel and how likely it is for them to respect the pedestrian’s priority. Mark “0” for when it is not perfectly safe. These conditions may apply to large avenues without any signal lights. Low exposure conditions is when all vehicles will stop for pedestrian crossing or on crossing with signalized intersections and no left turns.

C14 –Existence of Infrastructure for Disabled Access

Evaluate curb drop and tactile aid (Figure 9)

Presence of steps and tactile aid		
Presence of steps and no tactile aid (0)	Curb drop but no tactile aid (1)	Curb drop and tactile aid (2)

2. Arc

When evaluating arcs, please be aware of indicators **C21** and **C42** where the auditor is required to count a certain type of commercial and other activities throughout the path.

C53 - Availability of Signals Adapted to Pedestrians. Evaluate according to table:

Availability of Signals: Are there pedestrian oriented finding signs, such as maps, or street names?				
Nil (0): There was no directional information provided	Very Poor (1): The signs were pointing in the wrong direction and were not legible	Poor (2): The signs only included street names or were vague and not specific. Enough information on the arc is provided for the pedestrian to locate himself	Good (3): Adding to street names, the signs included directions to community services and areas of interest	Very Good (4): The signs provided a detailed map of where I was in relation to other community services and areas of interest areas including travel times.

C32 – Evaluate pavement quality and tripping hazards.

Pavement Quality

Very Bad (0): A large number of bumps, cracks, holes, weeds or overgrown vegetation e.g. tree roots protruding through surface or creating bumps, loose cobblestones, significant weeds and or significant potholes.	Bad (1): Condition between Very Bad and Moderate	Moderate (2): Some bumps, cracks, holes weeds or overgrown vegetation e.g. some elements of a bad footpath but not many.	Good (3): Condition between Moderate and Very Good	Very Good (4): Very few bumps, cracks, holes, weeds or overgrown vegetation: generally smooth, no missing cobblestones, no potholes

For examples of the pavements please look for Figures 1, 2 and 3 in Annex I. Fill respective column on the table.

To measure tripping Hazard: Answer the question: In adverse conditions (wet and presence of leaves) is this pavement very slippery? Is there the recurrent presence of tripping hazards such as holes or unsignalized steps?	
Yes (0)	No (1)

For examples of the pavements please look for Figures 4 to 7 in Annex I. Fill respective column on the table.

C14 and C22 – Evaluate presence of steps and walking width

Presence of steps in the arc higher than 15cm	
Yes (0)	No (1)

Walking width should be measured taking in account preemptions. Preemption values should be as follows:

- Sign Posts: 0.10m
- Buildings: 0.15m
- Low curb (≤ 125mm): 0.05m; High curb (≥ 125mm) 0.15m
- Tree Trunk Soft Foliage: 0.15m 0.05m
- Grass verge: 0.00m

Please consult Figure 8 for example of effective walking width.

C21 – Land Use Mix

For each Arc, answer the following: Is there Commercial land use? Is there residential land use? Are there services/offices? For each yes, add one point to the maximum of 3.

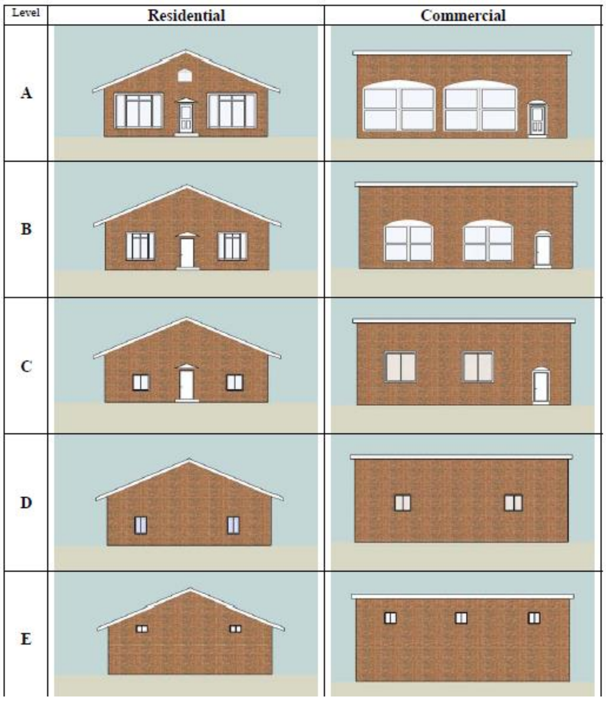
C41 – Existence of public meeting places

Rank arc (0 to 2) according to : 0- There is not is an esplanade or street furniture in the arc, nor one is visible; 1-There is not is an esplanade or street furniture in the arc, but it is visible; 2- There is an esplanade or street furniture in the arc.

