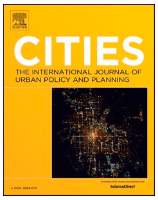
Cities 127 (2022) 103724

Contents lists available at ScienceDirect

Cities

journal homepage: www.elsevier.com/locate/cities



Where can the elderly walk? A spatial multi-criteria method to increase urban pedestrian accessibility

Federica Gaglione[a], Carmela Gargiulo[b], Floriana Zucaro[b,*]

[a] Department of Engineering, University of Sannio, Italy
[b] Department of Civil, Building and Environmental Engineering, University of Naples Federico II, Italy

ARTICLE INFO

Keywords:
Urban accessibility
Elderly
Pedestrian paths
GIS
Spatial multicriteria analysis
Sensitivity analysis

ABSTRACT

In terms of residual physical activities suitable for most elderly individuals, walking is also the favoured form of mobility in this group, in particular for those aged 75 and over. For this segment of the population, walking represents the main means of accessing urban services and actively participating in community life. It is thus essential to improve both the physical and functional organization of urban areas to develop comfortable and safe walking paths for the elderly and the other weak segments of population. Therefore, this study provides a methodology for classifying a neighbourhood as more or less accessible for the elderly to reach urban services on the basis of its favourable characteristics.

Based on the results of a literature review and Delphi analysis, the fuzzy technique was applied to evaluate the security and urban context characteristics, both in terms of the pedestrian network and built environment.

The obtained weights, validated by a sensitivity analysis, were then used to calculate a walking attractiveness index for the elderly using a GIS tool.

The methodology was then tested in two neighbourhoods of Naples; the outputs show the areas that local decision-makers should prioritise to improve the safety and attractiveness of routes to access urban services.

1. Overview

Recent demographic projections of the European Union estimate that the old-age dependency ratio is likely to more than double in the next forty years: in practice, the ratio between the number of persons aged 65 and over (i.e., the age when they are generally economically inactive) and the number of persons aged between 15 and 64 will grow from 25.4% in 2019 to 53.5% in 2060 (Eurostat, 2020; Jacobs-Crisioni et al., 2019). These changes will put increased strain on social, economic and urban transformation policies in order to provide suitable actions and interventions to make cities "more inclusive, accessible and efficient" for the elderly (Ga, 2015).

In addition, the Universal Design principle and the most recent advances in the field of urban accessibility have changed the focus from the land use-transport nexus to characteristics of the urban built environment that make it suitable for walking (D'Orso & Migliore, 2020; Forsyth & Southworth, 2008; Wang & Yang, 2019). These changes have promoted several initiatives and projects aimed at increasing the quality of the urban built environment by improving pedestrian movement. The EU Innovation Partnership on Active and Healthy Ageing, the Healthy Ageing Programme (WHO) and the Health Programme (European Institute of Innovation and Technology) are all relevant examples of initiatives aimed at creating opportunities for social and civic engagement among people aged over 65, in addition to increasing their independence in day-to-day activities.

In practice, there is wide recognition that local decision-makers and urban planners should engage in making cities places where individuals at every stage of life can readily participate in activities and access urban services (Saelens & Handy, 2008; Wang et al., 2020).

The concept of urban accessibility is described as the possibility for a place to be reached on foot, without barriers (Gaglione et al., 2019); in this study, urban accessibility also refers to the characteristics of the built environment that encourage people to walk. The characteristics taken into consideration include (i) socio-economic characteristics (age, sex, level of education, etc.), (ii) functional characteristics such as activities and services located within a neighbourhood that can be reached on foot, (iii) physical characteristics that also describe the quality of urban space (e.g., the state of flooring, street furniture, thermal comfort, etc.) and (iv) characteristics that not only make it possible to easily reach a place or a service but also influence individuals' perception and,

---

* Corresponding author.
E-mail addresses: federica.gaglione@unisannio.it (F. Gaglione), gargiulo@unina.it (C. Gargiulo), floriana.zucaro@unina.it (F. Zucaro).

https://doi.org/10.1016/j.cities.2022.103724
Received 15 March 2021; Received in revised form 10 November 2021; Accepted 23 April 2022

Table 1
Set of variables used and their weights according to previous studies that used AHP and FAHP techniques. Those shown in bold were used for FAHP analysis. Numerical values of physical variables refer to Italian regulations and Codes, while those relating to the sense of security refer to the specific context of analysis. The last column refers to the MCDA weights calculated by the previous studies (References column).

ID	Variable	Measure	References	MCDA weight
Physical characteristics				
1	Slope of street network links	>5% = 0 < 5% = 1	Joo & Kim, 2011 Moon et al., 2016	0.131 0.195
2	Sidewalk width	< 1.5 m = 0 > 1.5 m = 1	Joo & Kim, 2011 Moon et al., 2016	0.050
3	State of sidewalk pavement	0 = poor good = 1	Joo & Kim, 2011 Moon et al., 2016	0.150 0.190
4	Presence of crossings	No = 0 Yes = 1	Moon et al., 2016 Bivina & Parida, 2019 Wey and Chiu, 2013	0.171 0.146 0.259
Characteristics related to the sense of safety				
5	Presence of traffic lights	<0.056 = 0 > 0.056 = 1	Bivina & Parida, 2019 Wey and Chiu, 2013 Lee & Park, 2014	0.390 0.118 0.048
6	Presence of pedestrian crossings	>17.5 m = 0 < 9 m = 1	Bivina & Parida, 2019	0.101
7	Lighting density	No = 0 Yes = 1	Lee & Park, 2014	0.045
8	Presence of escalators / elevators	No = 0 Yes =1	Moon et al., 2016	0.268
Urban context characteristics				
7	Presence of green areas	No = 0 Yes = 1	Joo and Kim, 2011 Moon et al., 2016 Bivina & Parida, 2019 Sayyadi & Awasthi, 2012	0.104 0.028 0.020
8	Presence of panoramic points	No = 0 Yes = 1	Lee & Park, 2014 Sayyadi & Awasthi, 2012	0.066 0.119
9	Non-main roads	No = 0 Yes = 1	Bivina & Parida, 2019 Wey and Chiu, 2013	0.097 0.207
10	Presence of benches	No = 0 Yes = 1	Lee & Park, 2014	0.040

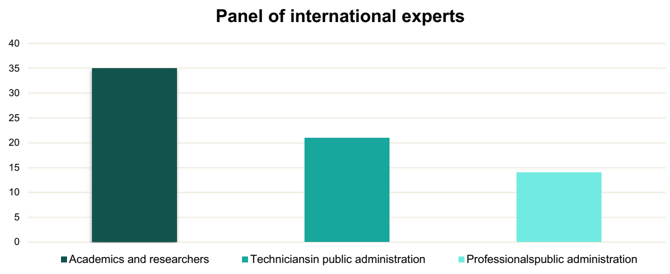


Fig. 1. Composition of the experts' panel in relation to the profession who filled the electronic survey.

consequently, choice of a path (Deehr & Shumann, 2009; Fancello et al., 2020; Leslie et al., 2005; Ruiz-Padillo et al., 2018). In other words, the characteristics taken into account to measure the age-friendliness of a neighbourhood refer to the overall quality of the built environment, from a holistic and systemic perspective of urban transformation (Gaglione et al., 2019 and 2021).

Table 2
Correspondence scale between linguistic judges and fuzzy triades.

Linguistic judges	AHP scale (Saaty scale)	FuzzyAHP scale	FuzzyAHP reciprocal scale
Equal important	1	(1,1,1)	(1,1,1)
Important	2	(1,2,3)	(1/3,1/2,1)
Moderately more important	3	(2,3,4)	(1/4,1/3,1/2)
Intermediate	4	(3,4,5)	(1/5,1/4,1/3)
Strongly more important	5	(4,5,6)	(1/6,1/5,1/4)
Intermediate	6	(5,6,7)	(1/7,1/6,1/5)
Very strongly more important	7	(6,7,8)	(1/8,1/7,1/6)
Intermediate	8	(7,8,9)	(1/9,1/8,1/7)
Extremely more important	9	(8,9,10)	(1/10,1/9,1/8)

(Source: Chang, 1996).

Thus, in this context, the main objective of this study is to support policy-makers in identifying the optimal urban areas where changes could be made to improve pedestrian accessibility for the elderly to the main urban services to help encourage active ageing.

This work provides a qualitative-quantitative method that first integrates Multi-Criteria Decision Analysis (MCDA) and spatial analysis; the degree of comfort and pleasantness linked to the characteristics of pedestrian paths through the sensitivity analysis is then validated, allowing the attractiveness of walking in a neighbourhood to be assessed. A walkability index was also determined in a Geographic Information System (GIS) environment, representing a decision-making tool to support local decision-makers.

This study is structured as follows: Section 2 describes the theoretical background of the walkability problem, with particular reference to the elderly population; Section 3 describes the methodology and study area, located in the city of Naples; Section 4 systematically describes the results of each step of the proposed method; and, finally, the study's conclusions are presented in Section 5.

2. Walkability and the elderly: state of art

Walkability can be defined as "the extent to which the built environment is 'conductive' to walking on" (Liao et al., 2020). The purpose of walking and perceptions of urban space both play a key role in individuals' willingness to walk (e.g., Brown, 2007; Chu, 2017; Evans, 2009; Stafford & Baldwin, 2017). For instance, some built environments features can facilitate or restrain walking (e.g. poorly lit areas or steeply sloping roads) and the location of activities can influence individuals' daily routine activities (e.g. travelling from home to market or from home to recreation services).

Abley (2005) proposed the following definition of the characteristics of a network that improve its walkability: connected, pedestrian-friendly, visible, convenient and comfortable streets. Subsequently, Saelens and Handy (2008) investigated the correlation between urban features and walking inclination at a neighbourhood scale; their findings were later analyzed by Ewing and Cervero (2010), who identified six components of walkability, namely, density, diversity, design, distance, destination and demand management.

Promoting walking to reach and benefit from urban places and services also has positive effects in terms of reducing the social exclusion of the most vulnerable segments of the population (Allen & Farber, 2020; Simoes & Marin-Lamellet, 2002), improving urban accessibility (Gaglione et al., ,2018, 2019; Litman, 2017; Wittowsky et al., 2019) and reducing pollution levels and vehicular congestion, particularly in larger urban areas (Cepeda et al., 2017; Howell et al., 2019).

Over the past 15 years, walkability studies have largely focussed on the population aged over 65. The interest in this segment of the population is due to the ongoing ageing process, and, thus, the need to

Fig. 2. Correspondence scale between linguistic judges and fuzzy triades.
(Source: Chang, 1996).

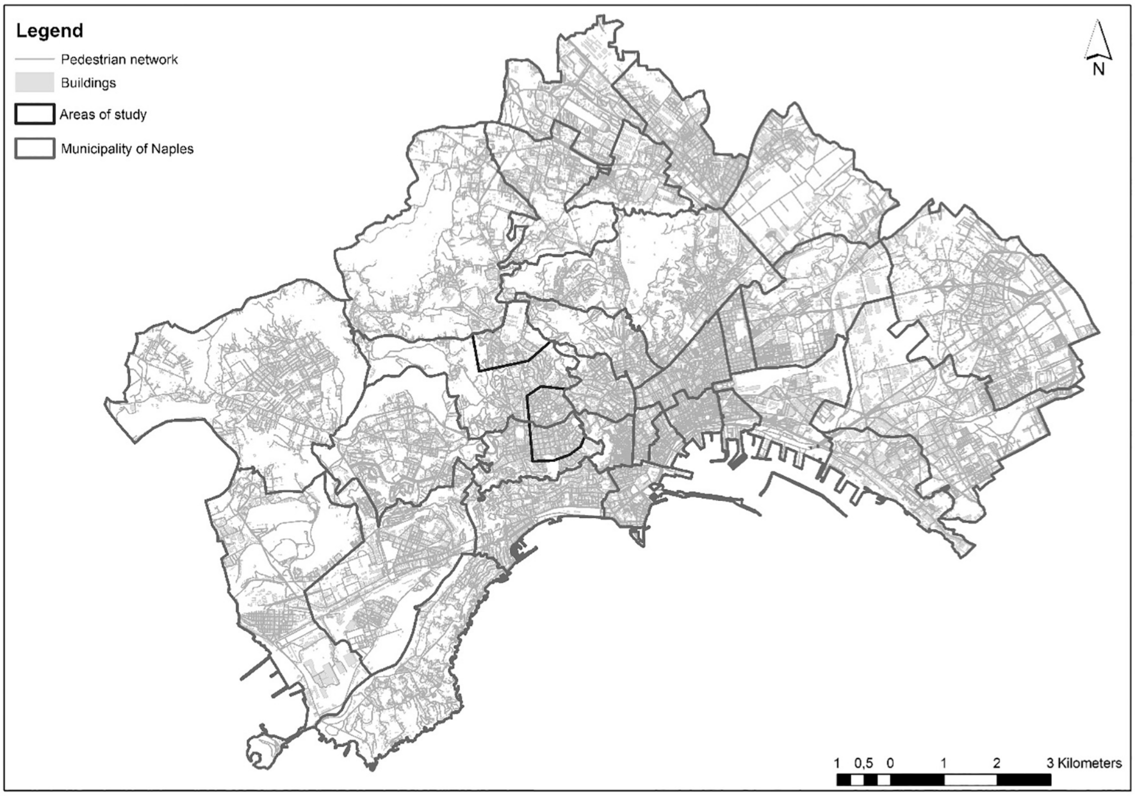


Fig. 3. Areas of study within Vomero and Arenella districts in the city of Naples (Italy).

