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# Combining multi-criteria and space syntax analysis to assess a pedestrian network: An application for pedestrian network of Porto (Portugal) and Qazvin (Iran)

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# Combining multi-criteria and space syntax analysis to assess a pedestrian network: An application for pedestrian network of Porto (Portugal) and Qazvin (Iran)

Thesis plan under the Doctoral Program in Civil Engineering

Supervisor:
**Prof. Doutor Rui Ramos**

September, 2018

STATEMENT OF INTEGRITY

I hereby declare having conducted my thesis with integrity. I confirm that I have not used plagiarism or any form of falsification of results in the process of the thesis elaboration.

I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

University of Minho, ___ 04/09/2018______

Full name: ___Mona Jabbari___

The life is mortal; you have to find the meaning of immortality, in the scope of humanity!

"Fereydoon Moshiri"

# Acknowledgements

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# Abstract

Walkability is seen as an important concept for sustainable urban development and urban mobility. In urban context, the improvement of walkable areas promote personal, social, economic and environmental benefits to cities and their inhabitants.

The main aim of this thesis was to make and evaluate a method to identify and assess pedestrian paths and networks in a central area of a city. The Pedestrian Network Assessment (PNA) Model has been developed as a methodological procedure to assess walkable conditions of streets and to evaluate the connectivity. So, this research describes a Geographic Information System based and integrated model to assess and identify streets as a pedestrian network, by using multi criteria and space syntax analysis. The multi criteria analysis covers a large number of walkable attributes (nine sub-criteria grouped in four main criteria) and a quantitative weight method was used to define the relative importance of the criteria following the experts' vision. Space syntax was used to evaluate street connectivity.

The PNA model was implemented in two cities with different urban morphologies, Porto (Portugal) and Qazvin (Iran). Findings show that in Porto there are few streets providing good conditions for pedestrians and that they are not connected as a network; in Qazvin, streets provide good conditions and they are better connected. In addition, the two case studies (Qazvin and Porto) have been presented to demonstrate the proposed methodology in order to be able to have a comprehensive evaluation of the PNA model under different urban morphologies. Moreover, the Angular Segment Analysis by Metric Distance (ASAMeD) was used to assess the impact of urban morphology of both cities on walking in urban area assessed and the results are compared to evaluate the PNA model comportment. The comparison between the PNA model and ASAMeD approach shows that the PNA model assesses the streets providing better information on walking conditions than ASAMeD. Thus, the Pedestrian Network Assessment Model is an innovative method that can be a useful tool to plan urban streets for pedestrians and to develop spatial relationships in street networks for walking. The PNA model has potential to provide planning guidelines for walkability improvement and to consolidate an urban pedestrian network in the central area of cities. Furthermore, the PNA model can potentially be replicated in other cities in terms of improving the walkability and to promote sustainable urban mobility.

**Keywords:** Walkability, Pedestrian network, Multi-criteria analysis, Space syntax, GIS.

# Resumo

Facilidade de caminhar é visto como um conceito importante para o desenvolvimento urbano sustentável e para a mobilidade urbana. No contexto urbano, melhorar as condições oferecidas para caminhar promove benefícios pessoais, sociais, económicos e ambientais para as cidades e seus habitantes.

O principal objetivo desta tese foi elaborar e avaliar um método para identificar e avaliar percursos e redes pedonais numa área central de uma cidade. O Modelo de Avaliação de Rede Pedonal (PNA: Pedestrian Network Assessment) foi desenvolvido como um procedimento metodológico para avaliar as condições de andar a pé nas ruas e a respetiva conectividade. Assim, esta pesquisa descreve um modelo integrado e baseado em Sistema de Informação Geográfica para avaliar e identificar ruas como parte de uma rede pedonal, utilizando análise multicritério e sintaxe espacial. A análise multicritério abrange um número elevado de atributos relacionados com andar a pé (nove subcritérios agrupados em quatro critérios principais) e foi utilizado um método de ponderação quantitativo para definir a importância relativa dos critérios seguindo a visão de especialistas. A sintaxe espacial foi usada para avaliar a conectividade das ruas.

O modelo PNA foi implementado em duas cidades com diferentes morfologias urbanas, Porto (Portugal) e Qazvin (Irão). Os resultados mostram que no Porto existem poucas ruas que oferecem boas condições para os peões e que não estão ligadas em rede; em Qazvin, as ruas oferecem boas condições e estão mais bem conectadas. Além disso, os dois estudos (Qazvin e Porto) foram implementados para demonstrar a metodologia proposta de forma a ter uma avaliação abrangente do modelo PNA em diferentes morfologias urbanas. Também, a Análise Angular de Segmentos pela Distância Métrica (ASAMeD: Angular Segment Analysis by Metric Distance) foi utilizada para avaliar o impacto da morfologia urbana de ambas as cidades na forma de caminhar nas área urbana avaliadas e os resultados são comparados para avaliar o comportamento do modelo PNA. A comparação entre o modelo PNA e a abordagem ASAMeD mostra que o modelo PNA avalia as ruas fornecendo melhores informações sobre as condições de caminhar do que a ASAMeD. Deste modo, pode-se dizer que o Modelo de Avaliação de Rede Pedonal é um método inovador que pode ser uma ferramenta útil para planear as ruas urbanas para os peões e para estabelecer relações espaciais em rede. O modelo PNA tem potencial para definir diretrizes de planeamento de forma a melhorar e consolidar uma rede pedonal urbana na área central das cidades.

Além disso, o modelo PNA pode facilmente ser replicado em outras cidades, assumindo o pressuposto de melhorar as condições que facilitam caminhar e promover a mobilidade urbana sustentável.

**Palavras-chave:** Facilidade de caminhar, Rede pedonal, Análise multicritério, sintaxe espacial, GIS.

# List of appended papers

This thesis is based upon the following four (main) scientific articles and project.

**First paper:** **Jabbari, M.** & Ramos, R. (2015) "Evolution of Urban Morphologies: Comparison between Porto (Portugal) and Qazvin (Iran)"Journal of Civil Engineering and Architecture Research **(Print ISSN: 2333-911X, Online ISSN: 2333-9128).**

Jabbari proposed the main idea, made the literature review and made the main paper structure. Ramos suggested the methodology for evaluation, contributed with discussions about the results and assisted with the paper editing. This paper contributed to the concept of the thesis and also helped with the formulation of the thesis outline.

**Second paper:** Altieri, M.; **Jabbari, M.;** Lopes, J. (2015) Aplicação da space syntax como ferramenta de simulação, Diferentes Abordagens No Estudo Da Forma Urbana, (77-86), Rede Lusófona de Morfologia Urbana FEUP Edições, **ISBN: 978-972-752-197-5.**

Web address:

http://pnum.fe.up.pt/index.php/download_file/view/255/

Altieri made a comprehensive literature review, formulated the main results and outlined the discussion. Jabbari made the main calculations, contributed to the literature review, research discussion and conclusions. Lopes helped to delimit the paper outline and assisted with the paper editing. This paper helped to understand urban morphology with different interpretations by applied space syntax software and it has the significant role in order to create the connectivity component of the model.

**Third paper:** **Jabbari, M**., Fonseca, F. & Ramos, R. (2017) "Combining multi-criteria and space syntax analysis to assess a pedestrian network: the case of Oporto", Journal of urban design.

Web address:

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Jabbari proposed the main idea of this research and she did the literature review, data processing, calculations and formulated the results. Fonseca contribute to consolidate the data and GIS calculations, contributed in the discussion of the results and in the conclusions. Ramos helped to formulate the paper outline and assisted with the paper editing. This paper presented the implementation of the model to the city of Porto and provided some important remarks to consolidate the structure of the thesis.

**CIVITAS project:** Award and funded by Ref.No. MOVE/FP7/604778/CAPITAL.

This project highlight innovation of this thesis and report the work done between 2014 to 2015. The report of the project is systemized in the Civitas report: "Voices: Inspiring stories and expert ideas for better urban mobility", September 2016 - "*Identifying priorities for a Smart Pedestrian Network in Porto (Portugal)*" pages 16-19 by M. **Jabbari.**

Web address:

http://civitas.eu/sites/default/files/civitas_voices_inspiring_stories_and_expert_ideas_for_better_urban_mobility.pdf

Also, the following web page report the work done within the funded project:

http://civitas.eu/content/innovation-method-design-syntactic-and-fuzzy-logic-model-assess-cohesion-connection-cities

# Abbreviations

| | |
|---|---|
| ASAMeD | Angular Segment Analysis by Metric Distance |
| GIS | Geographic Information System |
| ITS | Intelligent Transpotation System |
| MCA | Multi-Criteria Analysis |
| PNA | Pedestrian Network Assessment |
| SPN | Smart Pedestrian Network |
| WLC | Weighted by Linear Combination |

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# 1. Introduction

Walkability is seen as one of the most important concepts for sustainable urban development and sustainable mobility (Forsyth, Michael Oakes et al. 2009). The personal, social, economic and environmental benefits of walking are well-documented: walking reduces traffic congestion and pollution, it is beneficial to individuals' health and well being, it provides health-economic benefits, it has impact on real estate prices and enhances the sociability and vitality of urban spaces (Bahrainy and Khosravi 2013, Kim, Park et al. 2014, Lee and Talen 2014, Longo, Hutchinson et al. 2015).

For these reasons, encouraging walking has been placed at the centre of a number of policies and has been the main issue for urban planners over the last decades. For instance, the White Paper on Transport (European Commission 2011) and the Sustainable Urban Mobility Plans, launched by the European Union, propose to include walkability in the urban planning process aiming to change the behavior of people in order to encourage walkability in cities.

## 1.1 Purpose of the study

Actions to encourage walkability have focused mainly on making this mode of transport easy and attractive by improving the general quality of built environments (Kim, Park et al. 2014); providing walking facilities (Koh and Wong 2013, Li, Gao et al. 2013, Longo, Hutchinson et al. 2015) and green areas (Panagopoulos, Duque et al. 2016); and by enhancing the physical and functional linkage in the city (Kasemsuppakorn and Karimi 2013, Babiano 2016). Understanding the factors that influence walkability is essential to meet pedestrian needs and to support planning decisions. Therefore, as mentioned by several authors, the conditions provided to pedestrians influence the decision of walking, as well as aspects such as the walking distance, the walking time and the satisfaction of walking.

This thesis seeks to address the following question: How to make and evaluate a model for the city pedestrian network based on analysing the walkable conditions of the streets? In order to answer this question, there are a few aspects that need to be explored. First, it is necessary to review the criteria to analyse the urban streets in the context of walkability and to study the street network connectivity. Second, it is important to understand how to assess a pedestrian environment on a GIS platform as a model. Third, it is necessary to clarify how to recognise the best conditions of the street network for walkability in the prioritization of the model. These thesis topics are discussed in Chapter 2 in detail. Finally, the purpose of this thesis is to assess the walkability streets in order to identify a pedestrian network in a central area of a city. Thus, the Pedestrian Network Assessment (PNA) model was developed and tested in two cities.

Conducting a survey with the pedestrians improves the perception and understanding of the model as it performs calibration and validation. This thesis will address the issue of validity testing of the method in the future. The Discussion section in Chapter 6 concerning the analysis model called Angular Segment Analysis by Metric Distance (ASAMeD) consolidated and validated the PNA Model. Furthermore, in the future, the Research and Development (R&D) project that started in 2017 will address and go into more depth in these topics.

## 1.2 Methodology

The thesis describes a GIS-based integrated model called the PNA model to assess the street network in the city centres of Porto, Portugal and Qazvin, Iran, using multi-criteria and street network connectivity analysis. The multi-criteria analysis (MCA) was performed using four criteria and nine sub-criteria that mostly influence walkability. The criteria selection was supported by an extensive literature review and by expert evaluations. Moreover, space syntax was used to evaluate the street network connectivity. The results of the multi-criteria and street network connectivity were normalised by fuzzy logic. In fact, the PNA model combines multi-criteria assessment with the validation of the level of the street network connectivity analysis. The result is a ranking of the streets according to the walkable conditions highlighted in the street network. By identifying the walkable streets by MCA, strong linkage by street network connectivity analysis can be used by urban planners to improve the walkability in the urban streets. In fact, the obtained results of this model can be applied as a walkability guideline including: (1) establishing a guide for Land Use and density, development walkability character, and the future growth of the network; and, (2) identifying key improvements for the pedestrian network to enhance the overall feature and quality of streets. This research makes an innovative contribution to the literature on walkability in cities and presents a useful tool for urban planning and management on a macro scale of the city.

The results of the PNA model are compared with ASAMeD according to the effect of urban morphology on walking for two different structures of the cities. This means, the direct impact of street configuration on the pedestrian movement is dependent on urban morphology (Hillier, Perm et al. 1993). The literature of ASAMeD states that the key measures are the combination of two kinds of movement potentials that can be used in any trips: the *to-movement* and the *through-movement*. The *to-movement* refers to the selection of a destination from an origin (integration), and the *through-movement* corresponds to the choice of spaces to go through between origin and destination (choice). According to this hypothesis, Y. Li, Xiao, Ye, Xu, & Law (2016) explained that the street network configuration influences people´s preferences and/or behavioral characteristics. Hence, these two syntactical properties can then define the types of urban morphology that would match the patterns of pedestrian movements.

Finally, the research shows a comparison between results from the PNA model and ASAMeD approach, for the two cities of Porto (Portugal) and Qazvin (Iran) in order to comprehensively evaluate the PNA model.

## 1.3 Thesis structure

The The thesis comprises seven chapters. The first chapter is the introduction which states the purpose of the study, brief methodology and the thesis structure.

The second chapter, the literature review, presents the theoretical background of the study and provides a review of the research topics, including the multi-criteria and methodology related to walkability and the main parameters of the research.

The third chapter, methodology, shows the theoretical framework and the methodology of data preparation.

The fourth chapter, case studies, briefly describes the cities of Porto and Qazvin.

The fifth chapter, Implemented Model and Results, presents the results of the PNA model and the ASAMeD approach, as well as procedures that are used in this research.

An introduction and a summary, at the beginning and end of Chapters two, three, four and five highlight the core findings and provides readers with a quick textual overview of each intermediate chapter.

The sixth and seventh chapters include the discussion and conclusion of the thesis, as well as potential future studies.

# 2. Literature Review

## 2.1 Introduction

The aim of the literature review is to provide a thorough overview of the field of urban planning focusing on pedestrians, walkability and street networks to answer the research questions questions explained in the previous chapter. Historically, walking has been an essential element of city life and urban space has its own social logic (Hillier and Hanson 1984, Hillier and Hanson 1998, Penn, Hillier et al. 1998). Urban space has been defined as “a street or a place” designed to increase pedestrian movement. Urban space and pedestrians′ needs should be considered in order to improve the quality of life in cities. Hence, the specific topics that are covered in this chapter include walkability and the pedestrian environment; criteria affecting walking; network streets, urban morphology; accessibility; relationships between walking and assessing criteria concerning walkability using some software such as the Geographic Information System (GIS) platform and Space Syntax software.

Walkability has many parameters that can be attributed to space and pedestrians. Various research projects conducted in Europe and Asia over the last eleven years have assessed walkability by analysing the influential parameters, as well as methods for combining these parameters in a model. As can be seen in the literature, some researchers including Erinsel and Gigi (2010), Wook Seo (2013), Hernbäck (2012), NES, Berghauser, and Mashhoodi (2012), Serra and Pinho, (2012) investigated how to connect two separate parts of the city to each other by building pedestrian paths. These researchers focused on improving the functionality of the traditional central urban tissue and joining new urban tissues to the old one by following the original form. Some other researchers including Dalton, R. and Dalton, N. (2007), Giannopoulou (2012), Griffiths (2012) and Rosália (2012) suggested a strategic network plan for designing streets and squares. Various researchers used the GIS software to analyse the network. Some investigators used GIS to find a street hierarchy for walkability by combining multicriteria, while others used GIS to analyse the effect of spatial configurations on walkability (Dalton and Dalton 2007, Erinsel and Gigi 2010, Giannopoulou, Roukounisb et al. 2012, Griffiths 2012, Hernbäck 2012, NES, Berghauser et al. 2012, Rosália 2012, Serra and Pinho 2012, Ismail, Bakr et al. 2013, Lee and Wook Seo 2013, Rukayah 2013, Sheng 2013, Hall and Ram 2018).

Street networks are essential resources in a wide range of applications, especially in transportation and urban planning projects (Kaparias, Bell et al. 2012, Kasemsuppakorn and Karimi 2013). The aim of this chapter is to investigate different points of views studied in the literature in terms of walking parameters and methodologies that have been used to assess street networks in the urban environment.

## 2.2 Background Research

The option to walk and the chosen route are influenced by several factors. Individuals' decisions about whether and where to walk are highly complex and typically represent a consideration of multiple factors, including perceived facility , comfort, safety, security, convenience, proximity, attractiveness of the route, age, ethnicity, income, gender, household size, car ownership, built environment, route characteristics, among others (Nasir, Lim et al. 2014, Ferrer, Ruiz et al. 2015, Babiano 2016). Particularly, the distance and time to walk are critical in terms of making the decision to walk or not (Agrawal, Schlossberg et al. 2008). Nonetheless, Koh and Wong (2013) also show that the determinants for defining a particular route can range from whether the route is safe, to the level of comfort and attractiveness. Understanding what a pedestrian considers as an attractive route can allow planners to build more walkable and livable cities.

The literature on the criteria affecting walking has dramatically increased over the last two decades. The built or physical environment is one of the most analysed topics (Cervero, Sarmiento et al. 2009, Walford, Samarasundera et al. 2011, Nasir, Lim et al. 2014, Ferrer, Ruiz et al. 2015, Lamíquiz and López-Domínguez 2015). It corresponds to the physical context in which people spend their time (e.g., home, neighbourhood, school) and includes factors related to urban design, human scale, walking facilities, traffic safety, aesthetics and slopes (Ferrer, Ruiz et al. 2015). The physical environment influences perceptions such as safety, security and comfort, which in turn determine satisfaction and the decision to walk (Bahrainy and Khosravi 2013, Nasir, Lim et al. 2014, Peiravian, Derrible et al. 2014, Gilderbloom, Riggs et al. 2015).

Urban design comprises several perceptual qualities that may affect the walking environment (Bahrainy and Khosravi 2013, Wey and Chiu 2013, Kim, Park et al. 2014, Garcia and Lara 2015). Besides being difficult to define, other researchers proposed the five following qualities: imageability, enclosure, human scale, transparency and complexity (Ewing and Handy 2009). These criteria have been used to create urban design quality indexes to capture aspects of the physical environment pertaining to facets directly relevant to people's emotive responses to aesthetics and structure in urban areas (Walford, Samarasundera et al. 2011). Aesthetic quality has also been associated with walking for transportation (Adkins, Dill et al. 2012, Ferrer, Ruiz et al.

2015). Aesthetics includes sensorial effects and stimulus that pedestrians can have, creating pleasant walking experiences (Ferrer, Ruiz et al. 2015). Thus, the physical environment, urban design and aesthetics are interconnected and depend on appropriate planning.

Terrain slope is also an important factor as small positive increments in slopes decrease travel speeds while increasing energy use (Lundberg and Weber 2014). If a route has steps or upward slopes, pedestrians may tend to avoid this route especially if they have another option with less slopes or a flat route. In turn, a slight downward slope will help people to walk as less effort is needed (Koh and Wong 2013). The physical environment is formed by the built characteristics of the space that create an overall perception relative to walkability in terms of safety, comfort and level of interest, encouraging or not walking behavior.. For these reasons, many studies focusing on pedestrians found in the literature are related to behavioural aspects associated with the physical environment (Mehta 2008, Forsyth, Michael Oakes et al. 2009, Bahrainy and Khosravi 2013, Nasir, Lim et al. 2014, Peiravian, Derrible et al. 2014, Gilderbloom, Riggs et al. 2015, Lamíquiz and López-Domínguez 2015).

In addition to the influence of the physical environment on pedestrian movement, other criteria influence pedestrian movement and usage. Urban function is an important criterion influencing walking and it contains two subcriteria, which are Land Use and Population density. Land Use as one of urban function subcriteria influences the satisfaction and distribution of pedestrians in urban spaces (Bahrainy and Khosravi 2013, Lamíquiz and López-Domínguez 2015, Lerman and Omer 2016). Several studies show that mixed Land Uses and commercial areas increase pedestrian movement (Lamíquiz and López-Domínguez 2015, Lerman and Omer 2016). In particular, there are correlations between residential areas, population density and pedestrian movement (Christiansen, Toftager et al. 2014, Peiravian, Derrible et al. 2014, Lerman and Omer 2016). The population and residential density are the most used variables in this topic. They were used by Lerman and Omer (2016) in their study of spatial distribution of pedestrians, by Grecu and Morar (2013) in their model to improve pedestrian accessibility and by Peiravian et al. (2014) in the development and application of a pedestrian environment index. However, in Tel Aviv, Lerman and Omer (2016) found higher pedestrian movement in traditional areas of relatively low density than those detected in denser areas.

Accessibility is another criterion analysed by several authors regarding pedestrians. Accessibility is the way people reach a certain destination without making excessive efforts (walking), therefore it sometimes requires using the public transportation service and Intelligent Transportation System (ITS), which is a more sustainable model of urban mobility. (Grecu and Morar 2013). Walking to access other modes of transport, mainly public transport, is very common and encouraged in many countries (Cubukcu, Hepguzel et al. 2015). Besides public transport, access to facilities in the neighbouring area can be considered, such as shops and stores (Koh and Wong 2013), amenities such as schools (Christiansen, Toftager et al. 2014), green areas (Panagopoulos, Duque et al. 2016), mixed used areas (Cubukcu, Hepguzel et al. 2015), among others. Advanced transport technological solutions, such as real-time passenger information systems, are also seen as ways to enhance accessibility (Velaga, Beecroft et al. 2012). Accessibility is strongly linked with urban function and the physical environment, such as suburban areas are more car-dependent while walking in dense areas is oriented by transportation purposes and in lower density areas by leisure goals (Gilderbloom, Riggs et al. 2015, Lamíquiz and López-Domínguez 2015). Walking to transportation and to public transport has been encouraged as an active living strategy in many countries (Cubukcu, Hepguzel et al. 2015). Moreover, accessibility was considered by several authors in pedestrian studies, namely by Millward et al. (2013), Wey and Chiu (2013), Lundberg and Weber (2014), Cubukcu et al. (2015), among others.

The natural environment of streets and urban areas is also an important criterion, which influences walking (Lundberg and Weber 2014, Panagopoulos, Duque et al. 2016). Comfortable conditions, including temperature, green space, sunlight, shade and wind are important for walking (Koh and Wong 2013). Green spaces not only direct pedestrian flow in wide streets, improving pedestrians' perception of privacy and safety regarding car traffic, but also benefit the natural environment conditions of the streets and urban areas. (Caprì, Ignaccolo et al. 2015). Due to this, some authors developed urban green space walkability approaches to improve walkability in urban areas (Lwin and Murayama 2011, Caprì, Ignaccolo et al. 2015).

In the literature on planning, considerable research has focused on relationships between walking and all the criteria mentioned above. Some authors used surveys to understand pedestrian needs and their degree of satisfaction with the aim of formulating and pursuing planning policies (Bernhoft and Carstensen 2008, Manaugh and Geneidy 2013, Wey and Chiu 2013, Kim, Park et al. 2014, Babiano 2016). Other authors developed walkability measures or walkability indexes to help urban planners using data to compare and evaluate different solutions to improve walking conditions.

These indexes usually comprise several criteria and sub-criteria that are co-related but weighted in different ways (Millward, Spinney et al. 2013). A Multi-Criteria Analysis (MCA) approach was used in the PNA model to address the complexity of urban mobility issues reflected in the wide range of sustainability indicators. When prioritizing the variables, the MCA analysis creates an evaluation structure that reflects the pedestrians´ view.. These approaches were inspired by the study carried out by Frank (2005) that built a combined walkability index of three urban criteria to analyse their influence in physical activity (Frank, Schmid et al. 2005). More recently, Lamíquiz and Domínguez (2015) used five indexes including one related with accessibility calculated using Space Syntax to study the effects of the built environment on walking in Madrid, concluding that the street network and built environment criteria are clearly associated with the percentage of walking in urban areas.

Increasing availability of spatial data with greater disaggregation encouraged the use of GIS in studies on walkability. GIS have been used by many authors in various tasks such as identifying high and low walkability, providing information on walkability characteristics of a given region and generating a standardized benchmark to compare different settings in terms of characteristics shown to promote walking (Badland, White. M. et al. 2013, Kim, Park et al. 2014). In fact, many pedestrian attributes, namely density, land-use mix, street network, and accessibility can be analysed in GIS (Guo and Loo 2013). According to these authors, combining GIS data has proven to be a valid instrument for assessing the pedestrian environment. . GISs have been used in spatial analysis to: assess street network connectivity for bicycles and pedestrians (Lundberg and Weber 2014); support pedestrian surveys with environmental variables (Kim, Park et al. 2014); measure the impact of the built environment in relation to walkability (Bahrainy and Khosravi 2013, Guo and Loo 2013, Kim, Park et al. 2014) and develop pedestrian indexes (Peiravian, Derrible et al. 2014). GIS techniques are often used in combination with other approaches, namely with: agent-based simulations, where GISs provide geographical data for modeling neighbourhood walkability (Badland, White. M. et al. 2013); space syntax to study the effects of urban morphology on walking by using specific software and statistical functions (Lamíquiz and López-Domínguez 2015, Lerman and Omer 2016); land satellite images to use green-space areas to calculate ecofriendly walk scores (Lwin and Murayama 2011); gravity-based models where different weights are assigned to different criteria to obtain walk scores or rankings (Manaugh and Geneidy 2011).

Concerning the definition of walking scores and index, the MCA is also a commonly used tool especially in spatial planning. The MCA evaluates decision problems and different options based on specific criteria or decision maker preferences, by using a number of qualitative and/or quantitative criteria with different weights (Durmuş and Turk 2014). The attribution of weights to specific criteria is often a difficult and subjective task that requires a suitable way to make such trade-offs. Weighting the criteria and sub-criteria also requires a suitable way to make trade-offs between the criteria, having a direct influence on ordering the alternatives and, consequently, the results. In this approach, a quantitative weight method was used to define the relative importance of the criteria following the experts' opinion. Regarding walkability, the MCA was used by several authors. For instance, Beukes et al. (2011) used a GIS with a spatial multiple criteria evaluation by analyzing the effect of alternative weighting schemes on planning streets for five main modes, including walking. More recently, Socharoentum and Karimi (2016) developed an innovative algorithm called multi-modal transportation that selects walking routes by considering multiple criteria and parameters related to travelers´ behavior and physical capabilities, location and environment. The methodology identifies walking routes according to the characteristics of each traveler and also considering criteria such as parking lots and the topography available in GIS. The attributes/criteria of the model identify the basic structure of the city, in which the pedestrian network is inserted. The pedestrian network requires a special continuity of the city.(Yücel 1979). Street network connectivity has an important impact on walking and defining how the streets are networked (Bahrainy and Khosravi 2013, Azmi and Ahmad 2015). Street network connectivity can be understood as the directness and availability of alternative routes. A higher number of street intersections provides more potential routes for walking (Azmi and Ahmad 2015). High street network connectivity is typically found in areas with denser street networks. Nonetheless, some research also shows that a high connectivity may represent more street crossings, which may increase waiting times and safety risks (Ferrer, Ruiz et al. 2015). Thus, a convenient design of pedestrian crossings should be provided to encourage walking and to keep obstacles to a minimum. Street network connectivity can be defined as the number of intersecting streets per land-area unit (Azmi and Ahmad 2015, Garcia and Lara 2015). Space syntax has been used to assess street network connectivity because it has several advantages compared to more simple street network connectivity measures such as passive graphic notions. By using axial lines, space syntax is more suitable for calculating movements in network-configured human settlements and functional connectivity in networks (Tianxiang, Dong et al. 2015). Furthermore, street network connectivity analysis has contributed to a greater understanding of the street spatial configuration, street network, the location of economic activities and the numerical levels of street life (Millward, Spinney et al. 2013, Kim, Park et al. 2014, Peiravian, Derrible et al. 2014, Gilderbloom, Riggs et al. 2015, Lerman and Omer 2016).

In addition, the urban structure determines how serviceable and flexible an urban area is and how well it integrates into its surroundings. The urban structure contributes to both the function and feel of an area and creates a sense of place. A well-functioning urban structure has connected neighbourhoods, where activity centres are within a convenient walking distance. Walking supports this development and becomes conducive to create economic value and social vibrancy (Lindelöw, Svensson et al. 2017). The type of urban spatial structures influences the possibility of walking (Scoppa, Bawazir et al. 2018). Sun (2010) found Chinese cities are more sustainable and walkable such as Shanghai, Tianjin and Chongqing, which all have a polycentric urban structure design. Dai et al. (2014) concluded that the polycentric urban structure of Shenzhen may be an effective way to reduce pressure on transport to the city centre (Zhao, Diao et al. 2017). The spatial distribution of buildings and the arrangement of streets is seen as having a great influence on the means and intensity of human activities, social interactions, spatial mechanisms and human activities. The impact of urban structure on walking is a well-documented area, as can be observed by the various studies carried out in this field (Kerr, Frank et al. 2007, Song and Jeong 2016).

In turn, urban configuration is the primary generator of pedestrian movement patterns (Hillier, Perm et al. 1993). Peponis et al. (1989) presented some findings about the morphology of Greek towns and their patterns of pedestrian movement. This study compared the pattern of pedestrian movement and the urban configuration by the typological model of urban layouts. Various measures of urban configuration are correlated with aspects of social life. Accessibility is based on the relationships that each space has with others in an urban system (Jeong and Banyn 2016). Places that are most directly linked to other environments will be more accessible and tend to attract more movement (Baran, Rodríguez et al. 2008). The space syntax theory sustains that accessibility depends on people's wayfinding skills and mental conceptualizations of the environment. The most accessible locations are not necessarily those closest to all other locations, but those closest in terms of topological turns (Hillier et al., 2007). Angular dimension through angular segment analysis (ASA) in space syntax was introduced in the early 2000s by Dalton and Turner. ASA divides axial lines into street segments and then calculates their depths by considering the angles turned from the initial segment. (Jeong and Ban 2016). The angular sum is seen as the "cost" of a potential journey between two segments in a graph (Alasdair 2007). Some researchers found that a geometric or least angle analysis within a metric catchment area is an excellent predictor of movement (Hillier and Iida 2005, Charalambous and Mavridou 2012) called ASAMeD (Angular Segment Analysis by Metric Distance).

