Assessing Walkability Conditions

Contributions of the Space Syntax Methodology

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Caminhando e cantando

E seguindo a canção

Somos todos iguais

Braços dados ou não

Nas escolas, nas ruas

Campos, construções

Caminhando e cantando

E seguindo a canção

Vem, vamos embora

Que esperar não é saber

Quem sabe faz a hora

Não espera acontecer

Os amores na mente

As flores no chão

A certeza na frente

A história na mão

Caminhando e cantando

E seguindo a canção

Aprendendo e ensinando

Uma nova lição

- Geraldo Vandré –

À resistência.

Declaração

Declaro que o presente documento é um trabalho original da minha autoria e que cumpre todos os requisitos do Código de Conduta e Boas Práticas da Universidade de Lisboa.

Declaration

I declare that this document is an original work of my own authorship and that it fulfills all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

Abstract

Pedestrians are the fairest mode of transportation, as it is inherent to every person and there is no cost associated. Nevertheless, during the last century, pedestrians were left aside, due to the ascension of the motor vehicle. That choice, made by society, has caused great transformations in the city, particularly, in less walkable environment. Nowadays, the many challenges that cities are facing are leading to an emerging mindset, aligned with the sustainable planning, where active modes (pedestrians and cyclists) are regaining importance, due to the numerous benefits it encompasses.

This work aimed to understand the walking environment and pedestrian behavior, and to develop a tool to assess this context, therefore, supporting the urban planning toward a more inclusive and walkable city. That was accomplished through an extensive research about the pedestrian mode and the state of art regarding walkability. Based on that, two methods were employed to build up the assessing tool, “IAAPE walkability score” (IAAPE) and “Space Syntax” (SS). The first is a walkability index, that deals with the walking environment and was built upon the perception of different types of pedestrians. The second refers to a well-known method to analyze the urban configuration and flows.

A syntactical model (sidewalk-centerline network) and measures were adapted to be incorporated within IAAPE, resulting in an improved walkability index, easier to handle and more efficient. The tool is flexible and can be used for other purposes, helpful to the urban planning and design fields.

Keywords

walkability, walkability index, pedestrians, space syntax, IAAPE, Lisbon

Resumo

O modo pedestre é a forma de transporte mais justa e acessível, uma vez que engloba todas as pessoas e pode ser realizado sem custos. No entanto, ao longo do século passado, os pedestres foram deixados de lado, em função da ascensão do transporte motorizado. Essa escolha, feita pela sociedade, ocasionou grandes transformações nas cidades e acarretou um ambiente menos caminhável. Atualmente, diversos desafios urbanos têm levado ao surgimento de uma linha de pensamento, alinhada ao planejamento sustentável, onde os modos ativos (ciclistas e pedestres) voltam a ter importância, visto estarem associados a inúmeros benefícios.

Este trabalho tem por objetivo compreender o ambiente caminhável, bem como a percepção do pedestre, e desenvolver uma ferramenta para analisar esse contexto, assim, contribuindo para o planejamento de uma cidade mais inclusiva e amiga do pedestre. Para tanto, foi realizada uma extensa pesquisa sobre o modo pedestre e a caminhabilidade. Com base nisso, dois métodos foram empregados para construir uma ferramenta de análise, o índice de caminhabilidade IAAPE e a sintaxe espacial (SE). O primeiro avalia o ambiente caminhável e foi formulado tendo em conta a percepção de diferentes tipos de pedestres. O segundo corresponde a um método reconhecido de análise da configuração e fluxos urbanos.

Um modelo e indicadores sintáticos foram adaptados para posteriormente serem incorporados ao IAAPE, resultando em um índice de caminhabilidade aperfeiçoado, mais fácil de operar e mais eficiente. A ferramenta é flexível, podendo ser usada para outros propósitos, servindo de auxílio para as áreas do planejamento e desenho urbanos.

Palavras-chave

Caminhabilidade, índice de caminhabilidade, sintaxe espacial, IAAPE, Lisboa

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1 Introduction

1.1 Background and motivation

When do we, as pedestrians, have a great experience walking in the cities? How should a comfortable and attractive walking environment be thought and designed?

The answer, an urban planner would say, is far too complex. Indeed, the issue involves many dimensions of the urban life. Walkability, the subject of this dissertation, corresponds to the extent that an urban space supports and encourages walking and meets the pedestrians' needs (Southworth, 2005). It is, therefore, at the core of pedestrian planning, and, like any urban concerns, it must be understood within a global context, knowing how it relates to other modes and where it stands in the agendas of the cities.

Motor vehicles have undoubtedly an important role in the development of the cities (for good or for bad), but as it has happened to any innovation in the urban mobility, they will eventually be replaced by another new technology. Walking, on the other hand, will always exist. Besides, it is the fairest mode, since everyone is a pedestrian, and the mode requires no costs to be performed. It helps reducing traffic congestion, which impacts positively on the environment in terms of pollution reduction (air, noise, soil) and, therefore, it is also reflected in public health. Health, in turn, is fostered due to a reduced exposure to pollution and for being a physical exercise as well. All these effects influence the economy, given the reduction on health and congestion expenses, and the boost on local economy (ARUP, 2016; OECD/ITP, 2012).

In spite of the importance of walking to society, this mode has lost priority and space along our recent History, mainly due to the appearance of other means of transportation (Southworth, 2005). This fact has caused not only a lack of investments on the pedestrian mode, but also resulted in an aggressive and dangerous environment for them (Norton, 2008). On the other hand, because of changes in paradigm, especially related to a sustainable planning, active modes are once again receiving attention and priority (Lo, 2009). It is important to contextualize the subject over time to perceive how it has evolved regarding its concept, political role, planning, and physical infrastructure. Such a holistic approach, caring about the evolution of the process as well as the many facets of the issue, makes it easier to identify what really matters and, ultimately, to illuminate the way ahead. In this case, to help find what fosters a walkable environment and, consequently, to achieve a more inclusive and fairer city.

The pedestrian mode depends on a wide range of issues, from the individual characteristics to some global ones, like local culture, context, and the built environment. Every single aspect helps to determine walking behavior, encouraging it or inhibiting it (Moura, Cambra, & Gonçalves, 2017). Consequently, many fields of study have been researching this subject caring for its different dimensions (Ewing & Cervero, 2010; D'Arcy, 2013).

This dissertation focuses on the pedestrian topic within the fields of urban planning and design and intends to bring some contributions to the understanding of the walkable environment. The research starts by outlining important facts and studies about pedestrians and walkability and, based on this knowledge and on already established methods, it aims to bring the discussion to a pragmatical level.

Many methods and tools are currently being used to evaluate the pedestrian environment; however, none of them has been taken as a standard procedure. Some are too simplistic, others are time-consuming, there is divergence of what aspects to consider, and so on. Other than creating more tools, this dissertation takes advantage of existing ones, exploring methods that can be combined to achieve better processes and/or outputs.

In addition to sociological and political approaches to study the urban space, tools are needed to see it objectively, to gather data about it, analyze it, and, ultimately, go back to the first step and evaluate it from a critical point-of-view.

1.2 Research questions

Some questions were formulated to be answered by the present research, desirably.

- Everyone in the city is a pedestrian, at least during a period of the day. How has the pedestrian environment evolved to its current state? Is the public environment shaped to meet the needs of a pedestrian?
- Space syntax and IAAPE walkability score are tools that help researchers understand the pedestrian environment. Should the space syntax methodology be adapted to better simulate the urban pedestrian movement? Can space syntax and IAAPE walkability score, intertwined, obtain a more complete, pragmatic and easy-to-use tool for urban walkability analysis?
- Can the results of the second question be of any help to answer the first one? Or, in other words, can they be used to improve the pedestrian environment?

1.3 Objectives

This dissertation focuses on two main objectives, which complement each other.

1. Understanding the walkable environment, minding its political, social, economic and environmental importance, as well as its transformation over the years.
2. Combining existing and complementary methods to deliver a tool to support urban planning, decision-making and urban design towards a more walkable and more inclusive urban environment.

Some specific objectives were determined:

1.1 Understanding the role of the pedestrians in the urban life: who they are, their diversity, needs and interests, their importance in the urban mobility, how much attention they get, etc.;

1.2 Understanding the historical and political process that shaped the walkable environment, synthesizing the main facts/movements that had the strongest impact on it;

1.3 Describing which dimensions have been studied concerning pedestrians: the built environment, social interaction, pedestrian perception, and behavior.

2.1 Combining two methodologies, IAAPE walkability score and space syntax, which are already used to analyze the urban space (although from different perspectives), in order to achieve, possibly, a more comprehensive and efficient tool that contributes to get a better appreciation (or evaluation) of the walking environment.

2.2 Experiment with different scenarios to test the usability of the new tool.

1.4 Methodology and outline of the dissertation

The methodology of this dissertation is divided into four parts, which is also reflected in the outline described below and illustrated in Figure 1.

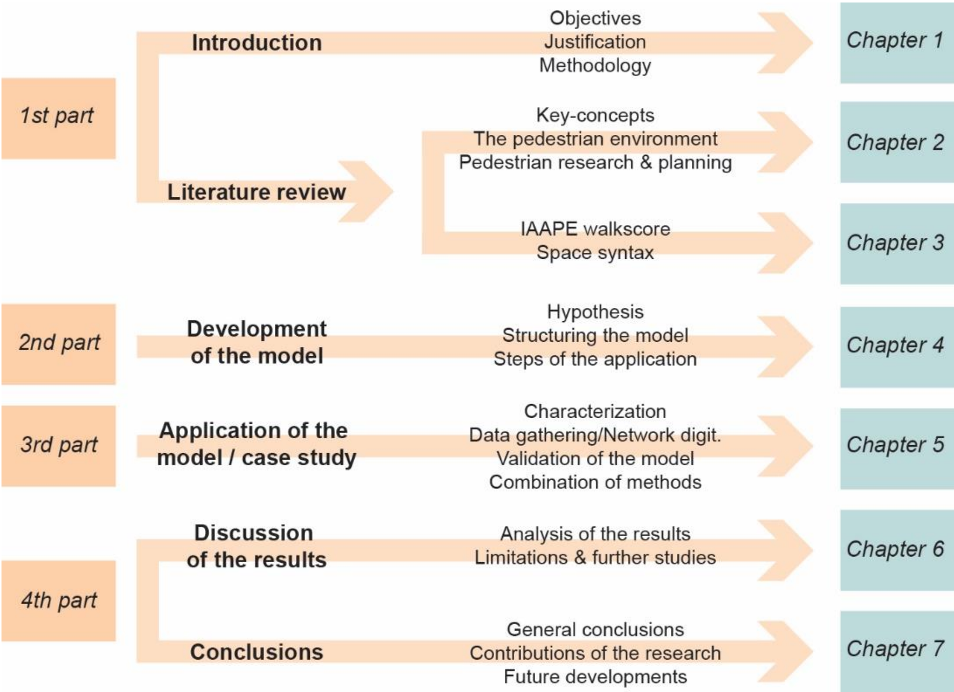


Figure 1. Structure of the dissertation

1st part: introduction and literature review

The work begins with an **introduction (chapter 1)** that delimitates and contextualizes the problem, while describing the objectives, justification, and the methodology of the dissertation.

The literature review starts in **chapter 2, “The pedestrian and the city”,** where the main concepts are introduced, as well as, the physical and political evolution of the pedestrian environment. It also covers the importance of walking (in general and as a mode of transportation) and it describes how walkability has been studied. Also, the dimensions of the problem are presented.

Next, in **chapter 3, “Review of methods”,** the two methods that support this study are explained, namely, the walkability index “Indicators of Accessibility and Attractiveness of Pedestrian Environments (IAAPE)” and “The Spatial Logic of the Space”, or simply “Space Syntax”.

2nd part: development of the model

In **chapter 4, “Development of the model**”, some hypotheses are made on how to contribute to the study of walkability using those methods. Based on that, the model is structured in two parts: (1) the study of adaptations/variations of space syntax method; and (2) the combination of the two presented methods, in order to achieve better results in assessing the pedestrian environment.

Additionally, the necessary resources are specified. The technological resources consist of specific software to apply each method and to analyze the results. Regarding the data, it is pointed out the available sources and what needs to be produced from scratch.

Finally, the exercise is outlined step-by-step.

3rd part: application of the model (case study)

The **case study** is delineated in the **chapter 5**. It corresponds to two different areas in the Municipality of Lisbon. In this section, the areas are characterized in relation to their configuration, topography, population, density, land use and the existence of equipment and facilities.

The steps of the exercise are as follows:

- A description of the construction of the network, to be used in the space syntax model: approaches to digitalize them, definition of rules for the digitalization, calculations of syntactical measures, correlations between networks and the selection of the most suitable approach;
- The comparison of the created pedestrian network with the standard road-centerline network: calculation of the space syntax measures, correlations between networks, correlations with pedestrian counting, conclusion;
- The validation of the model: definition of parameters (buffer size, radius of analysis, measures), comparison with the characteristics of the area;
- The combination of space syntax and IAAPE methods: transformation of the syntactical values, calculation of final walkability scores, comparison of walkability scores, results;
- Test of adaptation of the created walkability score.

4th part: discussion of results and conclusions

In **chapter 6, “Discussion of the results”**, the results obtained in each test realized are commented, pointing out their implication, limitations and remarking what should be further investigated.

Finally, the **chapter 7, “Conclusion”,** outlines what was done along the dissertation, the major findings are highlighted, the contributions and limitations of the research are discussed, as well as some possible further steps.

2 The pedestrian and the city

In this chapter, a framework about the city and the urban mobility is introduced to set the bases for further discussions. It begins with some basic concepts, followed by a brief chronology of the pedestrian environment and it ends with a summary of the main points within the walkability field.

2.1 Key concepts

In any discussion, it is essential to define some concepts, to discern their limits and avoid misinterpretations.

The concept of the **pedestrian** embraces any person who moves within the public space, irrespective of its sensorial and physical condition, its sojourning time or the purpose of the trip (utilitarian, exchanging between modes, access, leisure) (Silva & Lara, 2005; Lo, 2009). Although many dictionaries define it as “a person walking”, it is important to understand a pedestrian as a temporary role of the person in the urban environment (Gold, 2003), which implies that more than just a modal share, pedestrians are the totality of the population. Furthermore, it comprehends a wide heterogeneous group of people, not only with respect to their physical and mental conditions, as already mentioned, but also diverse in gender, age range, nationality, and socioeconomic level (Melo, Torres, & Jacques, 2004).

Then, since pedestrians move about in an urban space, it is important to define the latter. **Cities** are complex and relational systems, formed by some elements which are in constant interaction, transformation, and evolving over time. Hillier (2002) describes the urban environment through three elements (Figure 2): the urban grid, also seen as its physical environment or the configuration of the city; the social forces, which comprehend the interactions among people and environment or, in other words, the culture; and the movement, which holds the whole system together, and could also be seen as the flows or trips realized in the urban space. The configuration of a city, other than its physical environment, can also be seen as an active support, meaning that it allows flows and interactions, but is also modified by them. Those are some of the reasons why the urban environment must be studied as a whole, or, at least, consider the interrelation of its dimensions.

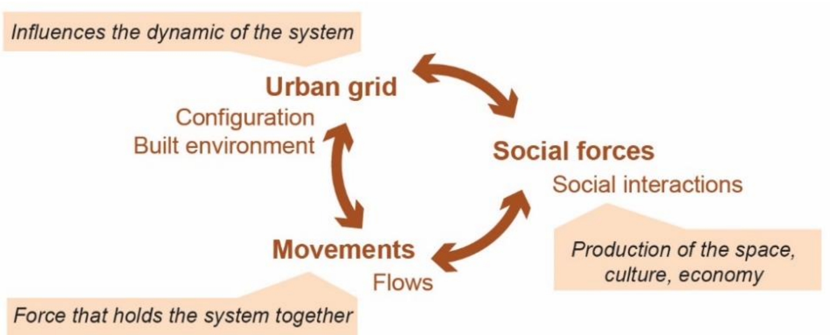


Figure 2. The dimensions of the urban environment. Source: author

Furthermore, when referring to pedestrians in the city, one must be aware of the concepts of **accessibility** and **mobility** in the transportation field. For Handy (2005), these terms are closely connected, although very distinct in meaning. She defines accessibility as the “ability to get what one needs, if necessary by getting to places where those needs can be met”, whereas mobility is the “ability to get from one place to another, an ability to move around”. These are very precise definitions. However, following the diagram above (Figure 2), it could be complemented by Jensen’s words, who defends the importance of taking mobility (as well as accessibility) beyond its technical scope and recognize it as a trigger for people’s encounters and for connecting them with the physical environment (Jensen, 2009).

Another term that is worth outlining for this work is **transportation planning**. It is a comprehensive concept, which involves the planning, implantation, and operation of transports facilities. Complementary, Vasconcellos (2001) sustains that, besides its technical aspect, it has to be seen from both sociological and political perspectives which are equally important. The former is constrained by the other two, which varies largely in time and space, therefore, it is essential to integrate all for a better planning of the circulation in the cities. This broad understanding implies, for example, that every issue in transportation must be studied taking into account the diversity of a social group; or that each decision taken is, even if based in technical assumptions, always a political one, grounded in values of the individuals that are planning. This said and considering the finiteness of the urban public space, decisions about transportation planning must be made based on the most equitable and sustainable scenario, providing better opportunities for all and caring for the environment.

Here is where the concept of **walkability** emerges. It is a quite new term, not yet defined by many dictionaries, however, the use of it by researchers and practitioners is wide-spreading. As Forsyth (2015) lists, walkability has been defined according to either the physical environment conditions (an adequate space to walk), or the perceived outcomes of walking (a lively, sociable-pleasant, or exercise-inducing environment), or even as a standard for better design/planning (a measurement or a set of measures). These dimensions show how wide this definition can be and how much it can vary. Indeed, researchers and institutions limit or enlarge its meaning according to the undertaken research and that is comprehensible because walkability is a multidisciplinary concept. For the sake of this dissertation, a definition by Southworth (2005) is adopted: “walkability is the extent to which the built environment supports and encourages walking by providing for pedestrian comfort and safety, connecting people with varied destinations within a reasonable amount of time and effort, and offering visual interest in journeys throughout the network.”

These concepts are continuously evolving and assuming other meanings, according to the current norms and practices. Within the scope of this work, an effort was made for presenting a multidisciplinary and updated version of them. For a deeper comprehension of the temporal dynamics of these concepts, a historical contextualization of the active modes, especially the pedestrian one, is later described.

2.2 A brief evolution of the pedestrian environment in cities

Walking is the first mean of transport of human beings and it remained as their unique mode for millennia until humans started developing some technologies, such as sleighs (7000 BC), or taming animals (around 4000 BC) (Gondim, 2014). Only much later, the wheel was invented (3500-3000 BC) and with that, little by little, all sorts of carts were developed, together with improvements in technology and a slow increase of speed.

Human settlements, from the beginning, were located and dimensioned according to the foot distance to reach the needs for living and to facilitate communication. Gondim (2014) describes that the first settlements, found in Western Asia (10000 to 7500 BC), were shaped by a set of houses without any evidence of streets. It was only afterward, in the region of Anatolia, that some settlements were found with narrow passages in between the buildings. Following the development of these early streets, Gondim shows how the vehicles and other means of transport reshaped and broaden these thoroughfares. Sleights, animals and, finally, wheels demanded these paths to be clear and leveled, therefore without obstacles and, eventually, paved.

But it was not until the Romans that streets started being standardized and ruled (Southworth & Joseph, 2003). Laws were then written to determine its geometric measurements, such as width and height (of the façades). By 15 BC, even the side streets were paved, being at least 4.5m wide, and with elevated sidewalks on both sides, occupying half of its width. This type of street with unlevelled sidewalks would, many centuries later, be assumed as a standard of the modern street.

Interesting to notice back then, Romans were already facing traffic congestion problems and in 47 BC, Caesar forbade the traffic in the city center of wheeled vehicles during daytime (Southworth & Joseph, 2003), in a way, prioritizing pedestrians and a comfortable environment. Later on, this approach was applied in the whole Empire.

In Europe, after the decay of the Empire (476 AD), the Roman infrastructure, such as streets and roads, were not maintained and, thereafter, deteriorated. During the medieval period, inside the walled cities, streets were narrow, without any physical separation, but still presenting a hierarchy of main and secondary levels (Benevolo, 2011); and, what is worse for pedestrians, with very unhealthy conditions (poor drainage, dirt, etc.) (Gondim, 2014).

It was only much later, starting in the 13th century, that the design and the conditions of the streets started once again to be thought of (Southworth & Joseph, 2003). By then, the urban population arose, cities were already becoming crowded and streets congested. The Renaissance architects, studying the ancient Classical documents, started attempting to configuration, geometry, healthy conditions, aesthetics and symbology. New standards and techniques were developed, where streets received pavement, as well as drainage systems, and unleveled separation of pedestrians and vehicles reappeared.

From then on, streets were to be rectified and/or widened, in order to promote better circulation and health. And whereas Roman streets were equally divided between pedestrians and vehicles, in the 19th century, standards would save much more space for the latter, such as in Paris, where new thoroughfares should dedicate 8m for traffic lanes with 2m sidewalks on both sides (Gondim, 2014).

Additionally, it is important to notice that in the 19th century there was the introduction of mass public transportation, which improved mobility for hordes of people, as well as configure itself as a new “player” in the urban scene, also competing for space on streets. At first, as animal-dragged vehicles, such as the trams in Paris, in 1855, it evolved, at the end of the century, to steam and electric vehicles, like the metro system of London, from 1863 on (Gondim, 2014).

Even though streets were carefully designed, there were no mandatory traffic rules. Pedestrians, for example, would circulate freely around occupying the whole width of a street, as it had always been. However, with the increase of other transport modes and of more powerful machines, the rising complexity would demand new approaches in mobility and, eventually, restrictions on movement.

The introduction of the individual motor vehicle in the beginning of the 20th century would generate one of the biggest disruptions of the urban history. A disruption that would change the way pedestrians were seen in the city and how they should gather and move around. A set of factors, such as the serial production, the affordability of a car by an increasing middle class, the development of good roads, among others, boosted the number of cars in an impressive way. In the USA, for example, the amount of privately-owned motor vehicles jumped from 8000 in 1900 to 8 million by 1920 (Southworth & Joseph, 2003).

Despite that, cars were initially seen as a problem and a hazard, due to the consequences of their noise and speed. Indeed, because of this fast increase and the lack of regulations to avoid conflicts, the number of accidents and deaths rose considerably, mainly of pedestrians and, especially of children (Norton, 2008). For a while, motor vehicles were seen as intruders and motorists were blamed exclusively for road accidents and fatalities. Concurrently, due to the lack of rules, pedestrians continued to walk freely, either on sidewalks or among cars (Figure 3).

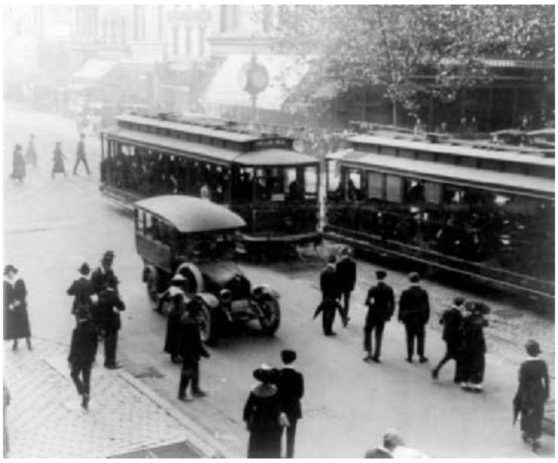


Figure 3. 11th & F Streets, NW, Washington, ca. 1915. Source: Library of Congress (https://www.loc.gov/item/2001706122/)

Soon enough, accidents, together with traffic congestions, forced city authorities to a quick response. A series of experiences with policing, signs and rules took place; many of them failed and were continuously being changed. In England, for example, a kind of crossing sign for pedestrians was introduced only in the 1930s, but it kept on changing until the late 40s when the current zebra cross was worked out (Moran, 2006).

During the first decades of the 20th century, it was the police officers' duty to organize traffic. Apart from being on streets signaling and whistling, they also started imposing fine to motorists based on an empirical failure-and-success process.

The increasing complexity of the issue, which was growing fast according to the expansion of the vehicles fleet, made it impractical for the police force to solve with its current knowledge and practices. Along the 1920s, the engineer class, which had been studying and optimizing other public utility infrastructures such as railroad transportation and water supply, turned to traffic and developed a new approach to deal with it. Invoking the principles of “social utility”, “equity” and “efficiency”, engineers developed scientific methods to establish traffic control (Norton, 2008). Consequently, instruments like traffic surveys and statistical analysis started being used to support new regulations. Taking the streets as a “finite” asset, restrictions were formulated to optimize their capacity, envisioning the benefit of the majority, which was to be focused on public transportation, because of its higher capacity (i.e. carrying more people per vehicle, and per time period).

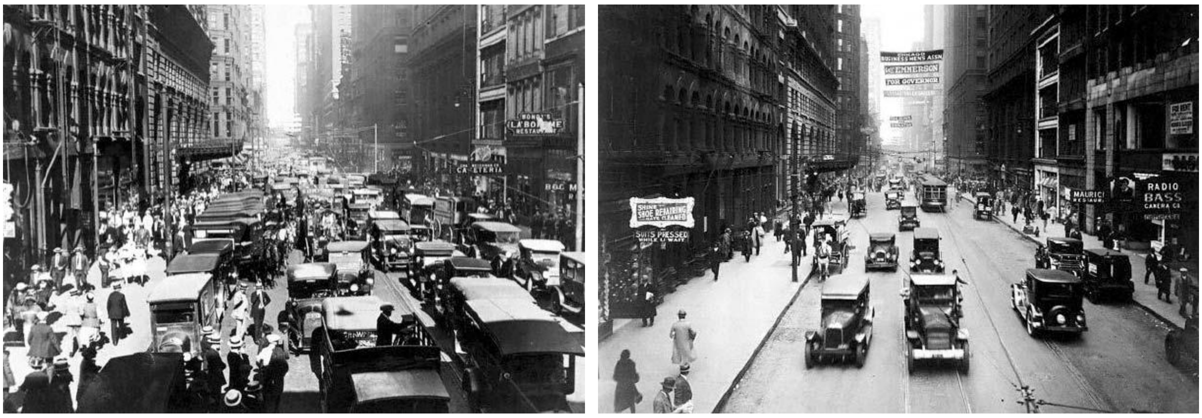


Figure 4. A Chicago street in 1929, before and after the implementation of engineer traffic control regulations. Source: Schenectady Museum and Suits-Bueche Planetarium in (Norton, 2008)

In this rush to organize the streets, sidewalks were taken as an exclusive space for pedestrians and, consequently, traffic lanes were asserted as exclusively for vehicles. Thus, a strict separation of modes started being settled in the public space. Moreover, the same traffic engineers, went on to reconceptualize thoroughfares, setting them as a monofunctional space, dedicated only to transportation (Norton, 2008). The many other activities that take place in public spaces (streets included) were excluded from the traffic studies framework and, consequently, from urban planning and design. Pedestrians were only one type of user that moves around and should follow rules; no attention was paid to their diversity and/or needs.

Furthermore, besides the conflict between cars and walkers, a second one, congestion, was increasing fast and worrying not only drivers but also street commerce owners and the car industry. Engineers were trying to solve the problem with traffic control measures and giving priority to public transport. Although claiming to be using a purely technical approach, they were taking a political position in advocating for the majority. In doing so, they also neglected the interests of some powerful groups, such as the automobile associations and chambers of commerce, which started organizing themselves in order to defend their businesses.

The car industry, represented by newly-founded associations and foundations, was interested in selling ever more and its concern comprehended traffic externalities, as well as the restrictions being imposed to motorists; businessmen, organized in chambers of commerce, wanted the traffic to flow and to bring them more costumers. As an important economic power, they had the means to hire experts, invest on propaganda and spread their point of view. They were also strong enough to influence politicians to carry on their interests. During the 20s and 30s, in many countries, but especially in the United States, they got to turn the tide, in favor of cars and against pedestrians (Moran, 2006; Norton, 2008).

This shift set the bases of transport planning for the rest of the century. If cars were seen, at first, as a nuisance for the urban realm and the only culprit for the traffic accidents and fatalities, after the car industry interference, they would be thought as a modern life's necessity. Pedestrians, on the other hand, started being blamed for the accidents, besides getting less consideration by planners and politicians. This change of priorities was accomplished through scientific studies (sometimes manipulated), advertisement, educational campaigns (for drivers, pedestrians, and in schools, for children) and punishment of pedestrians – much of what, was funded by the car-related companies and associations (Norton, 2008). From then on, pedestrians became a kind of "second-class" citizen, being disregarded in the transportation planning process (Vasconcellos, 2001).

On one side, pedestrians were accused of causing accidents due to reckless walking or jaywalking (Moran, 2006), thus being forced to keep confined in the spaces "reserved" to them. In the urban stage, it is reasonable that every actor must be careful and responsible for a harmonious coexistence of all, nevertheless, the inversion of priorities in traffic caused an excessive load on pedestrians. On the other side, infrastructure for pedestrians started receiving less attention, urban space, and investment. As the pressure for prioritizing cars was resulting well, a new way of thinking the urban public space was taking place. Instead of the early traffic engineers' mindset of optimizing the existing streets, the new approach claimed for more "floor space" – to use an expression from the time – for motor vehicles (Norton, 2008), which would lead, later, to the construction of bigger car infrastructures, reshaping and dehumanizing cities. Progressively, the pedestrian environment got fragmented, full of barriers, with over and underpasses, difficult crossings, etc. (Figure 5).

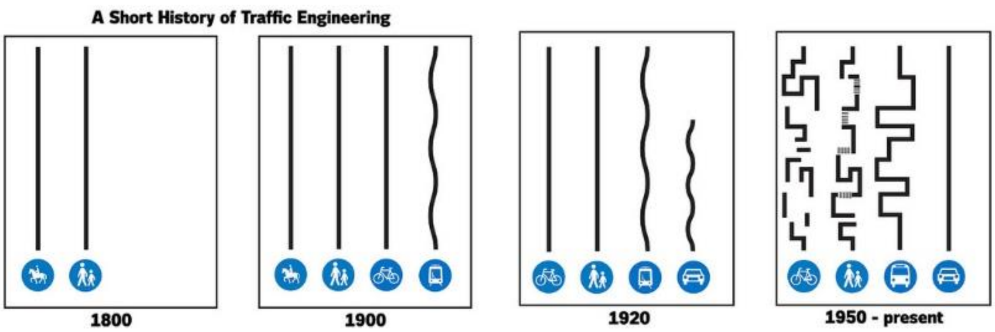


Figure 5. Infographic "A short history of traffic engineering". Source: Copenhagenize Design Co.

The era of the individual motor vehicle was settled, creating an unbalance between modes and a great burden for pedestrians and the social life in public spaces. Besides traffic engineers and the car industry, the transformation of streets in favor of automobiles was also fostered by a new movement of architects that appeared in the beginning of the 20th century, Modernism. Architects such as Le Corbusier, Walter Gropius, among others, amazed with new technologies of mobility and construction, got together to rethink the city and architecture (Southworth & Joseph, 2003). The "machine-age revolution", as Le Corbusier has called it, was the motto for the modern city, a place where efficiency, movement, and speed should rule, and which would, in turn, give priority to the individual motor vehicle. Even if the modernist's search was focused in a new aesthetic and a more functional city, it ended up having a strong political role, considering how it reshaped the way people live in cities, especially regarding displacement and gathering.

Despite the good intentions of modernist architects and engineers to promote more modern and efficient cities, the social impact of (re)building the city with the focus on the motor vehicle was devastating, mainly by optimizing individual person irrespectively of the collective and common welfare. This new logic of thinking the city led to some urban changes that had an enormous impact in the street life, such as the great elements of the rational urban planning listed by Montaner & Muxí (2014): the urban highway, the shopping mall, and the suburbs; all of what, far from a pedestrian's and/or a social life's logic.

As the car culture became the mainstream, some counterculture movements and studies started questioning this framework. From individuals to governments, it came from many fields. An emblematic book of Jane Jacobs, from 1961 questioned it through a political-sociological approach. 'The Death and Life of Great American Cities' (Jacobs, 1961) advocated the sidewalk and the street social life, being against, among other things, the planning for the automobile, arguing that it was destroying the livability and the human scale of neighborhoods. Jacobs went further, and, besides the impact of her writings, she had also an activist role in fighting against the governing powers, i.e., traffic engineers and the car industry.

On the other hand, from the institutional side, governments were also investigating those externalities. Still in the 60s, a report commissioned by the Ministry of Transports of the United Kingdom (Buchanan, 1963) became one of the first official documents warning about the problems caused by motor vehicles. The report's working group was led by Sir Colin Buchanan, an architect, civil engineer, and planner. It was a comprehensive study, with the analysis of the current situation, trends, case studies and a proposal of a set of measurements to be applied in traffic planning in the UK. The problems pointed out are all very timely, concerning traffic accidents, deterioration of the environment (visual, sound and noise pollution) and its health consequences, and the frustration of car owners by not being able to properly use their vehicles, due to the amount of the existing fleet versus the limitation of space. Some of their recommendations and conclusions also remain timely, for example, the emphasis given to a comprehensive approach to traffic. In fact, despite focusing on the motor traffic, they saw pedestrians as an essential part of a transport system; however, in caring for pedestrian safety, they suggested the segregation of this mode to specific paths, following some Garden City Movement concepts. Therefore, although the Buchanan's group tried to see a more sustainable alternative for motor traffic combining it with environmental issues and land use patterns, they ended up restricting the pedestrian's flexibility and freedom.

