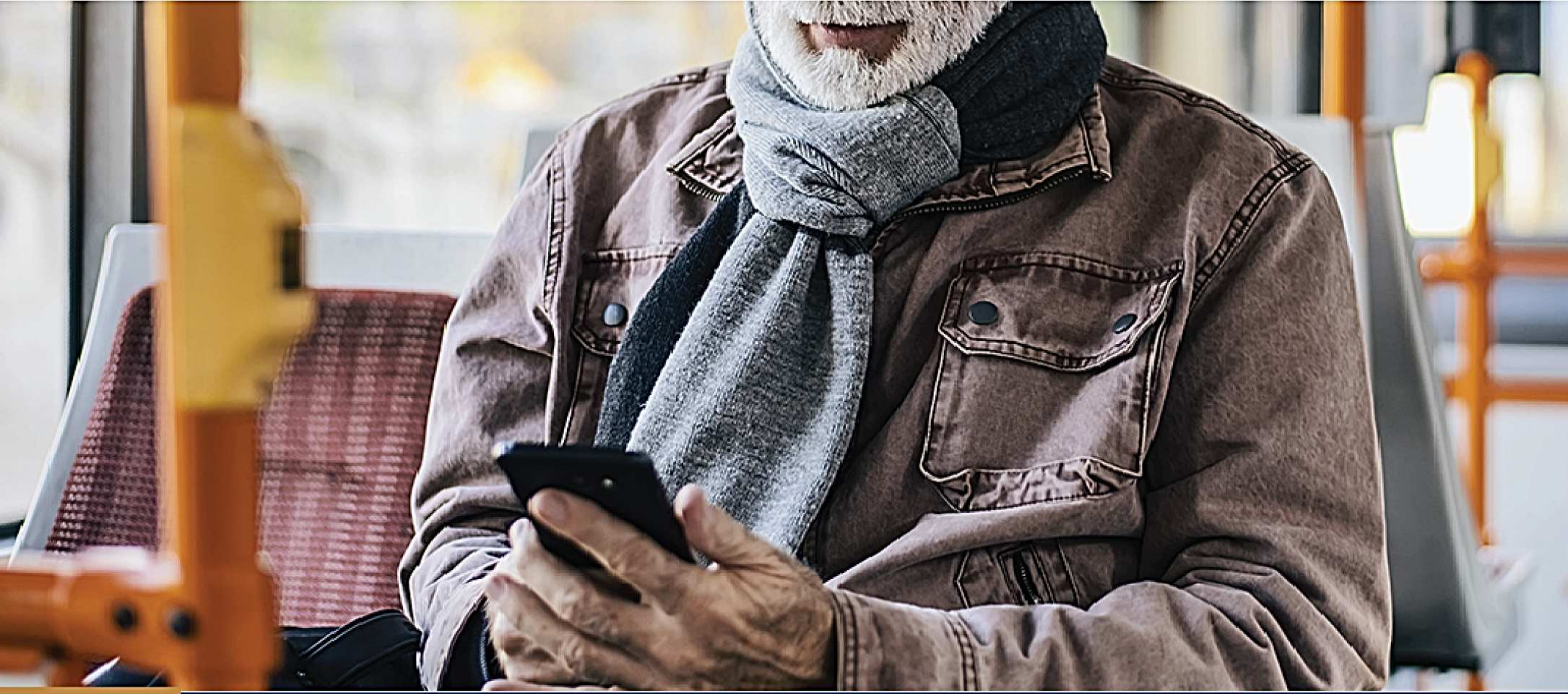

Ph.D. Thesis in **Civil Systems Engineering XXXIV cycle**

Ageing in cities
Innovative accessibility-oriented tools to limit age inequalities in urban environment

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Department of Civil, Building and Environmental Engineering

Ph.D. Program in Civil Engineering Systems
XXXIV cycle

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CHAPTER 1. THE RESEARCH PROJECT

1.1 Introduction

The ageing of the world population is undeniably one of the most demanding economic and social challenges that have ever been faced in human history. It is expected to have significant impacts on employment, education, and health (Arup, 2019). In the European Union at the beginning of 2016, the population over 65 was 19%, 2.4% more than in 2006. According to some projections, this trend will accelerate in the coming years, until the share of older adults reaches 30% of the world population in 2080 (European Commission – EU, 2019; Istituto Nazionale di Statistica - ISTAT, 2020).

This phenomenon, combined with a substantial increase in infertility rates and a decline in births, will lead to a radical demographic change. Cities will inevitably suffer from this change due to their complex structure and the high rate of human activity of both digital and physical environments (Alidoust et al., 2014; Arup, 2015; Gargiulo et al., 2021). Hence, the consequences in urban areas might be amplified: the elderly population residing in cities will increasingly suffer from limited participation in decision-making processes, from poor accessibility to urban services, such as healthcare facilities and local public transport, due to the presence of barriers and obstacles to public spaces, and poor health because of pollution and a sedentary lifestyle (Lee K. & Park, 2006; Gargiulo et al., 2018). Bearing this in mind, the question this research wants to answer is: how to improve the quality of life of the elderly population in cities?

Urban environments have faced multiple challenges in recent decades: industrial revolutions, economic crises, the advent of new forms of mobility, climate change, and not least the outbreak of a new coronavirus and its consequent disease, Covid-19 (Verma & Raghubanshi, 2018; Lee V. et al., 2020; Marvuglia et al., 2020). The sequence of these phenomena has led to a significant change in the original structure of the cities. Hence, the city of the 21st century is no longer the organization of the socio-anthropic system and its activities (functional system) on a specific surface (territorial or geomorphological system).

The spread of new transport technologies (especially private transportation modes) and mobile devices, economic and financial events, global capitalism and the birth of the Internet have unquestionably contributed to changing the management and governance of urban environments (Papa E. & Bertolini, 2015; Papa E., 2021). These outstanding infrastructural, social, and economic changes have resulted in an extension of metropolitan areas, with the disorderly and uncontrolled spread (commonly referred to as urban sprawl) of human activities on the territory, especially in the peripheral areas (Mehriar et al., 2020).

The standard tools and planning processes for managing urban and territorial transformations have not taken into account the accessibility to essential services, such as sites of interest and workplaces, as a driving force for designing more equal cities (Papa E. et al., 2016). Policy-makers and stakeholders paid inadequate attention to this critical issue for developing infrastructures, services and activities of urban environments. Moreover, accessibility has often been studied as a problem to be solved within the transport system domain, and not as a matter influenced by other aspects (for instance, by the location and distribution of available resources on the territory) (Metz, 2008; Banister, 2019).

All this has had highly impacting consequences for both the physical and functional subsystems. Some activities, such as education or infancy care systems, are still chosen based on proximity attributes. Many others, such as general services (distribution and commercial centres, healthcare and sports facilities), must be located outside urban centres because of great potential attractiveness in terms of flows. Hence, large distribution centres are replacing small family-run businesses and places outside the administrative boundaries of the municipalities are becoming production units, logistic and commercial hubs, and therefore great economic attractors (Spickermann et al., 2014). The consequences of these phenomena on the entire urban system are significant and have powerful impacts on user behaviour and perceived quality of life, especially for those who live outside the city centre.

Within this framework, mobility represents an indispensable condition of access to goods, services, and activities. It can make the difference between users who have tools, opportunities and capabilities to move around and those trapped in increasingly marginal places (Zhao, 2010).

However, the relationship between mobility and accessibility is not as straightforward as it may seem since accessibility does not only correspond to the possibility of reaching more opportunities but also to the ability to access the repertoire of activities and places, according to personal expectations. In this regard, the concept of *mobility capital* has found a wide following among scientific literature, both in social sciences and urban and transport planning. Mobility capital has replaced the usual mobility paradigm in order to take into account the available resources and the constraints of access to services and products. According to this approach, mobility represents a resource for action available to citizens to achieve their personal goals. Like other forms of capital, mobility capital is heterogeneously distributed in society. A lack of resources and capabilities may be a potential form of social and spatial exclusion. On the other hand, high levels of mobility capital may be a symptom of forced mobility, which requires high personal and social costs (pollution, congestion, road safety, etc.). In this context, it can be easily imagined how the near future cities will increasingly suffer from social inequalities, as the population over 65 is constantly growing.

The World Health Organization (WHO, 2018) states that the global share of older adults will double from 11% (2011) to 22% in 2050. For the first time in human history, the over 65s will exceed those under 15 years old due to longer life expectancies and lower birth rates.

Furthermore, older people contribute in different ways to the life of their families and the communities where they reside. Years of extra and healthy life allow seniors to pursue more activities, such as a new career or education, or indulge in long-neglected passions. However, the perceived accessibility to these opportunities strongly depends on a single factor: health. In fact, as people age, people inevitably become weaker due to hearing loss, sight problems, back and neck pain, chronic lung diseases, diabetes, depression, senile dementia, which can affect the mobility of the elderly, with instability, inability to move by car, etc. However, a large body of academic and grey literature supports that older people are healthier than previous generations. This is primarily due to improvements in nutrition, health and medical care. However, the quality of ageing involves several factors, such as genetics, socio-economic status, culture, and healthcare services. Hence, growing old is still associated with greater vulnerability.

Policymakers and urban planners have to work in order to bring cities closer to the needs of the elderly population. Moreover, transforming cities into age-friendly environments is as necessary as logical to promote the well-being of elderly citizens and ensure the city is active and alive. Urban areas must prepare to change their shape and structure to be accessible and inclusive, taking into account and respecting the different needs and capacities of the over 65 population.

The spread of the new coronavirus and the consequent pandemic have raised further challenges and emergencies with undeniable impacts on urban life due to the high density of population, services and activities, which act as multipliers of the epidemic's effects (De Falco, 2018). Local and national authorities have worked (and are still working) to strengthen the health system, prevent new peaks of the epidemiological curve, and ensure efficient and effective vaccination campaigns. At the same time, they strive to improve the resilience of urban areas to limit economic and social problems in the medium and long term. In fact, in the management of any health crisis, cities must fulfil two fundamental functions: to guarantee health care with a sudden and increasing number of sick people and to preserve the social life of the city for all citizens (WHO, 2008), especially for the weakest, like the elderly. These actions are needed to offer all citizens adequate health and social assistance, especially in emergency conditions. Epidemiological data have dramatically shown how much, among adult people, the risk of becoming seriously ill from Covid-19 infection increases with age. The population over 65 is the most at risk—considering the data relating to infections and deaths, the probability of getting seriously ill increases with age. Furthermore, for the European context, 8 out of 10 deaths related to Covid-19 were recorded among adults over 65 (Carpentieri et al., 2020). Because of the ongoing pandemic, in an age-friendly city the contribution of the elderly population to an active social life should be further protected, with both material and immaterial actions.

Many academic researchers have developed methodologies to measure urban accessibility to essential services from the elderly perspective. Thus, decision-making hardly considers these spatial methods for the governance of territorial transformations aimed at improving the quality of life in all spheres of urban society. Common territorial governance practices lack a holistic and integrated approach involving all interested actors and stakeholders to locate, design and ultimately provide available services on the territory (UK Social Exclusion Unit, 2003).

The research project aims to design a holistic methodology to assess urban accessibility to essential services from the perspective of people aged 65 and over. In the light of the existing hiatus between policy-making and academic results, the second aim of the research is to integrate the methodology into innovative, technological and user-friendly tools to support decision-makers, stakeholders and users.

This thesis represents a concluding product of a Ph.D. executive programme in Civil Systems Engineering that has been funded by PON Ricerca e Innovazione 2014-2020 - Asse I "Investimenti in capitale umano" of the Italian Ministry of Education, University and Research (MIUR – Minitero dell'Istruzione, dell'Università e della Ricerca), with D.D. 4th May 2018, n.1090. The research has been developed in partnership with the Département de Géographie of the Universitè Cöte-d-Azur (Nice, France) and Energent S.p.A., an IT company based in Rome (Italy). The synergy among the involved partners made the fulfilment of each research ambition possible.

1.2 Aim and Goals

The research aims to define innovative methods and tools for supporting decisions relating to territorial and urban transformations in order to prepare cities for the challenge of demographic change in terms of their physical and spatial management.

The evolution of the research was supported by two partners, one academic, the Department of Geography of the Université Côte-d-Azur in Nice (France), and one industrial, Energent S.p.A., based in Rome (Italy). The work with the French unit delved into the available modelling tools of the territory, such as Geographic Information Systems (GIS), to support the definition of the architecture of the IT products, which were developed with the support of Energent S.p.A., that contributed to the engineerization process of scientific results. The theoretical knowledge, programming skills and a holistic approach led the work to both methodological and applicative results.

In this way, the research project of the Ph.D. program aimed at covering the existing gap between scientific results and urban planning practice. The research was driven by the theoretical and methodological knowledge disseminated in the scientific literature in order to design and then develop:

- an accessibility assessment M2SFCA (Multimodal 2 Steps Floating Catchment Area) methodology to measure the level of accessibility to essential urban services, taking into account the mobility capital of older people, location and distribution of facilities and their resources and urban features;
- a Research to Business (R2B) tool, a WebGIS that will allow the interaction, through the internet, of the cartography and the data associated with it, to know the accessibility to urban services perceived by people aged 65 and over, in the current state and to provide a ranking of the most effective interventions;
- a Research to Users (R2U) tool configured as an elderly-friendly virtual assistant designed to improve accessibility to essential urban services and, in general, improve the quality of life by integrating more functionality into a single mobile application.

1.3 Research steps and themes

The research was structured into three macro phases. The first two were developed in partnership with the Universitè Cöte-d-Azur. In contrast, the last one was carried out in co-operation with the industrial partner Energent S.p.A. Although the Covid-19 pandemic considerably limited to performing the foreseen activities on site (respectively in Nice and Rome), each phase was fully completed using telematic communication and smart-working modes. The main work phases carried out during the Ph.D. are listed and described below:

Phase 1) **State of the Art:** I performed a systematic review of the research problem in scientific literature and urban accessibility evaluation methodologies, as well as available technological and innovative urban planning tools. Chapters 2 and 3 present the main results of this first research phase;

Phase 2) **Methodology & Applications:** Once the gap in scientific literature, academic knowledge, and urban planning practice is defined, a GIS-based methodology to measure urban accessibility to essential services has been designed. Three applications were carried out (Naples, Milan and Nice), contributing to testing, improving, and validating the methodology. Chapters 4 and 5 describe this second iterative phase;

Phase 3) **Engineering products:** The last phase was dedicated to the engineering and development of technological products, based on the main results of previous phases.

1.4 Significative contents

This research project proposes some innovations, both methodological and analytical-applicative.

The most significant element of innovation, concerning the scientific and academic sector, refers to the opportunities that can arise from the use of new digital technologies to improve ordinary urban planning tools.

Within the debate on Smart Cities and Smart Communities, the critical role played by technology is well-recognized. The integration of such technologies assumes that both public administrators and citizens can use and compete through big data and digital technologies. Unfortunately, this claim is hardly ever valid, especially for older adults, often defined as digital illiterates.

Furthermore, a city's competitiveness is measured not only through the provision of infrastructures and services but also by the availability of reliable information and the ability to communicate with city users, both digital natives o technologically illiterate, active subjects or traditionally excluded people.

The commitment of the research project is the definition of new tools for the accessibility-oriented government of urban transformations. Based on reliable scientific knowledge, these open-source tools can innovate and optimise this process and forcefully become part of the consolidated urban planning process.

A further element of innovation of the research is the attempt to overcome the barriers between different disciplinary sectors that currently limit understanding the complex factors that influence ageing conditions in contemporary cities. Therefore, the debate on social studies of ageing in Italy and Europe can benefit from the integrated approach that this project intended to develop integrating the spatial dimension and the problems of mobility as relevant factors that influence the accessibility to services and, hence, the quality of life of older adults.

Finally, the GIS-based automation platforms that have been developed with the industrial partner represent innovations also in the panorama of ICTs applications in the Smart Living and Smart Mobility sector.

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CHAPTER 2. THE INCREASE OF AGE INEQUALITIES TO ACCESS TO ESSENTIAL SERVICES IN URBAN AREAS

2.1 Introduction

Population ageing is one of humanity's greatest triumphs. On the other hand, it is also one of our greatest challenges. Global ageing, as well as increasing urbanism, are breaking economic and social grounds in all countries. At the same time, older people are a precious resource that makes an essential contribution to the fabric of our societies. Therefore, they cannot be ignored, quite the contrary. Policy-makers should guarantee them the opportunity to contribute to social and family life actively. They require the joint and coordinated work of the scientific community, local, regional, and national governments, social enterprises, local and national businesses and industry leaders (such as design agencies, manufacturing, fin-tech), architects and urban planners, construction companies, and the creative industries.

Population ageing is a universal phenomenon: almost every country in the world is experiencing growth in the size and share of older adults. Currently, 728 million persons are 65 years and over globally. In the next 30 years, this number is expected to increase to more than double its present value (Sanderson & Scherbov, 2010). Moreover, it is worth noting that this number is 2.5 times greater than in 1980 (382 million) and is projected to reach nearly 2.1 billion by 2050 (United Nations, 2020). In 2070, life expectancy at birth may reach 86.1 years for men, up from 78.2 in 2018. For women, it is estimated at 90.3 – up from 83.7. Nevertheless, where people live has a significant influence on life expectancy, and it is more evident in developed countries than in developing nations (World Bank Group, 2018).

A second and inexorable trend seems to be in the spotlight of the 21st century. It is already intersecting demographic turn-over: today, more than 4 billion people live in urban areas (Zhang, 2016; Bodo, 2019). This trend means that over half of the world (55%) live in urban settings. The UN estimates in 2007 the number of people in urban areas overtook the number in rural settings (Figure 2-3). For most of human history, most people across the world lived in small communities. Over the past few centuries – and particularly in recent decades – this has shifted dramatically. There has been a mass migration of populations from rural to urban areas.

This chapter takes an in-depth look at ageing in cities: the social and economic consequences are discussed, starting with significant numbers and trends of the phenomenon at global and national levels; then, in the last paragraphs, the relations with urban development are investigated, including well-being and perceived quality of life. Concluding the chapter, the leading intervention domains for making cities more age-friendly are exploited.