Consequently, ASAMeD in urban studies is increasingly more used and has been developed in recent years. For instance, Li et al. (2016) measured the spatial configuration of street networks in the Chinese city of Gulangyu using ASAMeD with the aim of shaping planning and tourism management policies and tourist preferences. Peponis et al. (1989) presented some findings about urban morphology of Greek towns and their pedestrian movement patterns. This study compared the pedestrian movement pattern and the urban configuration by the typological model of urban layouts. Hillier & Vaughan (2007) discussed the relationship between activity and space and how patterns of spatial structure influence the classification of locations and urban segregation. By using Space syntax, the ASAMeD analysis (which represents and quantifies aspects of spatial pattern) has found that urban structure patterns strongly correlate with pedestrian movement patterns (Hillier and Hanson 1984, Hillier, Burdett et al. 1987, Peponis, Ross et al. 1997, Hillier and Hanson 1998). Hermida et al. (2017) analysed the behaviour of the population in different areas of the Tomebamba River, Ecuador. Cutini (2016) also used space syntax in order to analyse the relationship between pedestrian movement and the urban structure of Florence to investigate how the pedestrian movement pattern has changed over time and whose main reason is the progressive transformation of the city grid. Thus, this approach is likely to be useful for further comparisons with another model to support walking because it deals with both spatial and functional aspects of urban form.

## 2.3 Main concept

This study has three key words which are: Pedestrians; Connectivity and Multicriteria. As shown in Figure 2-1, these three terms are related to each other in the contexts of activities, urban tissue and street networks.

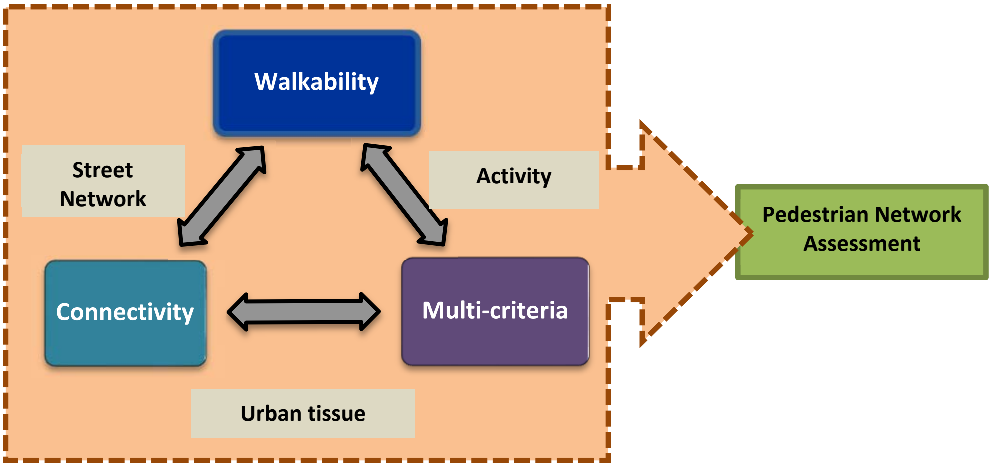

**Figure 2-1: Diagram showing key words**

The main concepts are defined as follows:

*Walkability* : Over the past decade, numerous studies have been conducted to identify the walkability potential effects on urban space. Improving pedestrian paths, especially in street networks, is a key activity to reduce the huge environmental costs of motorized transport which is the main transport activity for urban and regional travels (Tonga and Cheng 2013, Guo, Xu et al. 2017). In fact, walkability is one of the main parameters in the framework of this research, and it has e an active role in terms of promoting the quality of the urban environment. (Havard and Willis 2012, Hajrasouliha and Yin 2015, Babiano 2016).

*Multi-criteria:* Walkability in the urban tissue is related to a set of parameters, called "multi-criteria". Multi-criteria as a combination of various features of the streets, is an important parameter for pedestrians to chose a suitable street network. In an advanced multi-criteria analysis by Grecu and Morar (2013), Land Use parameters have been identified as important street features that can improve the pedestrian accessibility in Roman cities. Generally, some researchers applied a multiple criteria decision-making method to analyse the conditions of pedestrian paths in a city. This method matches pedestrian needs with walkability-oriented development. (Bernhoft and Carstensen 2008, Manaugh and Geneidy 2013, Wey and Chiu 2013, Kim, Park et al. 2014).

*Connectivity:* The structure of a city evolves from the oldest part of the city according to the main communication routes (streets).(Jabbari 2007, Velaga, Beecroft et al. 2012, Nyseth and Sognnaes 2013, Lundberg and Weber 2014, Ellis 2015, Tianxiang, Dong et al. 2015, Boulos 2016). The combination of multicriteria in the urban tissue is a reason for the "connectivity" between the streets with adequate potential for walking, which can result in a street network formation for pedestrian walking.

Overall, a combination of the above mentioned concepts (walkability, multi-criteria and connectivity), could be applied to the model proposed in this study to identify the best environmental quality for pedestrian access to travel destinations (such as shopping centres, parks,..). For this reason, this study presented a pedestrian network model on a macroscale, including two main components of connectivity and multi-criteria.

## 2.4 Summary

This chapter presents various researchers´ analyses (both national and international) who published works related to the topic of this study. The aim of this chapter is to study different points of views to identify walkability factors, as well as various techniques applied to these parameters to analyse street networks in cities.

When a pedestrian decides to walk, he/she tends to choose a route based on a number of factors. Individuals' decisions about whether and where to walk are highly complex and typically represent a consideration of multiple factors, including perceived facility, comfort, safety and convenience (Havard and Willis 2012). Multi-criteria as the main concept of this work, include four components: the Physical Environment, Urban function, Accessibility and Natural environment. The physical environment comprises three subcriteria including Terrain Slope, Human Scale and Visual Dimension. Urban Funcion contains two subcriteria including Land Use and Population Density. Accessibility consists of two subcriteria: Intelligent Transportation System (ITS) and Public Transportation Service. Finally, Natural Environment comprises two subcriteria: Green Space and Microclimatic Conditions (Temperature) (Mehta 2008, Forsyth, Michael Oakes et al. 2009, Galanis and Eliou 2011, Bahrainy and Khosravi 2013, Grecu and Morar 2013, Koh and Wong 2013, Christiansen, Toftager et al. 2014, Lundberg and Weber 2014, Nasir, Lim et al. 2014, Peiravian, Derrible et al. 2014, Cubukcu, Hepguzel et al. 2015, Gilderbloom, Riggs et al. 2015, Lamíquiz and López-Domínguez 2015, Lerman and Omer 2016, Panagopoulos, Duque et al. 2016).

Some authors used surveys to understand pedestrian needs and their degree of satisfaction with the aim of formulating and pursuing planning policies (Agrawal, Schlossberg et al. 2008, Bernhoft and Carstensen 2008, Manaugh and Geneidy 2011, Wey and Chiu 2013, Kim, Park et al. 2014, Babiano 2016). Walking indexes usually comprise several criteria and sub-criteria that are co-related but weighted in different ways (Millward, Spinney et al. 2013, Christiansen, Toftager et al. 2014). The MCA (multi-criteria analysis) is a tool often used to rank walking scores. It is a decision-making tool to evaluate different options based on specific criteria or decision maker preferences. This tool is frequently used in spatial planning to help decision makers (Jeong, Moruno et al. 2013) to choose approaches to improve walkability and pedestrian accessibility (Beukes, Vanderschuren et al. 2011, Grecu and Morar 2013, Blečić, Cecchini et al. 2015), to assess the impact of pedestrian scenarios (Vermote, Macharis et al. 2014), to define walking routes (Socharoentum and Karimi 2016) and to enhance the urban design of the pedestrian space (Wey and Chiu 2013), among others.

Lee and Seo (2013) also used space syntax and GIS to examine the impact of the built environment on walking. Thus, this research uses a combination of the two pieces of software (GIS and space syntax).

Both are useful tools to understand the role of the street network and streets in walkability because both deal with the spatial relationship and functional aspects. . There are less studies in the literature that analyse the impact of street network connectivity on walking.(Azmi and Ahmad 2015). Over the years, street network connectivity analysis has contributed to a greater understanding of the spatial configuration of street networks and how these kinds of configuration affect movement flows, the location of economic activities, etc. With the help of space syntax computer software, such as DepthmapX, the spatial hierarchy of streets can be visualised so that we can develop a picture of a particular street network (Li, Xiao et al. 2016). Spaces with high intersection densities provide more potential routes for walking and greater accessibility (Azmi and Ahmad 2015). The street network connectivity analysis defines the axial line through space syntax that is used for measuring the number of street intersections per line. A connection graph is defined depending on how each line connects to its surrounding lines (Penn, Hillier et al. 1998, Jiang and Liu 2009). This analysis focuses on the spatial relationships between streets within a network (Hillier, Burdett et al. 1987). Finally, this study identifies another space syntax function that identifies patterns in the urban structure based on segments (Jiang and Liu 2009). This analysis called ASAMeD was used by Jiang (2009) to predict patterns of pedestrian movement in individual urban morphology. Some researchers adopted the theory of graphs, which evaluates pedestrian movement through the ASAMeD tool (Hillier and Iida 2005, McCahill and Garrick 2008, Önder and Gigi 2010, Lerman, Rofè et al. 2014, Li, Xiao et al. 2016). The ASAMeD approach can be applied to evaluate the PNA model.

# 3. Methodology

## 3.1 Introduction

This model takes into consideration the experiences and lessons learned shown in the chapter on the Literature Review. This study presents a new methodology to assess a pedestrian network on a macro scale. This model was carried out with the aim of assessing the walkability in streets in order to identify a pedestrian network in a central area of any city. The ''pedestrian network'' can be understood as defined by Kasemsuppakorn and Karimi (2013): a topological base map that delineates the geometric relationship between pedestrian paths. The pedestrian network assessment (PNA) as a model could be an essential resource in a variety of applications, especially in urban planning and pedestrian navigation services and applications (Kasemsuppakorn and Karimi 2013, Tianxiang, Dong et al. 2015, Guo, Xu et al. 2017, Jabbari, Fonseca et al. 2017).

The methodological procedures adopted in the study will be described according to the following order (Figure 3-1): (i) Criteria selection; (ii) Description of the data collection; (iii) Weight assignment and aggregation method; (iv) Connectivity Evaluation; (v) Assessment of the pedestrian network; (vi) Evaluation of the PNA model by another approach.

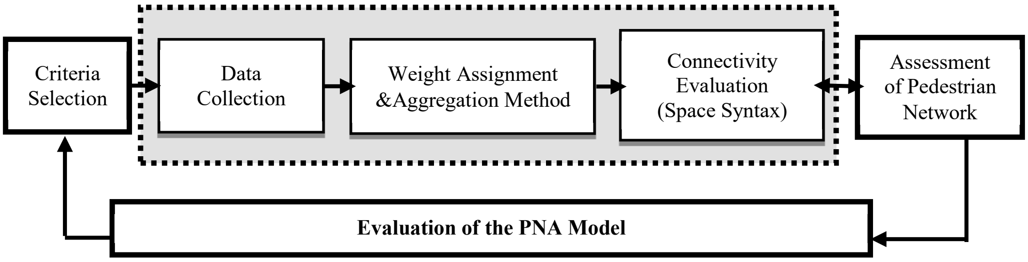


**Figure 3-1: Steps followed to assess a pedestrian network**

The model defines a general tool to analyse the walkability and connectivity of the pedestrian network. The Multi-Criteria Analysis (MCA) was adopted because it evaluates different alternatives by using a number of qualitative and/or quantitative criteria with different weights (Ramos and Fonseca 2016). By using MCA, the streets can be ranked according to their walkable conditions, identifying the more and less walkable ones. This tool is often used in mobility studies (Longo, Hutchinson et al. 2015), including in soft modes such as walking (Socharoentum and Karimi 2016). Finally, this research evaluates the output of the PNA model through ASAMeD, which had previously been used for the same purpose. Thus, by combining several criteria and sub-criteria and by having a spatial analysis component, the methodological approach can be an important contribution to supporting decisions and providing guidance in mobility planning

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## 3.2 Criteria Selection

The first step of the work consists of defining the attributes or the criteria that mostly affect the definition of the pedestrian network. The literature review presented an extensive number of research and interrelated attributes linked to walkability.

first criterion is related to the Physical Environment. This topic is one of the most analysed in pedestrian studies, as the literature review demonstrates. In the approach developed, the physical environment comprises three sub-criteria mostly related with urban diversity and design.

The terrain slope is the first of such sub-criteria. In fact, the topography affects the potential of walking, the way of walking, the travel speed and the energy required to walk (Guo and Loo 2013). Many walkability indexes, models and studies were developed considering terrain slope in articulation with other variables, such as length and street network connectivity (Guo and Loo 2013, Kasemsuppakorn and Karimi 2013, Lundberg and Weber 2014, Klein, Gutiérrez et al. 2015).

The second sub-criterion is similar to the previous one and considers the information of how difficult or easy it is to walk in a street. Human scale is related with size, texture and articulation of physical elements that match the size and proportions of humans and correspond to the speed at which humans walk (Ewing and Handy, 2009). This sub-criterion refers to the physical environment aspects relevant to the facade height and street width as this proportion influences the way of walking. This criterion is considered by Walford et al. (2011), Bahrainy and Khosravi (2013).

The third sub-criterion is related with visual dimension. This attribute is important because it encompasses many planning decisions and variables that create a pedestrian friendly environment by providing quality spaces to walk, infrastructures, solutions that could decrease the existing barriers to walk, by preserving the building design, memorability of places, their visual richness (complexity) and functional diversity, etc. There are urban design quality index measures to capture aspects of the physical environment relevant to people's emotive responses to aesthetics and structure in urban spaces (Walford, Samarasundera et al. 2011, Bahrainy and Khosravi 2013, Guo and Loo 2013, Wey and Chiu 2013, Lundberg and Weber 2014, Garcia and Lara 2015).

The second criterion includes the urban function and is divided into Land Use and population density.

The first sub-criterion is Land Use, which is seen as one of the criteria that mostly influences pedestrian movement. Land Use refers to the changes in Land Use morphology of a certain region over a certain period of time driven by socio-economic change and needs. The pattern of Land Use in a city is a reflection of the planning policies adopted over the years, determining the intensity and diversity of Land Uses in a city, its physical and functional structure and internal linkages. Land Use is one of the initial attributes considered by Cervero and Kockelman (1997) in their concept and has a strong impact on the population distribution and on their movements. Thus, Land Use is an attribute extensively used in pedestrian studies (Manaugh and Geneidy 2013, Millward, Spinney et al. 2013, Kim, Park et al. 2014, Lamíquiz and López-Domínguez 2015, Lerman and Omer 2016).

The population density is the second sub-criterion. The density distribution in a city is influenced by many criteria such as the distribution of residential areas, their density, the location of services and economic activities, coverage by public transport, among others. Population density also determines other phenomenon which have an impact on mobility such as traffic, as well as on the quality and diversity of infrastructures provided to walk. This criterion was used by many authors in pedestrian studies, such as Grecu and Morar (2013), Christiansen et al. (2014), Peiravian et al. (2014), Lerman and Omer (2016).

The third criterion is related to accessibility, which encompasses two sub-criteria: Public Transportation Service and the Intelligent Transportation System (ITS). The inclusion of accessibility can be explained by the insufficient exploitation that walking still has in current transportation planning (Boulos 2016) and by the fact that space-time accessibility is a very common concept in Land Use planning (Danalet, Farooq et al. 2014). Furthermore, Accessibility is considered a first level in the hierarchy of walking needs. Garcia and Lara (2015) and Gilderbloom et al. (2015) argue that accessibility-based criteria are more indicative of walkability and encourage walking behaviour than other suitability attributes. As a result, accessibility is widely used in pedestrian studies (Grecu and Morar 2013, Millward, Spinney et al. 2013, Kim, Park et al. 2014, Lamíquiz and López-Domínguez 2015, Marquet and Miralles-Guasch 2016).

The sub-criterion of the public transportation service has been used by many authors to study and measure accessibility since walking is essential to access public transportation and is one of the travel modes used by people between an origin and a destination. Such approaches can be found in the studies carried out by Morency et al. (2011), Wey and Chiu (2013), Cubukcu et al. (2015), Garcia and Lara (2015).

The Intelligent Transportation System (ITS) is another accessibility sub-criterion that encourages pedestrians to make decisions more easily. An ITS is based on advances in information and communication technologies and aims at improving traffic management monitoring, transmission and managing crucial knowledge. The use of this sub-criteria focused on public transportation, namely on systems that provide real-time information for passengers at bus-stops, inside buses, and over the internet to websites and mobile applications; and on systems to improve the security provided to pedestrians namely by detection systems (Kala 2016, Schmeidler and Fencl 2016, Xia, Zhang et al. 2016, Paul, Chilamkurti et al. 2017).

The natural environment is the fourth and last criterion considered in the analysis. This criterion comprises two sub-criteria: green space and microclimatic conditions (temperature). As accessibility, walking in the natural environment is an important issue in urban planning and some authors argue and demonstrate that natural environments encourage pedestrian movements (Foltête and Piombini 2007, Caprì, Ignaccolo et al. 2015).

Urban green space (urban greenery) can bring beneficial microclimatic effects, including air temperature (improving thermal comfort), wind reduction and air quality (Ng, Chen et al. 2012, Caprì, Ignaccolo et al. 2015, Panagopoulos, Duque et al. 2016). However, it has a positive impact on the urban landscape and on the visual quality of a city that also influences walking (Vojnovic, Elmoore et al. 2006).

Nevertheless, environmental criteria may have a great impact on walking. For instance, Socharoentum and Karimi (2016) argue that people may prefer driving cars or riding buses rather than walking due to rain, snow or air pollution. In turn, Lundberg and Weber (2014) argue that weather and temperature among other variables affect walking speeds. The urban climate is characterized by the nature of its immediate surroundings, such as building orientation, albedo, emissivity, thermal properties, wetness, etc. Urban microclimate refers to the characteristics of climate in the urban canopy layer between the buildings' rooftops and ground surfaces, e.g., the pedestrian level (Ng, Chen et al. 2012). Nevertheless, the quantitative relationship among the thermal comfort of pedestrians, microclimate variables and walking attitude at the scale of the street is still an unexplored issue (Caprì, Ignaccolo et al. 2015).

According to the theoretical background carried out, the study was supported using four criteria and nine sub-criteria, as presented in Table 3-1.

**Table 3-1: Criteria and sub-criteria used to assess streets in a pedestrian network**

| Criteria | Sub-criteria |
|---|---|
| Physical environment | Terrain Slope |
| | Human Scale |
| | Visual Dimension |
| Urban function | Land Use |
| | Population Density |
| Accessibility | Public Transportation Service |
| | Intelligent Transportation System(ITS) |
| Natural environment | Green Space |
| | Microclimatic Conditions (Temperature) |

## 3.3 Data Collection, implementation and Information Normalization

Database development is one of the most important activities in this model. The first issue or decision is how to incorporate data into the model. Commonly called database design, it is the first step in database development. Database implementation follows data modelling for database design. The final part of data capturing consists of providing the data based on the vector in this model in which vector data is split into three types: polygon, line (or arc) and point data. Figure 3-2 shows the different types of data adopted in this research and how these data are converted into "vector data and linear shape" formats that represent the linear street network system. The linear data system allows each line of the network to merge various data. The street network data is obtained from merging sub-criteria and criteria data. This part of research explains how data collates from different sources and how to implement them per sub-criteria.

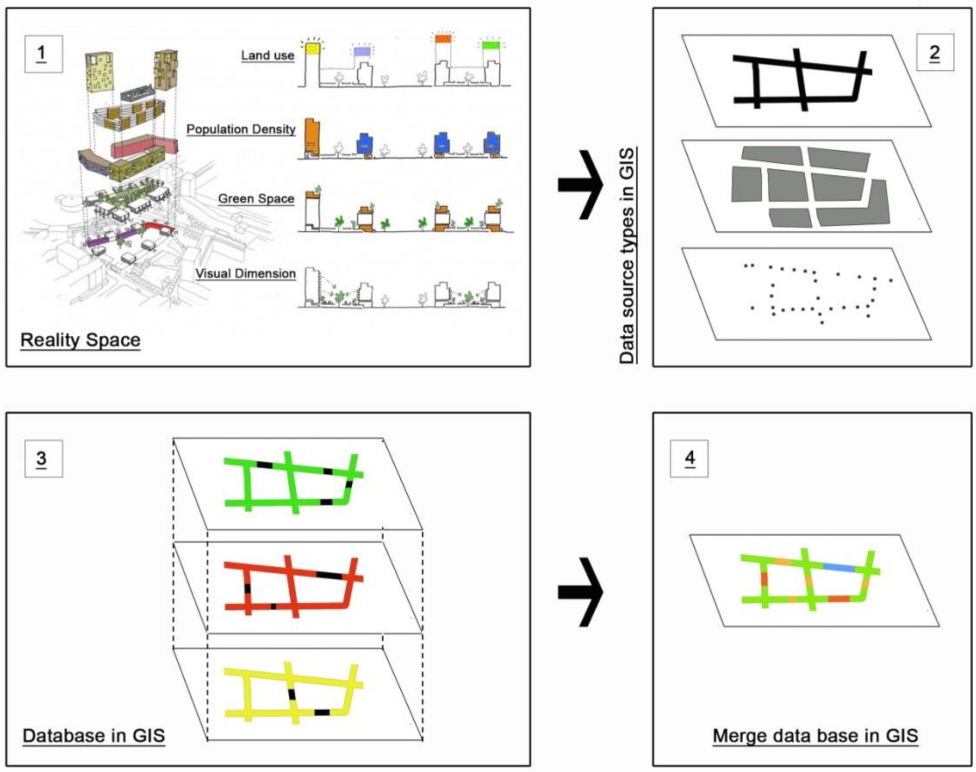
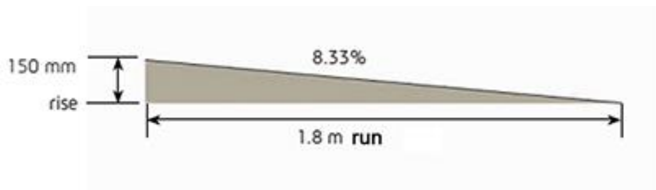


**Figure 3-2: Scheme of merging data of streets with GIS for the PNA model**

Sub-criteria data was obtained from different sources, therefore their valuation scales are different, and it is not possible to compare them. This is why it is necessary to standardize or normalize the value of the sub-criteria to be comparable. Most of the normalization or standardization methods use maximum and minimal values for defining a scale. In order to overcome this shortcoming, the Fuzzy Set theory, introduced by Zadeh in 1965, can solve the problem and it plays a significant role in this situation (Kuo, Tzeng et al. 2007). In the Fuzzy Set theory, the membership of an element to the fuzzy set is only a single value between one and zero. However, in reality, the degree of non-membership of an element in the fuzzy set is certainly not equal to one minus the degree of membership. That is, there may be some hesitation degree. The theory of the intuitionistic fuzzy set is characterized by a membership degree, a non-membership degree and a hesitation degree (Roostaee, Izadikhah et al. 2012, Alkan B. H. and Üstüntaş 2014, Montajabiha 2016). In fact, the fuzzy set theory is a solution to organise each sub-criterion and create a relevant database to apply the MCA sub-criteria and street network connectivity analysis. Moreover, this process shows some instances from Porto and Qazvin cities to clarify the database of the model by GIS in Chapter 5.

### 3.3.1 Terrain Slope

The terrain slope is one of the main parameters that influences the attractiveness and convenience of pedestrian streets (Kasemsuppakorn and Karimi 2013). As shown in Figure 3.3, the street slope is the relationship of the vertical rise to the horizontal run, expressed as a percentage or the percent change in the slope of the terrain. Based on ADA Standards for Accessible Design (2010), 8.33% is the maximum slope percentage that all users in an urban space could walk comfortably along (Department of Justice 2010).




$$\frac{\text{Vertical (rise)}}{\text{Horizontal (run)}} = \frac{0.15\text{ m}}{1.8\text{ m}} = 0.0833 = 8.33\,\%$$

**Figure 3-3: Basic measurement of Slope**

However, the street slope is significantly deviated from 8.33% for some streets. Hence, in order to build a walkable street for pedestrians, an average slope of 10% between the start and end points of the street has been considered (Czogalla and Herrmann 2010, Department of Justice 2010). Moreover, this average could be increased to 20% for streets in landscapes such as parks, gardens, etc. Based on the literature, Table 3-2 shows the classification of terrain slope within the urban space (Authority 2013, Clifton, Singleton et al. 2016, Gitelman, Carmel et al. 2016, Villa, Loiret et al. 2016).

**Table 3-2: Terrain Slope standard for pedestrian**

| Characteristics of the slope of the routes according to the different users´ capacities | **Any user** | **People who find it easy to walk** | **Young people** | **Not suitable for walking** |
|---|---|---|---|---|
| Standard | 8.3% as the Max slope for comfortable walkable streets | 10% as the average slope to build walkable streets in urban space | 20% as the Max slope to build walkable streets in landscapes such as parks | |
| Gradient Classification | 0<x≤8.3 % | 8.3%<x≤10 % | 10%<x≤20 % | 20%<x |
| Class for walking: Normalization | Easy: 1 | Medium: 0.66 | Hard: 0.33 | Very Hard: 0.05 |

Source: (Department of Justice 2010, Authority 2013, Clifton, Singleton et al. 2016, Gitelman, Carmel et al. 2016)

Fuzzy logic is a form of many-valued logic in which the truth values of variables may be any real number between 0 and 1, considered to be "fuzzy". Normalization is the process of efficiently organizing data from a fuzzy set in the database. The normalization process is carried out in the GIS and organises the database. The figure identifies the slope normalization process to be considered.

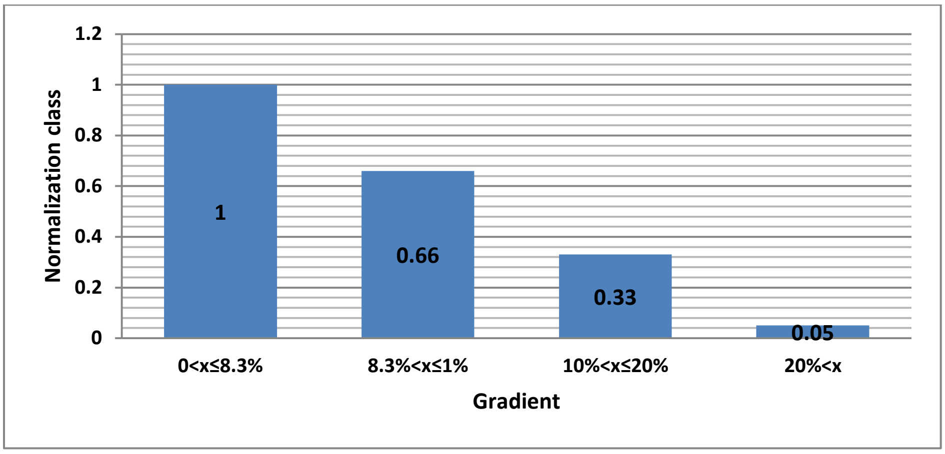
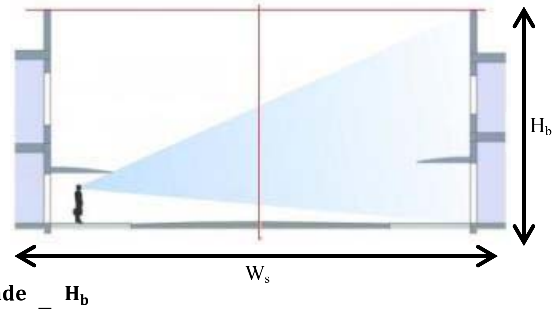



**Figure 3-4: Normalization of Terrain Slope**

### 3.3.2 Human Scale

Using a human scale as the main parameter influencing urban space proportions has ancient roots in Greek and Roman architectures (Korten 1999). The human scale is related to the size of the human body. In urban spaces, combined height and width (mass) of buildings are monumental. Human scale development is recognized based on human needs. When a human scale is applied in an urban space, the investigators understand the relationships among size and humans, as well as the proportion between the buildings and urban space. Buildings are the primary feature of urban contexts that create a sense of definition and enclosure. This sense is important for urban design elements that helps to create the experience of being in a place that is comfortable for pedestrians. As shown in Figure 3-5, the human scale is quantified as the ratio of the building facade height ($H_b$) to the width of the street ($W_s$). The optimum human scales for all the comfortable walkable streets has been identified as 1:2 and 1:3 (CSS 2014). Figure 3-6 shows examples of human scale classification in various types of streets from the walkability point of view. Pedestrians perceive the enclosure of buildings from a ratio of 1:4 in relation to the height of the buildings and the distance between buildings in the street in which they circulate. Allan Jacobs (1993) is more lenient in this regard, suggesting that the proportion of building heights to street width should be at least 1:2. Other designers have recommended proportions as high as 3:2 and as low as 1:6 for a sense of enclosure (Ewing and Bartholomew 2013, Moura, Cambra et al. 2017). These definitions of human scale provide a classification between human scale and enclosure space for pedestrians shown in Table 3-3.

**Figure 3-5: Illustration of height to width ratios that create a scale on thoroughfares that is comfortable for people and encourages walking (human scale). Human Scale ratios fall 1:2 as measured from the building fronts.**
**Source: (CSS 2014)**
Source: (CSS 2014)




$$\text{Human Scale} = X = \frac{\text{Height of Building facade}}{\text{Width of street}} = \frac{H_b}{W_s}$$

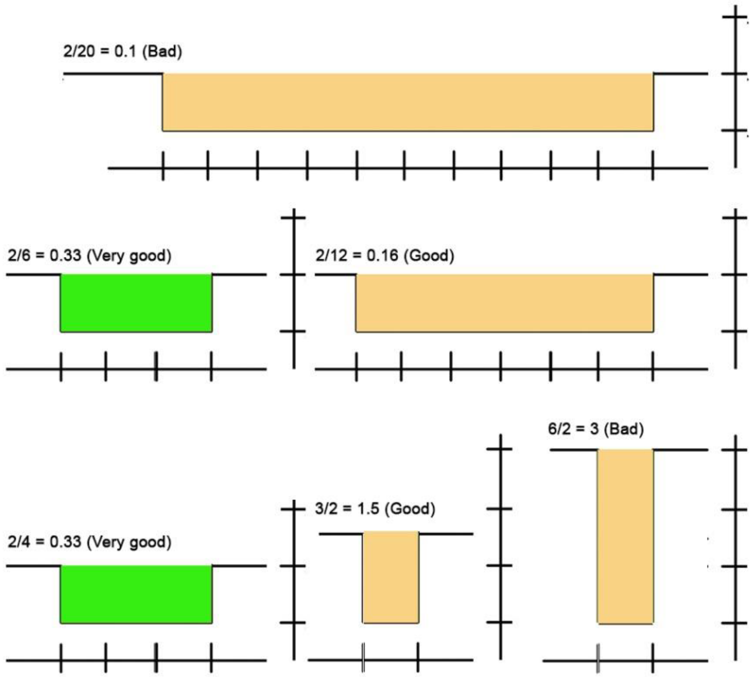



**Figure 3-6: Pictures of Human Scale classifications**

**Table 3-3: Human Scale standard for pedestrian**

| Height of Building Façade to Width of Street | x<0.1 | 0.1≤x<0.16 | 0.16≤x<0.33 | 0.33≤x≤0.5 | 0.5<x≤1.5 | 1.5<x≤3 | 3<x |
|---|---|---|---|---|---|---|---|
| Class for walking: Normalization | Very bad: 0.05 | Bad: 0.33 | Good: 0.66 | Very good: 1 | Good: 0.66 | Bad: 0.33 | Very bad: 0.05 |

Source: (Jacobs 1993, Ewing and Bartholomew 2013, CSS 2014, Moura, Cambra et al. 2017)

There are different forms of membership functions such as triangular, trapezoidal, piecewise linear, Gaussian or singleton in a fuzzy set. The graph in Fig. 3-7 presents a trapezoidal shape for the fuzzy set relative to the indicator representative of a human. When the values are within the range of 0.33 and 0.5, the indicator is very good. If the urban space proportion deviates from the above-mentioned values (less than 0.33 or greater than 0.5), the human scale is not so "good", due to the fact that the shape of the fuzzy set is triangular.