Despite these early warnings, what prevailed in the transports field was the concern to solve the motor vehicles issues, disregarding the other modes. The result can be seen across the globe through the many infrastructures (and sometimes whole cities) built for the car (in movement or stationary). Examples comes from the outskirts, like the monstrous freeways of Los Angeles, to the enlarged avenues in the city centers, like the famous Avenida 9 de Julio, in Buenos Aires, in which a pedestrian must wait for more than one red traffic light to be able to cross to the other side (Figure 6); not to mention the great space dedicated to keep the whole fleet when parked and idling (on average, 95% of their life time).

Figure 6. Pregerson Intechange, Los Angeles and Avenida 9 de Julio, Buenos Aires. Source: Citydata and ARQA

In the process of the automobile ascension, the pedestrian was moved to the back of the queue or even ignored, despite their importance of being the most inclusive mode. Indeed, the current urban public space is mostly configured in terms of space, dimension, and signage towards the motor traffic. For “slower” modes, the routes are normally disrupted (Figure 5), less maintained and less signalized. Nevertheless, it is important to recall that, contrary to other modes, everyone in the city is a pedestrian, at least for a while, what should make it a priority in planning, even because no other mode can be achieved without walking.

Taking from another perspective, Vasconcellos (2001) brings the political side of traffic, as people acquire multiples roles in an urban space and, accordingly, defend their own needs and interests. He argues that, likewise, urban planners act based on political beliefs, because, other than having a technical knowledge, they are committed to their perceptions of reality. Traffic management, therefore, was (and still is) shaped by and for a middle class, from where normally city planners are from, prioritizing their main mode of transportation, i.e. the automobile, rather than active modes or public transport.

As it has been seen so far, traffic management has never been neutral. Even when justified as having a scientific or technical approach, it was always a product of people’s mind; people with a cultural background, expectations, trained and financially supported by institutions, etc. Under those circumstances and having in mind that every intervention of a government will benefit ones and hinder others, decisions about urban mobility and accessibility, as well as planning in general, must be an outcome of a broad consensus, reflecting multiple viewpoints.

Finally, it should be highlighted that all means of transportation are important and useful in the current cities. However, due to the finiteness of urban space and the advantages/disadvantages of each mode, decisions must be taken to solve conflicts and, for certain, it will bring benefits for ones and cause restriction for others. These decisions must be discussed continuously, to find a more balanced and fairer solution for all, which can vary from time to time. Currently, an unfair scenario is settled, especially for the pedestrians, but the shift is underway.

2.3 Change of paradigm

Over the last decades, a series of issues related to urban mobility have been emerging, confirming the inconsistency of the traffic management decisions taken in the last century. Pozuela (2000) groups those in three main topics: (1) concerns about environment preservation – a discussion rekindled by the sustainability concept –, which embraces the transportation issues of pollution, resource consumption, health and quality of life; (2) social concerns, mainly about the inequalities resulting from policies and technology, which causes difficulties of mobility and accessibility for the lower class and/or active modes; and (3) technical concerns, which relates to congestion and its consequences.

These topics are not exclusive of the mobility field, on the contrary, they characterize a more comprehensive urban context that congregates different agendas, such as sustainable cities, climate change, public health, local economy, among others (OECD/ITP, 2012). Grounded on these agendas, the endeavor of many people, institutions and governments is causing a shift in the transportation paradigm and the so-called active modes, that is walking and cycling, are regaining importance in the planning field (ARUP, 2016).

The change from a “car culture” to a “pedestrian culture” (or a “human scale culture”) has been occurring at a slow pace, however, some developments and results can already be seen, especially in countries of the Global North. Such outcomes are noticeable from lifestyle patterns, like the decrease of car ownership among younger generations, to planning practices, such as the inclusion of pedestrian-target policies or even the change of concept, in which “active mobility” replaced the derogatory “non-motorized transport modes”.

Together with the transportation paradigm shift, another concurrent (and converging) change is occurring: instead of planning based in standards, pluralist points of view are being taken into account and planning for diversity is gaining momentum (Fainstein, 2005). When multiculturalism, inclusivity and social justice are the watchwords, the one-size-fits-all approach makes no sense anymore. Complexity is being recognized as an essential part of urban planning and it is being tackled as it is in order to achieve a more democratic and pluralist city. And it goes (or should go) as far as to treat pedestrians as a heterogeneous group and embrace their different needs and interests (Figure 7).

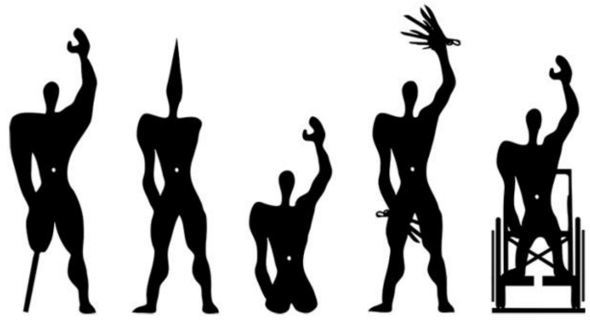


Figure 7. “Modulor”, reinterpreted by Thomas Carpentier. Source: failedarchitecture.com

In sum, the great change consists in having a more sociological approach to urban mobility, rather than a solely engineering one. It is about quantity, quality and relationships or, in other words, to see people not as simple figures, but as political beings who have different and ever-changing roles in traffic (Vasconcellos, 2001). For that, transport planning must be seen through the lens of interdisciplinarity, to seek for a humanistic and comprehensive approach to the matter.

2.4 Pedestrian research and planning

Active modes are currently receiving great attention in the research and planning fields, for the reasons previously mentioned, such as climate change, public health, sustainable cities, etc. In fact, walking and cycling have countless benefits and, because of them, they could be an answer for many of urban problems, i.e., public health and pollution, besides fostering important issues, like spatial justice/equity and local economy.

Models that challenge the car-culture urban configuration have been appearing since its establishment, for instance, Radburn in the USA (1929), which accepted the logic of the roads, but searched for a better environment for pedestrians. However, it was only much later that some models took shape. Southworth & Joseph (2003) bring some example of those: the *woonerf*, a kind of shared street with full priority to pedestrians, was inspired in some ideas from Traffic in Town (Buchanan, 1963) and has been firstly applied in Deft in 1969; neotraditional development, inspired in the classic small town of the USA, with a walkable environment, mix of uses and a clear civic structure; transit-oriented development (TOD), where dense, mixed-use areas are organized around transit and commercial hubs and emphasis is given to pedestrians and public transportation; and shared space, a concept developed in the Netherlands, in the 90s, which assumes the street as a meeting area, where cars and pedestrians share the same space, but the priority is always the pedestrians'.

These are some of the many strategies and new concepts that tried to turn the tide in favor of pedestrians. Some were empirical experiences, others were engineer-based proposals. More recently, especially from the 2000s on, the walkable environment and the pedestrian behavior started being studied in their many dimentions. That is to say, not only the built environment was considered, but also other essential aspects for pedestrians, such as the urban context, local culture, personal perception, purpose of the trip and individual characteristics (physical, mental, etc.) (Moura, Cambra, & Gonçalves, 2017).

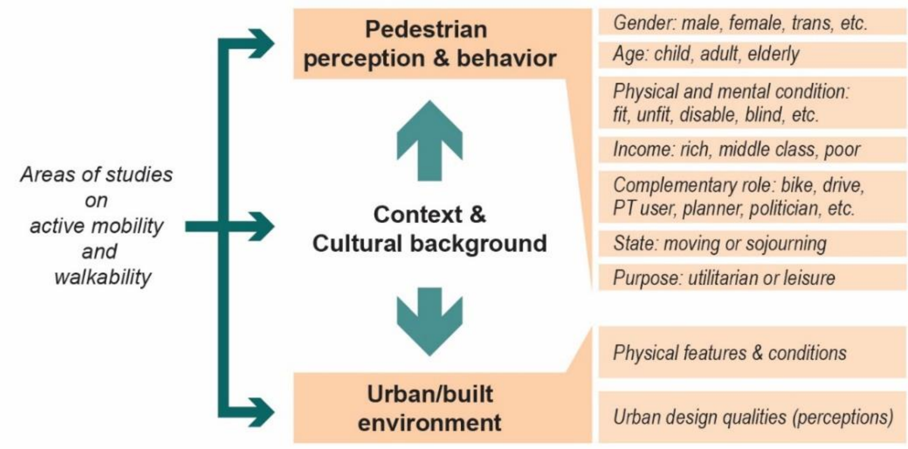


Figure 8. Some of the dimensions that influence a walkable environment. Source: author.

Even with that much of complexity, the current approach to pedestrian planning is normally based in standard manuals and car-based methodologies. To deconstruct these established concepts, it is important, first, to be aware of the relevance of the pedestrian mode, then to have a look at how it is being studied.

2.4.1 The importance of walking

Walking has been linked to a myriad of benefits. The report 'Cities Alive: Toward a walking world' (ARUP, 2016), for example, has compiled a list of fifty benefits, sorted in four frameworks: social, economic, environmental and political (Figure 9). Social benefits are the ones related to health and wellbeing, safety, placemaking and social cohesion and equity. The economic ones include the local economy, urban regeneration, cost savings, and city attractiveness. Environmental benefits are linked to ecosystem services, virtuous cycles, livability, and transport efficiency. And political benefits, to leadership, urban governance, sustainable development, and planning opportunities.

Figure 9. Walking benefits framework. Source: (ARUP, 2016)

For each benefit, the report brings data from many cities of the world that prove how much walking has enhanced the urban environment and the community's life. From a better mental health to increase in local economy and decrease pollution, walking is one answer (among others) to many of the current urban challenges.

Furthermore, focusing on the equity topic, it must be stressed that for many people, especially in the Global South, that can sometimes be the only choice of transportation, therefore, more than a mere benefit, an actual necessity. To understand the magnitude of this statement, it can be observed that in low-income cities, this mode of transport is often the predominant one (Vasconcellos, 2001). In Brazil, for example, in cities with more than 60 thousand inhabitants, 36.5% of all trips are made on foot (ANTP, 2016) (Figure 10). For comparison purposes, in Portugal, the walking share drops to 16,4% (INE, 2011), while in Germany, it appears with 22% (infas, 2018), both showing a greater share of private vehicles (Figure 10).

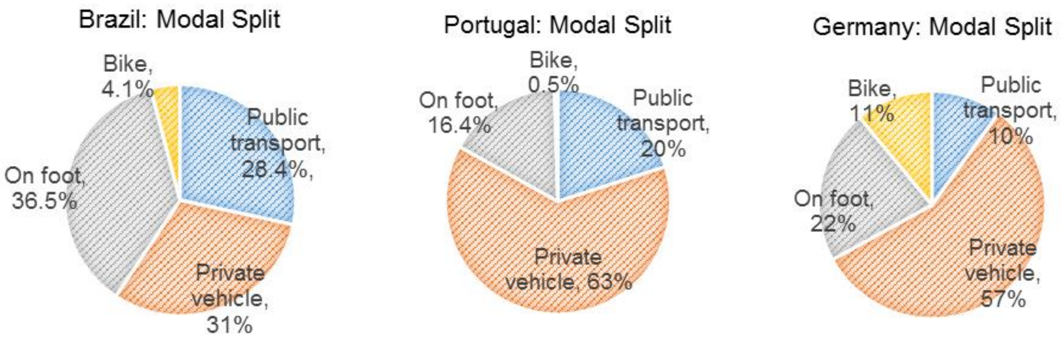


Figure 10. Modal split from Brazil, 2014, Portugal, 2011 and Germany, 2017. Sources: (ANTP, 2016; INE, 2011; infas, 2018)

Even when analyzing great metropolitan areas, where public transportation counts the most, because of its capacity, the pedestrian mode must still receive attention, since every single trip is a combination of walking and any other modes. In other words, improving walking conditions, besides all benefits associated, is also a high democratic and equitable measure, which influences the urban dweller's life.

2.4.2 Walkability and its dimensions

Having those benefits in mind, it is comprehensible why cities around the world started investing in pedestrian planning and in the promotion of a walkable environment. It has also been accompanied (and supported) by an increasing number of related researches, from academia and other institutions. As to simply illustrate this flow, the chart below (Figure 11) shows how many times "walkability" and "walkable" appeared in books written in English (from Google Books repository) from 1960 to 2008. Considering the increasing popularity of this concepts, it is much likely that the rise has been going up since then.

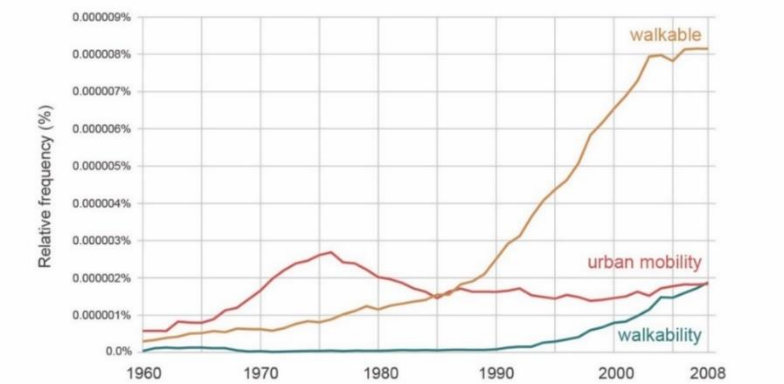


Figure 11. Citation of the concepts of "walkability", "walkable", "urban mobility" in books from 1960 to 2008. Source: Google Books - Ngram Viewer

Since this subject relates to many areas, professionals from different fields are dealing with it and bringing up its complexity within the urban environment. It has been studied through many methodologies, which contributes to characterize different aspects of it.

In fact, pedestrian research and planning is taking root also due to a sum of different points of view. It embraces sociological, anthropological, architectural, engineering, economic, ecological, health and psychological approaches; it goes from the micro scale of a street to the macro scale of a metropolitan area (D'Arcy, 2013); and it covers theoretical issues, such as models, criteria selection, observational studies, walk indexes, etc., as well as practical experiments, like implementation of new technologies, street designs (complete streets, shared spaces), primers, etc.

As with any other subject, it is essential to understand which variables should be studied and the relation between them. Although, it can become a tough task since a great part of the variables depend on subjective evaluation and their relationship are not always clear. Authors from distinct background consider different inputs according to the contextual purpose of the study, the detail of the information required and scale of interest (D'Arcy, 2013).

In some cases, researchers have taken a very restrictive approach, for example, when professionals from transport planning study walkability solely based on levels of service (LOS) method, as if pedestrians would flow as cars on a street/road (TRB, 2000). This simplistic view misses the complexity of a pedestrian system, misrepresenting the real situation and eventually, misleading the researcher/decision-maker. For this reason, a multidisciplinary research is desirable and needed, in order to better understand the many facets of walkability (Lo, 2009). To grab a sense of it, some different approaches are presented as it follows.

Jan Gehl, from an urban design and psychological perspective, starting in the 60s, has been studying the behavior of people in the public spaces and how the built environment influences it (Gehl, 2010). He accredits livable and used spaces to compact city structure, acceptable walking distances to key destinations, reasonable population density, diversity of functions, and good-quality city space. Specifically about footpaths, some of his findings are: the path should be as straight as possible, there must not be interruptions, pedestrians should have priority, the streets' façades should not be "blind" (there should be doors and windows along it), among other perceptions as safety, protection, and pleasant sensorial experience.

From an anthropological view, William Whyte, during the 70's, has conducted a study of people's behavior in public spaces. His group has done years of observational studies and ethnography. He then summarized the characteristics of public space that do and do not invite people to walk and sojourn (Whyte, 1980). Besides identifying the type of users and how they use the space, he has also pointed out positive aspects which attracts people/walkers: the presence of other people and movement, places to sit, availability of direct sun, trees and water, wind protection, places to eat and retail, visual accessibility to other spaces, among others.

Reid Ewing, from an engineering and transport planning background, has compiled a primer for pedestrian- and transit-friendly design (Ewing, 1999), where his team has selected a list of 23 features that would contribute to the pedestrian movement. Among them, there are factors like medium-to-high densities, a mix of land uses, short to medium length blocks, safe crossing, traffic calming along access routes, nearby parks and other public spaces, coherent and small-scale signage, especially public art, etc. They cover a very wide range of physical aspects and although the author has picked most of them from existing literature, many had no empirical evidence.

Later on, Ewing himself, together with Susan Handy, have made an attempt to measure subjective qualities of the pedestrian environment (Ewing & Handy, 2009), stating that physical features alone would not be of much help in explaining walking behavior (Figure 12). Focusing on people's perception of the environment, they selected and measured five urban design qualities: imageability, enclosure, human scale, transparency, and complexity. These concepts were taken from other authors and reflect the qualities of the urban design. It is an interesting approach, even though they have based it on an experts panel and, as they pointed out, it could not reflect the perception of pedestrians in general.

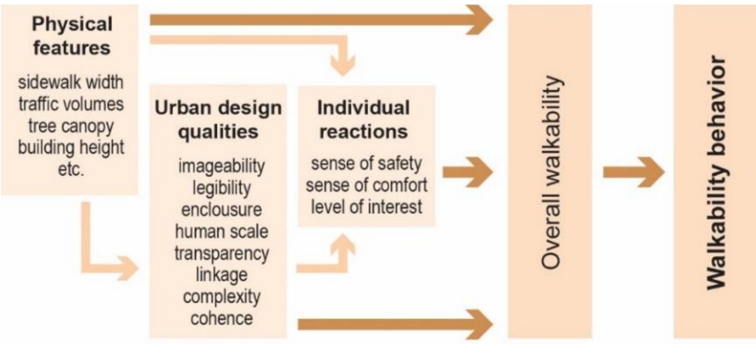


Figure 12. Conceptual framework of Ewing and Handy. Source: adapted from Ewing & Handy (2009)

The operationalization of such subjective factors has been a great challenge for researchers. Complementary, a lot has been done to combine different fields of knowledge to achieve better results; that is to say, having a more multidisciplinary and systemic approach to deal with the subject. Still, as D'Arcy (2013) has pointed out, these researches vary so much in literature, methods, and vocabulary that it becomes sometimes difficult to communicate the findings to other professionals. Inside this topic, D'Arcy brings the socio-ecological model, arguing it has been taken as an appropriated framework to analyze the relationship between the built environment and physical activity. It is based on ecological models, which considers multiple levels of influences that interact and reinforce one another and can affect the individuals differently, according to their own beliefs and conditions (Figure 13).

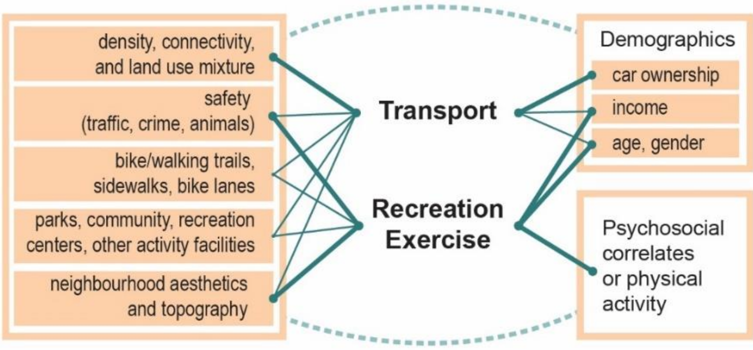


Figure 13. Ecological model of neighborhood environment influence on walking and cycling, by Saelens, Sallis and Franck. Source: adapted from (D'Arcy, 2013)

The socio-ecological model goes beyond and incorporates some perceptual elements. In doing so, it brings importance to variables of behavior outcomes, either the ones from the individual, like personal characteristics and motivations or external to the individual, such as the context, the social and physical environment. Figure 14, for example, is an adaptation of a socio-ecological model regarding walkability. Besides the attention to the user's perceptions, the author also included accessibility and feasibility.

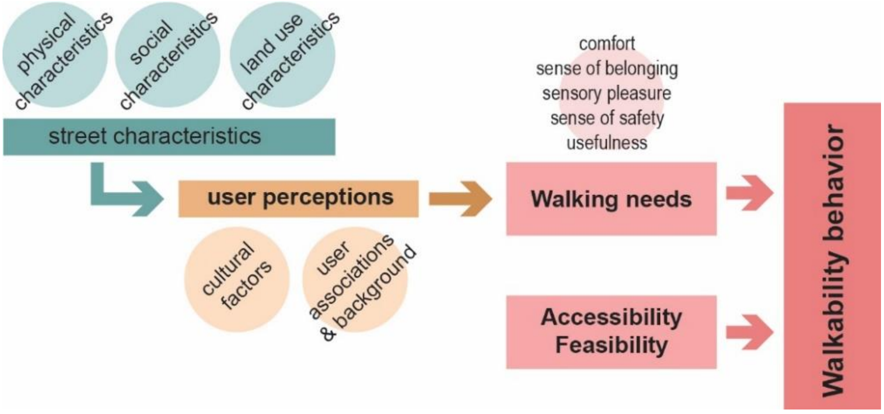


Figure 14. Conceptual framework from Mehta, based on socio-ecological models It also includes accessibility and feasibility variables. Source: adapter from (D'Arcy, 2013)

Walkability is already being improved in many countries regarding accessibility, mainly with respect to physical disabilities (blindness, deafness and of locomotion). This is extremely important, although it reflects just a small part of the individuals' perception and, thus, of their behavior. Age, gender, income level, needs, interests, transport choice, culture, etc., are all aspects that can alter the appreciation of the urban space from the pedestrian perspective. There is, therefore, a long path to be "walked" and understood related to this subject.

2.5 Considerations

This overview demonstrates how dense and complex the study of pedestrians can be.

The purpose was to show the importance of walking and how this mode evolved over time. Beginning from the firsts settlements, where the distances achieved on foot shaped the city, and continuing to other periods, when, even with the introduction of new means of transportation (or other function to the urban life), walking has remained the most essential mode of transport, due to its universality and because it is the mode which gives access to places and to all other transports.

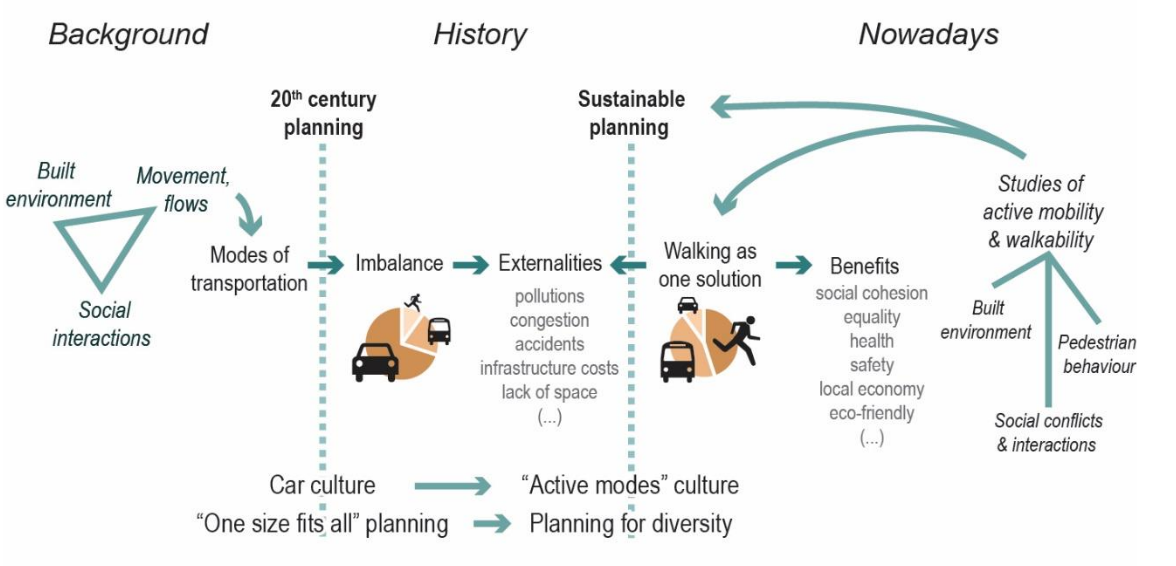


Figure 15. Framework of the literature review. Source: author.

Nonetheless, very recently, during the 20th century, pedestrians started losing attention by city planners and being put aside as an urban issue. The focus, instead, turned to mass transportation and, above all, to motorized vehicles. It was the "machine-age revolution", as the architects from the modernism movement would celebrate, as to justify their megalomaniac theories for a modernist city. It is understandable that engineers, architects, planners were thrilled with the new possibilities of speed and load capacity of vehicles, but the monofunctional and "monodisciplinary" approach used caused problems to arise in other fields and/or populations, as it was the case of pedestrians.

Besides that, this ranking of priorities was also politically boosted by some economic (and powerful) agents, such as the car industry and chambers of commerce. That move has worsened the unbalance between modes, promoting the image (and the sales) of the individual motor vehicle. That, of course has had tremendous consequences on urban planning and urban culture.

From a contemporary point of view, one could argue that planners should have had a stronger critical analysis about the impacts of the decisions taken, as their role is to strive for the rights of each citizen. Planners must take into consideration every player, care about how one affects the other and search for measures (restrictions, priorities, etc.) that lead to more equality of rights and that permit a balanced life in society. There will always be losses for every group, but gains should not be impositions from the strongest or the most powerful player.

Nowadays, the tide is turning to a more **sustainable planning** and **active modes** (pedestrian and cyclist) are receiving more attention due to the numerous benefits associated to them. Researchers from many fields are studying the pedestrian mode through different perspectives, trying to prove the advantages of it and to understand what makes people walk. At the same time, governments and institutions are investing in pedestrian planning and design, in order to mitigate some of the urban problems (pollutions, congestion, traffic accidents, equity, etc.) and to promote a better quality of life in the city.

Therefore, studies have been carried out, as it was briefly mentioned, regarding the built environment, social interactions, pedestrian perception and behavior. Several approaches, from psychology, social sciences, architecture, engineering, urban planning and medical science, have expanded the concept of pedestrian and its dimensions and made it clear that it is also about facing it as a political matter, which demands a **change of mindset** and **priorities**.

To study pedestrians and walkability and to truly understand it, one must be aware of the characteristics of the pedestrians and of the context. These variables, when confronted with each other, results in different behaviors and ways of using (or not using) the public space. The simplistic view of the pedestrian by the modernists or the traditional transport planning must be left behind and a more **multidisciplinary and comprehensive** (yet feasible) **framework** has to be worked out. Also, pedestrians cannot be seen as a homogeneous group anymore, instead, the diversity of them (as of the society itself) must be acknowledged.

Finally, walkability is at the core of **pedestrian planning**, what makes it an essential knowledge to be developed so as to support any urban policy and/or design towards a more inclusive and equal environment.

Seeking to apply this theoretical knowledge, the following chapter covers a review on some methods that are used to study pedestrians and walkability. These methods, together with the explained theory, supports the exercise of the proposed case study.

3 Review of methods

Every method that deals with walkability have benefits and limitations and their suitability depend on the detail of information required, the contextual purpose and the spatial scale of interest (D'Arcy, 2013). As a practical matter, the application of a method can also be restricted by the availability of data or difficulties in producing it.

Based on the previous literature review, this dissertation draws upon existing methodologies to work the case study out. Instead of searching for a specific set of variables on walkability, which, as previously mentioned, can be by itself an exhausting task, the study relies on pre-selected variables of selected methods. Later, variations and/or a combination of these methods are tested in order to search for contributions to the field.

This chapter presents a brief review of these methodologies, emphasizing their connections with the walkability field and the justification of this choice. The selected methods are (1) IAAPE, a walkability evaluation method (Moura, Cambra, & Gonçalves, 2014); and (2) Space Syntax, a method that deals with movement and configuration of the built space.

3.1 Indicators of Accessibility and Attractiveness of Pedestrian Environments (IAAPE)

A walkability index is a tool that combines a set of variables to measure the quality of the walking environment and the walking behavior. Its results can be used to assess the walkability of an area, either to propose improvements, establish design guidelines, or to simply compare it with other places or over time. Hitherto, many indexes have been developed and tested, though none has been fairly accepted.

The selected method, Indicators of Accessibility and Attractiveness of Pedestrian Environments (IAAPE), has been developed at Instituto Superior Técnico (UTL, Lisbon) and aims to assess walkability by combining factors of pedestrian accessibility and attractiveness and assembling them in a GIS-based tool. The resulting walkability score can be used to support urban planning and design (Moura, Cambra, & Gonçalves, 2014). The selection and weighting of the factors had derived from a participatory process, that was carried out through an expert panel and stakeholders' sessions. The IAAPE method was applied in two case studies located in the Municipality of Lisbon (Figure 16).

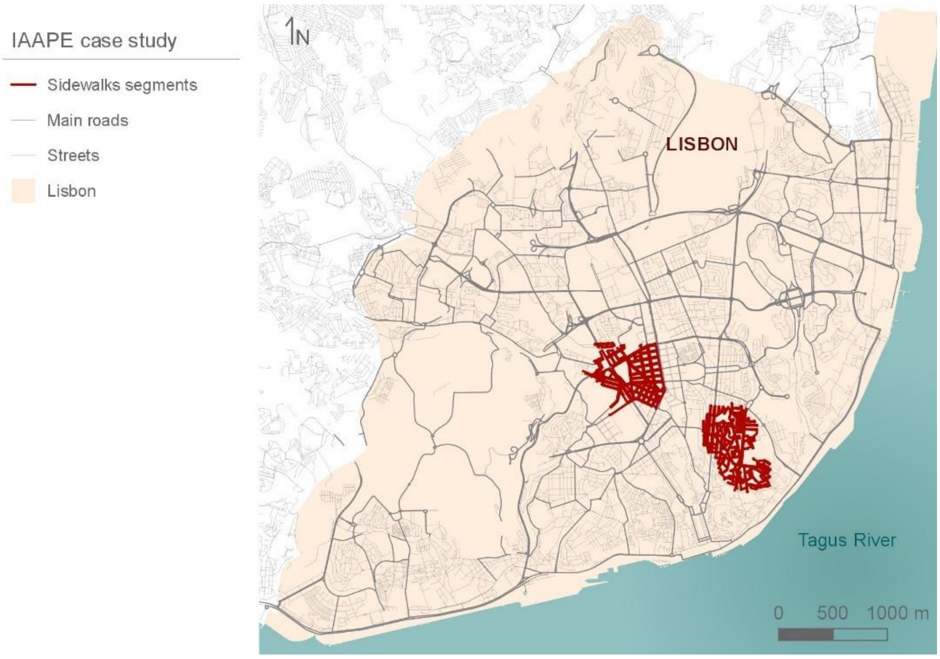


Figure 16. IAAPE case study. The method was applied in the highlighted sidewalk segments. Source: author.

The selection of this method for this dissertation was based on the following reasons: first, its broad and careful choice of factors concerning walkability and its social inclusive and participatory nature; second, the possibility to combine other tools within IAAPE structure; finally, for the convenience of the proximity and easiness to work and exchange information with the authors.

3.1.1 Variables and workflow

The selection of the factors that influence walking was based on a careful literature review and they were sorted into seven groups, the 7Cs layout (Cambra, 2012). As mentioned in the previous chapter, other researchers have already done an attempt to set lists of variables that determine walking. One example is the D variables (Ewing & Cervero, 2010), which comprehends variables related to density, diversity, design, destination accessibility, distance to transit and demand management. Another example is the '5Cs of Good Walking Networks', elaborated by Transport for London (Transport for London, 2005), where the groups of variables were named after the characteristics of a good walkable environment: connected, convivial, conspicuous, comfortable, convenient.

IAAPE has evolved from the latter and, taking it further, has incorporated other two dimensions, namely, coexistence and commitment. Therefore, the 7Cs can be described as:

1. Connectivity: to what extent the pedestrian environment is connected, linking origins and destinations. This group is about the existence of a pedestrian infrastructure and the links with other modes;
2. Convenience: how appropriate, useful and time-saving the pedestrian environment is. It relates to the accessibility of the network and to street diversity in terms of land use;
3. Comfort: how easy, protected and untroubled the environment is. It deals with some street characteristics and the existence and quality of street elements;

4. Conviviality: how pleasant the environment is for social life and, therefore, walking. This group has to do with the opportunity for interactions, social encounters, and the built and natural environment;
5. Conspicuousness: how easy it is to walk around. It is linked to the concepts of legibility and wayfinding;
6. Coexistence: how pedestrians and other transportation modes exist in the same place and time. It relates to conflicts and safety issues;
7. Commitment: the existence of engagement and liability toward the pedestrian environment. It has to do with government policies and walking promotion.

Most of the walkability indexes gather a set of indicators and apply it in a case study. The IAAPE project went further on and a method was created to choose and validate these indicators. For this purpose, different groups of pedestrians were invited to expose their perceptions about the indicators.

