Smart Pedestrian Network: An Integrated Conceptual Model for Improving Walkability

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Abstract. Smart and sustainable mobility have recently emerged as a solution to the problems incurred by the intensive use of motorised transport modes. For many decades, cities have been planned based on the needs of vehicle traffic, neglecting basic human needs for active mobility and the adverse effects of motorised traffic on the natural environment. However, walking is an environmentally friendly transport mode and a healthy form of making physical activity. Thus, walking becomes an essential component of the transport and urban policies for achieving a more sustainable development process. This paper presents the research project Smart Pedestrian Network (SPN) that aims at promoting walkability as one of the critical dimensions of smart and sustainable mobility in cities. The paper analyses the various components linked to SPN that can make a pedestrian network "smart" and, therefore, a feasible alternative to motorised transport modes. Three integrated components are analysed: (i) an urban planning component supported in a GIS-based multi-criteria model to assess the conditions provided to pedestrians and to support the adoption of planning policies; (ii) a smartphone app for pedestrian navigation, displaying optional routes according to the pedestrian preferences and needs; and (iii) a business component to estimate and disseminate the multiple benefits of walking as well as the market potential of SPN. By promoting an innovative linkage of these three components, SPN has a great potential for improving walkability and, therefore, for creating more sustainable and liveable urban spaces.

Keywords: Smart Pedestrian Network · Walkability · Urban planning · Smartphone app · Walking benefits

1 Introduction

It can certainly be said that the last century was the century of cars. Private motorised vehicles nurtured the sense of individual freedom and radically changed the way cities

P. Pereira et al. (Eds.): SC4Life 2019, LNICST 318, pp. 1–18, 2020.
https://doi.org/10.1007/978-3-030-45293-3_10

have been designed and conceived. Throughout the past century, cars colonised the spaces of everyday life, generating visible effects in cities around the world such as public spaces invaded by parked vehicles, large streets serving huge suburbs, giving birth to an uncontrolled urban expansion that consequently generated situations of social isolation and segregation. As highlighted by Jacobs [1] cities are no longer conceived as a set of spaces and buildings, but only as individual buildings. High motorisation rates in conjunction with functionalism theories increased the separation of urban activities and spaces, turning the cities more fragmented and car-dependent. Nowadays, in the European cities, the private car is intensively used including for short urban trips: about 30% of the car trips are lower than 3 km, while 50% are lower than 5 km [2]. The intensive use of the car on urban trips is not only a matter of space and distance. It also produces environmental and health impacts. In European cities, 40% of CO_2 emissions and up to 70% of other pollutants are related within the intensive use of cars [3]. Noise pollution, consumption of non-renewable resources are other environmental consequences related to the use of the car. In the health domain, the use of car contributes to physical inactivity, which is a leading risk factor for premature mortality and various health problems associated to sedentary lifestyles, such as obesity, diabetes and depression [4].

In Europe, 73% of the population lives in cities, and it is expected that this number will rise to 80% by 2050 [5]. The concentration of the population in cities is causing several environmental, spatial, economic and social problems. One of the main problems is related to the intensive use of private cars, namely for short urban trips. In Europe, about 30% of the urban car trips are lower than 3 km, while 50% are lower than 5 km [2]. Note that a viable alternative transport mode for such short distances could simply be walking.

The intensive use of motorised vehicles causes several well-known problems, including pollution, traffic congestion, energy consumption, accidents and sedentary lifestyles [6]. In European cities, 40% of CO_2 emissions and up to 70% of other pollutants are related within the intensive use of cars [3]. By 2050, the EU has the goal of cutting transport emissions to 60% below 1990 levels to make cities more sustainable and liveable [7]. It is recognised that effective urban and transport planning policies should mitigate these problems namely by developing disruptive mobility solutions [8] so that the United Nations' Sustainable Development Goals can be achieved [9]. To make the transition to a low-carbon society, a new mobility paradigm, less supported on private car, is necessary [10]. The concepts of smart mobility and smart city have recently emerged to overcome these problems. To be considered smart, mobility must be sustainable [11]. The sustainable mobility concept encourages a modal shift towards more sustainable forms of transport namely by increasing the use of active modes such as cycling and walking [12]. The benefits of adopting more sustainable modes of transport are generally appreciated by people, but the various approaches to shift mobility paradigm failed due to the complex factors that prevent people for adopting behavioural change [13].