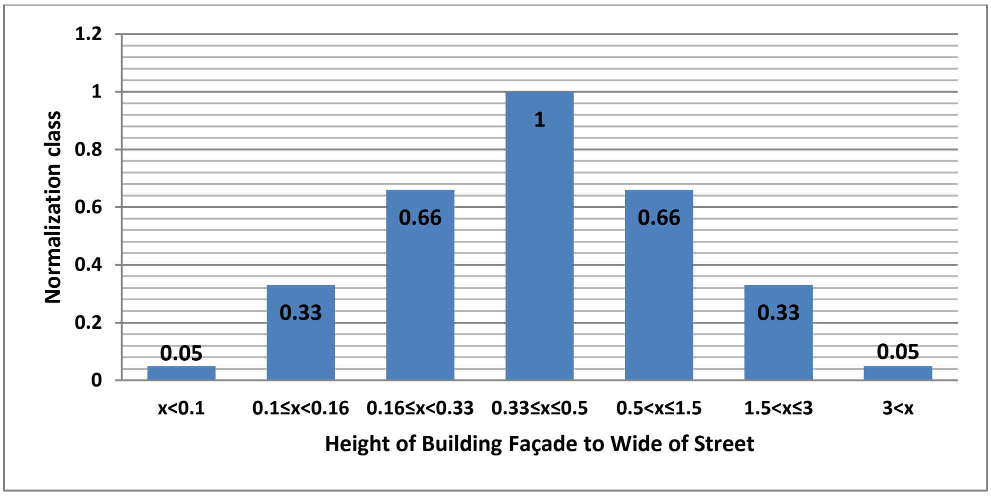



**Figure 3-7: Normalization of Human Scale**

### 3.3.3 Visual Dimension

Attractive architecture and improving the visual quality in the urban space is associated with walkability. However, some researchers found that by improving the visual dimension in urban spaces attracts pedestrians to them. (Humpel, Owen et al. 2004). By improving visual dimension, urban design attempts to join pedestrian perception to urban space. Urban spaces include elements such as plazas, courtyards and squares, as well as building facades, which are readily identifiable objects serving as external reference points (Gonzalez and Woods 2008, Cohen and Sloan 2016).

Aesthetic appreciation of the urban environment is primarily visual.. This sub-criteria could be related to how to integrate three main components individually, including the landmark, urban space and building facades. Consequently, this research considers a street as being in a "very good” condition, when it has three elements, which are combined, i.e., a beautiful space, an attractive building faced and a clear landmark. Table 3-4 illustrates the classification of streets according to the four levels based on the number of visual dimension components in the street. Figure 3-8 shows details of the normalization trend.

**Table 3-4: Street Classification for Visual Dimension**

| Description | Urban space compounds | | | Value Rating Landmark | Class for walking: Normalization Urban Space |
|---|---|---|---|---|---|
| | Landmark | Urban Space | Building Facade | | |
| An image of extremely high quality, as good as you could desire | | | | Very good | 1 |
| An image of high quality, providing enjoyable viewing. Interference is not objectionable | | | | Good | 0.69 |
| | | | | | |
| | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| An image of acceptable quality. Interference is not objectionable | | | | Bad | 0.37 |
| An image of poor quality; you wish you could improve it. Interference is somewhat objectionable | | | | Very Bad | 0.05 |

Source: (Humpel, Owen et al. 2004, Gonzalez and Woods 2008, Cohen and Sloan 2016)

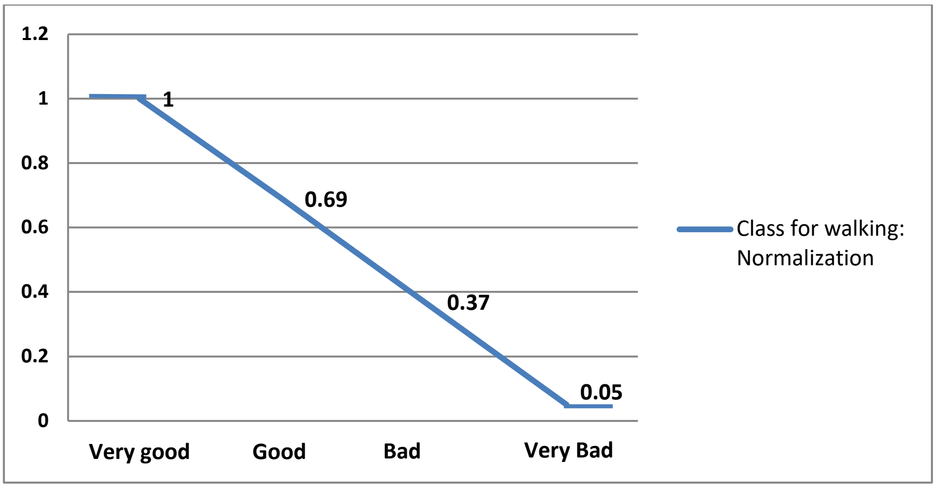



**Figure 3-8: Normalization of Visual Dimension**

### 3.3.4 Land Use

Land Use sub-criterion clarifies the characteristics of space according to what type of located activity there is in the street. Support activity analysis is used to identify what types of activities can be attractive for pedestrian movement in the streets. The literature review showed that pedestrian volume in business areas has a close relationship with the spatial network, which was demonstrated from the statistical analysis results to be the highest correlation among a variety of Land Uses. Therefore, it can be said that the pedestrian volume in business areas is almost determined by Trade, Education and Culture (Woo Shin, Ook Kim et al. 2007, Rizal Sutikno, Surjono et al. 2013).

The results of the Pedestrian Surveys were obtained from the University of California showing that Land Use is one of the main reasons for walking. A total of 367 surveys were completed by pedestrians from 25 locations where intercept interviews were conducted. As shown in Table 3-5, the primary reasons for walking given by respondents were Culture & Green space (25.2%) and Commercial purposes (24%) of the total number of trips (Jones, Ryan et al. 2010, Rizal Sutikno, Surjono et al. 2013, Moura, Cambra et al. 2017). This means that the purposes of most trips were Commercial and Culture & Green space.

**Table 3-5: Purpose of walking**

| Land Use | Culture & Green space | Commercial | Other | Residence + Commercial (30+70) | Office | Office + Residence (60+40) | Residence + Commercial (90+10) | Residence | Education | Transportation |
|---|---|---|---|---|---|---|---|---|---|---|
| Purpose of walking Percent of Respondents | 25.2% | 24% | 22.1% | 14.16% | 12.5% | 9.54% | 9.24% | 7.6% | 4.6% | 4.1% |

Source: (Jones, Ryan et al. 2010, Rizal Sutikno, Surjono et al. 2013, Moura, Cambra et al. 2017)

According to Table 3-5, the ranking of Land Use in the urban block is between one to ten. After applying this classification by GIS, this research defines four classes based on Land Use value divided into four colours, consequently, including Red, Orange, Yellow and Green. Each side of the street includes different Land Uses that are identified by block. On the other hand, this research assesses the streets. In order to classify the streets, the research uses a mechanism that characterizes the blocks (areas are on both sides of the street) and then transfers to the street (one line). This is possible using binary relations approach data.

Binary relations are the most important relations. There are two ways to represent a binary relation, one by a directed graph and the other by a matrix. The collection of all such related ordered pairs is simply a subset of the product set X × Y. A binary relation (or just relation) from X to Y is a subset or R ⊆ X × Y. Table 3-6 represents transmission data from block to street using the binary approach. After this stage, Tables 3-7 & Figures 3-9 show normalization of the streets that are related to the purpose of walking.

**Table 3-6: Binary relation in four colour classes**

| Color | Red | Orange | Yellow | Green |
|---|---|---|---|---|
| Red | R-R | R-O | R-Y | R-G |
| Orange | O-R | O-O | O-Y | O-G |
| Yellow | Y-R | Y-O | Y-Y | Y-G |
| Green | G-R | G-O | G-Y | G-G |

➡

| Color | Red | Orange | Yellow | Green |
|---|---|---|---|---|
| Red | 0.1 | 0.2 | 0.3 | 0.5 |
| Orange | 0.2 | 0.4 | 0.6 | 0.8 |
| Yellow | 0.3 | 0.6 | 0.7 | 0.9 |
| Green | 0.5 | 0.8 | 0.9 | 1 |

**Table 3-7: Normalization of Land Use**

| Land use data (transfer from block classification on both sides of the street - four levels of classification on each side of the street - for street normalized classification): Red, Orange, Yellow & Green | G_G | G-Y | G-O | Y_Y | Y-O | G-R | O_O | Y-R | O-R | R-R |
|---|---|---|---|---|---|---|---|---|---|---|
| Normalization | 1 | 0.9 | 0.8` | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 |

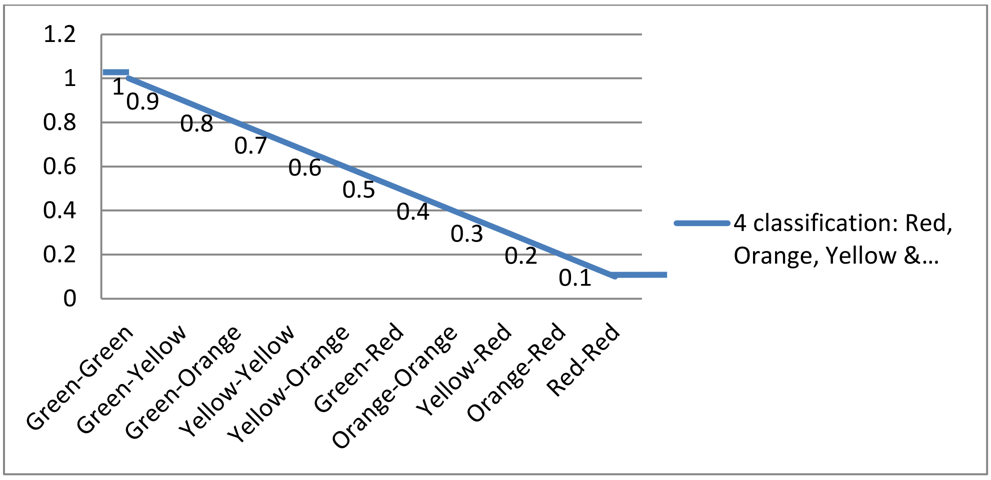



**Figure 3-9: Normalization of Land Use**

### 3.3.5 Population Density

This sub-criterion is the number of people per unit of area. This is usually estimated per square kilometre. The density is only a rough estimate to measure a population's distribution across the land. For this reason, this research considers the number of pedestrians there are in the Residential Land Use. Density can be computed for any area as long as the size of the land area and the population within that area are known. The population density is the number of people per unit of area that almost equals the average household size multiplied by the number of floors. The population density of each block group area is calculated by dividing the population (number of residents in the area) by area of each block group. Again, the quantile feature in GIS is used to categorize block groups by the levels of population density with low (less than 10,000 persons per square mile), medium (10,000 to 20,000 persons per square mile) and high density areas (greater than 20,000 persons per square mile) (Valdemarin 2005, Miranda-Moreno and Lahti 2013, Bosina and Weidmann 2017). Population density of neighbourhoods has a statistically significant effect on the pedestrian frequency. Areas with medium levels of population density have the highest percentage (43%) of pedestrian frequency, compared to (39%) in low density and (18%) in the lowest density areas (Valdemarin 2005) where these are examined in terms of their horizontal and vertical components (Table 3-8).

**Table 3-8: Population Density**

| Population density (mile) | Population density (meter) | Pedestrian Frequency | Classification of blocks in terms of the number of residents |
|---|---|---|---|
| Less than 10,000 persons per square mile | Less than 10,000 persons per 3 square kilometers | 18% | Low |
| 10,000 to 20,000 persons | 10,000 to 20,000 persons per | 39% | Medium |

| | | | |
|---|---|---|---|
| per square mile | 3 square kilometers | | |
| Greater than 20,000 persons per square mile | Greater than 20,000 persons per 3 square kilometers | 43% | High |

Source: (Valdemarin 2005, Miranda-Moreno and Lahti 2013, Lili Lu, Gang Ren et al. 2015, Bosina and Weidmann 2017)

All the streets have the same amount of pedestrian frequency in the case study which is not enough for the pedestrian network assessment. This research offers another approach proposed by several authors who assert that the census resident density population in the block is a good indicator to define streets with the potential for pedestrian movement (Cervero and Kockelman 1997, Frank, Stone Jr. et al. 2000). Consequently, this research considers the resident population density in blocks in order to detect the number of users that use the streets. Hence, the residence population density was calculated as follows:

Population Density = number of floors * number of units * household size

The ranking of population density is between the household size of the district to the maximum capacity of the block. After applying these amounts by GIS, it could be observed that the ranking spectrum was different in each city, or even district. Therefore, this research divided the population density into four colour classes (Red, Orange, Yellow and Green). In this model, the study aims to rank streets by their resident population density on the block and assess the pedestrian network based on this ranking by the binary relations approach, as shown in Table 3-9 and Figure 3-10.

**Table 3-9: Normalization Population Density**

| Density population data (transfer from block classification on both sides of the street - four levels of classification on each side of the street - for street normalized classification) | G_G | G-Y | G-O | Y_Y | Y-O | G-R | O_O | Y-R | O-R | R-R |
|---|---|---|---|---|---|---|---|---|---|---|
| Normalization | 1 | 0.9 | 0.8` | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 |

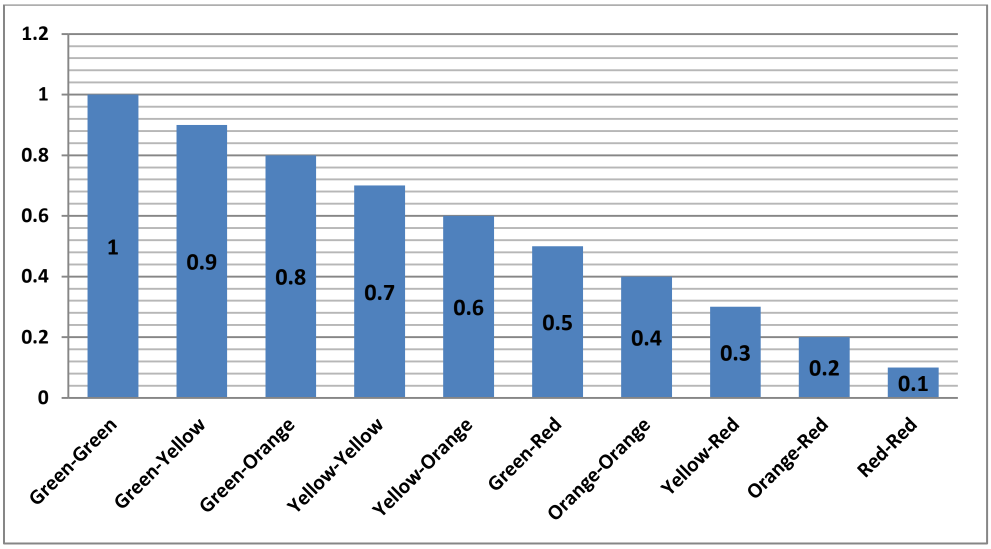



**Figure 3-10: Normalization of Population Density**

### 3.3.6 Public Transportation Services

Walking is the basic form of transportation that most people rely on every day. Pedestrian access to transit is a particularly important issue because most pedestrians use at least one public transportation mode during their trip. Better pedestrian access to public transportation services can encourage more walking. Access to public transportation services includes a wide range of facilities, such as large intermodal centres, city centre bus stops, subway stops and train stations. A key aspect of transit access is proximity. Considering this aspect, travelling by public transportation will be more convenient and comfortable. Moreover, the quality of the public transportation will be enhanced. After improving the quality, more and more people will tend to travel by public transportation (Nosa 2009, Shi and Yang 2013, Matsumoto and Hidaka 2015, Almodfer, Xiong et al. 2016).

Some researchers define classification from the area based on existing well-served areas for pedestrians. The results from the research suggest trip purposes whereby individuals might be willing to walk considerably farther than the 400-meter (quarter mile) and 800-meter thresholds considered standard in transit planning (El-Geneidy, Grimsrud et al. 2014). It is important to note that walking distances to a specific bus stop are generally shorter than to suburban trains and the subway, which is due to the differences in types of service, comfort, frequency of service and distance between stations. Therefore, this research considers a buffer with a radius of 800 meters based on metro stations and the streets were ranked accordingly.

In this measurement, all the streets have the same values to access the metro station in the case study, which is not enough for the pedestrian network assessment. Considering the public transportation service in the study area where the bus line system operates, there is a need to identify and determine the number and locations of the terminals and consequently define the number of routes to be served by taxis, the bus stops in the street and subway stations that show this classification and normalization in Table 3-10 and Figure 3-11. This table is divided into four classes according to how many service numbers are accessible for the place. For instance, one street has a taxi rank and a bus line that serves the pedestrian and it is placed in the second class of the classification.

**Table 3-10: Type of Public Transportation Service**

| Type of Public Transportation Service | Value Rating | Qualitative | Class for walking: Normalization |
|---|---|---|---|
| None | Class 4 | Bad | 0 |
| Bus line | Class 3 | Quite Good | 0.33 |
| Taxi station and Bus line | Class 2 | Good | 0.66 |
| Metro station, Bus stop and Taxi stations | Class 1 | Very Good | 1 |

Source: (Nosa 2009, Shi and Yang 2013, Matsumoto and Hidaka 2015, Almodfer, Xiong et al. 2016)

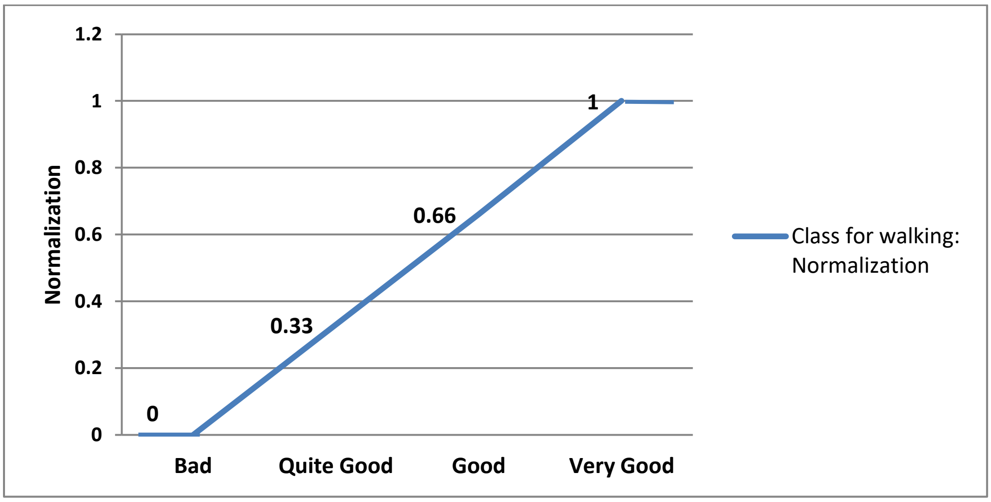



**Figure 3-11: Normalization of Public Transportation Services**

### 3.3.7 Intelligent Transportation Systems (ITS):

The term "Intelligent Transportation System" (ITS) refers to the application of information systems, telecommunications, sensors and control systems to road transport (Catling 1994). Given the wide range of intelligent transportation systems, it is useful to classify them based on their primary functional intent (acknowledging that many ITS applications can serve multiple functions or purposes) (Schmeidler and Fencl 2016, Kuang, Xu et al. 2017). This is related to systems that provide real-time information for passengers at bus-stops, inside buses and over the internet on websites and mobile applications. It includes systems to improve the security provided to pedestrians, especially by detection systems. Therefore, road safety has received much concern by governments and social organizations in cities in the European Union, such as developments associated with ITS. The object of these technologies is to enhance the comfort and safety of drivers and pedestrians (Vallejo, Albusac et al. , Gandhi and Trivedi 2007, Guo 2012). This list includes all ITS applications that are used to improve walkability in the city. (see Table 3-11). ITS applications can be grouped within five primary categories: Advanced Traveller Information Systems (ATIS), Advanced Transportation Management Systems (ATMS), ITS-Enabled Transportation Pricing Systems and Advanced Public Transportation Systems (APTS) (Ezell 2010) Table 3-11. In this classification, Advanced Traveller Information Systems (ATIS) are useful for pedestrian trips.

**Table 3-11: Classifying Mobile Applications for Pedestrian**

| ITS Category | Specific ITS Applications |
|---|---|
| **1- Advanced Traveler Information Systems (ATIS)** | Real-time Traffic Information Provision |
| | Route Guidance/Navigation Systems |
| | Parking Information |
| | Roadside Weather Information Systems |
| **2- Advanced Transportation Management Systems (ATMS)** | Traffic Operation Centers (TOCs) |
| | Ramp Metering |
| **3- ITS-Enabled Transportation Pricing Systems** | Electronic Toll Collection (ETC) |
| | Fee-Based Express (HOT) Lanes |
| | Variable Parking Fees |
| **4- Advanced Public Transportation Systems (APTS)** | Real-time Status Information for Public Transportation System (e.g. Bus, Subway, Rail) |
| | Electronic Fare Payment (for example, Smart Cards) |

Source: (Ezell 2010)

Regardless of the exact function, wireless connections are essential in the overall traffic network infrastructure. Wireless Communications Systems for Intelligent Transport Systems and Road Transport and Traffic Telematics will provide street network connectivity to vehicles and interconnect them (Bocian, Brownjohn et al. 2016). This technology for ITS applications works on the 5.8GHz band (in Japan and Europe) (Ezell 2010, ETSI 2015). Modern ITS networks require ever-increasing data rates to facilitate real-time communications between a wide variety of remote field devices and traffic control centres by Wireless Communication. This assessment with the necessary standards is shown in Table 3-12. Better bandwidth based on user demand should be provided to increase accessibility to urban space.. This technology uses hotspots that are installed throughout the urban space and this network covers public space for users. Table 3-12 and Figure 3-12 show the urban space classification based on access to a Wi-Fi network and normalization.

**Table 3-12: Quality and normalization of Intelligent Transport System**

| Place/wireless service (Band GHz >5.8) | Streets with wireless connection | Public transportation service with wireless connection | No wireless connection |
|---|---|---|---|
| Quality of Wireless Communications: Normalization | High: 1 | Medium: 0.5 | Low: 0 |

Source: (Frendendall and Behrend 1960, ETSI 2015, Bocian, Brownjohn et al. 2016)

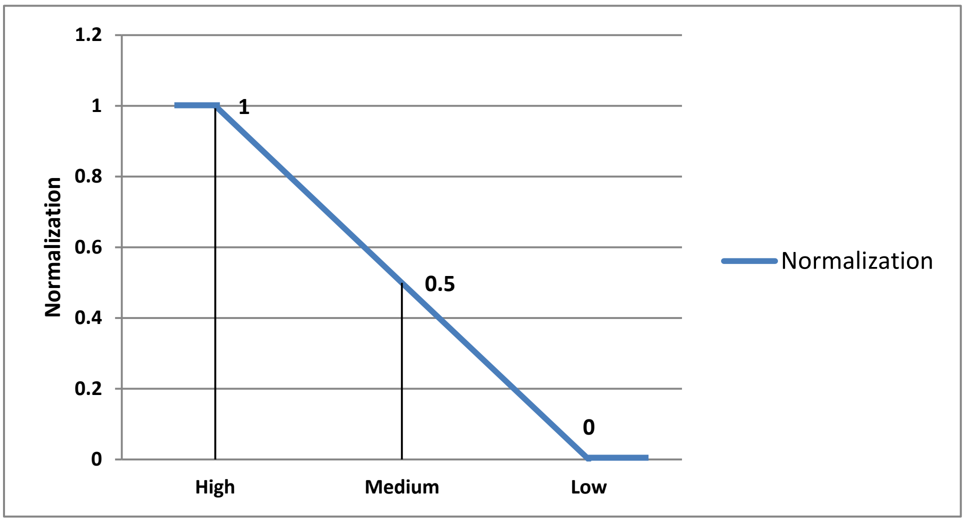



**Figure 3-12: Normalization of Intelligent Transportation Systems (ITS)**

### 3.3.8 Green Space

Urban greenery can benefit the climate and the urban environment. Key benefits include improving the thermal comfort, air quality, reduction in urban noise and wind speed (Caprì, Ignaccolo et al. 2015, Panagopoulos, Duque et al. 2016). It also has a positive impact on the urban landscape, which also influences walking (Vojnovic, Elmoore et al. 2006). Some research defines four main types of green spaces (parks, corridors, squares and forests) and determines that the minimum limit of public green space per person is 26 $m^2$ (as will be described later). Accessible green spaces are defined as places available free of cost for the general public (Morar, Radoslav et al. 2014). Some standards determine a maximum distance to a green space, which can be defined based on walking time to accessible local parks (2–20 ha). It takes 6–8 min to walk up to 400 metres (Authority 2004, Moseleya, Marzanoa et al. 2013, Park, Kim et al. 2017). This research considers this distance as the best condition to access green space for pedestrians. It should be mentioned that the rest areas are less important in terms of access to green space, as can be seen in Table 3-13 and Figure 3-13. The types of green space include urban parks, green corridors (green streets), buffers of urban parks to a radius of 400 meters, common green areas (green small spaces) and no access to green spaces.

**Table 3-13: Different types of Green Space and Normalization**

| Green space types | Classification | Class for walking: Normalization |
|---|---|---|
| Urban parks | Very Good | 1 |
| Green corridors (green streets) | Good | 0.75 |
| Buffer of urban parks (to a radius of 400 meters) | Reasonable | 0.5 |
| Common green areas | Bad | 0.25 |
| No access to green spaces | Very Bad | 0.05 |

Source: (Authority 2004, Moseleya, Marzanoa et al. 2013, Morar, Radoslav et al. 2014, Panagopoulos, Duque et al. 2016, Park, Kim et al. 2017)

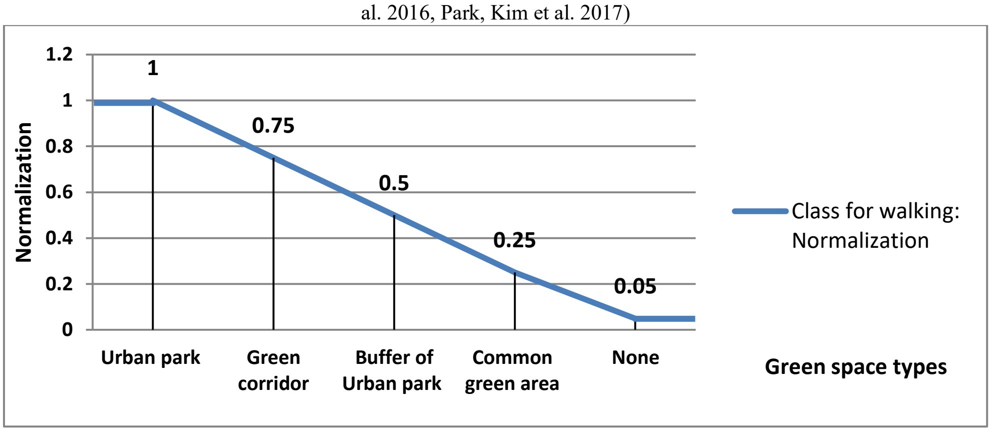



**Figure 3-13: Normalization of Green Space**

### 3.3.9 Microclimatic conditions (temperature)

The heat island effect is related to higher urban temperatures in city centres compared to the surrounding rural or suburban areas. The phenomenon is mainly related to the high density of buildings and urban structures that absorb solar radiation, the use of highly absorbing materials, the lack of green spaces and the characteristics of urban canyons and production of anthropogenic heat (Oke, Johnson et al. 1991). These are related to the characteristics of climate in the urban canopy layer between the building rooftops and ground surfaces, e.g., the pedestrian level (Ng et al. 2012). Nevertheless, the quantitative relationship among the thermal comfort of pedestrians, microclimate variables and pedestrian behaviour at the scale of the street network is still a rarely addressed issue (Caprì, Ignaccolo et al. 2015, Rosso, Pisello et al. 2016).

Consequently, energy in all of these surfaces contributes to urban heat island formation. Paved areas, which can absorb and store much of the sun’s energy contributing to the urban heat island effect, accounted for nearly 30 to 45 percent of land cover. Traditional roofing materials have low solar reflectance of 5 to 15 percent, which means they absorb 85 to 95 percent of the energy reaching them instead of reflecting the energy back out to the atmosphere. In fact, a roof exposed to the sun acts as a solar energy collector and heats the air in the boundary layer adjacent to its exterior surface. For example, a ‘‘hot’’ opaque roof with a solar reflectance of 0.05 will absorb 95% of the incident solar flux (EPA's 2008, EPA's 2008, EPA's 2008, Wray and Akbari 2008, Chatzidimitriou and Yannas 2015). According to these studies, Table 3-14 summarizes the solar reflectance on roof and the solar reflectance index (SRI).

**Table 3-14: Solar Reflectance Index (SRI) for material**

| Build up | Solar Reflectance Index (SRI) |
|---|---|
| **Dark Gravel** | 19% |
| **Tile (Natural clay-roman-terracotta)** | 57% |
| **White Gravel** | 58% |
| **White Coating** | 113% |
| **Asphalt** | 10% |
| **Concrete** | 40% |
| **Smooth natural stone-mosaic** | 56% |

Source: (EPA's 2008, EPA's 2008, EPA's 2008, Santamouris M., Synnefa A. et al. 2011, Santamouris 2013, Alchapar, Correa et al. 2014, Chatzidimitriou and Yannas 2015)

One of the more important factors influencing the environment temperature is using materials on the building roof. Hence, this research considers buildings´ roof-covering material to assess the microclimatic conditions (temperature) sub-criterion in the city. Urban blocks can be classified according to three main material types including Dark Gravel, Asphalt and Tiles. Data from roof-covering materials of buildings relevant to each block are located on both sides of the street. Therefore, in this case, this research considers two options that are pavement-covering material or green space-covering. The first option ranked worst and the second option ranked best based on the environment temperature.On the other hand, assessment of this research is based on the street (one line). Therefore, using the binary relations approach is a useful way to transmit roof-covering materials data (per block on both sides of the street) to the street (one line) (Table 3-15).