It is an important step as it is socially responsible since it takes into consideration not only the point of view of the researchers but rather a plural perspective of the urban environment. It was worked out through an exhaustive work with an experts' panel, followed by some stakeholders' sessions. The groups of people involved were local authorities, community-engaged people, elderly people, people with disabilities and professionals from distinct fields of practice. People who participated in the stakeholders' session were divided according to the different "roles", corresponding to "types of pedestrians", for instance, adults, children, seniors and persons with mobility impairments.

The step-by-step of the method corresponds to Figure 17 and is described below (Moura, Cambra, & Gonçalves, 2017).

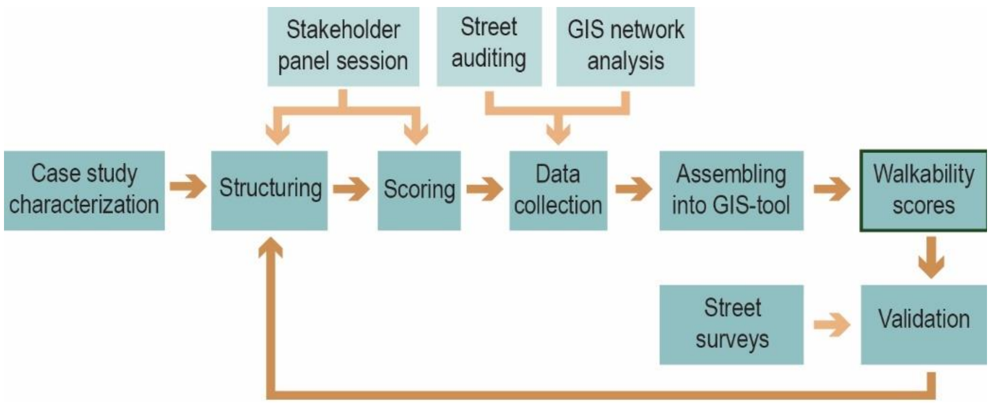


Figure 17. Conceptual framework of IAAPE. Source: adapted from (Moura, Cambra, & Gonçalves, 2017).

1. Case Study characterization: the available information about the site to be studied was gathered and the pedestrian network of the area was built in a GIS platform. The network corresponded to the sidewalk segments;
2. Structuring the evaluation: consultations (from experts and stakeholders) were carried out for the selection of the key-concern corresponding to the 7C's layout. They were picked up from a list provided by the researchers and resulted in different selections and rankings for each represented pedestrian group (adults, parents of children, seniors and people with mobility

impairments). For the next stage, because of time constraints, only the highest rated key-concerns from each group were taken into consideration (highlighted in blue in Table 1);

Table 1. Key-concerns related to the 7Cs. The concerns highlighted in blue got the highest rates from the pedestrian groups. Source: adapted from (Moura, Cambra, & Gonçalves, 2014).

Connectivity	Street density (alternative routes)	Pedestrian infrastructure (path continuity)	Path directness	Accessible pedestrian network	Network integration in the urban fabric
Convenience	Land use diversity	Sidewalk effective width	Obstacles (absence of)	Daily commerce (e.g., bakery) and services (e.g.,ATM)	Facilities for accessing steep streets
Comfort	Vigilance effect or perception by pedestrians	Pavement quality	Amenities (e.g., trees, bench)	Climate protection	Sensory quality of urban environment
Conviviality	Opportunities for meeting and sojourning	Existence of anchor places (e.g. public facilities)	Service hours	Active edges (absence of blank walls, empty lots)	Population density
Conspicuousness	Existence of landmarks (e.g., monument, square)	Clear sightlines	Street toponomy (e.g., street names, signposting)	Architectural complexity	Sense of place
Coexistence	Traffic safety (at pesdestrian crossings)	Pedestrian crossing location ("desire lines")	Appropriate spatial segregation of transport means	Proportion of pedestrian friendly streets	Pedestrian space "invasion" (e.g., parked cars)
Commitment	Enforcement of pedestrian regulations (laws)	Street cleanliness	Means for public participation	Existence of design standards and public space interventions	Walking initiatives (e.g., walk to school, to work)

3. Scoring key-concerns and selecting indicators: the key-concerns were weighted by the pedestrian groups, according to their personal interests/needs and to the trip purposes (either utilitarian or leisure). This step was done through a guided-Delphi session, resulting in weights for each key-concern. Then, in order to measure them, the researchers elected some indicators, as shown in Table 2;

Table 2. Indicators defined for each key-concern. Source: adapted from (Moura, Cambra, & Gonçalves, 2017).

7 Cs	Key-concerns	Indicators
Connectivity	Ped. infrastructure (continuity)	Least nr. of segments: ratio between Euclidean distance and shortest path
	Path directness	Shortest distance: ratio between shortest path and Euclidean distance
	Accessible pedestrian path	Yes/no. Existence of barriers, steps, etc.
Convenience	Land use diversity	Number of distinct land use types
	Sidewalk effective width	Sidewalk effective width
	Daily commerce & services	Number of distinct commerce and services in use on a daily basis
Comfort	Vigilance effect	Qualitative evaluation of façade transparency
	Pavement quality	Qualitative evaluation of pavement (regularity, smoothness, slippery)
Conviviality	Meeting places	Yes/no. Existence of public meeting places
	Existence of anchor places	Yes/no. Existence of equipments and facilities
	Service hours	Yes/no. Existence of activities with extended service hours
Conspicuousness	Existence of landmarks	Yes/no. Existence of reference elements
	Street toponomy	Yes/no. Existence of street naming and wayfinding signs
Coexistence	Traffic safety (ped. crossings)	Crossing type, pedestrian visibility & nr. of potential conflicts with vehicles
	Pedestrian crossing location	Ratio between formal intersection and total road crossing
Commitment	Enforcement of pedestrian regulations (laws)	% of inaccessible pedestrian network with respect to total
	Existence of design standards & public space interventions	Yes/no. Existence of comfortable walkways

4. Data collection: data were collected from maps, aerial imaging and street audits, and stored in a GIS platform, where the network was created. Then, the indicators were assigned as attributes

of the segments of this network. Also, the spatial indicators (Connectivity dimension) had to be calculated using a GIS network analysis module;

5. Assembling walkability scores: in the GIS platform, indicators were first normalized with value functions, converting all to a 0-100 range scale, then summed up resulting in walkability scores for each pedestrian group and each trip purpose and weighted accordingly (weights from step 3). For more detailed understanding of the transformation and weighting of the values, see "Annex A. IAAPE Indicators and weights". The results were translated into maps, where walkability scores can be visualized by pedestrian group and by trip purpose (Figure 18);

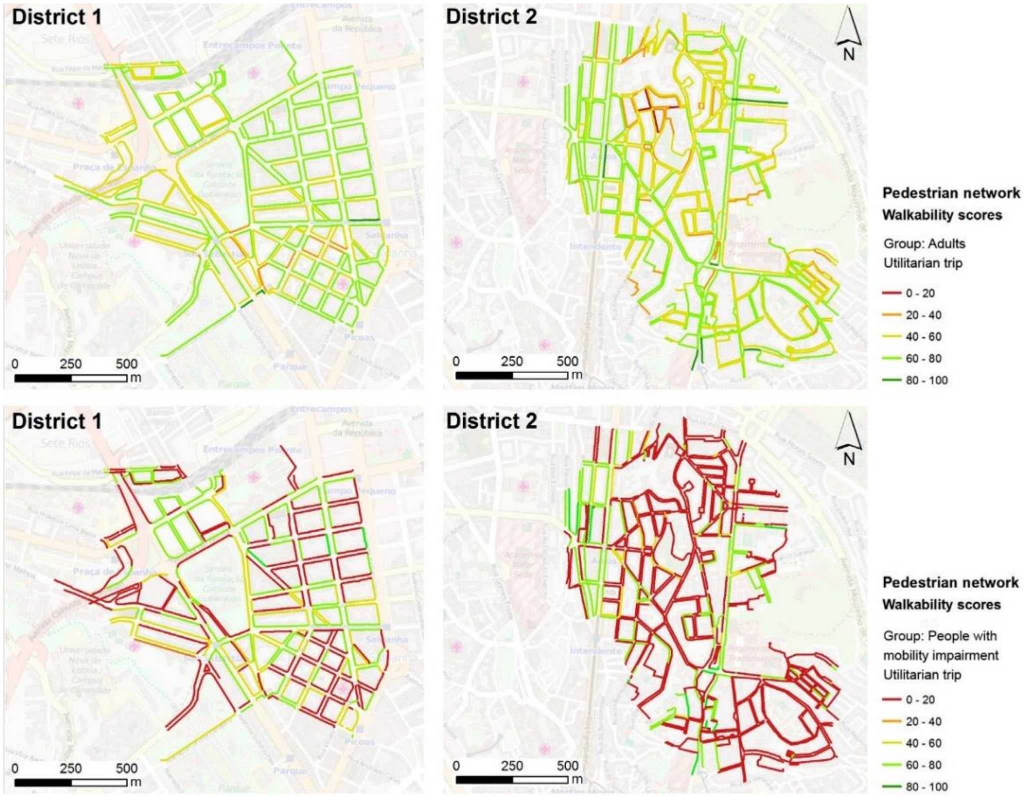


Figure 18. Examples of maps showing results of the applications of IAAPE. Above: walkability scores for adult pedestrians in utilitarian trip. Below: walkability scores for pedestrians with mobility impairment in utilitarian trip. Source: (Moura, Cambra, & Gonçalves, 2017)

6. Validation: the walkability results can be validated through some methods, including stakeholders' appreciation, street surveys, home-based surveys, etc., to find out if the objectively-measured scores correspond well to the pedestrians' perception. IAAPE project adopted a home-based survey. It comprised 400 valid responses, where people were asked to identify the most and least walkable street in their neighborhood. IAAPE results showed a good match for higher walkability scores, although lower scores presented low matches, which could suggest that other influence factors were missing.

   Validation with pedestrian counts was also tested (Cambra, 2015), resulting in significant and positive association between the walkability scores and pedestrian activity (pedestrian flows plus stationary pedestrians) of r = 0.496.

The authors concluded (Moura, Cambra, & Gonçalves, 2017) that treating pedestrians as a heterogeneous group had a significant impact on the walking environment evaluation and recommended that this detailed analysis must be pursued. The results could be used, for example, for specific improvements in urban design and mobility planning.

Other than considering different pedestrian groups, the authors also pointed out other contributions of this method, such as building a framework with quantitative and qualitative indicators; having a participatory process with stakeholders to decide about key-concerns, as well as using their opinion to weight the indicators, instead of simply adding them up; considering different trip motives (utilitarian and leisure); creating a network based on the pedestrian paths; and the validation of the results.

3.1.2 Street auditing and pedestrian counting

Since the street data compiled within IAAPE project is used in this dissertation, the data gathering is described as it follows.

To accomplish the fourth stage, data collection, an extensive street auditing has been undertaken, which was then used to calculate the selected indicators. To accomplish that, 6 auditors covered an extension of 81,34 km of pedestrian paths (216 streets), gathering qualitative and quantitative information related to the indicators mentioned before (Table 2). The auditors followed an auditing guide and were trained in on-site sessions.

Besides that, pedestrian counts were also carried out to be used in the validation stage (Cambra, Moura, & Gonçalves, 2017). The objective was to check if high walkability scores would correspond to high pedestrian activity. The counting was carried out in a sample of the case study corresponding to 60 sidewalk segments (5% of the total). The moving observer method was adopted, which is suitable to record moving and static people. In this method, an auditor walks along a segment, back and forth, in a regular pace, recording every person in movement or sojourning. Moving pedestrians are the ones that walk in the same or in the opposite direction of the auditor and people entering/leaving buildings. Sojourning pedestrians are the ones standing on the streets, sitting on benches or tables and socializing.

The counting was conducted in the year 2015. It was undertaken simultaneously by 10 auditors who worked five weekdays and a Saturday, covering five daily periods, namely, a peak and off-peak hour in the morning (8 to 9 AM and 10 to 11:30 AM), lunch hour (12:30 to 2 PM) and an off-peak and peak hour in the afternoon (3 to 4:30 PM and 5 to 6:30 PM).

3.1.3 Pros and cons of the method

IAAPE methodology is a comprehensive walkability index, that considers quantitative and qualitative data related to several aspects of the pedestrian environment, from the physical characteristics of the sidewalk to law enforcement issues, corresponding to the 7Cs layout. Then, similar to what is proposed in this dissertation, IAAPE also set a network based on the pedestrian paths.

To set the objective measurements, it embraces a participatory process. It aims to deal with pedestrian perception, which is a subjective evaluation of the urban environment. Therefore, it searches for a socially responsible approach, covering a diversity of pedestrian “types”, which could express their opinion on what influence their walking trips, either utilitarian or for leisure.

Furthermore, the methodology was also well validated through a home-based survey and pedestrian counting, what showed the robustness of its application.

Conversely, the authors suggest some limitations of the method (Moura, Cambra, & Gonçalves, 2014), such as the disagreement among the inputs from literature, experts, and stakeholders; some constraints when dealing with groups of people, regarding time and fatigue; the variability that can occur in the results according to the composition of the expert's and stakeholder's panel; and about the lack of empirical evidence on the factors that impact walking behavior.

It can also be complemented by signalizing the lack of representation (or differentiation) of some important pedestrian groups, especially regarding gender (women, men, trans, etc.), social class (or incoming), and other disabilities (blindness, deafness, intellectual disability, etc.), which could possibly bring different perceptions. One "external" group that could also be explored are the "non-residents" or "tourists", which would probably differ from locals, particularly in the "conspicuousness" dimension. Of course, this is not an easy task, since these groups overlap each other, although rethinking how we "divide" society in these researches is always a valid discussion. Another underrepresented aspect is the perception of the urban environment along the day and, particularly, at night, when some factors would probably receive more attention, as in the case of lightning or the vigilance effect.

Then, in respect to the definition of the key-concerns, during the stakeholder's sessions, different approaches could also be used or incorporated to help the understanding of the concerns, which can be, sometimes, too abstract – some dimensions/concerns are not easily perceived by the individual person or in a short-term period. Other tools, such as street photographs or mental maps, could be used to facilitate the work.

Finally, and regarding the focus of this dissertation, the construction of the pedestrian network and the calculation of the spatial indicators were very time-consuming. The digitalization of the network was done segment by segment and, afterwards, each line had to be classified according to some categories. The calculation of the spatial indicators demanded some additional steps, such as the transformation of the data, besides requiring a licensed software.

Taking advantage of the great amount of data that has been produced about the pedestrian environment and perception, this dissertation tries to improve the method by testing a combination with another tool, the space syntax.

3.2 Space Syntax or the Social Logic of Space

Can society be explained by the space it occupies?

Space syntax is a theory of space, as well as a tool, developed by Bill Hillier, Julienne Hanson and other colleagues at the University College London in the 1970s. Its main goal is to investigate the relationship between the built environment and social existence through the study of the space configuration and the movement of entities (Hillier, 2007). Hence, it brings together two broad areas: the softer and qualitative field of social sciences and the hard and analytical field of the configurational and morphology studies.

Indeed, this theory follows a relational approach, which states that every element of the system is interconnected, and its search is to understand the relationship between elements and how they interact in order to capture the whole. Accordingly, space syntax searches for links between spatial patterns and cultural patterns, starting from a particular point of view: it assumes that some cultural factors are determined by spatial ones. It tries to prove that the social-spatial relationship follows three stages: (1) spatial patterns (urban configuration), (2) spatial life (or social encounters patterns) and, (3) social life (or cultural patterns) (Holanda, 2018).

To explain it, Hillier et al. (1993) argued that the urban grid is the primary generator of pedestrian movement patterns. The mentioned researchers named 'natural movement' the proportion that the grid itself determines the urban movement. Due to its configuration, the grid establishes hierarchies of movement, attracting uses such as retail to areas with high natural movement and others like residences to areas with low natural movement (Figure 19). Later, movement itself and attractors[1], such as equipment or commercial areas, would reinforce this logic of movement, creating, at last, the urban centralities (Medeiros, 2006).

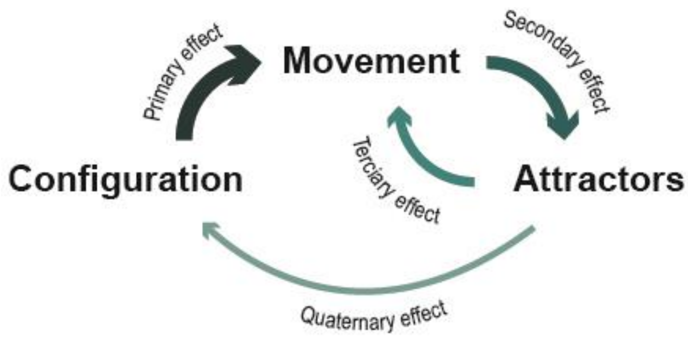


Figure 19. Movement cycle explained by the natural movement theory. Source: adapted from (Medeiros, 2006).

Although the urban grid acquires different forms for distinct cultures and along the time, this theory states that the logic that connects configuration and movement remains more or less invariant. Therefore, one of the aims of space syntax is to understand spatial rules that guide this process of generating and restraining movements, or, in other words, the properties of the grid.

Over the years, space syntax has been developed by many researchers around the world, assisted by software created specifically for its purpose (Depthmap, Mindwalk, etc.). Their findings show a strong correlation between space syntax's configuration measures and observed movement patterns. Subsequently, it has evolved from the original objectives and has been applied in many other research areas, such as archaeology, criminology, geography, anthropology, information technology, and cognitive science. It has also been studied considering different spatial scales, from the layout of a house to the extent of a metropolitan area.

Besides the configuration of the urban grid (or its layout), other data are taken into consideration in these researches, for correlations purposes or to calibrate the model. They have to do with the location of the site, connections with the wider network, land-use distribution, and landscape design.

[1] Elements of the urban environment that generate movement to itself, such as urban equipment and facilities, commercial centers, etc.

For the sake of this dissertation, which deals with walkability, attention is drawn to pedestrian movement and to the city scale, especially the neighborhood scale. Regarding the complementary data, this work concentrates on the set of indicators selected by the IAAPE project.

Henceforth, some considerations are made about how space syntax is used to analyze the urban space, followed by a brief review of researches that combine space syntax and walkability.

3.2.1 Representation and analysis

In the framework of space syntax descriptive methods, the city is represented as a network of spaces, which are the voids between buildings (or other physical barriers). As to represent those spaces and their relationship, space syntax has different forms of representation according to the type of analysis that is being undertaken (Al_Sayed & al., 2014), and they correspond to convex spaces, viewsheds and linear maps. The latter are used to investigate issues related to movement and vast systems, like cities (Medeiros, 2006). For this reason, this dissertation focuses on those, which are explained as it follows.

Axial analysis

An axial line represents a “line of sight” in an urban space. And an axial map is a network composed of the minimum amount of lines of sight necessary to cover all the spaces. In other words, all the open spaces of the city become axial lines connected one to the other. This network is then transformed into a graph, where the “vertices” represent the axial lines, as it is shown in Figure 20. From the graph, it is possible to calculate many relational properties of the network configuration.

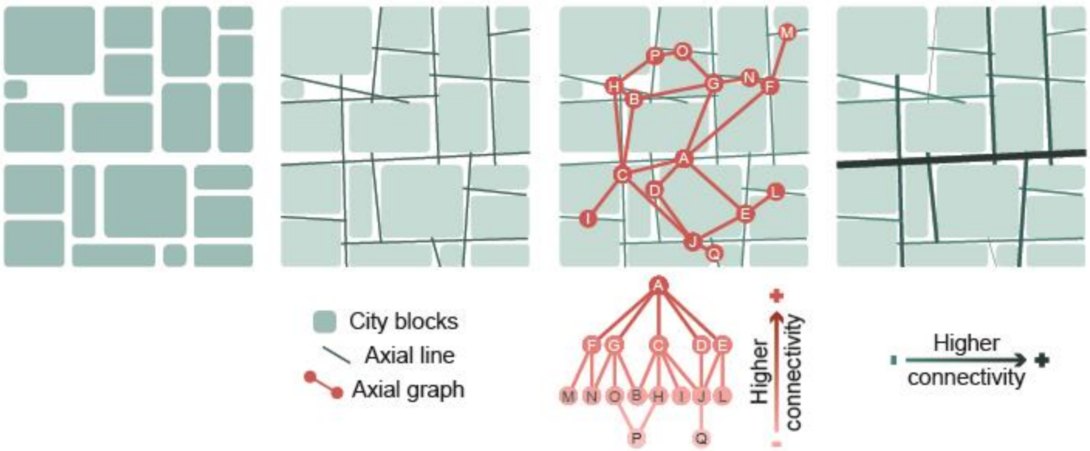


Figure 20. The axial representation of Space Syntax. Source: author

In the axial analysis, the distances are topological, which means that they are relational measures, not geometric ones. For instance, “depth” is identified as the change in direction (steps) from one axial line to another – the more steps, the “deepest” the path. It makes sense, because most people prefer the simplest and more direct paths, instead of the shortest ones (Figure 21) (Hillier & Iida, 2005).

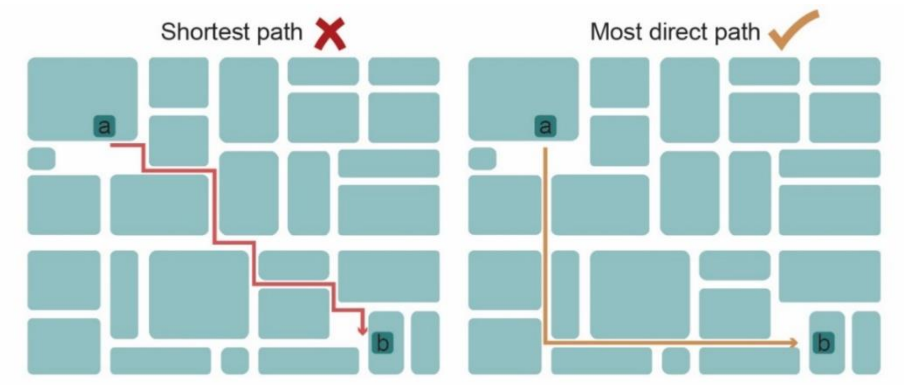


Figure 21. Most people prefer the simplest paths. Source: author

Axial maps can be analyzed through syntactic measures, such as:

- Connectivity (degree): represents the number of immediate neighbors directly connected to the space (axial line);
- Step depth: counts the many changes in direction ("steps") between one axial line to another;
- Integration ("to" movement): measures how deep or shallow a space is in relation to all others; in other words, it shows how integrated or segregated a space is. This measure indicates how many people are likely to be in a space, therefore, it highlights the main centralities of the area (Figure 22);
- Control: measures the degree to which a space controls the access to its immediate neighbors;
- Choice ("through" movement): measures movement flows through spaces. A space with a high choice value is located on the shortest paths from all origins to all destinations (Figure 22). However, other than only the shortest path, choice also considers the path directness in its equation, therefore, translating cognitive preferences (Medeiros, 2006; Hillier & Iida, 2005). This measure is useful to forecast movement potentials, for it highlights the routes that feed dynamic areas, such as the commercial ones;

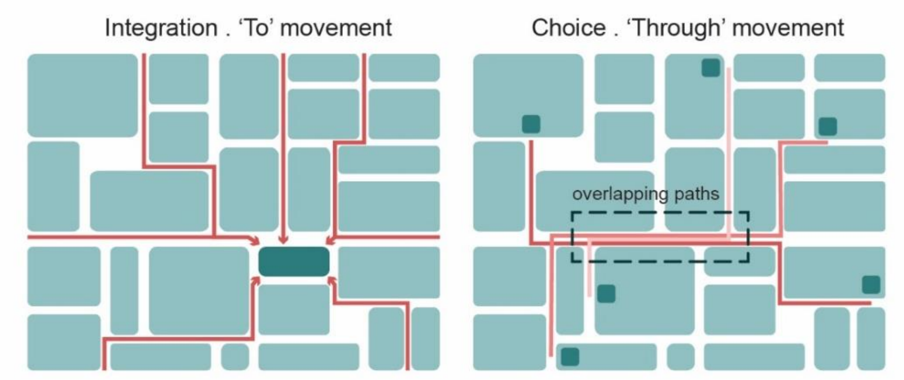


Figure 22. "To" and "through" movement. Source: author.

- Synergy: the correlation between global and local integration values. It evaluates how dependent one variable is in relation to the other, therefore using the coefficient of determination R^2. This measure shows how much the local street system is a reliable predictor of the whole urban system. Thus, smaller or more regular grids present a higher synergy (Medeiros, 2006);

- Intelligibility: the correlation between connectivity and global integration. Similar to synergy, it is calculated by the coefficient of determination R^2. It reveals the degree to which what can be seen from one point of the system (local scale) gives an idea of what cannot be seen (global scale). An intelligible system would both be well-connected and well-integrated. It can be compared to the Lynch's concept of legibility or imageability.

For further understanding, the respective mathematical equations of the syntactical measures are listed in "Annex B. Space syntax measurements".

These axial analyses consider the distances between spaces, what makes it possible to have global or local measurements. The global ones relate one space to all other of the system, for example, how accessible (on average) is a street from every point in the city. It is calculated using a radius '*n*' (or Rn). Local measures, instead, deal with the characteristics of a specific space, such as its length, the number of connections, etc. Since axial maps use topological distances, local measures are calculated with radii 2, 3, and so on; the number, indicating the many steps from the initial point (or, the many changes in direction).

The results from these calculations can be organized in tables and charts or can be visualized through color-spectrum maps, where one can identify easily where the higher and lower values are, as well as check their distribution throughout the layout.

Although much has been studied through the axial analysis, it has a series of limitations, especially when considering an urban configuration. Figueiredo (2004) points out: the degree of abstraction of an axial map, which could be considered over-simplified to its purpose; the subjectivity of the map construction, a factor that can be at least minimized by the automation of the process; the excessive long axial lines, that does not correspond to real lines of sight or accessibility, depending on the physical characteristics of the site; and curved paths or semi-linear connections, which cause misinterpretation of, for example, organic networks.

To tackle these issues and to better represent the urban network, another syntactic representation was developed, the segment analysis, that considers the topological, metric and angular connections of the streets.

Segment analysis

Each segment corresponds to a line between two intersections. Said differently, a segment map is a "broken" representation of an axial map. Segments have geometric properties, making it possible to calculate the angle between each pair. In this dissertation, segment maps are used associated to angular analysis, which was found to better correspond to spatial navigation (Al_Sayed & al., 2014).

The angular analysis minimizes the mentioned limitations of the axial analysis, bringing more information and accuracy to the model. The angular segment depth goes beyond the axial depth, because instead of just adding steps, it sums up the weighted value of the lines, where the weights are given by the angle of connection (Figure 23). Hence, the "shortest path" in this case is the one that presents the least angular cost from one segment to all others (Turner, 2007). Furthermore, in a segment map, the angular analysis is calculated with metric radius constraints, instead of topological, and was considered effective to detect “to” and “through” movement paths.

Turner (2007) highlights some studies and experiments that have demonstrated a good correlation between angular segment analysis measures and pedestrian movement. He also mentions that cognitive scientists have suggested that angles of turn have to do with how people perceive the world, which supports, once again, this type of representation and analysis.

Some syntactic measures for segment maps are:

- Angular connectivity: the cumulative turn angle to other lines (Figure 23);
- Step depth: measures the steps (turns) from the segment to all others, being the turns weighted according to their angle (Figure 23);
  - Total angular depth: measures the cumulative shortest angular paths to all segments;
  - Angular mean depth: the sum of the shortest angular paths divided by the sum of all angular intersections of the system. It indicates centralities;

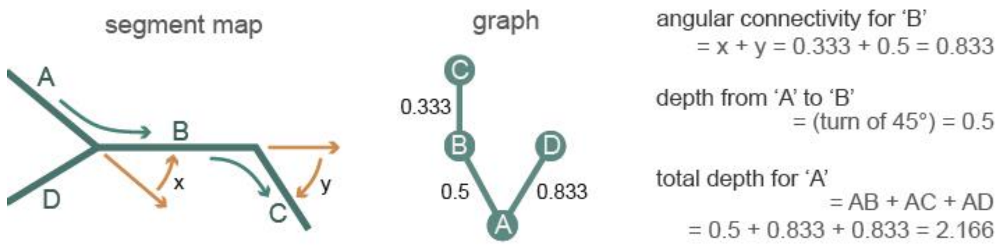


Figure 23. Paths through a network and its associated graph. Source: adapted from (Turner, 2007).

- Integration: similar to axial analysis, this indicator forecasts the “to-movement” potentials for each segment. It is a good predictor of the potential for a segment to be a desired destination;
- Choice: it calculates the potential for each segment to be selected as the shortest path, in other words, it shows the through-movement potential;
- Normalized measures: enable the comparison between systems of different sizes.
  - Normalized choice: high values indicate a grid with a deformed or interrupted structure, while mean values indicate a continuous structure.
  - Normalized integration: maximum and mean values are related to the ease of accessibility in the street network.

Radius of analysis

Just as the axial analysis, segment maps can be analyzed globally and locally. But differently from the previous one, angular segment analysis was found to work better with a metricradius cut-off (Al_Sayed & al., 2014). Small radius, like 400 or 800 meters, can be used to represent pedestrian movements, while higher radius distances should be used for vehicular flows. Remembering that 450 meters corresponds, on average, to a 5 minutes’ walk and 900 meters, to one minute’ walk (Gehl, 2010). Still, the minimum and maximum radius of analysis must be decided according to the context of the study.

Related to the radius issue, there is also the matter of the ‘edge effect’, which is the tendency of the segments close to the model boundaries to perform differently from the inner part, because of their less-connected position (outwards to the zone being analyzed). The use of local radius (cut-off distances) is commonly used to eliminate this effect, although it has not been fully studied yet. Gil (2015), however, advises that for local radius analyses, a buffer beyond the study area should be used and the extent of this buffer should be as much as the catchment area. This procedure eliminates the ‘edge effect’ for local analyses.

Space syntax measures and cognition

After this brief explanation of how space can be analyzed by syntactic measures, some comments must be made about the effectiveness of those analyses in explaining real pedestrian and vehicular flows. Once again, space syntax theory states and tries to prove that the configuration of the grid is the element that most determines movement patterns. Complementary, it states that the topological and geometrical characteristics of the network influence navigation. In order to prove this point, Hillier and Iida (2005) have calculated integration and choice through three approaches: in terms of least length (corresponds to metric distance), fewest turns (topological) and least angle paths (geometrical). Then, they correlated the results with pedestrian and vehicular counts. The outcome showed clearly that geometrical and topological measures explain much better the movement flows, meanwhile metric-based measures present low correlation values. The authors explain that although people look for the shortest path, cognitive choices are influenced by the geometric and topological properties of the network, making it difficult to calculate metric distances. Therefore, as already mentioned, people follow the more direct path, because cognitively, it seems shorter.

3.2.2 Space syntax and walkability

Space syntax can be a powerful tool to evaluate walkability. It has already been used to evaluate pedestrian movement and, in fact, several studies showed that configuration approaches can predict 55 to 75% of pedestrian movement (Lerman, Rofè, & Omer, 2014).

The researches vary significantly in scale, geographic location and complementary data used. In general, authors choose a set of environmental and behavioral factors that seem to fit the issue being studied. Because of this variance, they cannot be compared. Therefore, three of them were chosen to be shown as examples of how space syntax is being used within the walkability field.

Baran et. al (2008), have analyzed the street design and walking behavior of two different neighborhoods: one that follows the New Urbanism design and a conventional suburban one. They also have taken into consideration the purpose of the walking trip, if utilitarian or for leisure. The authors have studied the relationship of three quantitative measures of syntactical properties of teh space and the walking behavior. Among other findings, they have identified a positive correlation between both recreational and utilitarian walking trips and the space syntax measures of control and integration in both neighborhoods. From that, they state that walking trips are influenced by the configuration of urban space, which is relevant for urban planners and designers.

Lerman et. al (2014) have used space syntax to create a pedestrian prediction model to evaluate and forecast pedestrian movement in the city of Bat Yam (Israel). In their conclusions, they assured that the configuration of the urban grid can explain most of the pedestrian movement distribution and that commercial fronts strengthen its volume. They concluded that predictions of the volume of pedestrians are inaccurate. However, the model could be used to estimate the differences in pedestrian distribution throughout the city, in relative terms instead of absolute measures. They also point out that, when overlapping this study with other modes' networks, an analysis of the conflicts could be made for planning purposes.

On a macro scale, Dhanani and Vaughan (2016) have developed a walkability modeling tool to study the Greater London area in terms of pedestrian activity. They have combined space syntax analysis with three other factors, namely, land use intensity and diversity, residential density, and public transport accessibility. The chosen measures have been constructed from data available for the whole UK, making it possible to replicate the study in other zones of the country. Some of their findings relate to the clustering of pedestrian activity, to the correspondence between transport accessibility and pedestrian activity, among others. The aim of the study is to serve as support for urban planning and transport infrastructure development.