Walking is an environmentally friendly transport mode and a viable alternative mode of transport for short urban trips. Walking has many advantages when compared with car trips. In the environmental domain, walking consumes less non-renewable resources, reduces the emission of air pollutants, CO_2, and noise [14, 15]. In the economic domain, walking is costing far less than motorised transports, both in direct user costs and public infrastructure costs. Walking reduces health care costs, improves work productivity and has high accessibility and low complexity [14]. As the only energy required is provided by the traveller, walking also presents several health outcomes in terms of reducing obesity, cardiovascular diseases, diabetes, stress, among others [13, 15]. For all these benefits, walking gained enormous popularity for its potential to promote more sustainable mobility and healthier lifestyles.

In this context, the goal of this paper is to present the research project "SPN - Smart Pedestrian Net". SPN is a pilot innovative European research project to assess and improve the walkable conditions provided to pedestrians. The overall goal is to develop a model to support European cities to become people-oriented by improving walkability as one of the important dimensions of smart, sustainable and inclusive cities. The paper explains the concept of the Smart Pedestrian Network and how the multiple dimensions attached to it in the planning, technological and business domains were considered.

2 Literature Review

Pedestrian studies can be divided into two main groups: (i) studies focused on assessing the conditions provided to pedestrians; and (ii) studies focused on analysing pedestrians behaviours and preferences. The first group integrates the studies on walkability, a concept widely used that reflects the quality of the walking conditions or, in other words, the extent to which the built environment supports and encourages walking safety [16]. Walkability is a multidimensional concept that combines several attributes or criteria with an impact on walking [17]. These criteria traditionally rely on 3Ds (density, diversity, and design) features of the built environment proposed by Cervero and Kockelman [18] plus the 2Ds (distance to transit and destination accessibility) added later by Cervero et al. [19]. Thus, physical environment mesoscale attributes such as land use mix, proximity to destinations, density and connectivity have been widely used in walkability studies [20, 21]. Microscale walkability approaches at the level of streetscapes have also been developed for evaluating walkability [22–24]. Objective measures have been predominantly used in walkability research by developing walkability audits [25, 26] and indexes [27–29] that evaluate and score the conditions provided to pedestrians. Such objective measures have been supported in Geographic Information Systems [30, 31], multi-criteria analysis [25, 32], virtual technologies [29, 33], Web-based services, such as WalkScore, among others. Subjective measures have been supported on qualitative assessments based on stated preferences and individual perceptions usually collected through questionnaires or by consulting expert panels [34].

Walkability has been analysed by assessing different criteria. Such criteria can be grouped in the following dimensions: accessibility, safety/security, pedestrian facilities, and land use. Accessibility is in the first level of walking needs [35] and can be described as the ability to reach desired destinations, making an acceptable effort [26]. Accessibility has been often quantified as the distance to public transport [36] and key amenities, such as schools , shops and urban parks [37]. It is widely recognised that 400 and 800 m are the referential walking distance to get bus stops and train stations, respectively [38]. In turn, safety refers to pedestrians being protected from traffic. Traffic safety is critical for making walkable environments and plays a significant role in the decision to walk [39], particularly for children and seniors. The characteristics of traffic (speed, volume), the characteristics of roads (lanes and directions) and the facilities for protecting pedestrians from traffic are factors with impact on walking. Public security is also a criterion with some impact on walking, mainly in cities characterised by urban violence [32]. Pedestrian facilities are infrastructure provided to enhance the pedestrian environment, to improve pedestrian mobility, safety, access, and comfort. For that reason, pedestrian facilities have been one of the most analysed factors, namely by considering the following criteria: the characteristics, maintenance and continuity of sidewalks [28], the presence of obstacles on sidewalks that creates discomfort and affects pedestrian safety [40]; slopes, as small positive increments in slopes decrease travel speeds and increase the energy and the effort required for walking [41, 42]; the presence of trees and greenery that bring several environmental, safety and aesthetic benefits and encourage people to walk and the walking experience [25]; and street furniture that helps in creating a more pleasant and attractive walkable environment [43]. Finally, the characteristics of land use have been found to affect mode choice and walking [44]. Land use is often operationalised using density, diversity and design measures. Areas with high densities (population, residential, commercial) usually generate more people walking, by decreasing the appeal of driving through congested areas where parking is often scarce [25, 45]. Densities are usually analysed by developing ratios and indexes. Diversity expresses the degree to which there is a mix of land uses within an area [46]. Mixed land use is found to be one of the most correlated characteristics with utilitarian walking [42, 45]. Entropy and dissimilarity indexes have been adopted to evaluate the level of diversity [26]. Urban design and planning practices also have a determinant impact on walking [22, 24, 39]. Some authors, such as Ewing and Handy [47] and Ewing et al. [22], developed tools and specific methods for measure urban design.