**Table 3-15: Roof-covering material Classification and Normalization**

| Roof-covering material Classification in two side of street | Solar Reflectance Index (SRI) | Classification | Class for walking: Normalization |
|---|---|---|---|
| Tile - Tile | 57% | Very Good | 1 |
| Tile - Gravel | 38% | Good | 0.75 |
| Tile - Asphalt | 33.5% | Reasonable | 0.5 |
| Asphalt - Gravel | 14.5% | Bad | 0.25 |
| Asphalt - Asphalt | 10% | Very Bad | 0.05 |

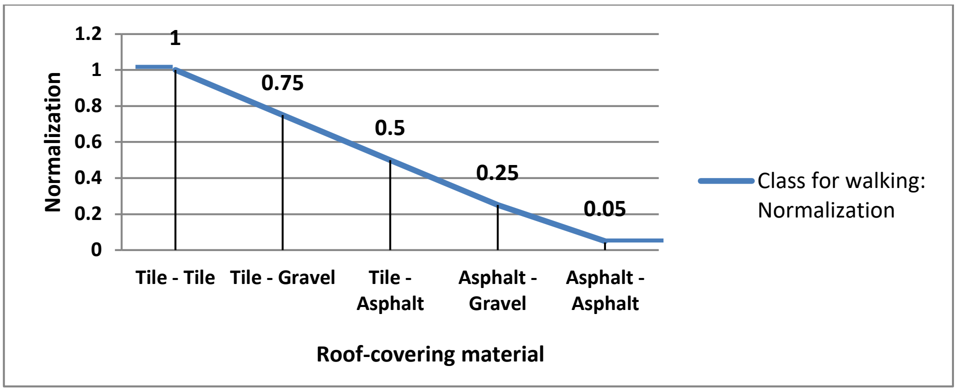



**Figure 3-14: Normalization of Microclimatic conditions (temperature)**

## 3.4 Survey, Weights Assignment and Aggregation Method

The decision to walk depends on fully understanding the factors that influence walking. The factors or criteria selected in this study were based on a literature review and on the involvement of a group of experts. This group consisted of experts who are specialised in urban and transportation planning, such as Civil Engineers, Geographers, Urbanists and Architects, PhD students, researchers and lecturers. Experts were involved because they are increasingly recognised as an essential element of successful planning decision making (Ferretti and Montibeller 2016). Furthermore, involving experts is a common process in MCA with the purpose of reducing subjectivity in the weighting process (Longo, Hutchinson et al. 2015, Ferretti and Montibeller 2016, Ramos and Fonseca 2016). Weighting also requires a suitable way to make the trade-off between the criteria. This approach directly influences the alternatives and, consequently, the results. In this approach, a quantitative weight method was used to define the relative importance of the criteria following the experts' opinions.

Thus, the experts ' participation focused on two main issues considering the specific conditions found in each city: (i) the criteria definition and (ii) weighting and prioritizing the criteria. Their involvement followed collaborative decision support systems by filling in an online participation form: a survey. The purpose of the survey and the range of questions were previously explained to experts in individual working sessions. The survey was previously structured and based on a semi-closed question format and consisted of two main parts containing 12 questions and this questionnaire is presented in the appendix.

The next step was to develop the MCA to prepare and evaluate all the sub-criteria and criteria by using the fuzzy set theory. All the information was entered into the GIS database for analysis. As the data from the criteria was expressed on different quantitative and qualitative scales, the values had to be normalized, so that they could be compared. The process was implemented through fuzzy logic with linear normalisation, a common approach used in MCA and decision problems (Forés, Bovea et al. 2014). The fuzzy theory is based on a fuzzy membership grade (possibility) that ranges from 0.0 to 1.0, indicating a continuous increase from non-membership to complete membership. The calculation was estimated by using the following linear normalisation:

**$X_i$ -** Element of the network (i= 1, 2,…., n) **X - $X_i$** of elements of the network

$$f(x_i) = \begin{cases} x = x_{min} = 0 \rightarrow f(x_i) = 0 \\ x_{min} < x_i < x_{max} \rightarrow f(x_i) = \dfrac{x - x_{min}}{x_{max} - x_{min}} \\ x = x_{max} \rightarrow f(x_i) = 1 \end{cases}$$

The purpose of assigning weights to the criteria and sub-criteria is to express the degree of importance for each criterion in relation to the others in the evaluation process. There are several methods for assigning weights to criteria, among which are those based on criteria ranking (ranking methods), score scales (rating methods), score distribution, criteria comparison by pairs (pairwise comparison matrix methods) and trade-off analysis. The simplest method to assign weights to the criteria is the pairwise comparison matrix method based on user surveys. According to the final weights, the criteria mostly valued by the experts were the natural environment and accessibility. These results are in accordance with other pedestrian studies where natural environment (Caprì, Ignaccolo et al. 2015, Socharoentum and Karimi 2016) and accessibility (Cervero, Sarmiento et al. 2009, Millward, Spinney et al. 2013, Garcia and Lara 2015, Gilderbloom, Riggs et al. 2015, Lamíquiz and López-Domínguez 2015) are seen as having a central role in decisions and the satisfaction of walking.

The last step of this stage was the aggregation that consists of incorporating the weights assigned by the experts for each sub-criteria and criteria. The method used was the Weighted Linear Combination (WLC), because it is an analytical method that can be used when dealing with multi-attribute decision making (Silva 2015). In the WLC, the combination resulted in applying the weights obtained by the pairwise combination to the conditions offered by the streets. The ranking prioritizing the walkable conditions provided by the streets is obtained by summing the results of each criterion. The higher the score, the more walkable the street is. WLC allows criteria to full trade-off their characteristics, meaning that a street with one very bad condition can be compensated by having other strong qualities. The WLC was performed on GIS and was calculated by using Equations 1 and 2.

**$S_k$ ($x_i$)** - Assessment of element **$X_i$** for all the sub-criteria **j** of criteria **k**

$$j = 1,2,\dots,9 \qquad S_k(x_i) = \sum_{i=0}^{n} f_j^k(x_i)\ w_{kj} \qquad (1)$$

**T ($x_i$)** - Assessment of all the criteria **k** for the element **$X_i$** of the network

$$k = 1,2,\dots,4 \qquad T(x_i) = \sum_{i=0}^{n} S_k(x_i)\ w_k \qquad (2)$$

## 3.5 Obtain the PNA Model by Streets network connectivity Analysis

This research argues that assessing a pedestrian network requires a street network connectivity analysis. In fact, the connectivity measures the degree to which the dense and diverse urban activities are accessible. The principle is that in order for the streets to be walkable, they must be connected. Even if a street provides good conditions for walking, it must be linked with other streets and spaces, otherwise people hardly go there on foot. In the study, connectivity was accessed with space syntax, by using the DepthmapX software. This software performs a set of spatial network analyses designed to understand social processes within the physical environment (Jeong and Banyn 2016). Based on the graph theory, the connectivity of a node can be defined as the number of other nodes directly connected to it.

## 3.6 Evaluation of the PNA Model

For evaluation purposes, this research intends to compare the result of the PNA model with another approach. The ASAMeD approach uses space syntax and identifies pedestrian movement patterns in urban space according to urban structure (Hillier and Iida 2005, McCahill and Garrick 2008, Önder and Gigi 2010, Lerman, Rofè et al. 2014, Li, Xiao et al. 2016).

## 3.7 Summary

In this chapter, the methodology of this research is first clarified from the larger picture of the conceptual framework of research methods. Then, in the rest of this chapter, the methodology of how to collect essential datasets and establish the GIS-based model is described. In addition, this research explains the PNA model step by step. The first step was to define the criteria and sub-criteria and the next step was to collect data which included geographic data and the survey, to build the model. Afterwards, the PNA model was completed by assessing the street network. City modelling is a powerful tool which analyses the complex urban environment. Therefore, this research combines the results of the MCA and connectivity analysis and the final result covers all the dimensions. Furthermore, the final stage of the model considers 0.5 weights for MCA outputs and the street network connectivity analysis based on the fuzzy set and the WLC method to obtain the final result.  The study presented the PNA model by incorporating all the data required at each stage, shown in Figure 3-15.

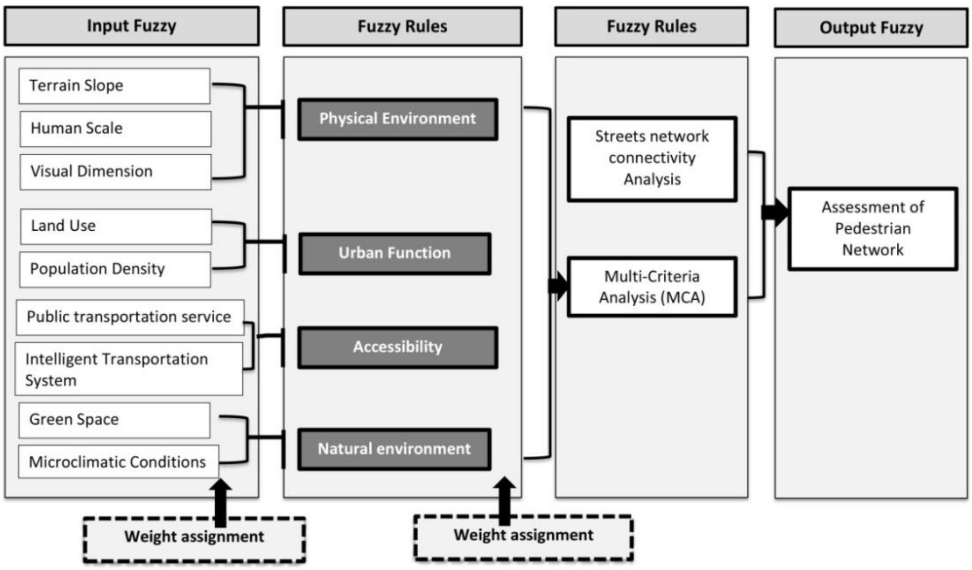



**Figure 3-15: Processing of PNA model**

# 4. Case Studies

## 4.1 Introduction

The aim of this research is to develop the PNA model in order to prioritize the walkability potential in the urban space. For this reason, the research used and evaluated the PNA model for different urban morphologies. For the case studies, the two cities of Porto (Portugal) and Qazvin (Iran) were chosen. These two cities represented the main characteristics of urban form and development processes for pedestrians in Portugal and Iran. In this chapter, the two cities and their characteristics are described in more detail, while the next chapter will explain how the PNA model was used in these cities.

## 4.2 Porto City in Portugal

Nowadays, the Porto metropolitan area is the economic centre of a region that influences most of the Northwest section of the Iberian Peninsula–Portugal and Galiza, comprising seven million people. The metropolitan area has more than 1.2 million inhabitants, divided between nine municipalities. Porto has 237,559 (Statistics Portugal 2012) inhabitants, the Baixa district has 70,000 inhabitants and the historical centre around 13,000 inhabitants (VIVO 2005, Jabbari and Ramos 2015). Currently, Porto boasts the most visited museum of modern art in the country and has a good street network (VIVO 2005). Nearby Porto is a modern airport and a dynamic seaport and these are the most important infrastructures in the region of Porto.

### 4.2.1 Porto

Silva (2008) explains that products, such as Porto wine produced in the Douro valley, were transported to Porto in Rabelo boats in the 13th century. Today Porto is well known for its Porto wine. Considering this, it is extremely important to understand the dynamics of the city and its evolution until nowadays. Porto city centre has various landmarks. The centre is located in Aliados avenue and includes the whole area of Carlos Alberto Square and Leões to Santa Catarina street and Batalha. To the north of the city centre is Lapa and to the south the Douro River. In the mid XX century, it was very common in this area for each street to have its own market. For instance, 31 de Janeiro street was specialised in gloves and hats while Dos Clérigos street sold material (Silva 2008).

At that time, economic trading and services were already established in the city centre. The central area of the city grew out of the commerce and services in the streets:

• Bonjardim street, where global commerce and cafes were the most popular;

• Almada street, where all kind of tools and hardware could be found;

• Flores street, also known as “Gold Street” because of the large number of jewellers;

• Santa Catarina street, where specialized commerce had just started.


**Figure 4-1: Commercial and Services Streets in the streets in the central area**

Moreover, Silva (2008) found all kinds of financial activities such as banks and insurance companies around Sá da Bandeira street, João I square and Liberdade square. Later in the XX century, increasing economic activities brought about some changes in the city centre, as many shoe shops opened in 31 de Janeiro street and clothes shops in Santa Catarina street. The fact that each street specialised in something different had a more significant impact on the customers. At that time, there were not many cars and people had to walk in the city. Porto city centre was always full of people and life. The cafés and theatres were full of intellectuals and the vibrant rhythm of development continues until today.

Nowadays, Space Syntax can encompass the entire axis from the past to the present. The most important axis of the overall structure of Porto was identified by Olivera & Pinho (2010). These authors identified that syntactic analysis illustrates the importance of the following axis: Almada street (the longest axial line between 1813 and 1833 with the highest connectivity between 1813 and 1865, the highest control between 1813 and 1833 and the highest local integration between 1813 and 1865); Boavista street (the longest line between 1839 and 1865) and Boavista Avenue (the longest line between 1892 and 2005 with the highest connectivity and control between 1892 and 2005 and the highest local integration between 1892 and 1960); and Constituição street (the line with the highest global integration in 1892, 1903 and between 1937 and 2005, and with the highest local integration between 1978 and 2005). Besides these streets, axial analysis has also highlighted the importance of other axes that have been somehow devalued in previous analyses, Calçada dos Clérigos/ Santo António street, Santa Catarina street and Fernandes Tomás street (Oliveira and Pinho 2010).

**The main structure:** Figure 4-2 shows the changing process of Porto city centre. It underwent changes in different periods of history from the 12th century to the 16th century. In the first urban structure centre around the Cathedral, there was an open space which was created mainly for religious activities. The second centre near the river and old trading zone, which is called Mercado Pereira Barcelos nowadays was created in medieval times. Finally, in the Renaissance period, the third centre ''Aliados avenue'' was made into the Boulevard. It was located outside the city wall and included the Town Hall. The map below illustrates the urban structure and how it changed over the three periods (Jabbari and Ramos 2015).

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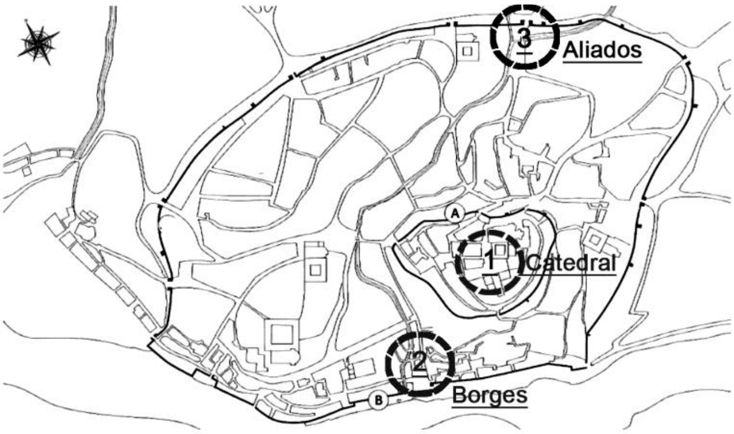



**Figure 4-2: Analysis of Main Structure: Organisation of Territory in the Middle Ages (1 - Boundary of the Bishop Hugo wall built in the twelfth century; 2 – Boundary of the Fernandina Wall built in the fourteenth century 3- Renaissance Period (without a wall)**

Source: (Jabbari and Ramos 2015)

**Visual features:** From the landscape view, the city of Porto is located in a good position. The city has a slight slope from north to south, which can be clearly observed on the city skyline. The visual feature of the city extends along the river and seafront. This structure shows the strong connection between the city and nature, shown in Figure 4-3.

**Figure 4-3: Landscape view of Porto**

Source: (Colorbox, 2017)

### 4.2.2 Planning in Porto

The Porto municipal plan is a good example of this morphological trend. Porto is the centre of the metropolitan area and the most important city in Northern Portugal, taking advantage of a unique location facing the Atlantic Sea and the Douro River. At the beginning of the 1980s, the city had a population of 327,368 inhabitants (Portugal 1981). This number dropped to 221,000 in 2007 mainly due to the relocation of the population within the metropolitan area (1.6 million inhabitants), particularly to the surrounding cities of Maia and Gaia. Part of the city, corresponding to the medieval borough located inside the 14th century Romanesque wall, was classified as a UNESCO World Heritage Site in 1996 (Pinho and Oliveira 2009). Table 4-1 shows the list of Porto plans between 1813 and 2005.

**Table 4-1: Porto town plans: 1813-2005**

| Number | Year | Title |
|---|---|---|
| 1 | 1813 | Round Map - George Balck |
| 2 | 1824 | City of Porto plan- José Francisco de Paiva |
| 3 | 1833 | Porto - W. B. Clarke |
| 4 | 1839 | City of Porto Topographic plant Porto - Joaquim da Costa Lima |
| 5 | 1865 | City of Porto plant - Frederico Perry Vidal |
| 6 | 1892 | City of Porto Topographic plant– Telles Ferreira |
| 7 | 1903 | City of Porto plant - STCMP |
| 8 | 1932 | City of Porto Topographic plant - STCMP |
| 9 | 1937 | City of Porto Topographic plant - STCMP |
| 10 | 1948 | Military Charter of Portugal - IGE |
| 11 | 1960 | City of Porto Topographic plant - STCMP |
| 12 | 1978 | Aerophotogrammetric Survey - DGPU |
| 13 | 1992 | Digital Cartography - STCMP |
| 14 | 1997 | Military Charter of Portugal - IGE |
| 15 | 2005 | Plant of the Existing Situation - STCMP |

Source: (Pinho and Oliveira 2009)

### 4.2.3 Porto Framework

Tavares (1996) explains that Porto is one of the oldest European cities and has traces of civilization from the late Bronze Age. Moreover, Tavaras and Vale (2012) describe the urban morphology as being shaped by the river Douro and the topography. The city started as a small medieval settlement on a hill and developed along the River Douro. Later on it expanded to include another small settlement near the sea. Porto´s historical centre developed under organic forms and narrow streets shaped by the rough terrain between the river and the city centre. Porto's historical centre has many monuments and buildings that represent cultural values from Romanesque, Gothic, Renaissance, Baroque and Neoclassical art, as well as more recent pieces of work, which have an important architectural meaning. In 1996 and based on the outstanding universal value of the urban tissue and its many historic buildings, the historic centre of Porto was classified by the UNESCO as a World Heritage Site. The site is based on the medieval walls and has an area of around 90 hectares (Tavares 1996, Tavares and Vale 2012).

Figure 4-4 shows the study area of this research that encompasses the historical centre of Porto. The selected area corresponds to 7% of the city surface that is around 2.6 km$^2$ and defines the border which is surrounded by Santa Cantarina street, Boavista street, Casa da Musica Square, Júlio Dinis street, Cristal Palace and the river. This area consists of a park, open space, sloped terrain, riverfront and historic tissue, Figure 4-5 and Figure 4-6. This vegetation and historic urban tissue are good elements to develop the pedestrian network. The pedestrian network has natural sceneries and organic forms and creates open and closed spaces. These spaces provide a variety of places, turning the place into a varied and multifunctional space for pedestrians.

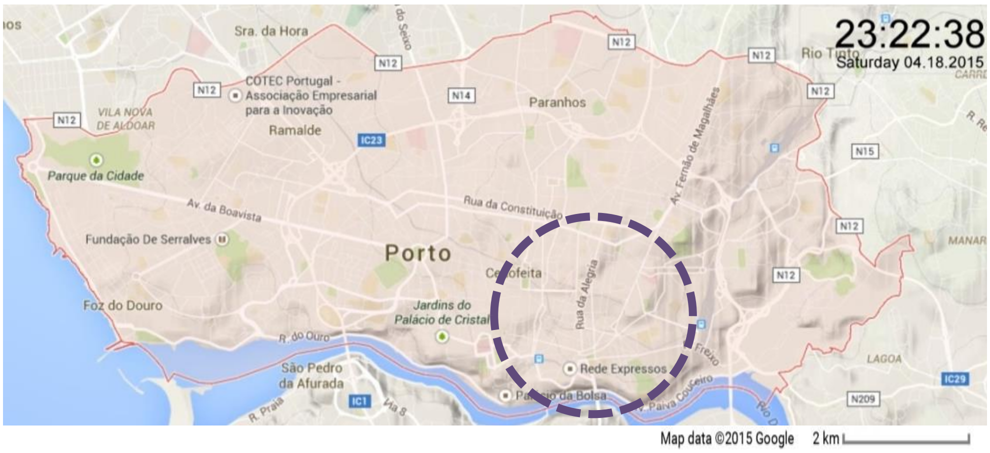
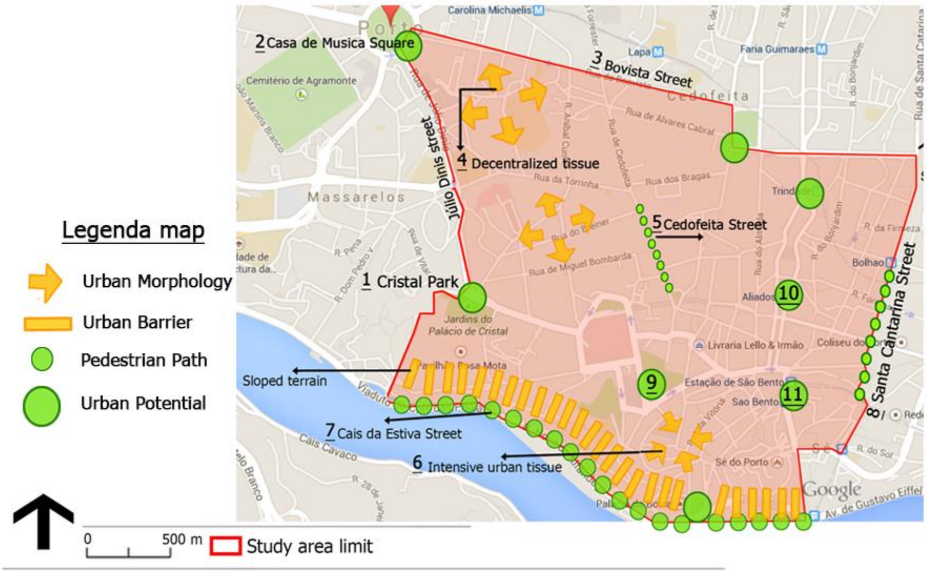



**Figure 4-4: Map of Porto City**

Source: (Google Map, 2015)




Note: Points 1 to 11- Photos in Figure 4-6

**Figure 4-5: Framework experimental work in Porto city**

1- Cristal Park

7- Cais da Estiva Street (Ribeira District)

2- Casa de Musica Square

8- Santa Catarina Street (Pedestrian path)

3- Boavista Street

9- Cordoaria's Garden

**4- Decentralized Urban Tissue**

**10- Aliados Avenue**

**5- Cedofeita Street (Pedestrian area)**


**6- Intensive Urban Tissue**

**11- São Bento Train Station**

**Figure 4-6: Photographs showing locations in Porto (Points identified in map in Figure 4-5**

Source: Pictures 4&6 (Google Earth,2015), 1 to 4, 5 & 7 to 11 (Author)

## 4.3 Qazvin City in Iran

Qazvin is the largest city and capital of the Province of Qazvin in Iran. Qazvin was an ancient capital in the Persian Empire and nowadays is known as the calligraphy capital of Iran. In the 2010 census, its population was 572,916 (Statistics Center of Iran 2011). It has been an important cultural centre throughout history and today, and it is a provincial capital. Qazvin is a pleasant city with a wonderfully restored caravanserai- and some quirky museums. The City of Qazvin was chosen as the 'City Prosperity Initiative – Metropolitan Cities Global Pilot City' to monitor urban stand-alone goals (SDGs). The 'City Prosperity Initiative – Metropolitan Cities (CPI-MC) Global Pilot Project' enables local authorities to create baseline information on the state of the city related to monitoring the urban SDG indicators. The city of Qazvin will be one of the first cities in the world to use CPI as a platform for the city and SDG monitoring (UN Habitant, 2016)

### 4.3.1 Qazvin

There are some natural barriers in Iran such as mountains and deserts and Qazvin is located in the central part between the barriers, which is a good reason why it became the capital in the Safavid (1524-1576) period. Archaeological findings in the Qazvin plain have revealed urban agricultural settlements for at least nine millennia. Qazvin geographically connects Tehran, Isfahan and the Persian Gulf to the Caspian seacoast and Asia Minor. Hence, it has been a strategic location throughout the ages. Given the geographical position of Qazvin at the centre of the Iranian plateau, it is known as one of the most important trade centres of Iran. This position occasionally makes it the bridge between the East, West, South and North. Its bazaar (market) has developed in the parts of the city that are closely connected with producers and customers.

Figure 4 7 shows the structural changes of the city during two periods before and after becoming the capital of Qazvin. Before becoming the capital, the main part of the city of Qazvin was a small bazaar located in the Southern part. In early Islam, the core or backbone of the city (along the East-West axis) was the Silk Road that ran through the middle of the city. The "Jame mosque" formed within this core and the bazaar, as a strictly linear element, extended from two sides of the core and along the main axis. During the Safavid period, the King decided to move his court away from the old city. He connected the old core to Chovgan Square through one street called Sepah Street, which was the first avenue to be formed in Iran. He created the Chovgan square as the central core of his plan in the north of the city. With the connection of the new bazaar around the Chovgan Square and the old bazaar alongside the square, the invigorated socio-economic life of the city continued. In the next period, residential neighbourhoods formed around the bazaar that became the heart and spirit of the town (Jabbari 2007, Jabbari and Ramos 2015).

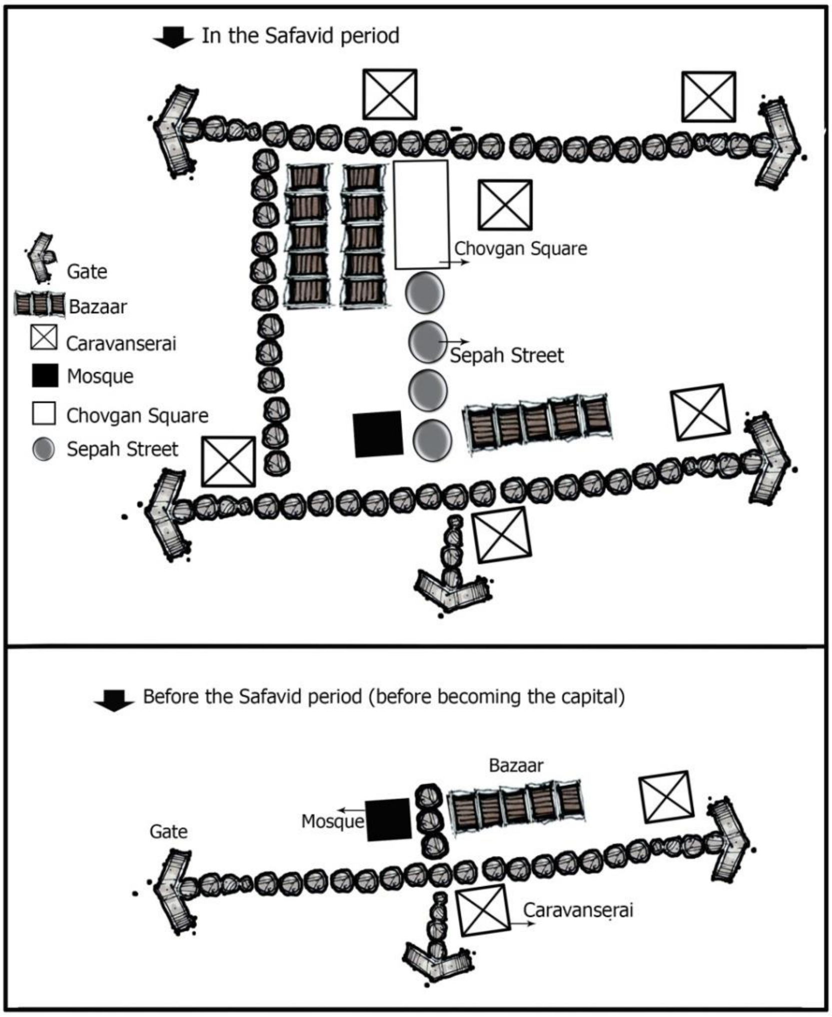



**Figure 4-7: Analysis of Main Structure: Before and after becoming the Capital of Qazvin**

**The main structure:** The main structure of Qazvin is polycentric and it was formed this way throughout different periods of history. In the structure, space was created due to activities and the neighbourhood. Besides this structure, there is a main area which comprises government buildings, the main mosques and the commercial area (Bazaar), etc.

**Visual features:** The location of Qazvin is based on the landscape view. There is a slight slope from north to south, which can be clearly observed on the city skyline. This leads to the southwest direction ending in the traditional gardens. Moreover, there are two religious places called "Musala", which are located at the top and bottom of the city (Figure 4-8).

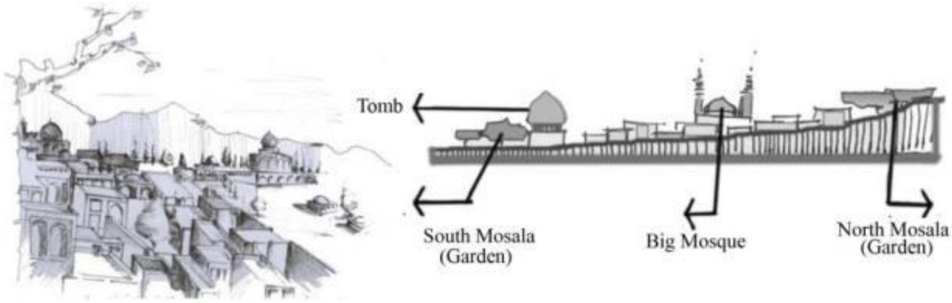



**Figure 4-8: Northern to Southern section town and three-dimensional perspective**

## 4.3.2 Planning in Qazvin

The first comprehensive plan of Qazvin was requested from the consultant Manda in 1964 (4 years before providing the comprehensive plan of Tehran) and it was adopted in 1971. This trend of Qazvin being a pioneer in urban planning has continued in recent years. This can be concluded because despite the fact that there are less than ten cities in Iran which have CDSs (City Development Strategies), two CDSs have been proposed for Qazvin so far. Hence, a historical analysis of the processes of preparing and implementing urban development plans in Qazvin can be considered a proper way to study the transformation of approaches towards planning in Iran (Table 4-2).