3.2.3 Pros and cons of the method

Space syntax deals with the urban environment through a holistic and relational approach. To find the relations between society (social patterns) and space (spatial patterns), it focused on movement and configuration (Heitor & Pinelo-Silva, 2015). This systemic approach has demonstrated great potential to study the pedestrian movement and environment, being the reason why it has been chosen to be used in this dissertation.

On the other hand, space syntax focuses on the collective or aggregate approach and not individuals. Therefore, it analyzes the big picture, not the small specificities of society, where some nuances do appear. In the case of pedestrians and of the small scales, it is sometimes essential to put on a magnifier glass to apprehend some groups' perceptions, as it is the case of children or people with disabilities.

Also, space syntax deals with isotropic models, in other words, it does not consider the physical qualities of the urban grid, such as pavements, slopes, façades, etc. However, these are substantially influential on how pedestrians perceive the walkable environment. These are aspects that walkability assessment methods and tools (such as IAAPE) can capture effectively. Then, although space syntax is a powerful tool to work with the urban environment and, specifically, with the pedestrian mode, complementary data and/or tools are required for the purpose of this research.

3.3 Considerations

There are many methods and approaches to deal with pedestrians and walkability. From the literature review presented in the second chapter, two methods were chosen to be worked in this dissertation. IAAPE and Space syntax were briefly described in this chapter to demonstrate their potentials and to justify this choice.

Importantly to say, a first approach to compare IAAPE and space syntax has already been made by Cambra et. al (2017). However, the researchers did not go much deeper and used only some basic tools and measures of space syntax. Even so, they corroborated with evidences that configuration plays a large role in explaining walkability (up to 40%) and that it would be worth exploring it further.

Following this path, this dissertation seeks, first, to acknowledge what is the role of the pedestrian in the city and what is important to them. Second, how it can be objectively studied, and which tools can be used to capture the global and the specific perspectives on the issue.

Space syntax covers the global view, revealing the patterns and the relations on how people move about in the space. It demonstrates a holistic view of the city, connecting built environment, flows, and social activities. It has long been used to study pedestrians and, more recently, walkability. Yet, as any other theory, it has great space for improvements. In the same way that space syntax has evolved from axial to segment maps, there are also other kinds of representation that can be tested to get to better results. Also, as already mentioned, space syntax does not cover many of the characteristics of the space, thus, it must be used in combination with other data/tools to compose the whole picture.

On the other side, IAAPE has a great potential to evaluate the more specific characteristics of a walkable environment. Besides caring about a long list of factors that influences walking, it has also a responsible social and participatory approach, considering that the project has worked with groups of different pedestrians (stakeholders) to select and weight the aspects of the environment that most affect them. This raises a multiple-perspective and site-specific analysis, which can be of great use for urban planning/design purposes. Besides Lisbon, IAAPE was also tested in another city (Almada), although more experiments are to be developed. Other than testing it in other places, one way to develop the tool is to adjust and improve the way it measures the pedestrian environment; and that is the point of this dissertation.

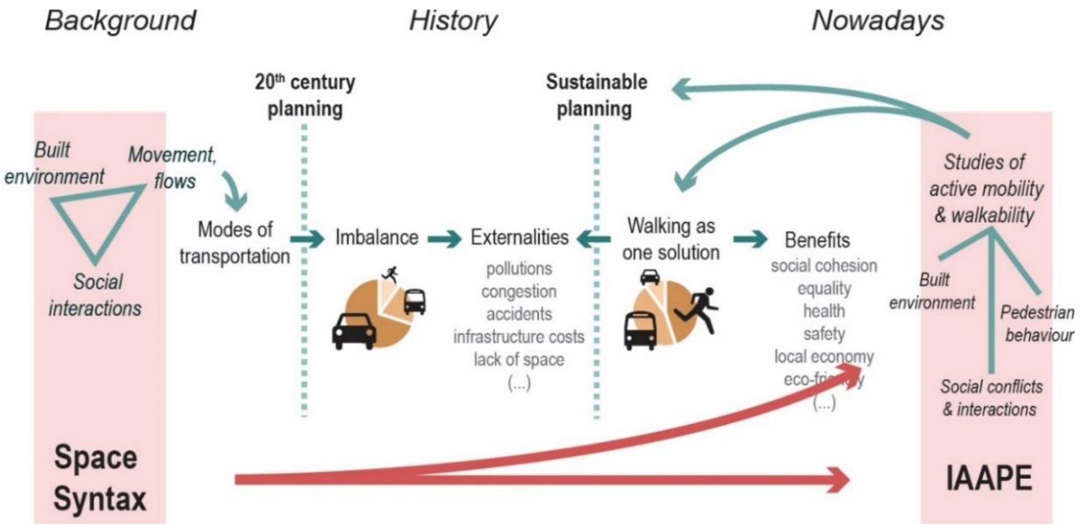


Figure 24. Framework of the pedestrian chapter and how the selected methods are related to it. Source: author.

Lastly, this topic is worth studying, because it impacts society. In fact, both these methods can be applied in urban studies. The applications range from the analysis and evaluation of existent urban spaces, assessment of urban interventions, for decision-making, etc. Ultimately, this dissertation seeks to contribute to urban planning and design, and that necessarily entails an understanding of where we are, how we got here, to where can we go and how we can get there.

4 Development of the model

In chapter 2.2, “A brief evolution of the pedestrian environment in cities”, it has been shown how the pedestrian environment has evolved over time and why some of the decisions that transformed this space were taken. This long description is important to realize the essential features regarding walking and what could be abandoned or rethought, e.g., the physical separation of modes (sidewalk and road) evolved from a necessity to avoid conflicts, but in places like residential neighborhoods, where there is little traffic and speed is low, does this separation make sense? Or would another layout be more comfortable for pedestrians, and yet, still safe?

It was also pointed out how much the urban environment has become unfair and uncomfortable for pedestrians and that the mindset is currently changing, while active modes are regaining importance. In chapter 2.4, “Pedestrian research and planning”, it has been described the importance of walking, due to its many benefits, as well as the efforts that have been done to understand the walkable environment and to plan for pedestrians.

A huge effort comes from academia, on the study of the various aspects of pedestrians and walkability. Among the different approaches, two of them were selected to be used in this dissertation. The chapter 3, “Review of methods”, presents both methods: “IAAPE walkability score” and “Space Syntax”. It was described how these methods work and how they relate to walkability research. Both have been used to evaluate the existing pedestrian environment and to identify solutions to improve it.

This chapter explains what contributions are intended to the study of walkability and how the workflow was set for that. It starts by pointing out how the mentioned methods are employed. Then, the construction of the model and the step-by-step of its application are presented. Further on, in the next chapter, the model is tested in a case study.

4.1 Hypotheses

As mentioned before, this exercise intends to prove if the IAAPE method and space syntax can deliver a better appreciation of the walkable environment when combined. For that, some reflections should be made.

It has previously been mentioned that space syntax is a powerful tool to analyze the city’s configuration and flows. It has also been shown that this tool has been in continuous development. Regarding walking, space syntax has been used in the analysis of pedestrian activity and as a prediction tool to help the urban design process. However, the representation of the pedestrian network has always ignored the complexity of the real walkways. Thus, instead of caring for the zig-zag that a pedestrian has to face when walking along the sidewalks, crosses, staircases, underway, etc., the space syntax models represent the urban space only through a road-centerlines network (Figure 25). Nevertheless, the pedestrian’s perception of a pedestrianized street, a street with few crossings or an expressway would be different in terms of navigation and behavior.

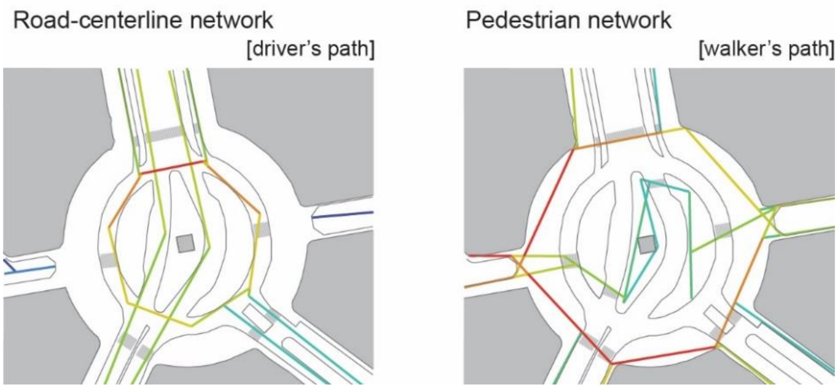


Figure 25. Example of two network representations for space syntax of the Saldanha roundabout (Lisbon). The colored lines represent the road-centerline network (left) and a pedestrian network (right). Source: author

Then, part of the exercise comprises the adaptation of the space syntax model and the understanding if it makes any difference to have a more detailed representation of thoroughfares when addressing pedestrians.

Moreover, since space syntax does not cover some aspects of the urban environment that can influence walking, it becomes imperative to combine it with other methods. In this case, IAAPE tool counts already for many other factors, corroborated by the perception of the pedestrian groups who were involved in the study.

On the other side, the IAAPE method has also room for improvements, especially regarding the indicators that deal with the urban configuration (connectivity, path directness, intelligibility, etc.). Cambra et. al (2017) have already noted that the built environment can be largely explained by its configuration, which makes it one of (if not the most) important indicator. The IAAPE tool consumes much more resources than space syntax to produce the necessary data to analyze those indicators. So, the second issue of this exercise is to answer if space syntax can improve the IAAPE method, and, therefore, help on the evaluation of walkability. This improvement can be made by either replacing indicators by syntactical measures or adding measures not yet addressed.

Next, it is explained how the model was structured and how the application was planned.

4.2 Developing the model

First of all, a **characterization of the area** of study must be prepared. This is useful to understand the context and for further analyses of the results since pedestrian behavior is dependent on the context.

Simultaneously, the new representation of the pedestrian network must be set for the space syntax analysis. This network corresponds to the pedestrian paths, in other words, it is a **sidewalk-centerline representation**. This approach is also helpful for the second part of the exercise, as it matches the network produced in the IAAPE project, which was based on the sidewalk segments. To proceed with this step, some decisions have to be made on how to draw the space syntax axial lines. For example, how to represent the pedestrian network at the crossings; or which equipment/facilities (public or private) should be incorporated in this network. Hence, some rules were defined to standardize the process of digitalization, assuming some simplifications with respect to reality. Yet, since this tool can eventually be used by decision-makers for urban interventions, it made sense to **adopt the formal pedestrian paths**, which, as shown, has evolved over the last century and is currently an established practice in most of the western cities. “Formal pedestrian paths” relates to all the conventions and signage defined by law/code to determine how the pedestrians must move about in the city, in other words, the pedestrianized streets, sidewalks, zebra crosses, staircases, paths across plazas and parks, pedestrian bridges and tunnels. Another advantage of using this criterion is to be able to analyze the efficiency of the traffic rules.

Also, internal paths of some public and private facilities with public access, for example, universities, foundations, and hospitals, are not included in the network. The reason is because these spaces can be closed during parts of the day (or the week) and these paths are not obvious to every pedestrian.

Concomitantly, the corresponding road-centerline network needs to be produced to allow the comparison of results and to verify how it performs in relation to the sidewalk-centerline network. A road-centerline network is commonly used in space syntax. If the results are alike, it would be meaningless to produce a more detailed network, which demands more time to build. Both the sidewalk centerline and the road centerline networks can be correlated with the available pedestrian counting.

The second part of the exercise is **combining the IAAPE method with the space syntax measures**. In order to proceed with this step, the data from the previous step and from the IAAPE walkability score must be checked and prepared.

When dealing with local analyses, it is necessary to define a **radius of analysis** to calculate the syntactical measures. Some investigation has been done (not restricted to space syntax research) to verify what a median walking distance and/or catchment area are, and, to date, there is no agreement on a value to be used. The commonly accepted distance is 400 meters (1/4 mile), although the used values vary until 4 kilometers (Vale, Saraiva, & Pereira, 2016).

Larsen et. al (2010) questioned the quarter-mile distance, and, based on O-D surveys from Montreal region, they showed that the median walking distance was 650 meters, increasing to 800 if only the utilitarian purpose were considered. Bielik et. al (2017) also investigated this parameter when dealing with some syntactical measures for the city of Weimar. They applied the choice measure with different radii and found out that the highest correlation with pedestrian flows was achieved with the 600-meters radius (seven-minute walk).

As there is no established value for this parameter, some correlations must be undertaken relating the pedestrian flows and the syntactical measures. Based on the distances from previous studies, tests may cover a range from 400 to 2000m.

Regarding the IAAPE walkability score, the necessary data must be selected and organized, according to the limits of the area to be studied. Finally, to insert the syntactical measures in the corresponding model of the IAAPE method, there are two possibilities: either the indicators of IAAPE can be replaced, or the syntactical measures can be added up to the index. Table 3 shows the possible replacements and additions concerning two from the 7Cs, namely, connectivity and conspicuousness. In relation to Connectivity, the measures of integration and choice can replace the key-concerns of ‘continuity’ and ‘path directness’, according to what was described in the item “3.2.1. Representation and analysis”. Also, synergy and intelligibility measures indicate some proprieties of the urban configuration that helps explaining wayfinding, therefore, it can be used within IAAPE tool to calculate the ‘conspicuousness’ dimension.

Table 3. Space syntax measures to replace IAAPE indicators.

	Key-concerns	IAAPE Indicators	Space syntax measures
Connectivity	Ped. infrastructure (continuity)	Least nr. of segments	**Replace by Integration**
	Path directness	Shortest distance	**Replace by Choice**
Conspicuousness	Existence of landmarks	Existence of reference elements	**Add Synergy and intelligibility**

The indicators of the IAAPE index were rescaled to fit a 0-100 scale to be able to be summed up. In the same way, the syntactical values must pass through this transformation. For integration and choice, it must be evaluated if any cut-off of the minimum and maximum values has to be done and, then, according to the distribution of the data (statistically and spatially), a value function must be applied. The other measures, synergy and intelligibility, generates a global value for each area, which can be transformed into a percentage and, therefore, be added directly to the index.

4.3 Application of the tool

The adoption of the above-mentioned methods requires the use of two specific **software**, for instance, a GIS platform (in this case, Quantum GIS or QGIS) and a space syntax platform (Depthmap was chosen). Also, for handling or analyzing the data, another software is required: AutoCAD for drawings, Microsoft Excel for handling the numerical data, and SPSS for statistical analysis.

The definition of the **case study** followed the area studied within the IAAPE project, in the Municipality of Lisbon. The microscale (or local scale) was defined to be used since it corresponds to the pedestrian environment, which must be detailed enough to represent sidewalks and other elements that impact walking. Additionally, the size of the area also matches the area covered by the available pedestrian counting, which is important for the validation phase of the exercise.

Besides IAAPE project, other **sources of data** include: Google Satellite, OpenStreetMaps, Instituto Nacional de Estatística (INE) and Lisboa Aberta Portal.

That said, the application takes the steps illustrated in the flow chart below (Figure 26) and described as follows.

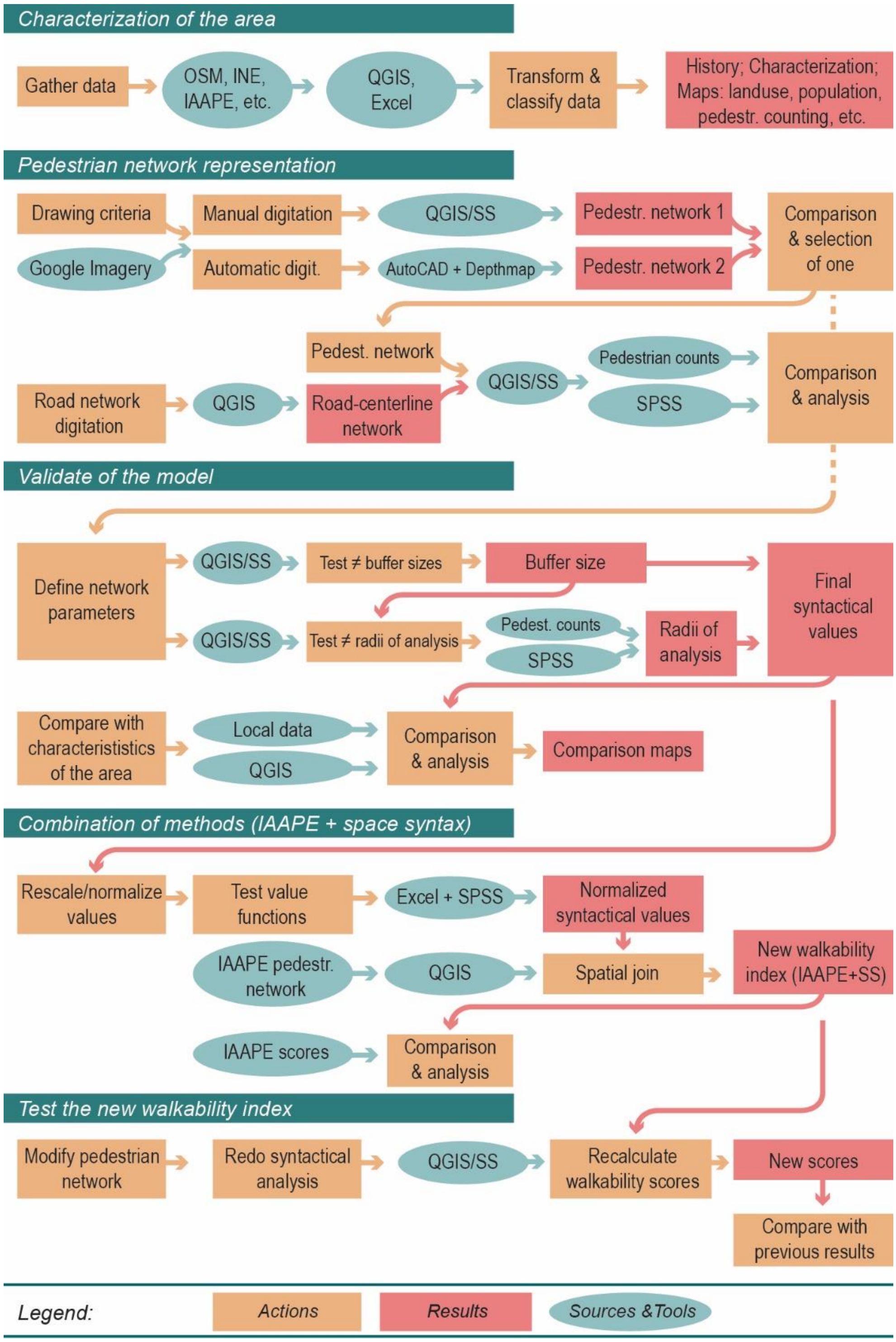


Figure 26. Flow chart of the construction and application of the model.

1. **Characterization of the area**, to contextualize the study area and for enabling further analyses. It includes gathering data about: location, history, spatial configuration, land use distribution, attractors (e.g. facilities and equipment), population density, among others.
2. **Pedestrian network drawing criteria.** Some criteria are set to guide the digitalization:
    a. The least number of lines-of-sight (axial lines) should be drawn;

    b. It should follow the formal pedestrian network[2], which comprehends every infrastructure that serves pedestrians (sidewalks, zebra crosses, stairs, paths across plazas and parks);
    c. In crossings where the zebra cross is clearly not aligned with the sidewalk, the axial line is interrupted;
    d. In crossings where there are 2 or less zebra crosses, normally in areas with little traffic, it was considered that pedestrians would continue a straight path across the street, therefore the axial line of the sidewalk is not interrupted;
    e. In complex or wider areas, such as plazas, parks, and roundabouts, the axial lines were automatically generated in the space syntax software and then simplified, if necessary.
3. **Pedestrian network representation.** Sample tests must be done to determine how to represent the paths in the software. Two approaches can be used:
    a. Manually drawing the axial lines above the satellite imagery;
    b. Drawing the boundaries of the formal pedestrian network and using Depthmap software to automatically create the axial lines.
4. **Comparison between pedestrian networks** and selection of the most convenient. From the result of the sample tests, one must be chosen based on their fidelity to the real pedestrian paths and the time needed to build.
5. **Comparison with a road-centerline network**. The created network must be compared to the road-centerline one. It can be done through correlations of their syntactic measures and with the available pedestrian counting.
6. **Validation of the model and its parameters:**
    a. Using the pedestrian counting to **define the buffer size and the radii of analysis**:
        i. Buffer size: to avoid the edge effect on the syntactical measures a buffer area must be digitalized around the study area. It must be set according to the radius of analysis.
        ii. Radii of analysis: in local scale analysis, a radius (which works as a cut-off) must be set. Tests have to be made to check which radii best correspond to the pedestrian analysis.
        iii. Correlations with the pedestrian counting: to validate the buffer size and radius of analysis, correlations with the available pedestrian counting can be done.
    b. Comparing the syntactical measures with the **characteristics of the area**. The data from the first step can be used to visualize how the syntactical values perform.
7. **Combining space syntax and IAAPE method**. When the model is set, the syntactical measures can be combined with the IAAPE method:
    a. Rescaling the values: to insert the space syntax measures within the IAAPE walkability index, the values must be rescaled to a 0-100 scale. For doing so, value functions must be tested and defined.

[2] Paths for pedestrians defined by the traffic code.

b. Join data into the same spreadsheet. Since space syntax and IAAPE data are in two separate databases and some spatial manipulation has to be undertaken to join the data together.
c. Combining indicators and validating the results. This test can be done in two steps: first replacing the IAAPE indicators by the syntactical values and validating it; then, added up the syntactical values which have no correspondent indicator, and validating it.
d. Comparison of results: IAAPE method and the new walkability index (IAAPE + space syntax). Different types of analysis can be made to check the validity of the new walkability index in relation to the original one, such as comparison of the score ranges, correlations, statistical tests, and visual comparison through maps.

8. **Adapting the walkability index to other analyses**. When the new walkability index is proved to be worthwhile, it can be tested for other types of analyses. One possible experiment is to modify the pedestrian network, increasing its connectivity, and watching the impact of the results of the walkability index.

In the next chapter, the described procedure is undertaken with the selected case study.

5 Case study

The area of the case study is located in the Municipality of Lisbon, Portugal. Its limits were defined accordingly to the area studied in the scope of the IAAPE project, which is also where the pedestrian counting took place, as it will be shown later.

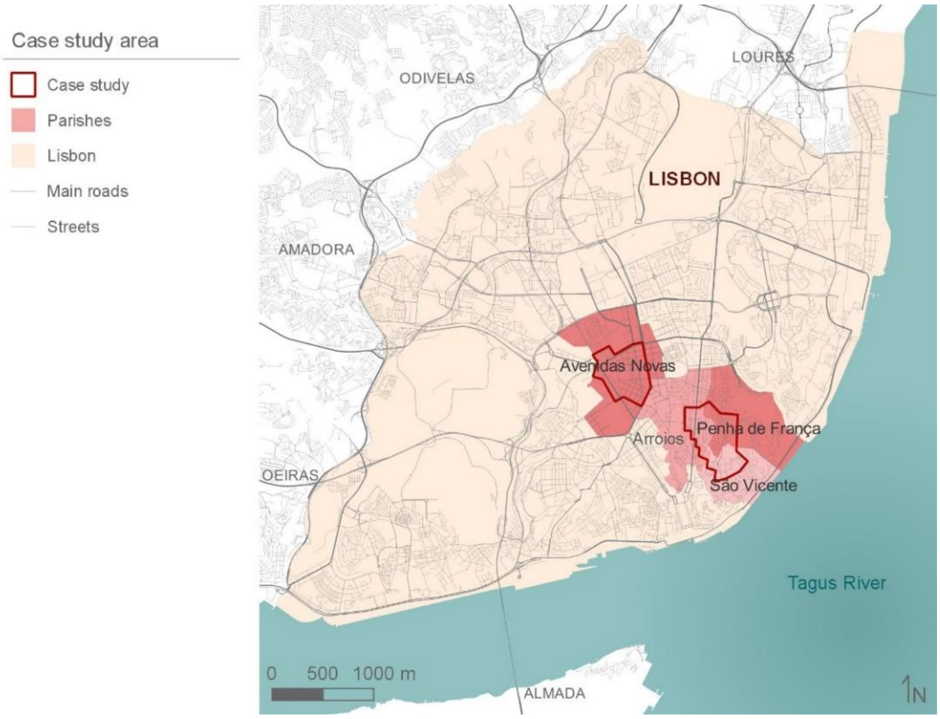


Figure 27. Map of Lisbon and the location of the case study area.

Figure 27 shows the location of the case study in the Lisbon parishes of Avenidas Novas, Arroios, Penha de França, and São Vicente. These parishes were developed since the end of the 19th century to the beginning of the 20th, due to the efforts of the government to occupy the hinterlands, and they reflect contemporary urban planning theories, resulting in a more regular urban layout, except when constrained by the topography (Salgueiro, 2002).

The area located in Avenidas Novas, henceforth “Area 1”, lies on a flat terrain and is composed by an orthogonal urban grid (Figure 28), with wide streets. It is a densely occupied area, with medium-rise buildings (5 to 10 stories), and a mix of uses, although it is best known for being a business district (Figure 29).

Conversely, the area located in the other parishes, henceforth “Area 2”, presents a mostly irregular grid, adapted to the steep slope (Figure 28), and formed by narrow streets of up to 2 lanes. It is a mixed-use dense-populated area, but with lower buildings (4 to 6 stories), and with a predominance of residential buildings (Figure 29).

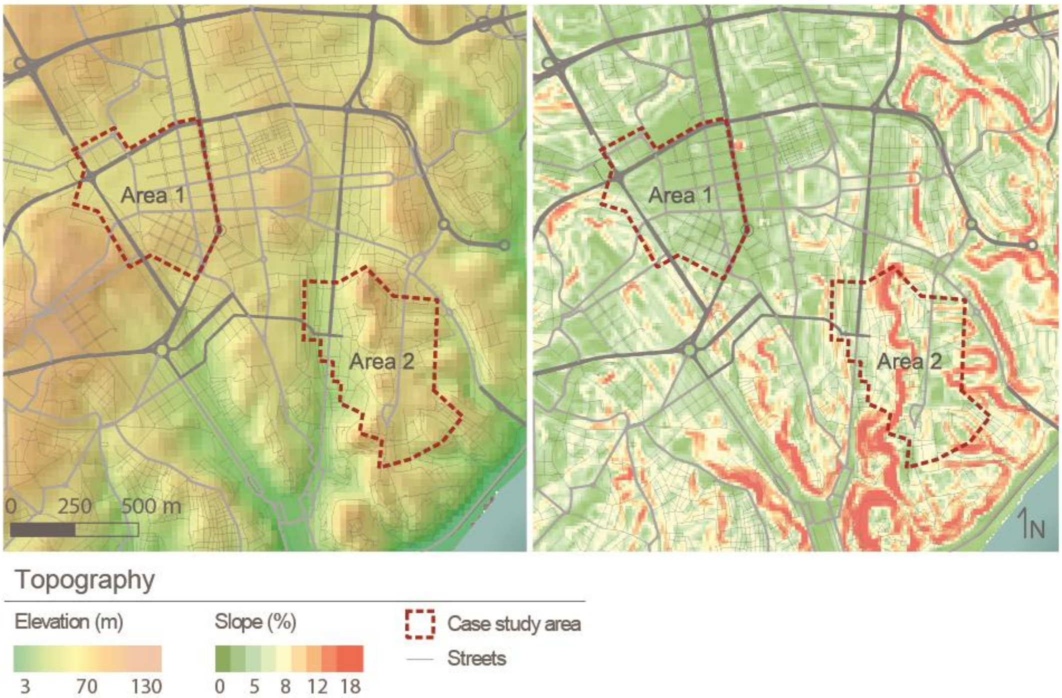


Figure 28. Maps of the topography of the area. Data source: Lisboa Aberta.

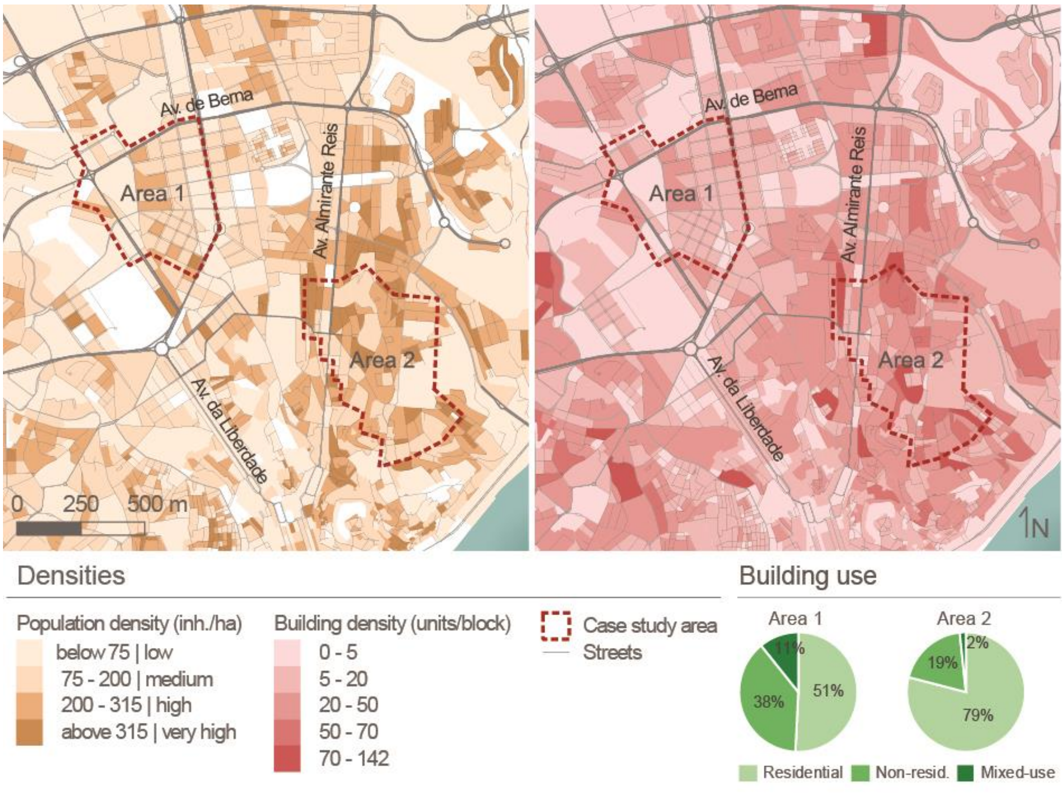


Figure 29. Maps of population and buildings densities. Data source: INE 2011.

Figure 30. Maps of retail and services: types, location and density. Data source: INE 2011.

Figure 31. Main infrastructures of transport. Data source: Lisboa Aberta and OpenStreetMaps

Figure 32. Map of the equipment and facilities. Data source: Lisboa Aberta and OpenStreetMaps.

The above maps illustrate some of the similarities and differences between the two areas of the case study. Apart from what was pointed out, the figures show how the population is distributed and how dense the street commerce is (retail and services). Regarding the differences, Figure 31 and Figure 32 show that Area 1 is better served by transportation infrastructure/services and equipment/facilities, which, in some cases, occupy large areas. On the other hand, Area 2 presents more quantity and density of population and buildings and, consequently, less open spaces.

The election of these areas to be studied also have taken into consideration the fact that, in being so distinct from each other, they can illustrate two different levels or patterns of walkability.

Other than generally characterizing the area, those maps show elements of the urban environment that can influence movement patterns. The maps of transportation and equipment, for example, correspond to some of the main existing attractors. It is important to notice that the variables here presented are not an exhaustive list regarding the movement and pedestrians, but the data available from official and open sources.

5.1 Data gathering and/or production

The data was gathered mainly from public open sources and from the IAAPE project.

The public sources include official (governmental) portals, such as the Instituto Nacional de Estatística (the national statistical institute of Portugal) and Lisboa Aberta, a web portal that assembles data from many public institutions. These data were organized and processed according to what was needed. Other than that, OpenStreetMaps, a collaborative mapping project, was used to obtain some spatial data; and Google Satellite was the source for the satellite images.

The data from IAAPE project include the information about the built environment (qualitative and quantitative data), the pedestrian counting, and the walkability scores. This set of data was collected and calculated for the year 2015.

Besides, additional specific data had to be created, which corresponds to the networks to be used to calculate the space syntax measures.

Pedestrian counting

The data of the pedestrian counts were obtained from the IAAPE project. The counting methodology was described in the item “3.1.2. Street auditing and pedestrian counting” and refers to the sidewalks segments highlighted in the Figure 33.