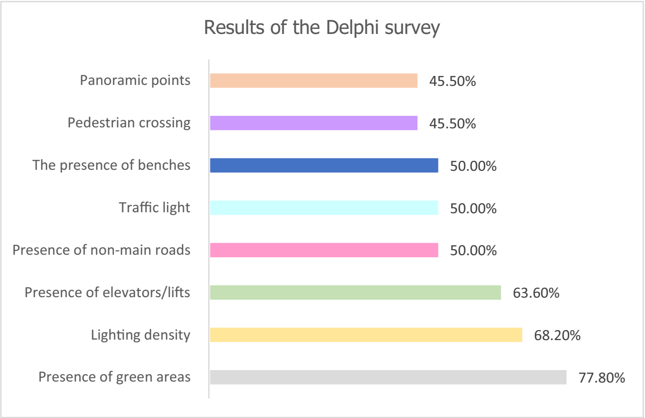


Fig. 4. Results of the Delphi survey.

support local policy-makers in developing urban built environments suitable for the "greys" (WHO, 2002; WHO, 2007).

According to the UN (2017), societies are becoming super-aged, with more than 20% of the total population now aged 65 and over. This increase in the elderly population will be most evident in developing countries, however, in industrialized countries, the segment of the population that will increase the most will be those aged over 80, whose absolute number, by 2050, will quadruple (Kinsella & He, 2009; WHO, 2007).

The scientific debate concerning the study of walkability for elderly individuals at a neighbourhood scale encompasses two main aspects. The first of these aspects is focussed on investigating which physical (relating to the geometry and characteristics of the road network and urban fabric), environmental (relating to the elements of urban furniture such as lighting and benches) and functional (relating to the location of urban services) characteristics are decisive for walkability (e.g. Cerin et al., 2007; Cheng et al., 2019; Furukawa and Wang, 2019; Gharaveis, 2020). Several studies have also highlighted how residential areas characterized by the presence of attractive destinations at limited distances are associated with a greater propensity to pedestrian mobility

Table 3
Pairwise comparison for the 8 sense of security and urban context variables of the two study areas.

Column j		1	2	3	4	5	6	7	8
Row i	**1**	(1,1,1)	(2,3,4)	(1,2,3)	(1,2,3)	(5,6,7)	(4,5,6)	(5,6,7)	(6,7,8)
	2	(0.25,0.33,0.5)	(1,1,1)	(3,4,5)	(2,3,4)	(2,3,4)	(3,4,5)	(3,4,5)	(3,4,5)
	3	(0.33,0.5,1)	(0,20,0.25,0,3)	(1,1,1)	(3,4,5)	(3,4,5)	(2,3,4)	(4,5,6)	(4,5,6)
	4	(0.33,0.5,1)	(0.25,0.33,0.5)	(0,20,25,0,33)	(1,1,1)	(3,4,5)	(3,4,5)	(4,5,6)	(3,4,5)
	5	(0.14,0.17,0.2)	(0.25,0.33,0.5)	(0,20,25,0,33)	(0,20,25,0,33)	(1,1,1)	(2,3,4)	(2,3,4)	(2,3,4)
	6	(0.16,0.2,0.25)	(0.25,0.33,0.5)	(0.25,0.33,0.5)	(0,20,25,0,33)	(0.25,0.33,0.5)	(1,1,1)	(1,2,3)	(2,3,4)
	7	(0.14,0.17,0.2)	(0,20,0.25,0,3)	(0.16,0.2,0.25)	(0.16,0.2,0.2)	(0.25,0.33,0.5)	(0.33,0.5,1)	(1,1,1)	(2,3,4)
	8	(0.13,0.14,0.1)	(0.25,0.33,0.5)	(0.16,0.2,0.25)	(0,20,25,0,33)	(0.25,0.33,0.5)	(0.25,0.33,0.5)	(0.25,0.33,0.)	(1,1,1)

Note: (1 lighting density, 2 presences of escalators and elevators, 3 Traffic lights, 4 Pedestrian crossings, 5 Presence of green areas, 6 Non-main roads, 7 Park Bench, 8 Presence of panoramic points).

Table 4
Fuzzy geometric mean value and weights of the 8 variables of the two study areas.

		Fuzzy geometric mean value r_i	Inverse vector	Fuzzy weight w_i	Centre of area (CoA) w_i	Normalization weight wi
Row i	1	(2.42,3.32,4.13)	8.05	(0.17,0.30,0.50)	0.32	0.305
	2	(1.56,2.13,2.74)	10.73	(0.11,0.19,0.33)	0.21	0.200
	3	(1.44,1.87,2.42)	13.79	(0.10,0.17,0.29)	0.19	0.181
	4	(1.07,1.38,1.82)	(1/8.05,1/10.73,1/13.79)	(0.07,0.12,0.22)	0.14	0.133
	5	(0.57,0.74,0.95)	(0.12,0.09,0.07)	(0.03,0.06,0.11)	0.06	0.057
	6	(0.42,0.57,0.77)		(0.029,0.05,0.09)	0.06	0.054
	7	(0.32,0.41,0.55)		(0.02,0.03,0.06)	0.04	0.038
	8	(0.25,0.31,0.41)		(0.02, 0.028,0.05)	0.03	0.031
					1.05	1.00

Table 5
Average of the ratios between the weighted averages and the relative weights.

Column j		1	2	3	4	5	6	7	8	Weighted sum value	Weighted sum value/weight wi
Row i	**1**	0,29	0,65	0,33	0,27	0,44	0,26	0,24	0,19	2,67	9
	2	0,10	0,22	0,67	0,40	0,22	0,21	0,16	0,11	2,08	10
	3	0,15	0,05	0,06	0,538	0,29	0,16	0,20	0,14	1,58	9
	4	0,15	0,07	0,04	0,13	0,29	0,21	0,20	0,11	1,21	9
	5	0,05	0,07	0,04	0,03	0,073	0,16	0,12	0,08	0,63	9
	6	0,06	0,05	0,06	0,03	0,02	0,052	0,08	0,08	0,44	8
	7	0,05	0,05	0,03	0,03	0,02	0,03	0,04	0,08	0,34	8
	8	0,04	0,05	0,03	0,03	0,02	0,02	0,01	0,03	0,24	10

Note: λmax = Average (Weighted Sum Value/Option Weight) = 9; Consistency Index (C.I.) = (λ_{max} − n) / (n − 1); where n = number of compared options (measures) = 8; Consistency Index (C.I.) = 0.138; Consistency Ratio = C.I./Random Index (R.I.) = 0.098 < 0.1 matrix consistency verified.

Table 6
Global weights of variables.

Measure		Weight (%)
1	Lighting density	29
2	Presence of escalators and elevators	21
3	Traffic lights	17
4	Pedestrian crossings	14
5	Presence of green areas	7
6	Non-main roads	5
7	Park Bench	4
8	Presence of panoramic points	3

(Barton et al., 2003; Haugen, 2011; Anciaes et al., 2017; Sun et al., 2019).

These studies have been mostly developed at a micro-scale relative to portions of neighbourhoods, due to the overall lesser tendency of the elderly to walk long distances (according to their health) and the number of detailed features (e.g. the presence of road crossings). The collection and localization of these characteristics is carried out by GIS tools that allow walkability indices to be developed, defining the walkability levels of the area under study. Some studies agree that access to sidewalks is a characteristic broadly favouring elderly walkability (Stathi et al., 2012), whereas, the lack of pedestrian crossings was reported to be a barrier to mobility (Mahmood et al., 2012).

The second aspect focussed on by previous studies is the perception of the built environment by the elderly, as this affects the choice of routes to urban services of interest. The perception of safety, the pleasure of walking and levels of familiarity with the environment (Carnegie et al., 2002) all affect both the decision to walk and the paths chosen for walking within the pedestrian network. Studies of these aspects mainly use: (i) surveys of representative samples of the elderly population to analyse their perceptions and opinions of the neighbourhoods where they live (Alidoust et al., 2018; Borst et al., 2008; Brookfield & Tilley, 2016; Mahmood et al., 2012; Spittaels et al., 2010); and (ii) tracking-based behavioural observation techniques (Pafka & Dovey, 2017; Shatu & Yigitcanlar, 2018; Yamagata et al., 2020; Zhang & Mu, 2020), to understand the emotions, feelings and any material or immaterial barriers encountered by the subject while moving.

Given the above scientific framework, two main gaps in knowledge are identified:

- Although there are numerous studies that relate urban characteristics to walkability of the elderly, few of these studies provide local decision-makers with strategies and interventions aimed at improving pedestrian accessibility. Furthermore, most of these studies were developed in Asia, Australia and North America, with very few in Italy. The outputs of these studies are mostly intended to provide indices to measure walkability or the significance of various walkability characteristics and the relations among them; however,

Table 7

Cluster urban characteristics and results increasing weights.

Measure	FuzzyAHP rank	FuzzyAHP weights	Cluster	Increasing Green areas	Increasing Presence panoramic points	Increasing park bench	Increasing non main roads
1	Lighting density	29%	Comfort	27%	28,6%	28,2%	28,3%
2	Presence of escalators/elevators	21%		20%	20%	20%	20%
3	Traffic lights	17%	Street environment	16%	16%	16%	16%
4	Pedestrian crossings	14%		13%	13%	13%	13%
5	Presence of green areas	7%	Amenity	13%	7%	7%	7%
6	Non-main roads	5%		5%	5%	5%	7%
7	Park Bench	4%		4%	4%	8%	5%
8	Presence of panoramic points	3%		2%	5%	2%	3%

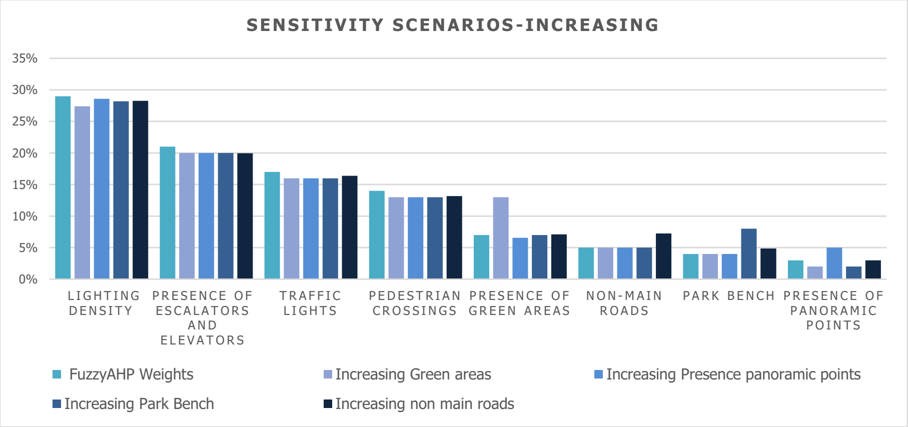


Fig. 5. Sensitivity outputs, urban context characteristics.