The key question that this chapter investigates is whether the elderly will benefit from improved health and a better quality of life, social inclusion and income security (Shrestha et al., 2020; Lundy et al., 2021). Ageing is likely to have far-reaching implications for all sectors of society, including labour markets, financial and health systems, political participation, demand for goods and services, urban planning, and infrastructure development, as well as family structures and intergenerational relations (Tinker, 2002; Cann, 2009). Hence, preparing for the economic and social transformations associated with ageing and old age may be essential for political agendas. Policymakers should promote the necessary conditions to enable older persons to lead independent, healthy, and productive lives and empower them to exercise their right to make decisions and choices affecting their lives. Therefore, older persons must be recognized as the active agents of societal development to achieve transformative, inclusive, and sustainable development outcomes.

Figure 2-1. Sustainable Development Goals (United Nations, https://sdgs.un.org)

Policy measures to address population ageing are leading issues for achieving the Sustainable Development Goals (SDGs). They were introduced in 2015 by United Nations (UN) Agenda 2030 (Figure 2-1) and promote actions to eradicate poverty, ensure healthy lives and well-being at all ages, gender equality and full and productive employment and decent work for all, reduce inequalities between and within countries, and make cities and human settlements inclusive, safe, resilient, and sustainable. From the perspective of social equity, everyone should have the opportunity to access essential services and opportunities equally, especially people who need them the most to maintain a good quality of life (Blichfeldt & Nicolaisen, 2011; Andrade & Dorneles, 2012; Stjernborg, 2019).

In order to strengthen this doctrine, the United Nations have established a Decade of Healthy Ageing (Figure 2-2) for the 2020-2030 period. It is a global collaboration aligned with the last ten years of the SDGs and brings together governments, civil society, international agencies, professionals, academia, the media, and the private sector to improve the lives of older people, their families, and the communities in which they live.

Figure 2-2. The United Nations Decade of Healthy Ageing logo (www.decadeofhealthyageing.org)

The Decade of Healthy Ageing promotes policies and strategies to improve the quality of life of older people, according to four intervention areas:

- Area 1 – Age-friendly Environments. Physical settings play an important role in determining social and mental capacity across a person's life course and into older age; also, they influence how well people adjust to the loss of function and other forms of adversity that they may experience at different stages of life, and in particular in later years;
- Area 2 – Combatting Ageism, which affects how people usually think, feel and act towards others based on age. It may create barriers to developing good policies and programmes for older and younger people and have profound negative consequences on older adults' health and well-being.;
- Area 3 – Integrated Care. Older people require non-discriminatory access to good-quality essential healthcare services;
- Area 4 – Long-term Care. Such care systems enable older people, who experience significant health declines, to receive the support to pursue their basic rights, fundamental freedoms and human dignity.

The implementation of cross-cutting actions is needed since several features contribute to health and well-being: genetics and personal characteristics and physical and social environments, for instance. As explored further below, environments play an important role in determining our physical and mental capacity across a person's life course and into older age. Also, they influence how well we adjust to the loss of function and other forms of adversity that we may experience at different stages of life, particularly in later years. Both older people and the environments in which they live are diverse, dynamic and changing. In interaction with each other, they hold incredible potential for enabling or constraining Healthy Ageing. Hence, urban dynamics have to be taken into account to achieve the SDGs and the Decade of Healthy Ageing goals.

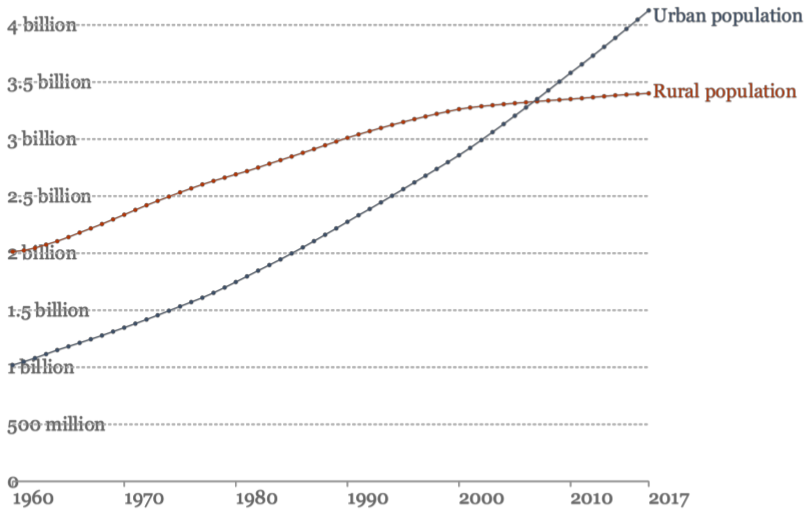

Figure 2-3. Number of people living in urban and rural areas, 1960-2017 (Our World in Data, 2021)

Both the demographic turn-over and urbanism require adopting an intergenerational view of growth and development (Bloom et al., 2010). According to the OECD report (2015), ageing trends seem different between metropolitan and non-metropolitan areas. In large urban areas, the older population is growing faster than the total population, which means the challenges are more significant to overcome. However, cities have more and better resources and offer more compelling opportunities.

At the beginning of 2020, a further unexpected and impactful challenge hit the whole world. The pandemic outbreak stressed the vulnerabilities of an ageing population and the resilience of cities: data show that the highest incidence of Covid-19 cases per capita was recorded in cities and that older adults are more likely to get very sick from Covid-19 as they may need hospitalization, intensive care, or a ventilator to help them breathe, or they might even die (Banerjee, 2020; Daoust, 2020).

At the same time, as Covid-19 has led to a deep economic crisis, further social, gender and ageing inequalities have been stressed out. In this new recovery phase, the achievement of SDGs becomes even more necessary.

Concerning these observations, more age-friendly approaches are needed in our cities. It would be a challenge to prepare for these developments so that both current and future generations of older people can benefit from age-friendly urban planning strategies.

2.2 Global ageing trends

In 1950 there were 2.5 billion people on the planet. Now in 2021, there are 7.7 billion. The UN expects a global population of 11.2 billion by the end of the century, and its age structure will be fully redesigned. The visualization of the population pyramid and its evolution over the last 70 years make it possible to understand this enormous global transformation (Figure 2-4).

Population pyramids visualize the demographic structure (Saroha, 2018): the width represents the size of the population of a given age, while the number of women is on the right and men on the left side. The bottom layer represents the number of newborns, and above it, the chart shows the numbers of older cohorts. With this depiction, the population structure of societies with high mortality rates resembled a pyramid – this is how this famous type of visualization got its name (Ritchie & Roser, 2019).

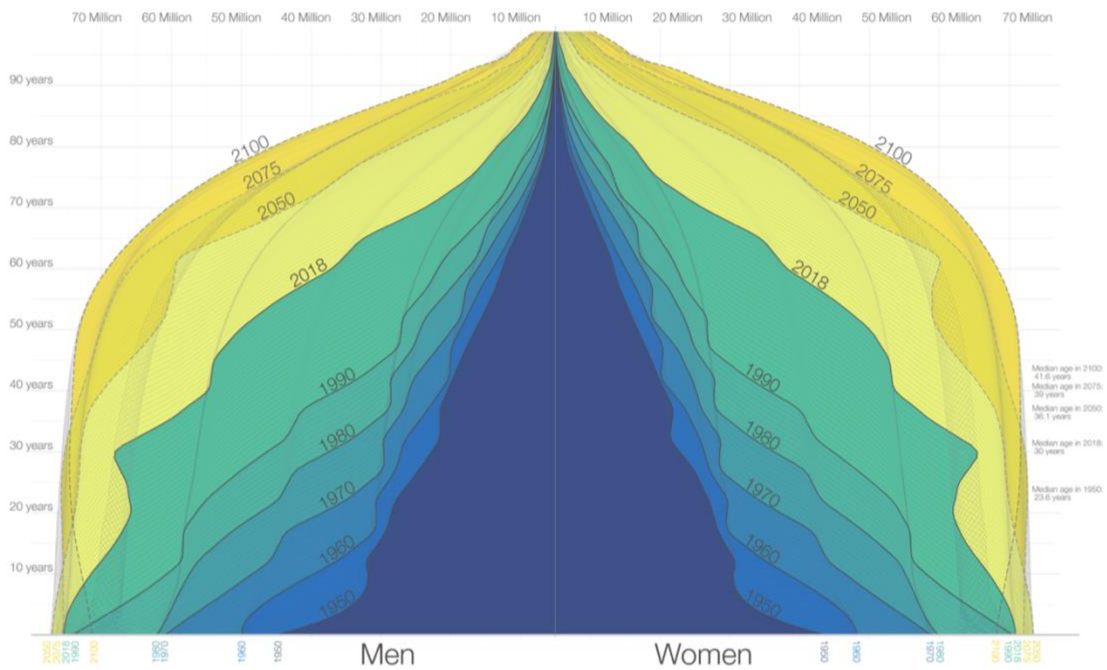

Figure 2-4. The demography of the World Population from 1950 to 2100 (UN – Population Division, 2020)

In the darkest blue, the pyramid reports the structure of the world population back in 1950. Two factors are responsible for the pyramid shape in 1950: an increasing number of births broadened the base layer of the population pyramid, and a continuously high risk of death throughout life is evident by the pyramid narrowing towards the top. There were many newborns relative to the number of people at older ages. That phenomenon has been called the *baby boom*, and it is closely related to the second post-war recovery.
The narrowing of the pyramid just above the base testifies that more than 1-in-5 children born in 1950 died before they reached five.
Through shades of blue and green, the chart shows the population structure over the last decades up to 2018. In each subsequent decade, the population pyramid gets fatter than before – in each decade, more people of all ages were added to the world population.
The green pyramid for 2018 shows that the narrowing above the base is much less intense than back in 1950: hence, the child mortality rate fell from 1-in-5 in 1950 to fewer than 1-in-20 today. In comparing 1950 and 2018, it is worth noting that the number of children born has increased – 97 million in 1950 to 143 million today – and that the mortality of children decreased at the same time. Comparing the base of the pyramid in 2018 with the projection for 2100, it becomes clear that the coming decades will not resemble the past. According to the projections, fewer children will be born at the end of this century than today. The base of the future population structure is narrower than before.
The global population is at a turning point in its history. Since 1950, a widening of the entire pyramid – an increase of children – was responsible for the increase in the world population. From now on is not a widening of the base but a fill-up of the population above the base. The number of children will barely increase and then start to decline. However, the number of working and older people will increase very substantially. As global health is improving and mortality is falling, the people alive today are expected to live longer than any generation before.
A "*peak child*" is often followed by a time when the country benefits from a "*demographic dividend*" when the proportion of the dependent young generation falls and the share of the population in working age increases. This is now happening on a global scale. For every child under 15, there were 1.8 people in working-age (15 to 64) in 1950. Today there are 2.5, and by the end of the century, there will be 3.4. Richer countries have benefited from this transition in the last decades. Thus, they are now facing the demographic problem of an increasingly

larger share of retired people that are not contributing to the labour market. In the coming decades, it will be the poorer countries that can benefit from this demographic dividend.

The change from 1950 to today and the projections to 2100 show a world population becoming healthier than before. When the top of the pyramid becomes wider and more box-shaped, the population lives through younger ages with a shallow risk of death and dies in old age. The demographic structure of a healthy population at the final stage of the demographic transition is the box shape foreseen for the entire world by 2100.

Countries worldwide have been going or are about to go through this demographic transition: from young to increasingly ageing populations. As was mentioned above, in 2018, the number of people aged 64 years old and over surpassed the number of children under 5 years old for the first time in recent human history. This transition is clear looking at the population by age bracket in the chart – this is shown from 1950 onwards, with UN projections to 2100 (Figure 2-5). This chart shows the projected age structure of future populations – for any country or world region.

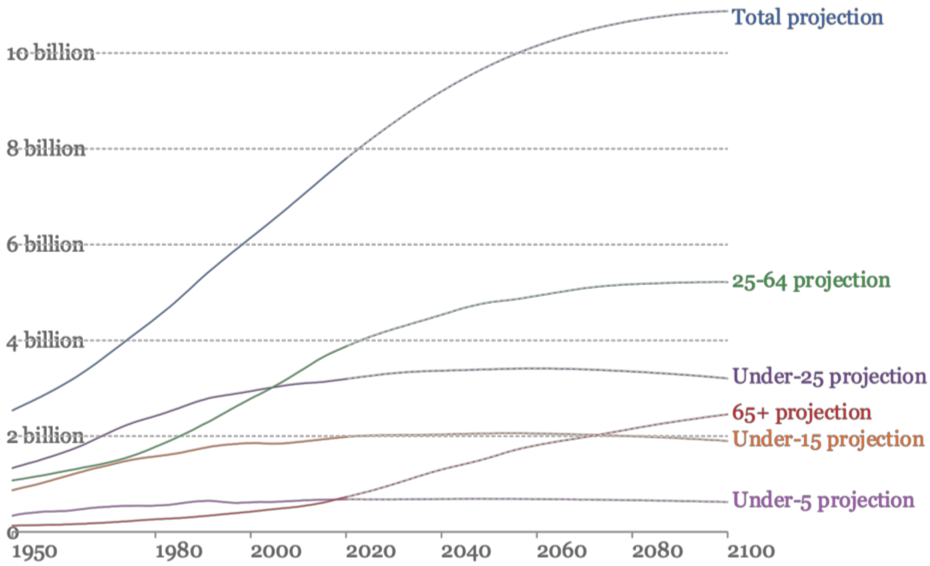

Figure 2-5. World population by age bracket with UN projections (UN - Population Division, 2019)

Going beyond the global perspective, it is worth noting that this crossover point differently occurred and developed in countries worldwide.

The timing varied significantly between countries: it has been shifting for decades in higher-income countries with low fertility rates and longer life expectancies. For instance, in the United States, under-5-years-old children were already outnumbered by those older than 64 by 1966. In Spain, it was 1970; in South Korea, it was 2000.

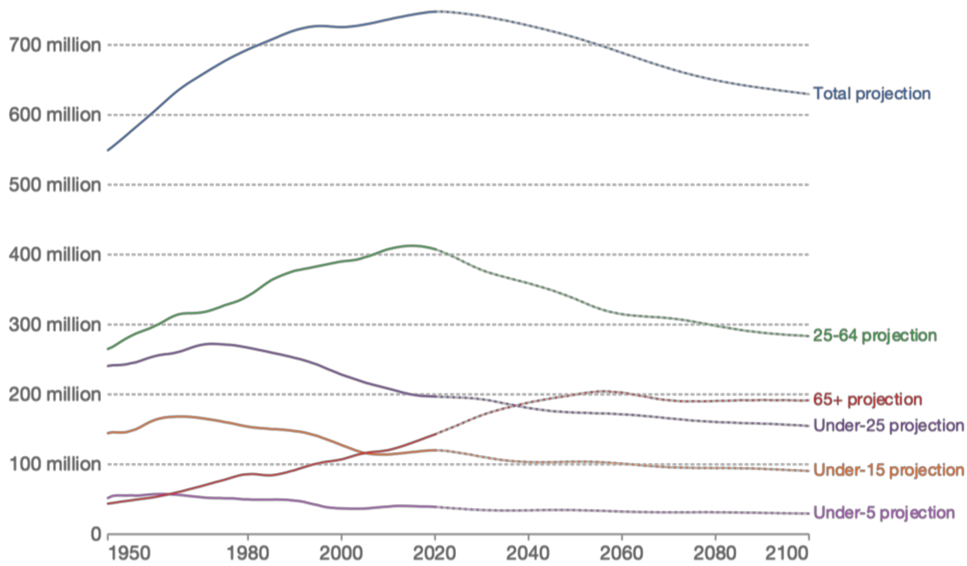

Figure 2-6. European population by age bracket with UN projections (UN - Population Division, 2019)

Figure 2-6 focuses on the evolution of the European population structure: in 2004, people aged 65 and above outnumbered those under 25. For many other countries, this crossover point is still to come. In India, it is projected to be 2028; in South Africa, it is expected by 2036. In low-income countries with high fertility rates and lower life expectancy, this point is still many decades away. In Nigeria, under-5s will outnumber those older than 64 around 2087.

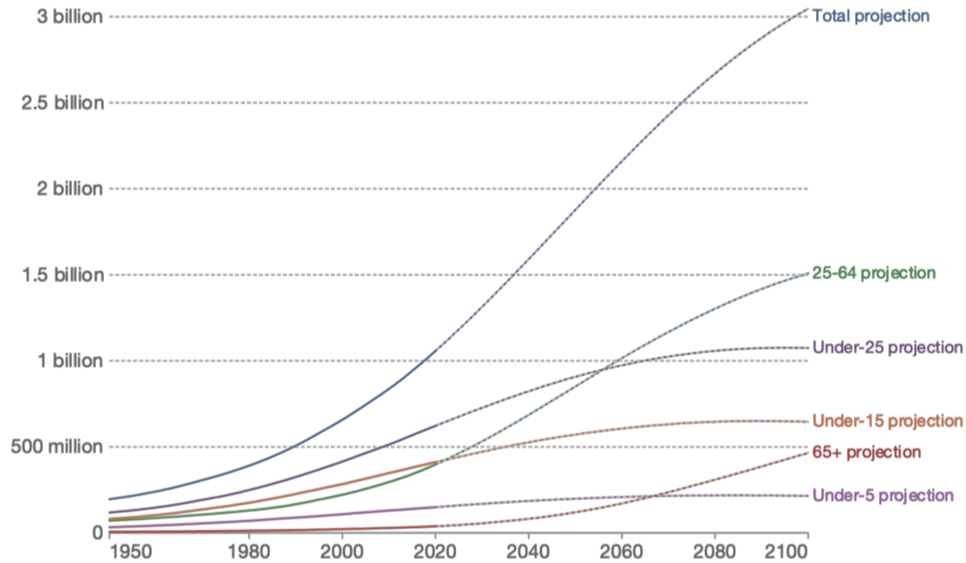

Figure 2-7. Population by age bracket, in the least developed countries, with Un projections (UN - Population Division, 2019)

The number of children under 5 years old is projected to peak and plateau for most of the 21st century. Moreover, as the global population of people older than 64 years continues to grow, we are clearly moving towards an ageing world.

Figure 2-7 represents UN projections for least developed countries: on average, in 2066, people aged 65 and over are expected to outnumber younger children.

Different countries with different age structures face different challenges. Lower-income countries typically have a pretty young population due to high fertility rates. Hence, a large share of the population are children who are not (or should not) be in the productive working population. On the other hand, high-income countries with a large elderly population face the same challenge for working-age populations.