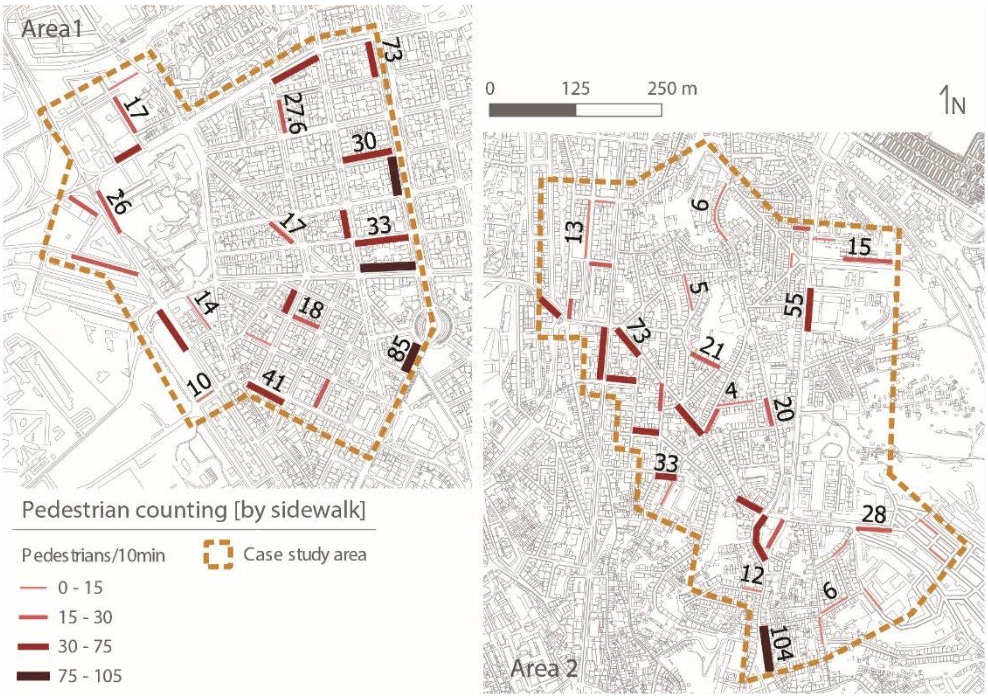


Figure 33. Sidewalk segments where the counting took place and respective flows. Source: author

Similar to the IAAPE project, the pedestrian counting is used in this case study to validate some of the outcomes. The pedestrian movement was already reported as having spatial and temporal variability (Cambra, Moura, & Gonçalves, 2017; Pinelo, 2017), what makes it difficult to deal with these data. Aggregating or averaging the counts are strategies used to find out volume patterns. However, the more aggregated the values, the more detail of the sample is lost. Therefore, it should be evaluated how far data aggregation should go.

Different forms of aggregation of the counting were tested (e.g. by segment, by time, by day), and what proved to fit better to the purpose of this dissertation was aggregating the counts by period of the day, and then averaging them per weekdays (Saturday was ignored for not being a working day). In such a way, the values of each of the 60 segments were preserved, as well as their variability along the day (Table 4). Additionally, two averages were considered, one that aggregates only moving pedestrians and another that sums moving and static (sojourning) pedestrians.

Table 4. Pedestrian counting: aggregated by period of the day and averaged per week.

	Average of pedestrians in movement per week (divided by 5 days)					Average of pedestrians in movement and sojourning per week (divided by 5 days)				
Segment	Peak morning	Off-peak morning	Lunch	Off-peak afternoon	Peak afternoon	Peak morning	Off-peak morning	Lunch	Off-peak afternoon	Peak afternoon
1003	23.80	7.94	11.07	7.53	11.10	41.60	50.80	59.20	47.20	77.00
1006	83.200	22.395	30.846	18.085	23.317	150.800	181.200	299.000	197.200	203.200
1021	16.600	7.393	22.566	9.822	12.741	25.800	24.800	46.600	32.400	41.600
(...)	(...)	(...)	(...)	(...)	(...)	(...)	(...)	(...)	(...)	(...)

Note: peak morning (8-9:30); off-peak (10:00-11:30); lunch (12:30-14:00); off-peak (15:00-16:30); peak afternoon (17:00-18:30)

It is important to highlight some limitations regarding the data. First, the temporal validity of the data. Raford & Ragland (2004) suggest that the utilization of pedestrian counting over a 3-year period reduces its effectiveness as a parameter, due to changes in the city. In the case of the area of study (and Lisbon in general), some recent changes could be observed regarding population and land use, although, the urban grid itself was not modified substantially. Another limitation is the number of counts to get to a statistically significant value. Pinelo (2017) defends that the same point/segment should be counted at least 30 times in the same day of the week to be statistically valid, different from what was done in the case of the available counting.

Assuming these limitations, this work tries to profit as much as possible from the data already available. Further developments of this work can eventually tackle these limitations.

5.2 Network digitalization

The digitalization of the network started by a sample area where two approaches were tested: (1) manually drawing the axial lines and (2) automatically generating these lines in the Depthmap software. The sample area corresponds to a small portion of the case study area (0.8 km²).

5.2.1 1st approach: manual digitalization

The QGIS software was used in this approach. As mentioned above, it consists in drawing the syntactical axial lines intuitively over a satellite image, aiming for the longest and fewest lines to cover the whole area and following the criteria presented in chapter 4.3. The following steps were made:

1) In QGIS software, the network was digitalized over a satellite image from Google:
    a) For the whole process, only images from the same source were used, to avoid positioning errors;
    b) The satellite imagery was considered the best choice because it is more updated than other sources and it enables the identification of horizontal signs on the streets (i.e. pedestrian crosses);
    c) When necessary, the information was checked using Google StreetView; and when that was not enough, field visits were paid.
2) The digitalization followed the axes from sidewalks, pedestrian crosses and staircases;
    a) As mentioned, priority was given to the formal pedestrian network:

Figure 34. Digitalization of the axial lines of the pedestrian paths.

b) For complex areas, such as squares and parks, where it is difficult to outline which should be the fewest/longest lines, the axial lines were first generated automatically in Depthmap and then incorporated into the QGIS model. The following steps were undertaken for this task:
   i) In AutoCAD: based on satellite images, the boundaries of the pedestrian area were drawn;
   ii) These limits were imported in Depthmap, where the tool “all-line map” was used to generate every possible line of sight inside that boundary; then, the tool “reduce to fewest line map” was applied, which reduced the lines to the minimum set necessary to cover the whole area. The result was exported in .mif format (a readable format in QGIS);
   iii) Since it preserved its geographic coordinates, it was imported in QGIS and incorporated into the model;
   iv) Depthmap returned the minimum set of axial lines that covers the whole space. Invariably, the result had to be refined by the researcher, who had to include some important formal paths not marked or to remove some lines, when in excess.

3) In the QGIS, the Space Syntax Toolkit plugin was used to calculate the syntactical measures:
   a) Bridges (the so-called ulinks[3]) were marked when paths were unlevelled;
   b) A verification tool from the plugin was used to check for error. It pointed out drawing error such as duplicated lines, polylines, short lines, orphans, islands, and coinciding points. Each had to be corrected before the calculation;
   c) Finally, the space syntax measures could be calculated, either for axial lines or segments.

Regarding the time, the digitalization of the axial lines in QGIS took around 25 min per square kilometer.

5.2.2 2nd approach: automatically processing

The automatic processing of the network was done in Depthmap software. In this process, the program generates every possible line connecting all endpoint/corner of the geometries of the model. Which means that the input corresponds to the boundaries of the pedestrian network (Figure 35). During the drawing process, it is important to simplify the geometries to get the straightest lines possible, in order

[3] It is possible to indicate to the software when two paths are unlevelled, such as in the case of bridges, so these are not computed as a possible path.

to avoid overloading the program. Also, the same rules of the first approach were followed, considering the formal pedestrian paths.

Figure 35. Digitalization of the boundaries of the pedestrian paths.

The taken steps were:

1) The boundaries of the pedestrian network were drawn in AutoCAD software with the support of a vector file from the Municipality and some aerial images from Google Earth. The final drawing was exported to Depthmap, in .dxf format;
2) In Depthmap (Figure 36):
    a) The tool “all-line map” was used to generate every possible line of sight inside that boundary;
    b) The result was reviewed to look for errors. In some cases, the software could not recognize some boundaries and errors occurred. Thus, the boundaries had to be redrawn in AutoCAD and exported once again;
    c) That set, the tool “reduce to fewest line map” was applied, which reduced the lines to the minimum set necessary to cover the whole area. The result was exported in .mif format;

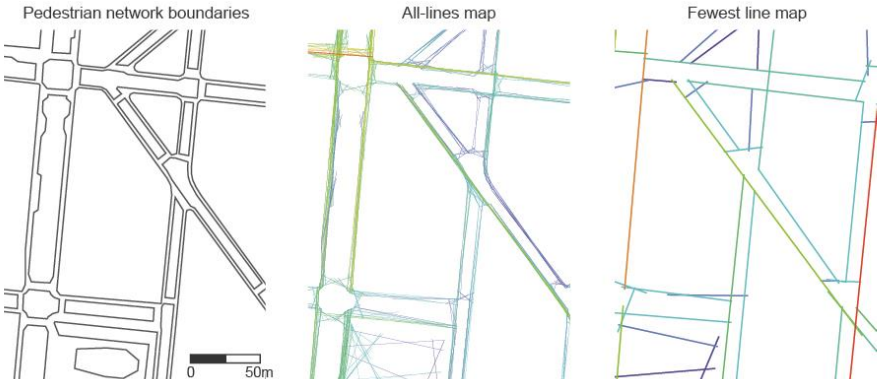


Figure 36. Steps of the automatic generation of the axial lines in Depthmap.

    d) A second revision of the axial lines was done in QGIS to eliminate the excess of lines that Depthmap generated in some areas.
3) Finally, in QGIS, the Space Syntax Toolkit was applied in the same way as the previous approach.

This second approach took much more time than the first to be drawn in the AutoCAD software. Besides, the back-and-forth process to correct errors regarding the boundaries was also time-consuming. When dealing with a bigger area, this revision could become a severe problem.

5.2.3 Comparison of the digitalization approaches

The objective of this comparison was to determine which digitalization approach should be used. Both an axial and a segment map were created for each approach, and correlations were carried out to check if different approaches result in different analytical outcomes (measured by syntactical indicators).

Comparing axial maps

The axial maps from both approaches resulted in 368 matching axes. The syntactical measures were used to calculate the correlations coefficients. For integration values, outcomes from the two approaches present a high correlation of 0,896. The respective chart of the values can be seen below.

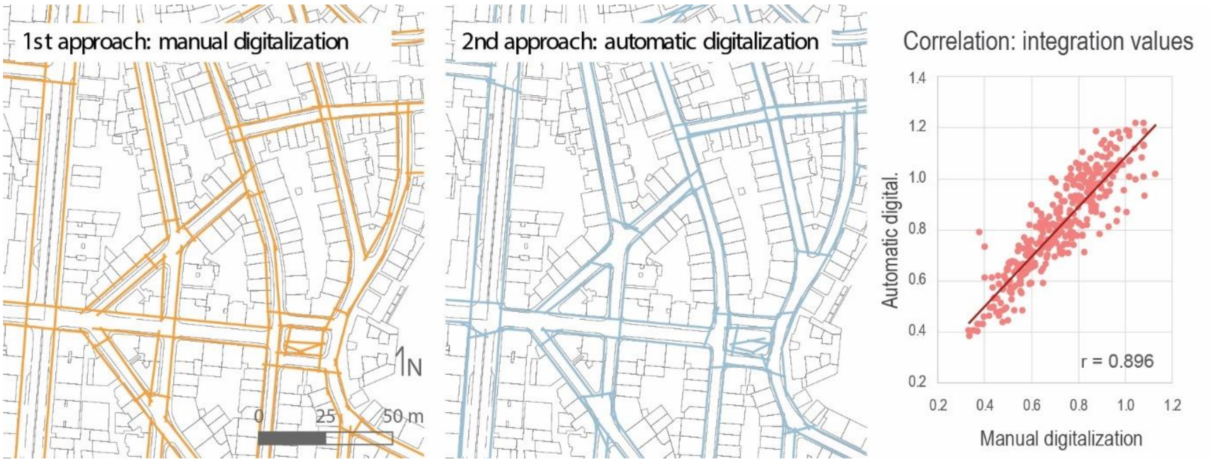


Figure 37. Example of the axial maps and chart of the values of integration.

Comparing segment maps

The correlation of the segment maps had similar results. In this case, there were 590 matching segments. Their values of integration were compared, resulting in a high correlation of 0,817.

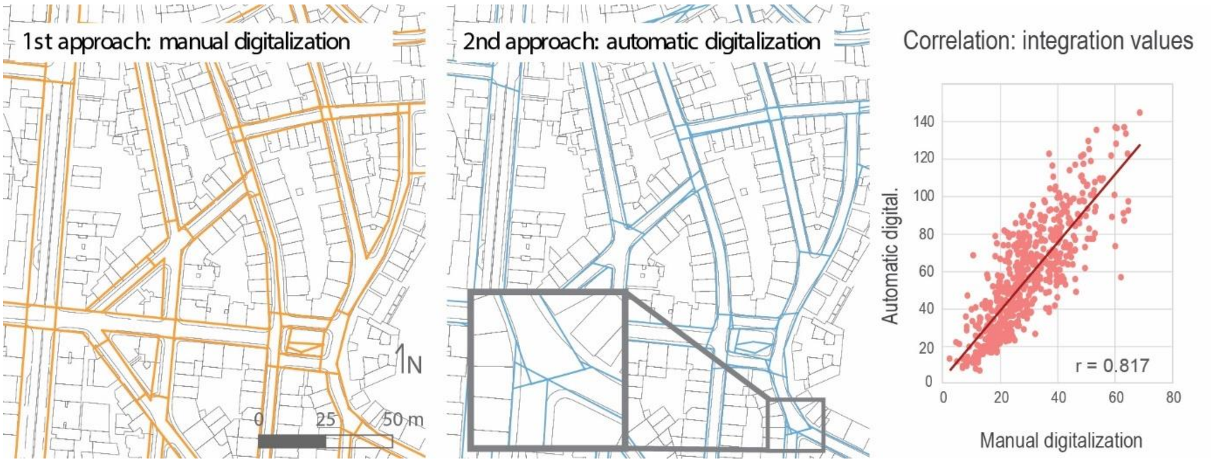


Figure 38. Example of the segment maps and chart of the values of integration.

The segment maps are generated from the axial maps and the previous comments are again valid to this case. Besides that, since the axial map from the 2nd approach resulted in much more lines, its correspondent segment map also presented an excess of lines, especially in the crossings (see Figure 38).

5.2.4 Conclusions and selected model

Both approaches were tested to define the best representation of a pedestrian network for the space syntax analysis.

The high correlation between their values (taking integration values as a reference) demonstrated that the outcomes are similar and, therefore, the most convenient network can be chosen.

The second model, generated automatically by Depthmap, is more time-consuming, because it takes longer to draw the boundaries of the pedestrian environment. Besides that, its axial and segment maps resulted in an excess of lines, which can be misleading for the syntactical analysis. Taking these reasons into account, the first approach (manual digitalization) was chosen for this research.

Figure 39. Case study area with a buffer of 500m.

From this point, the rest of the case study were digitalized. Since the syntactical measures are relational, the study area had to include a buffer area (Figure 39), in order to avoid the edge effect, as described in chapter 3.2.

5.3 Comparison with the road-centerline network

The standard representation of the network in space syntax considers the streets as great canals, without any differentiation. This dissertation attempts to verify if a more accurate representation of a pedestrian network would make any difference in the syntax analysis. For this reason, it was important to compare both networks.

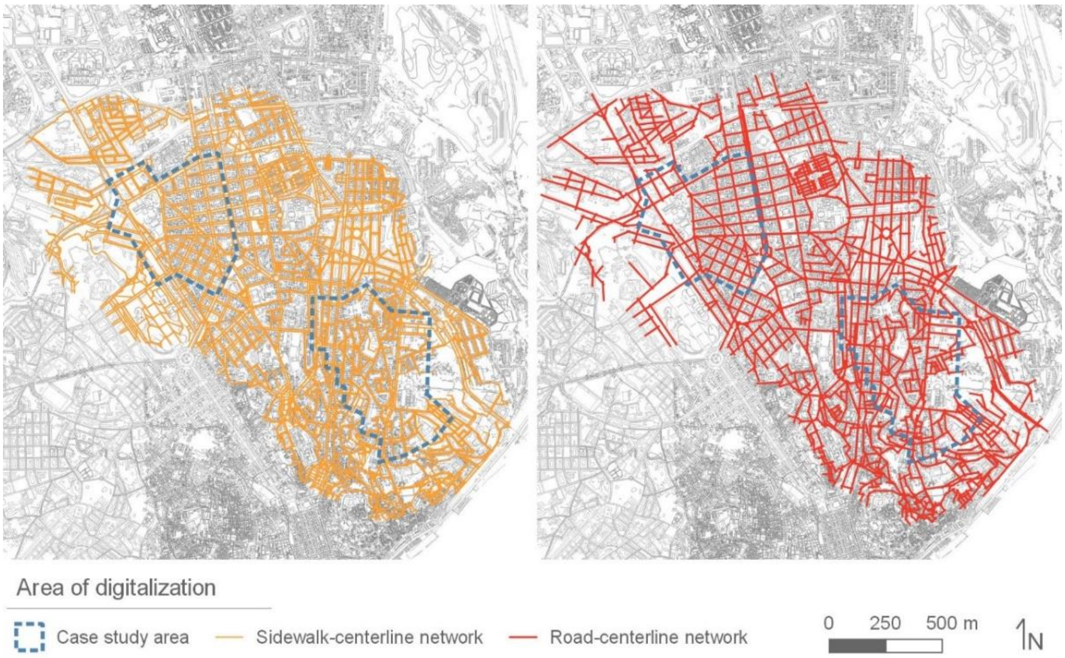


Figure 40. Sidewalk- and road-centerline networks.

The necessary data, for instance, the road network, was provided by the nucleus of space syntax of the IST (ULisboa). This network was built for the metropolitan area of Lisbon and dated from 2015, therefore it was necessary to be updated. The road-centerline network was cut out to correspond to the same limits of the pedestrian one, making it possible to compare both. Then, similar to the pedestrian network, unlinks were assigned to the road network and the syntax measures were calculated. These steps were done in QGIS.

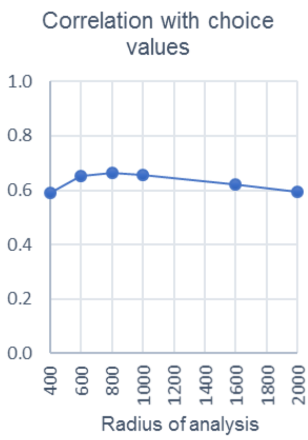
Two correlations were performed between the syntactical measures outcoming from both the sidewalk- and the road-centerline networks, and the available pedestrian counting. The idea of these correlations is to compare if there are differences using one network or the other, in terms of syntactical analysis.

5.3.1 Correlation between pedestrian and road networks

This correlation compares the values of the correspondent segments. Since the pedestrian network has at least double the number of segments of the other, it was necessary to calculate the average of the values of each pair of sidewalk segments. In other words, each road segment (centerline of the street) was compared to the average of the correspondent pedestrian segments (centerline of the sidewalk).

It resulted in 293 matching segments, and their values of integration and choice were correlated (Figure 41). For choice values, the correlation was high, mainly for local radii (above 0.6), slightly reducing toward global radii. Regarding integration values, it resulted in high correlations (between 0.6 and 0.8), but the opposite trend occurred, that is to say the correlation increased toward the global radii.

Choice	
Radius	Correlation
400	0.59
600	0.65
800	0.67
1000	0.65
1600	0.62
2000	0.59
n	0.55



Integration	
Radius	Correlation
400	0.69
600	0.72
800	0.71
1000	0.73
1600	0.79
2000	0.82
n	0.73

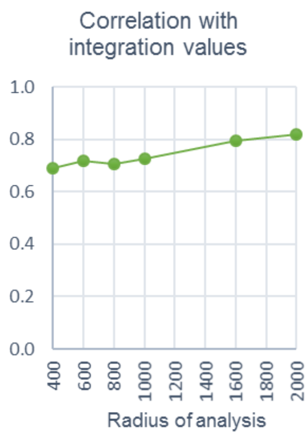


Figure 41. Charts of correlations of the two networks for their values of choice and integration.

5.3.2 Correlation between networks and pedestrian counting

The correlation with the pedestrian counting compared the values of integration and choice of the networks with the averages of pedestrians per period of the day. The results for integration (for all the radii of analysis) can be seen in Table 5 below. Both networks show a better correlation for integration radius 1000m, however, the pedestrian network presents slightly higher correlations. It happens not only for integration radius 1000m, but also for smaller radii, which are normally associated to pedestrian movement, and, therefore, with relevance for this work.

Table 5. Correlations between pedestrian counts and integration values (for 60 records), for both networks. The best correlations among the integration values are highlighted in yellow.

			Sidewalk centerline - segment analysis						Road centerline - segment analysis					
	Integration radius:		600	800	1000	1600	2000	n	600	800	1000	1600	2000	n
Avg. of pedestrians in movement	peak morning	Pearson Correlation	.508**	.494**	.571**	.453**	.375**	.332**	.326*	.341**	.401**	.356**	.321*	.352**
	off-peak morning		.487**	.453**	.514**	.426**	.357**	.314*	.455**	.461**	.509**	.463**	.405**	.408**
	lunch hour		.578**	.577**	.619**	.526**	.453**	.405**	.418**	.450**	.475**	.464**	.436**	.429**
	off-peak afternoon		.503**	.516**	.588**	.457**	.381**	.337**	.504**	.537**	.580**	.522**	.464**	.461**
	peak afternoon		.522**	.502**	.557**	.468**	.397**	.327*	.515**	.537**	.576**	.547**	.485**	.439**
Avg. of pedestrians in mov. &sojourning	peak morning	Pearson Correlation	.481**	.456**	.529**	.411**	.341**	.314*	.323*	.334**	.390**	.343**	.320*	.374**
	off-peak morning		.462**	.427**	.482**	.338**	.278*	0.248	.345**	.388**	.442**	.381**	.355**	.399**
	lunch hour		.528**	.511**	.543**	.393**	.326*	.306*	.326*	.392**	.427**	.399**	.395**	.433**
	off-peak afternoon		.536**	.528**	.588**	.458**	.387**	.353**	.409**	.469**	.536**	.497**	.479**	.510**
	peak afternoon		.543**	.510**	.569**	.419**	.340**	.297*	.431**	.472**	.531**	.480**	.455**	.483**

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

Comparing the integration chart (Figure 41) to the table, it can be noticed that where correlation between networks are weaker (for smaller radii), the correlations with pedestrian counts are higher for the sidewalk-centerline network.

Additionally, the Fisher's r-to-z transformation test was undertaken to confirm if the differences between the correlations from both networks are statistically significant. Despite the slight differences of correlations shown in the table above, the test results indicate that, for a degree of confidence of 95%, these values are not significantly different (for results, see Annex C. Fisher's r-to-z transformation).

Thereafter, based in the available data, it cannot be statistically proved that one network correlates better than the other with the pedestrian counting.

However, two issues may be influencing the results: the limitation of the counts sample size, as mentioned before; and, to how the pedestrian counts were carried out, because they covered only one side of the street (one sidewalk), which match the sidewalk-centerline network, but it can be misleading when correlating with the road-centerline network.

Although the correlations did not prove that the sidewalk-centerline is better or worse than the road-centerline network, still the former fits better to the study that follows, because all the available data from IAAPE project, from its network to its audits, were produced based on sidewalk segments.

If the sidewalk-centerline performs better in syntactical analysis with respect to the pedestrian movement has still to be proved, though it will depend on the acquisition of more data.

5.4 Validation of Space Syntax model

Prior to inserting the values of the space syntax measures in IAAPE's walkability score, a step of validation of the results was undertaken. The network was once again compared with the pedestrian counting and, furthermore, contrasted with the characteristics of the area.

5.4.1 Comparison with pedestrian counting

This first step of the validation was important to define some adjustments of the sidewalk-centerline network regarding the buffer size adopted during the digitalization phase. As already seen, since syntactical analyses are relational, the outcomes can be affected by an **edge effect.** To avoid this effect, a network larger than the area being studied has to be built. For this reason, an initial test was made with a buffer of 500 meters around the case study. This buffer must also be set according to the radius used in the analysis and, following what Gil (2015) defines, the buffer has to be at least the same size of the radius of analysis in use, in order to eliminate the edge effect.

Therefore, based on the correlations with the pedestrian counting, the radius of analysis was defined, and, consequently, the buffer size.

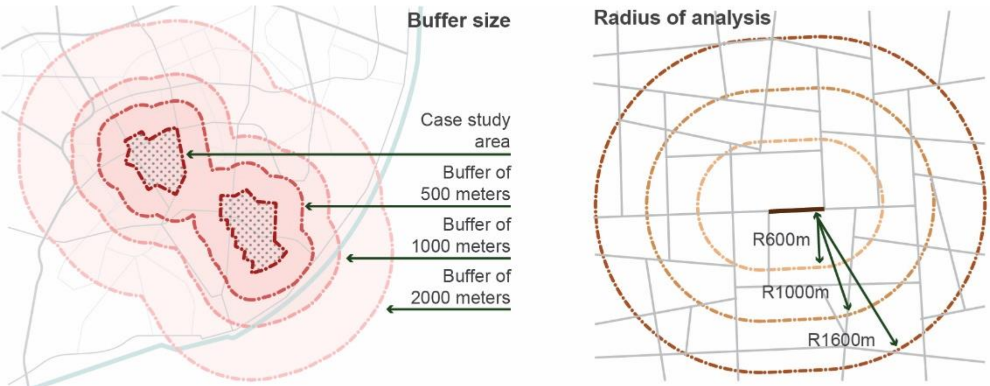


Figure 42. Schematic illustration of the buffer sizes and the radii of analysis.

First test: buffer of 500m

Starting from the network with a 500-meters buffer (Figure 39), the following steps were taken:

1. In QGIS, the segment map was generated using the Space Syntax Toolkit plugin. The syntactical measures were calculated for the radii: 400, 600, 800, 1000, 1600 and 2000 meters and for radius n (Rn) – corresponding to local and global measures;
2. Using a 'spatial join' tool, the pedestrian counting data was assigned to the created sidewalk segments;
3. The table associated to the sidewalk network shapefile was imported in Excel. After some handling of the data, some previous relations could already be tested. However, for more precise results, a statistics software was used;
4. The data related to the 60 segments of the pedestrian counting were imported in SPSS. The software calculated the correlations between the averages of the pedestrian counts and the integration and choice values for various radii of analysis. Table 6 below shows the outcomes.

Table 6. Correlations between pedestrian counts and integration and choice values (from the network with a buffer of 500m). The best correlations are highlighted in yellow.

Sidewalk centerline - segment analysis - buffer 500m (for 60 records)

			Integration						Choice					
	Radius:		600	800	1000	1600	2000	n	600	800	1000	1600	2000	n
Avg of pedestrians in movement	peak morning	Pearson Correlation	.508**	.494**	.571**	.453**	.375**	.332**	.318*	.407**	.467**	.591**	.622**	.674**
	off-peak morning		.487**	.453**	.514**	.426**	.357**	.314*	.443**	.494**	.525**	.578**	.576**	.532**
	lunch hour		.578**	.577**	.619**	.526**	.453**	.405**	.349**	.426**	.472**	.551**	.564**	.582**
	off-peak afternoon		.503**	.516**	.588**	.457**	.381**	.337**	.403**	.473**	.512**	.588**	.607**	.596**
	peak afternoon		.522**	.502**	.557**	.468**	.397**	.327*	.492**	.548**	.581**	.639**	.643**	.577**
Avg of pedestrians in mov. &sojourning	peak morning	Pearson Correlation	.481**	.456**	.529**	.411**	.341**	.314*	.320*	.402**	.462**	.583**	.615**	.656**
	off-peak morning		.462**	.427**	.482**	.338**	.278*	0.248	.338**	.411**	.461**	.531**	.537**	.510**
	lunch hour		.528**	.511**	.543**	.393**	.326*	.306*	0.231	.331**	.398**	.519**	.544**	.560**
	off-peak afternoon		.536**	.528**	.588**	.458**	.387**	.353**	0.245	.349**	.415**	.572**	.628**	.667**
	peak afternoon		.543**	.510**	.569**	.419**	.340**	.297*	.355**	.439**	.495**	.617**	.646**	.620**

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

Considering **integration**, higher correlations were obtained for radius 1000m, for all periods of the day. Nonetheless, the model has a buffer size smaller than this radius, which means that the outcome may be affected by an edge effect. Consequently, a larger buffer had to be tested.

Related to the **choice** values, it can be observed that, in general, the correlations increased together with the radius of analysis. This relation has already been reported by Gil (2016), when he explains that choice is a measure less sensitive to edge effect. Instead, is depends most on the number of nodes in the network, because it indicates the frequency of shortest paths, which are not equally distributed through the network.

Second test: buffer of 1000m

A second test of the network was done in which the buffer was expanded until 1000 meters from the case study boundaries.

The extension of the axial network was drawn manually over the satellite image in QGIS. Then, the same steps of the previous network were taken. The correlations with the pedestrian counting can be observed in the table below.

Table 7. Correlations between pedestrian counts and integration and choice values (from the network with a buffer of 1000m). The best correlations are highlighted in yellow.

Sidewalk centerline - segment analysis - buffer 1000m (for 60 records)

			Integration						Choice					
	Radius:		600	800	1000	1600	2000	n	600	800	1000	1600	2000	n
Avg of pedestrians in movement	peak morning	Pearson Correlation	.510**	.509**	.591**	.520**	.431**	.330**	.301*	.400**	.467**	.606**	.631**	.662**
	off-peak morning		.496**	.475**	.544**	.498**	.423**	.313*	.431**	.492**	.533**	.611**	.599**	.487**
	lunch hour		.577**	.585**	.646**	.614**	.536**	.427**	.336**	.420**	.470**	.582**	.590**	.546**
	off-peak afternoon		.513**	.535**	.617**	.560**	.474**	.350**	.392**	.469**	.516**	.623**	.637**	.574**
	peak afternoon		.532**	.520**	.584**	.541**	.464**	.333**	.481**	.543**	.582**	.663**	.660**	.531**
Avg of pedestrians in mov. &sojourning	peak morning	Pearson Correlation	.485**	.472**	.548**	.470**	.400**	.315*	.304*	.397**	.464**	.601**	.622**	.638**
	off-peak morning		.468**	.447**	.509**	.410**	.354**	.270*	.326*	.410**	.470**	.569**	.560**	.487**
	lunch hour		.524**	.518**	.555**	.459**	.404**	.335**	0.220	.324*	.393**	.536**	.555**	.538**
	off-peak afternoon		.538**	.537**	.597**	.527**	.464**	.376**	0.238	.343**	.410**	.581**	.632**	.654**
	peak afternoon		.550**	.528**	.586**	.487**	.416**	.316*	.349**	.438**	.498**	.631**	.650**	.595**

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

Similar to the first test, yet with better results, it continued to point out **integration** radius 1000m with the best correlations, which, in this case, are reliable, because the 1000m buffer covers a sufficient area to eliminate an edge effect.

As for the **choice** results, the correlations are also a bit better, however, the explanation remains the same as mentioned above.

Even if the integration values were confirmed and the values start decreasing after radius 1000m, another test was carried out with a buffer of 2000 meter beyond the case study area.

Third test: buffer of 2000m

This last expansion of the network was done only to assure the results above. Considering that there is no consensus on what radius of analysis should be used when dealing with pedestrians, it was reasonable to go a bit deeper into the issue.

Table 8 above shows that the correlations remained quite the same, with a slight increase in some values, but maintaining the order. That confirms the use of radius 1000m for integration, as well as, the global radii for choice.

Table 8. Correlations between pedestrian counts and integration and choice values (from the network with a buffer of 2000m). The best correlations are highlighted in yellow.

Sidewalk centerline - segment analysis - buffer 2000m (for 60 records)

			Integration						Choice					
		Radius:	600	800	1000	1600	2000	n	600	800	1000	1600	2000	n
Avg of pedestrians in movement	peak morning	Pearson Correlation	.510**	.513**	.598**	.527**	.444**	.310*	.299*	.400**	.468**	.607**	.630**	.641**
	off-peak morning		.497**	.477**	.546**	.492**	.416**	.262*	.430**	.493**	.533**	.611**	.597**	.463**
	lunch hour		.577**	.588**	.650**	.616**	.551**	.429**	.334**	.420**	.471**	.582**	.590**	.597**
	off-peak afternoon		.514**	.538**	.621**	.558**	.472**	.304*	.390**	.470**	.516**	.623**	.637**	.559**
	peak afternoon		.533**	.523**	.586**	.536**	.453**	.279*	.479**	.543**	.582**	.661**	.657**	.501**
Avg of pedestrians in mov. &sojourning	peak morning	Pearson Correlation	.485**	.476**	.554**	.471**	.404**	.305*	.302*	.398**	.465**	.602**	.621**	.603**
	off-peak morning		.468**	.449**	.512**	.405**	.348**	.277*	.325*	.411**	.471**	.570**	.560**	.447**
	lunch hour		.524**	.520**	.559**	.457**	.408**	.365**	0.219	.325*	.394**	.537**	.555**	.505**
	off-peak afternoon		.539**	.539**	.600**	.525**	.461**	.375**	0.236	.343**	.410**	.581**	.630**	.594**
	peak afternoon		.551**	.529**	.585**	.482**	.407**	.307*	.347**	.438**	.497**	.631**	.648**	.509**

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

Another fact that can also be noticed is that for radius 1000m and lower, the values for integration and choice from both networks should be the same, but they vary slightly. That issue remains open for further investigation.