**Table 4-2: Comparison of urban development plans in Qazvin**

| Second CDS-2009 | First CDS-2007 | Sharmand-1991 | Maskoon-1981 | Manda-1964 |
|---|---|---|---|---|
| A livable agglomeration with an industrial growth compatible with high-tech technology, cities relied on urban financial sustainability. A city with a high quality social life and scientific prestige | A city with an integrated, planning based, powerful, citizen-oriented urban management system. A sustainable, healthy, safe and happy city. Centre of excellence for national and international research and academic institutes. A historical, beautiful and attractive city for both Iranian and foreign tourists. It has a dynamic empowered knowledge-based, competitive Economy. | A historical city, developed with a regional balance | A better, healthier, more effective, pleasant environment was created. A pleasant environment was created for residents. | The city of Qazvin had a particular position in terms of immigration and became one of the main poles attracting immigrants while implementing the plan. |

### 4.3.3 Qazvin Framework

Qazvin is located 150 km northwest of Tehran, in the Qazvin Province at 36.26877o latitude and 50.0041o longitude. The valley of Alamut is situated in the northeast of Qazvin province. The region is an enclave in the form of a U-shaped valley in the central Alborz chain of mountains opening up to the fertile Qazvin plains (Figure 4-9). In the past, its components were an example of meaningful urban structure, which demonstrated the dynamic and flourishing existence of the City and its civic life. However, in 1920, the historical urban tissue of the city changed due to building new streets for cars and expanding the city. The historical urban tissue of the city consisted of an appropriate urban infrastructure and amenities coordinated with the residents' needs. It grew gradually and changed accordingly in the society (Jabbari 2007).

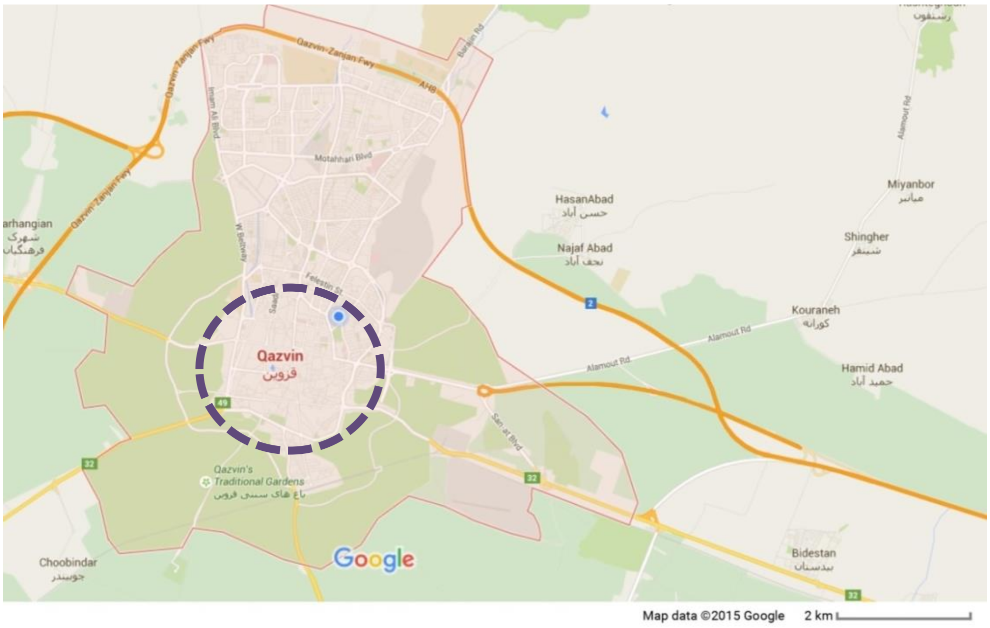
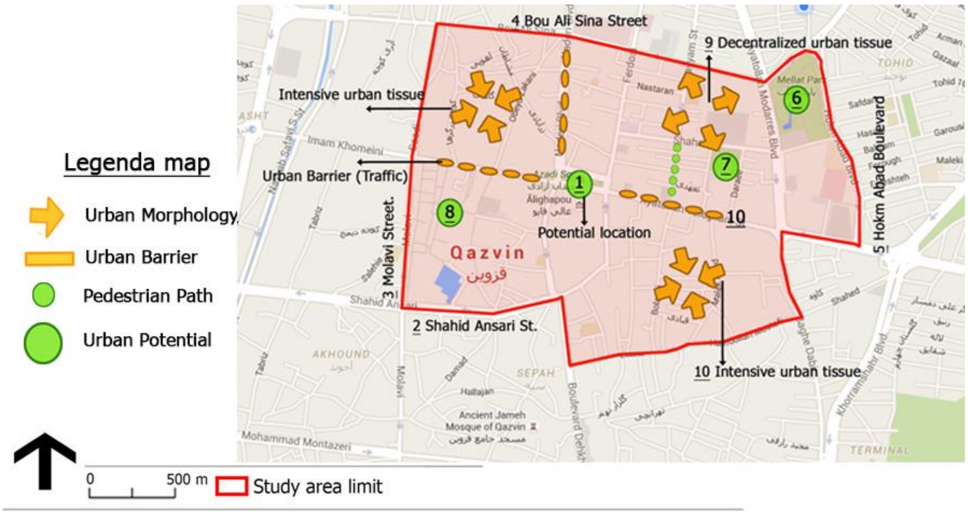



**Figure 4-9: Map of Qazvin City**

Source: (Google Map, 2015)

The framework of this research is limited to some streets such as Bou Ali Sina Street, Molavi Street, Shahid Ansari Street, Hokm Abad Garden and Boulevard, shown in Figure 4-10 and Figure 4-11. The area of the framework corresponds to 15% of the Qazvin city which is around 2.5 $km^2$. This area comprises a park, open space, market and historic urban tissue. This vegetation, market and historic tissue have the potential to develop in the pedestrian network.




Note: Points 1 to 10 - Photos in Figure 4-11

**Figure 4-10: Study area limit in Qazvin city**

Bazaars are normally located in the main part of Islamic and Iranian cities that consider this structure in the research framework. An Iranian city is often defined by a congregational Jame mosque and must have a main bazaar nearby. For economic and commercial activities in Iranian cities, the bazaar is the most important public space that is used for the development of the city (Pourjafar, Amini et al. 2014, Tavassoli 2016).

The urban structure of Qazvin reflects an old process of unplanned and planned urban growth. Qazvin has an identical morphological pattern strongly demarcated by the centre where the mosque and several public facilities can be found. Moreover, it contains other minor centralities supported in neighbourhood squares (Sharifi and Murayama 2013, Pourjafar, Amini et al. 2014). The main urban structure of Qazvin, shaped by several sub-centres of neighbourhoods, is widespread in the city as a polycentric structure. Polycentric structures are where those activities are decentralized and concentrated in suburban centres at the same time (Fujita and Ogawa 1982, Gabriel M. A. 2013, Badia, Estrada et al. 2016). After modern transformations, the green plaza was the main activity node in terms of the socio-cultural environment, and then changed to a traffic node in the city (Jabbari and Ramos 2015).


1- Chehel Sotoun Palace


2- Shahid Ansari Street


3- Molavi Street


4- Bou Ali Sina Street


6- Mellat (Hokm Abad) Park


7- Mashahir Park


8- Bazaar


9- Intensive Urban Tissue

5- Hokm Abad Boulevard

10- Intensive Urban Tissue

**Figure 4-11: Photographs showing locations in Qazvin city (points identified in the map in Figure 4-10)**

Source: Pictures 9&10 (Google Earth,2016) & 1 to 8 (Author)

## 4.4 Background urban morphology of case studies

The study was conducted considering two city centres with different urban structures: the Portuguese city of Porto and the Iranian city of Qazvin. Recent and historic advances reflect the complexity of the relationship between the urban structure and human travel behaviour (Susan 1996, Chen, Markus et al. 2015). In addition, ‘Organic’ towns which have grown over a long period seem to optimize certain key aspects of movement and land-use patterns by exploiting the structural properties of the urban grid (Hillier, Perm et al. 1993). Hence, this research focuses on two different case studies. We chose to analyse two cities because the urban structures of Porto and Qazvin reflect an old process of unplanned towns with different histories: European history (since the late Bronze Age for Porto) and Middle East history (since the Neolithic period for Qazvin). The case study has two main factors, which are organic settlements and the city centres before any modern transformations. Both cities provide a comparative analysis considering two different organic urban structures.

Thus, the urban structure takes shape during the city growth and creates a specific urban pattern. Understanding such a complex structure is challenging. Therefore, this research analyses the growth of the cities before any modern transformations. In addition, it includes a map showing historical information.

Urban structures of Porto and Qazvin reflect an old process of unplanned and planned urban growth. Porto presents a disorganized morphology, with narrowed and organic forms around a well distinguishable centre, with radial forms resulting from the medieval walls. Qazvin has an identical morphological pattern strongly demarcated by the centre where there is a mosque and various public facilities, but also contains other minor centres in neighbouring areas (Sharifi and Murayama 2013, Pourjafar, Amini et al. 2014). In both cities, the most recent urban areas are more rectilinear, sometimes orthogonal, as the result of deliberate planning actions.

Figure 4-12 shows the urban structure of both cities in the area of the city centre before any modern transformations. According to a historical explanation, the city centre of Porto moved out from the medieval walls and was organized around the Aliados Avenue. The city centre of Porto has a strong spatial articulation which is known as monocentric. Monocentric structures are those where centralization occurs in adjacent areas (Gabriel M. A. 2013, Badia, Estrada et al. 2016). Based on aerial photography of 1919 AD from Qazvin and interpreted historical information, Figure 1 shows the neighbourhood boundaries, centre and gates. The main urban structure of Qazvin shaped by several sub-centres of neighbourhoods, is widespread in the city as a polycentric structure. Polycentric structures are those where activities that are decentralized are concentrated in suburban centres at the same time (Fujita and Ogawa 1982, Gabriel M. A. 2013, Badia, Estrada et al. 2016).

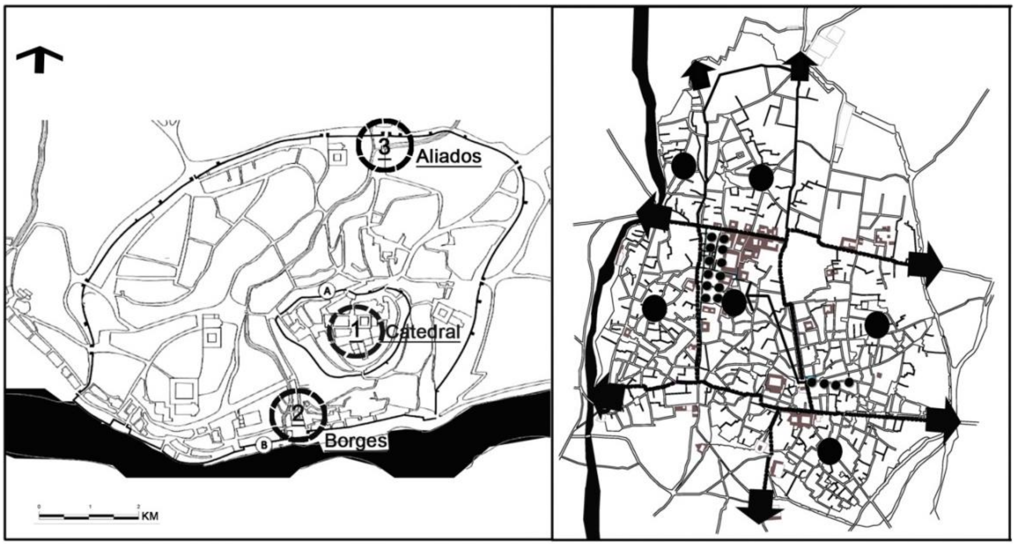



**Figure 4-12: Analysis of main structure Porto (Left) and Qazvin (Right).**

## 4.5 Background pedestrian street of the case studies

Over the last years, the Porto and Qazvin Municipal authority entities have implemented several urban planning policies to make them more walkable cities. For instance, some streets, such as Flores Street in Porto and Khayyam Street in Qazvin (Figure 4-13) were recently converted into pedestrian zones. At the same time, the city adopted many other urban policies having a direct impact on walkability. The physical and functional rehabilitation of the historical centre is perhaps the most visible policy. Rehabilitation makes cities more pleasant to walk in having a direct impact on the built visual dimension, human scale, Land Use, population density and public transportation services. Moreover, various researchers found that rehabilitation policies are important in terms of motivating people to walk (Vojnovic, Jackson-Elmoore et al. 2006). In functional terms, the city centre has been invigorated as a consequence of the increase in tourism over the last years. Several studies also show that commercial activities are related to greater pedestrian movement (Bahrainy and Khosravi 2013, Lamíquiz and López-Domínguez 2015, Lerman and Omer 2016). The green areas found in the central area of the cities and along some streets (Aliados avenue, Cristal Palace, Restauração, Mártires da Pátria square in Porto and Ferdousi street, Modares boulevard from Qazvin etc.) are also positive. In fact, green spaces are linked to higher walkable scores creating more attractive walking environments and having a positive impact on the microclimatic conditions found at the pedestrian level (Lwin and Murayama 2011, Adkins, Dill et al. 2012, Caprì, Ignaccolo et al. 2015).


**Figure 4-13: Flower Street from Porto (Left) & Khayyam Street from Qazvin (Right)**

Findings show that the multi-functionality and different population densities are in the centre of Porto and Qazvin. Although some streets are exclusively for pedestrians and have a strong commercial function (Santa Catarina, Cedofeita and Flores from Porto, Khayyam and Bazaar from Qazvin, for instance), the population density is relatively reduced in these areas. This problem shows unbalanced land use. It is a space for commerce and services, but where the population density is relatively low, meaning that probably some of the pedestrians do not live there. Building rehabilitation can be essential to attract more inhabitants to these areas. Enhancing the coverage using public transport, especially bus stops with suitable intelligent transportation systems, is also important to reduce car dependency and make urban mobility more sustainable. (Kim, Park et al. 2014, Garcia and Lara 2015). If the distance to walk is too long and no information is provided, people will be encouraged to use private vehicles.

## 4.6 Summary

This study was developed considering the Portuguese city of Porto and the Iranian city of Qazvin. Moreover, the study was carried out in the context of different structures and this helps to evaluate the pattern of pedestrian movement.

These areas show the necessary conditions to implement the methodology in order to analyse the impact of the criteria in an urban context for walkability. The areas integrate many urban functions and Land Uses with different population densities; including variable slopes, aesthetic and landscape values, which have different levels of accessibility.

These different features provide a considerable variety of conditions for pedestrians, creating a varied and multifunctional space in both cities.

# 5. Implemented and Results

## 5.1 Introduction

Regarding, potential, Porto and Qazvin are developing dynamic and vibrant urban spaces. This will enhance the residents´ and visitors´ quality of life. Moreover, the case study analysed in this thesis will help to develop the pedestrian network.

Hence, this chapter presents the results of the methodology (PNA model) applied in Porto and Qazvin. Several factors influenced the PNA model. Therefore, this research aims to use the PNA model in Porto and Qazvin which is defined in the four steps based on the proposed methodology in the third chapter. Afterwards, the final result of the PNA model in these cities will be evaluated using the ASAMeD approach.

## 5.2 Data Collection

This stage illustrates the impact of the sub-criteria on the streets of Porto and Qazvin according to a fuzzy set theory using GIS. The research organizes information of the sub criteria for each street. This is why we used a special code for each street in which the code was an articulation between the all the scores from the sub- criteria and the criteria in the analysis process. In the coding structure, the streets of Porto and Qazvin were coded respectively by 490 and 464 whose codes are defined by the column in the table of GIS vector data. In fact, this column joins all the data related to the criteria and sub-criteria. Firstly, it shows an analysis of the sub-criteria in two case studies.

### 5.2.1 Terrain Slope

According to the normalization table of the terrain slope in the third chapter, firstly, the terrain slope of the streets is detected by the mapping tool. The terrain slope amount is classified between 8.3% and 20% based on the defined standard of terrain slope. Therefore, this research creates a new column for the classification of the street terrain slope. For example, the terrain slope of 31 de Janeiro street is higher than 20%, hence the score in the normalization column is 0.05. Moreover, to clarify the input data processing, Figure 5-1 shows some samples. Finally, Figure 5-2 presents the terrain slope of both cities using some examples of the street. The terrain slope of Qazvin is almost monotonic and creates a smooth surface for pedestrians. While in Porto, the terrain slope is slightly higher in the south.

Porto: 31 de Janeiro Street
Slope: 30%   Normalization: 0.05

Porto: Aliados Avenue
Slope: 9%   Normalization: 0.66


Porto: Cais da Estiva Street
Slope: 2%   Normalization: 1

Qazvin: Sepah Street
Slope: 2%   Normalization: 1

Qazvin: Sepah Street
Slope: 0%   Normalization: 1

**Figure 5-1: Terrain Slope database and Normalization**

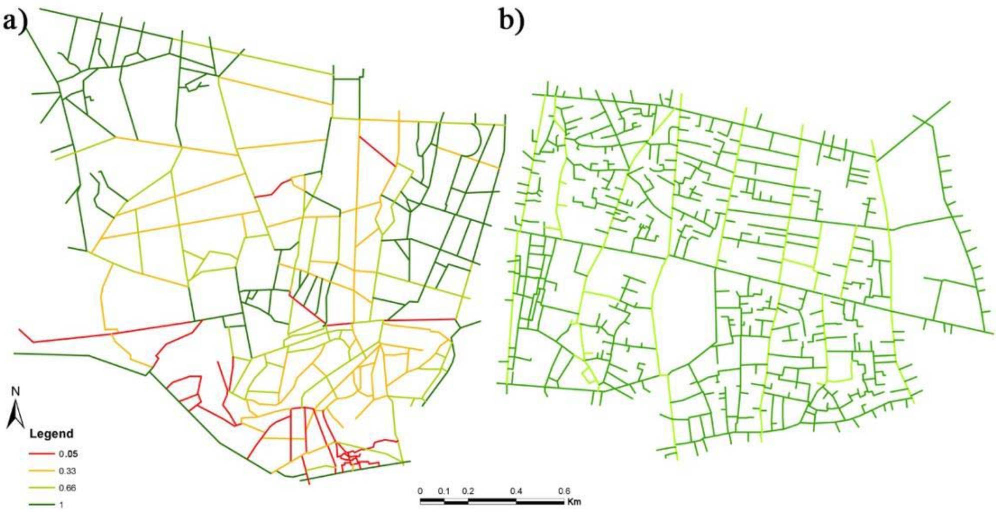



**Figure 5-2: Terrain Slope in Porto (a) and Qazvin (b)**

### 5.2.2 Human Scale

The human scale obtained a ratio of the building facade height ($H_b$) to the width of street ($W_s$). The street includes many different heights of buildings. Therefore, this research considers the average height of the building facade along two sides of the street in order to detect the human scale. For example, Boavista Street in Porto has a 6.5 metre rise and a 12 metre run, which is 0.54 human scale of Boavista Street (Figure 5-3). Based on Table 3-3, the human scale of Boavista Street has a "good" value. In addition, Figure 5-4 shows some examples of both cities.

As can be seen, from the maps in Figure 5-5, the streets of Qazvin have more human scale than Porto. This is due to the fact that it is related to the urban tissue history. The historical urban tissue of Porto belongs to the medieval period when houses were four storeys high and were located in narrow streets. This explains why the streets do not have enough human scale in the urban space (Allen and Faloutsos 2009, Moura, Cambra et al. 2017). Conversely, the historical urban tissue of Qazvin is relevant to the urban morphology philosophy of Iranian cities and the human scale is one of the factors (Tavassoli 2016). However, the located streets in the new urban tissue from both cities have a poor condition of the human scale.

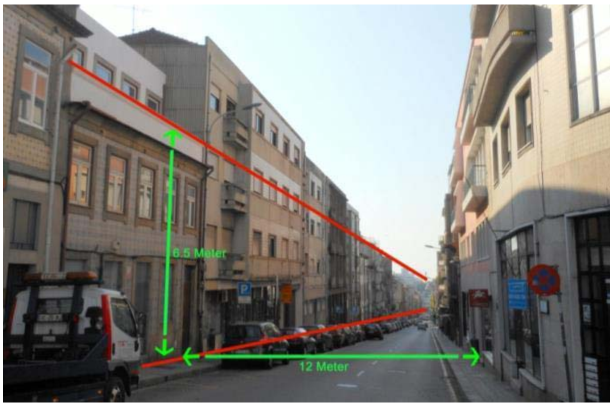
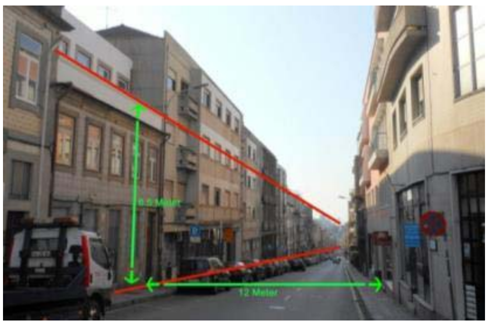



**Figure 5-3: Human Scale of Boavista Street in Porto city**




Porto: Boavista Street

Human Scale (Classification)= $\frac{H_b}{W_s} = \frac{6.5}{12} = 0.54$

Normalization: 0.66

Porto: Aliados Avenue

Human Scale (Classification)= $\frac{H_b}{W_s} = \frac{18}{60} = 0.3$

Normalization: 1

Porto: 31 de Janeiro Street

Human Scale (Classification)= $\frac{H_b}{W_s} = \frac{12}{8} = 1.5$

Normalization: 0.66

Qazvin: Bazzar Alley

Human Scale (Classification)= $\frac{H_b}{W_s} = \frac{3}{2} = 1.5$

Normalization: 0.66

Qazvin: Ferdowsi Street

Human Scale (Classification)= $\frac{H_b}{W_s} = \frac{5}{10} = 0.5$

Normalization: 1

Qazvin: Sepah Street

Human Scale (Classification)= $\frac{H_b}{W_s} = \frac{12}{24} = 0.5$

Normalization: 1

**Figure 5-4: Human Scale database and Normalization**

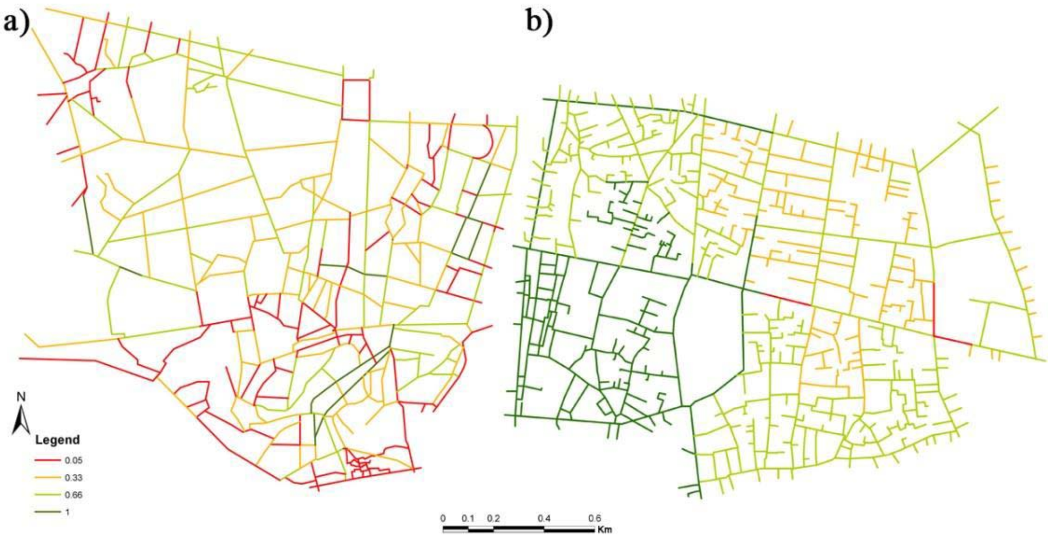



**Figure 5-5: Human Scale in Porto (a) and Qazvin (b)**

### 5.2.3 Visual Dimension

The research investigates the visual dimension through Walter Benjamin's aesthetic perspective approach. He utilized the portraying of cities and introduced Naples and Moscow (Benjamin 1986, Durante 2013). Indeed, Benjamin's experience of the city as a 'spatial practice' emerges from the visual rather than the textual aspect. More precisely, it shows perceptions and visions of the city and presents different patterns of urban experiences. This research has been greatly influenced by experienced researchers and professional visual artists. Furthermore, photographs are important tools for the investigation because they offer legibility space. The pictures are similar to the piece of the puzzle that finally forms the big picture.

The evaluation of the visual dimension structure includes 3 components, which are: space, building facades and landscape. Each component is evaluated using adjectives (beautiful, nice and unimpeded view of the surroundings). For example, analysing the quality of Cais da Estiva street by picture technique involves three compounds of visual dimension. Therefore, this street obtains a score with a very good quality (Figure 5-6). Figure 5-7 shows some examples of both cities that assessed the visual dimension using this technique.

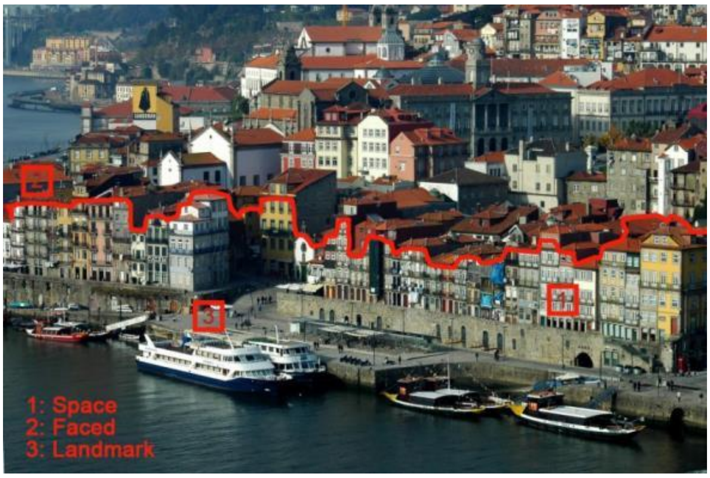
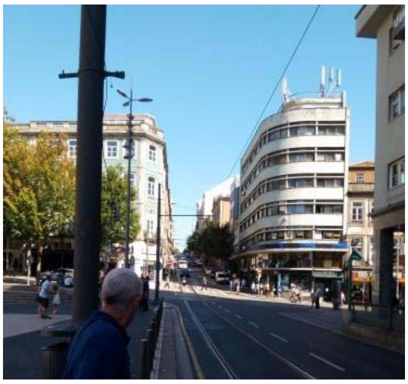



**Figure 5-6: Visual Dimension quality of Cais da Estiva street (Porto) using photograph**

Porto: Aliados Avenue
Landmark, Urban Space, & Buildings Façade
(Three compounds) Normalization: 1



Porto: Passos Manuel Street
Urban Space, & Buildings Façade
(Two compounds) Normalization: 0.69

Qazvin: Taleghani Street
Buildings Façade
(One compounds)
Normalization: 0.37

Qazvin: Azadi Square
Landmark, Urban Space, &
Buildings Façade
(Three compounds)
Normalization: 1

**Figure 5-7: Visual Dimension database and Normalization**

According to Figure 5-8, the visual dimension of both cities shows that most of the main streets have a "Good" value rather than other kinds of streets. In addition, the streets in Porto with acceptable quality are more sprawled out than the Qazvin streets. This means that in terms of the visual dimension Porto is attractive and may encourage more pedestrians to walk in the urban tissue (Cohen and Sloan 2016).

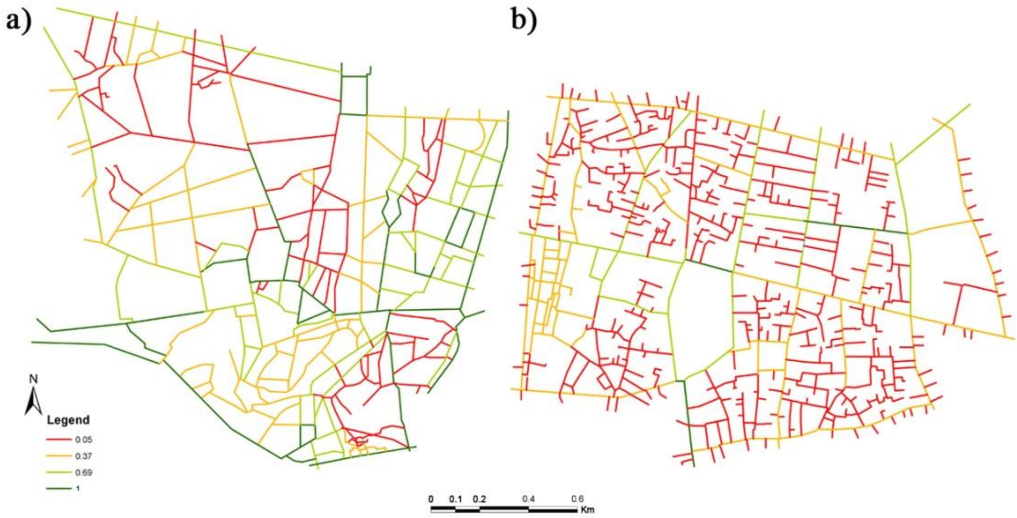



**Figure 5-8: Visual Dimension in Porto (a) and Qazvin (b)**

### 5.2.4 Land Use

According to Table 3-5, the ranking of Land Use in the urban block is between one to ten. After ranking a block, this classification shows a wide range. This ranking is difficult to assess this research. Firstly, this research is analysed based on the streets and the data is located in blocks (areas are on both sides of the street). Secondly, the researcher has to recognize which land use from both sides of the street has more impact to attract people to the street.

. Therefore, this research defines four classes based on Land Use value divided into four colours: red, orange, yellow and green. This new classification is based on the Binary relations approach. For instance, Figure 5-9 shows two sides of Santa Catarina Street (Porto) and Taleghani street (Qazvin) which are coloured yellow (Y_Y). Based on Table 3-7, Y_Y blocks obtain the 0.7 score. Moreover, Table 5-1 shows some samples of the two cities that explains the database processing for the Land Use sub-criterion.