Nevertheless, how is this expected to change in the future? In the two charts (Figure 2-8 and Figure 2-9), we see the breakdown of two example populations – Italy and Niger – by age between young (under 15 years old), working-age (15-64 years old) and elderly (65+ years old). After Japan, Italy is the second country globally with the highest share of people aged 65 and over. Niger, indeed, is the youngest country: more than 50% of the population is under 15. This is shown until the year 2100 based on the UN's population projection.

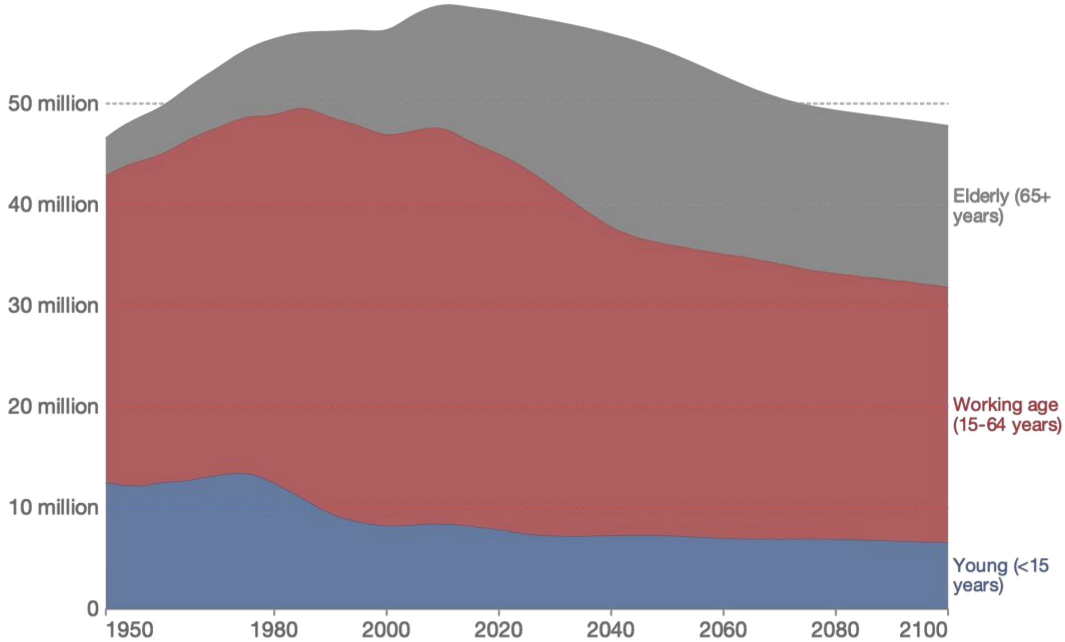

Figure 2-8. Size of young, working-age and elderly populations in Italy, from 1950 to 2100 (UN World Population Prospects, 2017)

For Italy and other high-income countries, people aged 65 and over will likely continue to increase in the coming decades. Since projections do not foresee a significant change for the youth population, the share of the working-age population is expected to fall further.

Niger currently has a very young population. Nevertheless, these children and adolescents will move into the working-age bracket soon. The share of the productive, working-age population will increase significantly in the coming decades.

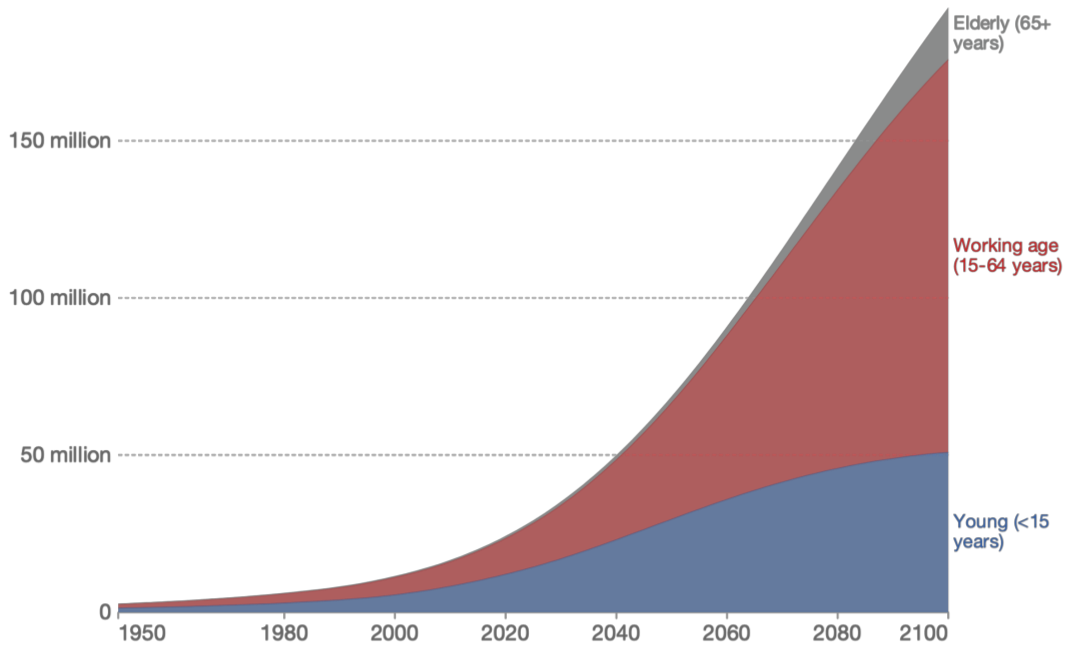

Figure 2-9. Size of young, working-age and elderly populations in Niger, from 1950 to 2100 (UN World Population Prospects, 2017)

As fertility rates continue to decline, the working population will continue to increase throughout this century as a share of the total population. The most significant increase (+300 million persons) will occur in Eastern and South-Eastern Asia, from 272 million persons aged 65 years or over in 2020 to 572 million in 2050. Other regions expecting significant increases include Central and Southern Asia (+204 million persons) and Europe and Northern America (+91 million persons).

In a nutshell, the combination of lower fertility rates and improved life expectancy has increased the number and share of people in the older age groups. At the same time, the working-age population (20-64 years) is projected to decrease (from 59% nowadays to 51% in 2070). Hence, the role and contribution of older people to families, communities, and social, political, and economic well-being will be even more significant than it is today. On the other hand, ageing is associated with an increased vulnerability and dependence on medical care (Hellström & Hallberg, 2008), which may cause the occurrence of social isolation, loneliness, and depression due to age-associated limitations that further complicate mobility (Figure 2-10).

This issue is the focus of the following paragraphs: albeit, on average, older adults of today seem to benefit from improved health, they also show undeniable vulnerabilities, which are the main challenges in designing age-friendly environments.

Figure 2-10. Leaflet promoting an activity carried out by a local association to collect stories told by older adults. The photo was taken in Castellammare di Stabia (Naples, Italy), August 2021

2.3 Older people in cities: challenges for today and tomorrow

Older people are often assumed to be frail or dependent and a burden to society. Public health and society need to address these and other ageist attitudes, leading to discrimination and limiting the opportunities older people have to experience healthy ageing.

By the term *Healthy Ageing,* we usually refer to the "*development and maintenance of optimal physical, mental and social well-being and function in older adults*", as defined by the Centres for Disease Control and Prevention (Land et al., 2006). It is "*likely to be achieved when physical environments and communities are safe, and support the adoption and maintenance by individuals of attitudes and behaviours known to promote health and well-being, and by the effective use of health services and community programs to prevent or minimize the impact of acute and chronic disease on the function".*

At the biological level, ageing leads to a gradual decrease in physical and mental capacity, a growing risk of disease, and ultimately, death. Common conditions in older age include hearing and sight loss, back and neck pain and osteoarthritis, chronic obstructive pulmonary disease, diabetes, depression, and dementia. Furthermore, as people age, they are more likely to experience several conditions at the same time.

Several complex health states characterize old age. They tend to occur only later in life and do not fall into discrete disease categories. These are commonly called geriatric syndromes. They are often the consequence of multiple underlying factors and include frailty, falls, delirium. However, these changes are neither linear nor consistent, and they are only loosely associated with a person's age in years. While some 70-year-olds enjoy excellent health and functioning, other 70-year-olds are frail and require significant help from others.

Beyond biological changes, ageing is also associated with other life transitions such as retirement, relocation to more appropriate housing, and the death of friends and partners. In developing a public-health response to ageing, it is essential to consider approaches that ameliorate the losses associated with older age and reinforce recovery, adaptation, and psychosocial growth.

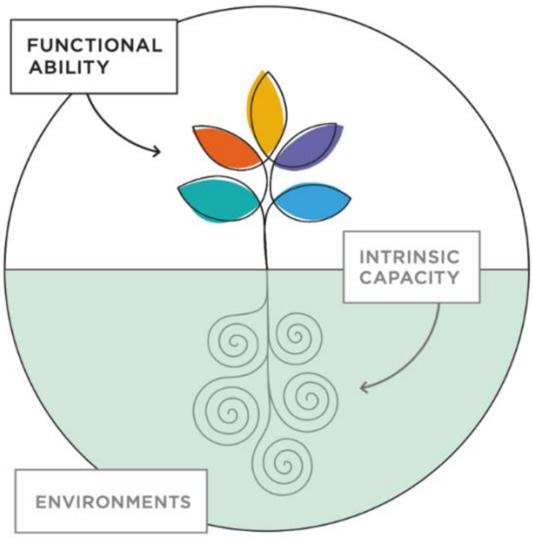

Figure 2-11. The Decade of Healthy Ageing (WHO - Baseline Report, 2021)

Although some of the variations in older people's health are genetic, much is due to people's physical and social environments – including their homes, neighbourhoods, cities, and communities, as well as their characteristics – such as their socioeconomic status, personal education, professional life. These factors start to influence the ageing process at an early stage in human life. Thus, they also influence the development and maintenance of healthy behaviours. Moreover, the diversity seen in older age is not random. A large part arises from people's physical and social environments and their impact on their opportunities and health behaviour. The relationship we tend to have with the environments we live in is skewed by personal characteristics such as family, gender, and ethnicity, leading to health inequalities. A significant proportion of the diversity in older age is due to the cumulative impact of these health inequities across the life course. Public health policy must be crafted to reduce, rather than reinforce, these inequities.

Within this frame, supportive environments enable people to do what is important to them, despite losses in capacity. The availability of safe and accessible public buildings, services and transport, as well as public spaces which are easy to walk around, are examples of supportive and age-friendly environments.

Since there is no typical older person, a comprehensive public ageing-friendly response must address this wide range of older people's experiences and needs.

Urbanization, technological developments (e.g., in transport and communication), and the provision of new services influence older people's lives directly and indirectly.

The paragraph highlights how the quality of life of the elderly may be affected by some essential traits of urban settings. The availability of services, activities and mobility choices, the perception of safety and security are among the most controversial issues discussed by researchers and policy-makers.

Cities are a melting point of opportunities for living a long and fulfilling life, even into adulthood. However, urban dynamics and characteristics influence whether a city has high levels of crime and violence (Fonad et al., 2006; Rudwiarti & Vitasurya, 2020). Spatial, social, and economic fragmentation and exclusion feed insecurity and vice versa. Segregation, economic, gender and age inequalities and loss of positive social cohesion are primary drivers of higher rates of crime and violence (Sharkey, 2018; Blattman et al., 2021). This results in creating slums and gated communities, exploitation of the poor in unstable and informal employment, and marginalization groups of citizens and city-users (Pavoni & Tulumello, 2020). Moreover, an unsafe and insecure city may be affected by huge taxes on its quality of life (Alexander & Pain, 2011; Recasens et al., 2013). The economic costs due to crime and violence entail consequences that range from the loss of investments and, consequently jobs, to the abandonment of specific neighbourhoods (Yin & Yeakey, 2018; Moncada, 2020; Gupte & Zahan, 2021). They include the direct cost of private security and "hardening" to protect assets that lead to the development of an "architecture of fear[1]" and the

[1] "Architecture of fear" refers to the ways in which the contemporary landscape is shaped by our society's preoccupation with fear, as apparent in the design of homes, security systems, gated

stigmatization of the urban poor, particularly vulnerable in human settlements (Datta, 2021). In this context, promoting sustainable urban development improves the conditions for creating safe, secure and age-friendly cities (Chau & Jamei, 2021).

Inclusion of all inhabitants is an underlying principle of decision-making, implementation, and follow-up related to urban safety and security strategies. Discrimination, lack of economic opportunities and livelihoods, weak governance, inequality and inadequate access to and control over resources create different forms of exclusion and vulnerabilities for all, including women, girls, boys, men and the elderly (Buhaug & von Uexkull, 2021). Urban safety and security strategies should at all times include measures that contribute to gender and age equality and inclusion. Hence, investments and actions need to acknowledge the specific needs of women and girls, children and youth, and people in vulnerable situations, including migrants, persons with disabilities and older persons, in order to leave no one behind when addressing social and gender norms surrounding safety and security.

Figure 2-12. A road signal for an age-friendly city (or ageism?) (https://blogs.iadb.org/ciudades-sostenibles/en/age-friendly-cities-2/)

There are two dimensions of safety and security: actual and perceived (Schuilenburg & Peeters, 2018). The actual dimension refers to the risk of becoming a victim, and the perceived dimension refers to people's perception of insecurity through the lens of fear and anxiety. The concept of safety commonly refers to the control of hazards, usually not caused by deliberate human action but are instead the result of a daily and unavoidable interplay

communities, semi-public spaces (shop- ping malls, theme parks, casinos, office atriums), zoning regulations and cyberspace.

between human and material/environmental factors (e.g. fires, natural disasters, road accidents or the outbreak of a pandemic, such as Covid-19 disease). While security measures often seek to eliminate the risk from hazards entirely, safety measures primarily aim to reduce the risk of hazards and their consequences. Hence, safety measures are concerned with strengthening the resilience of people's material environment and developing human coping mechanisms for managing hazards (Takahashi et al., 2017).

Talking about perceived urban safety from the elderly perspective, phenomena that might not affect other population segments represent a source of insecurity and fear, further limiting personal capability and mobility capital for the elderly. Some qualitative and quantitative studies show that elderly users are afraid of falling on roads with uneven pavements or because of cyclists or scooters. Also, the increasingly frequent heat waves pose a real risk to the health of the elderly and limit the use of urban open spaces more than for other groups of citizens (van Steen et al., 2019). Physical conditions such as urban decay, physical disorder, and high crime levels may generate more chronic levels of stress and fear for older adults than for other city users.

Hence, the term "urban safety and security" should take a holistic and people-centred perspective on the complex vulnerabilities of city populations. It can refer to the prevention of crime and violence and the enhancement of individual rights, including physical, social and psychological integrity.

In everyday thinking, the fulfilment of the needs and wishes of the elderly population also depends on their ability to move independently. Scientific communities agree that the prevalence of functional limitations and disability is associated with ageing (Centers for Disease Control and Prevention, 2009). About travel and mobility concerns, 31.7% of adults aged 65 years and older report difficulty walking city blocks. In comparison, only 11.3% of adults aged 45 to 64 years have similar difficulties (Saraiva et al., 2021). Another study reported that 20% of adults aged 65 years and older do not drive a motor vehicle (Satariano et al., 2012). These data describe the possible limitations that older people usually face in urban environments.

First, limitations in walking and driving reduce access to goods and services, which leads to poor health outcomes (Marottoli et al., 200; Patterson & Chapman, 2004; Oxley & Whelan, 2008). For example, older adults with walking limitations and difficulties with driving are less likely to travel to grocery stores and supermarkets, resulting in fewer nutritional options, compromising health, and impairing functioning (Lee & Frongillo, 2001; Webber et al., 2013).

Hence, they are also less likely to obtain health services promptly, including preventive services (Buktus et al., 2020).

Figure 2-13. Francisco Calvino/Moment Editorial/Getty Images

Second, limited mobility is independently associated with health problems and injuries: sedentary behaviour, such as restricted or limited walking, is implicated in the aetiology of obesity, cardiovascular disease, diabetes, colorectal cancer, breast cancer, poor cognitive function, and depression (Simonsick et al., 2005; Wang & Yang, 2019; Freiberger et al., 2020; Harvey & Griffin, 2020). Other studies show that stopping driving is also associated with an increased risk of depression among older adults (Ragland et al., 2005; Dabelko-Schoeny et al., 2021). Injuries from falls and motor vehicle crashes, an elevated risk for mobility-impaired persons, are leading causes of disability, nursing home placement, and premature death among people aged 65 years and older. Indeed, falls and motor vehicle crashes represent the second leading cause of accidental death among older adults (Montella et al., 2011).
Third, older adults with mobility difficulties are less likely to have regular social contacts (Haslam et al., 2018). Social isolation, in turn, is associated with a variety of health conditions, including all-cause mortality (Seeman, 1996; Plouffe & Kalache, 2010; Berkman et al., 2014).
Finally, older adults without access to different forms of mobility cannot participate in civic and social life, adversely affecting themselves and their community (Wilkinson, 2020). Indeed, the World Health Organization Global Plan for Age-Friendly Societies is based on the concept that older adults represent a significant resource. Moreover, the plan is designed to

ensure that older adults can contribute to the well-being of society (van Hoof & Marston, 2021).

It is crucial to understand why some older adults are less mobile than others considering the public health burdens associated with ageing and loss of mobility. Some models investigated the range of interrelated biological, behavioural, social, and environmental factors associated with patterns of health, function, and longevity over the life course (Committee on Capitalizing on Social Science and Behavioral Research to Improve the Public's Health, Division of Health Promotion and Disease Prevention, 2001; King et al., 2020; Wertz et al., 2021). Various models guide research on disablement and illustrate how environmental factors modify the association between ageing and well-being (Lawton, 1986; Payne & Isaacs, 2016). Ecological examinations of mobility tend to focus on one form of mobility at a time, such as walking (Kushkestani et al., 2020) or driving (Carr et al., 2013). By contrast, Menec et al. (2011) examined personal, social, and environmental factors affecting various mobility types. Impaired mobility is associated with a constricted life space (Stalvey et al., 1999; Prescott et al., 2020).

Although not exhaustive and certainly not inclusive of all the heterogeneous factors influencing the mobility of the elderly, this frame elucidates the potential limitations and restrictions suffered by older adults in urban environments and anticipates some of the methodological choices that will be explored in more detail below (Chapter 4).