Forth test: weighting by segment length

Parallel to the study on buffer sizes, another test was performed using the same segment analysis tool, but this time, choosing to weight the values with the segment lengths. This can make sense for pedestrian flows, because a long block (and consequently a long segment) is likely to have more entrances (shops, doors) and, therefore, generate more movement (Al_Sayed & al., 2014).

The correlations with the pedestrian counts are indicated in the table below.

Table 9. Correlations between pedestrian counts and integration and choice values weighted with segment length. The best correlations are highlighted in yellow.

Sidewalk centerline - segment analysis weighted with length - buffer 2000m (for 60 records)

			Integration						Choice					
		Radius:	600	800	1000	1600	2000	n	600	800	1000	1600	2000	n
Average of pedestrians in movement	peak morning	Pearson Correlation	.532**	.519**	.543**	.480**	.430**	.333**	.485**	.556**	.602**	.646**	.648**	.676**
	off-peak morning		.401**	.374**	.389**	.351**	.327*	.273*	.538**	.559**	.576**	.570**	.548**	.478**
	lunch hour		.642**	.622**	.644**	.601**	.561**	.444**	.604**	.647**	.657**	.647**	.631**	.585**
	off-peak afternoon		.439**	.432**	.456**	.406**	.381**	.314*	.534**	.579**	.600**	.611**	.605**	.561**
	peak afternoon		.429**	.397**	.416**	.366**	.345**	.283*	.616**	.643**	.653**	.631**	.606**	.516**
Avg. of pedestrians in movement & sojourning	peak morning	Pearson Correlation	.506**	.491**	.514**	.458**	.420**	.329*	.484**	.550**	.596**	.645**	.648**	.657**
	off-peak morning		.445**	.430**	.452**	.405**	.376**	.290*	.460**	.524**	.569**	.600**	.585**	.514**
	lunch hour		.588**	.575**	.589**	.532**	.492**	.383**	.453**	.542**	.595**	.649**	.649**	.598**
	off-peak afternoon		.550**	.542**	.558**	.511**	.480**	.391**	.450**	.541**	.595**	.675**	.695**	.679**
	peak afternoon		.518**	.495**	.513**	.444**	.412**	.322*	.524**	.595**	.636**	.673**	.668**	.607**

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

When weighted with the segment length, the lower radii of analysis had higher correlations. In fact, most of the results for 600m and 800m radii are higher than the previous analyses.

For integration values, radius 1000m continued resulting in most of the highest correlations, but radius 600m gained more relevance. However, the correlation for integration are all lower than in the previous test.

Choice, on the other hand, returned better correlations for most of the results, indicating that it could also be useful in walkability analysis.

These tests indicated which radii of analysis should be used when studying walkability. The results are interesting, because they contrast with the radius commonly used in pedestrian analysis (such as the quarter-mile) and with some studies from other countries, for example Larsen et. al. (2010), who found good correlations for 600m radius.

Regarding integration, the use of radius 1000m appears to fit best, which had good correlations in all tests. Finally, with respect to choice, the global analysis (Rn) should be used, since higher correlations were obtained for higher radii; or, alternatively, it can be tested with lower radii from choice weighted with the segment length.

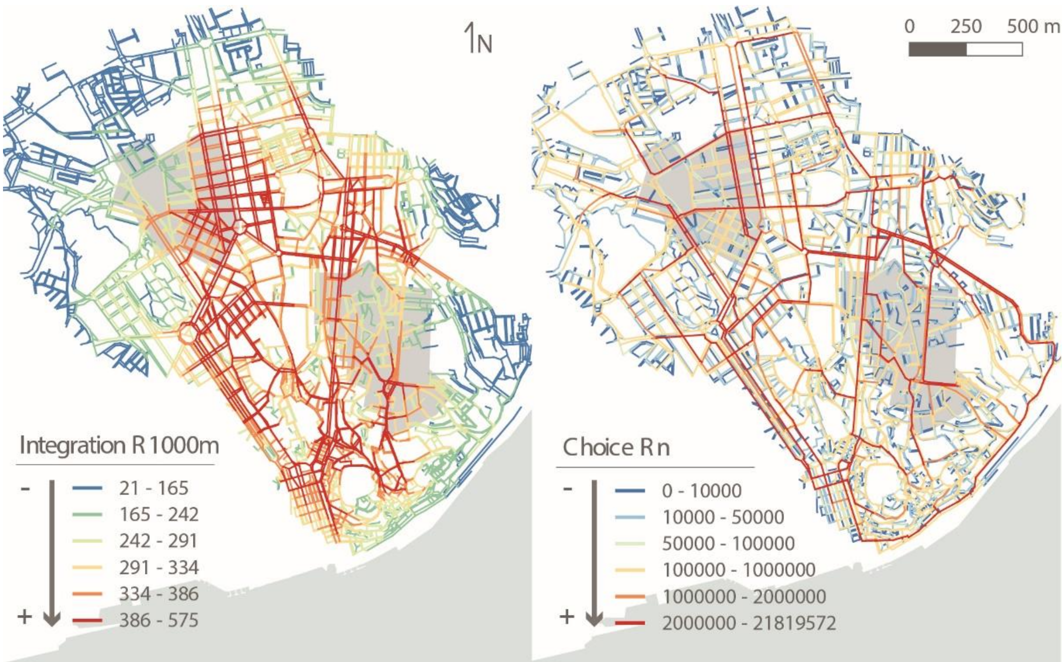


Figure 43. Maps of the syntactical measures of integration radius 1000m e choice radius n.

The tests also demonstrated how large the model must be, according to the used radius of analysis. In this case, considering the highest correlations for integration were with radius 1000m, the buffer around the case study area do not need to be larger than 1000m to avoid any edge effect.

The limits of the model are an important issue, because the larger it is, the longer it takes to build it, or, in other words, the more resources it consumes. Just to have a glimpse of such implications, the digitalization of the case study plus a buffer of 1000 meters took around 30 hours of work. To expand the model to a buffer of 2000 meters, 12 more hours were necessary. Of course, it will vary according to the complexity and size of the network and the experience of who is digitalizing. However, unnecessary work has to be identified and avoided.

5.4.2 Comparison with the characteristics of the area

The space syntax measures can also be analyzed in maps by contrasting them to the urban and physical elements of the area presented in the beginning of this chapter.

Starting by the physical environment, some assumptions can be made regarding slope and choice (Figure 44). Although the syntactical measures do not account for difference in elevation, a positive relation can be seen, especially in Area 2, where the terrain is steeper. Paths with higher choice values (red segments) are located in flatter areas (green patches), while paths that cross the steepest areas (red patches) have lower choice values (green and blue). It can, however, be related to a secondary phenomenon, i.e., the winding of the streets, which zigzag to overcome the slope. Because they change direction often, these are not good options for a more direct path and, therefore, present a low choice value.

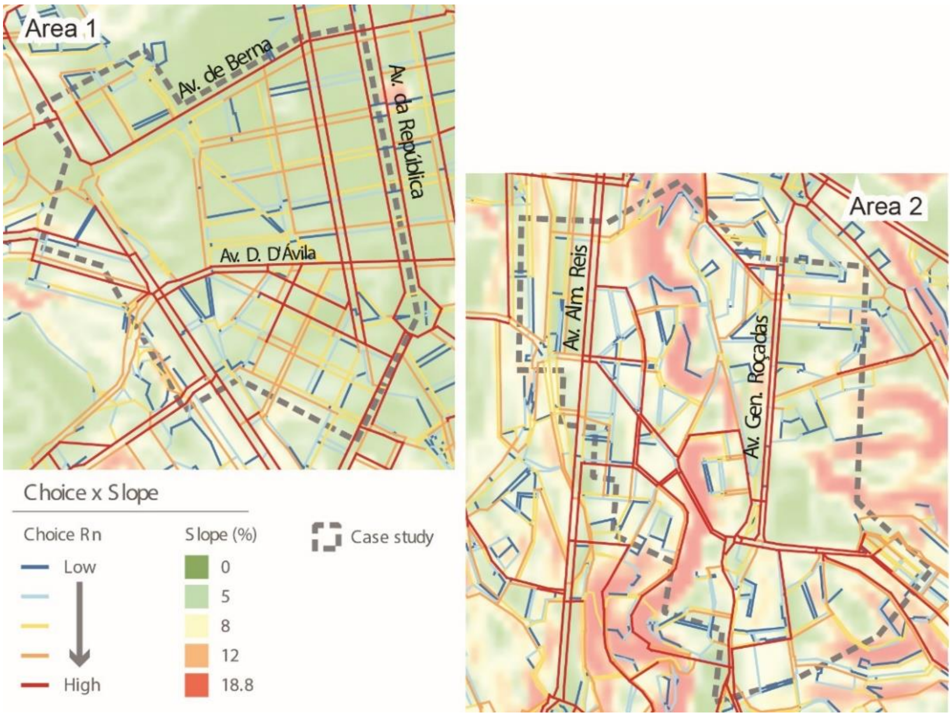


Figure 44. Map of Choice Rn and the slope of the terrain.

Regarding some urban elements, the activity in the area at the street level, which relates, among other factors, to the existing retail and services, is normally associated with integration. In fact, Figure 45 below shows a positive correspondence of the highest values of integration R1000m (red segments) and the higher density of commerce (dark blue patches). The opposite is also true: lower values of integration match lower density of retail.

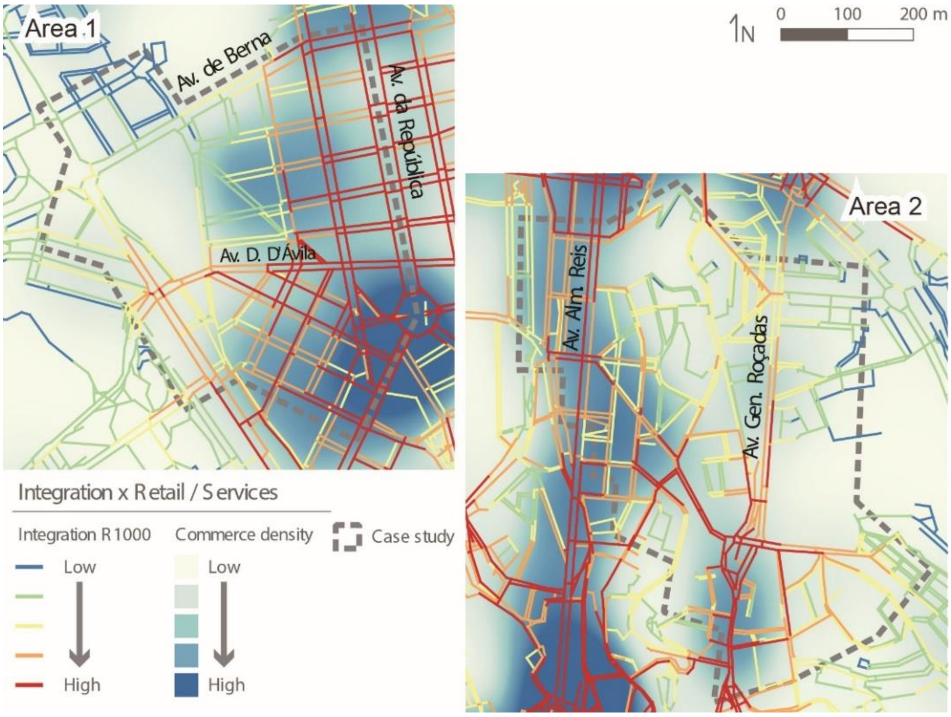


Figure 45. Map of Integration R1000m and the density of street commerce (retail/services).

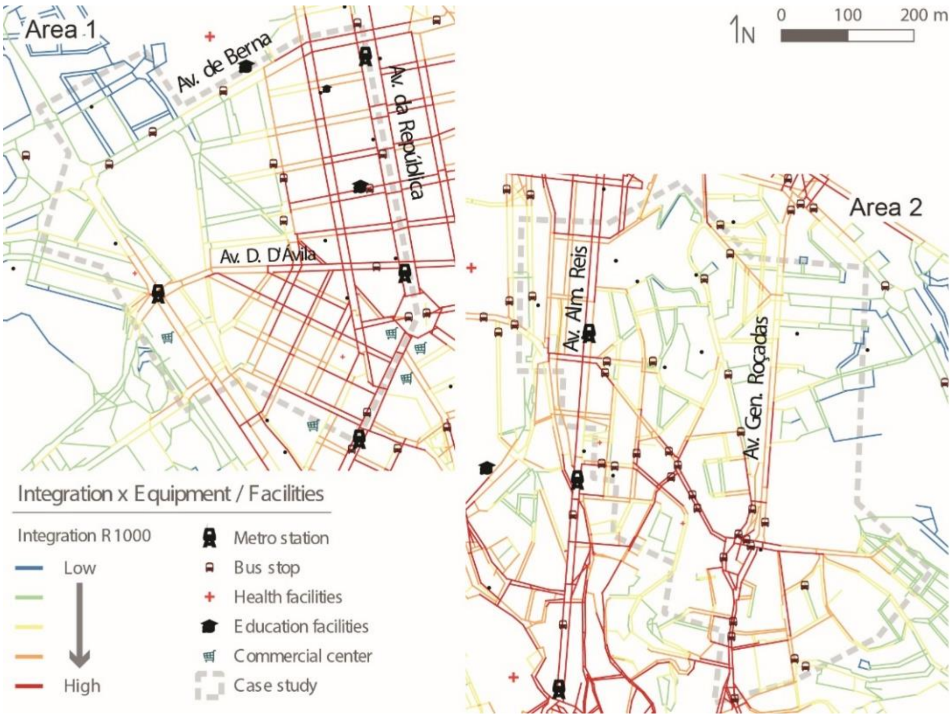


Figure 46. Map of Integration R1000m and some of the main equipment and facilities of the area.

Then, another possible comparison is to check if integration matches some major equipment and facilities of the area. In Figure 46, it is easy to notice that most of the equipment and facilities are located in well-integrated segments (in red), especially when it refers to public transportation interfaces (metro stations or bus stops).

Having checked the positive association with the pedestrian movement and with the urban elements, and having set the last parameters of buffer size and radius of analysis, the last phase of this work can be handled, which concerns combining space syntax analysis with the IAAPE method.

5.5 Combining Space Syntax with IAAPE

As it was already seen, pedestrian behavior depends on many variables, internal and external to the individual. For this reason, the configuration of the urban network will not be able to explain completely the pedestrian movements, although it contributes for a great share of it.

This part of the exercise searches an answer for the whole picture. Although it has already been addressed by IAAPE method, this work tries to improve the method by merging it with space syntax.

It was explained in chapter 3.1 that the IAAPE method calculates a final walkability score for each sidewalk segment summing up all the observed and measured parameters. In order to include the space syntax measures in the walkability score equation, space syntax values were adjusted as follows:

1. First, the space syntax results had to be normalized to fit the IAAPE index scale (0-100).
2. Then, the values had to be joined to the same database (linked to the pedestrian network), and, consequently, in the same spreadsheet.
3. Finally, the new walkability scores could be calculated with the syntactical values.

5.5.1 Rescaling space syntax measures

In the IAAPE method, the various indicators, qualitative and quantitative, are transformed to fit a scale from 0 to 100. As such, space syntax measures were normalized. However, since each measure has a different range of values, they were thought to be rescaled in different ways.

Considering that the space syntax measures are relational and, therefore, are calculated in respect to every segment of the system, the values from the whole model were taken into account, instead of only using the case study segments. Also, the value functions to transform the outcomes were defined and calibrated according to both the data distribution and spatial occurrence.

The measures to be inserted in the walkability index were: **integration radius 1000m, choice radius n (global), intelligibility and synergy**.

a. Regarding **integration R1000m**, the values from the model varied between 20.5 and 575.5, which were adopted as the minimum and maximum values of the function. This range can be visualized in the map of Figure 47, together with the its histogram.
   From the different functions that could be used to make this transformation, two of them were thought to fit better in the case:
   - a linear function, which is the simplest one and it is used in IAAPE project; and
   - a logistic function, which could work well because it seems that there are thresholds for the lowest and highest values of integration. In fact, it is said that segments with higher integration values form the 'core' of that system (Al_Sayed & al., 2014). In other words, it appears that in very-integrated or very-segregated areas of the map, the variation of

the integration values would not have a significant impact on the attractiveness of the segments, as perceived by pedestrians.

That said, for a **linear transformation**, the values were normalized according to the equation “a” from Figure 48, which scales them into the range [0,1], resulting in the orange line from the respective chart.

For a **logistic transformation**, the values were first standardized using the equation “b”, which reduced them to a [-1,1] interval, and then the logistic function (equation “c”) was applied, resulting in the sigmoid blue line from the chart.

Both functions were tested within the walkability index.

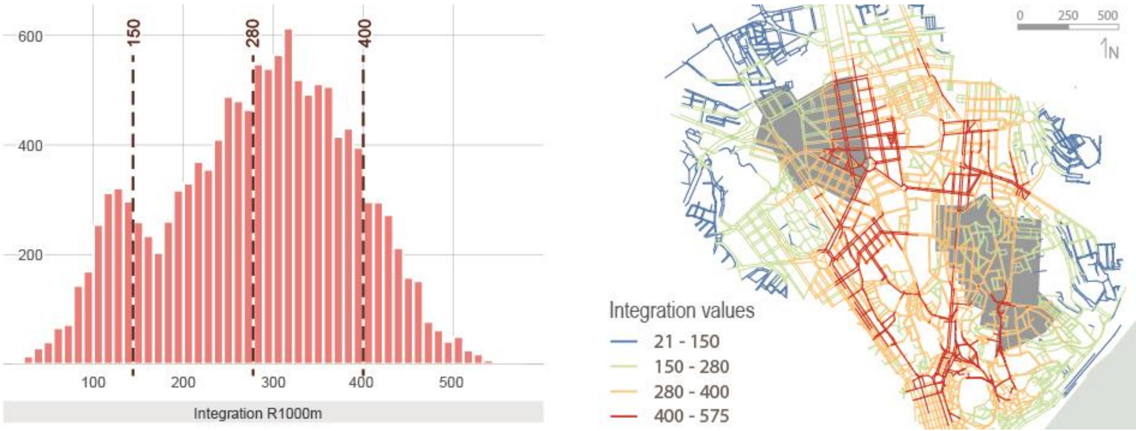


Figure 47. Distribution of the Integration R1000 data and the respective map.

Linear function

a) $$Int_{lin,i} = \frac{C_{Int,i} - min(C_{Int})}{max(C_{Int}) - min(C_{Int})}$$

Logistic function

b) $$Int_{standardized,i} = \frac{C_{Int,i} - \mu_{C_{Int}}}{\sigma_{C_{Int}}}$$

c) $$Int_{logistic,i} = \frac{1}{1 + e^{-2 * C_{Int,i}}}$$

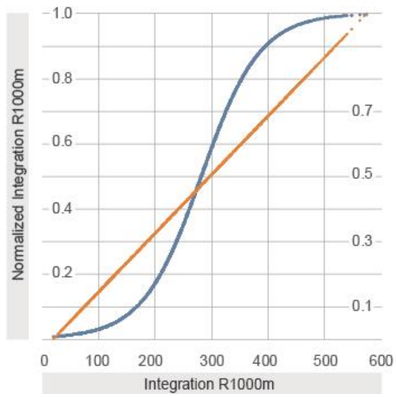


Figure 48. Functions used to rescale Integration R1000 data and the respective chart.

b. With respect to **Choice Rn (also Global Choice**), values varied from 0 to 22,000,000 and are exponentially distributed, as showed in Figure 49. This kind of distribution is common for this measure, because in any network, most of the segments have low values, while a few have very high values, which corresponds to the paths most used for through-movements. This type of distribution reflects the network hierarchies, commonly used for road networks categorization. In this case, since lower and higher values do not vary much, it was considered that the limit values should be tighter than the minimum and maximum. Therefore, the range was truncated in 5,000 and 2,000,000. These thresholds were defined visually by testing them on the map in GIS, as observed in the map of Figure 49. It was considered that, from these limits on, it would not make any difference for the pedestrian decision: values below 5,000 correspond to narrow or dead-end streets, and values above 2,000,000 correspond to key elements of the system, which are the most important thoroughfares of the area.

Then, to rescale the values, the same reasoning as the previous measure was adopted.

For the **linear transformation**, values were normalized using equation “f” (Figure 50), which resulted in the orange line of the respective chart.

For the **logistic transformation**, choice values were standardized (equation “g”) and, finally, a logistic function was applied, resulting in the sigmoid blue line from the chart.

Both functions were tested within the walkability index.

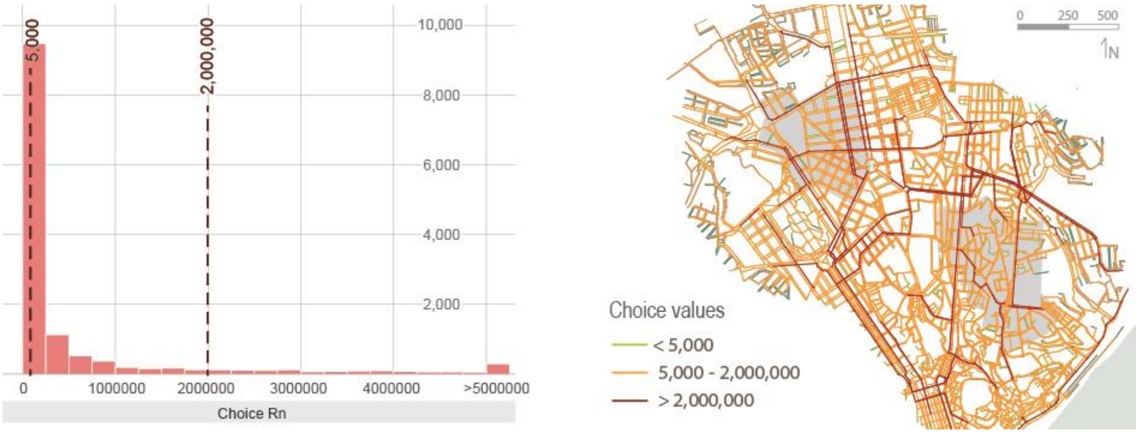


Figure 49. Distribution of the Choice Rn data and the respective map.

e)
$$Ch_{truncado} = \begin{cases} 5000, & C_{Rn} \leq 5000 \\ C_{Rn}, & 5000 < C_{Rn} < 2000000 \\ 2000000, & C_{Rn} \geq 2000000 \end{cases}$$

Linear function

f)
$$Ch_{lin,i} = \frac{C_{Rn,i} - min(C\_Rn)}{max(C\_Rn) - min(C_{Rn})}$$

Logistic function

g)
$$Ch_{standardized,i} = \frac{C_{Rn,i} - \mu_{C_{Rn}}}{\sigma_{C_{Rn}}}$$

h)
$$Ch_{logistic,i} = \frac{1}{1 + e^{-15 * C_{Rn,i}}}$$

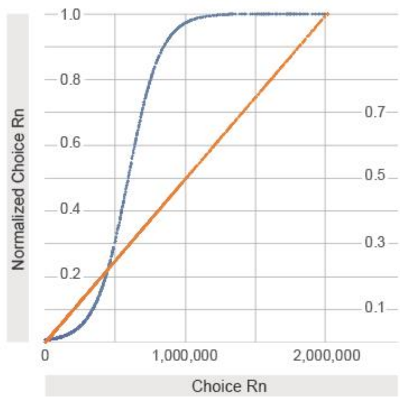


Figure 50. Functions used to rescale Choice Rn data and the respective chart.

c. The **Synergy and Intelligibility** measures work a bit different from the previous ones. These are correlations between two syntactical measures, as explained in chapter 3.2.1, which result in a value for the whole area of study. Still, to avoid the homogenization of the whole model, synergy and intelligibility where calculated separately for the two areas of the case study.

As shown in Figure 51, both Areas 1 and 2 presented **synergy** values of 64% and 29% respectively, which are higher that the Lisbon and the European context. These outcomes make sense, because in smaller areas, it is easier to apprehend the global structure from the local scale. Also, the higher value of Area 1 is explained by its regular grid, while the more irregular configuration of Area 2 entails a labyrinthic perception of the space, causing synergy to decrease.

Figure 52 shows that Areas 1 and 2 present an **intelligibility** of 16% and 8% respectively. This measure is greatly dependent on the presence of lines (paths) that cross the entire area, because they allow the user to see farther, promoting the legibility of that system. Accordingly, Area 1 presents longer lines of sight than Area 2, which has a more fragmented grid. Since these correlations vary in a 0-100 range, no normalization was required.

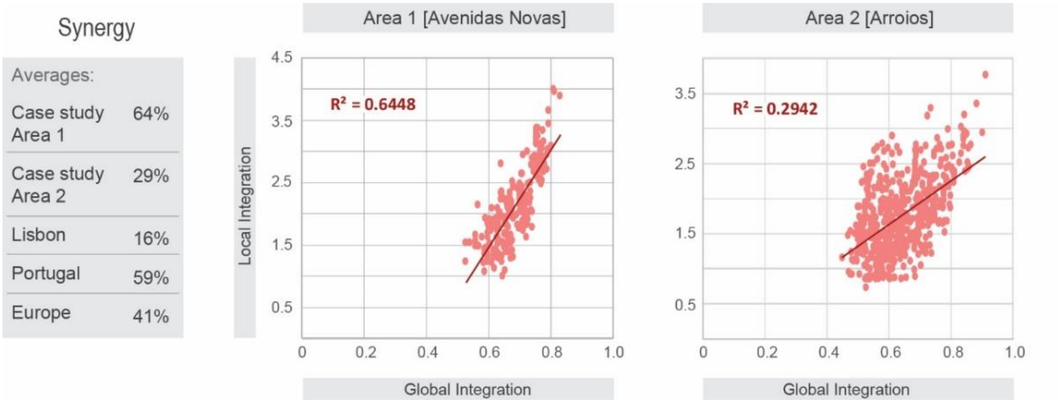


Figure 51. Synergy scatterplots for both areas of the case study and some reference values.

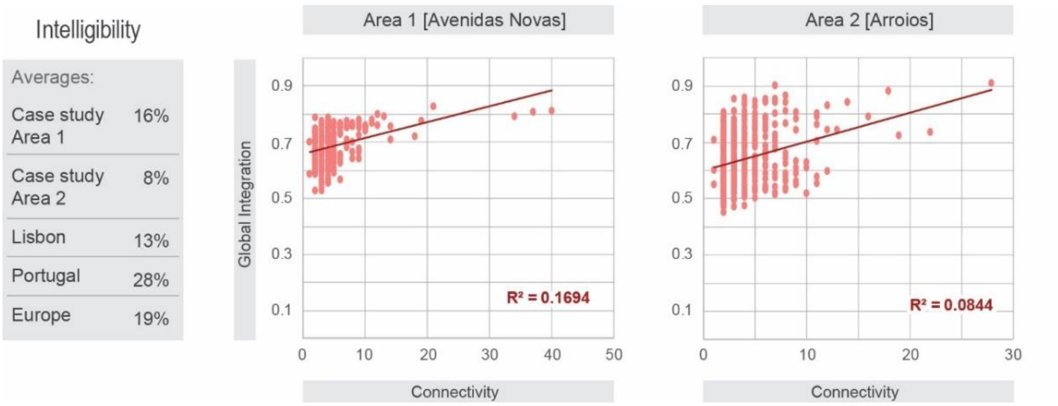


Figure 52. Intelligibility scatterplots for both areas of the case study and some reference values.

5.5.2 Joining indicators into the same database

This step was carried out in QGIS, since it required some spatial interactions.

During the IAAPE project, a pedestrian network was built based on some criteria that fit well the research. This network diverges from the space syntax method and, therefore, from the created sidewalk-centerline network. It caused some inconsistencies which would not happen if space syntax was adopted from the beginning of the project. Then, some decisions and steps were made to overcome the problem.

Since the IAAPE network has fewer segments, it was decided to use it to assemble both IAAPE and space syntax indicators. The procedure followed these steps:

1. The sidewalk-centerline network was transformed into a shapefile of points;
2. The point shapefile had to be cleaned up to avoid errors due to an excess of data;
3. A spatial join was applied to send the data from the points to the IAAPE segments;

4. The table from the resulting shapefile was reviewed and when errors were found (such as segments without any correspondent information), the spatial join had to be repeated.

Finally, all the data from the indicators was merged into the same database, making it possible to replace and/or combine them and calculate the new walkability scores.

5.5.3 Combining and validating the merge of space syntax measures and IAAPE

This step followed two stages of test and validation. First, IAAPE indicators were replaced by the normalized measures of integration and choice, followed by its validation with the pedestrian counts. Next, the measures of Synergy and Intelligibility were added and validated.

As a reminder, during the IAAPE project, each pedestrian group (adults, children, elderly and people with mobility impairment) had different indicators according to each pedestrian type revealed perception. Additionally, indicators were weighted differently for each trip purpose (whether utilitarian or leisure). The result of this process is shown in Table 10 below (see also Annex A).

Table 10. Pedestrian groups and the correspondent indicators and weights.

Adults	**Selected indicators**		C12. Pedestrian infrastructure	C21. Land use diversity	C32. Pavement quality	C43. Service hours	C51. Land-marks	C61. Traffic safety	C71. Pedestrian regulations
	Weights	**Utilitarian trip**	0.17	0.06	0.17	0.17	0.11	0.22	0.11
		Leisure trip	0.04	0.19	0.12	0.23	0.19	0.15	0.08
Children	**Selected indicators**		C13. Path directness	C21. Land use diversity	C31. Vigilance effect	C42. Anchor places	C51. Land-marks	C62. Crossing location	C75. Design standards
	Weights	**Utilitarian trip**	0.19	0.15	0.19	0.04	0.12	0.23	0.08
		Leisure trip	0.09	0.23	0.18	0.18	0.14	0.14	0.05
Elderly	**Selected indicators**		C12. Pedestrian infrastructure	C24. Daily commerce / services	C32. Pavement quality	C41. Metting places	C51. Land-marks	C61. Traffic safety	C71. Pedestrian regulations
	Weights	**Utilitarian trip**	0.11	0.16	0.21	0.11	0.05	0.21	0.16
		Leisure trip	0.07	0.27	0.17	0.17	0.03	0.17	0.13
People with mobility impairment	**Selected indicators**		C14. Accessible network	C22. Sidewalk width	C32. Pavement quality	C42. Anchor places	C53. Street toponomy	C61. Traffic safety	C71. Pedestrian regulations
	Weights	**Utilitarian trip**	0.11	0.16	0.21	0.11	0.05	0.21	0.16
		Leisure trip	0.15	0.1	0.2	0.15	0.05	0.15	0.2

Table 11. Indication of how the syntactical measures were added to the pedestrian groups' walkability score.

Adults	Selected indicators	C12. Pedestrian infrastructure	C21. Land use diversity	C32. Pavement quality	C43. Service hours	C51. Landmarks	C61. Traffic safety	C71. Pedestrian regulations
		Replaced by Integration R1000				**Addition of Synergy and intelligibility**		
Children	Selected indicators	C13. Path directness	C21. Land use diversity	C31. Vigilance effect	C42. Anchor places	C51. Landmarks	C62. Crossing location	C75. Design standards
		Replaced by Choice Rn				**Addition of Synergy and intelligibility**		
Elderly	Selected indicators	C12. Pedestrian infrastructure	C24. Daily commerce / services	C32. Pavement quality	C41. Metting places	C51. Landmarks	C61. Traffic safety	C71. Pedestrian regulations
		Replaced by Integration R1000				**Addition of Synergy and intelligibility**		
People with mobility impairment	Selected indicators	C14. Accessible network	C22. Sidewalk width	C32. Pavement quality	C42. Anchor places	C53. Street toponomy	C61. Traffic safety	C71. Pedestrian regulations
						Addition of Synergy and intelligibility		

The tests were done as follows:

1. In Excel, based on the original IAAPE walkability equations, two indicators were replaced by the syntactical measures, for instance, the indicator “Pedestrian infrastructure (continuity)” was replaced by “Integration R1000m” and “Path directness” was replaced by “Choice Rn” (Table 11).

   The outcomes from both the linear and the logistic normalization were meant to be tested, then it resulted in two walkability scores.

   In SPSS software, the three walkability scores (the two from the previous step, plus the original one, from IAAPE) were correlated with the pedestrian counting for validation. The results can be observed in Table 12 below. The walkability score with the syntactical measures normalized with a logistic function (IAAPE + SS_{logist}) return better correlations when considering only pedestrians in movement (upper part of the table). If sojourning pedestrians are also considered (bottom part of the table), the highest correlations vary mostly between both the walkability scores with the syntactical values.

   Then, to check if the differences between the results are statistically significant, the Fisher’s r-to-z test was applied to each pair of correlations. For a degree of confidence of 95%, the correlations of the new walkability indexes and the original IAAPE are not significantly different, which means that the replacement of the indicators did not change the final score.

   This test could not be applied to the disabled-people group, because they had not selected any of the exchanged indicators.

Table 12. First test, correlations between pedestrian counts and the walkability scores. The Pearson (r) correlation coefficient was used.