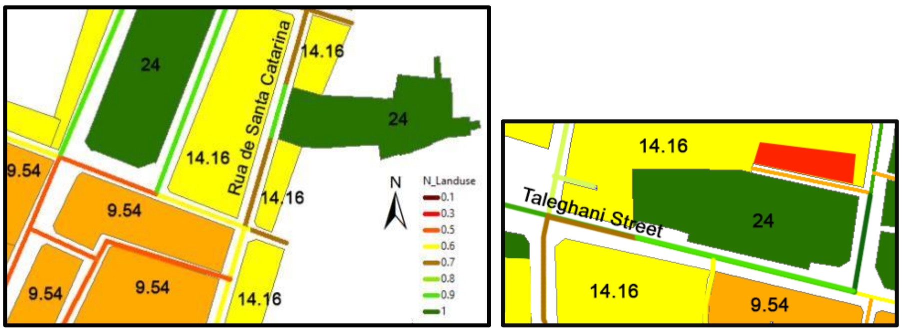



**Figure 5-9: Assessment process of Santa Catarina (Porto) and Taleghani (Qazvin) Streets in terms of Land Use**

**Table 5-1: Land Use database and Normalization**

| Name Street | Visual Dimension | Normalization |
|---|---|---|
| Porto: Santa Catarina Street | Y-Y | 0.7 |
| Porto: Santa Catarina Street | Y-O | 0.6 |
| Porto: Santa Catarina Street | Y-G | 0.9 |
| Qazvin: Taleghani Street | O-G | 0.8 |
| Qazvin: Taleghani Street | Y-Y | 0.7 |
| Qazvin: Taleghani Street | O-y | 0.6 |

As can be seen from the analyses of the two cities in Figure 5-10, the highest score of Land Use is for the commercial streets. In Qazvin, these streets include traditional modern markets and are joined to the street network through the main street. In Porto the most commercial areas are concentrated in two streets and not scattered around the city.


**Figure 5-10: Land use in Porto (a) and Qazvin (b)**

## 5.2.5 Population Density

According to the standard in Table 3-8, the area of the two case studies is less than 3 km$^2$. The case studies of this research are 2.6 km$^2$ in Porto city and 1.5 km$^2$ in Qazvin city, which is less than standard. On the other hand, as reported by the National Statistics Institute (INE) in Portugal (2011) and the Statistical Central of Iran (2006), the household size of Porto city is 2.5 and the sum of residence density population is 4724.5 people in 2.6 km$^2$, although the household size of Qazvin city is 3.6 and the sum of residence density population is 86778 people in 1.5 km$^2$. According to the standards in Table 3-8, the frequency of pedestrians is 43%, which is the highest value.. According to this standard, all the streets have the same values of pedestrian frequency in both cities which is not enough for the pedestrian network assessment. Therefore, this research offers another approach proposed by various authors who assert that the census resident density population in the block is a good indicator to define streets with the potential for pedestrian movement (Cervero and Kockelman 1997, Frank, Stone Jr. et al. 2000). Consequently, this research considers the resident population density based on blocks, Hence, the residence density population was calculated as follows:

Density population = number of floors * number of units * household size

The population density ranking based on the household size considered the maximum capacity of each block. After applying these amounts by GIS, the ranking spectrum is a wide range whose ranking is different in both cities. Porto has a ranking between 2.5 to 860 habitants in the urban block and Qazvin has between 3.6 to 502.5 habitants in the urban block. Thus, this research divided the population density into four colour classes (red, orange, yellow and green). In this model, the study attempts to simplify ranking the streets by using the binary relations approach. Figure 5-11 shows the resident population density of Taleghani (Qazvin) and Santa Catarina (Porto) streets. Moreover, Table 5-2 presents more samples from both cities.

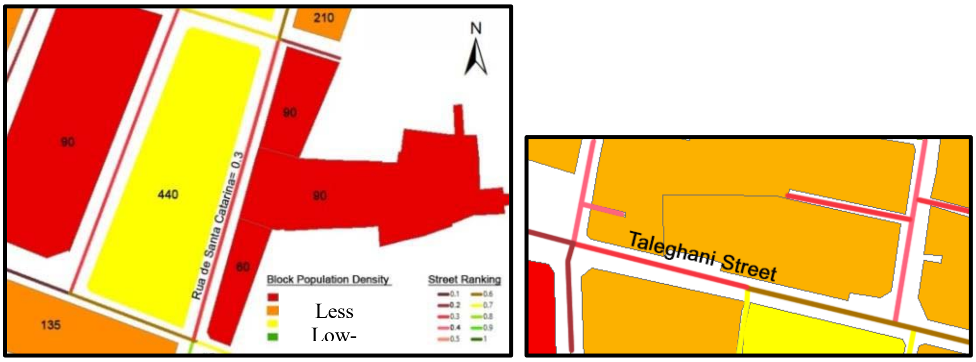



**Figure 5-11: Assessment Process for Santa Catarina (Porto) and Taleghani (Qazvin) Streets concerning the Resident Population Density**

**Table 5-2: Processing of Resident Population Density database using some examples of streets**

| Name Street | Visual Dimension | Normalization |
|---|---|---|
| **Porto: Santa Catarina Street** | Y-R | 0.3 |
| **Porto: Santa Catarina Street** | O-Y | 0.6 |
| **Qazvin: Taleghani Street** | O-Y | 0.6 |
| **Qazvin: Taleghani Street** | O-O | 0.4 |

Figure 5-12 shows that the density population of Qazvin is higher than Porto. People stay in the historical urban tissue of Qazvin, while in Porto people prefer to leave this area.

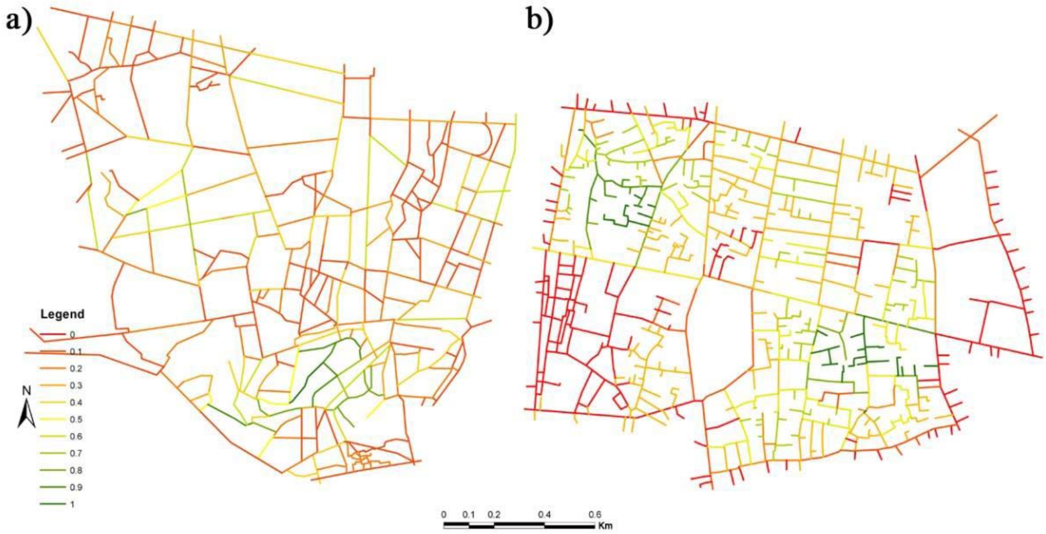



**Figure 5-12: Population Density in Porto (a) and Qazvin (b)**

### 5.2.6 Public Transportation Services

In the third chapter, it can be observed that some researchers classified the city districts based on the existence of infrastructures for pedestrians and mobility services with easy access. This classification includes different types of transit for pedestrians. This is based on trip purposes in which individuals might be willing to walk between 400 meters (quarter mile) and 800 meters. These distances are considered as standard in transit planning

The result suggests trip purposes that individuals might be willing to walk are considerably further than the 400-meter (quarter mile) and 800-meter thresholds considered standard in transit planning (El-Geneidy, Grimsrud et al. 2014). Therefore, this research considers a larger buffer with a radius of 800 meters based on metro stations. In Porto, the whole area is covered by the buffer zones of the metro stations. The radius of 800 meters covered all the streets in Porto. In the classification, the streets were not ranked and obtained the same value in Porto.

As there is no metro service in Qazvin, this measurement is not used for the PNA model in terms of the public transportation service. Hence, the streets are classified based on the location of different types of services, such as taxi ranks, the bus line and metro stations. Some examples from both cities are shown in Table 5-3.

Table 5-3: Public Transportation Service database processing using some examples of streets

| Name Street | Public transportation services | Value Rating | Normalization |
|---|---|---|---|
| Porto: Boavista Street | Bus stop and Taxi stations | Class 2 | 0.66 |
| Porto: Aliados Avenue | Metro station, Bus stop and Taxi stations | Class 1 | 1 |
| Porto: Cais da Estiva Street | None | Class 4 | 0 |
| Qazvin: Azadi Square | Bus stop and Taxi stations | Class 2 | 0.2 |
| Qazvin: Taleghani Street | Bus stop and Taxi stations | Class 2 | 0.6 |
| Qazvin: Obeyd Zakani Street | None | Class 4 | 0.4 |

Figure 5-13 illustrates how public transportation services have developed throughout Porto including the metro, buses and taxis, whereas Qazvin has buses and taxis in the main streets. Moreover, according to the above standard, Porto has better conditions in terms of public transportation services.

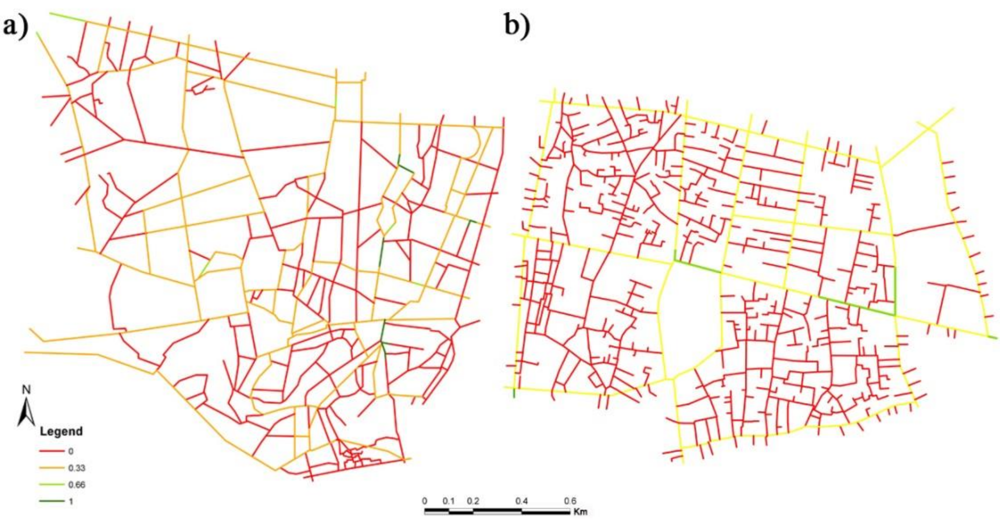



**Figure 5-13: Public Transportation Services in Porto (a) and Qazvin (b)**

### 5.2.7 Intelligent Transportation Systems (ITS)

This sub-criterion analyses the hotspots installed in the urban spaces. The Wi-Fi network has a wide coverage of the public space and it is easy for pedestrians to access information. In Porto, connecting to a free Wi-Fi signal is as simple as hopping on a bus or hailing a taxi. The city recently launched a Wi-Fi program that serves 70,000 people a month by offering free internet connections in more than 600 buses and taxis. Moreover, the most important public urban space in Porto has free Wi-Fi access. Therefore, this research considers bus lines, taxi ranks and also some locations. The classification of the ITS sub-criteria is shown by some examples in Table 5-4. However, there is no wireless service in Qazvin, which is shown in Figure 5-14. This is problematic for pedestrians in terms of access to city information.

| Name of Street | Location of access to Wireless (Band GHz >5.8) | Quality Classification | Normalization |
|---|---|---|---|
| Porto: Boavista Street | Line Bus | Medium | 0.5 |
| Porto: Aliados Avenue | Hotspot (Wi-Fi) & Line Buse | High | 1 |
| Porto: Santa Catarina Street | None | Low | 0 |
| Qazvin: Azadi Square | None | Low | 0 |
| Qazvin: Taleghani Street | None | Low | 0 |
| Qazvin: Obeyd Zakani Street | None | Low | 0 |

**Table 5-4: Intelligent Transportation Systems (ITS) database processing using some examples of streets.**

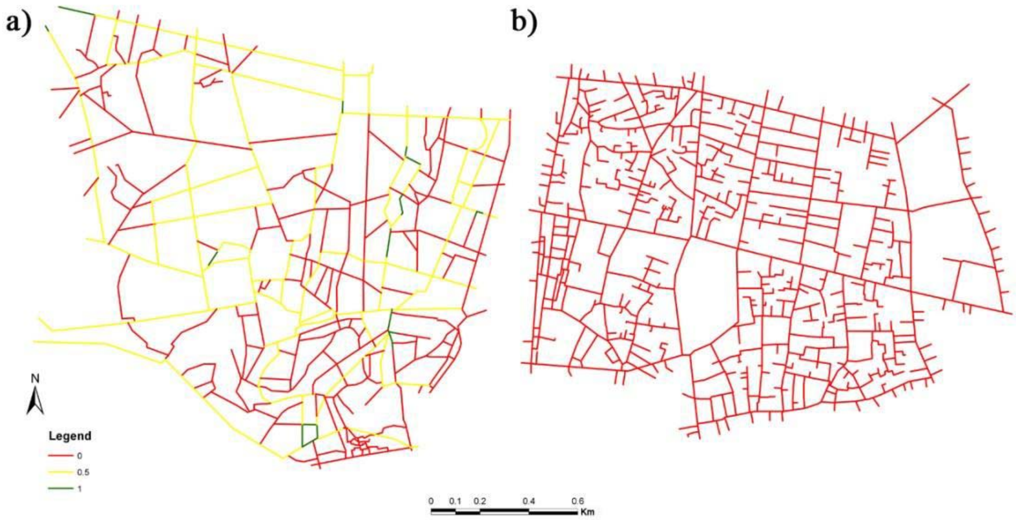



**Figure 5-14: Intelligent Transportation Systems (ITS) in Porto (a) and Qazvin (b)**

### 5.2.8 Green Space

The first stage of the green space sub-criterion measures the buffer of the Urban Park (radius of 400 meters) for both cities by GIS. Then, the blocks inside this buffer are detected. For example, this research defined the buffer of the urban parks for Porto Cristal Park and Qazvin Melat Park. The second stage, based on these data, classifies streets according to Table 3-13 and Figure 5-15 shows the green spaces in some examples of both cities.

Porto: Dom Manuel II Street
Green space types: Urban park
Normalization: 1

Porto: Santa Catarina Street
Green space types: None
Normalization: 0.05

Porto: Sá da Bandeira Street
Green space types: Green Corridor
Normalization: 0.75

Qazvin: Azadi Square
Green space types: Urban park
Normalization: 1

Qazvin: Shahdari Street
Green space types: Green Corridor
Normalization: 0.75

**Figure 5-15: Green Space database processing using some examples of streets**

Figure 5-16 shows the green space developed in Qazvin. These areas are located in the central part, such as the urban park and there is also a large area, which allows pedestrian access to green spaces. For this reason, the green spaces in Qazvin are better than in Porto. However, the green spaces from both cities are around 20 percent of the total area. These green spaces are not sufficient for the urban space to attract

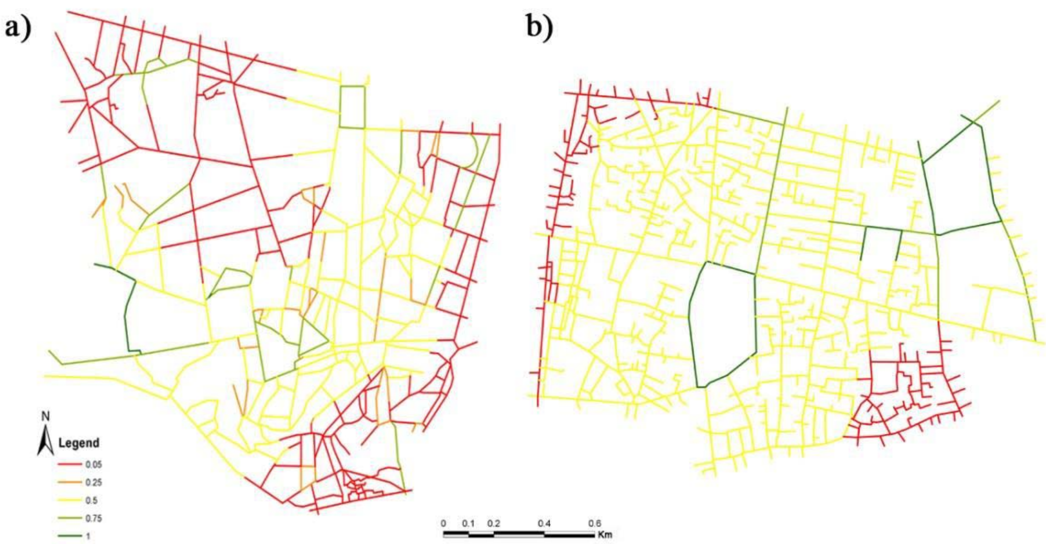



**Figure 5-16: Green Space in Porto (a) and Qazvin (b)**

### 5.2.9 Microclimatic conditions

The third chapter considers three types of material (dark gravel, asphalt and tiles). Each side of the street has different roof-covering materials, which are related to the block. This research assesses the streets. In order to classify the streets, the research uses a mechanism that characterizes the blocks (areas are on both sides of the street) and then transfers to the street (one line). This is possible using binary relations approach data. Table 5-5 shows the database process of the microclimatic conditions (temperature) using some examples of both cities.

**Table 5-5: Samples of processing database to Microclimatic conditions (temperature)**

| Name of Street | Roof-covering material classification on both sides of the street | Classification | Normalization |
|---|---|---|---|
| Porto: Jorge de Viterbo Ferreira Street | Tile - Gravel | Good | 0.75 |
| Porto: Aliados Avenue | Tile - Asphalt | Reasonable | 0.5 |
| Porto: Santa Catarina Street | Tile - Tile | Very Good | 1 |
| Qazvin: Azadi Square | Tile - Tile | Very Good | 1 |
| Qazvin: Taleghani Street | Gravel - Gravel | Bad | 0.25 |
| Qazvin: Obeyd Zakani Street | Tile - Gravel | Good | 0.75 |

Old towns are good examples of bioclimatic architecture according to the morphology (Rosso, Pisello et al. 2016). This is why Porto is using tiles on roofs, as it is a local material. It influences urban space due to the temperature of the district declining and, will consequently improve livability in the outdoor environment. (Ragheb, El-Darwish et al. 2016). Urban planning in Qazvin does not consider local architecture. However, it is mandatory to use local material in historic buildings in order to protect them (Sarvarzadeh and Abidin 2012). Figure 5-17 shows that concerning microclimatic conditions, Porto is better than Qazvin.

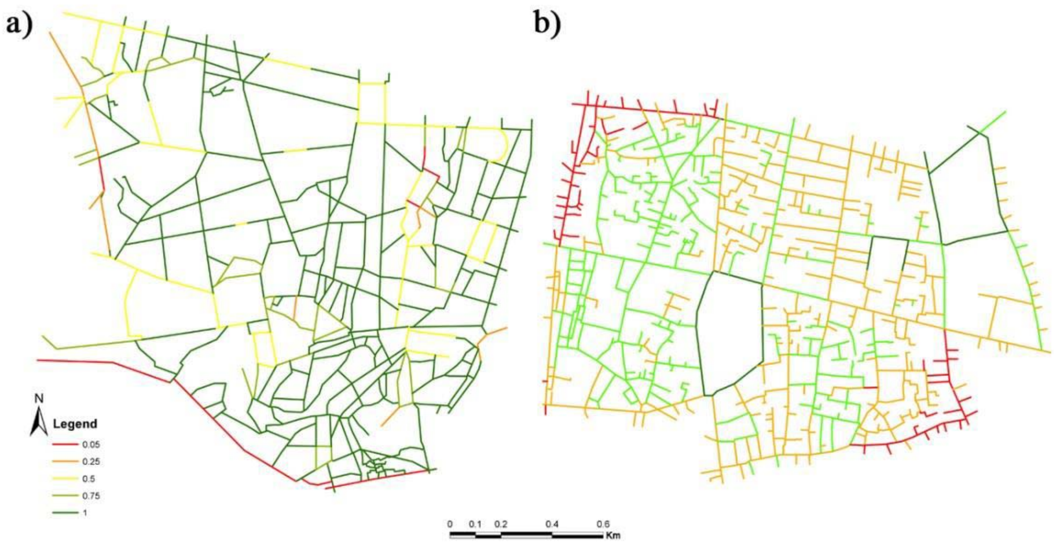



**Figure 5-17: Microclimatic conditions in Porto (a) and Qazvin (b)**

## 5.3 Weights Assignment and Aggregation Method

According to the methodology chapter, the first step identified the walkability level features of the streets in the city centres of Porto and Qazvin . The factors or criteria selected in this study were based on the literature review, as well as the opinions of a group of experts. The survey was conducted with 41 experts from Porto and 45 experts from Qazvin in July and September 2015, respectively. The first part consisted of selecting the criteria and sub-criteria with more impact on walking. The survey contained a list of sub-criteria and criteria to be selected by the experts according to their perception. The survey also allowed for the inclusion of sub-criteria not included in the given list. Nonetheless, experts largely confirmed the options given in the list as only very few comments and new sub-criteria were added. For instance, only few experts suggested including safety in the study demonstrating that this factor is not critical in Porto and Qazvin. In the second part, experts were invited to assign weights (prioritization) reflecting the importance the selected criteria have on walking. Based on this research, the following four criteria and respective nine sub-criteria were included in the study.

The results of the classification given by respondents to each sub-criterion and criterion are presented in Tables 5-6 & 5-7 concerning Porto. To assign the relative importance of the sub-criteria and criteria, two combinations were implemented. Where wj is the sub-criterion weight j and wk is the criterion weight k that was obtained by the pairwise comparison matrix method. The sum of all weights obtained using this method is equal to one.

**Table 5-6: Weights assigned to the sub-criteria using pairwise comparison matrix**

| Criteria | Pairwise of Sub-Criteria | Experts evaluation | Sub-Criteria | Weights |
|---|---|---|---|---|
| Built Environment | Built Visual Dimension | 72.5% | Built Visual Dimension | 0.498 |
| | Human Scale | 27.5% | | |
| | Built Visual Dimension | 60.4% | Terrain Slope | 0.273 |
| | Terrain Slope | 39.6% | | |
| | Human Scale | 50.0% | Human Scale | 0.229 |
| | Terrain Slope | 50.0% | | |
| Urban Functions | Land Use | 26.4% | Land Use | 0.264 |
| | Population Density | 73.6% | Population Density | 0.736 |
| Accessibility | Public Transportation Services | 57.6% | Public Transportation Services | 0.576 |
| | Intelligent Transportation System(ITS) | 42.4% | Intelligent Transportation System(ITS) | 0.424 |
| Urban Environment | Green Spaces | 56.5% | Green Spaces | 0.565 |
| | Microclimatic Conditions | 43.5% | Microclimatic Conditions | 0.435 |

**Table 5-7 Weights assigned to the criteria using pairwise comparison matrix**

| Criteria | Partial Weights |
|---|---|
| Built Environment | 57.1% |
| Urban Functions | 42.9% |
| Urban Environment | 61.3% |
| Built Environment | 38.7% |
| Built Environment | 35.7% |
| Accessibility | 64.3% |
| Urban Functions | 44.4% |
| Accessibility | 55.6% |
| Urban Environment | 67.3% |
| Urban Functions | 32.7% |
| Accessibility | 53.7% |
| Urban Environment | 46.3% |

| Criteria | Final Weights |
|---|---|
| Built Environment | 0.1794 |
| Urban Functions | 0.1990 |
| Accessibility | 0.3102 |
| Urban Environment | 0.3114 |
| Sum | 1.000 |

This process was used for the Qazvin survey. Tables 5-8 & 5-9 show the sub-criteria and criteria of both cities. Table 5-8 shows the highest sub-criterion value related to the population density in Porto city. The result in Table 5-9 is different in Qazvin where the highest sub-criterion is Land Use. In addition, the Human-scale is the least important among the sub-criteria in Porto. The Population Density is the least value among sub-criteria in Qazvin.

As mentioned, a pairwise comparison matrix was used to assign the weights of several criteria and sub-criteria. Thus, the weight assigned to the Natural environment criterion was the most important in the criteria of Porto and Qazvin. Hence, the Natural environment with the highest weights was considered as the most important parameters for designing the model. Besides, the importance of the Natural environment as the significant parameters for the model confirms the conclusions of other pedestrian studies (Choi, Ranasinghe et al. 2016, Jayasinghe, Sano et al. 2016, Stewart, Carlos et al. 2016). Urban environment parameters include thermal comfort, shadow, natural light, etc, which can influence walking conditions (Choi, Ranasinghe et al. 2016, Stewart, Moudon et al. 2016). Thus, the weight assigned to the natural environment criterion was the most important in the criteria of Porto and Qazvin.

**Table 5-8: Weight of Criteria and Sub-criteria in Porto city**

| Criterion | Weight | Sub Criterion | Weight |
|---|---|---|---|
| **Urban Function** | 0.199 | Land Use | 0.264 |
| | | Population density | 0.736 |
| **Physical environment** | 0.179 | Visual Dimension City | 0.497 |
| | | Human scale | 0.228 |
| | | Terrain Slope | 0.273 |
| **Accessibility** | 0.310 | Public transportation services | 0.576 |
| | | Intelligent Transportation systems (ITS) | 0.424 |
| **Natural environment** | 0.312 | Green spaces | 0.565 |
| | | Microclimatic conditions | 0.435 |

**Table 5-9: Weight of Criteria and Sub-criteria in Qazvin city**

| Criterion | Weight | Sub Criterion | Weight |
|---|---|---|---|
| **Urban Function** | 0.253 | Land Use | 0.875 |
| | | Population density | 0.125 |
| **Physical Environment** | 0.235 | Visual Dimension City | 0.415 |
| | | Human scale | 0.295 |
| | | Terrain Slope | 0.290 |
| **Accessibility** | 0.224 | Public transportation services | 0.50 |
| | | Intelligent Transportation systems (ITS) | 0.50 |
| **Natural environment** | 0.288 | Green spaces | 0.667 |
| | | Microclimatic conditions | 0.333 |

After analysing the sub-criteria and according to the WLC method, the next steps merge each sub-criterion to obtain the main criteria. Afterwards, this research shows the results from the criteria in Figure 5-18 and Figure 5-19. The green paths correspond to the streets with the highest scores while the red ones are those that ranked the worst.

In an individual analysis of Porto, the natural environment is the criterion with the most favourable situation. It is the only criterion where 50% of the streets and footpaths scored more than 0.50. The streets connect in some spatial continuities, starting from the Douro river, crossing the city centre and ending at the peripheries of the delimited.area. The scores reflect the green spaces widespread around the city and the trees and shrubs planted in the streets and sidewalks, as well as the favourable microclimatic conditions for walking provided by the city. The physical environment scores identically but lower with 47% of the streets ranking greater than 0.50. Particularly in the historical part near the river, there are many streets which scored poorly due to the slope, derelict buildings and narrow streets. The urban function performs much more poorly, as only six streets had the highest scores in the ranking. Globally, only 12% of the streets analysd scored above 0.50 in this criterion, reflecting a reduced diversity of Land Use and population density. However, the criterion that performs worst is accessibility, with only 5% of the streets scoring above 0.50. This is mostly due to the absence of intelligent information systems related with public transportation in the streets and distribution (and distance) of bus lines in the city.

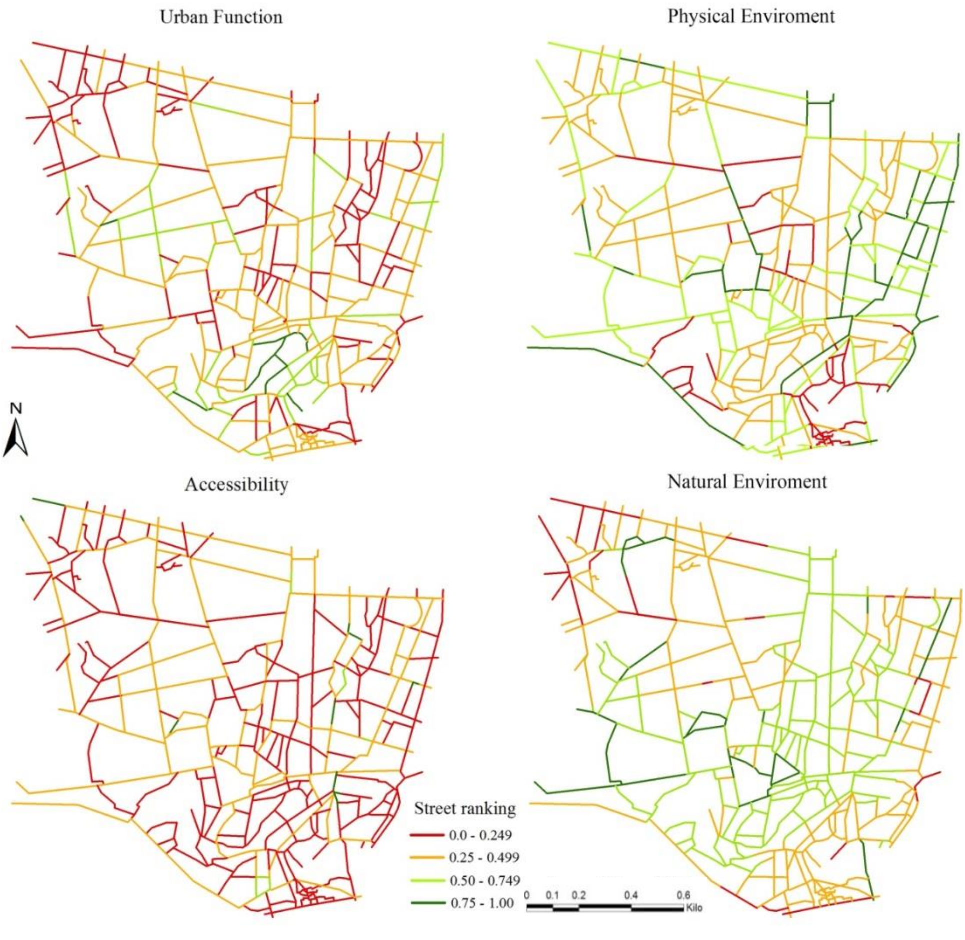



**Figure 5 18: Criteria result in Porto**

In the other analysis of Qazvin, the physical environment is the criterion with the most favourable situation. It is the only criterion where 50% of streets and others scored more than 0.50. The streets connected in some spatial continuities from the Melat park, crossing the city centre and ending at the traditional market (Bazaar). The scores of the physical environment reflect the visual dimension and human scale sub-criteria. Qazvin has beautiful spaces, nice building facades and clear landmarks on the pavements. In addition, it has favourable slopes for walking.