On the other hand, behavioural researches have been mostly focused on pedestrian choices and preferences [48]. As pedestrians move more slowly than vehicles, they are more sensitive to their surroundings, and numerous aspects affect the experience and behaviour of pedestrians [49]. These include aspect related to the neighbourhood environment (the meso and microscale criteria mentioned above), as well as individual factors, including demographic, socioeconomic and psychological aspects, such as the age, gender, and income. In this topic, some authors have studied how the individual characteristics of pedestrians and their physical condition influence their preferences and behaviours. For example, Bernhoft and Carstensen [50] demonstrated that older pedestrians prefer routes with crossings and signalised intersections more than young pedestrians. Giles-Corti et al. [39] also found that crossing major streets and areas with high intersection density were negatively associated with child's active travel to school. Walking behaviours are also affected by gender. Many studies on trips to school have found that girls are less likely to walk than boys [51]. Among university students, Delmelle and Delmelle [52] also found that females are less like to walk (and bike) to university than male students . Female students tend to be more cautious to the risk of active travelling on streets shared with traffic [52] and are also generally more concerned with security especially after dark [53]. Male students are found to be more likely to switch commuting modes throughout the year, while females are generally more likely to drive [52]. In turn, Moniruzzaman and Farber [54] also found that students from families with higher incomes are less available to use active modes and prefer to drive instead of walk. These walking behavioural approaches have been mostly carried through questionnaires and surveys [39, 51, 52] but also by using advanced spatial simulation tools [55] and mobile devices [24].

In sum, the literature shows that the option to walk and the choice of a specific route depend on a variety of different criteria. Individuals' decisions about where and whether to walk are highly complex and typically entail considering multiple factors, including internal factors related to the personal characteristics of individuals, as well as external factors related to the characteristics of the environment [38]. Distance and time to walk, perceived ease, comfort, safety, security, convenience, proximity and attractiveness of the route, as well as age, gender, ethnicity, income, household size, car ownership, among others are factors that influence the decision to walk and which route to take.

3 Method for a Smart Pedestrian Network

The concept of a Smart Pedestrian Network (SPN) aims at developing more walkable cities and increase the number of people who walk. The goal of SPN consists in developing an integrated concept to analyse the various aspects that can make a pedestrian network "smart" and therefore, a feasible alternative to motorised transport modes. SPN sustains that a "smart pedestrian network" is not reduced to a sustainable dimension resulting from replacing the car by walking, neither to the concept of an interconnected set of appropriate sidewalks covering a given urban area. The project sustains that implementing a Smart Pedestrian Network requires a broader and multi-linked integrated approach to support not only the adoption of efficient planning initiatives but also to provide data to pedestrians about the environmental, economic and health benefits of walking, by using the potential given by digital services and devices. Approaches only focused on specific issues can have a much-limited impact. For instance, the development of navigation tools for pedestrians only makes sense if the city provides minimum conditions for walking. Otherwise, people will not feel comfortable and safe and will prefer to drive instead of walk. Thus, a smart approach requires the development of innovative technological tools to help pedestrians in selecting routes according to their preferences as well as the dissemination of the benefits (externalities) of walking. Both components are vital for changing the paradigm of mobility, and for supporting policies and investments that could have a real impact on modal choice. In the following subsections, the roadmap to the smart pedestrian network is shown in Fig. 1, considering three dimensions: urban planning, smartphone app and externalities/business model.

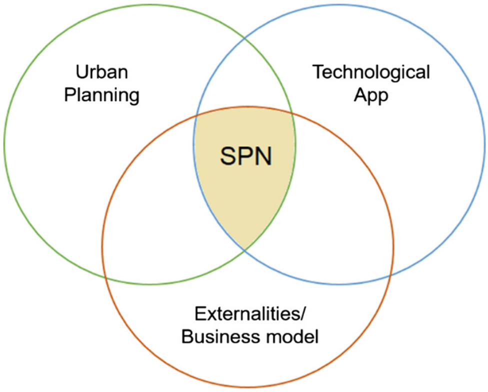

Fig. 1. Proposed roadmap for a Smart Pedestrian Network.

3.1 Roadmap for a Smart Pedestrian Network: Urban Planning

In the urban planning domain, the goal of SPN is to provide a tool to evaluate the conditions provided to pedestrians, to identify the areas more and less walkable and, therefore, to provide urban and transport guidelines for improving walkability and sustainable mobility. The core of the proposed tool is a GIS-based multi-criteria model, combining supply and demand-based walking fundamentals. The structure of the SPN model is presented in Fig. 2. Subsequent paragraphs, however, are indented.