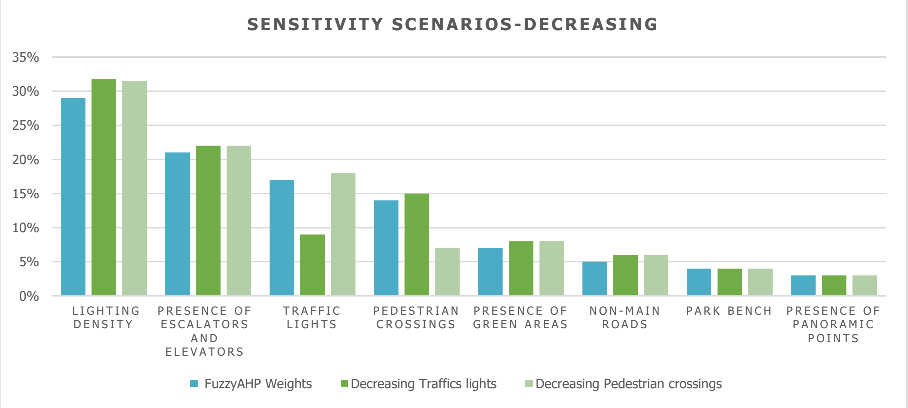


Fig. 6. Sensitivity outputs, characteristics related to the sense of safety.

Table 8

Cluster urban characteristics and results decreasing weights.

Measure	FuzzyAHP rank	FuzzyAHP weights	Cluster	Decreasing traffic lights	Decreasing pedestrian crossings
1	Lighting density	29%	Comfort	32%	32%
2	Presence of escalators /elevators	21%		22%	22%
3	Traffic lights	17%	Street Environment	9%	18%
4	Pedestrian crossings	14%		15%	7%
5	Presence of green areas	7%	Amenity	8%	8%
6	Non-main roads	5%		6%	6%
7	Park Bench	4%		4%	4%
8	Presence of panoramic points	3%		3%	3%

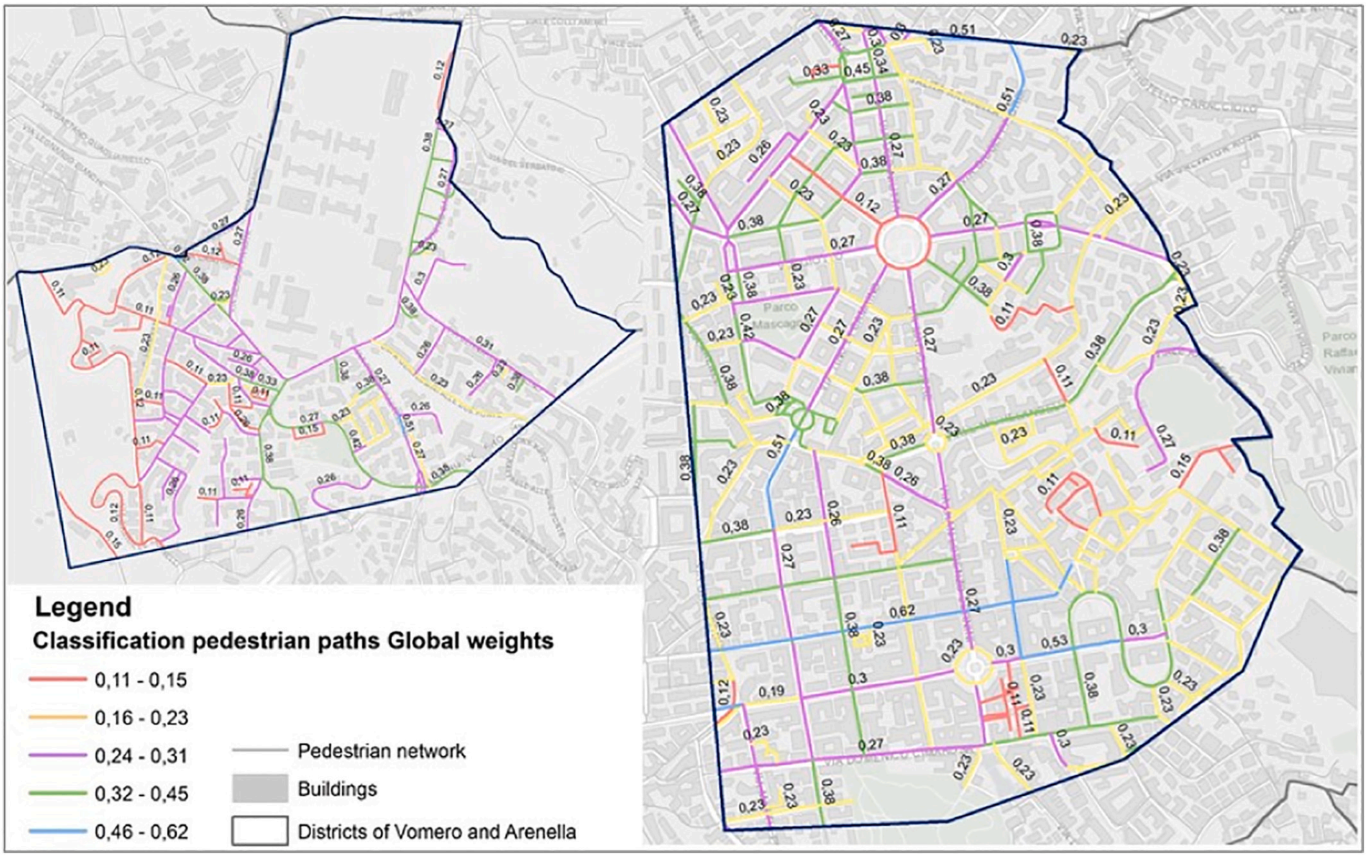


Fig. 7. Classification of pedestrian network according to Index walkability attractiveness.

the findings are not adapted into applicable recommendations for local authorities who are required to fulfil the needs and expectations of their elderly citizens.

- If walkability can be considered as a relevant metric to assess the suitability of a neighbourhood for individuals to walk through and reach other parts of cities, little attention has been paid to the most suitable locations and distributions of activities for the elderly. Few studies have addressed the issue of how the supply of local and welfare facilities for the elderly can contribute to increased urban accessibility levels. In particular, this issue is central to the holistic–systemic approach adopted in this study, where improving urban accessibility requires the integration of activities, open spaces (built and not built) and pedestrian behavior of the elderly.

To address the aforementioned limitations of current studies, the Mobilage project aims to define a decision support tool for public administrations to increase pedestrian access to urban services for the population aged over 65. The research group of the Mobilage project from the University Federico II is also working to improve elderly individuals' access to urban services by improving the characteristics of the pedestrian network.

In summary, the aims of this study are twofold: first, we aim to quantify the weight of each characteristic of the pedestrian network and the built environment using a Multi-Criteria Decision Analysis called the Fuzzy Analytic Hierarchy Process (FAHP); second, we aim to identify urban areas where improvements are needed to increase accessibility for pedestrians.

3. Methodology and study area

The proposed methodology, aimed at identifying pedestrian paths and related urban areas that are elderly-friendly in terms of accessibility, is based on three main steps. The first is the FAHP analysis to quantify the relative importance of each of the variables relating to walkability. The second is a sensitivity analysis to ensure the consistency and broad applicability of the FAHP output weights across a range of different areas. The third step is a GIS-based micro-scale spatial analysis to classify portions of neighbourhoods according to their pedestrian accessibility to urban services.

Prior to the FAHP analysis, we also undertook a comprehensive literature review and applied the Delphi method, in order to guarantee (i) the relevance of the variables used to measure the urban accessibility of the elderly at a micro-scale level and (ii) the reliability of the initial judgments attributed to them. In particular, we focussed on studies that used similar MCDA approaches.

As an example, Joo and Kim (2011) and Moon et al. (2016) found that pavement quality (e.g. type of material used) and absence of steps are among the main factors encouraging walking. Wang et al. (2016) and Bivina et al. (2019) identified safety (related to the perception of the built environment), security (related to the presence of barriers, such as crossings) and comfort (e.g. the presence of benches) as the major characteristics influencing elderly walkability. Sayyadi and Awasthi (2012), Lee and Park (2014) and Bivina and Parida (2019) also found that the presence and quality of amenities (e.g. green areas) and open spaces have the smallest impact and, thus, are among the lowest-ranked urban accessibility characteristics.

Table 1 reports the set of variables that mostly affect urban accessibility of the elderly, based on the results of previous studies of accessibility and walkability in urban areas. These variables range from the geometry of the pedestrian network to the aesthetics and pleasantness of the built environment to take into consideration the range of urban elements affecting the willingness of the elderly to walk to reach local services.

The variables were classified into three main categories, in line with

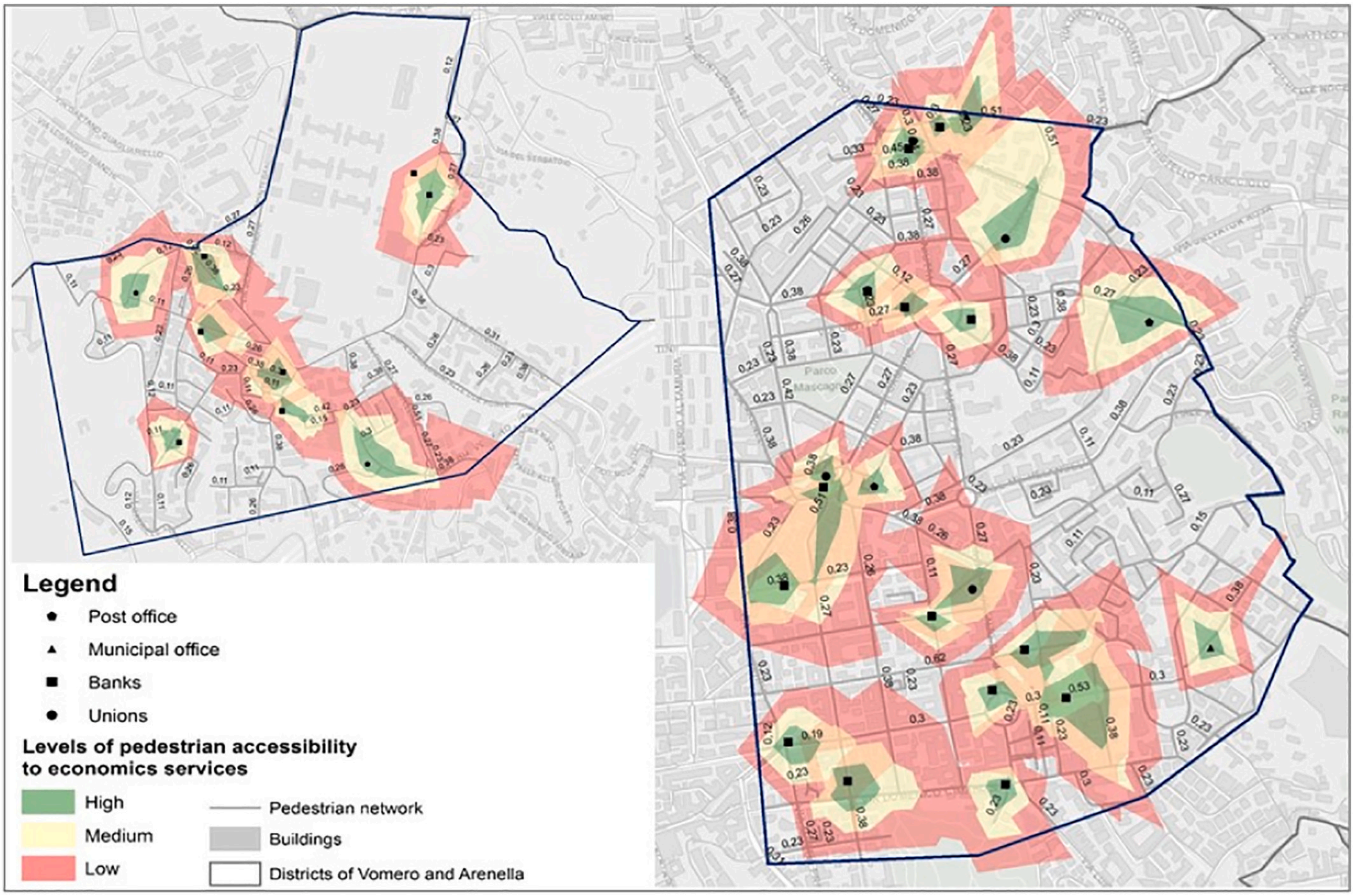


Fig. 8. Walkability attractiveness levels to reach economic services.

our previous studies (Cottrill et al., 2020; Zecca et al., 2020); we then applied the FAHP to the "sense of security" (related to perceived protection while walking the paths) and "urban context" categories (related to the attractiveness and amenities of the neighbourhood). In particular, the latter category of characteristics "relates to how much the built environment gives joy to the users aesthetically, attracts pedestrians to use the space, pleases them with opportunities offered" and thus, influences the choice of pedestrian paths (Ujang, 2013).