Accessibility has the lowest score and all the streets ranked lower than 0.50. Particularly in the historical part, there are many streets which scored poorly due to the public transportation service, derelict buildings and narrow streets. Moreover, this is mostly due to the absence of intelligent information systems related to public transportation in the streets. Urban function performed poorly as only 20 streets ranked in the highest class. Globally, only 40% of the streets analysed scored above 0.50 in this criterion, reflecting a reduced diversity of Land Use and population density. However, the criterion that performs badly is the urban environment, with only 45% of the streets scoring above 0.50 that reflect poor microclimatic conditions and green spaces.

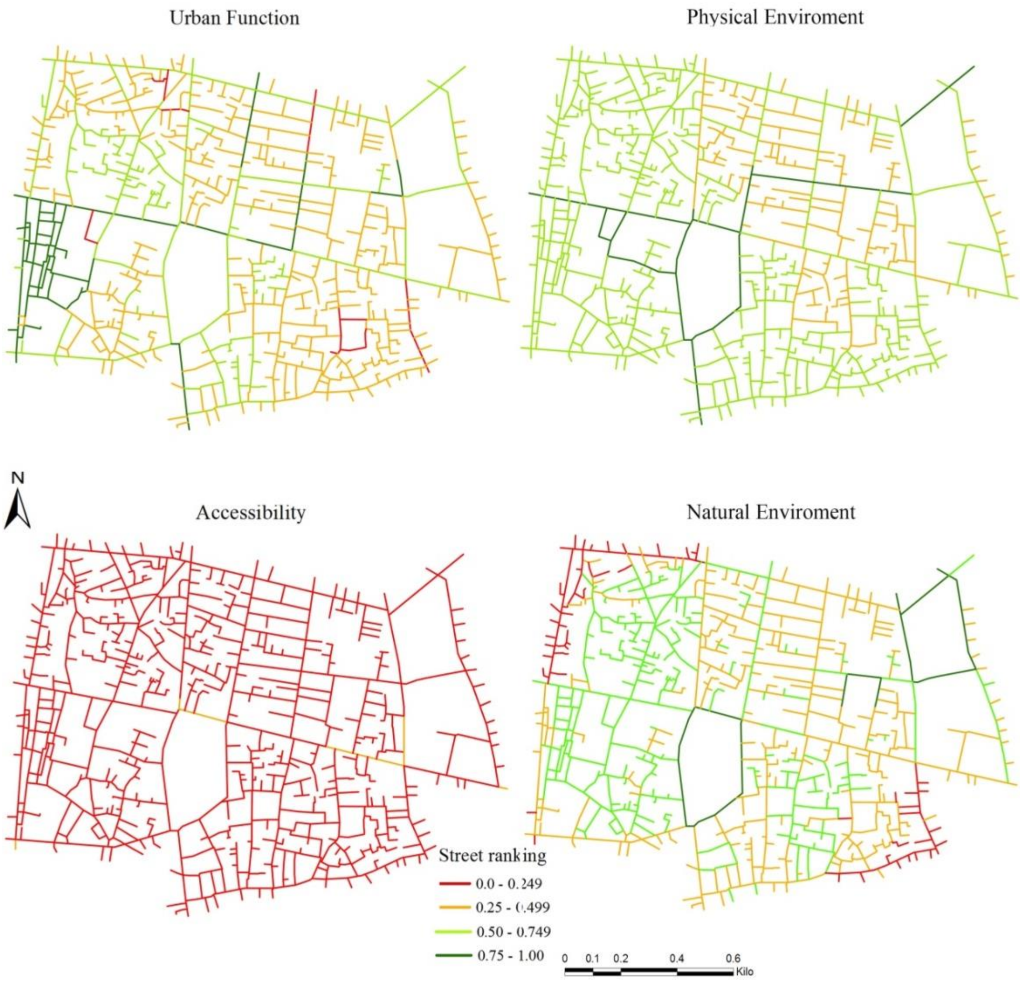



**Figure 5-18: Criteria result in Qazvin**

In this stage, the research combines the four criteria and the result is obtained by overlaying the four layers and using the weights from Tables 5-8 & 5-9. The MCA evaluation was implemented in GIS. Figure 5-20 presented the results of the MCA and the average data of Porto and Qazvin cities are 0.387 and 0.393. Two main conclusions can be obtained by analysing the results. The highest value of Porto and Qazvin are respectively 0.71 and 0.75.These values are almost the same in both cities. The distribution of streets which have lengths more than the average of the total streets are 52.2 percent for Porto and 56.4 percent for Qazvin. These streets provide suitable walking conditions according to pedestrian needs shown in Figure 5-20.

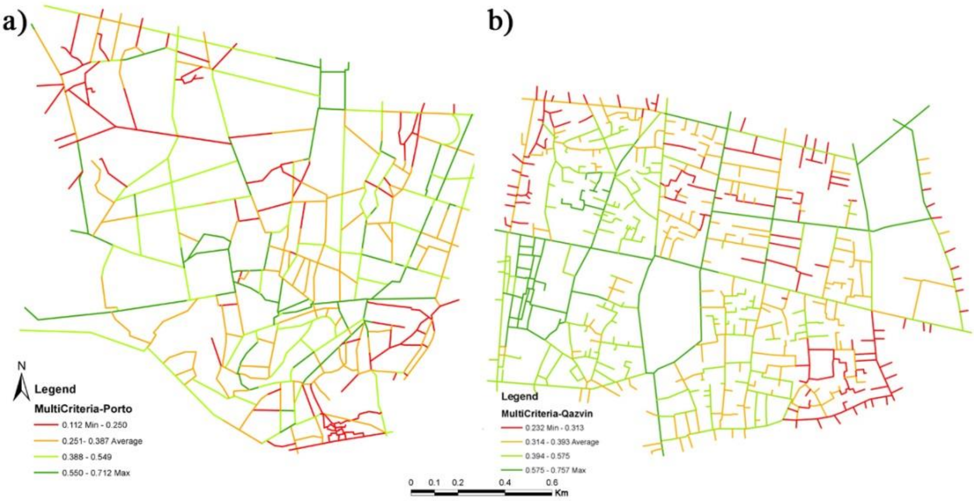



**Figure 5-19: Streets ranking considering the Multi-criteria (a) Porto; (b) Qazvin**

## 5.4 Connectivity Evaluation (Space Syntax)

As described in the methodology chapter, the street network connectivity analysis was also integrated into this model. The analysis performed with space syntax shows the street connectivity ranging between 1 to 14 (Table 5-10) in Porto and in Qazvin between 1 to 21. Higher space syntax values correspond to streets with many connections (nodes) and vice-versa. These values were then normalized between 0.0 and 1.0 by a fuzzy set theory and inserted in the GIS database. A WLC was calculated again to obtain the final scores by using a weight of 0.5 for the MCA and 0.5 for street network connectivity, as suggested by the experts. The result is an assessment of the pedestrian network, showing the most suitable streets for walking, reflecting not only the conditions provided to pedestrians, but also their connectivity.

**Table 5-10: Normalization for the Streets network connectivity in Porto & Qazvin cities**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | **Porto** | | | | |
| **Street connectivity** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| **Normalization in GIS** | 0 | 0.07 | 0.15 | 0.23 | 0.30 | 0.38 | 0.46 | 0.53 |
| **Street connectivity** | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| **Normalization in GIS** | 0.61 | 0.69 | 0.77 | 0.84 | 0.92 | 1.00 | | |
| | | | | Qazvin | | | | |
| **Street connectivity** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| **Normalization in GIS** | 0 | 0.05 | 0.10 | 0.15 | 0.20 | 0.25 | 0.30 | 0.35 |
| **Street connectivity** | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| **Normalization in GIS** | 0.40 | 0.45 | 0.50 | 0.55 | 0.60 | 0.65 | 0.70 | 0.75 |
| **Street connectivity** | 17 | 18 | 19 | 20 | 21 | | | |
| **Normalization in GIS** | 0.80 | 0.85 | 0.90 | 0.95 | 1.00 | | | |

Therefore, the street network connectivity analysis was applied by using the space syntax and the results for both cities are presented in Figure 5-21. The streets of Porto with higher levels of connectivity are in the central area, especially in Bolhão and Avenida dos Aliados and the distribution of streets which have lengths more than the average of the total streets is 39.2 percent. The lowest level of connectivity is in the west, which includes Boavista street. The distribution of Qazvin streets which have lengths more than the average of the total number of streets is 41.4 percent. The higher level of connectivity includes the main streets that are Nadri, the Ferdowsi, Bazar and Bu Ali Sina streets. They are surrounded by the old neighbourhoods. This pattern of linkage is based on a hierarchy pattern, which is very well-known in the historical urban tissue of Iranian cities. In addition, it is a solution to connect the bazaar to the neighborhood centre (Tavassoli, 2016, Velashania, 2015). In Qazvin, the streets with the lower levels of connectivity are in the southern area of the city. This pattern can be affected by new urban tissue. Some researchers noticed the lack of connectivity among these urban tissues (Falahat 2014, Jabbari and Ramos 2015, Kiani and Amiriparyan 2016).

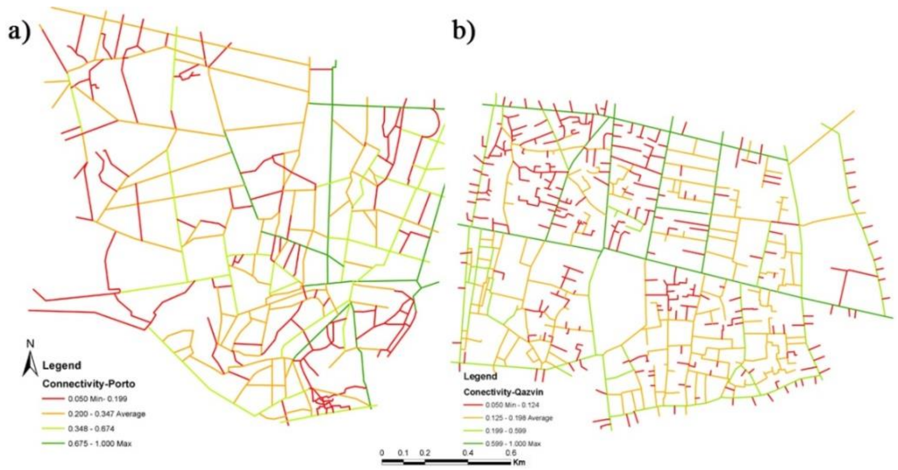



**Figure 5-20: Streets ranking based on the streets network connectivity (a) Porto; (b) Qazvin**

## 5.5 Assessment of Pedestrian Network (PNA)

The last stage of the PNA model was obtained by combining the MCA with the street network connectivity. The results are presented in Figure 5-22. The comparison with Figure 5-21 shows that the inclusion of the connectivity increased the ranking obtained by streets. In Figure 5-22, the highest value was increased from 0.71 to 0.771 in Porto, while in Qazvin, the highest value actually increased from 0.75 to 0.79. In terms of data distribution, the number of streets with a length above average reduces from 52.2 to 49.1 in Porto and increases from 56.4 to 56.5 in Qazvin. This comparison shows the importance of the street network connectivity analysis in the PNA model and evaluates the function of each one from the streets in the network. For instance, Almada Street in Porto obtained the highest score in the street network connectivity analysis, while the score in MCA is the second level. This means the street has good connectivity that urban planning has to consider to provide good conditions for pedestrians. This example shows the importance of the street network connectivity analysis in order to obtain the final result of the PNA model.

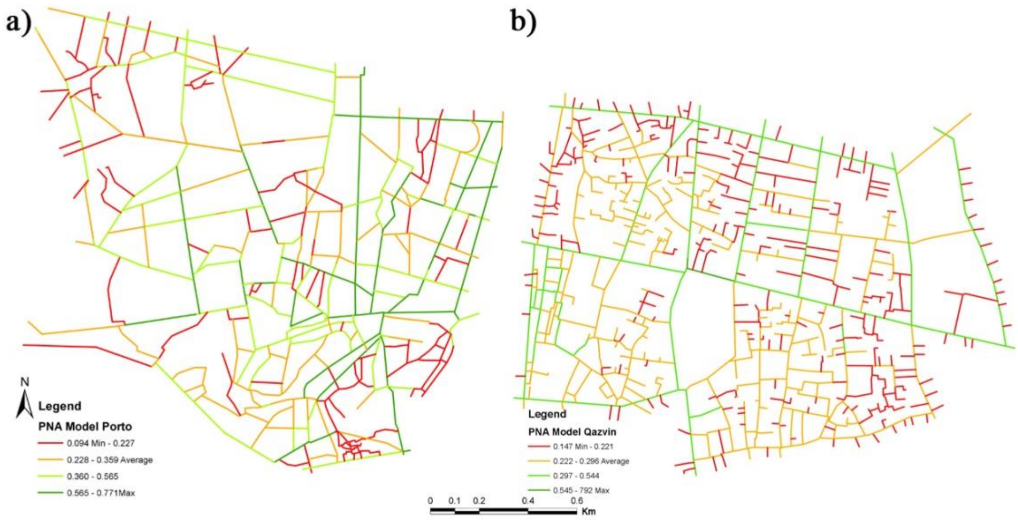



**Figure 5-21: The PNA model (a) Porto; (b) Qazvin**

## 5.6 ASAMeD approach Results

According to Figure 3-1, the last step presented the results related to the ASAMED approach in Porto and Qazvin to evaluate the PNA model. The ASAMeD considers urban morphology and has two measures: “closeness” and “betweenness”. They are related to the pedestrian movement in urban space. According to Hillier and

Iida (2005), Closeness (Integration) is $C_c (P_i) = (\sum_k d_{ik})^{-1}$, where $d_{ik}$ refers to the length of a geodesic (shortest path) between node $P_i$ and $P_k$. This equation reflects how close each segment is to all others under different types of distances. Betweenness (Choice) is $C_B (P_i) = \sum_j \sum_k P_{jk} g_{jk} (p_i) = g_{jk}(j < k)$, where $g_{jk}(p_i)$ is the number of geodesics between node $p_j$ and $p_k$ which contain node pi and $g_{jk}$ the number of all geodesics between $p_j$ and $p_k$. This equation reflects how much movement is likely to pass through each segment on trips between all other segments.

This research evaluated the performance of the PNA model in different case studies. Porto was formed around the city centre (mono-centric structure) and Qazvin's neighbourhood created minor centers as the centre (poly-centric structure). This different urban structure influenced the number of streets whose length is less than 200 m. Figure 5-23 shows these street numbers, in Qazvin equal to 94 percent, while in Porto it is 80 percent. Moreover, this research provides the same platform by using the street length average in two cities to obtain the exact assessment described in the sixth chapter.

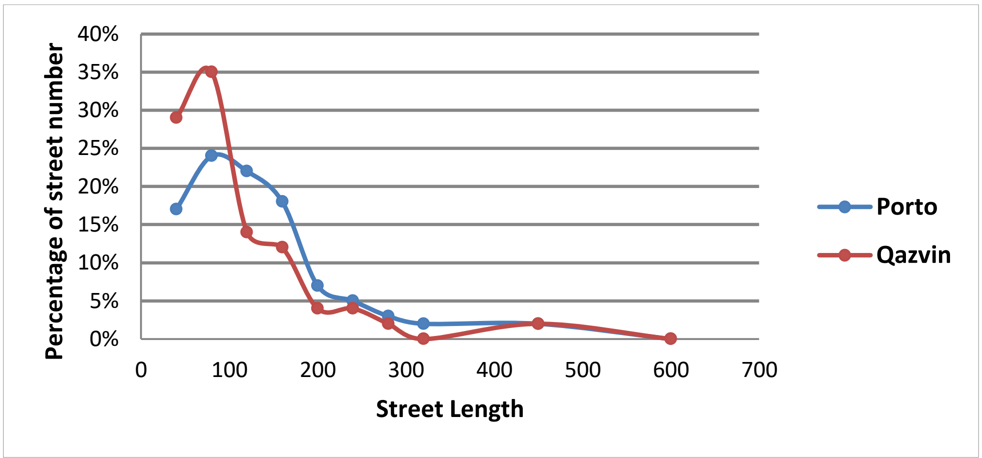



**Figure 5-22: Percentage of streets based on length (Porto & Qazvin)**

In ASAMeD, changes in direction from the starting segment to any other segment within the system are recorded ranging from 0 (no change) to 2 (180º turn) according to the angle centre being in the intersection from one segment to another. By applying this rule, the analysis performed shows the ranked streets changing from 8 to 140.9 in Porto and changing from 6.4 to 127.4 in Qazvin. As the values in Porto and Qazvin vary between 0 and 141, a simplified analysis is proposed in Table 5-11 by normalizing these values between 0 and 1, for the GIS representation.

**Table 5-11 Normalization of ASAMeD both cities**

| ASAMeD | 1 - 25 | 26 - 50 | 51 -75 | 76 - 100 | 101 -125 | 126 - 150 |
|---|---|---|---|---|---|---|
| Normalization in GIS | 0.05 | 0.25 | 0.45 | 0.65 | 0.85 | 1.00 |

Figure 5-24 shows the  ASAMeD result, which evaluates the PNA model in the discussion chapter. Moreover, the result of Porto shows the highest values in the city centre and the integrated configuration can be found in the urban tissue core. It confirms the mono-centric structure in terms of urban morphology.  The street length is 35 percent of the total. In fact, this area contains the main historical elements, which is the “cultural and tourism area” (McKercher 2016). The result of Qazvin shows the highest value of the integration and choice located in the neighbourhood centres (Tavassoli 2016), which is a polycentric structure. The street length is 47 percent of the total in Qazvin and more than Porto. Moreover, this analysis is based on the different structures. Different pedestrian movement patterns are created.

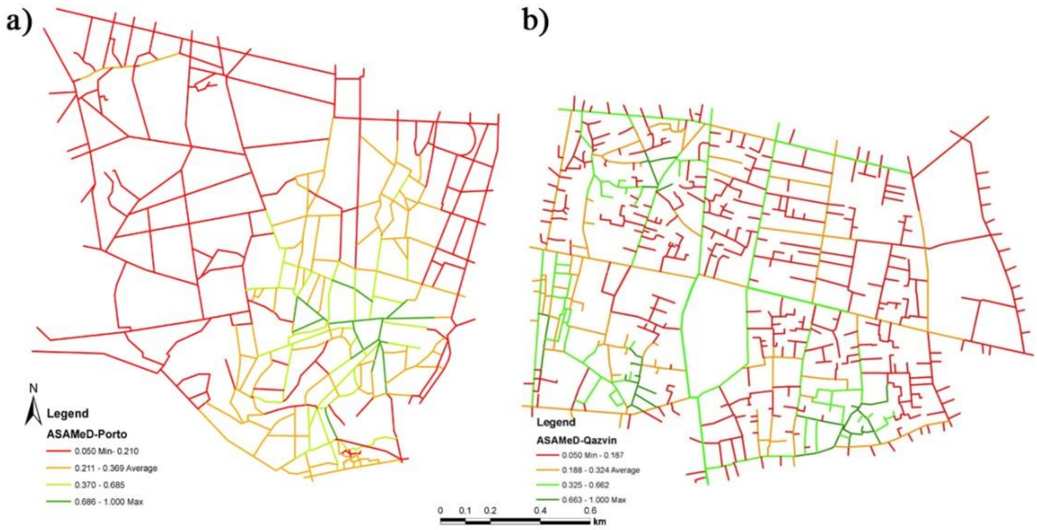



**Figure 5-23: ASAMeD approach Porto (a); Qazvin (b)**

## 5.7 Summary

This chapter presented all the stages of the PNA model and the results of the ASAMeD approach that will be used in order to evaluate the PNA model in the next chapter in both cities (Porto and Qazvin). Moreover, the study explains that the results obtained for the two cities may be related to the urban morphology, local culture, urban management and climatic condition.

# 6. Discussion

In the methodology and result chapters, this thesis presented the pedestrian network assessment (PNA) model to assess streets for walkability. The PNA model involves multi-criteria (MCA) and street connectivity analyses. On the other hand, ASAMeD was used to analyse the street structures in order to identify accessibility and walkability of urban areas. To summarise, the main goal of the discussion chapter is to evaluate the PNA model from two perspectives. The first one, through an inside outlook, analyses the model according to MCA and street network connectivity analyses, and the second one, by an outside outlook, compares the results of the PNA model with those of ASAMeD considering two different city structures, in terms of urban morphology.

## 6.1 PNA Model

The main aim of the PNA model is to obtain a cohessive pedestrian network with well- connected streets. Such a network can be obtained by identifying street hiearchy based on their walkability characteristics. Hence, after obtaining the two main components assessed for the walkability by the introduced PNA model, i.e., MCA and connectivity street analyses, the quadrant chart method was used. This method quickly finds the set of items that shares common traits or attributes by representing the data in separate quadrants (Oh and Jeong 2007, Zhou, Zhang et al. 2015).

The Four Quadrant – Matrix Model is a valuable decision making tool. The data of two variables are represented in four quadrant charts with X and Y axes. Hence, as shown in Figure 6-1, the horizontal axis represents the MCA index, whereas the vertical axis shows the street network connectivity analysis index. The axes were positioned at the respective averages of X and Y data. Thereafter, the points distributed in the quadrant charts refer to the assessed streets (for both Porto and Qazvin) that are analysed according to the average values. A brief description of the attributes used in the quadrant charts is shown below (Figure 6-1):

- First quadrant (high Multi-criteria, high Connectivity): Both the X and Y axes show the positive values of both analyses for each street (shown as points in the quadrants), illustrating the streets with the highest walkability.
- Second quadrant (low Multi-criteria, high Connectivity): the X axis is negative while the Y axis is positive. The walkability in the streets of this quadrant could be enhanced through Multi-criteria improvement.
- Third quadrant (low Multi-criteria, low Connectivity): Both the X and Y axes are negative, showing the streets with the lowest walkability characteristics.

• Fourth quadrant (high Multi-criteria, low Connectivity): the X axis is positive while the Y axis is negative. Even through the streets in this quadrant represent proper features for pedestrians, they are not properly connected.

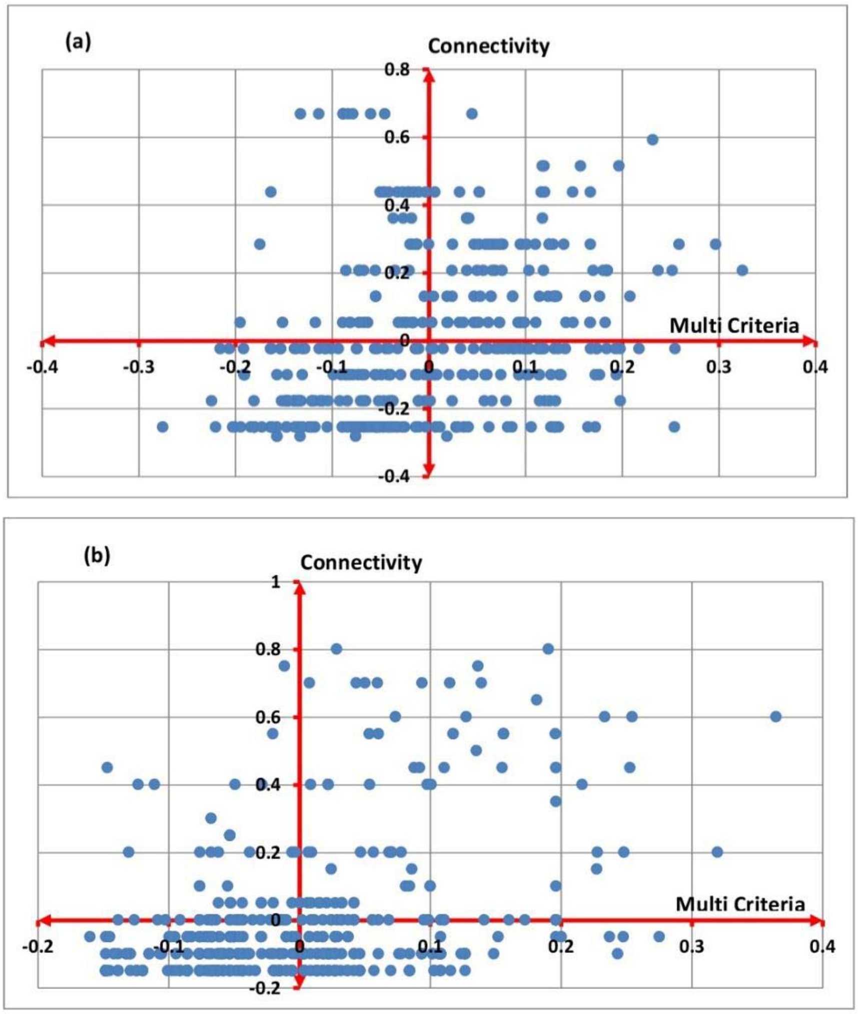



**Figure 6-1: Quadrant Chart According to data average Porto (a); Qazvin (b)**

Based on the street locations in the above mentioned quadrant charts and the outcome of the PNA model, three hierarchical levels were identified for the streets:

.The first level refers to the streets that have the highest potential to make a cohesive pedestrian network.

. The second level refers to the streets that have the potential to be improved in order to be considered for making a cohessive pedestrian network.

.The third level includes the streets that have no potentials to be considered for a cohesive pedestrian network.

In order to quantify the cohesiveness of the asssessed streets (for Porto and Qazvin) in the quadrant chart, the total lengths of the streets in each quadrant were measured, and are shown in Table 6-1. The results of the percentage of the sum of all the distributed street lengths in the first quadrant to the sum of all the streets of the quadrant chart show 41 percent for Qazvin compared to 27 percent for Porto, illustrating the streets with the highest lengths and consequently, highest walkability for Qazvin. Similarly, Figure 6-2 (b) proves that the first level streets in Qazvin are well-connected in the pedestrian network, representing a cohessive network. These results could be attributed to the  poly-centric structure of Qazvin, causing a strong network of walkable streets in Qazvin. Such a poly-centric structure is due to the traditional neighbourhoods that influence the urban structure and are explained thoroughly in the fourth chapter. As shown in Figure 6-2 (a), these streets do not make a cohesive pedestrian network, especially in the west area. The main reason could be due to the urban morphology of Porto that is a centralised structure with a core located around Aliados avenue.

**Table 6-1: Multi-criteria (X) & Streets network connectivity (Y) in Porto and Qazvin cities by quadrant chart**

| Area- Porto city | Quadrant | Street length (m) | Percent |
|---|---|---|---|
| X> 0.387 and Y> 0.330 | 1 | 12558.10 | 27% |
| X<= 0.387 and Y> 0.330 | 2 | 11137.34 | 24% |
| X<=0.387 and Y< =0.330 | 3 | 17355.02 | 37% |
| X>0.387 and Y<=0.330 | 4 | 5882.26 | 12% |
| Total length of Porto | | 46932.74 | 100% |
| **Area- Qazvin city** | **Quadrant** | **Street length (m)** | **Percent** |
| X> 0.392 and Y>0.198 | 1 | 18087.20 | 41% |
| X<=0.392 and Y>0.198 | 2 | 7019.98 | 16% |
| X<=0.392 and Y< =0.198 | 3 | 12400.02 | 28% |
| X> 0.392 and Y<=0.198 | 4 | 7042.90 | 16% |
| Total length of Qazvin | | 44544.32 | 100% |

Even though, the presented pedestrian network (shown in Figure 6-2 (a)) does not show a proper cohessive strucure for Porto, the introduced PNA model by this study has the potential to improve such a network to a cohesive one, using the second level streets of the quadrant chart. As a strategy plan for the future, the streets in the second quadrant of the quadrant chart (shown in Figure 6-3 (a)), could be improved through multi-criteria in order to make a cohesive pedestrian network. As explained in the literature, the attributes located in the second quadrant of the quadrant chart could be used for the advanced processes, by adopting strategies, in order to improve the performance of the main variables (Zhou, Zhang et al. 2015). This achievement is a proper solution for the poly-centric structure with lower network cohesion. All in all, the PNA model introduced by this work, is a comprehensive approach fulfilling the pedestrian needs, for the two types of the urban structure presented here.

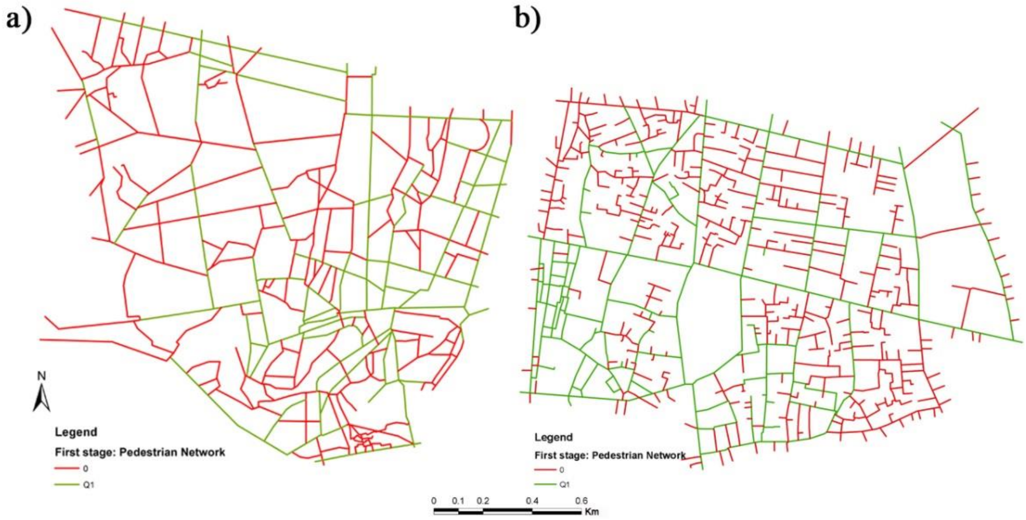



**Figure 6-2: First stage: Pedestrian Network that shows the streets in first quadrant Chart according to data average Porto (a); Qazvin (b)**

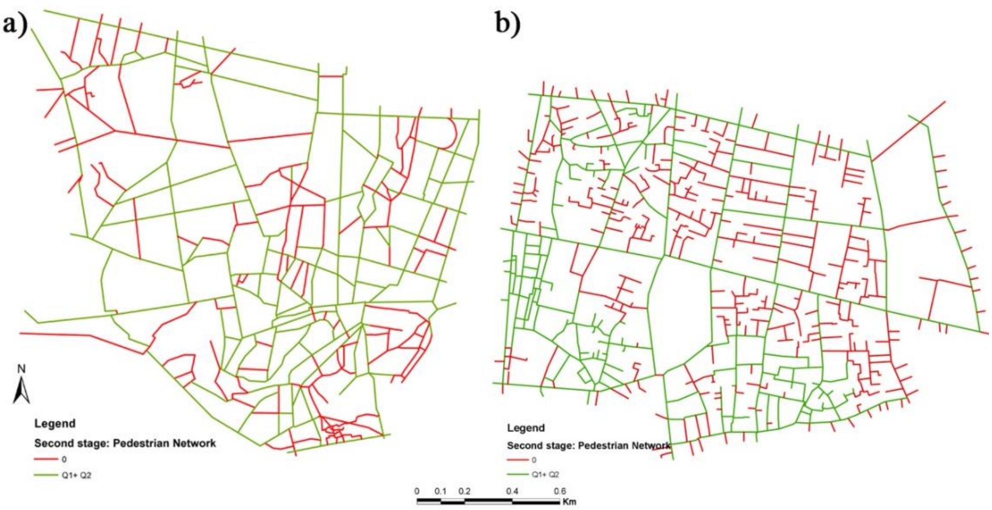



**Figure 6-3: Second stage: Pedestrian Network of Porto (a); Qazvin (b)**

## 6.2 The Pedestrian Network in Case Studies

Figures 6-4 and 6-5 show the maps of the pedestrian networks of both cities and tables with the walkability times between the points of origin and destination measured, based on the measurement made on the map. This time was measured based on the walking time by two approaches including an expert who walked through the pedestrian network and a relevant software which simulated each path related to the pedestrian network. At the beginning, google.maps was used due to its availability and user friendly interface. However, google maps do not consider terrain slope. For example, the google map showed a similar walking time between the starting and end points in 31 de Janeiro Street, in two opposite directions. However, this street has more than 10 percent slope resulting in almost 3 min difference in opposite directions.