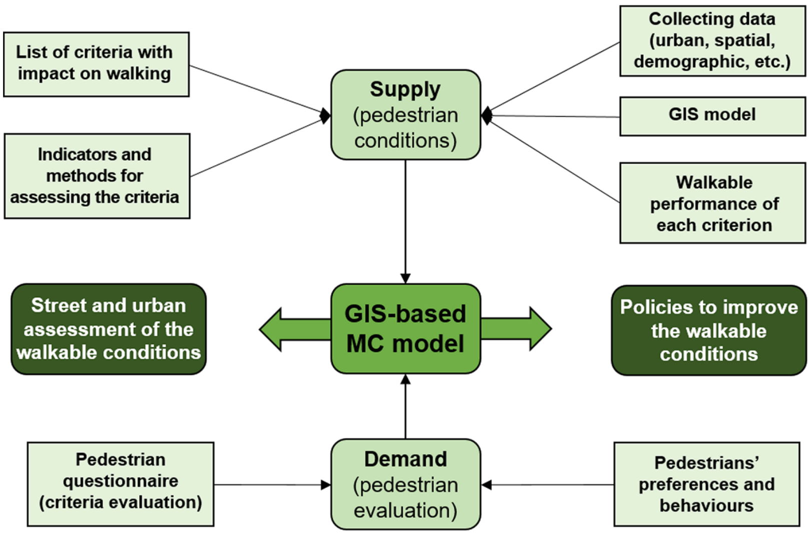

Fig. 2. Structure of the SPN GIS-based multicriteria model.

As shown in the literature review, walkability is related to multiple interconnected criteria. Multi-criteria analysis is considered an appropriate tool for dealing with a wide range of criteria, for solving complex problems by assessing multiple solutions, yielding results that are more effective, clear and logical than single-criteria approaches, for helping decision-makers in finding solutions [56]. For that reason, multi-criteria analysis becomes a widely used decision-making technique in the urban and transport domains [57].

On the supply side and for developing the multi-criteria analysis, the first step consists in defining an extensive list of interdependent criteria with an impact on walking. As emphasised by Lin and Wei [58], many authors have based their assessments on a limited and subjective number of criteria. To overcome this debility, SPN was supported in an extensive list of 23 micro and mesoscale criteria, divided by the following four dimensions: accessibility, safety and security, pedestrian facilities, land use and urban design. The list of criteria is presented in Table 1.

Table 1. Dimensions and criteria included in the SPN model.

Dimensions	Criteria
Accessibility	Distance to bus stop Distance to light rail stations Distance to train stations Distance to public amenities Distance to car parking
Street connectivity	Intersection density Street integration
Safety and security	Traffic speed (km/h) Traffic lanes (number) Pedestrian crossings Public security (street light, graffiti, abandoned buildings)
Pedestrian facilities	Width of sidewalks Condition of sidewalks Obstacles on sidewalks Street furniture Slopes (%) Trees and greenery
Land use	Population density Residential density Non-residential density Land use mix
Urban design	Human scale/enclosure Complexity Transparency

For each criterion shown in Table 1, the model specifies the respective indicators and how each criterion should be assessed. Indicators were depicted from literature review specifying, for instance, the distance from which transport stations are within a walkable distance, defining ratios for analysing densities, describing which slopes are more comfortable for pedestrians, minimum sidewalks width, etc. The assessment involves both quantitative and qualitative assessment that requires detailed spatial data, such as disaggregated census data at the tract level, street and traffic data, digital models of the terrain, among others. This data is also required for developing the GIS-based model, where each criterion should be represented by a specific shapefile (GIS file). In a GIS environment is possible to visualise, analyse and map the performance of each criterion within a specific study area, as well as to make broader walkable analyses by overlapping several criteria.

After defining the criteria and developing the GIS model, the next step consists in integrating the demand side on the model by performing an extensive questionnaire to pedestrians. The goal of the pedestrian questionnaire is to include the pedestrians' perception on the model (a people-oriented model), namely to (i) define the relative importance of criteria (weighting process); and (ii) to collect additional mobility data (routing preferences, use of mobile devices, pedestrian behaviour, etc.). Converting the pedestrians' evaluation into values require operations of fuzzy logic, linear normalisation and analytic hierarchy process. The result is an assessment reflecting not only the walkable conditions objectively assessed in the city but also the evaluation made by pedestrians. The assessment can be focused on a specific criterion or in a specific part of the network (microscale approach), as can be extended to analyse the conditions provided by multiple/interdependent criteria or to the city level (macroscale approach). Based on the overall walkable levels assessed by the model, several planning measures can be proposed to improve the conditions provided to pedestrians. Planning guidelines should be discussed in close collaboration with city planners, decision-makers and other experts considering the pedestrians' needs and the problems identified.