The physical characteristics (relating to the geometry and quality of paths) have not been included in our FAHP analysis as we considered these to be the "basic elements" of a pedestrian path for the elderly: e.g. streets with steep slopes, irregularity in sidewalk surfaces and restricted available width for walking make areas inaccessible for older adults, irrespective of their other characteristics.

Variables 5 to 10 (Table 1) extracted from previous studies were screened using the Delphi method, which is a type of expert investigation method (Rowe, 1994). The experts were selected from the Horizon2020 project platform, in particular taking into consideration their involvement in projects on thus study's main themes such as social inclusion, urban accessibility and walkability. Specifically, stakeholders and project managers belonging to various universities and research groups were useful in defining the panel of experts comprising permanent academics and Italian and European researchers. Furthermore, the selection of experts was also related to the Mobilage project and those working in sectors of interest in the city of Naples who, therefore, are familiar with the context of the area under study. In addition, professionals and technicians working in public administration and the elderly welfare sector were involved. In summary, to ensure practical and effective answers based on professional knowledge, experience and judgment on the topics studied (Özdağoğlu & Özdağoğlu, 2007; Shahbod et al., 2020), 100 international experts from different fields were invited to fill in an electronic questionnaire.

More than 70% of the experts filled in the electronic survey, which was structured into three sections (Fig. 1): (i) a brief introduction illustrating the aim of the work; (ii) control data (e.g. professional role); and (iii) evaluation of the characteristics influencing the choice of a pedestrian path for the population age over 65 by pairwise comparisons, to obtain scores for application to the FAHP analysis. The weights of the eight studied variables were obtained using a pairwise comparison matrix (Podvezko, 2009; Skulmoski et al., 2007).

3.1. Fuzzy AHP analysis

The FAHP analysis was used to calculate the weights of the considered variables. Laarhoven and Pedrycz (1983) proposed the earliest FAHP method, which is an extension of Saaty's (1980) theory, based on triangular membership functions describing the fuzzy comparison judgments.

In general, multi-criteria methods work with different kinds of variables (i.e., both qualitative and quantitative, such as the ones used in this study) by supporting decision-makers in sorting several alternatives based on the selected criteria (Brugha, 2004; El Gibari et al., 2019; Herva & Roca, 2013). In particular, fuzzy methods have been employed increasingly in recent years, especially in the fields of spatial and mobility planning, as they allow uncertainty and subjectivity related to users' activity choices and trip modes to be overcome (Arce et al., 2015; Sayyadi & Awasthi, 2012; Shafabakhsh et al., 2015; Wey & Chiu, 2013). For instance, in the context of urban accessibility, built environment characteristics (width of streets, presence of shade, etc.), trip purposes (shopping, health, work, etc.) and age population groups (children or

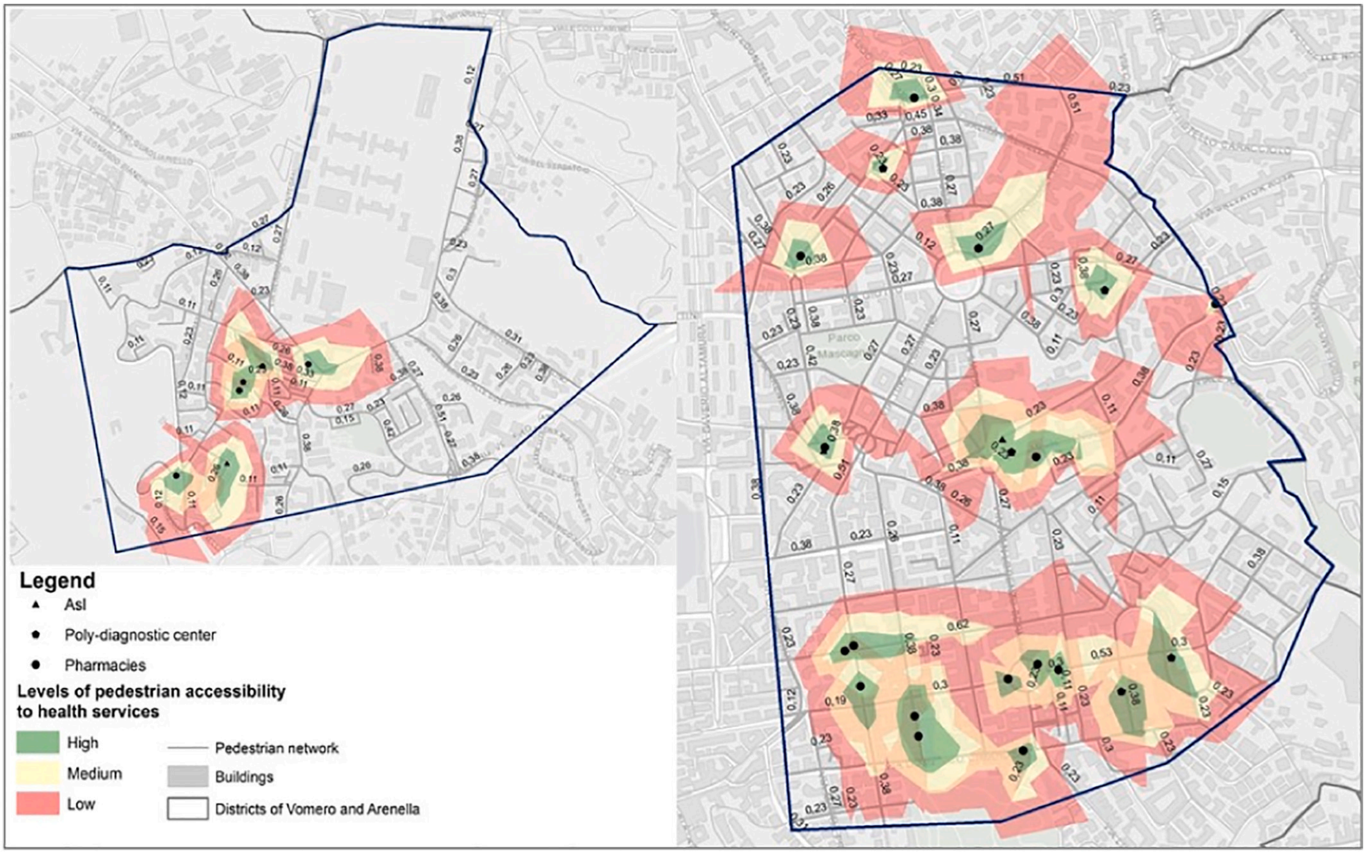


Fig. 9. Walkability attractiveness levels to reach health services.

elderly) can all represent conflicting criteria when making decisions to improve walkability (both at urban and neighbourhood levels) (Hansen & Ombler, 2008; Moura et al., 2014; Oswald Beiler & Phillips, 2015; Ruiz-Padillo et al., 2018).

Because of the triads of scores that the FAHP method assigns to each criterion (in this case the urban characteristics influencing walkability for the elderly), this method can take into account the uncertainty of the criteria judges and thus tries to avoid "imprecise judgments of decision-makers in conventional AHP approaches" (Özdağoğlu & Özdağoğlu, 2007). Accordingly, the FAHP method was selected as the most reliable MCDA to accomplish the aims of this study.

Fuzzy analysis is structured hierarchically — the goal of the analysis (i.e., the "friendliness" of pedestrian network) is placed at the highest level of the structure, followed by the criteria that help to specify the goal (the security and urban context categories) and, finally, the attributes that are a further specification of these criteria (the scores we associate to each variable).

As "humans are unsuccessful in making quantitative predictions, whereas they are comparatively efficient in qualitative forecasting" (Oguztimur, 2011), linguistic expressions can be a more useful and accurate approach to making evaluations by linking them to the Saaty scale, which transforms the linguistic variables to linear quantitative values from 1 to 9 (Table 2). As shown, Table 2 outlines the translation of the verbal judgment which defines the importance and influence of each of the variables, as reported by the values in the 'linguistic judgment' column. Furthermore, the table also shows a comparison between the two methods used to attribute quantitative values to each verbal judgment.

Table 2 shows the correspondence between the linguistic value and the triad of numeric scores upon which the fuzzy technique is based. The triad of scores (1, 2, 3) denotes the smallest possible value, the mean value, and the largest possible value that describe a fuzzy event, where 1 represents the smallest and 3 represents the largest value. Based on the above, using these triads of scores, the FAHP can overcome uncertainties in the preference judgments (Fig. 2).

Given that the FAHP procedure is widely reported in detail in literature (e.g. Saaty, 2003; Yedla and Shrestha, 2003; Pohekar & Ramachandran, 2004), only the main phases of the FAHP approach are described below.

FAHP analysis defines pairs of comparison matrices for all alternatives to determine which of them are most important. These are square ($n * n$), symmetrical and diagonal matrices. The result of the comparison is the dominance coefficient a_{ij}, representing an estimate of the dominance of the element i over the element j.

To compare row i with column j, a score on the previously illustrated scale is assigned (Fig. 1); note that the score of row j with respect to column i will be equal to the reciprocal of this value. For instance, for a very important decision in row i compared to column j, the score will be M2; conversely, the decision score for row j compared to column I will be equal to 1/M2 (Table 2).

Once the pairwise comparison matrix is obtained, the vector of the percentage weights for each variable was calculated (Buckley, 1985). The values were then normalized such that the weight of each variable is on a scale from 0 to 1.

After defining the vector of priorities, an important step involves verification of whether the matrix of pairwise comparisons is consistent or not, i.e., to "measure" whether the subjective judgments of the decision-maker in each comparison are consistent. Therefore, the weighted average (on the weights of the criteria) of the impact of each criterion on the decision needs to be defined, which allows the consistency of the assessments to be validated. This is accomplished by multiplying each column j of the matrix of the pairwise comparison by the weight relative to that column.