Like walkable roads and accessible public transport, services and activities ensure a good quality of life for older people. As people age, enjoying better health than in previous generations, basic needs and activities may have changed a lot through the years. The World Health Organization has taken a systematic approach to measuring healthy ageing. One of its assessments concerns the opportunity to reach, access and use essential or general services within urban areas.

The WHO accessed data from studies in 55 countries, with 52 released for WHO analysis by June 2020. United Nations population estimates for 2020 indicated that these 42 countries had 678.5 million older people, representing 16% of the total population and 65% of all older people worldwide.

Results across the 42 countries included information on 151718 older persons aged 60 years and over, with 68456 men (45%) and 83262 women (55%). The 14% of older people in the analysis cannot meet basic needs for a life of meaning and dignity – i.e., they cannot dress, get and take their medication or manage their own money, bills or finances. This percentage represents 71 million older persons in the 37 countries with data – and at least 142 million people aged 60 and over worldwide. Moreover, it is worth noting that the figure above (Figure 2-13) does not include older people living in long-term care facilities or other institutions.

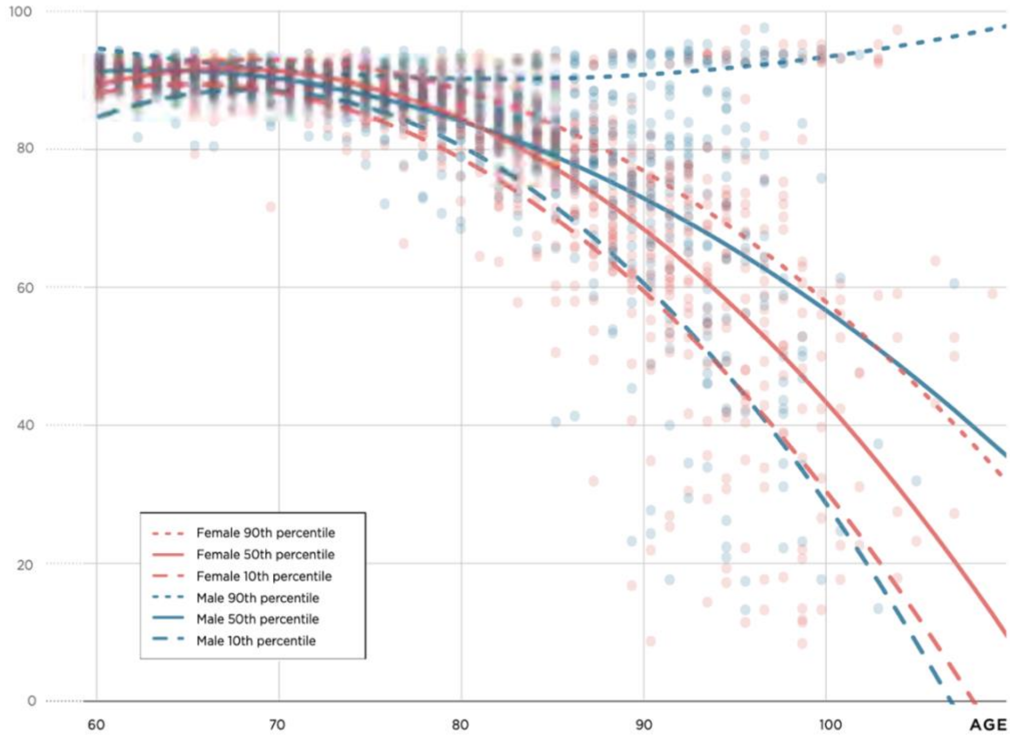

Figure 2-14. World Health Organization, Decade of Healthy Ageing, Baseline Report (2021). The chart presents on the x-axis the age of people, on the y-axis the basic need score. Meeting some basic needs was scaled from 0 (lowest) to 100 (highest). The highest score persons through a combination of maintaining intrinsic capacities, providing enabling environments and ensuring targeted support to those who need it. This is the case for all countries until 75 years, although there is much variation within each country

Basic needs should be met for all older people at any age, and approaches should mitigate inequalities in opportunities. Similar questions on other basic needs, such as adequate housing or diet, and all other abilities, are lacking in existing surveys. The regulation and list all possible services and activities that meet the needs of the elderly are almost impossibile, not least because much depends on social, economic and health conditions.

Combining geographical data and studies that include older adults is a promising way to investigate the interaction of environments and intrinsic capacity and the impact on functional ability. A feasibility study illustrates which places or services can be accessed (such as parks, clubs or health providers) in several cities from all world regions, analysing real-time data from mobile phones. Furthermore, it shows how accessible they are to older adults (whether by driving, taking public transportation or walking for each of them).

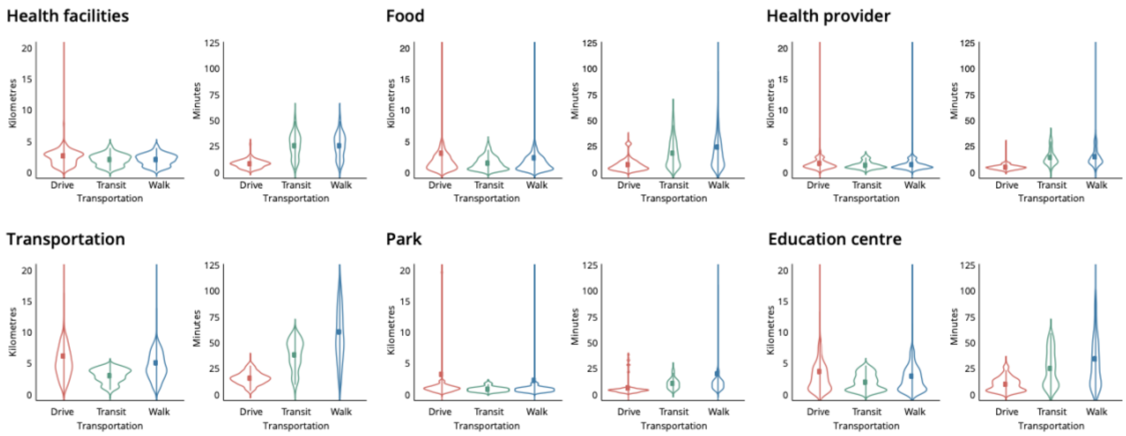

Figure 2-15. These violin plots are a combination of a box plot and density plot, rotated on its side to show the full distribution and shape of the data. A violin plot that sits on the floor, like a flat box with no line, means that services and people are near (WHO, 2021)

Figure 2-14 provides an example dashboard with each category as separate "violin plots" from Tokyo, Japan. In this case, the main features of cities and communities can foster the full participation of older people and play a crucial role in ensuring that no older person is left behind. As the supply of urban activities includes both tangible and not tangible services, decreasing the digital divide between younger and older people, particularly those in rural areas, will increase perceived accessibility. Hence, technological devices and ICTs would enable a broader range of older people to use real-time information to care for themselves or others, make informed decisions, and pursue what they value.

2.4 Towards age-friendly cities

In light of the progressive ageing of the population and the increase in the number of people living in urban areas, good practices to transform existing cities into age-friendly ones are more and more necessary.

The theme of developing age-friendly cities and communities is not entirely new. It emerged from a series of policy initiatives set in motion by the World Health Organization during the early 2000s. A leading idea running through these initiatives is related to promote 'active ageing' (Buffel et al., 2019). The ideas of active ageing were taken further in 2006 when the WHO launched a project that led to the Global Age-friendly Cities report (2007). As part of that project, several focus groups with older people, caregivers, and service providers were conducted in 33 cities in 22 countries. They were interviewed to identify factors that could make urban environments more age-friendly. The project defined an 'age-friendly city' as encouraging "*active ageing by optimising opportunities for health, participation and security* *in order to enhance the quality of life as people age"*. The study resulted in a guide that identified the key characteristics of an age-friendly city or community in terms of three main areas: service provision, the built environment, and social aspects (WHO, 2007). This Global Age-Friendly Cities guide has since become the most frequently used document to promote and evaluate the goal of age-friendliness (Plouffe et al., 2016; Rémillard-Boilard, 2018).

The notion of active ageing as a synonym of urban age-friendliness was initially developed in 1999, during the Year of Older People promoted by the United Nations. Other organisations further detailed it as the European Union (1999) and the WHO (2002). In broad terms, active ageing reflects the idea that people should continue to participate in all spheres of life in old age – social, cultural, civic, spiritual and economic. Active ageing policies and programmes require diverse interventions and actions to improve aspects of both the social and physical environment.

Over the past two decades, various studies have explored the issue of designing age-friendly cities. Taken together, they support the notion that growing old is a process that depends on countless factors - genetic, social, economic, psychological, family. However, such studies suggest a pertinent role of health and environmental conditions for maintaining a good quality of life. With the availability of public transport and accessible roads and pavements, the advantage of a wide range of services might be attractive forces of a city for older adults. Such environments would allow them to live and actively contribute to their families and the communities they reside in.

On the other hand, cities can be unsafe and chaotic places for the elderly (and not only). This is primarily due to the development of urban areas that have long been centred on car use, prioritizing vehicular traffic and discouraging the use of streets and public spaces. Moreover, the lack of knowledge about the opportunities older people could access due to the digital divide may affect the well-being of older adults. These and other issues of urban life restrict older people's participation in community life, contributing to social isolation, making the urban environment unsafe, and leading to unhealthy, sedentary lifestyles.

A public healthy-ageing response must take stock of these current and projected demographic trends, the average evolution of the well-being conditions of the elderly, and the influence of living environments. In the light of increasing urbanization, the first challenge is to address the ageing of the population in elderly-friendly environments.

New age-friendly cities are being built, for instance in the UK (Darlington, Fylde, Runcorn, Bicester, Barton Park in Oxford – Figure 2-16, Whitehill and Bordon, and so on) or in the USA (such as the famous retirement cities in Florida or Sun Cities – Figure 2-17 spread all over the country) with *ad hoc* retirement communities.

The real challenge for urban planners and stakeholders is to adapt existing urban environments to the needs of this growing segment of the population. In terms of financial and territorial resources, not all cities can afford to build new age-friendly neighbourhoods and communities. This does not mean they cannot include strategies and actions in urban agendas to promote a better quality of life for the elderly.

Figure 2-16. The image shows the community developed in Barton, in northeast Oxfordwill (UK). The plan was set up to limit social and economic exclusion of the elderly in the area: in 2010, 28% of Barton's residents lived below the poverty line and poverty among the elderly was particularly acute - with over 38% of over-65s in Barton and 23% in Northway living in poverty, compared to 17% across Oxford (Barton Regeneration Strategy Plan, Oxford City Council, 2013)

Figure 2-17. Known as the first modern 55+ active adult community in the United States of America, Sun City has a prime location near Phoenix, Arizona. The Del Webb development in the picture opened in 1960 and was the first of many Sun City communities now found throughout the country. Del Webb opened Sun City on New Year's Day in 1960 and it was an instant success, with over 100,000 visitors touring the community in the first weekend alone. Development was completed in 1978, with 27,492 homes, 11 golf courses, 19 shopping areas, recreation centers, swimming pools, sports courts and much more. While Sun City is older than many active adult communities in the Phoenix area, retirees are drawn to its well-established grounds, resort-style amenities, affordable homes, and prime location (55places.com)

There are many possible ways in which the urban environment may influence the health and well-being of older residents. Indeed, older people may be particularly vulnerable to the influence of urban characteristics. They may spend more time in their neighbourhoods, have increased biological, psychological, and cognitive vulnerability, have changing spatial use patterns, and rely more on community integration sources. However, good street design, access to public transport, and public buildings can make mobility easier. Attractive destinations and welcoming neighbourhood shopping may encourage individuals to remain engaged with their local community and maintain supportive social networks. Such features may also encourage walking and other physical activities, which not only reduce the risk of chronic disease but may also exert protective effects by strengthening the physiological systems of older adults and reducing functional limitation, for example, from osteoarthritis. A positive residential environment may also provide social resources that buffer the impact of life stressors. It might present readily accessible and affordable nutrition promoting a healthy diet or contain physical characteristics such as trees and parks that foster a sense of well-being. Moreover, an age-friendly setting may provide a recuperating environment that supports resilience. Prevailing cultural norms may steer residents to healthy, or in some cases unhealthy, behaviours and outcomes.

This view is supported by many researchers, organisations, and non-governmental agencies that delved into each urban feature's role in defining more age-friendly city models.

One of the most significant models for Age-Friendly cities and communities is the WHO's Age-Friendly Cities model, first presented in Global Age-Friendly Cities - A Guide (2007). This guide aimed to provide possible answers to questions on urban ageing and to grow old in the city, based on the outcomes of a global research endeavour. One of the main hypotheses of the research activities is that older people can stay independent and healthy for as long as possible if support is offered in several domains that pertain to every aspect of daily living. Based on this notion, the WHO proposed eight domains in which cities would encounter challenges and actions are needed. These eight domains are (1) outdoor spaces and buildings; (2) transportation and mobility; (3) housing; (4) social participation; (5) social inclusion and non-discrimination; (6) civic engagement and employment; (7) communication and information; and (8) community and health services (Figure 2-18).

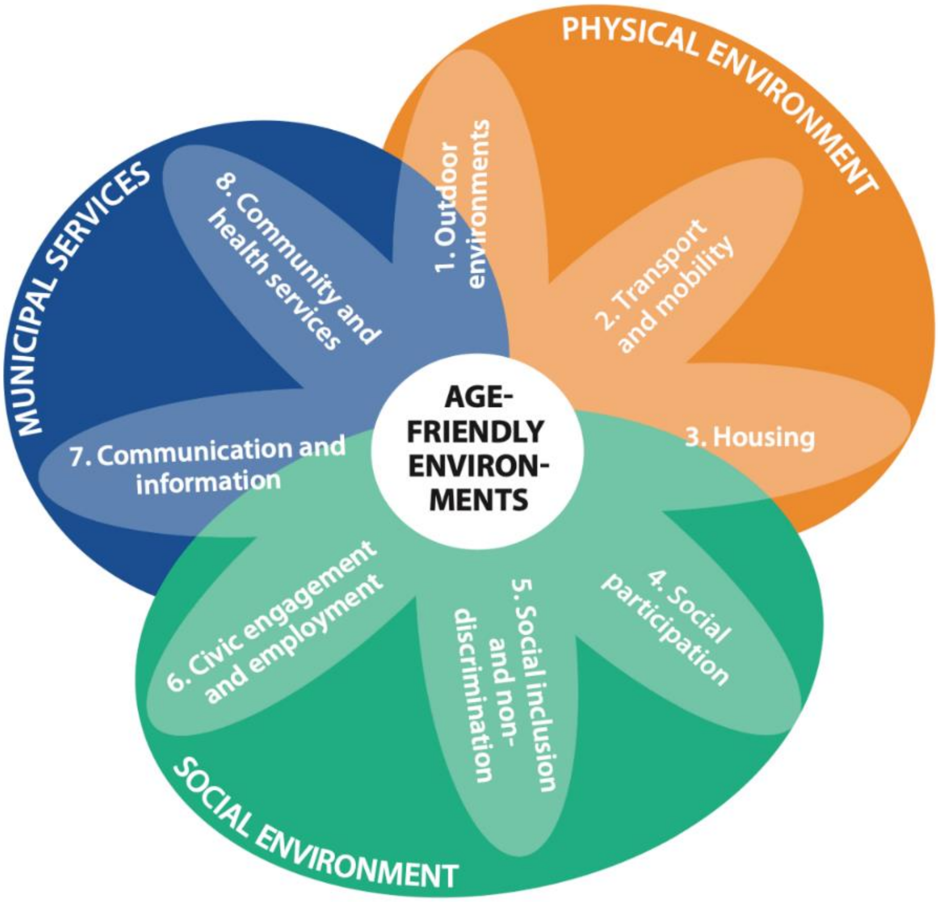

Figure 2-18. The model of an Age-Friendly City for the World Health Organization (2016)

The model suggests strong connections between different aspects of urban living and that only an integrated approach may be helpful to achieve such development goals for urban environments. For instance, the physical environment is covered by outdoor spaces and buildings, transportation and housing. Hence, what is needed is the coordination of actions across various domains of city policy and services to enable and facilitate a mutual understanding, reinforcement and approval. Therefore, each domain of the model should not be treated or considered separately.

Two primary inter-domain relationships affect the quality of life of the elderly: qualitative, quantitative, and territorial characteristics of demand and supply and the available mobility means to link them.

First, dwellers should live in areas safe from natural hazards and close to services, age cohorts, and public attractions that stimulate community integration and keep older people mobile and fit. Second, transportation services and infrastructures should be consistently connected to opportunities for social, civic and economic participation and health services.

These two relationships underline the importance of undertaking interdisciplinary action and collaboration between domains in order to achieve the goals of the age-friendly agenda. It is vital to be thoughtful that outdoor spaces and buildings and transportation and housing are also relevant to the built environment. A successful age-friendly development relies upon the other domains, such as social participation (in making decisions about the built environment), respect and social inclusion, and community support, which should be addressed in the design, operation, and management of the built environment.

Exploiting the notion of the need for multisectoral action, Fulmer et al. (2020) proposed an age-friendly ecosystem (Figure 2-19). In this ecosystem, various age-friendly initiatives can create alliances and interactions in times of continued population ageing. Their vision encompasses the lived environment (cities) and social determinants of health and a prevention-focused public health system and the healthcare system itself.