3.2 Roadmap for a Smart Pedestrian Network: Smart Pedestrian Assistant Mobile Application as IT Solution

The concept of smart city is usually linked to the use of technological tools, which allow modern cities to enhance the quality of the services provided to citizens [59]. A wide range of public services can be deployed as part of smart city initiatives, including in the transport domain. For that reason, the project sustains that implementing a Smart Pedestrian Network also requires developing technological tools, such as pedestrian navigation tools, to aid people to walk and to show the benefits of walking. There are many navigations systems in the market but they mainly address the needs of vehicle users and do not take into account the conditions provided to pedestrians [60]. Thus, a pedestrian navigation system running on mobile devices, such as smartphones, are particularly useful for providing navigational aid to users at unfamiliar places and additional data related to their trips (tracing the routes, obtaining health data, etc.).

The mobile app Smart Pedestrian Assistant (SPA) developed in SPN introduced an innovative design and multiple new functions realising the key project concepts as follows:

- Identifying optional pedestrian routes between one specific origin and destination according to the pedestrian preferences and interests, including typical walks with kids, dogs, friends, invalids, in green areas, etc.;
- Providing three types of routes corresponding to the selected criteria (Fig. 3);
- Changing the offered route options over time avoid always the same routes and offer to pedestrians novel walking impressions;
- Taking into consideration passed route evaluations and statistics by pedestrians;
- Proving optional selection of flat routes, green routes, and safe routes (e.g. including benches, avoiding high traffic noisy streets, etc.);
- Inserting pedestrian data (age, gender, disability) during the routing process. For instance, elderly or disable pedestrians may prefer flat routes because they require less physical effort;
- Allowing pedestrians to express their physical and psychological satisfaction (visual aspects, comfort, security, tranquility) to improve the linkage between the urban and technological components of SPN;
- Allowing pedestrians to define preferences regarding total route time, distance, points of interest to be visited (e.g. 1 park, 2 museums, 1 restaurant, 2 shops, etc.) and obtain recommended optional routes that allow the walk within the defined restrictions (e.g. be back at home by 17:00 or in 4 h);
- Considering only circle route staring from home or hotel that shall satisfy multiple conditions in timing, points of interests, number of steps, type of streets, etc.;
- Having the route monitored during the walk to review it ongoing status such as current duration of the walk, places visited and those which are left to be visited;
- Being promptly informed by real-time notifications during the route and specific current location of the pedestrian regarding optional events such as accidents, gas and water leaks, terror acts, etc.;
- Obtaining the municipality recommendations to change the route if necessary;
- Interrupting the route at any time by some reason and get assistance in finding the shortest routes to necessary city services (toilet, hospital, police, etc.);
- Providing feedback to the municipality regarding the quality of routes, streets and walkability conditions.

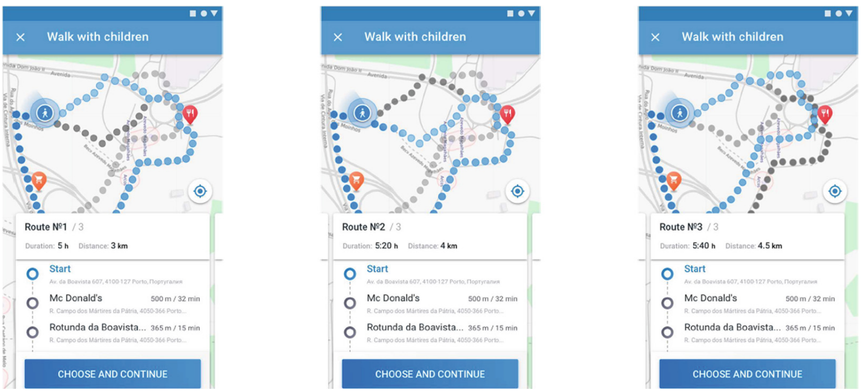

Fig. 3. Smart Pedestrian Assistant prototype support for SPN routing.