The weighted sum value vector and the weight vectors of all the

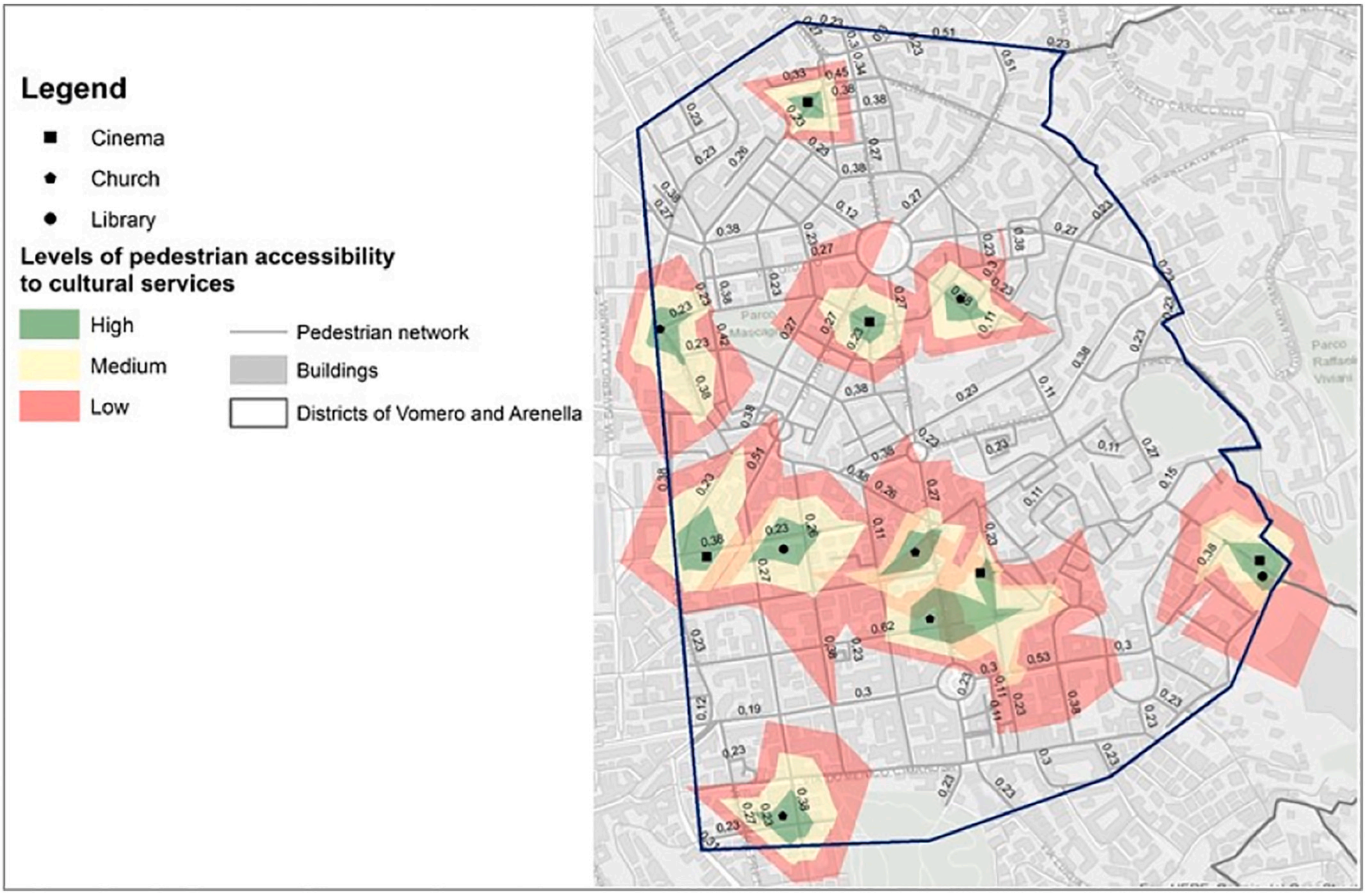


Fig. 10. Walkability attractiveness levels to reach cultural services.

variables allow the maximum eigenvalue of the matrix (λ_{max}), in order to calculate the consistency of the matrix (CI) that guarantees that the weights are coherent with their attributed scores:

$$CI = (\lambda_{max} - n)/(n - 1)$$

where λ is the maximum eigenvalue of the matrix and n represents the dimension of the matrix itself.

3.2. Sensitivity analysis

The sensitivity analysis allowed the effect of changes in weights of the input values and the assumptions on final outputs to be evaluated (Sayyadi & Awasthi, 2012; Tsai et al., 2010). The FAHP analysis ranking is heavily dependent on the weights associated with the main criteria; thus, small changes in the weights of criteria have a significant impact on the final classification of the variables.

According to Balusa and Gorai (2019), “Sensitivity analysis is an essential component of fuzzy-AHP decision-making models […] as it provides information about an alteration in the ranking of the alternatives”. Nevertheless, previous urban accessibility studies mostly refer to this type of analysis as a recommendation for future work. To date, seemingly only Sayyadi and Awasthi (2012) developed this technique to support decision-making processes in locating pedestrian zones. To this end, 20 sensitivity analysis experiments were conducted. For the variables that were assumed to have a minor role based on the FAHP sorting, the weights were increased in increments of 10%, up to a maximum increase of more than 50%; conversely, for the variables that were assumed to play a major role, the weights were decreased by up to 60% to verify if these weight perturbations validate the results obtained from the FAHP model. These tests were defined with the aim of assessing the influence of the lowest weighted variables on the final results (related to the urban context), as well as those that occupy an intermediate position in the final ranking of FAHP outputs (Table 6).

Finally, the findings achieved by the fuzzy method and confirmed by sensitivity analysis were integrated with spatial analysis, as, according to Chandio et al. (2013), “the GIS is a powerful tool in spatial modelling which involves a large number of spatial decision problems providing alternative scenarios in the context of maps”.

3.3. Spatial analysis - index of walking attractiveness

The weights from the FAHP analysis and the physical variables’ values (Table 2) were associated with the links of the pedestrian network in GIS. We then measured the walking attractiveness of the links whose geometry and quality allow the elderly to walk them by calculating the following index:

$$\text{Index of walking attractiveness} = \frac{\textit{length of the arch}}{\textit{length of the arch}^{*} \sum \textit{FAHP weights}}$$

This index was defined to take into account both the possible disadvantage caused by the distance that an older adult would need to walk and the advantages linked to the presence of physical, safety and urban context characteristics.

The walking attractiveness index values were then classified using the natural breaks method into three intervals; by considering the localization of the main services of interest to the elderly, the study area’s pedestrian network was then ranked according to the “friendliness” to the elderly using the GIS Network Analysis tool. In other words, the portions of the neighbourhood surrounding a service were classified into low, medium and high pedestrian attractiveness according to the values of the index. The choice of three levels of classification (low,

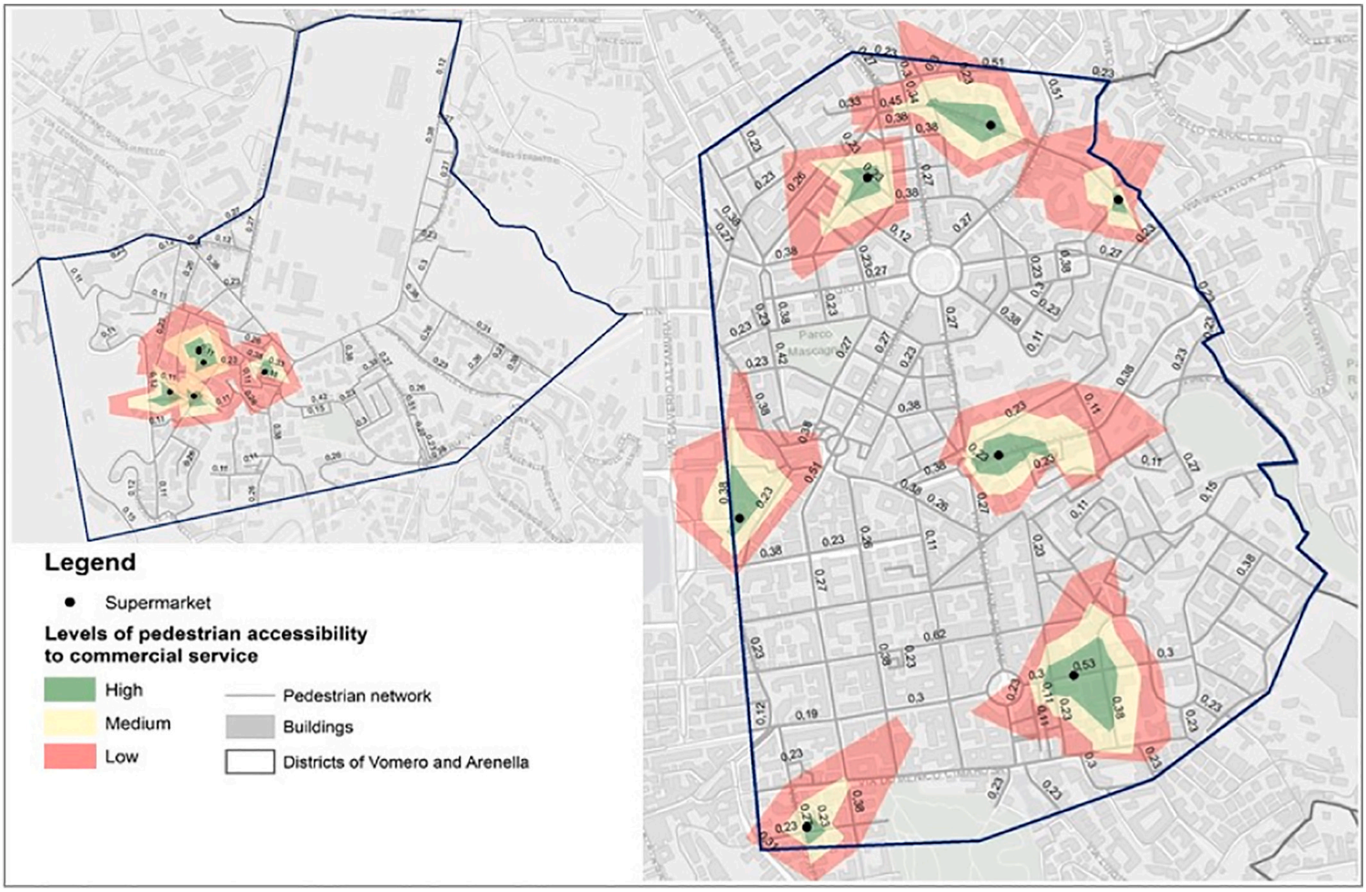


Fig. 11. Walkability attractiveness levels to reach commercial services.

medium and high) is in line with approaches used in previous studies (Saghapour et al., 2016; Yigitcanlar et al., 2007) and allows for an easy to interpret representation of the obtained results. Furthermore, we considered health, economic, cultural, leisure and commercial category services, as these represent the main activities of interest for the population aged over 65.

Overall, identifying urban areas with different degrees of walking suitability for the elderly represents a useful support tool for local decision-makers in defining where and how to best target their efforts to increase urban accessibility for the elderly and, accordingly, improve their quality of life.

3.4. *Study area*

The entire methodology was tested in two areas of the Arenella and Vomero districts of Naples (Fig. 3). These are were selected due to the relevance of their local context to this study, including demographic, morphological and settlement characteristics (Gaglione et al., 2019; Cottrill et al., 2020). These hilly areas represent opposing types of urban fabric (unplanned vs planned) and therefore require different types of changes to improve urban accessibility for the elderly given their differences in terms of physical and functional organization. The urban area near the hospital in the Arenella district is characterized by an unplanned fabric as the building process was a consequence of the saturation of the nearby Vomero district. The latter area, in contrast, is characterized by a compact and planned fabric with a higher functional mix than Arenella.

4. Results and discussion

4.1. *Delphi analysis results*

Fig. 4 shows the results of the Delphi survey. Experts identified all of the four characteristics related to the sense of security as the most relevant aspects influencing urban walkability for the elderly, which was an anticipated outcome given the importance of this aspect for access by those over 65. Lighting density and presence of elevators/lifts obtained the two highest scores (68.2% and 63.6% respectively), followed by factors that allow the elderly to move from one street to another and along it: traffic lights (50%) and pedestrian crossings (45.5%). Among the urban context characteristics, the presence of green areas has the greatest impact by far on the choice of a pedestrian path (77.3%), confirming that open but unbuilt spaces are recognised as a key element for the attractiveness of a walkable route (Hillsdon et al., 2006; Tribby et al., 2016). The presence of benches was recognised as the second most important urban element relevant for walking together with the presence of non-main roads (50%), unlike panoramic points received much lower importance scores (45.5%).