Pedestrian group:		**Adults**						**Children**						**Elderly people**					
Trip purpose:		Utilitarian			Leisure			Utilitarian			Leisure			Utilitarian			Leisure		
		IAAPE walkability score	IAAPE + SS linear	IAAPE + SS logistic	IAAPE walkability score	IAAPE + SS linear	IAAPE + SS logistic	IAAPE walkability score	IAAPE + SS linear	IAAPE + SS logistic	IAAPE walkability score	IAAPE + SS linear	IAAPE + SS logistic	IAAPE walkability score	IAAPE + SS linear	IAAPE + SS logistic	IAAPE walkability score	IAAPE + SS linear	IAAPE + SS logistic
Average of pedestrians in movement	peak morning	.504**	.535**	.535**	.527**	.531**	.533**	.557**	.617**	.618**	.589**	.620**	.625**	.405**	.420**	.424**	.349**	.352**	.357**
	off-peak morning	.475**	.531**	.541**	.524**	.533**	.536**	.513**	.598**	.606**	.552**	.595**	.603**	.411**	.448**	.459**	.394**	.409**	.418**
	lunch hour	.582**	.626**	.632**	.617**	.624**	.627**	.680**	.760**	.756**	.704**	.746**	.749**	.503**	.527**	.536**	.459**	.467**	.474**
	off-peak afternoon	.511**	.567**	.582**	.555**	.564**	.569**	.538**	.633**	.638**	.586**	.633**	.640**	.376**	.412**	.430**	.331**	.346**	.359**
	peak afternoon	.469**	.532**	.548**	.516**	.526**	.531**	.537**	.638**	.643**	.582**	.633**	.639**	.373**	.415**	.433**	.342**	.361**	.373**
Average of pedestrians in mov. and sojourning	peak morning	.536**	.557**	.548**	.574**	.576**	.576**	.599**	.639**	.639**	.635**	.655**	.659**	.447**	.451**	.448**	.415**	.412**	.412**
	off-peak morning	.528**	.544**	.533**	.579**	.580**	.580**	.585**	.597**	.597**	.624**	.631**	.635**	.425**	.426**	.421**	.415**	.410**	.409**
	lunch hour	.555**	.575**	.558**	.599**	.601**	.600**	.646**	.658**	.646**	.696**	.702**	.700**	.466**	.471**	.460**	.443**	.439**	.435**
	off-peak afternoon	.498**	.515**	.513**	.544**	.546**	.547**	.595**	.629**	.617**	.645**	.662**	.660**	.371**	.374**	.376**	.358**	.355**	.358**
	peak afternoon	.511**	.538**	.537**	.568**	.572**	.574**	.602**	.627**	.619**	.663**	.674**	.674**	.369**	.379**	.385**	.354**	.355**	.360**

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

Based on these results, the IAAPE method combined with the logistically-normalized syntactical measures had higher correlations with pedestrian counts and, therefore, it was the adopted approach in the following steps.

2. For the second test, the walkability scores were once again calculated, but this time, including synergy and intelligibility values (Table 11). These syntactical measures were tested because they seem to finely reflect the Conspicuousness dimension. However, they do not match the indicators selected by the pedestrian groups ("Existence of landmarks" and "Street toponomy"), and, for this reason, it was decided to simply add them to this dimension's indicators.

   Again, a correlation with the pedestrian counting was run in SPSS, resulting in the Table 13 below. In this case, the disabled people group was also included. The correlations were very similar to the original IAAPE walkability score. Indeed, checking the significance of the differences with the Fisher's r-to-z test, it resulted that, for a degree of confidence of 95%, the correlations remained statistically the same.

   Based on this test, the addition of synergy and intelligibility did not entail significant change to the walkability index.

Table 13. Second test, correlations between pedestrian counts and the walkability scores. The Pearson (r) correlation coefficient was used.

	Pedestrian group:	Adults				Children				Elderly people				Disabled people			
	Trip purpose:	Utilitarian		Leisure		Utilitarian		Leisure		Utilitarian		Leisure		Utilitarian		Leisure	
		IAAPE	+ synergy & intellig.	IAAPE	+ synergy & intellig.	IAAPE	+ synergy & intellig.	IAAPE	+ synergy & intellig.	IAAPE	+ synergy & intellig.	IAAPE	+ synergy & intellig.	IAAPE	+ synergy & intellig.	IAAPE	+ synergy & intellig.
Average of pedestrians in movement	peak morning	.504**	.501**	.527**	.488**	.557**	.600**	.589**	.612**	.405**	.396**	.349**	.339**	.317*	.315*	.323*	.321*
	off-peak morning	.475**	.502**	.524**	.485**	.513**	.582**	.552**	.580**	.411**	.430**	.394**	.399**	.311*	.307*	.311*	.307*
	lunch hour	.582**	.584**	.617**	.562**	.680**	.730**	.704**	.726**	.503**	.500**	.459**	.452**	.335**	.334**	.340**	.339**
	off-peak afternoon	.511**	.542**	.555**	.515**	.538**	.613**	.586**	.617**	.376**	.397**	.331**	.338**	.340**	.338**	.342**	.340**
	peak afternoon	.469**	.514**	.516**	.485**	.537**	.627**	.582**	.628**	.373**	.405**	.342**	.355**	.334**	.332**	.342**	.340**
Average of pedestrians in mov. and sojourning	peak morning	.536**	.509**	.574**	.528**	.599**	.617**	.635**	.644**	.447**	.418**	.415**	.393**	.286*	.284*	.290*	.287*
	off-peak morning	.528**	.493**	.579**	.533**	.585**	.572**	.624**	.616**	.425**	.390**	.415**	.390**	.271*	.268*	.273*	.270*
	lunch hour	.555**	.513**	.599**	.546**	.646**	.619**	.696**	.682**	.466**	.426**	.443**	.415**	.281*	.279*	.290*	.288*
	off-peak afternoon	.498**	.475**	.544**	.501**	.595**	.597**	.645**	.650**	.371**	.345**	.358**	.339**	.298*	.296*	.305*	.304*
	peak afternoon	.511**	.498**	.568**	.526**	.602**	.596**	.663**	.662**	.369**	.352**	.354**	.340**	.330**	.329*	.341**	.340**

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

Summing up this step, there are some results that are worth highlighting:

- The new walkability index, which includes some syntactical measure of integration and choice, proved to work well. When correlated with the pedestrian counting, the results were slightly better than the original IAAPE, although these differences were not statistically significant (for a confidence degree of 95%). The addition of synergy and intelligibility, however, did not make a consistent change.

- Regarding the rescaling of the data, the logistic function proved to fit well the purpose of the exercise. It also makes sense from a pedestrian point-of-view, for whom very-integrated or very-segregated segments do not count as much as the intermediate range.

5.5.4 Comparing results between walkability indexes

To compare both the original IAAPE walkability score and the new walkability index that includes space syntax measures, the values were analyzed as a whole and per score range, and the rank correlation with Spearman's coefficient was tested. Besides maps were used to visualize the data.

Observing the whole set of values, two patterns were noticed (Table 14): (1) in the groups that received the integration values, 75.5% of the segments' score increased, while the rest decreased; (2) in the children groups, which received the choice values, 24.8% of the segments' score increased, and 75.2% decreased. The changes of the score values varied between -15 and 19.

Table 14. Rise and fall in walkability score, in absolute terms, for each pedestrian group and trip purpose.

Pedestrian group:	Adults		Children		Elderly people	
Trip purpose:	Utilitarian	Leisure	Utilitarian	Leisure	Utilitarian	Leisure
Rise ↑ (nr. of segments)	837	837	275	275	837	837
% from total	75.5%	75.5%	24.8%	24.8%	75.5%	75.5%
Fall ↓ (nr. of segments)	271	271	833	833	271	271
% from total	24.5%	24.5%	75.2%	75.2%	24.5%	24.5%

The maps from Figure 53 and Figure 54 illustrate the differences between both walkability indexes and bring the information about the scores' ranges and the Spearman's correlation. The maps of the other groups can be found in Annex C. The values were sorted into classes following the IAAPE classification (Figure 18), i.e., divided in five ranges of 20 units each. This classification could also be translated into qualitative categories, for instance, "poor", "fair", "good", "very good" and "excellent". Setting both walkability scores' values to the same intervals enables the comparison of how much (in %) has remained or changed between classes.

It makes sense to analyze values by range, instead of individually by segment, because ultimately, for practical purposes, data is commonly aggregated in order to make patterns clearer and to facilitate the decision-making process.

From the maps below, few changes can be observed between the walkability scores, especially in Area 2. For example, in the adult group map (Figure 53), the use of the syntactical measures resulted in a change in 18% of the scores to higher classes. On the other side, the walkability score of the children group (Figure 54) presented a change toward lower classes in 34% of the scores. Nevertheless, the majority of the walkability scores maintained the same classification (80%, on average), what shows a consistency between the indexes. Table 15 presents how many segments have changed their classification, according to the group of pedestrians and to their class. Most that got a better classification were from intermediate ranges, but the segments which had a fall in classification were mostly from lower ranges.

The Spearman's ranks correlation coefficient measures if the elements of both variables are similarly ordered. In other words, it was tested if the segments maintained the same ranking, despite the variation of the final values. The correlations between the walkability scores of the pedestrian groups varied from 0.856 (for children/utilitarian trip) to 0.996 (to adults/leisure trip), demonstrating a very strong correlation between the original IAAPE and the combined IAAPE + space syntax index (see Annex C).

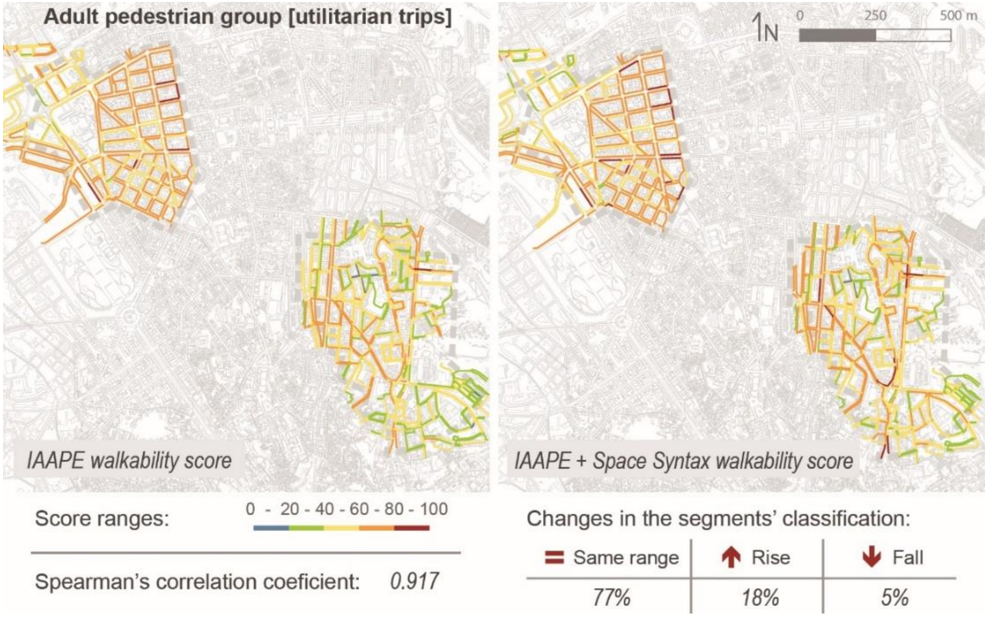


Figure 53. Maps illustrating the scores for the adult-pedestrian group from two indexes: the original one, from IAAPE project and the version with the syntactical values (normalized with logistic function).

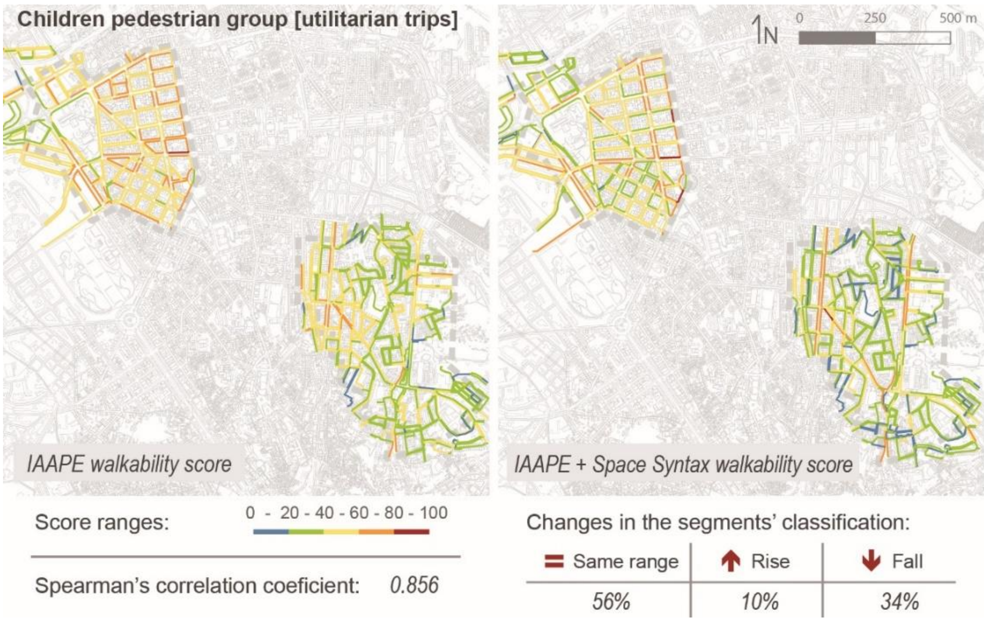


Figure 54. Maps illustrating the scores for the children-pedestrian group from two indexes: the original one, from IAAPE project and the version with the syntactical values (normalized with logistic function).

Table 15. Number of segments that changed in class with the new walkability score, for each pedestrian group, trip purpose and score class.

	Pedestrian groups:	Adults		Children		Elderly people	
	Trip purpose:	Utilitarian	Leisure	Utilitarian	Leisure	Utilitarian	Leisure
Nr. of segments with an increase of score class	To 20-40 range	3	2	6	14	1	2
	To 40-60 range	92	25	53	25	35	28
	To 60-80 range	89	27	46	15	77	49
	To 80-100 range	20	2	4	0	3	6
% from total		18%	5%	10%	5%	10%	8%
Nr. of segments with a decrease of score class	To 0-20 range	0	1	105	84	0	0
	To 20-40 range	24	8	218	85	21	11
	To 40-60 range	33	3	51	13	29	21
	To 60-80 range	0	0	0	0	2	1
% from total		5%	1%	34%	16%	5%	3%

All in all, the walkability scores presented a very high rank correlation (with Spearman's coefficient), which indicates that the segments follow a similar order in both methods. Also, despite the variation of the values due to the change of indicators, 80% of the segments maintained the same classification. The pedestrian group that had the biggest variation was the children one, for utilitarian trip, which relates to the replacement of the "path directness" indicator for "choice". That is to say, the new walkability score restates the results from former one.

Finally (and probably most important), other advantages in using the syntactical values instead of the correspondent IAAPE indicators are: (1) the time needed to build the network, which, in the case of syntactical model, it is +/- four times more time-saving; and (2) the fact that space syntax methodology is an already established tool, as it was explained in chapter 3.2.

5.6 Adapting the walkability index for other analyses

Many other studies and analyses can be made with this methodology. In this last exercise, an attempt was done to compare the impact of little changes in the urban configuration on walkability.

Considering what has been exposed about how political decisions (rather than technical ones) shaped the existing traffic rules and codes, if priority was given back to pedestrians, then those same rules had to be adapted to provide a more connected and comfortable walking paths.

Following this reasoning, adaptations were made in the space syntax model, improving the pedestrian network and, still, causing little impact in terms of implementation. Starting from the formal pedestrian network studied along this work, (1) desire lines, such as not marked crossings at intersections, were incorporated, and (2) coexistence zone/shared space were defined in side streets where sidewalks were too narrow or inexistent. This was done with maximum care for intermodal safety.

These simple changes generated a dramatic impact in the integration of the network (Figure 55), as well as some changes regarding choice (Figure 56).

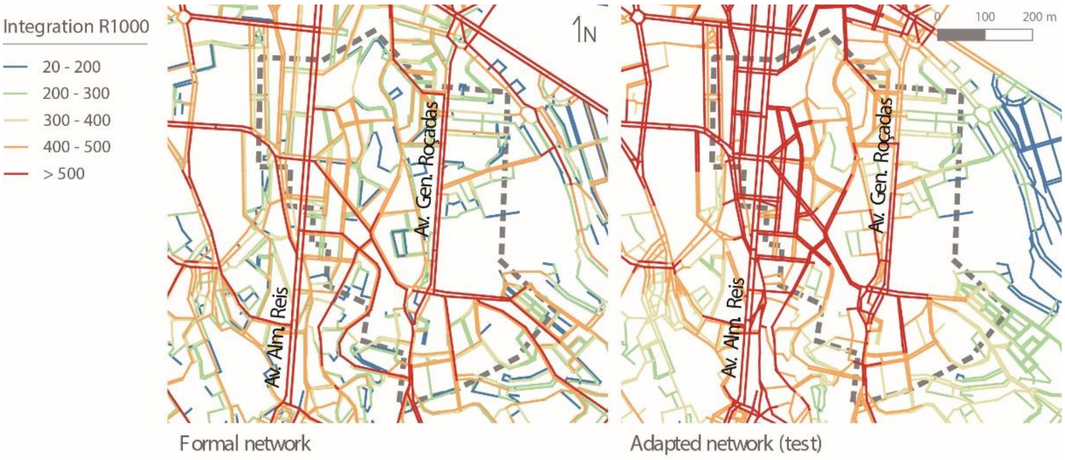


Figure 55. Changes in integration when introducing some adaptation to the pedestrian network.

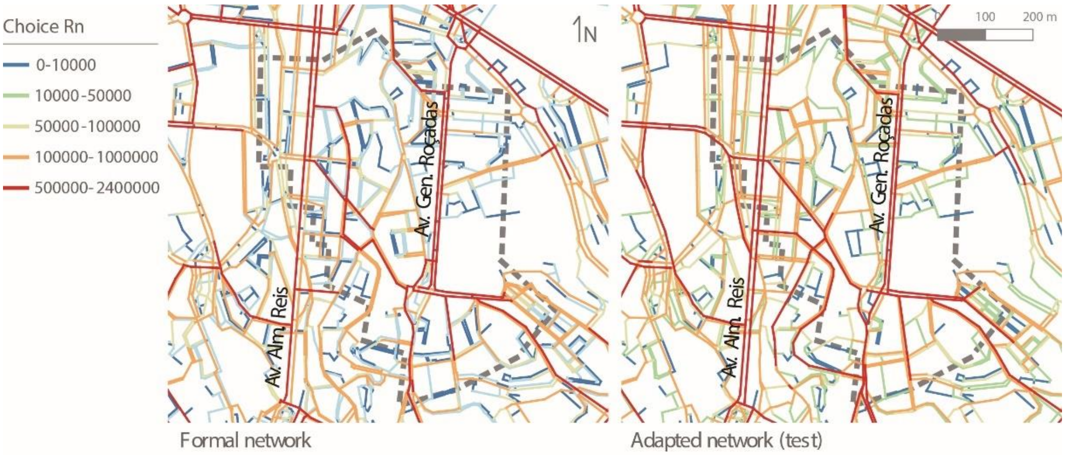


Figure 56. Changes in choice when introducing some adaptation to the pedestrian network.

To insert the new syntactical outcomes into the walkability index, the values had to be truncated according to the interval of the existing situation. This adjustment was necessary, because the new measures presented much higher values and since normalization transform the values proportionally, it would result in lower values for most of the segments. When the ranges were truncated, the before-after comparison was possible and the impact of the changes in the network could be seen on the walkability score.

Table 16 below shows the comparison between the scores of this exercise and the previous one. It was expected that the introduction of some improvements in the network would result in greater walkability scores.

Regarding the adult and the elderly pedestrian groups, who received the new integration values, virtually all segments (99.3%) had an increase in their score, enhancing walkability up to 12%. The children groups, however, did not perform the same, with an increase in only 63% of the segments, which happened because of the choice measure. The new links introduced in the network changed the configuration of the shortest paths, impacting choice in two ways. When the shortest paths remained along the same segments, there was an increase of the choice value; on the other hand, some segments lost attraction, causing an abrupt decrease of the choice values, and, consequently, a lower final score. Choice values varied from -19 to 19%.

Table 16. Rise and fall in walkability scores, in absolute terms, and for each pedestrian group and trip purpose.

Pedestrian group:	Adults		Children		Elderly people	
Trip purpose:	**Utilitarian**	**Leisure**	**Utilitarian**	**Leisure**	**Utilitarian**	**Leisure**
Rise ↑ (nr. of segments)	742	742	469	469	742	742
% from total	99.7%	99.7%	63%	63%	99.7%	99.7%
Maximum increase in walkability score	**12%**	**3%**	**19%**	**9%**	**8%**	**5%**
Fall ↓ (nr. of segments)	2	2	275	275	2	2
% from total	0.3%	0.3%	37%	37%	0.3%	0.3%
Maximum decrease in walkability score	**0%**	**0%**	**19%**	**9%**	**0%**	**0%**

This last exercise discloses the versatility of the tool, proving that it can be used to evaluate different scenarios. Nevertheless, every outcome must be interpreted according to the changes made and to the context.

6 Discussion of the results

This chapter discusses the findings from the application of the model to the Lisbon case study, explaining the outcomes, highlighting the best results, and pointing out limitations.

The proposed exercise involved two methodologies, space syntax and IAAPE walkability score, that were shown to be complementary to each other, as well as having a comprehensive and multidisciplinary approach. The exercise had an exploratory nature, in which variations of the space syntax parameters were tested, setting the indicators to be combined within the IAAPE walkability score.

Space syntax has already been used in some study walkability studies (Baran, Rodríguez, & Khattak, 2008; Dhanani & Vaughan, 2016; Lerman, Rofè, & Omer, 2014), however, there are still much to be studied and improved. The first performed test was an adaptation of the commonly used road-centerline network (RCL network) to a pedestrian one, named sidewalk-centerline network (SCL network). The most effective way to build it has proved to be the manual digitalization of the axial lines over a satellite image of the city. Although the quality of the outcome is much dependent on who is digitalizing it, this approach was preferred instead of the automatic generation of the lines-of-sight, because the latter took more time to be settled and resulted in an excess of lines, which would mislead the calculation of the syntactical measures.

The SCL network was then compared to the default RCL one. The correlations between the pedestrian counts and the integration values of both models resulted better for the SCL network in lower radii of analysis (R600m to R1000m). However, the Fisher's r-to-z test revealed that the difference of the results was not statistically significant (for a degree of confidence of 95%). Thus, through this validation, it was not conclusive if the SCL network is a better representation of the pedestrian environment. Nonetheless, it was considered that more data would be necessary to validate or reject the approach. Mainly because the available pedestrian counts were done only on one side of the street (one sidewalk), and to correlate them with the RCL network the counts ideally should be a sum of the pedestrians from both sides.

Still, the SCL network was adopted because it matches the network used in the IAAPE method, which was designed considering the sidewalk segments, and because all the available data corresponds to these segments. Also, it was considered that treating a network with more detailing renders more importance to pedestrians.

The validation of the SCL network comprised two steps: the definition of its parameters and a visual comparison with the characteristics of the area. Regarding the parameters, tests were carried out with respect to the size of the buffer area that must be digitalized around the case study to avoid the edge effect, and the definition of the radius of analysis. Three buffer sizes were tested (500m, 1000m, 2000m) and from 1000 meters on the correlation results remained stable, indicating that the edge effect had disappeared. The buffer area must be carefully defined because there is no standard value for it. Additionally, it is particularly important for local analyses, together with the definition of the radius of analysis (Gil, 2015). In fact, the 1000m-buffer was also accepted, because it matches the results for the radius. Different radii were testes (400m, 600m, 800, 1000m, 1600m, 2000m, Rn) and the greatest correlations with pedestrian counting were achieved using radius 1000m for Integration. Choice, on the other hand, presented better correlation for higher radii, which can be explained for it being more sensitive to the number of segments of the model, instead of its size (Gil, 2016). Since choice has either very high or very low values, the correlations are very much dependent on where the counts were made. In this case, these locations were chosen randomly, based on cluster analyses, which prevents major bias.

The second validation was the visual comparison between the syntactical measures and the characteristics of the area. Data about topography (slopes), land use (commerce density) and equipment and facilities were used. These analyses do not intend to demonstrate any mathematical precision but were useful to visualize if the syntactical measures indeed reflect some physical and social aspects of the area. Nevertheless, when more data or more detailed information from the site are available, further comparisons can also be tested.

Finally, the syntactical measures of Integration R1000 and Choice Rn were normalized to fit within IAAPE walkability score. A linear function and a logistic function were used to transform the values to a 0-100 range. Three walkability scores were, then, compared: (1) the original IAAPE walkability score – $IAAPE_{WScore}$; (2) IAAPE + space syntax measures with linear transformation – $IAAPE+SS_{linear}$; and (3) IAAPE + space syntax measures with logistic transformation – $IAAPE+SS_{logist}$.

The linear transformation was tested as it is the function used in the IAAPE method. However, considering the distribution of the values, the logistic transformation was thought to translate better the perception of the pedestrian. The reason for that was because, for pedestrians, the group of sidewalks with the highest values (well integrated or with higher choice) or the lowest values (very segregated or with lower choice) would impact less in their path decision than the middle ranges (Figure 47 and Figure 49). The sigmoid from the logistic function translated this argument, while the linear function treated the values homogeneously.

The final scores of each were validated with the pedestrian counting. The three performed similarly, although $IAAPE+SS_{logist}$ resulted in slightly higher correlations. Again, to confirm if the differences were relevant, the Fisher's r-to-z test was applied, revealing that the correlations are statistically the same (for a degree of confidence of 95%). Ideally, and to be more precise, the pedestrian counting should have been differentiated by types of pedestrians to proceed the correlations. If that was possible, then this exercise could be further validated.

Furthermore, regarding the syntactical measures of synergy and intelligibility, there was no clear contribution to the walkability index. Since there was no correspondent indicator in the index, these measures were summed within the Conspicuousness dimension and, differently from other indicators, they resulted in one value for each area, instead of one per segment. Although these measures are closed related to the perception of the environment, this approach did not impact significantly the outcome of the index.

Regarding the final scores of the new walkability index ($IAAPE+SS_{logist}$), the results showed consistency with respect to the syntactical measures. When integration was used (adult and elderly groups), most of the segments' score increased in the same proportion for all groups; meanwhile, when choice was introduced in the index (children groups), most of the scores decreased, in the same proportion for both children groups (Table 16). On the other hand, when analyzing the score by ranges of 20, most of the segments remain within the same range as in the original $IAAPE_{WScore}$. This can be explained by the little variation of the values.

In sum, the inclusion of the syntactical measures helped to improve the IAAPE walkability index and are worth using. The replacement of the indicators did not modify significantly the final scores, restating the $IAAPE_{WScore}$ results. Nevertheless, the use of space syntax renders the index efficiency, as it is less resource-consuming to be produced and calculated, other than being a well-established methodology. Moreover, the replaced IAAPE indicators ("path continuity" and "path directness") need more data to be calculated, take four times (average) more hours to be built and are calculated in a licensed software.

Lastly, the final exercise from chapter 5.6 tested the use of the walkability index for a different purpose. The attempt was to understand the impact of little changes in the urban configuration on walkability. As expected, the improvements in the pedestrian network resulted in higher integration values and, consequently, higher walkability scores for almost all segments, with an increase up to 12% (adult and elderly groups). Conversely, the choice values varied differently from integration, resulting in higher and lower walkability scores. It occurred because the addition of new links in the network made some path lose attractiveness and, in some cases, the choice values dropped dramatically. Therefore, the walkability scores for the children groups both increased and decreased.

Limitation of findings, inconclusive results and further investigation

Some limitations of this study are related to the data that can be considered outdated, for instance, the pedestrian counting from 2015, and/or to the lack of data, such as more parameters for validating the results (information about the area and the number of pedestrian counts). Also, it must be considered that most of the data produced by the author, such as the networks, are susceptible to subjective interpretations or even to human errors.

Moreover, it is important to point out some outcomes of the exercises that remained without explanation or need more investigation:

- Regarding the pedestrian counting, only the averages of moving pedestrians were considered, because their correlations were higher; however, attention must be paid to sojourning pedestrians, who are part of the system and should be further addressed;
- The 1000m radius of analysis presented the best correlations with the pedestrian data, although it is higher than the radii from the cited literature. Despite the lack of evidence on which radius to use for pedestrian analysis, the studies previously mentioned pointed smaller radii, such as 600 and 650 meters (Bielik et al., 2017; Larsen et al., 2010). Some possible explanation for such a difference can be either the different contexts analyzed or some bias due to the

pedestrian counting. This work adopted 1000m radius, although more research should be done specific about this topic;

- Synergy and intelligibility also deserved more attention, since these syntactical measures are related to spatial perception, which influences the pedestrian navigation. Further research could explore how these two parameters impact walkability and how they could be included in an index. For example, using other forms of syntactical representation, such as isovists, and searching for a different mathematical transformation of the values.

Other than that, it is worth noting that the results from the disabled people group could not be properly worked out, because their selected indicators for the first dimension (Connectivity) did not include any indicator that could be replaced by syntactical measures. The first intention of the exercise was to maintain the selected indicators of each group; still, it can also be considered that the configuration of the network should be always addressed among the indicators, because it is an inherent aspect in a mobility system, without which the system would not exist. In fact, it has been defended that configuration plays a major role in walkability (Cambra, Moura, & Gonçalves, 2017), thus, further variations of the walkability index can be tested, in which integration and choice measures are considered for all groups' walkability score, including pedestrians with disabilities.

7 Conclusion

This dissertation dealt with the pedestrian in the city, studying the issue from a global perspective to a specific point. First, it outlined the dimensions of a walkable environment and how it was transformed over time, who the pedestrians are and how they perceive and behave in this context. Then, the discussion was brought to a specific point, in which a comprehensive tool was worked out and applied in a real case study where the space usage was measured, in order to evaluate the theoretical capacity of the tool and demonstrate its relevance and, ultimately, to prove itself useful for planners and decision makers.

It was defended that everyone is a pedestrian, therefore, a key-player in urban planning; and that pedestrians are a heterogeneous group, whose diversity must be respected and addressed by policies, plans, and tools. Hence, it is important to understand walkability, which is the necessary condition of the urban environment for pedestrians to move around, reach destinations and socialize.

As a matter of fact, the urban environment has been shaped by the political vision of some groups according to their interests, resulting in the current car-centered cities, away from the pedestrian needs. This prioritization, reflected in the street design and traffic codes, is nowadays being questioned. The change for a pedestrian-centered paradigm comes associated with a myriad of benefits and plays an important role in a sustainable development. In this direction, this dissertation searched to subvert the dominant model, bearing in mind what has shaped the current walking environment and looking the urban space through the eyes of the pedestrians. With such knowledge and position, bad solutions can be easily detected, and new solutions can be envisioned.

Pedestrians and their environment have been studied for a while now and by many fields. Regarding walkability, the state of art comprehends three main research subjects: the built environment, social interactions, and pedestrian perception and behavior. This dissertation addressed these topics when working out a tool, or better, the improvement of a tool, which is intended to be pragmatical and useful for planners and the like.

The tool presented in this dissertation is a combination of IAAPE walkability score and space syntax methodology. IAAPE counts for many aspects of both the built environment and the pedestrian perception, including a participatory phase with different groups of pedestrians; space syntax, on the other hand, allows many analyses regarding the urban configuration and flows, which are easy to calculate, besides being a consolidated field of study. The inclusion of space syntax measures into IAAPE resulted in a walkability index easier to handle and more efficient.

Nowadays, we do not walk freely about, but rather we are bound to a ruled built environment that impacts the way we understand and navigate it. The walkability tool of this dissertation is one way to check the quality of a space for walking, opening space to envision improvements, which can, once again, place the pedestrian at the top of the priority list.

Contributions to the walkability field

Although no innovative idea was created, the theoretical part brought together many facets of walkability, setting up the big picture and putting into perspective many concepts that are normally taken as absolute in the planning field. How the pedestrian environment got to the current configuration and how the laws got to be settled are points somewhat foggy in the literature. Compiling those issues together restated the importance of the pedestrian mode and brought arguments to discuss established priorities.

The case study of this dissertation resulted in different outputs, indicating some paths that are either worth following or, that can be avoided. Moreover, it brought attention to parameters regarding pedestrians that lack evidence in the literature and contributed to give an answer to them. In sum, it set results that can serve as a reference for researchers from space syntax and walkability fields.

The usability of the final walkability index (IAAPE + space syntax) may comprise other studies and analyses. Besides its direct application in other contexts (other neighborhoods or other cities), it can be a useful tool for analyzing the evolution of an area over time and to test different scenarios. By being supported with evidence IAAPE + space syntax can inform short-term decisions with strategic medium- to long-term objectives. For example, the tool can be used to understand the impact of a new legislation/guideline, to test different solutions for an urban project design, to find out which changes would cause the greatest improvement for pedestrians, etc.