The structure of the novel SPN technological solution enabling these functionalities is presented in Fig. 4. It consists of the latest innovation cloud web platform SCM - Smart City Monitor (https://smartcity.pharosnavigator.com) that continuously collects various urban static and dynamic (real-time) data from different urban sources and systems and transforms it into rich set of information services for the municipality management including city/districts/streets status for pedestrians, transportation, waste, energy, pollution, among others. As powerful new AI-driven digital transformation technology, the SCM allows applying all the relevant criteria that impact on walking: street network, topography, transport stations, location of amenities, and the overall data necessary for using the selected criteria. SCM works with multiple SPA of the pedestrians walking the city and supports them by providing real-time walkability data linked to OpenStreetMap (used as standard mapping service and database) as well as static geographic data provided in GIS format (from the SPN urban planning component).

The integrated real-time urban information system consisting of SCM and multiple SPAs used by pedestrians walking in the city can support the variety of services for the urban community (street temperature, local pollution, air quality, weather and traffic variability) and provide updates regarding various local events. The services, however, depend on the availability of relevant urban data, city sensor networks and connectivity between SPA and SCM (Wi-Fi, cellular 4G, 5G) as well as the city information operational centre, which can support such complex urban processes monitoring and events management.

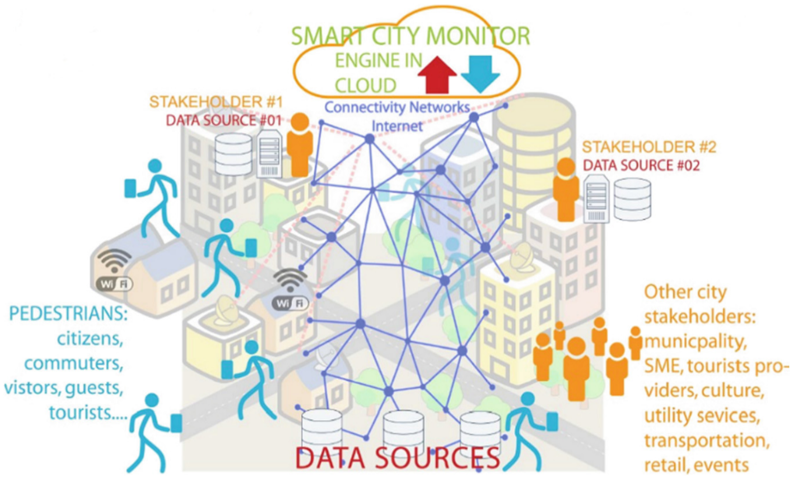

Fig. 4. Data sources and network objects for the SPN app.

3.3 Roadmap for a Smart Pedestrian Network: Externalities and Business Model

SPN provides information to pedestrians about the environmental, economic and health benefits of walking. The use of digital services and devices, such as SPA, has the potential for encouraging people to walk, including by providing data about the benefits of walking. Estimating the positive externalities of active travelling is a field not often analysed in the literature [61]. However, for SPN, a smart approach requires that providing data to people about the benefits of walking is vital for creating a paradigm shift in mobility, and for supporting policies and investments that could have a real impact on modal shift.

In this context, SPN also intends to estimate the benefits (externalities) of replacing the car by walking. Direct benefits for pedestrians include personal savings with fuel and car maintenance, travel time savings in short urban trips, health benefits resulting from walking, as well as benefits more difficult to quantify such as those resulting from social interaction with friends and family during group walks. Walking more and drive less also produce environmental benefits, namely in terms of reducing harmful emissions (CO_2, NOx, PMs, SO_2, noise) and reducing the consumption of non-renewable resources. Average travel distances, average speed and car emissions are variables that can be used for estimating these externalities. Some of these benefits are provided by the app namely those related to health (number of steps, calories burnt). The app can also be recalibrated for health recommendations namely for increasing the number of steps/day. The collaboration with some stakeholders is vital for estimating the many benefits that could potentially arise from SPN. For instance, in the case of the health benefits, working with insurance companies is critical to collect the necessary data to estimate the reduced healthcare costs incurred by insurance companies, governments and people.

A second component is related to the development of the business model for the SPN app. A business model is often described as the rationale of how an organisation creates, delivers and captures value [59]. Thus, a business model provides a coherent way to consider their options in uncertain, fast-moving and unpredictable environments. The SPN business plan [62] and model [63] is supported in a cost-benefit analysis for different scenarios related to the app. As shown in Fig. 5, the business model is divided into two phases. The first is related to the technological development of the tool and includes the following steps:

- Funding: secure funding and commitment for implementing SPA. Consult governments, municipalities other stakeholders, etc.;
- Research and design: attain the necessary tools, equipment and technology to begin the implementation of SPA;
- Testing and adapting: test the SPA with the participation of municipal authorities and end-users;
- Feedback: collect feedback from participants including pros and cons from their experience with SPN;
- Adjustments: make any necessary changes and adjustments to SPN to maximise its potential.