4.2. *Fuzzy AHP analysis results*

The previous outcomes allowed the weight of each criterion (variable) influencing the elderly's walkability to be calculated using the FAHP technique. Tables 3–6 illustrate the results of this MCDA according to its main steps (see Section 2). Relative to the main diagonal of the pairwise comparison matrix (Table 3), each row *i* compared to column *j* of the upper right-hand side of the matrix consists of the triads of scores as assigned by the judgments of the Delphi experts. The decision values of row *j* with respect to column *i*, equal to the reciprocal of the values

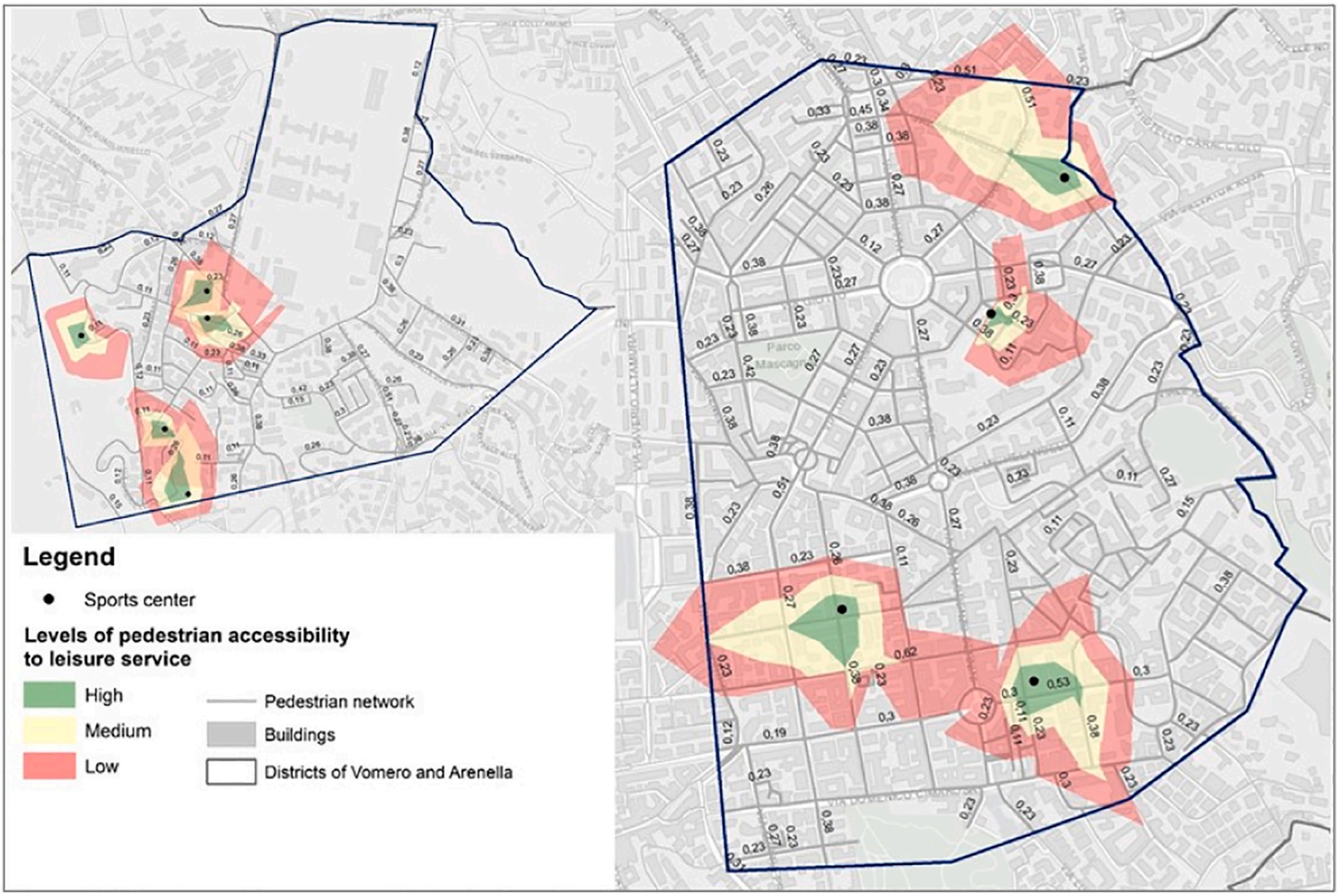


Fig. 12. Walkability attractiveness levels to reach leisure services.

above, are reported on the lower left-hand side of the matrix.

The values of this matrix were normalized (Table 4) and each column *j* of the pairwise comparison table (Tables 3 and 4) was multiplied by the weight of that column to obtain the weighted sum value (Table 5). By calculating the average of each row of the normalized pairwise comparison matrix, the normalized weight vectors (option weight vector) were obtained (Table 5). To verify the consistency of both the judgments attributed to the variables and the matrix itself, the maximum eigenvalue of the matrix was computed as the ratio between the weighted sum value and the option weight vector for each criterion (Table 5). Finally, Table 6 reports the percentage weight of each variable. The outputs obtained from the computer software, aimed at performing the FAHP, defined the global and local weights of each of the pedestrian characteristics under consideration.

Table 3 shows the outputs obtained from the matrix of the pairwise comparison between variables. This matrix has the characteristic of being symmetrical and diagonal — with respect to the main diagonal on the right of the table, the upper-right of the matrix contains scores for the triad of FAHP values defined by the panel of experts, in terms of values for row i with respect to column j. On the lower left, in contrast, the decision values of row j with respect to column i are shown, equal to the reciprocal of the values in the upper right.

Table 4 describes the matrix normalization process such that the sum of the elements is equal to 1. In particular, the table first shows the transformation of the triad of values into a single value by defining the centre of the area of each triad of values, which is useful for both normalizing them and defining the priority of each of the variables being considered.

To validate whether the matrix of the pairwise comparison is consistent or not, we try to "measure" whether the judgments defined by the panel of experts are consistent. For this verification, it is necessary to perform some intermediate steps, as shown in Table 5.

To define the coherence of the pairwise comparison matrix of the pairwise comparison, it is necessary to define the maximum eigenvalue of the matrix, λ_{max}, which is given by the average of the ratios between the weighted averages and the relative percentage weights.

Table 5 further outlines this relationship. In detail, the weighted averages are defined by multiplying each column j of the pairwise comparison (Table 3) by the weight relative to that column in order to define the weight sum value. The ratios between the weight sum values and weights and their averages define the maximum eigenvalue of the matrix. Having deduced this value, it was possible to define the overall consistency ratio and consistency index of this matrix, which confirmed the consistency of the judgments attributed.

Finally, Table 6 shows the ranking of the variables expressed in percentage terms.

The results obtained show the primary importance of characteristics linked to the sense of safety and protection during the walking experience for the elderly and, secondly, the characteristics of the urban context that are linked to the pleasantness and attractiveness of the pedestrian path, for example, due to the presence of street furniture that improves the degree of comfort during the journey.

4.3. Sensitivity analysis results

To ensure the reliability of the final weights of the input values (i.e. the FAHP scores), a series of sensitivity analyses were developed. As an example, of the 20 experiments undertaken, the weights of the pedestrian characteristics increased/decreased by 50% are reported, as these are the perturbations with the most significant weights. In particular, in the first four scenarios, the weights of variables such as “green areas”, “presence of panoramic points”, “bench” and “non-main roads” were increased by 50%, whereas, the “traffic lights” and “pedestrian crossings” variables were decreased by the same amount. These experiments were defined to also consider the rank of the FAHP scores, where three clusters of variables can be identified whose distances (between one group and another) are well defined (Table 7). The “comfort” cluster has such a high weight (over 20% compared to the others) that these values would remain the same size even if they vary; in contrast, the second and third groups, “street environment” and “amenity” have values far above and below 10%, respectively.

Figs. 5 and 6 report the results of the sensitivity analysis of the tests, showing that they do not differ much from the FAHP ranks. The weight values of the comfort variables’ cluster increased by three percentages in both the decreasing scenarios, whereas, they slightly decreased in the increasing scenarios. In all the increasing scenarios, the weights of the street environment variables’ cluster reduced by one percentage point (Fig. 5); however, not all features in the amenity variable cluster increased their values in the decreasing scenarios: both park bench and presence of panoramic points hold the same weights (Fig. 6). Finally, the presence of green areas and the presence of panoramic points are characterized by a higher decrease of weight (in the increasing scenarios) compared to the other two amenity variables (Fig. 5).

In summary, by observing these orders due to such changes, the first variable type is relatively insensitive to changes in weights. Therefore, it can be stated that the FAHP scores are consistent and reliable (Table 8).

4.4. Index of walking attractiveness results

The level of confidence attributed to the sensitivity analysis and FAHP findings allowed us to calculate the index of walking attractiveness of the pedestrian network, according to its physical characteristics.

More specifically, we linked the distance that an older adult has to walk to the pleasantness and the perceived safety during the walking experience and to the viability of a pedestrian path. This allowed us to not only classify the network but also highlight two key aspects: (i) identify the portions of the pedestrian network where improvements are required — these recommendations can be made based on the weights defined by the FAHP to improve both the individual characteristics considered and the overall usability and attractiveness (Fig. 7), and (ii) identify the “optimal” routes that currently possess all the qualities (characteristics) under consideration and that are already suitable for use by the elderly. Routes intended for pedestrian use only are also identified as suitable for the elderly using this approach.

In particular, the application of this approach to Naples highlights that the paths adjacent to the areas of Piazza Vanvitelli and Piazza Medaglie d’Oro (which can be identified as the “central areas” of the Vomero and Arenella districts, respectively) are suitable for elderly people, even if most of the pedestrian paths require improvement mostly in terms of the characteristics linked to the sense of safety and protection for the elderly. The pedestrian network of the first study area appears to be more “elderly” friendly than the other (Fig. 7). In fact, both in the area of the Rione Alto and the area adjacent to the hospital, the pedestrian paths require modifications for use by the elderly. Specifically, in the Arenella district, the only network links suitable for the elderly are Via Domenico Fontana and San Giacomo di Capri, both from the point of view of safety and of the urban context.

Furthermore, the Vomero district has paths intended only for pedestrians, whereas, these are entirely absent in the Rione Alto area. In addition, the pedestrian areas close to Piazza Vanvitelli, such as Via Scarlatti, have safety features and an urban context that make them pleasant to be walked by the elderly (e.g. pedestrian crossings, public lights and benches); in contrast, pedestrian paths such as Via Enrico Alvino, Piazzetta Arenella and Via Niccolò Piccinini do not present such urban context and safety characteristics, even though they are only pedestrian areas (Fig. 7).

In summary, the study area of Naples is characterized by better pedestrian accessibility in the Vomero district than the Arenella area due to gaps in the planning process. The Vomero area is characterized by a planned and unitary urban fabric compared to the Arenella area, which is characterized by an unplanned fabric, where little attention was paid to the linear elements (i.e. the roads) of the built environment, in particular, their arrangement both in terms of safety and comfort for pedestrian users.

The walkability index values were then related to the localization and distribution of services of interest for the elderly, in order to classify the study areas into the three levels of low, medium and high pedestrian attractiveness. Figs. 8–10 show how the affordability of reaching a service varies according to the safety and urban context characteristics of paths that are walkable (taking into account the physical characteristics given in Table 1).

The supply of economic (post office, banks, unions and municipal office) and health (pharmacies, poly-diagnostic centre and local health authority (ASL)) services is widespread in both districts of the study area, with economic urban facilities being more common (Figs. 8 and 9). Both types are distributed within the planned design urban fabrics, in particular along their main streets, such as via Alessandro Scarlatti and via Francesco de Mura in the Vomero neighbourhood and via Giulio Palermo and via Domenico Fontana in the Arenella neighbourhood. Nevertheless, the walking attractiveness for economic services is lower than that of health activities, as the paths of the pedestrian network that allow access to these economic services lack safety and urban context characteristics (Fig. 7).

In terms of cultural services (e.g. cinema, church, library), this type of facility is absent from the Arenella study area but is the most common type in Vomero. Compared to other recreational activities, such as commercial and leisure types, cultural services are not homogenously distributed in both neighbourhoods (Figs. 11 and 12). Cultural facilities are mainly concentrated near the Medaglie d’Oro and Vanvitelli squares, the latter of which has slightly better walkability attractiveness and characteristics of an age-friendly pedestrian network (Figs. 7 and 10). Other cultural services are located at the borders of the study area (along via Vincenzo Gemito), for example, commercial services (e.g. supermarkets) (Fig. 10); in some cases, these are characterized by high walkability attractiveness or suitability areas with strictly reduced dimensions (e.g. via Francesco Verrotti in Vomero district or via Giulio Palermo in the Arenella neighbourhood).

In line with the recreational activities, there is a lack of leisure facilities in both study areas (Fig. 12). The few unevenly distributed leisure services in the Vomero neighbourhood area are characterized by medium-low walkability attractiveness with suitable paths for the elderly, unlike the Arenella study area where the pedestrian routes do not correspond to the needs of the elderly.

The findings of this study show that to reach the main urban services, people over 65 have access to only short path areas that meet their physical, safety and urban context expectations, while almost the whole pedestrian network lacks them. As the low walkability attractiveness areas have high continuity, the high walkability attractiveness areas tend to be well separated; the low attractiveness represents a combination of not only the lack of security and urban furniture that would improve the comfort of the paths but also poor physical quality, such as inadequate pavement conditions. In fact, the high and the medium walkability attractiveness areas are often characterized by the presence of pedestrian-only streets that are suitable for the elderly by default.