Street furniture is defined as benches and tables installed by the municipality.

C31 – Evaluate vigilance effect:

How would you describe the majority of the buildings in the arc? Use Level of Service A through E.



C43 – Land use mix and service hours

Grade the arc from 1 to 3, according to its land use mix and service hours:

0: There is very little land use mix;
1: There is good land use mix but the service hours are only during the night/day;
2: There is good land use mix and service hours are extended

Good land use mix means that there are several commercial shops or services and residential use. Good service hours mean that the site will not lose most of its users after 7pm.

C51 – Sense of place and reference elements

Presence/visibility or not, from the majority of the segment, of landmarks which are: monuments, retail shops and restaurants of recognizable brands, religious buildings and large squares or plazas

0: Neither presence nor visibility of reference elements on all arc;
1: Neither presence nor visibility of reference elements on majority of arc;
2: Presence or visibility of reference elements in the majority of arc.

C24 – Everyday use Commercial Activities’ Density

Count pharmacies, ATMs, local grocery stores and cafes present on the arc.

C42 – Existence of Attractor Destinations

Count sporting facilities, public gardens, theatres, retail centres (local supermarkets), Schools and post office, metro station.

Annex for the Guide

Figure 44-Crossing with high visibility. Source: www.blueschoolofmotoring.com

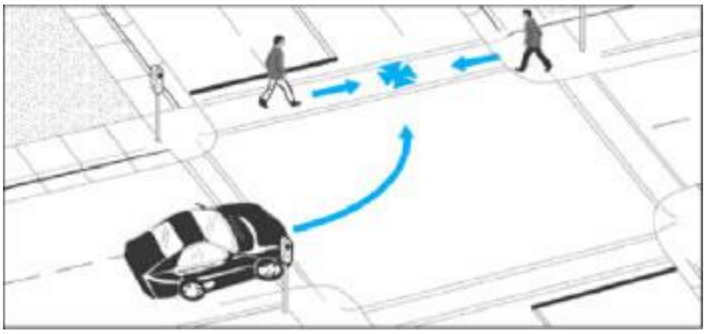


Figure 45- Crossing with average visibility. Source: www.pedbikesafe.org

Figure 46- Pavement in very bad condition

Figure 47- Pavement in Moderate Condition

Figure 48- Pavement in very good condition & Slippery pavement and anti-slippery cobblestones

Figure 49- Measuring effective width

Figure 50-Example of curb drop and tactile aid

Annex III – Correlation Matrix

Table 10- Correlation Matrix

Adults	*C12*	*C21*	*C32*	*C43*	*C51*	*C61*	*C71*
C12	1.000						
C21	0.000	1.000					
C32	0.000	0.212	1.000				
C43	0.000	0.578	0.152	1.000			
C51	0.000	0.181	0.134	0.251	1.000		
C61	0.000	0.236	0.207	0.268	0.313	1.000	
C71	-1.000	0.000	0.000	0.000	0.000	0.000	1.000

Children	*C13*	*C21*	*C31*	*C42*	*C51*	*C62*	*C75*
C13	1.000						
C21	0.063	1.000					
C31	-0.138	0.402	1.000				
C42	0.148	0.120	0.092	1.000			
C51	0.063	0.181	0.098	0.348	1.000		
C62	0.000	0.000	0.000	0.000	0.000	1.000	
C75	0.039	0.217	0.026	0.103	0.297	0.000	1.000

Elderly	*C12*	*C24*	*C32*	*C41*	*C51*	*C61*	*C71*
C12	1.000						
C24	0.000	1.000					
C32	0.000	0.160	1.000				
C41	0.000	0.250	0.154	1.000			
C51	0.000	0.189	0.134	0.569	1.000		
C61	0.000	0.222	0.207	0.266	0.313	1.000	
C71	-1.000	0.000	0.000	0.000	0.000	0.000	1.000

Disabled	*C14*	*C22*	*C32*	*C42*	*C53*	*C61*	*C71*
C14	1.000						
C22	0.103	1.000					
C32	0.133	0.272	1.000				
C42	0.101	0.088	0.082	1.000			
C53	0.091	-0.032	0.161	0.041	1.000		
C61	0.403	-0.019	0.207	0.127	0.218	1.000	
C71	0.000	0.000	0.000	0.000	0.000	0.000	1.000