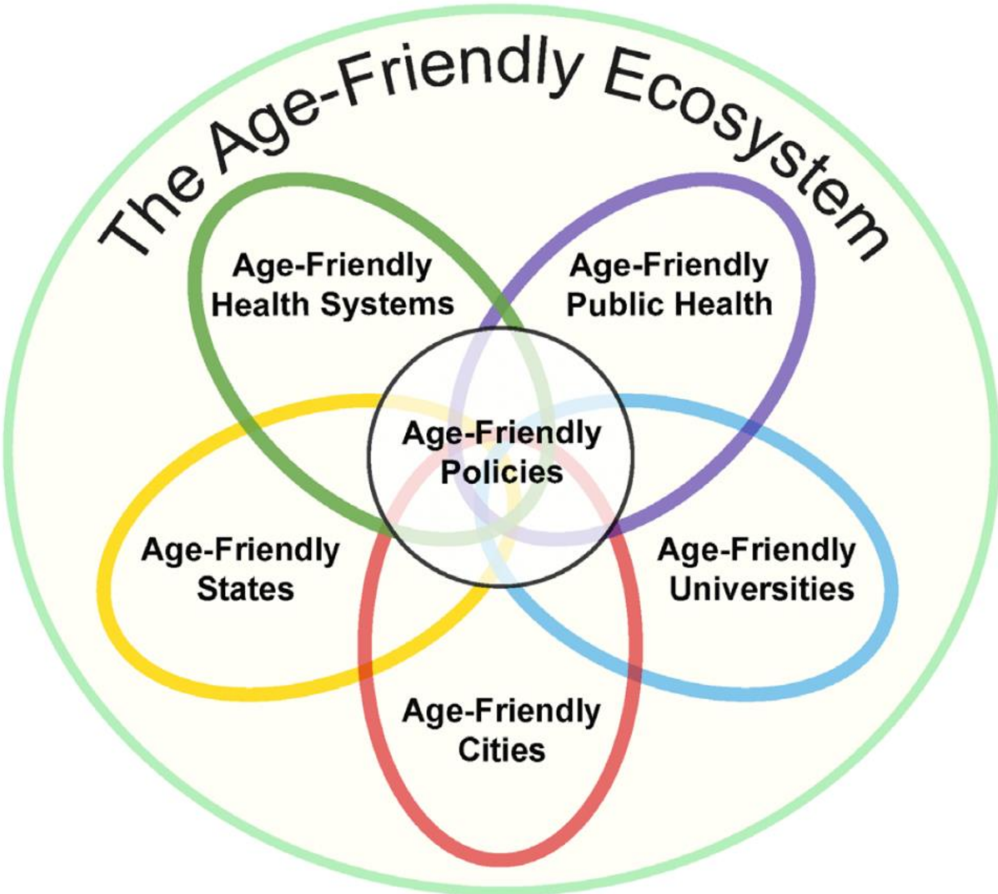

Figure 2-19. The age-friendly ecosystem: a synthesis of age-friendly programs (Fulmer et al., 2020)

Also, Marston and van Hoof (2019) highlighted the apparent lack of contemplation of technology in the scientific and grey literature on age-friendly cities and communities (Figure 2-20). They argue for the integration of technology in the elderly-friendly living environment in its broadest sense, including information and communication technologies (which is one of the traits of the Hong Kong Declaration on Sustainable Development for Cities – UN, 2004), as well as for the assessment of the age-friendliness of urban environments.

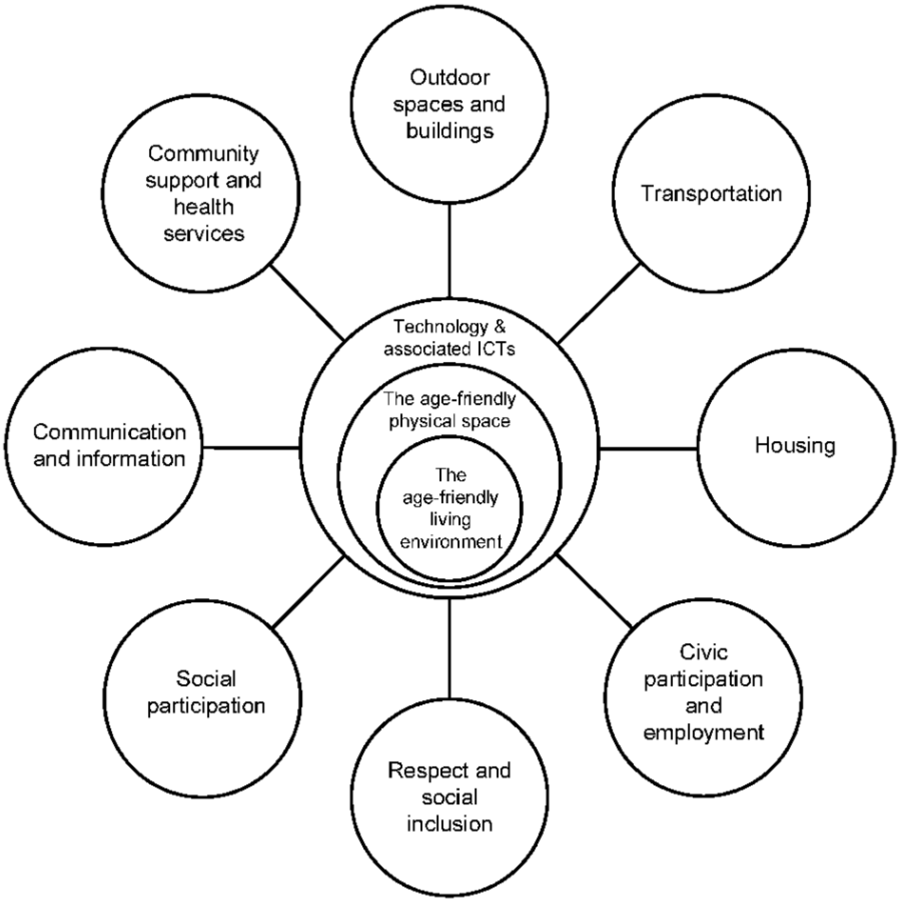

Figure 2-20. The technology-based age-friendly city model proposed by Marston and van Hoof (2019)

In a comprehensive study on the topic of age-friendly city development, Marston et al. (2020) proposed a new, innovative and theoretical framework (Figure 2-21) that builds on previous models and takes a holistic perspective. The Concept of Age-friendly Smart Ecologies (CASE) encompasses various outer and inner-spheres. For instance, technology is featured within the inner quadrants of the framework to highlight the interconnection of information and communication technologies with other urban elements.

The second innovation implemented by Marston et al. concerns two main areas of interest, which embrace the whole age-friendly city model: sustainability and environmental factors and accessibility. The former sphere ensures that all citizens, companies, organizations, and educational institutions can actively contribute to a greener, more resilient, and sustainable environment. This could relate to local, regional, and national environments.

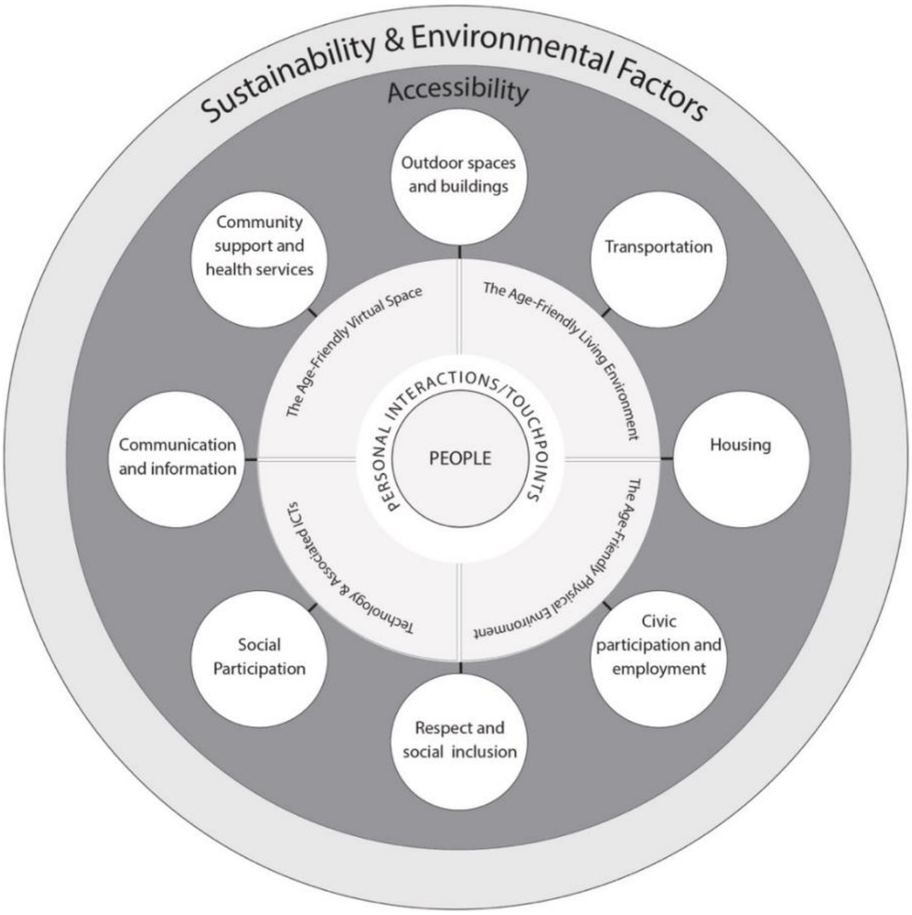

Figure 2-21. The Concept of Age-friendly Smart Ecologies (CASE) framework (Marston et al., 2020)

The inner sphere relates to accessibility. It represents the intersection between the physical and digital ecosystems experienced by citizens, businesses, educational institutes, and community hubs. Accessibility is incorporated through buildings and transport, business, educational institutes and community hubs and services, and technology. Ensuring a good level of accessibility to physical and over-the-air spaces is necessary to facilitate and adapt to the age-friendly concept for all citizens.

In other words, improving urban accessibility is the key to efficiently meeting the two main challenges of the 21st century: population ageing and urbanization.

Experiences from real-world practice show that cities that have addressed accessibility are likely to be ahead of the game in age-friendliness (Liddle et al., 2014; Novek & Menec, 2014; Feng & Lei, 2021).

The models developed in the academic and grey literature and summarised in this paragraph have inspired numerous initiatives worldwide to make cities age-friendly. Most of them are collected in an ongoing project whose aim is to stimulate and enable cities and communities worldwide to become increasingly age-friendly. In 2010, the WHO established the Global

Network for Age-friendly Cities and Communities. The project aims at connecting cities, communities, and organizations worldwide with the shared vision of making their community a great place to grow old in. As a response to global population ageing and rapid urbanism, the network focuses on the action at the local level that promotes the full participation of older people in community life and healthy and active ageing.

The improvement of urban accessibility is the focus of many Age-Friendly Programmes and Plans. One of them is the Older Adult Plan of Ottawa (Canada), first adopted in 2012 and revised in 2015. Ottawa is home to almost 1 million residents (Canada Statistics, 2016). People aged 65 and over accounted for 15.4% of the city's population in 2016. This is expected to rise to 22% by 2031 (City of Ottawa, 2011). In the light of older adults' diverse backgrounds (ethnical and linguistic), recognising and meeting the needs of the sub-groups is essential to make the city age friendlier. The City has developed Accessibility Design Standards that respond to the needs of older adults, thanks to consultation sessions with diverse older people, including those living with a low income, experiencing isolation, dwelling in a rural area, or speaking French. These standards are intended to be mandatory for all new construction and the redevelopment of existing facilities owned, leased or operated by the City of Ottawa. They would be applied to the greatest extent possible for retrofit, alterations or additions to existing facilities owned, leased or operated by the City of Ottawa. In addition, the standards are encouraged to be implemented by other sectors and organizations within Ottawa. They are recognized as addressing the needs of diverse users, with or without disabilities, to ensure inclusive environments for all. In addition to developing these standards, the City is committed to a barrier retrofit program that has made accessibility improvements at over 250 City sites and facilities to remove barriers to accessibility. The program identifies barriers to accessibility through a barrier audit program. It assigns resources to the retrofit and installation of accessible amenities, such as accessible ramps and stairs, guards and handrails, rest areas, washrooms, lighting, signage and way-finding systems.

Thus, accessibility is not only an issue that concerns and is influenced by the built environment. It is a much broader concept, as the case study of Saint Louis County (Missouri, USA) proves. In order to extend the reach of the Age-Friendly Community Action Plan and assist municipalities in making decisions to promote the active ageing of their older residents, St. Louis County has created an Age-Friendly Municipal Toolkit. The purpose of the toolkit is to provide concrete resources municipal leaders and staff can use to build their capacity for an ageing population and age-friendly community. An extensive part of any age-friendly assessment is creating an inventory of resources within the community. This can be done with asset mapping, an exercise that reveals the various strengths within a community. The network of people, organizations, and services in the St. Louis community that contribute to the desired outcome are recorded and mapped. Asset mapping is participatory and inclusive, enabling persons of diverse backgrounds the experience to identify what they consider to be assets in the community they live in. Hence, municipal leaders must include dwellers, business owners, and at-large community members in the stakeholder group.

A similar initiative has been developed for Derio- Bizkaia region in Spain. The municipalities with a higher level of an ageing population are discussed at the census section level, taking information from the diagnosis of the building stock in the Basque country. This initiative aims at taking an accurate picture of the problems older people find in the actual building stock of the Basque Country. The methodology hypothesises concerns the increase in disability of the elderly, loss of autonomy due to the limitations of the environment where they live. That is why it is necessary to identify where people live and the different characteristics of the buildings and surroundings. This information can help authorities develop active ageing policies, basically from the urban and housing point of view, but depending on the indicators selected, there are wide possibilities for this kind of instrument. In order to exploit this initiative, a cross-sectional approach is needed, as well as cooperation among municipalities and administrations and different departments (social, urbanism and health department). The crosschecking of the information results in a characterization of urban schemes and constructive types related to high levels of ageing of the population. Once the typologies and built environments are identified, the specific problems are analysed for each one of them. The rural environment, historical centres and working-class neighbourhoods of the '50-'60s result in the most vulnerable due to the ageing of their populations. The final aim is to adapt the building types and the built environments to promote the autonomy of the elderly and the inclusion of support technologies to redesign the care map of the Basque country.

More and more cities and regions are preparing for the challenge of an ageing population. As stated above, the outbreak of the Covid-19 pandemic has raised further issues concerning the vulnerability of the elderly population. At the same time, new financial and economic instruments put in place for recovery and increasing resilience represent a not-be-missed opportunity for adapting cities to the needs of older adults of today and tomorrow.

The results of this chapter indicate that several domains of the urban environment contribute to defining the age-friendliness of a city. Moreover, they highlight that accessibility, in a holistic sense, is the key to improve and monitor the quality of life of older adults over time. Therefore, the next chapter moves on to discuss the multidisciplinary meaning of urban accessibility through a systematic literature review.

The availability of walkable roads or reliable public transport modes is not the only element that needs consideration. Due to the multidimensional nature of accessibility, safety and security aspects must also be taken into account. Crime and accidents are some of the risk factors limiting the accessibility of older people to goods and services in urban areas and risks related to the increasingly frequent occurrence of extreme weather phenomena (summer heat, water bombs, heat islands). In addition, the lack of services or their unequal distribution can lead to isolation and marginalization of the elderly population, resulting in a significant deterioration in living conditions.

Mobility, land use and the individual perception of the urban environment represent the back end of all accessibility measures and the domains of any age-friendly initiatives. Numerous strategies and actions have been implemented to make cities more supportive of older populations. While distinct in their emphases, these generally share the common goal of addressing needs related to health (accessible and affordable health and health care services, opportunities to be physically active and embrace healthy lifestyles); continuing education (models of lifelong learning that foster the acquisition of new skills, new knowledge); participation (access to relevant information, public transportation, recreational programmes, social connections, volunteer opportunities, places to worship, being valued and respected); and security (home and community safety, transportation safety, financial security, affordable housing and services).

A further worthwhile consideration is needed: senior-friendly initiatives generate benefits for people of all ages. The clean air and healthy environment aspects of WHO's Age-Friendly Cities initiative will benefit everyone, particularly children and people with respiratory diseases. The aspects of safety and security help ensure family-friendly environments. Furthermore, finally, creating barrier-free cities will help improve the mobility of many citizens.

In conclusion, cities that strive to meet age-friendly planning principles will undoubtedly become friendly to all.

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World Health Organization (2002). Active Ageing: A Policy Framework. World Health Organization, Geneva, Switzerland

World Health Organization. (2007). Global age-friendly cities: A guide. World Health Organization, Geneva, Switzerland. Retrieved from: https://www.who.int/ageing/publications/Global_age_friendly_cities_Guide_English.pdf

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CHAPTER 3. URBAN ACCESSIBILITY IN SCIENTIFIC LITERATURE

3.1 Introduction[2]

The chapter aims at defining the scientific frame of the research project, whose objective is to develop methods and procedures to assess urban accessibility, especially for the elderly and, hence, support decision-making processes using information technology tools (Papa E. et al., 2016; Silva et al., 2017; Carpentieri, et al., 2020; Gaglione et al., 2019).

The scientific literature concerning urban accessibility has been deeply analysed in order to build a GIS-based accessibility measure methodology on solid theoretical foundation.

The principle of accessibility had a new rise in Article 9 of the United Nations Convention on the Rights of Persons with Disabilities (2007) and it confirms that every person has the right to live independently and participate fully in all spheres of life (United Nations, 2006). Hence, local authorities are required to take all necessary measures to ensure accessibility to physical environments, transport systems, information and communication technologies and other facilities and services open to public, both in urban and rural areas (Hansen, 1959).

Mobility clearly represents one of the indispensable access conditions to goods and services and to daily activities management, and it can make the difference between people that gain occasions and tools to move, and people trapped in increasingly marginal places (Geurs and Van Wee, 2004). The relationship between mobility and accessibility is not easy and direct as it may seem, since accessibility does not only correspond to the possibility to reach more opportunities, but also to the capabilities to access to the activity repertoire, to values and goods, responding to personal expectation (Hansen, 1959; Bhat et al., 2000, Geurs & Van Wee, 2004).

In literature, the concept of accessibility replaced the ordinary notion of mobility paradigm, in order to take also into account both the available resources and the limiting bonds to access services and goods. Through this lens, mobility is just one of the necessary resources for action, available to people, in order to achieve their own aims. More in general, a lack of resources (also temporal, monetary, etc.) and capabilities (physical or psychological limits) represents a potential form of social and spatial exclusion. In the light of this, new and old social inequalities could rise in the next decades: physical environments of urban areas have

[2] This chapter is a formal elaboration of a scientific paper published by the author in a class A scientific Journal.
Guida, C., & Caglioni, M. (2020). Urban accessibility: the paradox, the paradigms and the measures. A scientific review. TeMA - Journal of Land Use, Mobility and Environment, 13(2), 149-168. https://doi.org/10.6092/1970-9870/6743

always been designed for an average adult person; however, in the 21st century the definition of inclusivity has begun to change as public awareness of sustainable and inclusive practices has increased. So, public governance and spatial scientists, including geographers, urban planners and architects, are confronted with the push for new definitions and design strategies for designing sustainable cities, which are not just about people with traditionally acknowledged disabilities but about all people regardless of age, gender and race.