5. Conclusions

Urban pedestrian accessibility has received increasing attention among both the scientific community and public administrations because of the consequences caused by the Covid-19 pandemic in all urban areas.

An improved understanding of service proximity and the surrounding network of open built spaces and streets can be an important tool to address issues raised within cities during the pandemic, such as the profound modifications of ways and times that city users have had undergo to organize their travel at both local and territorial levels (Delponte et al., 2020; Zecca et al., 2020).

In terms of the broader perspective of improving the safety and pleasantness of "active travel" (pedestrian and cycle paths), the Mobilage project aims to increase quality of life (in particular of those over 65) by improving pedestrian accessibility to urban services.

The results of this study allow the accessibility levels on a micro-scale to be defined through an integrated analysis of the distribution and location of urban services and the attractiveness of pedestrian paths. The further research steps described in this paper relate to a methodology integrating different multicriteria decision, statistical and GIS analysis types. This approach allows different levels of pedestrian accessibility to the main urban services to be defined by taking into account several characteristics of footpaths such as the sense of security perceived by the elderly in walking them, in addition to their usability and attractiveness.

The FAHP technique is significant for the analysis of spatial planning issues as it can effectively weight numerous urban characteristics influencing pedestrian accessibility to support complex decisions by planners and decision-makers, including competing criteria. The integration of this process with GIS techniques allowed a useful walkability index to be obtained to help achieve the project's aims of social inclusion and ageing friendliness.

Using these innovative research tools, our results highlight the portions of the municipal area to be prioritized, including areas where it is possible to increase the levels of safety and attractiveness of a route in relation to access to urban services. Considering integrated actions between urban services in terms of both their localization and distribution and neighbouring pedestrian paths is an element that contributes to increased urban accessibility (Gargiulo et al., 2018; Koohsari et al., 2018). According to Fancello et al. (2020) "understanding how space and the environment influence citizens' preferences and values is a fundamental step to achieve spatial and social justice in the access to urban opportunities".

In addition, the range of possible actions and improvements, defined on the attractiveness and safety of a path and the distribution and localization of urban services, constitute a future development aim for this research; our approach also represents a support tool for local decision-makers which aims to integrate multiple criteria to improve the quality of life of the elderly population and reduce their social exclusion.

However, it is important to also recognise the limitations of this study. The primary issue is the direct distribution of a questionnaire on access for the elderly; while useful for defining the preferences and choices of these users in choosing one path over another, the set of characteristics under investigation of the pedestrian paths and the built environment was somewhat limited. This was a result of the characteristics precisely relating to specific links of the pedestrian network since there are no specific datasets at a local level affecting the definition of the weights. In turn, future versions of the walkability index could take into account a wider set of characteristics in relation to the distance an elderly person should travel.

CRediT authorship contribution statement

Federica Gaglione wrote sections 3.1, 3.3, 4.2; Carmela Gargiulo wrote sections 3, 3.4, 4.1 and 5; Floriana Zucaro wrote sections 3.2, 4.3 and 4.4; all the atuhors contributed to sections 1 and 2.

Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of competing interest

The authors declare that they have no competing interests.

Acknowledgements

None.

References

Abley, S. (2005). *Walkability scoping paper*. New Zealand: Christchurch.

Alidoust, S., Bosman, C., & Holden, G. (2018). Talking while walking: An investigation of perceived neighbourhood walkability and its implications for the social life of older people. *Journal of Housing and the Built Environment, 33*(1), 133–150. https://doi.org/10.1007/s10901-017-9558-1

Allen, J., & Farber, S. (2020). Planning transport for social inclusion: An accessibility-activity participation approach. *Transportation Research Part D: Transport and Environment, 78*, Article 102212. https://doi.org/10.1016/j.trd.2019.102212

Anciaes, P. R., Nascimento, J., & Silva, S. (2017). The distribution of walkability in an African city: Praia, Cabo Verde. *Cities, 67*, 9–20. https://doi.org/10.1016/j.cities.2017.04.008

Arce, M. E., Saavedra, Á., Míguez, J. L., & Granada, E. (2015). The use of grey-based methods in multi-criteria decision analysis for the evaluation of sustainable energy systems: A review. *Renewable and Sustainable Energy Reviews, 47*, 924–932. https://doi.org/10.1016/j.rser.2015.03.010

Balusa, B. C., & Gorai, A. K. (2019). Sensitivity analysis of fuzzy-analytic hierarchical process (FAHP) decision-making model in selection of underground metal mining method. *Journal of Sustainable Mining, 18*(1), 8–17. ISO 690 10.46873/2300-3960.1069.

Barton, H., Grant, M., & Guise, R. (2003). *Shaping neighbourhoods: A guide for health, sustainability and vitality*. New York: Spoon Press.

Bivina, G. R., Gupta, A., & Parida, M. (2019). Influence of microscale environmental factors on perceived walk accessibility to metro stations. *Transportation Research Part D: Transport and Environment, 67*, 142–155. https://doi.org/10.1016/j.trd.2018.11.007

Bivina, G. R., & Parida, M. (2019). Prioritizing pedestrian needs using a multi-criteria decision approach for a sustainable built environment in the Indian context. *Environment, Development and Sustainability, 1–22*. https://doi.org/10.1007/s10668-019-00381-w

Borst, H. C., Miedema, H. M. E., de Vries, S. I., Graham, J. M. A., & van Dongen, J. E. F. (2008). Relationships between street characteristics and perceived attractiveness for walking reported by elderly people. *Journal of Environmental Psychology, 28*, 353–361. https://doi.org/10.1016/j.jenvp.2008.02.010

Brookfield, K., & Tilley, S. (2016). Using virtual street audits to understand the walkability of older adults' route choices by gender and age. *International Journal of Environmental Research and Public Health, 13*(11), 1061. https://doi.org/10.3390/ijerph13111061

Brugha, C. M. (2004). Structure of multi-criteria decision-making. *Journal of the Operational Research Society, 55*(11), 1156–1168. https://doi.org/10.1057/palgrave.jors.2601777

Buckley, J. J. (1985). Ranking alternatives using fuzzy numbers. *Fuzzy Sets and Systems, 15*(1), 21–31. https://doi.org/10.1016/0165-0114(85)90013-2

Carnegie, M. A., Bauman, A., Marshall, A. L., Mohsin, M., Westley-Wise, V., & Booth, M. L. (2002). Perceptions of the physical environment, stage of change for physical activity and walking among Australian adults. *Research Quarterly for Exercise and Sport, 73*, 146–155. https://doi.org/10.1080/02701367.2002.10609003

Cepeda, M., Schoufour, J., Freak-Poli, R., Koolhaas, C. M., Dhana, K., Bramer, W. M., & Franco, O. H. (2017). Levels of ambient air pollution according to mode of transport: A systematic review. *The Lancet Public Health, 2*(1), e23–e34. https://doi.org/10.1016/S2468-2667(16)30021-4

Cerin, E., Macfarlane, D. J., Ko, H. H., & Chan, K. C. A. (2007). Measuring perceived neighbourhood walkability in Hong Kong. *Cities, 24*(3), 209–217. https://doi.org/10.1016/j.cities.2006.12.002

Chandio, I. A., Matori, A. N. B., WanYusof, K. B., et al. (2013). GIS-based analytic hierarchy process as a multicriteria decision analysis instrument: A review. *Arabian Journal of Geosciences, 6*(8), 3059–3066. https://doi.org/10.1007/s12517-012-0568-8

Chang, D. Y. (1996). Applications of the extent analysis method on fuzzy AHP. *European Journal of Operational Research, 95*(3), 649–655.

Cheng, L., Chen, X., Yang, S., Cao, Z., De Vos, J., & Witlox, F. (2019). Active travel for active ageing in China: The role of built environment. *Journal of Transport Geography, 76*, 142–152. https://doi.org/10.1016/j.jtrangeo.2019.03.010

Chu, N. S. (2017). Walkability and accessibility: Users' perspectives of a planned neighborhood. Retrieved from: https://dc.uwm.edu/etd/1455/. Thesis dissertation.

Cottrill, C., Gaglione, F., Gargiulo, C., & Zucaro, F. (2020). Defining the characteristics of walking paths to promote an active ageing. In *Pedestrians, urban spaces and health:*

Proceedings of the XXIV International Conference on Living and Walking in Cities (pp. 209–213).

Deehr, R. C., & Shumann, A. (2009). Active Seattle: Achieving walkability in diverse neighborhoods. *American Journal of Preventive Medicine, 37*(6), S403–S411.

D'Orso, G., & Migliore, M. (2020). A GIS-based method for evaluating the walkability of a pedestrian environment and prioritised investments. *Journal of Transport Geography, 82*, Article 102555. https://doi.org/10.1016/j.jtrangeo.2019.102555

El Gibari, S., Gómez, T., & Ruiz, F. (2019). Building composite indicators using multicriteria methods: A review. *Journal of Business Economics, 89*(1), 1–24. https://doi.org/10.1007/s11573-018-0902-z

Evans, G. (2009). Accessibility, urban design and the whole journey environment. *Built Environment, 35*(3), 366–385. https://doi.org/10.2148/benv.35.3.366

Ewing, R., & Cervero, R. (2010). Travel and the built environment: A meta-analysis. *Journal of the American Planning Association, 76*, 265–294. https://doi.org/10.1080/01944361003766766

Forsyth, A., & Southworth, M. (2008). Cities afoot—Pedestrians, walkability and urban design. *Journal of Urban Design, 13*(1), 1–3. https://doi.org/10.1080/13574800701816896

Fancello, G., Congiu, T., & Tsoukiàs, A. (2020). Mapping walkability.A subjective value theory approach. *Socio-Economic Planning Sciences*. https://doi.org/10.1016/j.seps.2020.100923

Furukawa, H., & Wang, Z. (2019, March). A route evaluation method considering the subjective evaluation on walkability, safety, and pleasantness by elderly pedestrians. In *International Conference on E-Business and Telecommunications* (pp. 408–416). Switzerland: Springer, Cham.

Ga, U. (2015). *Transforming our world: The 2030 Agenda for Sustainable Development*. USA: Division for Sustainable Development Goals.

Gargiulo, C., Zucaro, F., & Gaglione, F. (2018). A set of variables for the elderly accessibility in urban areas. *TEMA Journal of Land Use, Mobility and Environment, 53-66*. https://doi.org/10.6092/1970-9870/5738

Gaglione, F., Gargiulo, C., & Zucaro, F. (2019). Elders' quality of life. A method to optimize pedestrian accessibility to urban services. *TEMA Journal of Land Use, Mobility and Environment, 12*(3), 295–312. https://doi.org/10.6092/1970-9870/6272

Gaglione, F., Cottrill, C., & Gargiulo, C. (2021). Urban services, pedestrian networks and behaviors to measure elderly accessibility. *Transportation Research Part D: Transport and Environment, 90*, Article 102687. https://doi.org/10.1016/j.trd.2020.102687

Gharaveis, A. (2020). A systematic framework for understanding environmental design influences on physical activity in the elderly population. *Facilities*. https://doi.org/10.1108/F-08-2018-0094

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

Haugen, K. (2011). The advantage of 'near': Which accessibilities matter to whom? *European Journal of Transport and Infrastructure Research (EJTIR), 11*(4), 368–388. https://doi.org/10.18757/ejtir.2011.11.4.2941

Herva, M., & Roca, E. (2013). Review of combined approaches and multi-criteria analysis for corporate environmental evaluation. *Journal of Cleaner Production, 39*, 355–371. https://doi.org/10.1016/j.jclepro.2012.07.058

Hillsdon, M., Panter, J., Foster, C., & Jones, A. (2006). The relationship between access and quality of urban green space with population physical activity. *Public Health, 120*, 1127–1132. https://doi.org/10.1016/j.puhe.2006.10.007

Howell, N. A., Tu, J. V., Moineddin, R., Chen, H., Chu, A., Hystad, P., & Booth, G. L. (2019). Interaction between neighborhood walkability and traffic-related air pollution on hypertension and diabetes: The CANHEART cohort. *Environment International, 132*, Article 104799. https://doi.org/10.1016/j.envint.2019.04.070

Jacobs-Crisioni, C., Kucas, A., Lavalle, C., Ahrend, R., & Lembcke, A. C. (2019). *Ageing in regions and cities: High resolution projections for Europe in 2030. EUR 30032 EN*. Luxembourg: Publications Office of the European Union, 2020, ISBN 978-92-76-14649-0.