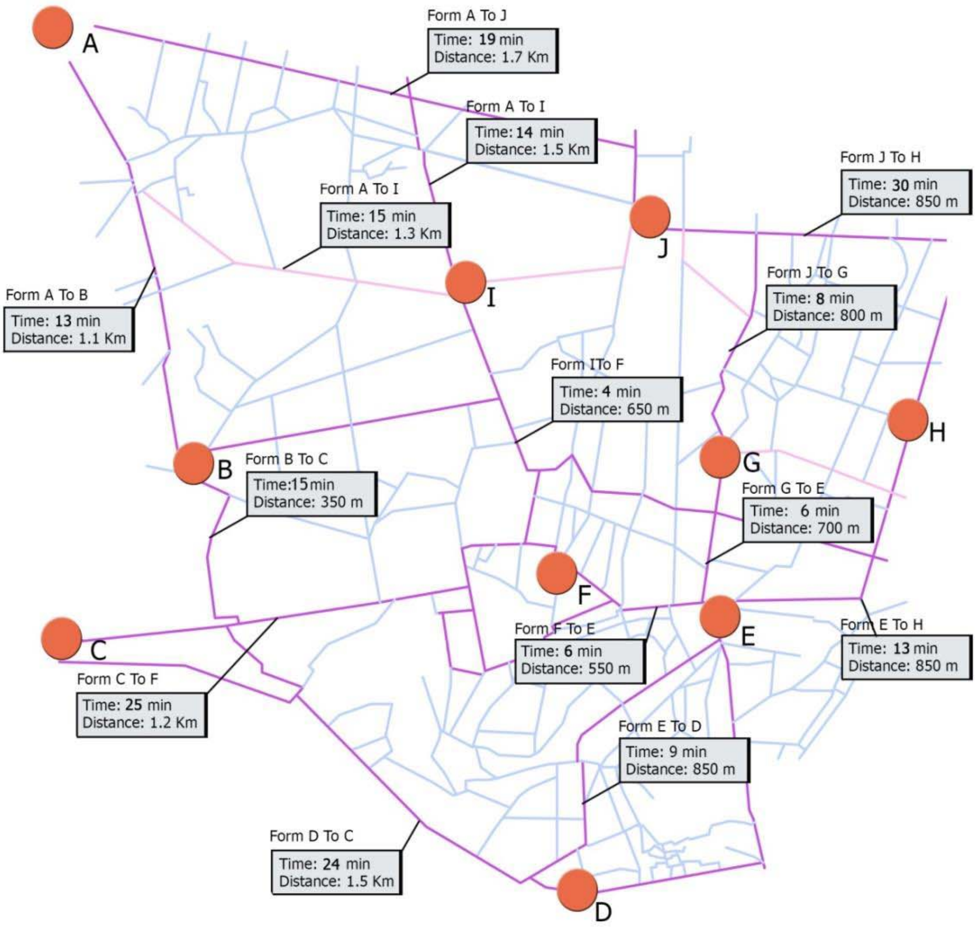
Therefore, the Plotaroute.com Software was used instead. The results of the software were validated by the expert, showing similar values, while google maps represented different results. In addition, some streets (combination of the first level and second level streets in the quadrant chart), were defined as second paths in this network, which could replace the main streets in order to provide pedestrian needs, as well as improve the walkability in two cities. The selection of these streets were based on the fact that they were easily connected to each other in order to make a more direct route to the main travel destinations point. Travel destination points are those locations that are mostly targeted by pedestrians. These points can be divided into different categories such as parks, shopping centres, historical places and so on (Table 6-2 and 6-3). Finally, this network improves access to the pedestrian network by adopting secondary routes. These pedestrian networks are compatible with the needs of pedestrians nowadays in two cities such as:

• having access to real-time information about their journeys;

• detecting main locations including parks, shopping centres, etc, as travel destinations;

• introducing second paths in order to have fast access.

The maximum times spent between travel destinations in the pedestrian network of two cities were identified as 44 minutes in one direction and 33 minutes in the opposite direction, for Porto, while a time of 25 minutes was measured for the two directions for Qazvin. All the relevant data is presented in the thesis appendix. These maps help the pedestrian to manage time and adapt their needs by effective walking. Moreover, these are essential results for urban management for a better urban integration. In fact, the final outcome of this model is a plan for the pedestrian network which is ready to be confirmed by the users and subsequently, implemented by the city management authority, in the future.




Walking time (min)

To → / From ↓

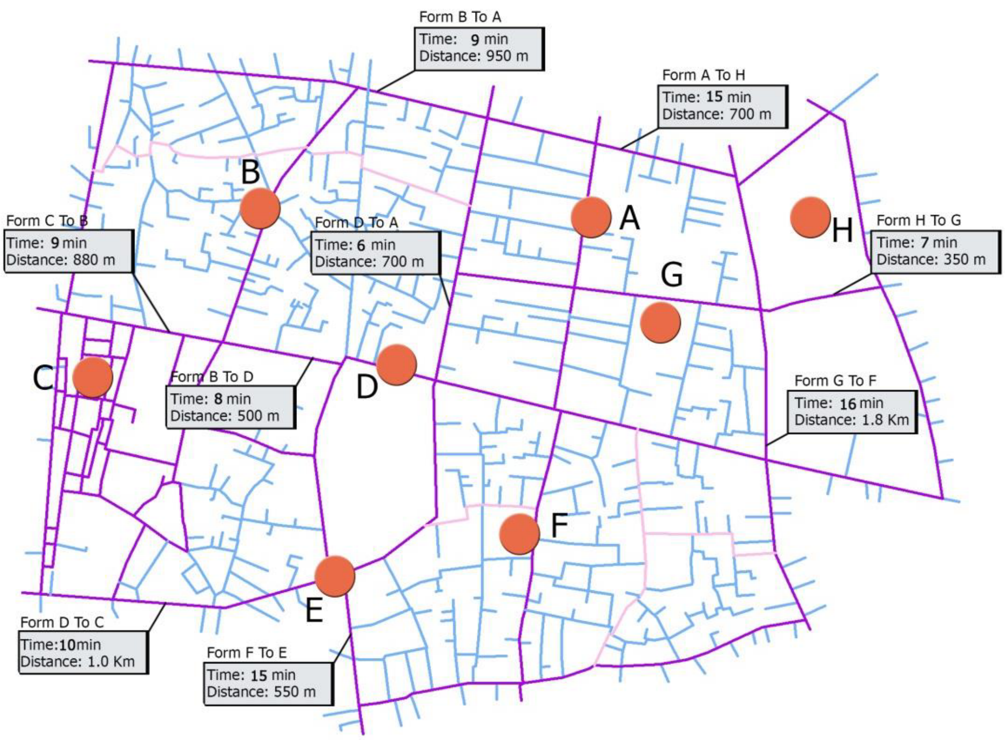
| | A | B | C | D | E | F | G | H | I | J |
|---|---|---|---|---|---|---|---|---|---|---|
| A | 0 | 13:14 | 27:21 | 30:23 | 33.07 | 25:53 | 29:47 | 34:07 | 14:41 | 19:47 |
| B | 13:58 | 0 | 15:22 | 20:38 | 20:12 | 12:00 | 23:49 | 33:14 | 13:44 | 35:26 |
| C | 33:54 | 21:12 | 0 | 24:55 | 18:34 | 25:40 | 30:13 | 38:43 | 25:13 | 43:53 |
| D | 37:42 | 27:24 | 24:32 | 0 | 15:58 | 24:11 | 21:53 | 29:58 | 30:01 | 19:47 |
| E | 35:37 | 22:41 | 12:33 | 9:29 | 0 | 9:29 | 6:32 | 12:32 | 15:20 | 32:40 |
| F | 25:49 | 11:31 | 21:23 | 14:38 | 5:39 | 0 | 13:01 | 20:02 | 4:06 | 28:46 |
| G | 30:35 | 25:10 | 24:26 | 15:09 | 5:30 | 13:16 | 0 | 6:55 | 16:12 | 10:35 |
| H | 33:28 | 31:13 | 31:02 | 19:24 | 10:16 | 19:24 | 7:15 | 0 | 16:27 | 30:13 |
| I | 14:50 | 14:39 | 17:44 | 20:31 | 11:56 | 4:06 | 16:10 | 14:26 | 0 | 13:45 |
| J | 17:00 | 31:27 | 33:20 | 36:22 | 27:07 | 25:59 | 8:35 | 30:54 | 16:22 | 0 |

**Figure 6-4: Schedule table and map of the Pedestrian Network in Porto**

Source: (Plotaroute.com,2015& Author)

**Table 6-2: Travel destination in Porto**

| | Name | Capability location | Picture | | Name | Capability location | Picture |
|---|---|---|---|---|---|---|---|
| A | Casa da Música Square | Park & Historical Place |  | F | Cidade de Lisboa Plaza | Historical Place, shopping and bar |  |
| B | Cristal Park | Garden |  | G | Aliados Avenue | Historical Place, center city |  |
| C | Restauração Street | River |  | H | Santa Catarina Street | Pedestrian way & shopping |  |
| D | Ribeira Plaza | River, Historical Place & Restaurant |  | I | Cedofeita Street | Pedestrian way & shopping |  |
| E | São Bento Station | Historical Place & train and metro station |  | J | República Plaza | Park & Historical Place |  |




Walking time (min)

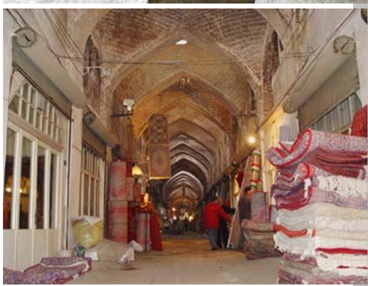
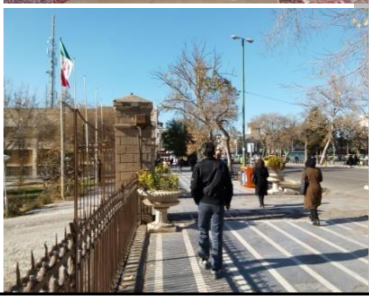
To ➡ / From ⬇

| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| A | 0 | 10:00 | 15:01 | 6:00 | 10:42 | 13:18 | 6:56 | 14:51 |
| B | 9:29 | 0 | 9:11 | 8:18 | 12:29 | 17:25 | 17:44 | 15:00 |
| C | 14:31 | 8:45 | 0 | 8:59 | 13:43 | 18:29 | 18:20 | 25:12 |
| D | 5:41 | 8:41 | 9:52 | 0 | 6:46 | 9:16 | 9:09 | 16:25 |
| E | 11:35 | 12:52 | 14:16 | 7:01 | 0 | 15:02 | 14:43 | 21:23 |
| F | 14:02 | 17:01 | 19:18 | 9:42 | 15:14 | 0 | 16:43 | 24:34 |
| G | 7:29 | 17:43 | 18:58 | 9:17 | 14:39 | 16:33 | 0 | 7:52 |
| H | 14:28 | 15:04 | 25:16 | 17:05 | 20:54 | 23:25 | 7:04 | 0 |

**Figure 6-5: Schedule table and map of the Pedestrian Network in Qazvin**

Source: (Plotaroute.com,2015& Author)

**Table 6-3: Travel destination in Qazvin**

| | Name | Capability location | Picture | | Name | Capability location | Picture |
|---|---|---|---|---|---|---|---|
| A | Khayyam Street | Shopping Street |  | E | Sardar Alighapoo | Historical Place & Garden |  |
| B | Obeyd Zakani Street | Shopping Street & Historical Place |  | F | Ameneh khaton | Historical Place |  |
| C | Market (Bazar) | Traditional Market & Historical Place |  | G | Mashahir Park | Historical place & Garden |  |
| D | Azadi Square | Historical Place & Garden |  | H | Hokm Abad Park | Park |  |

## 6.3 ASAMeD Approach & PNA Model

"Urban integrationis'' a term used for the relationship between the Land Uses and the strategic role of a node within the whole network (Carpio-Pinedo, Martínez-Conde et al. 2014). "Urban integration" takes into account the hierarchy of the network of streets and public space (Hillier and Hanson 1984, Hillier and Vaughan 2007) and investigates relationships between spatial layout and a range of social, economic and environmental phenomena through a configurational analysis of the urban street network. This research studies the urban integration using the ASAMeD to evaluate the network, which identifies the pedestrians´ movement patterns. Thus, the hierarchy of streets identified by ASAMeD can be compared with that obtained by the PNA model.

The ASAMeD assessment of Porto shows the highest values of the integration in the city centre, illustrating the strong role of monocentric structure in the city configuration (Oliveira and Pinho 2010, Jabbari and Ramos 2015). In fact, this area is in accordance with the main historical elements in the area called the "cultural-tourism area" (McKercher 2016). While the ASAMeD assessment of Qazvin shows the highest value of the integration located in the neighbourhood centre (Tavassoli 2016) which is a poly-centric structure. This approach explains that the two cities, as the case studies of this research, have different structures that influence the distributions of pedestrian movement in urban space.

The ASAMeD approach evaluates the PNA model, by the Quadrant chart, in order to compare data distribution in terms of urban morphology, shown in Figure 6-6, 6-7 and Table 6-2. The assessment adopted the quadrant chart method that used scatterplot as a tool to decompose the global spatial autocorrelation statistics into four types of association. These four types correspond to the four quadrants in the scatterplot. This scatter-plot is a way of representing the numerical difference obtained from this study and compares the result obtained by PNA and ASAMeD. The PNA and ASAMeD with the quadrant chart can greatly help us to understand the location of the pedestrian network in urban space and find patterns of pedestrian movement according to the urban morphology. (Oh & Jeong, 2007; Zhou, Zhang, & Shen, 2015).

Hence, the PNA model index is the horizontal axis and ASAMeD approach index is the vertical axis, considering the structures for the two cities. The axes have been positioned at their respective averages of X and Y data. The points distributed in the quadrant chart refer to the assessed streets (for both Porto and Qazvin) that are analysed according to the average values. A brief description is given below of the attributes used in the quadrant charts (Figure 6-6):

•The first quadrant (high PNA model, high ASAMeD approach): Both X and Y axes show the positive values of both analysis for each street (shown as points in the quadrants), confirming the streets with the highest walkability, with both methods.

•The second quadrant (low PNA model, high ASAMeD approach): the X axis is negative while the Y axis is positive. The streets of this quadrant were confirmed to have the highest potential for walking by ASAMeD, while these streets are not confirmed by the PNA model.

•The third quadrant (low PNA model, low ASAMeD approach): Both the X and Y axes are negative, showing the streets with the lowest walkability potentials that were confirmed by both methods.

• The fourth quadrant (high PNA model, low ASAMeD approach): the X axis is positive while the Y axis is negative. The streets in this quadrant represent proper features for pedestrians, however, they do not follow the urban integration concepts.

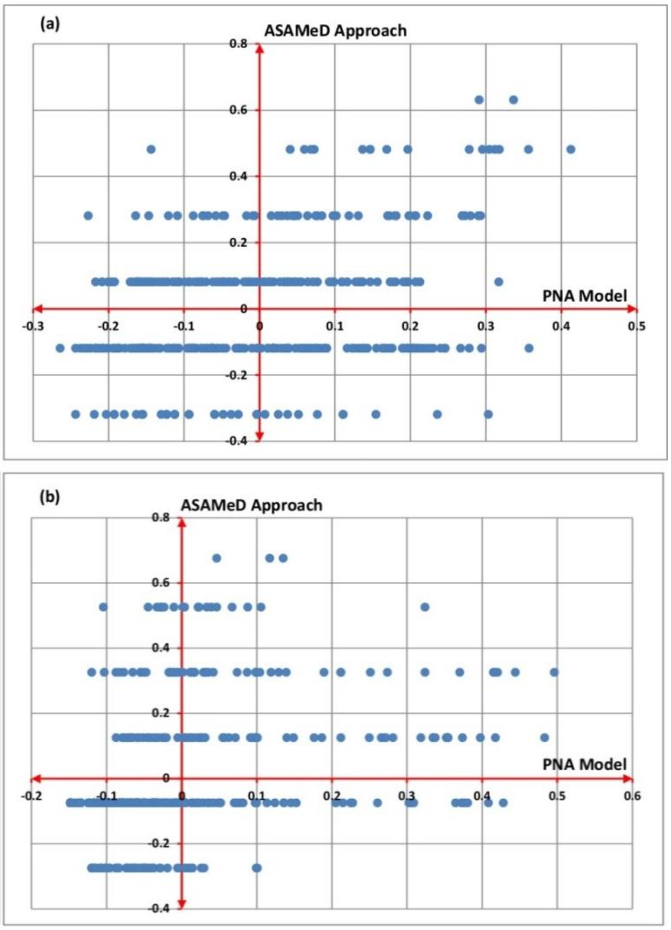



**Figure 6-6: Quadrant Chart according to data average Porto (a); Qazvin (b)**

These comparisons explain that the PNA model is relevant for the main structure of the two cities in terms of urban structure. In addition, Table 6-4 represent the percentage of the sum of all the distributed street lengths in the first quadrant to the sum of all the streets of the quadrant chart, which show 37 percent for Qazvin compared to 23 percent for Porto. This means the poly-centric structure (Qazvin) is more effectual than the monocentric structure (Porto) for the pedestrian movement. This structure expanded throughout the area and distributes the urban functions through several neighbourhood centres. Moreover, as it has already been mentioned in previous discussions, the poly-centric structure strongly affected the pedestrian network. Thus, among the main types of urban structure, the polycentric structure strengthens the pedestrian network and increases its cohesion in the new area of the city.

**Table 6-4: PNA Model(X) and ASAMeD (Y) in Porto and Qazvin cities by quadrant chart**

| Area- Porto city | Quadrant | Street length (m) | Percent |
|---|---|---|---|
| **X> 0.358 and Y> 0.368** | 1 | 10928.70 | 23% |
| **X<= 0.358 and Y> 0.368** | 2 | 9601.15 | 21% |
| **X<= 0.358 and Y< =0.368** | 3 | 15129.26 | 32% |
| **X> 0.358 and Y<=03.68** | 4 | 11273.62 | 24% |
| | | 46932.74 | 100% |
| **Area- Qazvin city** | Quadrant | Street length (m) | Percent |
| **X> 0.295 and Y> 0.324** | 1 | 16378.71 | 37% |
| **X<= 0.295 and Y>0.324** | 2 | 3813.85 | 8% |
| **X<=0.295 and Y< =0.324** | 3 | 16094.86 | 36% |
| **X> 0.295 and Y<=0.324** | 4 | 8262.66 | 19% |
| | | 44550.10 | 100% |

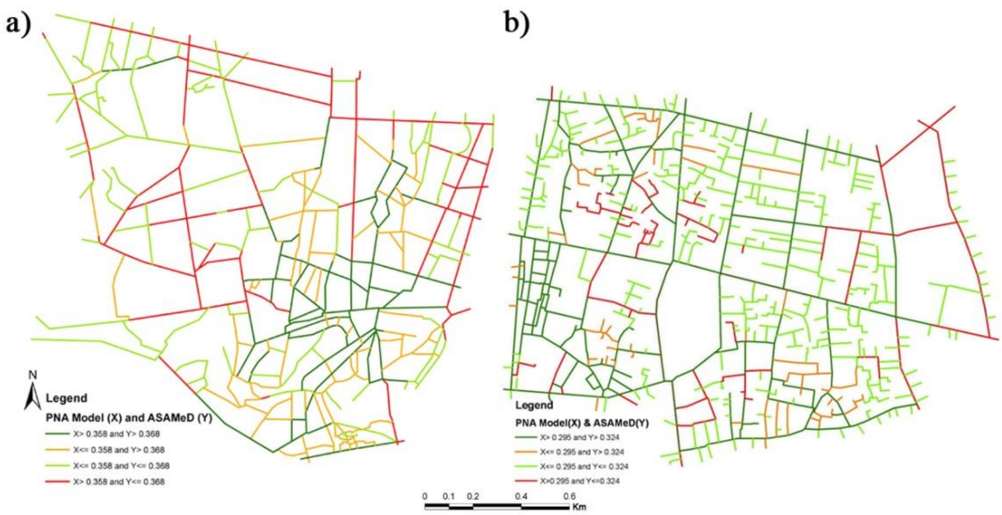



**Figure 6-7: Maps of the Quadrant Chart According to data average Porto (a); Qazvin (b)**

Table 6-5 present some salient features between the PNA model and ASAMeD. The PNA model assesses relevant criteria involved in the network and urban space for the pedestrian needs, through the combination of some analyses. The ASAMeD model identifies the pattern of pedestrian movement for a particular type of urban morphology. Therefore, the APN model results in more accurate and comprehensive informaion than the ASAMeD approach. While the PNA model has the possibility of development planning in the future, the ASAMeD only presents the existing conditions of paths which are used by pedestrians.

**Table 6-5: Comparison between PNA model and ASAMeD**

| | PNA Model | ASAMeD |
|---|---|---|
| **Software** | GIS (MCA) + Space syntax ( street network connectivity analysis) | Space syntax (Angular Segment Analysis by Metric Distance) |
| **Aim** | Assesses urban space and walkability criteria | Detect the pedestrian behaviour |
| **Time** | Work in field & analyse using software | Analyse using software |
| **Result** | Obtain new area to develop pedestrian network and can be matched with the current patterns of pedestrian movement | Achieve the patterns of pedestrian movement |
| **Efficient** | Planning capability by multi-criteria and street network connectivity analysis considering space and network | Limitation Planning according to urban morphology |

# 7. Conclusions

Based on the literature review, it can be stated that sustainable development is one of the most challenging issues, not only in the scientific world, but also in our everyday lives, work, and business. Providing good walkable areas in cities should be a focus of current planning policies in cities as this would bring various health, economic and environmental benefits to citizens and visitors (Bahrainy and Khosravi 2013; Kim, Park, and Lee 2014; Babiano 2016), and consequently, the liveability would also be improved, making the cities more sustainable.

To fulfill this aim, this thesis created a link between engineering studies and sustainable issues. It especially considered the criteria of walkability in urban streets and the connectivity of the street network for pedestrians. As an important contribution to more healthy cities, this research combines the Multi-Criteria Analysis (MCA) and the Street Network Connectivity analysis within the Pedestrian Network Assessment (PNA) model. The PNA model assesses streets in terms of walkability as an innovation method in order to be a new decision-making model for urban planners and transportation engineering. This model takes into consideration the project's urban design and planning aspects, and includes information about pedestrian needs and the space potentials for walking to choose from among the assessed criteria based on expert surveys. The model can assess the walkable streets in a central area of a city to identify the potential for a pedestrian network and to improve mobility.

This chapter presents the main conclusions of this thesis, especially, the main features of the PNA model and future studies in order to implement a smart pedestrian network in cities.

## 7.1 Conclusions

The main aim of this thesis was to make and evaluate the PNA model for planning walkability networks in cities. The PNA model involves multi-criteria assessment and the street network connectivity analysis. It should be noted that the streets considered in this model are the first priority used by pedestrians and the streets are (by default) very important for pedestrians. In addition, the PNA model evaluated by the Angular Segment Analysis by Metric Distance (ASAMeD) approach highlights urban morphology and the relevance to the patterns of pedestrian movement in urban space. In fact, the ASAMeD approach shows that the urban morphology structure reflected the pedestrian movement patterns. This evaluation was carried out in two different urban structures, in the multi- nuclear structure of Qazvin (Iran) and in the nuclear structure of Porto (Portugal). Findings show that in Porto there are few streets providing good conditions for pedestrians and that they are not connected as a network; in Qazvin, streets provide good conditions and they are better connected. In addition, the two case studies (Qazvin and Porto) have been presented to demonstrate the proposed methodology in order to be able to have a comprehensive evaluation of the PNA model under different urban morphologies. Moreover, the comparison between the PNA model and ASAMeD approach shows that the PNA model assesses the streets providing better information on walking conditions than ASAMeD. The PNA model can be a useful tool to plan urban streets for pedestrians and to develop spatial relationships in street networks for walking. The described model can potentially be replicated in other cities in terms of improving the walkability and promoting sustainable urban mobility.

The thesis also includes some ideas about the new technique, which was created in order to simplify the datasets merging. Firstly, the PNA model is based on the spatial database. In fact, this model adapted the different types of data by the same unit. Secondly, the existence data has not been produced on the same scale in urban planning. Therefore, this method transfers all data to the urban streets macro scale. This merge of data is used by a special code for each street, and the role of this code is to connect the street data. Thirdly, identifying and assessing a pedestrian network is challenging mainly in large areas with multi-functionality and different urban and natural characteristics. The model is supported in a GIS multi-criteria analysis where nine sub-criteria and four criteria were selected and weighted according to a panel of 41 experts from Porto and 45 experts from Qazvin. The street network connectivity was also included in the approach by using space syntax. To obtain the final ranking, all the values were normalised and aggregated.

The PNA model will be very useful to identify how walkable the streets are and to understand their linkages and spatial connectivity. These rankings can be used to identify existing problems, and to propose and assess new solutions. The results clearly show that a significant number of streets are not very attractive for pedestrians in the Porto and Qazvin central areas. On the contrary, several paths present changeable conditions, with discontinuous and irregular streets, which can encourage car usage. Urban planning needs to include decisions aiming at improving walkability and promote better street network connectivity for pedestrians. Hence, this thesis presents the pedestrian network using the PNA model according to two main components of the included MCA and street network connectivity analysis in the first section of the discussion chapter.

Finally, to refine our knowledge of pedestrian movements in the pedestrian network framework, it seems better to carry out further studies in other cities in the future.

## 7.2 Future study

There are some aspects that could be improved in future developments. Firstly, it will be particularly important to support the weighting process in a larger and representative sample. A combined system involving not only a group of experts, but also the residents' opinions could be useful to strengthen the robustness of the approach. The inclusion of other criteria/sub-criteria could also be relevant, because there are still some components, such as safety, that were not included in the model. Some authors, such as Agrawal, Schlossberg, and Irvin (2008) show that besides minimizing time and distance, safety is a secondary factor influencing route choice, as well as the attractiveness of the route and the quality of the pavements. In Porto and Qazvin, safety was not perceived by the majority of experts as being critical, but in other future applications the inclusion of this criterion could be considered. By using specific criteria included in the database, the approach has the potential to be upgraded and included in smart navigation systems and applications for pedestrians. Similar systems were developed with the aim of encouraging walkability when pedestrians encounter unfamiliar environments (Fang, Li et al. 2015). Traditionally, pedestrian navigation is based on the guidance of pedestrians walking between identifiable origins and destinations.

Secondly, in order to confirm the results, the described approach needs to be properly validated. The literature on walking models shows that, depending on the researchers' objectives, several methods have been used to test the reliability of such procedures. For Moura et al. (2017), the lack of an organised set of validation methods for walkability assessment tools is a challenge when the assessment results are to be interpreted and applied in urban and transport planning. Nonetheless, three main methods have mostly been used: (i) pedestrian counts relating walkability scores to pedestrian flows. This method was used by several authors (Yin, Cheng et al. 2015, Yin 2017) (ii) street surveys, linking walkability scores to people's perception of the conditions provided. This method was adopted by several authors (Kelly, Tight et al. 2011, Sung, Go et al. 2015); (iii) and home-based surveys, relating walkability scores to people's travel routines and lifestyle to understand pedestrian personal characteristics. This method was used, for example, by Millward, Spinney and Scott

(2013) and by Moura et al. (2017). One of these methods will be used in the future to test the PNA model. A first option consists of counting the pedestrians to confirm if the better ranked streets have more people walking. Alternatively, the pedestrians can be asked about their perception of walking on the Porto streets, identifying the most and least walkable streets. The intention is to present the results of this validity testing in future work.

Thirdly, by using the PNA model, the second section of the discussion chapter introduces a primary walking table based on the pedestrian network. This table needs to be compatible with the Intelligent Transportation System (ITS) in order to be used by pedestrians. This application can be used by pedestrians to identify paths between a specific origin and destination with different characteristics: flat paths, green paths, paths crossing heritage areas, commercial zones, etc. As urban areas are becoming more complex, the system will provide an integrated response in real time, meeting the physical and psychological needs of pedestrians.

Therefore, in future studies it would be possible to provide useful insights into the research entitled a Smart Pedestrian Network (SPN) as a comprehensive framework to implement in real space. The following could be considered: safety criterion, validation by pedestrians and, also, information technology services. The SPN is highly potential in terms of urban planning and technological application, to improve walkability in cities towards a more sustainable pattern of urban development. In this context, the main objective of SPN could be to develop the PNA model to identify and implement the pedestrian network and a technological application to support the decision-making process in developing more walkable cities and help pedestrians select streets by using specific criteria. The SPN will be useful to support the implementation of suitable urban and transport planning policies in order to improve the walkability and create a continuity of streets..

The SPN will also support the development of a navigation system to assist pedestrians and encourage walkability in the cities. Similar systems were developed with the aim of encouraging walkability when pedestrians encounter unfamiliar environments (Fang et al., 2015). Traditionally, pedestrian navigation is based on the guidance of pedestrians walking between identifiable origins and destinations. The mobile application resulting from the SPN project will support and enhance spatial interaction, behaviours of different types of pedestrians (inhabitants, workers, visitors, tourists) with environments taking into consideration their preferences. Finally, the navigation system is also innovative as it will be based on a people-centric approach, allowing for the selection of routes based on the pedestrian network. This system will encourage interactions between pedestrians´ behaviours and environments, while traditionally they are only focused on selected routes between two points.

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