The second is more linked to marketing issues and includes the following steps:

- Marketing: with the expertise of the marketing team of SPN, the cities with the highest potential benefit of walking can be targeted.
- Launch: implement SPN in various European municipalities.

- Observe: collect data on SPN implementation, performance and feedback. Feedback will be collected continuously.
- Adjustments: make any necessary additional changes to SPN depending on user needs, geographical location, demographics etc.
- Global markets: once the team have enough experience with the European Market, the next target is the global market.

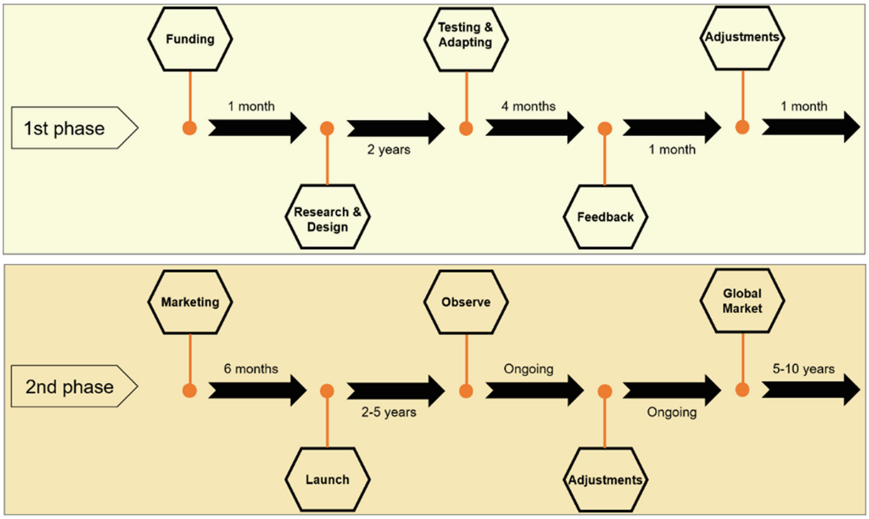

Fig. 5. Phases and steps of the SPN business model.

For each city of SPN prototype implementation, the SPN business model considers three scenarios: a Worst Case (1% users), an Average case (3% users), and a Best case (5% users). For each scenario, the business model takes into account incomes, as well as direct and indirect expenses for the premium version of SPA. Considering the multiple benefits of walking, there is an enormous potential for creating a truly disruptive innovative revenue model by buying and selling steps. Thus, the SPA can create measurable value for multiple stakeholders, including not only the SPA users (segmented customers) but also municipalities, governments, companies, among many others. As the navigation systems already available in the market do not include the quality of the pedestrian network and do not allow to communicate directly with local authorities, the business model estimates that there are many benefits of implementing SPN and that far outweigh the costs.

4 Prototype Implementation

SPN was developed, applied and tested considering the central areas of two medium-sized European cities: Porto and Bologna (Fig. 6). Porto is the second largest city in

Portugal and has a population of about 250 thousand inhabitants. Bologna is the capital of the Emilia-Romagna region in Italy and has about 390 thousand inhabitants. Both Porto and Bologna were walled cities with a long and rich history and culture. Based on the outstanding universal value of the urban fabric and its many historic buildings bearing remarkable testimony to the development over the past thousand years, the historic centre of Porto was classified by UNESCO as a World Heritage Site. Bologna is also an old city and contains an immense wealth of significant medieval, renaissance, and baroque artistic monuments. The city is particularly famous by the monuments and by the extensive porticoes and arcades that covered part of the city centre. The conditions provided to pedestrians in both cities are quite different, but both cities are engaged in improving walkability, particularly in the central areas. The prototype implementation of SPN includes SCM cloud engines for Bologna and Porto and their integration with SPA mobile applications. Thus, it is expected that SPN can improve walkability in both cities.

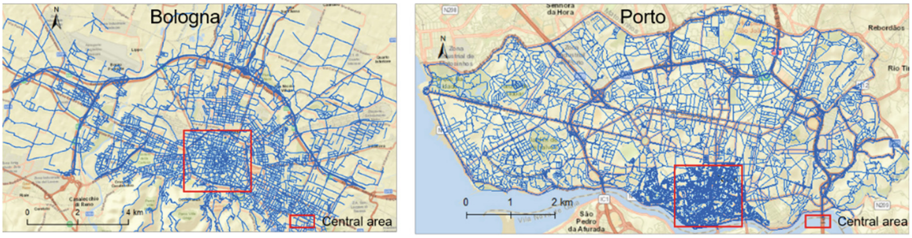

Fig. 6. Street network and central areas of Bologna and Porto.