Populations around the world are ageing at a faster pace than in the past and this demographic transition will have an impact on almost all aspects of society (World Health Organization, 2018). Due to improvements in nutrition, sanitation and medical care, older people are healthier than previous generation, but ageing is also associated to an increased vulnerability; these reasons make the elderly a noticeable group of interest (Gargiulo et al.,2018).

In this context, making cities more age-friendly is a necessary and logical response to promote well-being for older city dwellers and to keep cities thriving. Urban environments should adapt their form and structure so that they could be accessible to and inclusive of older people, considering their different needs and capacities. Although physical changes in well-established urban fabrics could be very difficult, even small innovations can make the difference to make sure older people continue to play an active role in the community and don't become isolated: reducing the distance between transport stops, shops, benches, trees for shade, public toilets and improving pavements and allowing more time to cross the road all encourage older people to move and, hence, maintain good quality of life standards. More in general, the natural and the built environments should be prepared to be available for users with low level of mobility capital, rather than being conceived for an average adult person. That makes a challenge to improve elderly quality of life in all spheres of urban society. These statements represent the hypotheses of the whole research work.

In this chapter, a review of worldwide literature of urban accessibility definitions and measures is discussed, and the main trends and research gaps are pointed out, through bibliometric and statistical analyses, structured by authors' affiliations and countries. They were run in R Studio environment through a tool, developed in 2017, named bibliometrix (Aria & Cuccurullo, 2017).

The number of academic publications concerning urban accessibility has grown exponentially to remain current with everything that is being published about this multidisciplinary and complex topic. According to Scopus database, in the field of Urban Studies and Social

Sciences, from 1959 to January 2020 about 6,000 documents were published on the theme, including articles, books, conference papers, with an average annual percentage growth rate of 7.5%. Furthermore, interesting insights could be highlighted studying the academic geography on the topic.

Following this introductive paragraph, the urban accessibility topic is deeply investigated: paragraph 3.2 is dedicated to the accessibility paradox and to the reasons that brought the scientific academia to further investigate this topic; the third paragraph (3.3) presents a systematic review of the relevant literature regarding the development of the accessibility concept during the 1959-2020 period; paragraph 3.4 and 3.5 are dedicated to the main traits of accessibility paradigms and measures, based on an in-depth literature review, highlighted by the statistical and bibliometric analyses. In the conclusion paragraph, key-elements of the topic are highlighted, as they represent the path for the further developments.

3.2 The paradox of urban accessibility

Historically, nobody has been responsible for ensuring that people can get to key services, employment sites, places of interest, etc. and, as a result, services have been developed with inadequate attention to accessibility (Farrington J. & Farrington C., 2005). At the same time, accessibility has been often seen as a problem for transport planners to solve, rather than one that concerns and can be influenced by other organizations, for example by locating, designing and delivering services that are easily and conveniently available (Social Exclusion Unit, 2003). Although urban environments have significantly changed their forms and structures, for a considerable long time, the city did not change its main defining characteristic: people with heterogeneous needs and characteristics living in a certain and well-defined urban structure, sharing facilities and activities. During the last century, this frame was completely upset by the widespread of new mobility systems, especially by the increasing use of private cars. This deep changing, started in USA and then in Europe, brought to a process of metropolitan growth to suburban areas (Caglioni et al., 2006; Schneider & Woodcock, 2008). Furthermore, financial and economic events, the global capitalism, the rise of Internet increased the sprawl of activities and people on a wide urban territory (Townsend, 2011), despite first innocent predictions.

Although some services tend to keep a proximity attribute, such as educational systems and infant care (Levasseur et al., 2015; Meşhur, 2016), the strength of privatization processes, rationalization and relocation tend to drop an even higher number of activities from residence: family-based corner shops are replaced by great distribution structures; places out of municipality boundaries are becoming distribution spaces of productive units, shopping and leisure centres. The consequences of these phenomena on the transportation system are significant, deeply transforming people lifestyle, especially for those dwelling in suburbs. Mobility phenomenon has increased even more, in terms of growth of number of movements, daily travelled distances, time spent moving and actors involved. Looking at the Italian scenario (ISTAT, 2018), everyday 30 million people move to get from their residences to work or study places: over one third of them (35.5%) move for work purposes, while 18.5% of them move for study reasons. About one in five people (19.1%) chooses an active mode to move: 17.4% walks to work or study places, while 1.7% uses a bike. The share of people that move by foot slight increases, from 16.2% in 2007 to 17.4% in 2019, while the use of private car, the most common mode of transport, is broadly stable. Public transit is used by only 8.0% of people that make daily movements. The Italian Institute of Statistics (ISTAT, 2019) proved that there was a decrease of 5 minutes on the journey average in an ordinary weekday (1h 16 minutes) during 2019, with respect to data collected in 2014. This value is in line with the European average, with Germany and Estonia. The European country with the lowest time spent for movements (less than 1 hour) is Romania, followed by Greece and Hungary, while the highest (1h and 32 minutes) is recorded in Luxemburg, followed by Netherlands and Norway (EUROSTAT, 2013). For what concerns the Italian scenario, although the reduction recorded for the mean value, many differences are highlighted for some categories such as working mums or suburban residents, whose movements are sensibly longer than the national average (respectively 1h and 32 minutes and 1 hour and 39 minutes) (ISTAT, 2018). These data hide a widespread forced mobility that can be translated in high individual and collective costs: mobility, indeed, is neither a necessary nor a sufficient accessibility condition (Legacy et al., 2019). A city with great mobility concerns, such as congestion and pollution, can have a good accessibility if its inhabitants live close to the main activities; at the same time, people can have a bad access to urban services even in case of great mobility infrastructure. Having a greater accessibility means having a greater degree of freedom when choosing between available resources and activities. Considering technology and society developments, during the last century, worldwide policies were much more mobility-based rather than oriented towards the accessibility paradigm (Banister, 2019): they focused (and still focus) on transport infrastructure capacity, underestimating the relevance of the land-use and activity systems. As a result, cities' dwellers and users are now facing a deep lack of accessibility, which figures among the challenges that urban environments have to face during the current century.

It may seem a paradox, because, since its birth, accessibility to activities and places for a wide and heterogeneous group of people has been one of the essential and inalienable traits of urban life (Amin, 2006). From the second half of the XX century, the spatial structure of the urban systems deeply changed, because of the technology innovations, the well-being growing and the changes in family lifestyles. The land-use system, the metropolitan functions allocation, the transport system configuration, as well as the multiplication of space-temporal fractures bring, as a result, uncertainties, lack of transparency and inadequacy. Urban complexity and its spatial and temporal fragmentation (Gargiulo, & Papa R., 1993; Fusco et al., 2017) make mobility more difficult and fruition times longer, creating new forms of exclusion. In this view, the paradox is only apparent.

The principle of accessibility is clearly raised in order to adapt cities to these challenging and wide phenomena. Hence, accessibility cannot be assessed as a simple count of facilities or services by some geographical units, without regard to factors such as spatial externalities, the structure of the transport network and the choice behaviour of travellers, the frictional effects of distance, properties of the supply side and measurement issues related to the large scale of analysis. The concept of accessibility, which will be defined in paragraph 3.4 and calculated in paragraph 3.5, is a broad concept through various aspects including physical, psychological, economic and social features, which can be dependent on per capita land use and transport network. Through this lens, this idea of accessibility is quite far from the notion of place-based accessibility traditionally used in transport studies, namely related to the costs needed to reach a destination. Following, a bibliometric and statistical analysis of worldwide literature is presented. The main traits developed by these analyses were useful to identify common accessibility definitions in the scientific panorama, as well as some significant accessibility measures.

3.2.1 A worldwide literature scenario: a bibliometric analysis

This paragraph presents the results of an extensive and systematic literature review of journal articles, and conference papers published within the 1959 and 2019, from the Scopus database. Between the main bibliographic multidisciplinary databases (CrossRef, Dimensions, Microsoft Academic, etc.), Scopus and Web of Science are the ones supported in bibliometrix, the R-studio tool used to carry out the bibliometric analyses. Since no software currently allows the merging of both databases and due to the high overlapping rate among them, we preferred to use Scopus because it has a greater number of documents then Web of Science (27 M vs 22.9 M) and because it has a better management of BibTex files than the latter. Figure 3-1 below summarizes the working flow used to select the elements in the sample, which refers to a Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) diagram (Liberati et al., 2009).

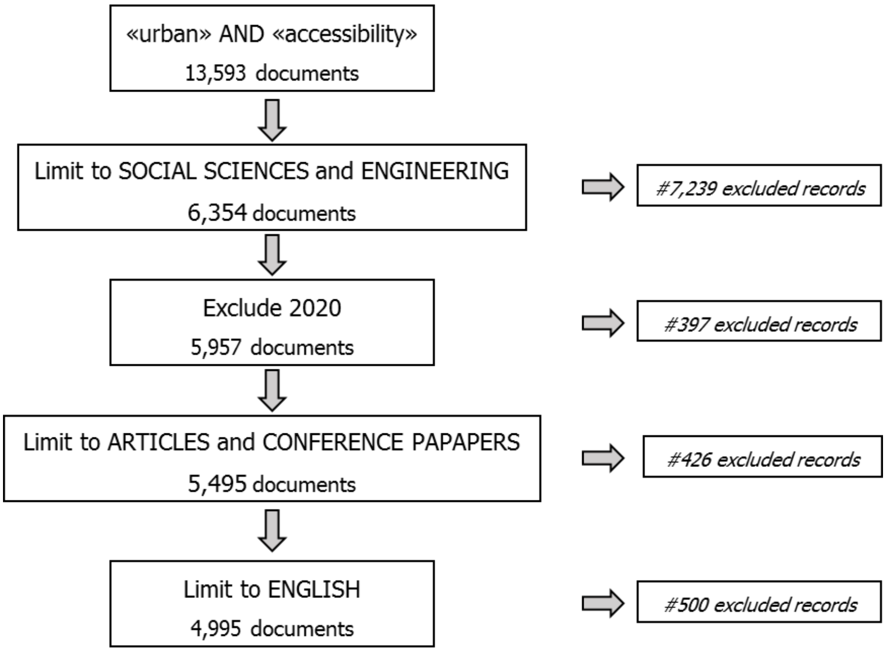


Figure 3-1. PRISMA diagram describing the workflow of documents selection (author's elaboration)

The workflow described in the above figure aims at defining a minimum set of items, in order to improve meta-analyses and systematic review. The documents were automatically selected as they contain the words "urban" and "accessibility" in their title and/or keywords, and/or abstract. Then, the results were limited to the fields of Engineering and Social Sciences to select the documents for the bibliometric analyses. Also, the sample was limited only to articles and conference papers. For what concerns the language only English records were chosen, in order to provide an international scientific panorama to the review. According to this selecting procedure, the SCOPUS dataset contains almost 5,000 documents.

Additionally, the average citation count per article is 13.88 while the median is equal to 3, and the curb shows a Pareto's distribution: the number of citations is inversely proportional to its frequency. For what concerns the authorship, the dataset contains 1,467 single-authored articles on urban accessibility. The other 4,495 articles are co-authored by a total of 12,670 different individuals. The average number of co-authors per article is 2.81, which suggests that scientific products concerning urban accessibility tend to be the result of collaborative research efforts. Table 3-1 below presents the summary of bibliographic statistics for urban accessibility documents indexed in SCOPUS, for the 1959 – 2019 period. The trends revealed in Figure 3-2 correspond with the integration of the urban accessibility concept into government policies and consequently the expansion of its research, in scientific field. This shift is mostly due to the United Nations Convention on the Rights of Persons with Disabilities which became effective in May 2008. Its purpose was to ensure that the estimated 650 million people with disabilities worldwide could enjoy the same rights and opportunities as everyone else and lead their lives as full citizens who can make valuable contributions to society. For the first time accessibility is defined as the integration of many human rights, from matters of work and employment to participation in political and cultural activities. The 2008 Convention recognized the importance of accessibility to the physical, social, economic, and cultural environments, including health, education and ICT, demanding implementation from governments and local authorities.

Data	
Documents	4,983
Sources (Journals, Books, etc.)	1,259
Author's Keywords	9,851
Period	1959 – 2019
Average citations per document	17.12
Authors	11,258
Authors of single authored articles	1,001
Authors of multi authored articles	10,257
Documents per Author	0.443
Authors per Documents	2.26
Co-Authors per Articles	2.91

Table 3-1. Summary bibliographic statistics for urban accessibility journals indexed in SCOPUS, 1959– 2019.

Similar shifts have occurred at the local level and the international level, as suggested by clustering the whole sample, according to the country affiliation of authors.

The review, through bibliometric analyses run for different clusters of the whole sample of documents, discusses different aspects of accessibility literature at different scales. First, the temporal and geographical evolutions of the studies are examined. Second, considering the most cited documents and authors, a collection of definitions is presented. Finally, since the main objective of literature review is to build a scientific frame in order to develop innovative planning tools to support decision-making processes, a deep insight is given to accessibility measures to urban services.

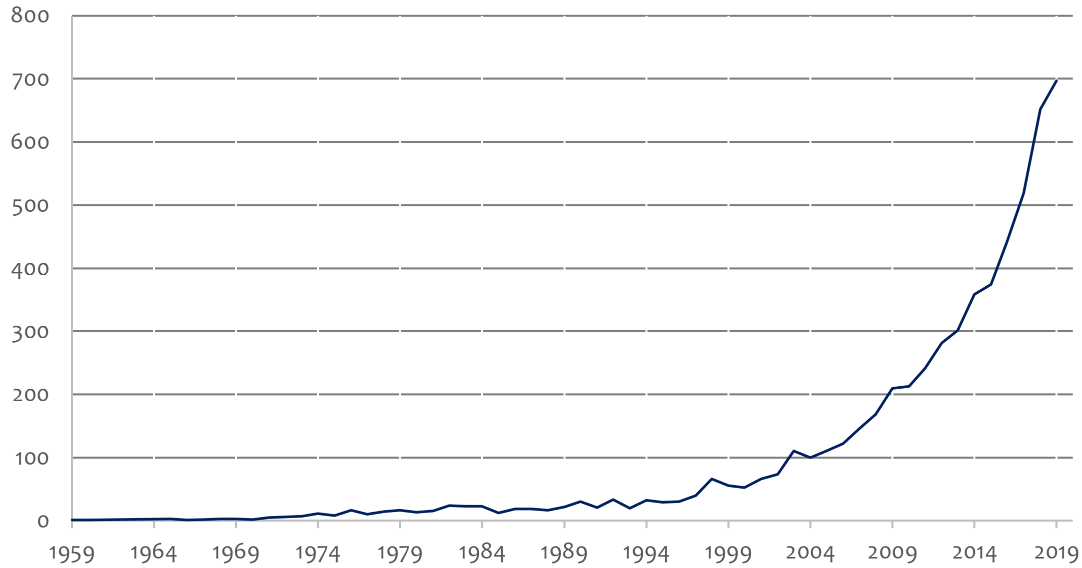


Figure 3-2. Annual number of urban accessibility documents published in SCOPUS, 1959–2019

The large sample of documents from the Scopus database was analysed using a R-tool named *bibliometrix*, developed by Aria and Cuccurullo from University of Naples Federico II in 2017. This statistical tool is very helpful in mapping science, providing a structured analysis to a large body of information, to infer trends over time, researched themes, identify shifts in the boundaries of the disciplines, and to detect most the prolific scholars and institutions. Several analyses were run, in order to review the evolution of scientific literature both in temporal, within 60 years of research production on the theme, and spatial frames, clustering documents according to their country affiliation (North America, China and European countries are the places where the most productive institutions are located, as highlighted below). In the 1959 – 2019 period, accessibility studies were geographically distributed as follows: 24.4% of them were performed in North America (USA and Canada); 18.9% of documents were produced in European countries (United Kingdom, Spain, France, Netherlands and Italy are the more productive countries) and 5.6% were developed in China. The sum of the scientific products of these three regions represents the 50% of the world scientific production on the topic of urban accessibility. On the basis of the geographical distribution of scientific productions, the percentages above suggest that accessibility has not received enough attention in developing countries, most probably due to particular urbanization dynamics and planning practices, at regional and urban levels. In fact, a Sankey plot was obtained from *bibliometrix* analyses (Figure 3-3) in order to identify the main research contents and their intellectual and geographical routes: the three-fields plot is helpful to highlight main relationships between most frequent Keywords, their Country Affiliation and Scientific Sources.

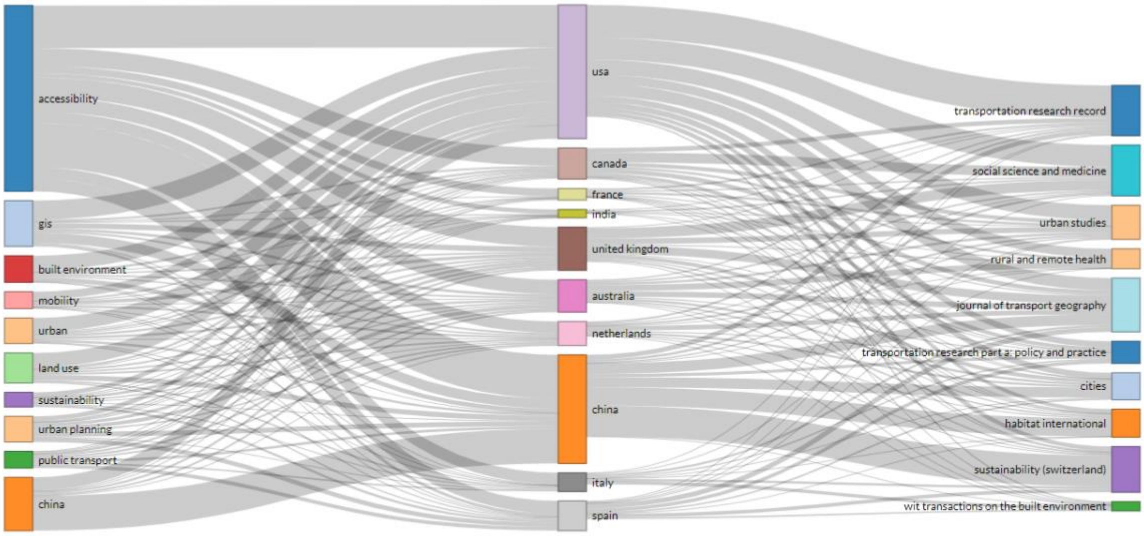


Figure 3-3. Relationship among most frequent Keywwords, Country Affiliations and Sources

Figure 3-3 is also helpful to define the weight in the scientific panorama of both country affiliations and urban accessibility main topics. It is worth noting that North America (USA and Canada) and China have both a key-role defining the academic routes of accessibility.