Joo, Y. J., & Kim, S. H. (2011). A new route guidance method considering pedestrian level of service using multi-criteria decision making technique. *Spatial Information Research, 19*(1), 83–91.

Kinsella, K., & He, W. (2009). *An aging world: 2008. US Census Bureau. International population reports (P95/09-1)*. US Gov Printing Office.

Koohsari, M. J., Nakaya, T., & Oka, K. (2018). Activity-friendly built environments in a super-aged society, Japan: Current challenges and toward a research agenda. *International Journal of Environmental Research and Public Health, 15*(9), 2054. https://doi.org/10.3390/ijerph15092054

Laarhoven, P. J. M., & Pedrycz, W. (1983). A fuzzy extension of Saaty's priority theory. *Fuzzy Sets and Systems, 11*, 229–241.

Lee, H. S., & Park, E. Y. (2014). Comparing the environment for elderly pedestrians among different-sized cities of Gyeonggi province in Korea. *International Journal of Urban Sciences, 18*(1), 76–89. https://doi.org/10.1080/12265934.2013.863449

Leslie, E., Saelens, B., Frank, L., Owen, N., Bauman, A., Coffee, N., & Hugo, G. (2005). Residents' perceptions of walkability attributes in objectively different neighbourhoods: A pilot study. *Health & Place, 11*(3), 227–236. https://doi.org/10.1016/j.healthplace.2004.05.005

Liao, B., EW van den Berg, P., van Wesemael, P. J., & A Arentze, T. (2020). How does walkability change behavior? A comparison between different age groups in the Netherlands. *International Journal of Environmental Research and Public Health, 17*(2), 540. https://doi.org/10.3390/ijerph17020540

Litman, T. A. (2017). *Economic value of walkability*. Canada: Victoria Transport Policy Institute.

Mahmood, A., Chaudhury, H., Michael, Y. L., Campo, M., Hay, K., & Sarte, A. (2012). A photovoice documentation of the role of neighborhood physical and social environments in older adults' physical activity in two metropolitan areas in North America. *Soc. Sci. Med., 74*, 1180–1192. https://doi.org/10.1016/j.socscimed.2011.12.039

Moon, M., Lee, Y., Yu, K., & Kim, J. (2016). Optimized path finding algorithm for walking convenience of the people with reduced mobility. *Journal of the Korean Society of Surveying, Geodesy, Photogrammetry and Cartography, 34*(3), 273–282. ISSN: 1598-4850.

Moura, F., Cambra, P., & Gonçalves, A. (2014). IAAPE–pedestrian accessibility and attractiveness assessment tool when planning for walkability. Retrieved from. In *Joint Conference CITTA 7th Annual Conference COST TU1002 Final Conference Bridging the Implementation Gap of Accessibility Instruments and Planning Support Systems* https://pdfs.semanticscholar.org/4c13/.

Oguztimur, S. (2011). Why fuzzy analytic hierarchy process approach for transport problems?. In *Proceedings of 51st Congress of the European Regional Science Association New Challenges for European Regions and Urban Areas in a Globalised World, Barcellona*.

Oswald Beiler, M. R., & Phillips, B. (2015). Prioritizing pedestrian corridors using walkability performance metrics and decision analysis. *Journal of Urban Planning and Development, 142*(1), 04015009. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000290

Özdağoğlu, A., & Özdağoğlu, G. (2007). In *Comparison of AHP and fuzzy AHP for the multi-criteria decision making processes with linguistic evaluations* (pp. 65–85). Retrieved from: https://www.ticaret.edu.tr/uploads/Kutuphane/dergi/f11/M00178.pdf.

Pafka, E., & Dovey, K. (2017). Permeability and interface catchment: Measuring and mapping walkable access. *Journal of Urbanism: International Research on Placemaking and Urban Sustainability, 10*, 150–162. https://doi.org/10.1080/17549175.2016.1220413

Podvezko, V. (2009). Application of AHP technique. *Journal of Business Economics and Management, 10*(2), 181–189. https://doi.org/10.3846/1611-1699.2009.10.181-189

Pohekar, S. D., & Ramachandran, M. (2004). Application of multi-criteria decision making to sustainable energy planning—A review. *Renewable and Sustainable Energy Reviews, 8*(4), 365–381. https://doi.org/10.1016/j.rser.2003.12.007

Rowe, W. R. (1994). Understanding uncertainty. *Risk Analysis, 14*(5), 743–750. https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1539-6924.1994.tb00284.x.

Ruiz-Padillo, A., Pasqual, F. M., Uriarte, A. M. L., & Cybis, H. B. B. (2018). Application of multi-criteria decision analysis methods for assessing walkability: A case study in Porto Alegre, Brazil. *Transportation Research Part D: Transport and Environment, 63*, 855–871. https://doi.org/10.1016/j.trd.2018.07.016

Saaty, T. L. (1980). *The analytic hierarchy process*. New York: McGraw Hill.

Saaty, R. W. (2003). *Decision making in complex environment: The analytic hierarchy process (AHP) for decision making and the analytic network process (ANP) for decision making with dependence and feedback*. Pittsburgh: Super Decisions. ISBN: 1-888603-00-3.

Saelens, B. E., & Handy, S. L. (2008). Built environment correlates of walking: A review. *Medicine and Science in Sports and Exercise, 40*(7 Suppl), 550. https://doi.org/10.1249/MSS.0b013e31817c67a4

Saghapour, T., Moridpour, S., & Thompson, R. G. (2016). Public transport accessibility in metropolitan areas: A new approach incorporating population density. *Journal of Transport Geography, 54*, 273–285. https://doi.org/10.1016/j.jtrangeo.2016.06.019

Sayyadi, G., & Awasthi, A. (2012). AHP-based approach for location planning of pedestrian zones: Application in Montréal,Canada. *Journal of Transportation Engineering, 139*(2), 239–246. https://doi.org/10.1061/(ASCE)TE.1943-5436.0000493

Shafabakhsh, G., Mirzanamadi, R., & Mohammadi, M. (2015). Pedestrians' mental satisfaction's relationship with physical characteristics on sidewalks using analytical hierarchy process: Case study of Tehran,Iran. *Transportation Letters, 7*(3), 121–132. https://doi.org/10.1179/1942787514Y.0000000039

Shahbod, N., Bayat, M., Mansouri, N., Nouri, J., & Ghodousi, J. (2020). Application of Delphi method and fuzzy analytic hierarchy process in modeling environmental performance assessment in urban medical centers. *Environmental Energy and Economic Research, 4*(1), 43–56. https://doi.org/10.22097/eeer.2020.197686.1103

Shatu, F., & Yigitcanlar, T. (2018). Development and validity of a virtual street walkability audit tool for pedestrian route choice analysis—SWATCH. *Journal of Transport Geography, 70*, 148–160. https://doi.org/10.1016/j.jtrangeo.2018.06.004

Skulmoski, G. J., Hartman, F. T., & Krahn, J. (2007). The Delphi method for graduate research. *The Journal of Information Technology Education, 6*(1), 1–21. https://doi.org/10.28945/199

Simoes, A., & Marin-Lamellet, C. (2002). Road users who are elderly: Drivers and pedestrians. In R. Fuller, & J. A. Santos (Eds.), *Human factors for highway engineers*. Amsterdam: Pergamon. https://doi.org/10.1016/B978-008043412-4/50019-9.

Spittaels, H., Verloigne, M., Gidlow, C., Gloanec, J., Titze, S., Foster, C., … De Bourdeaudhuij, I. (2010). Measuring physical activity-related environmental factors: Reliability and predictive validity of the European environmental questionnaire ALPHA. *International Journal of Behavioral Nutrition and Physical Activity, 7*(1), 1–19. https://doi.org/10.1186/1479-5868-7-48

Stafford, L., & Baldwin, C. (2017). Planning walkable neighborhoods. *Journal of Planning Literature, 33*(1), 17–30. https://doi.org/10.1177/0885412217704649

Stathi, A., Gilbert, H., Fox, K. R., Coulson, J., Davis, M., & Thompson, J. L. (2012). Determinants of neighbourhood activity of adults age 70 and over: A mixed-methods study. *Journal of Aging Physic. Act., 20*, 148–170. https://doi.org/10.1123/japa.20.2.148

Sun, G., Webster, C., & Zhang, X. (2019). Connecting the city: A three-dimensional pedestrian network of Hong Kong. *Environment and Planning B: Urban Analytics and City Science.* , Article 2399808319847204. https://doi.org/10.1177/2399808319847204

Tribby, C. P., Miller, H. J., Brown, B. B., Werner, C. M., & Smith, K. R. (2016). Assessing built environment walkability using activity-space summary measures. *Journal of Transport and Land Use, 9*(1), 187. https://doi.org/10.5198/jtlu.2015.625

Tsai, H. Y., Chang, C. W., & Lin, H. L. (2010). Fuzzy hierarchy sensitive with Delphi method to evaluate hospital organization performance. *Expert Systems with Applications, 37*(8), 5533–5541. https://doi.org/10.1016/j.eswa.2010.02.099

Ujang, N. (2013). Pedestrian satisfaction with aesthetic, attractiveness and pleasurability: Evaluating the walkability of Chaharaghabbasi Street in Isfahan,Iran. *ALAM CIPTA, International Journal of Sustainable Tropical Design Research and Practice, 6*(2), 13–22.

United Nations Population Division. (2017). *World population prospects: The 2017 revision—Key findings and advance tables; working paper no. ESA/P/WP/248*. New York, NY, USA: United Nations Population Division.

Wang, Y., Chau, C. K., Ng, W. Y., & Leung, T. M. (2016). A review on the effects of physical built environment attributes on enhancing walking and cycling activity levels within residential neighborhoods. *Cities, 50*, 1–15. https://doi.org/10.1016/j.cities.2015.08.004

Wang, H., Kwan, M. P., & Hu, M. (2020). Social exclusion and accessibility among low- and non-low-income groups: A case study of Nanjing,China. *Cities, 101*, Article 102684. https://doi.org/10.1016/j.cities.2020.102684

Wang, H., & Yang, Y. (2019). Neighbourhood walkability: A review and bibliometric analysis. *Cities, 93*, 43–61. https://doi.org/10.1016/j.cities.2019.04.015

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

WHO - World Health Organization. (2002). *Active ageing: A policy framework*. Geneva: World Health Organization.

WHO - World Health Organization. (2007). *Global age-friendly cities: A guide*. France: WHO.

Wittowsky, D., van der Vlugt, A. L., & Nadler, R. (2019). *Editorial–accessibility: Its role in the sustainable transformation of cities*. https://doi.org/10.1080/23800127.2019.1609389

Yamagata, Y., Murakami, D., & Yoshida, T. (2020). Evaluating walkability using mobile GPS data. In *Spatial analysis using Big Data* (pp. 239–257). Academic Press.

Yedla, S., & Shrestha, R. M. (2003). Multi-criteria approach for the selection of alternative options for environmentally sustainable transport system in Delhi. *Transportation Research Part A: Policy and Practice, 37*(8), 717–729. https://doi.org/10.1016/S0965-8564(03)00027-2

Yigitcanlar, T., Sipe, N., Evans, R., & Pitot, M. (2007). A GIS-based land use and public transport accessibility indexing model. *Australian Planner, 44*(3), 30–37. https://doi.org/10.1080/07293682.2007.9982586

Zecca, C., Gaglione, F., Laing, R., & Gargiulo, C. (2020). Pedestrian routes and accessibility to urban services: An urban rhythmic analysis on people's behaviour before and during the COVID-19. *TEMA Journal of Land Use, Mobility and Environment, 13*(2). https://doi.org/10.6092/1970-9870/7051

Zhang, X., & Mu, L. (2020). Incorporating online survey and social media data into a GIS analysis for measuring walkability. In *Geospatial technologies for urban health* (pp. 133–155). Switzerland: Springer, Cham. https://doi.org/10.1007/978-3-030-19573-1_8.