5 Conclusions

Walking is one of the least expensive and most broadly accessible and sustainable mode of transport. Therefore and, as highlighted by Jabbari et al. [64], the quality of life in cities depends on the existence of suitable conditions to walk. The main goal of this paper was to enhance the concept of walkability in cities developed in the context of the undergoing project SPN - Smart Pedestrian Net. More particularly, the paper explains the concept of Smart Pedestrian Network and the multiple dimensions attached to it to improve walkability. Actions to promote walkability have mainly concentrated on making this sustainable form of travel easy and attractive by improving the general quality of built environments [65]. SPN argues that improving walkability and developing smart pedestrian networks requires a broader and multi-linked integrated approach. The proposed multi-linked approach is complementary supported on three components: urban planning, technological development and business case.

In the planning domain, SPN is supported on a GIS-based multi-criteria model. This model was built to assess the walkable conditions provided to pedestrians and to support the adoption of planning guidelines for improving walkability. The model can be distinguished by the existing multi-criteria assessment methods for the number of criteria involved (23) at both micro and mesoscales, by defining how each criterion should be evaluated and by involving the pedestrians in weighting each criterion. The goal is to make an assessment as much objective as possible and adopt a people-oriented approach: in each city, the model is adjustable according to the pedestrian's perceptions, because criteria with impact on walking are changeable from city to city. Moreover, the urban component is innovative because the criteria more valued were used as routing options in the SPN app. By identifying the streets more and less walkable and the respective causes, the model can be helpful for guiding planning policies to improve walkability and to provide an interconnected (network) set of sidewalks providing good conditions to pedestrians.

To strengthen the smart component of SPN, the project is also supported on the development of a new mobile app (Smart Pedestrian Assistant) to improve the walkability of citizens and tourists. In relation to the existing tools, the SPA is an innovative tool. As emphasised by Papageorgiou et al. [66], many of the existing routing systems were developed for driving or just for monitoring physical activity. However, common concepts used in car navigation tools are inappropriate for pedestrians, mainly because the complexity of human spatiotemporal behaviour requires other route functions than the shortest path. The designed SPA navigation tool has great potential to fill the gap between pedestrian needs and the existing navigation tools due to its useful and innovative features. The app is solely focused on pedestrian use and will enable routing based on the users' preferences and needs. Depending on the pedestrian evaluation (urban planning component), routing options can include, for instance, flat routes, green routes, safe routes, among other possible options. The app will support adjustable functions that can be used according to the characteristics of each user, their preferences in terms of the type of walk, its duration, distance, visits of various points of interests and quick changing of the route to address specific situations. Moreover, the tool is designed to have the ability to communicate directly with the information systems of the city administration to accumulate statistics and to provide information about the pedestrian conditions and urgent or planned events.

Finally, the business component has two goals. Firstly, to disseminate the several benefits (externalities) of walking. The goal is to estimate the benefits of walking instead of driving a car in daily urban trips. Positive externalities include travel time, fuel costs, harmful emissions and health benefits. The dissemination of the benefits of walking is vital for creating a paradigm shift in urban mobility, by promoting a walking mindset and supporting policies and investments to improve the conditions provided to pedestrians. Secondly, a business model was also developed for the SPA app. Preliminary results show that public would be interested in using the app, that could create value for multiple stakeholders namely for users (economic and health benefits), municipalities/public entities (less pollution, healthcare and cleaning costs), and insurance companies (fewer healthcare costs). Promoting the SPA app and involving key stakeholders, particularly those interested in promoting health, increased quality of life, sustainability and urban development is vital for disseminating the tool, attracting funds and increasing market share. In sum, SPN intends to improve walkability by considering three interlinked components that include quantitative and qualitative multiscale assessment, technological development and business components. In the future, the authors expect to present in detail the main findings resulting from the prototype implementation of SPN in Porto and Bologna.

Acknowledgments. FCT co-financing (ENSUF/0004/2016) - The authors gratefully acknowledge ERA-NET Cofund Smart Urban Futures for funding the research project SPN - Smart Pedestrian Net. The authors also acknowledge the national agencies for science, research and technology from Portugal, Italy, Austria and Cyprus for co-funding the project.

https://jpi-urbaneurope.eu/project/smart-pedestrian-net.

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