Rank	Keywords	Frequency
1	ACCESSIBILITY	683
2	GIS	148
3	CHINA	104
4	LAND USE	94
5	URBAN PLANNING	91
6	PUBLIC TRANSPORT	88
7	BUILT ENVIRONMENT	70
8	MOBILITY	68
9	SUSTAINABILITY	66
10	URBAN	63

Table 3-2. Author's keywords ranking for urban accessibility documents indexed in SCOPUS, 1959-2019

At the same time, looking at the right side, sources like "Social Science and Medicine" or "Rural and Remote Health" show that the topic at the base of this systematic literature review is not only related to urban and mobility studies, but it also concerns health and wellbeing issues that cannot be neglected. The next step of the bibliometric analysis investigated the most recurring keywords, in order to further investigate the accessibility definitions and their temporal and spatial inclinations and developments. The ten most prevalent keywords associated with the articles in our dataset are identified in Table 3-2.

The keywords analysis was done in two parallel ways. The first was run on five different groups of documents, according to their publication year. The first period falls between 1959 and 1980, when the number of urban accessibility publications totals about 70 records. The average number of published documents for this period is 4.3. The second period falls between 1981-1990, when the number of documents published increased to 173, with an average production per year of 17.3. During the third period, the number of scientific documents concerning urban accessibility increased to more than 300 with a year production, on average, of 32.7 documents. The 2001-2010 period recorded a number of documents close to 1,100. The average number of published documents for is 108.6. The last period (2011-2019) sample contains more than 3,000 documents and recorded an average publication per year equal to 369.3. Table 3-3 presents a summary of the sample classification, according to the year of publication. This classification results from some considerations related to many interesting and significant historical events (economic booms, social crisis, publication of fundamental documents, etc.) that have certainly influenced urban and social studies, as well as the accessibility paradigm evolution.

Period	N. documents
1959-1980	73
1981-1990	173
1991-2000	327
2001-2010	1086
2011-2019	3324

Table 3-3. Sample classification per year of production

Indeed, the second keywords analysis was run on three groups of documents, classified by their affiliation country, in order to highlight the main trends of the research on the topic from the European, North American and Chinese perspectives, since they represent about the 80% of the world scientific production on the theme.

Region	N. documents
North America (USA and Canada)	1702
Europe	1592
China	568

Table 3-4. Sample classification per country

Keyword co-occurrence of each manuscript can effectively reflect the hotspots in the discipline field, thus providing auxiliary support in scientific research on the topic. In fact, the temporal segmentation of the whole sample of documents brought to interesting insights due to some significant differences between the ten most recurring keywords for the five periods. For the first cluster of documents (1959 – 1980), the most relevant keywords are "population", "urban planning", "developing countries" and "health services accessibility" as reported in Table 3-5 below. This means that the accessibility concept was closely related to population and their location, in rural or urban environment. Moreover, the issue starts being related to healthcare provision rather than with the whole urban system and that it was considered an essential form of equity between citizens. The presence of the words "Asia" and "developing countries" means that documents from this period were strongly influenced by this matter, even though their production comes mostly from USA, United Kingdom and France.

Rank	Keywords	Frequency
1	POPULATION	14
2	URBAN PLANNING	13
3	RURAL POPULATION	12
4	ASIA	11
5	HUMAN	11
6	URBAN POPULATION	11
7	DEVELOPING COUNTRIES	10
8	HEALTH SERVICES ACCESSIBILITY	10
9	HEALTH	9
10	INFRASTRUCTURE	3

Table 3-5. Author's keywords ranking for urban accessibility documents indexed in SCOPUS, 1959-1980

For the second group of documents (1981 – 1990), the most recurring keywords are still closely related to demographic issue and to health provision system: "population", "demography" and "health services accessibility" are the most frequent. (Table 3-6).

Rank	Keywords	Frequency
1	ACCESSIBILITY	95
2	POPULATION	77
3	URBAN POPULATION	74
4	HEALTH SERVICES ACCESSIBILITY	63
5	POPULATION DYNAMICS	54
6	DEMOGRAPHY	53
7	DEMOGRAPHIC FACTORS	47
8	HUMAN	45
9	UNITED STATES	45
10	DEVELOPING COUNTRIES	44

Table 3-6. Author's keywords ranking for urban accessibility documents indexed in SCOPUS, 1981-1990

Although the 1981-1990 period is significantly different from the 1959-1980 period, which also lived many fundamental historical events that shaped contemporary age (e.g., 60's economic boom and then 70's crisis), it seems that the academic notion of accessibility is still close related to demographic and population dynamics more than with urban system's issues.

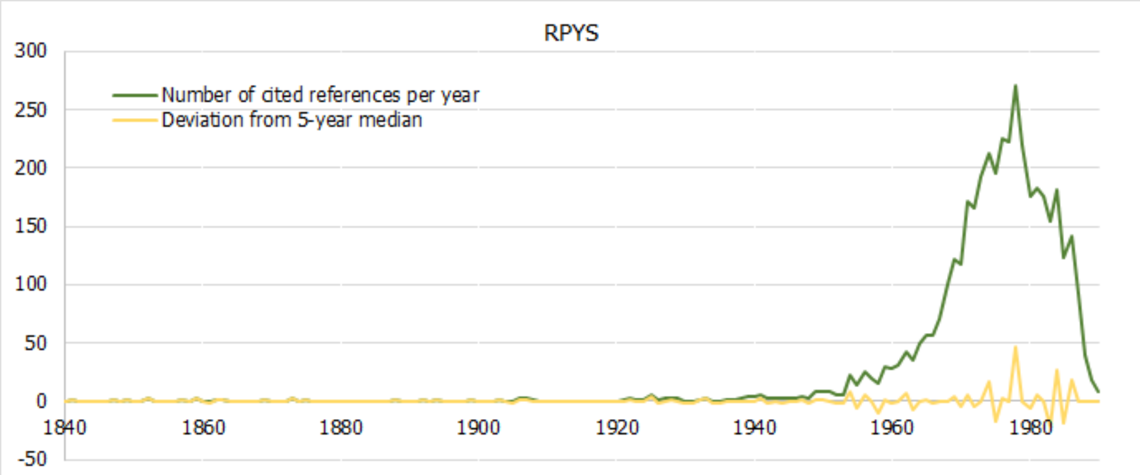


Figure 3-4. Reference Publication Year Spectroscopy (RPYS) for 1959-1990 period

The Reference Publication Year Spectroscopy (RPYS) of the first two periods confirms how the academic evolution of urban accessibility paradigm was deeply influenced by economic and social phenomena. Figure 3-4 above shows the RPYS plot: it represents the temporal profile of cited references for a set of papers, that emphasizes years where relatively significant finding were published. Its method, developed by Marx et al. in 2014, is helpful for identifying historical origins and academic roots of a discipline. This analysis was used to identify key publications, according to peaks of both curves, which represented kind of milestones developing the urban accessibility paradigm in the academic panorama.

For what concerns the third period of analysis (1991-2000), it is worth noting that, within the most frequent keywords, there are "female", "adult", "male", "adolescent" which represent a step forward in defining urban accessibility according to different groups of people. This information may lead to significant consideration: according to the principle of quality of life, that began to impose itself in the choices of urban planning and management during 90's, there cannot be a unique and universal urban accessibility definition since it must take into account different people's needs and vulnerabilities in urban environments.

This may reflect the development of a different perspective to urban accessibility concept, which becomes affected both by the urban form and by the land use system, also thanks to the wide spread of Geographical Information Systems (GIS), developed at the end of XX century. This confirms that the knowledge of space and its representation in GIS environment are essential elements to thoroughly investigate the accessibility concept and to integrate it in urban planning practices. Moreover, it is worth noting the word "sustainability" which underlines that, at least in the academic scenario, the accessibility concept is being developed according to the sustainability perspective and consequently with referment to the reduction of use of non-renewable, or difficult to renew, resources, including land or infrastructure (Bertolini et al., 2005).

Rank	Keywords	Frequency
1	ACCESSIBILITY	110
2	FEMALE	100
3	HEALTH SERVICES ACCESSIBILITY	87
4	HUMAN	85
5	ADULT	77
6	URBAN PLANNING	77
7	MALE	70
8	UNITED STATES	66
9	URBAN POPULATION	61
10	ADOLESCENT	54

Table 3-7. Author's keywords ranking for urban accessibility documents indexed in SCOPUS, 1991-2000

For the four period of analysis (2001-2010), the most frequent keywords significantly change, as reported below, in Table 3-8.

Rank	Keywords	Frequency
1	ACCESSIBILITY	321
2	GIS	312
3	LAND USE	256
4	URBAN	254
5	URBAN FORM	247
6	CHINA	246
7	MOBILITY	238
8	URBAN PLANNING	222
9	RURAL	201
10	SUSTAINABILITY	191

Table 3-8. Author's keywords ranking for urban accessibility documents indexed in SCOPUS, 2001-2010

The annual percentage growth rate of the 2001 – 2010 period is of almost 14%. The more productive countries are still USA, UK and Canada, with respectively 26.2%, 6.3% and 6% of documents produced for the first decade of XXI century. In the fourth place, with more than 5% on the total of worldwide scientific production, there are Chinese institutions, which started playing a key role in developing contents concerning urban accessibility.

In fact, for the third analysed period, with an annual percentage growth rate of about 13%, scientific production of Chinese affiliations doubled in half of the time, compared to the previous ten-years period. USA remains the more productive country with more than 17% of total scientific production, while Italy and other European countries (such as Spain, France and Netherlands) start having a more significant role in the global scientific panorama.

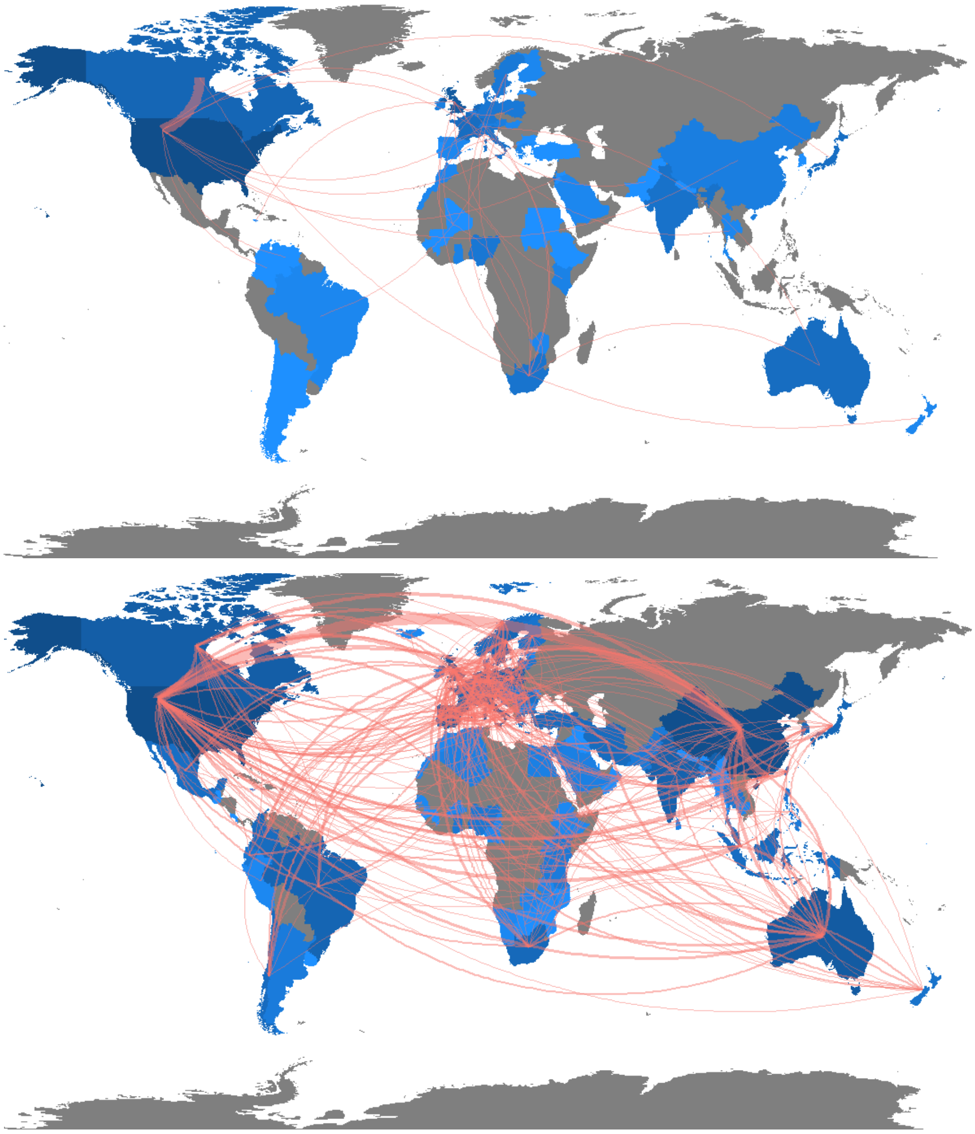
Moreover, it is worth noting that 2011-2019 period is the most numerous sample of analysis. From the keyword analysis, it appears the strong occurrence of "mobility", "land use" and "urban planning" issue when dealing with accessibility matter, as shown in Table 3-9 below.

Rank	Keywords	Frequency
1	ACCESSIBILITY	317
2	GIS	81
3	LAND USE	44
4	MOBILITY	43
5	URBAN PLANNING	41
6	CHINA	39
7	PUBLIC TRANSPORT	35
8	BUILT ENVIRONMENT	33
9	SPACE SYNTAX	31
10	BEIJING	26

Table 3-9. Author's keywords ranking for urban accessibility documents indexed in SCOPUS, 2011-2019

Hence, the bibliometric analysis of scientific productions shows a coherence with the development of the main policies and instruments of the years considered. The R-tool was used to perform other analysis on the same sample of products, divided according to their country affiliation, as explained above. This second way of analysis was run to highlight potential geographical trends on the topic of urban accessibility, and their strengths.

The countries selected for the second analysis are characterized by a wide variety of urban forms, spatial and urban transportation structures, as well as associated social and economic systems: the dense urban cores of many European and East Asian cities, for example, enable residents to make between one third and two-thirds of all trips by walking and cycling; on the other end of the spectrum, the dispersed urban forms of most North American cities, which were built more recently, encourages automobile dependency and are linked with high levels of mobility; still, Chinese cities have experienced a high level of motorization, implying the potential of convergence towards more uniform urban forms. Consequently, the accessibility paradigm has been differently developed and applied to real world practices. However, Figure 3-5 shows how the accessibility issue was contaminated, internationally and intercontinentally, involving developed and developing countries. In fact, the improvement of accessibility in urban areas is an aim that has now made its way into mainstream transport planning and policy making worldwide.



(a)

(b)

Figure 3-5. Elaborations from biblioshiny: Collaboration WorldMap for scientific products developed within 1959 and 2000 (a) and within 2016 – Jan 2020 (b)

For what concerns urban accessibility research in USA, the analysis was carried out for more than 1,700 documents, which have an average citation per article equal to 24.9. Some of the most cited documents focus on the potentialities of spatial analysis tools (Ewing & Cervero, 2010; Proffitt et al., 2019), developed in GIS environment, to explore the relationships between the build environment and mobility. The statistical analysis classified the authors keywords in three main clusters: the first one refers to land use and transport planning, which are both recognized as the main features to define accessibility; the second cluster contains words related to age and gender of population, which shows the strong influence of accessibility on the individual perceptions; the third words cluster refers to socioeconomic and demographic context, which also plays a key role in urban accessibility research.

For what concerns the European context, almost 1,600 documents were produced, with an average citation close to 10. As the most cited articles show, much more attention has been paid to the sustainability paradigm (Bertolini et al., 2005; Mayaud et al., 2019) and walkability (García-Palomares et al., 2013; Lamíquiz & López-Domínguez, 2015) as two key elements defining urban accessibility. In fact, two main keywords clusters were identified through the bibliometric analysis: the first one concerns, as for the USA, land use and transport systems but words like "sustainable development" and "smart city" prove a different approach to the research topic.

China is the third productive country, 568 documents that collected an average citation equal to 7.5. As for Europe and USA, the keywords analysis shows that accessibility concept is closely related to urban and transport planning. A third word cluster refers to interesting and significant applications, mainly focused on measurement of accessibility to grey infrastructures, such as high-speed rail (Wang et al., 2009; Shaw et al., 2014), green areas, learning centres, etc.

These first statements represent the premise to further analyse the broad concept of urban accessibility, and all its multidisciplinary features, which will be in depth explained in the following paragraphs. The more cited products were selected from the whole sample of documents in order to define lines of research, through space and time, both for definitions and computational measures of urban accessibility.

3.3 The paradigm(s)

Accessibility is often defined as the number of places that can be reached within a given travel time and/or cost (Bertolini et al., 2005). Hansen (1959) defined accessibility as the different possibility/ability to negotiate space and time in the everyday life to accomplish practices and maintain relationships that people take to be necessary for normal social participation. According to Hansen (1959), a greater accessibility among a society is a means of achieving greater social inclusion, social justice and hence, social sustainability. Geurs and van Wee (2004) give another gateway to accessibility, as the extent to which the land-use and the transport system enable (groups of) individuals or goods to reach activities or destinations by means of a (combination of) transport mode(s). This definition suggests that accessibility is closely related to the interplay between transport system and land use pattern and is used when referring to a location's perspective. Bhat et al. (2000) define accessibility as a measure of the ease of an individual to pursue an activity of a desired type, at a desired location, by a desired mode and at a desired time.