The reflections and findings of this work did not intend to establish fixed parameters, but they can be used as references, always considering the context (scale, time, culture) of the study.

Future developments

An effort can be made to continue improving the walkability index tool. From a sociological and inclusive perspective, other forms of participatory processes can be tested, in order to embrace a greater diversity and/or to facilitate its application. From a more technical point-of-view, further investigation of the improvement of indicators could be made, possibly incorporating other syntactical measures not yet tested.

Another path to follow is to continue applying the tool and continue testing/proving its effectiveness. This can be done in different forms: reapplying it in the same area, which would configure a diachronic analysis, and which allows an evaluation of the changes made to favor pedestrians; or testing it in a different context (city, country), which would also enable to perceive differences in the understanding of walkability.

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Annexes

Annex A. IAAPE Indicators and weights

The information presented in this annex refers to IAAPE Project (Moura, Cambra, & Gonçalves, 2014).

The first table shows the dimensions (7Cs), key-concerns and correspondent indicators of the IAAPE walkability index. In the third column, the indicators are briefly described, followed by the correspondent parameters. The last column shows the equations for transforming the values of each indicator into a 0-100 range, in order to be able to sum them together.

The second table exposes the information related to the pedestrian groups that participated in the project. The second column indicates which indicators was chosen and weighted by each group. Below the weights, the equations to calculate the final walkability score are presented.

Table 17. List of the indicators used in IAAPE walkability score, with the correspondent parameters considered and the transformation calculation.

7cs	Key-concerns	Indicators (description and audits)	Transformation to 0-100 range
Connectivity	C12. Pedestrian infrastructure (path/sidewalk continuity)	Topological sinuosity indicator. Calculated in GIS platform. SIG1: ratio between least-cost path and Euclidean distance	$C12(\%) = \begin{cases} 0, & if\ SIG1 < 1 \\ (2 - SIG1) \times 100, & if\ 1 \leq SIG1 \leq 2 \\ 100, & if\ SIG1 > 2 \end{cases}$
	C13. Path directness	SIG2: ratio between shortest path and Euclidean distance	$C13(\%) = \begin{cases} 0, & if\ SIG2 < 1 \\ (2 - SIG2) \times 100, & if\ 1 \leq SIG2 \leq 2 \\ 100, & if\ SIG2 > 2 \end{cases}$
	C14. Accessible pedestrian network	Existence or barriers (steps, sidewalk width and slopes). Aud8: evaluate the presence of steps (0 to 2). Aud9: walking width in meters. SIG3: slopes (%).	$C14(\%) = \begin{cases} 0, & if\ Aud9 < 1.2\ or\ Aud8 = 0\ or\ SIG3 > 10 \\ 100, & if\ not \end{cases}$
Convenience	C21. Land use diversity	Number of distinct land use types (residential, commerce, services and public facilities). Aud10: land use mix (0 to 4).	$C21(\%) = \left(\frac{Aud10}{4}\right) \times 100$
	C22. Sidewalk available width	Effective sidewalk width for walking. Aud9: walking width in meters.	$C22(\%) = \begin{cases} 0, & if\ Aud9 < 1.2 \\ (1.25Aud9 - 1.5) \times 100, & if\ 1.2 \leq Aud9 \leq 2 \\ 100, & if\ Aud9 > 2 \end{cases}$
	C24. Daily commerce and services	Number of distinct commerce and services that are used daily. Aud15: number of everyday use commercial activities.	$C24(\%) = \left(1 - \frac{(\max[Aud15] - Aud15)}{(\max[Aud15] - min\ [Aud15])}\right) \times 100$

Comfort	C31. Vigilance effect or perception by pedestrians	Qualitative evaluation of façade transparency. Aud12: evaluate vigilance effect (levels of service).	$C31(\%) = \left(\frac{Aud12-1}{4}\right) \times 100$
	C32. Pavement surface quality	Qualitative evaluation of pavement (based on regularity, smoothness, slippery characteristics). Aud6: evaluate pavement quality (very bad, bad, moderate, good, very good) Aud7: no presence of tripping hazards (0 or 1).	$C32(\%) = \left(\left(\frac{Aud6}{4}\right) \times 0.5 + Aud7 \ \times 0.5\right) \times 100$
Conviviality	C41. Opportunities for meeting and sojourning (benches, tables, terraces)	Existence or visibility of public meeting places. Aud11: existence of public meeting places (0 or 1)	$C41(\%) = \left(\frac{Aud11}{2}\right) \times 100$
	C42. Existence of anchor places (shopping malls, public facilities, etc.)	Existence or visibility of anchor places. Aud16: number of attractor destinations.	$C42(\%) = \left(1 - \frac{(\max[Aud16] - Aud16)}{(\max[Aud16] - min\ [Aud16])}\right) \times 100$
	C43. Service hours	Existence of activities with extended service hours (bars, cinema, etc.). Aud13: activities open after service hours (0 or 1).	$C43(\%) = \begin{cases} \left(\frac{Aud13}{2}\right) \times 100, if\ Aud10 = 0\ or\ 1 \\ \left(\frac{Aud13+1}{2}\right) \times 100, if\ not \end{cases}$
Conspicuousness	C51. Existence or visibility of landmarks	Existence of visibility of landmarks. Aud14: sense of place and reference elements (0, 1 or 2).	$C51(\%) = \left(\frac{Aud14}{2}\right) \times 100$
	C53. Street toponomy (Street names, signposting, waymarking)	Existence of street naming and wayfinding signs. Aud5: availability of signals adapted to pedestrians (None, poor, moderate or good).	$C53(\%) = \left(\frac{Aud5}{3}\right) \times 100$
Coexistence	C61. Traffic safety (at pedestrian crossings)	Composite indicator between crossing type (crosswalk, signalized intersection), pedestrian visibility and number of potential conflicts with road vehicles. Aud1: configuration (score1) Aud2: visibility (score 2) Aud3: conflicts (score 3) $AF = \frac{Score_1 + Score_2 + Score_3 - 3}{7} + 0{,}5$ $CWS = \frac{ScoreT \ \times AF - 0{,}5}{14{,}5} \times 100$ SIG4: crossing safety score.	$SIG4 = \frac{CWS_1 + CSW_2 + \cdots + CWS_8}{8}$ $C61(\%) = SIG4$
	C62. Pedestrian crossing location	Ratio between formal intersection (crosswalk, signalized intersection) and total road crossing (including informal crossings) SIG5: crossings located in the main desired lines.	$SIG5 = \frac{N_{crosswalks}}{N_{crosswalks} + N_{desirelines}} \times 100$ $C62(\%) = SIG5$

Commitment	C71. Enforcement of pedestrian regulations (laws)	Percentage of inaccessible pedestrian network with respect to total pedestrian network $Aux = \begin{cases} 1, if\ Aud9 < 1.2\ or\ Aud8 = 0\ or\ SIG3 \\ 0, if\ not \end{cases}$ SIG6: legislation enforcement.	$SIG6 = \frac{N_1}{N_1 + N_0} \times 100$ $C71(\%) = 100 - SIG6$
	C75. Existence of design standards and planned public space interventions	Existence of walkway characteristics (no tripping hazards; no steps; effective width > 1.2m).	$C75(\%) = \begin{cases} 0, if\ Aud6 = 0\ or\ Aud7 = 0\ or\ Aud9 < 1.2 \\ 100, if\ not \end{cases}$

The codes used of the key-concerns and of the indicators were taken from the IAAPE project.

Table 18. Groups of pedestrians and the weighting system.

Groups of pedestrians	Selected indicators, trip motive and weights and equation							
Adults	Selected indicators	**C12**	**C21**	**C32**	**C43**	**C51**	**C61**	**C71**
	Transport weights & equation	0.17	0.06	0.17	0.17	0.11	0.22	0.11
		$Walkscore_{Transport} = W_{TC12} \times C12 + W_{TC21} \times C21 + \cdots W_{TC71} \times C71$						
	Leisure weights & equation	0.04	0.19	0.12	0.23	0.19	0.15	0.08
		$Walkscore_{Leisure} = W_{L12} \times C12 + W_{L21} \times C21 + \cdots W_{L71} \times C71$						
Children	Selected indicators	**C13**	**C21**	**C31**	**C42**	**C51**	**C62**	**C75**
	Transport weights & equation	0.19	0.15	0.19	0.04	0.12	0.23	0.08
		$Walkscore_{Transport} = W_{TC13} \times C13 + W_{TC21} \times C21 + \cdots W_{TC75} \times C75$						
	Leisure weights & equation	0.09	0.23	0.18	0.18	0.14	0.14	0.08
		$Walkscore_{Leisure} = W_{L13} \times C13 + W_{L21} \times C21 + \cdots W_{L75} \times C7$						
Elderly people	Selected indicators	**C13**	**C24**	**C32**	**C41**	**C51**	**C61**	**C71**
	Transport weights & equation	0.11	0.16	0.21	0.11	0.05	0.21	0.16
		$Walkscore_{Transport} = W_{TC13} \times C13 + W_{TC24} \times C24 + \cdots W_{TC71} \times C71$						
	Leisure weights & equation	0.07	0.27	0.17	0.17	0.03	0.17	0.13
		$Walkscore_{Leisure} = W_{L13} \times C13 + W_{L24} \times C24 + \cdots W_{L71} \times C71$						

People with disability	Selected indicators	**C14**	**C22**	**C32**	**C41**	**C53**	**C61**	**C71**
	Transport weights & equation	0.11	0.16	0.21	0.11	0.05	0.21	0.16
		$Walkscore_{Transport} = \begin{cases} 0, if\ C14 = 0 \\ W_{TC14} \times C14 + W_{TC22} \times C22 + \cdots W_{TC71} \times C71 \end{cases}$						
	Leisure weights & equation	0.15	0.1	0.2	0.15	0.05	0.15	0.20
		$Walkscore_{Leisure} = \begin{cases} 0, if\ C14 = 0 \\ W_{L14} \times C14 + W_{L22} \times C22 + \cdots W_{L71} \times C71 \end{cases}$						

Annex B. Space syntax measurements

Annex B lists the syntactical measures, their description and equations. Most of them came from the graph theory and were adapted to the urban/architectural context.

The syntactical measures can be global or local. When calculating it for a local context (such as a neighborhood), a radius is considered within the calculation as a cut-off.

Axial measure	Description	Equation
Connectivity	Number of spaces to which one space is directly connected.	$C_i = \sum_{i \neq j} 1$
Depth	Topological distance (step-distance) between spaces.	$d_i = d_{ij}$
Total depth	Sum of all depths from a given origin	$TD_i = \sum_{j=1}^{n-1} d_{ij}$
Mean depth	The average topological distance between the space i and every other space j of the system	$MD_i = \frac{1}{n-1} \sum_{j=1}^{n-1} d_{ij}$
Control	How much a space controls the access to other spaces.	$ctrl_i = \sum_{i \neq j} \frac{1}{c_j}$
Relative asymmetry	Represents the centrality of an axial line. It is the normalized value of the mean depth.	$RA_i = \frac{2MD_i - 1}{n-2}$
Real relative asymmetry	In order to enable a comparison between different size and scales, a D-value is computed to normalize graphs. Then, RRA is calculated to make RA independent from the size of the graph	$D_n = \frac{2\{n[log_2(\frac{n+2}{3}) - 1] + 1\}}{(n-1)(n-2)}$ $RRA_i = \frac{RA_i}{D_i}$
Integration **(centrality closeness)**	The degree to what a space is integrated or segregated in an urban system. Higher values indicate greater topological accessibility and lower values, lower accessibility.	$I_i = \frac{1}{RRA_i}$
Choice **(centrality betweenness)**	How often (number of n times) that a space is used in the shortest paths from every space to every other space of the system. Higher values indicate that the space makes part of many shortest paths.	$Ch_i = \frac{\sigma_{s,t}(i)}{\sigma_{s,t}}$
Intelligibility	Correlation between connectivity and integration. It measures how much the local properties of the space reveal the global proprieties	
Synergy	Correlation between local and global integration. It shows the relation between local and global accessibility.	

Annex C. Fisher's r-to-z transformation

The Fisher's r-to-z transformation is a statistical test to assess the significance of the differences between tow correlation coefficients. In this dissertation, it was used in two cases: (1) to compare the results from sidewalk-centerline and the road-centerline networks; and (2) to compare the results from the combined walkability indexes (IAAPE+SS) and the original one ($IAAPE_{WScore}$).

1. Correlations with pedestrian counting: sidewalk-centerline network x road-centerline network

			Sidewalk centerline - segment analysis						Road centerline - segment analysis					
	Integration radius:		600	800	1000	1600	2000	n	600	800	1000	1600	2000	n
Average of pedestrians in movement	peak morning	Pearson Correlation	.508**	.494**	.571**	.453**	.375**	.332**	.326*	.341**	.401**	.356**	.321*	.352**
	off-peak morning		.487**	.453**	.514**	.426**	.357**	.314*	.455**	.461**	.509**	.463**	.405**	.408**
	lunch hour		.578**	.577**	.619**	.526**	.453**	.405**	.418**	.450**	.475**	.464**	.436**	.429**
	off-peak afternoon		.503**	.516**	.588**	.457**	.381**	.337**	.504**	.537**	.580**	.522**	.464**	.461**
	peak afternoon		.522**	.502**	.557**	.468**	.397**	.327*	.515**	.537**	.576**	.547**	.485**	.439**
Average of pedestrians in movement & sojourning	peak morning	Pearson Correlation	.481**	.456**	.529**	.411**	.341**	.314*	.323*	.334**	.390**	.343**	.320*	.374**
	off-peak morning		.462**	.427**	.482**	.338**	.278*	0.248	.345**	.388**	.442**	.381**	.355**	.399**
	lunch hour		.528**	.511**	.543**	.393**	.326*	.306*	.326*	.392**	.427**	.399**	.395**	.433**
	off-peak afternoon		.536**	.528**	.588**	.458**	.387**	.353**	.409**	.469**	.536**	.497**	.479**	.510**
	peak afternoon		.543**	.510**	.569**	.419**	.340**	.297*	.431**	.472**	.531**	.480**	.455**	.483**

Fisher R-to-Z transformation: Difference						p-value (probability that they are equal, for alpha = 0,05)					
600	800	1000	1600	2000	n	600	800	1000	1600	2000	n
1.183	0.994	1.197	0.620	0.328	-0.121	0.237	0.320	0.231	0.535	0.743	0.904
0.220	-0.054	0.036	-0.246	-0.300	-0.578	0.826	0.957	0.971	0.806	0.764	0.563
1.143	0.925	1.104	0.439	0.113	-0.155	0.253	0.355	0.269	0.661	0.910	0.877
-0.007	-0.155	0.065	-0.457	-0.540	-0.789	0.994	0.877	0.948	0.648	0.589	0.430
0.051	-0.256	-0.149	-0.569	-0.584	-0.702	0.959	0.798	0.881	0.569	0.559	0.483
1.011	0.774	0.945	0.423	0.126	-0.363	0.312	0.439	0.345	0.672	0.900	0.716
0.748	0.250	0.272	-0.264	-0.457	-0.903	0.455	0.803	0.786	0.792	0.648	0.366
1.329	0.800	0.812	-0.038	-0.424	-0.787	0.184	0.424	0.417	0.970	0.672	0.431
0.876	0.420	0.406	-0.270	-0.605	-1.035	0.381	0.675	0.685	0.787	0.545	0.301
0.786	0.267	0.291	-0.408	-0.731	-1.178	0.432	0.789	0.771	0.683	0.465	0.239

2. Correlations with pedestrian counting: sidewalk-centerline network x road-centerline network

Adults								Children								Elderly people							
Utilitarian				Leisure				Utilitarian				Leisure				Utilitarian				Leisure			
IAAPE walkability score	IAAPE + SS linear	IAAPE + SS logistic	+ synergy & intellig.	IAAPE walkability score	IAAPE + SS linear	IAAPE + SS logistic	+ synergy & intellig.	IAAPE walkability score	IAAPE + SS linear	IAAPE + SS logistic	+ synergy & intellig.	IAAPE walkability score	IAAPE + SS linear	IAAPE + SS logistic	+ synergy & intellig.	IAAPE walkability score	IAAPE + SS linear	IAAPE + SS logistic	+ synergy & intellig.	IAAPE walkability score	IAAPE + SS linear	IAAPE + SS logistic	+ synergy & intellig.
.504	.535	.535	.501	.527	.531	.533	.488	.557	.617	.618	.600	.589	.620	.625	.612	.405	.420	.424	.396	.349	.352	.357	.339
.475	.531	.541	.502	.524	.533	.536	.485	.513	.598	.606	.582	.552	.595	.603	.580	.411	.448	.459	.430	.394	.409	.418	.399
.582	.626	.632	.584	.617	.624	.627	.562	.680	.760	.756	.730	.704	.746	.749	.726	.503	.527	.536	.500	.459	.467	.474	.452
.511	.567	.582	.542	.555	.564	.569	.515	.538	.633	.638	.613	.586	.633	.640	.617	.376	.412	.430	.397	.331	.346	.359	.338
.469	.532	.548	.514	.516	.526	.531	.485	.537	.638	.643	.627	.582	.633	.639	.628	.373	.415	.433	.405	.342	.361	.373	.355
.536	.557	.548	.509	.574	.576	.576	.528	.599	.639	.639	.617	.635	.655	.659	.644	.447	.451	.448	.418	.415	.412	.412	.393
.528	.544	.533	.493	.579	.580	.580	.533	.585	.597	.597	.572	.624	.631	.635	.616	.425	.426	.421	.390	.415	.410	.409	.390
.555	.575	.558	.513	.599	.601	.600	.546	.646	.658	.646	.619	.696	.702	.700	.682	.466	.471	.460	.426	.443	.439	.435	.415
.498	.515	.513	.475	.544	.546	.547	.501	.595	.629	.617	.597	.645	.662	.660	.650	.371	.374	.376	.345	.358	.355	.358	.339
.511	.538	.537	.498	.568	.572	.574	.526	.602	.627	.619	.596	.663	.674	.674	.662	.369	.379	.385	.352	.354	.355	.360	.340

Fisher R-to-Z transformation: Differences in relation to IAAPE walkability score

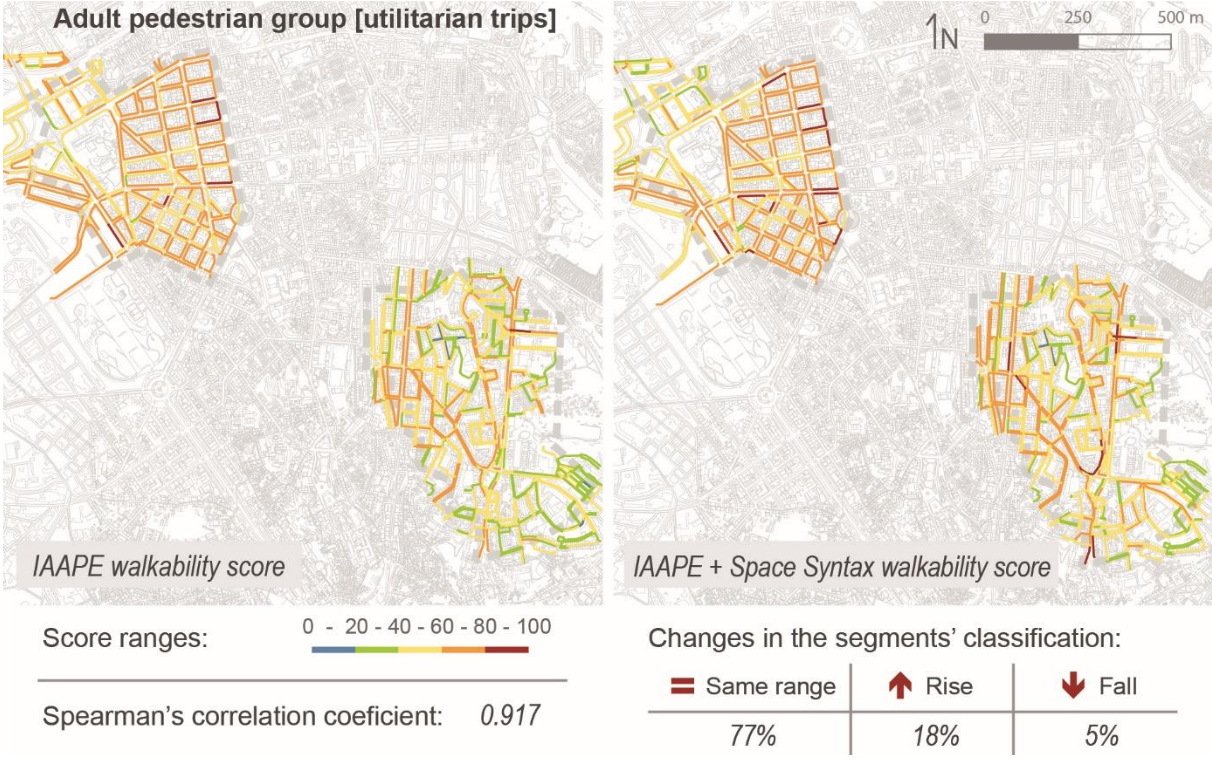
0.23	0.23	-0.02	0.03	0.04	-0.28	0.49	0.50	0.35	0.26	0.30	0.19	0.10	0.12	-0.06	0.02	0.05	-0.06
0.40	0.48	0.19	0.07	0.09	-0.28	0.66	0.72	0.53	0.34	0.41	0.22	0.24	0.32	0.12	0.10	0.15	0.03
0.37	0.42	0.02	0.06	0.09	-0.45	0.89	0.84	0.53	0.47	0.51	0.24	0.17	0.24	-0.02	0.05	0.10	-0.05
0.42	0.54	0.23	0.07	0.11	-0.30	0.77	0.82	0.60	0.40	0.46	0.26	0.23	0.34	0.13	0.09	0.17	0.04
0.45	0.57	0.32	0.07	0.11	-0.22	0.83	0.87	0.73	0.43	0.49	0.39	0.27	0.38	0.20	0.12	0.19	0.08
0.16	0.09	-0.20	0.02	0.02	-0.35	0.35	0.35	0.15	0.18	0.22	0.08	0.03	0.01	-0.19	-0.02	-0.02	-0.14
0.12	0.04	-0.25	0.01	0.01	-0.36	0.10	0.10	-0.10	0.06	0.10	-0.07	0.01	-0.03	-0.22	-0.03	-0.04	-0.16
0.16	0.02	-0.31	0.02	0.01	-0.42	0.11	0.00	-0.24	0.06	0.04	-0.14	0.03	-0.04	-0.27	-0.03	-0.05	-0.18
0.12	0.11	-0.16	0.02	0.02	-0.32	0.29	0.19	0.02	0.16	0.14	0.05	0.02	0.03	-0.16	-0.02	0.00	-0.12
0.20	0.19	-0.09	0.03	0.05	-0.32	0.21	0.14	-0.05	0.11	0.11	-0.01	0.06	0.10	-0.10	0.01	0.04	-0.08

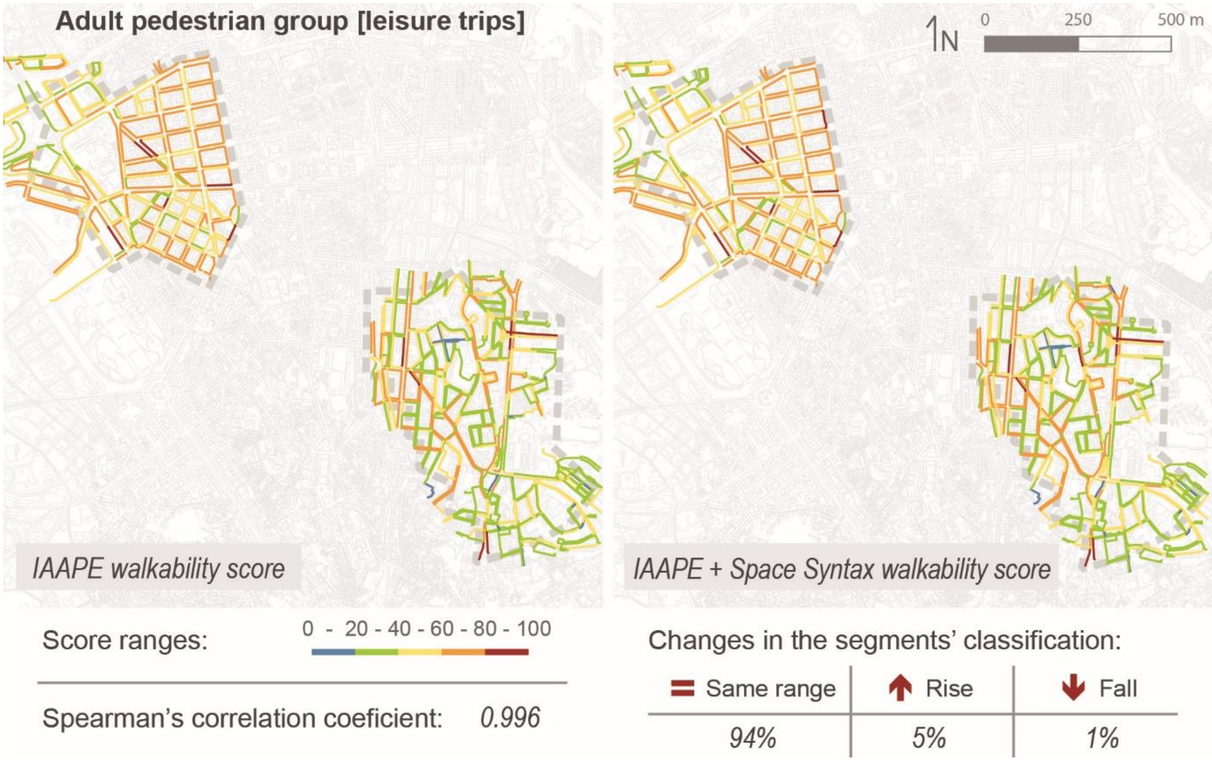
p-value (probability that they are equal, for alpha = 0,05)

0.82	0.82	0.98	0.98	0.96	0.78	0.62	0.62	0.73	0.79	0.76	0.85	0.92	0.90	0.95	0.99	0.96	0.95
0.69	0.63	0.85	0.95	0.93	0.78	0.51	0.47	0.60	0.73	0.68	0.83	0.81	0.75	0.90	0.92	0.88	0.97
0.71	0.67	0.99	0.95	0.93	0.65	0.37	0.40	0.59	0.64	0.61	0.81	0.86	0.81	0.98	0.96	0.92	0.96
0.67	0.59	0.82	0.94	0.91	0.76	0.44	0.41	0.55	0.69	0.64	0.80	0.82	0.73	0.90	0.93	0.87	0.97
0.65	0.57	0.75	0.94	0.91	0.83	0.41	0.38	0.47	0.67	0.63	0.70	0.79	0.70	0.84	0.91	0.85	0.94
0.87	0.93	0.84	0.99	0.99	0.72	0.73	0.73	0.88	0.85	0.83	0.94	0.98	0.99	0.85	0.98	0.98	0.89
0.90	0.97	0.80	0.99	0.99	0.72	0.92	0.92	0.92	0.95	0.92	0.94	0.99	0.98	0.82	0.97	0.97	0.87
0.88	0.98	0.75	0.99	0.99	0.67	0.91	1.00	0.81	0.95	0.97	0.89	0.97	0.97	0.79	0.98	0.96	0.85
0.90	0.91	0.87	0.99	0.98	0.75	0.77	0.85	0.99	0.87	0.89	0.96	0.99	0.98	0.87	0.99	1.00	0.91
0.84	0.85	0.93	0.97	0.96	0.75	0.83	0.88	0.96	0.92	0.92	0.99	0.95	0.92	0.92	1.00	0.97	0.93

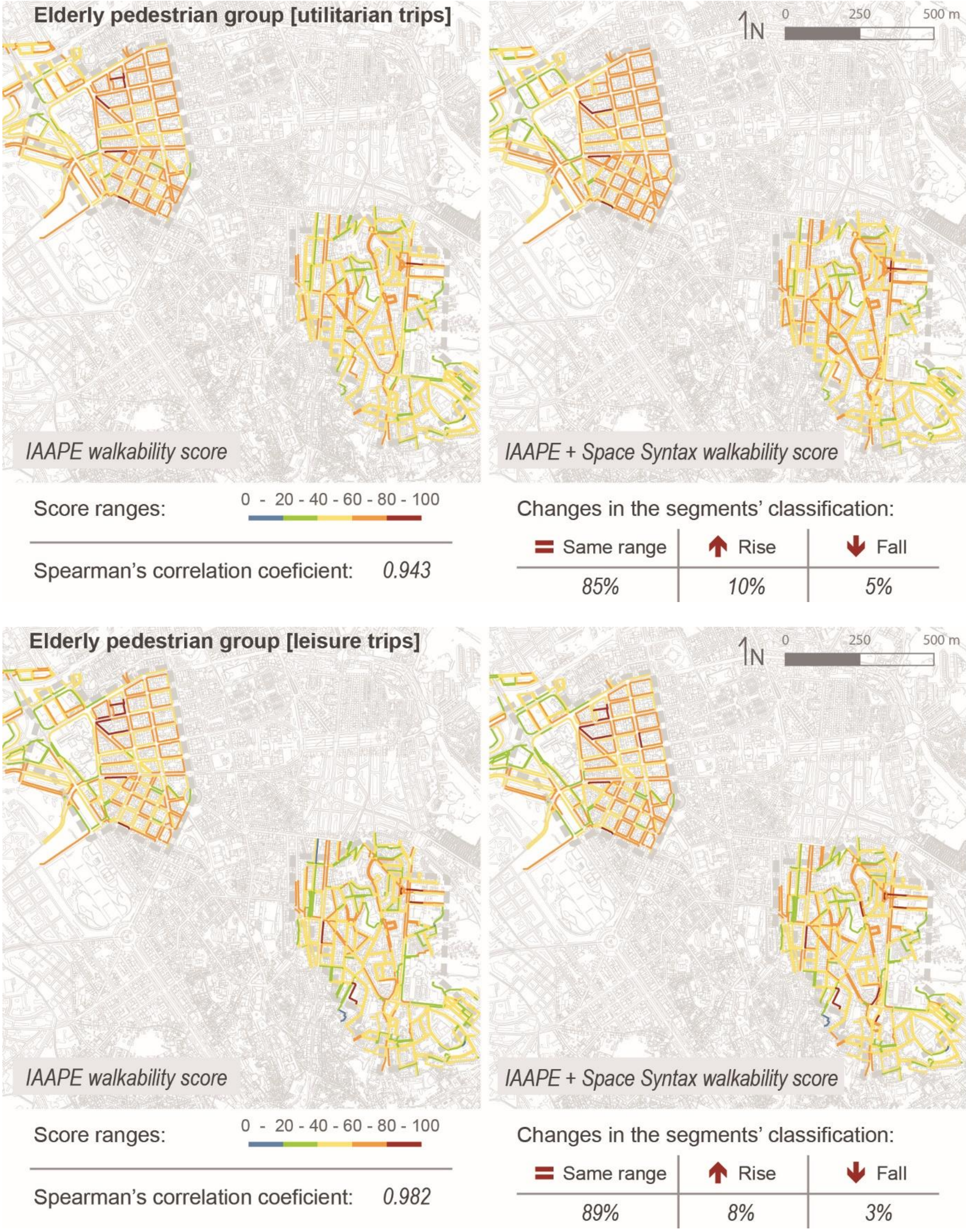
Annex D. Walkability score maps

The maps presented in this annex compare the application of both walkability indexes (IAAPE and IAAPE + space syntax), illustrating the differences of score range classification, for each pedestrian group and trip purpose. It is also pointed out the correlation between methods using the Spearman's ranking coefficient and it is indicated how many segments changed class (in percentage).






Children pedestrian group [utilitarian trips]
N
0
250
500 m
IAAPE walkability score
IAAPE + Space Syntax walkability score
Score ranges:
0 - 20 - 40 - 60 - 80 - 100
Spearman's correlation coeficient: 0.856
Changes in the segments' classification:
Same range
Rise
Fall
56%
10%
34%
Children pedestrian group [leisure trips]
N
0
250
500 m
IAAPE walkability score
IAAPE + Space Syntax walkability score
Score ranges:
0 - 20 - 40 - 60 - 80 - 100
Spearman's correlation coeficient: 0.958
Changes in the segments' classification:
Same range
Rise
Fall
79%
5%
16%


Elderly pedestrian group [utilitarian trips]
N
0 250 500 m
IAAPE walkability score
IAAPE + Space Syntax walkability score
Score ranges:
0 - 20 - 40 - 60 - 80 - 100
Spearman's correlation coeficient: 0.943
Changes in the segments' classification:
Same range | Rise | Fall
85% | 10% | 5%
Elderly pedestrian group [leisure trips]
N
0 250 500 m
IAAPE walkability score
IAAPE + Space Syntax walkability score
Score ranges:
0 - 20 - 40 - 60 - 80 - 100
Spearman's correlation coeficient: 0.982
Changes in the segments' classification:
Same range | Rise | Fall
89% | 8% | 3%