According to scientific literature, different physical, social, physiological, and economic variables need to be taken into account. Four types of components can explain the accessibility paradigm:

- the land-use component, which is made by both demand characteristics, such as people origin locations, and the supply system features (activities, jobs, services, etc. within the study area).
- the land-use component, which is made by both demand characteristics, such as people origin locations, and the supply system features (activities, jobs, services, etc. within the study area);
- the transportation component, which is made, as well as for the land-use component, by both supply and demand systems, in order to define accessibility, in terms of passengers (or freight) and in terms of network infrastructures and generalized costs (pocket money, travel time, comfort, etc.);
- the individual component that considers people's needs, abilities and opportunities (annual income, age, household car-ownership, etc.);
- the temporal component which is useful to match transport and activity schedules to the individuals' available time, to participate in certain activities.

Figure 3-6 below shows the main relationships between components. Accessibility needs to relate to changes in travel opportunities and land-use, in constraints on demand activities and/or personal capabilities and limits; it should also consider personal access to travel and land-use opportunities.

The main consequence of this multidisciplinary and complex approach to accessibility issue is the hiatus between rhetoric and real practices. In contrast, the mobility paradigm assesses empirical measures that are easier to compute and to interpret (road or transit capacity, travel frequencies, level of service, etc.), but they are not able to holistically consider the urban environment.

Moreover, the accessibility paradigm considers mobility and proximity both as parts of it, in tension with one another (Weast & Proffitt, 2018). In fact, densifying urban areas and mixing uses, to bring origins closer to destinations (or vice versa), could result in decreasing vehicle congestion but increasing in pedestrian congestion and non-roadway users; indeed, pursuing auto mobility improvements could decrease accessibility over the long term by including more vehicle trips and encouraging sprawling development that increases dependence on automobiles. This is a cause-and-effect loop.

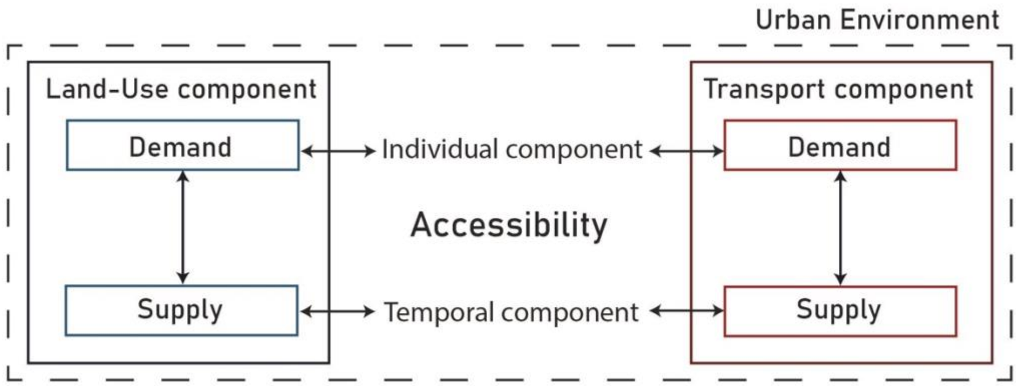


Figure 3-6. Accessibility components (author's elaboration)

In the light of this, accessibility measures need to be designed considering three different criteria: strong theoretical basis, to take into account the multidisciplinary aspects of the accessibility concept; easy operationalization, so that the measures can be used in practice policies; they also have to be easy to interpret and communicate, in order to use them in social and economic evaluations.

Next paragraph summarizes the main developed accessibility measures, highlighting for each of them advantaged and drawbacks.

3.4 The measures

The systematic literature review, supported by bibliometric statistical analysis, was helpful to highlight some of the main scientific products developed on the theme. Since the main purpose of this study is to design an accessibility-oriented planning tool for local authorities, the research through SCOPUS database was further improved, to highlight some of the scientific measures developed to assess accessibility to services in urban environments. This paragraph presents drawbacks and advantages of the most used and studied measures, in order to develop a methodology and implement it in urban and transport planning practices.

During last decades, scientific literature developed several accessibility measures. They vary a lot for main objective, theoretical basis and application: usually, the more they tend to include urban system features, the more they are complex both to compute and interpret. Following, a review of the most used measures is presented.

Contour measures (or opportunity measures, or isochrones measures) define catchment areas by drawing one or more travel time contours around a node and measure the number of available opportunities within each boundary. The general formula of contour measure is reported below:

$$Acc_i = \sum_{j=1}^{n} W_j \qquad \text{Equation 3-1}$$

The accessibility around the node *i*, Acc_i, is the sum of the opportunities represented by *n* zones *j*. The weight W_j is equal to 1, if C_{ij} (monetary cost, distance, or travel time between *i* and *j*) is lower than a threshold C_{ij}*, or 0 otherwise. This measure takes into account the land-use component and infrastructures constraints, by using, for example, travel time between two zones as indicator for impedance, even though the definition of travel time contours can be arbitrary, and it could be difficult to differentiate it in relation to different activities and travel purposes. On the other hand, this measure is easy to compute and interpret.

Gravity-based measures (or potential accessibility measures) were introduced in scientific literature field during the late 1940's. Since then, they were widely used in social and geographical studies, defining catchment areas by measuring travel impediment on a continuous scale. The general formula of gravity-based measures is reported below:

$$Acc_i = \sum_{j=1}^{n} a_j \times f(C_{ij}) \qquad \text{Equation 3-2}$$

The accessibility around a node i is the sum of the opportunities in *n* zones *j* (a_j), multiplied by an impedance function *f(Cij)*, depending on distance, travel time, efforts or monetary costs. In literature, several impedance functions were developed to evaluate accessibility such as power, Gaussian or logistic functions; the most used is the exponential function since it is more closely related to travel behavior theory.

$$f(C_{ij}) = e^{-\beta C_{ij}} \qquad \text{Equation 3-3}$$

The measure evaluates the combined effects of land-use and transport elements and incorporates assumptions on a person's perceptions of transport by using a distance decay function. One of the main drawbacks is that this method neglects the variations across individual living in the same area. Despite this disadvantage, gravity-based measures are the most used in academic and practical fields because they can be easily computed using state-of-practice land-use models and transport demand models.

Utility-based measures interpret accessibility as the outcome of a set of travelers' choices. They are able to measure individual or social benefits on accessibility, even in monetary terms. Utility-based measures have a sound theoretical ground, because of the Domencich and McFadden (1975) random utility theory: it is founded on the assumption that people select the alterative with the highest utility:

$$U_{k|n} = V_{k|n} + \varepsilon_n \quad \text{Equation 3-4}$$

The perceived utility ($U_{k|n}$) of the alternative k for the decision-maker n is the sum of systematic utility ($V_{k|n}$), depending on choice cost attributes (travel time, pocket money, etc.), and a random rate ε_n. The outputs of utility-based models are the probabilities of choice within the set of perceived alternatives, and they vary a lot in relation to the statistical distribution of the random rate ε_n. In this framework, the choice set is given and no variability in individual behavior can be modelled. A utility-based accessibility measure is the logsum, the denominator of Multinomial Logit model (MNL).

$$Acc_i = ln(\sum_{k=1}^{m} e^{V_k}) \quad \text{Equation 3-5}$$

The main drawback is that measures obtained with different specification of ε_n cannot be compared.

The explained measures vary a lot for what concerns main hypotheses, application as well as results. What all these researches have in common is that, when dealing with C_{ij} (cost to reach destination j from origin i), they do not only refer to monetary costs or travel distances, but they also take into account living and walking environments, number of available activities, safety and security issues, overall congestion level, etc. The complexity of the urban system is the main hypothesis at the base of the methodology we are working on. Hence, with respect both to infrastructure and activity demands and supplies, we deepen our knowledge about methods and procedures to assess urban accessibility, also in real-word practices. In the scientific panorama the floating catchment area (FCA) method is one of the most recent and popular approaches to measure spatial accessibility. It is a special application of a gravity model, with its main positive aspects, proposed for the first time by Radke and Mu (2000). Since then, the FCA method was modified and improved several times and mostly used in healthcare access researches (Hu et al., 2012; Ahn et al., 2014; Ding et al., 2015; Tao et al., 2018) public transport (Langford et al., 2012; Kanuganti et al., 2016) and green areas (Dony et al., 2015). In fact, the method evaluates access to a service site in terms of provision (with variables describing the supply side) and need (considering the social features of the demand) as well as the distance between them to identify unserved areas, which make the FCA method a great candidate to investigate the spatial accessibility for the elderly.

3.5 Takeaway for improving urban accessibility for the elderly

The present chapter gives a comprehensive overview about urban accessibility literature and its current research status, in order to introduce its assessment in planning practices. The systematic literature review presented in this chapter aims at defining the scientific frame for wider research oriented to develop accessibility-oriented urban planning tools to improve elderly's quality of life within urban areas.

According to the survey, made of almost 5,000 scientific documents (articles, and conference papers), accessibility to essential services in urban areas has gained greater attention in recent decade, due to ever increasing interest in planning practices. By dividing the whole sample of documents in different groups, according to their year of production and country affiliation, and then by applying a keywords analysis, findings showed that the term "accessibility" has been differently associated to broad and heterogeneous concepts. In fact, the extensive and systematic literature review, whose main results have been reported in this document, shows that for many years much of this scientific production has a deep theoretical nature, rather than practical. That was mostly due to difficulties in computing and introducing accessibility measures in decision-making practices. The advent of GIS has made much more practical the development of accessibility-oriented planning tools, and many commercial packages are now available. Furthermore, the systematic literature review highlights that accessibility is a function of the main urban accessibility components and of their interrelations, especially for what concerns the land use and transport systems. Urban infrastructures are notably fixed, while cities are dynamical entities, even if changes can take decades. Social and demographical changes will lead to different attitudes and needs, and urban places may eventually face spatial obsolescence. Accessibility-oriented urban planning practices may prevent this issue and enhance social equity and justice, considering personal mobility capitals especially of those who are more vulnerable than others.

The literature review presented in this paper represents a part of a wider research focused on the elderly quality of life within urban environment and aimed at designing innovative tools for both public administrations and elderly citizens. An interesting result of the systematic literature review is that urban accessibility to essential urban services from the elderly perspective is not yet statistically appreciable.

The research is focused on developing an accessibility-based tool to support decision-making processes in urban practices. The scientific experiences which are reported in the above paragraphs are some of the researches that I studied to design the methodology framework at the basis of the products. They were selected and studied in greater depth since they have potential to transform academic experiences in real world urban planning practices, supporting decision-making processes and, eventually, best practices. In fact, the scientific frame depicted in this chapter represents a summary of the hypotheses at the base of a wider research program: when dealing with urban accessibility for the elderly it is essential to provide a minimum level of quality of life, which depends on many features such as availability of essential services and activities, good walking environment as well as public transport infrastructures, high level of safety and security in cities. The challenge of the research project, and of its methodology in particular, is to include all these elements in a GIS-based methodology, in order to model the complexity of urban system, and, at the same time, transform it in a tool available for decision-making processes and procedures.

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CHAPTER 4. THE GIS-BASED METHODOLOGY

4.1 Introduction

This chapter is dedicated to the first theoretical result of the research work: a GIS-based (Geographical Information System) methodology for measuring urban accessibility. It has been designed to evaluate the level of accessibility to services and activities within a city. According to a broader concept of accessibility, the GIS-based method takes into account the mobility of the elderly, the land-use characteristics and the supply features of services, and their locations.

As highlighted in the previous chapters, the construction or the adaptation of existing cities to more age-friendly environments cannot neglect the improvement of accessibility to built and open and green spaces, services and activities. At the same time, innovative methodologies and tools must be available in order to integrate this approach into ordinary spatial and urban planning instruments.

According to National Geographic (2021), urban planning dates back to the 19th century when illnesses ran rampant through dirty, overcrowded cities. City planners deduced that situating people far from industrial centres, foul odours, and pollution would improve public health. During this time, zoning ordinances came into effect: separating urban areas into residential, business, and industrial districts. Some argue that, though there may have been health benefits, moving people further from their jobs increased reliance on cars: increasing traffic and air pollution. As such, modern city planning must consider things like bike lanes, walkability, and traffic flow.

While early city planners were generally concerned with rapid population growth and urban sprawl, modern urban planners are faced with the opposite issue. Most cities are not growing: many face population loss, while others are experiencing a definite generational shift as the population ages. Moreover, cities are complex and dynamic systems: even scheduled events can have unforeseeable effects on the subsystems that shape cities, both long and short term. Hence, urban planners need to do their best to plan for an unpredictable future. Therefore, the support of technological and innovative tools to guide the choices of decision-makers becomes essential to respond to the multiple and heterogeneous challenges of cities, also in real-time. Fortunately for today's urban planners, technology has advanced in a way that can effectively help.

Geographic information systems (GIS) have become an invaluable tool for urban planners, providing support for database creation, spatial analysis and modelling, and visualization.

Initially, the high costs of installation and operation stunted the adoption of GIS in urban planning. Since then, its adoption has increased as hardware has become less expensive while software got more user-friendly.

There are numerous benefits of using GIS in urban planning. The five main benefits are summarised below:

- Improved mapping. With a single repository for current and historical data and maps, GIS can improve map currency (whether or not a map is up-to-date), increase the efficacy of thematic mapping, and lower expenditures for data storage;
- Increased access to vital information. Desktop GIS makes it easier to store, manage, and access data from a variety of sources. Cloud GIS offers that same benefit while enabling access from any device;
- Improved communication. With a unified system for data storage and management, internal parties can access the information they need immediately - rather than sifting through documents, hard drives, or trying to track down data across departments;
- Increased quality and efficiency. GIS can be used to create a public-facing portal (such as WebGIS), opening the flow of information between government organizations and the public. Government officials can share information quickly, while members of the public have self-serve access to the information they need;
- Increased support for strategic decision making. Planners can create informed strategies more effectively with speedier access to a wider range of important geographic information. More than that, they can explore a broader range of 'what-if' scenarios - ideally leading to more effective long-term strategies.

GIS technologies provide these results to urban planners and policy-makers thanks to their ability to manage alpha-numeric and spatial data, map and visualize them, and run spatial analyses.

Database management is the creation, import, maintenance, and use of all data travelling in and out of a GIS platform. For urban planning, this trial involves storing environmental data, socioeconomic data, land use maps and plans, and planning applications. Cities produce huge quantities of data in many different formats and from heterogenous sources. GIS provides a single database where all that data can be stored and easily organized. Once data has been added to the database, urban planners can quickly use spatial queries to access the information and visualize it in thematic maps.

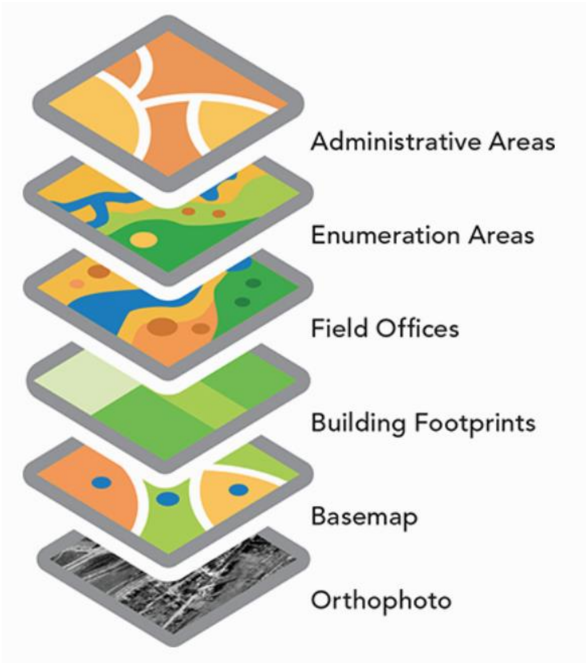

Figure 4-1. Thematic layers for organizing GIS database (https://people.utm.my/shahabuddin/?p=4541)

Desktop GIS and webGIS offer powerful mapping visualization tools, enabling planners to create maps (sometimes even in 3D). Environmental and socioeconomic data can help create these maps or add after the fact as a secondary data source. Digital maps make it easier for urban planners to make decisions and explore solutions.

Moreover, GIS in urban planning enables spatial analysis and modelling, contributing to various important urban planning tasks, including site selection, land use and transport modelling, the identification of planning action areas, and impact assessments. GIS functionality such as interpolation, buffering, map overlay, and connectivity measurement help urban planners to achieve these tasks.

The capabilities of GIS tools perfectly suit the knowledge, measure, and assessment of urban systems development: the possibility of simultaneously managing copious data sources and visualizing their main messages have made this technological innovation a fundamental ally of urban and territorial planning. The use of GIS has been differently declined in urban studies practice: some examples are given below.

For instance, GIS platforms, especially those used with remote sensors, decrease the time spent collecting land-use and environmental information. With remote images, urban planners can detect current land use, as well as changes to land use for an entire urban area. These images can also be used to create compelling visualizations with 3D CAD models.

Moreover, future land-use maps act as a community's guide to incoming infrastructure, build plans, and public spaces. These maps help ensure that a city's urban planning accounts for environmental conservation, pollution, mitigating transportation issues, and limiting urban sprawl.
Thirdly, with GIS, urban planners can quickly create maps of the city today and then use various modelling and predictive data techniques to explore scenarios for the future. Ideally, using this exercise to create a future land-use map that is thoughtful, sustainable, and sound.
Moreover, GIS can help the government and businesses process and organize planning applications. Many GIS portals can be made public-facing: citizens can access data such as parcel outlines and information, county/district boundaries, and area zoning. With vital information more widely available to all, government resources (which might have been spent fielding these requests and finding the data) can be used elsewhere.
Moreover, with all the applications stored in a central database, organization, processing, and status tracking become simpler.
Creating future land-use maps must take into account several environmental scenarios, as well as project future demand for land resources. Modelling must include population data, economic activities, and spatial distribution. The visual component of GIS makes analyzing location-based data (like socioeconomic and environmental trends) simpler and more effective. GIS enables thematic maps, i.e. maps that combine data and location with exploring correlation and display trends.
With data sets stored in a database, users can create layered images that include topography, street maps, thematic maps, and more - helping to identify ideal spaces and potential conflicts. GIS tools like map overlay enable urban planners to conduct land suitability analysis, an important step in site selection.
Remote sensing, spatial queries, and environmental data analysis help urban planners find areas of environmental sensitivity. By overlaying existing land development on land suitability maps, they can identify any conflict areas between the environment and potential development. GIS geoprocessing functions like map overlay, buffering, and spatial analysis help urban planners to conduct connectivity measurements. Connectivity refers to how easy it is to walk or bike in a given city. A highly connected area will give its residents numerous options to get from A to B quickly.

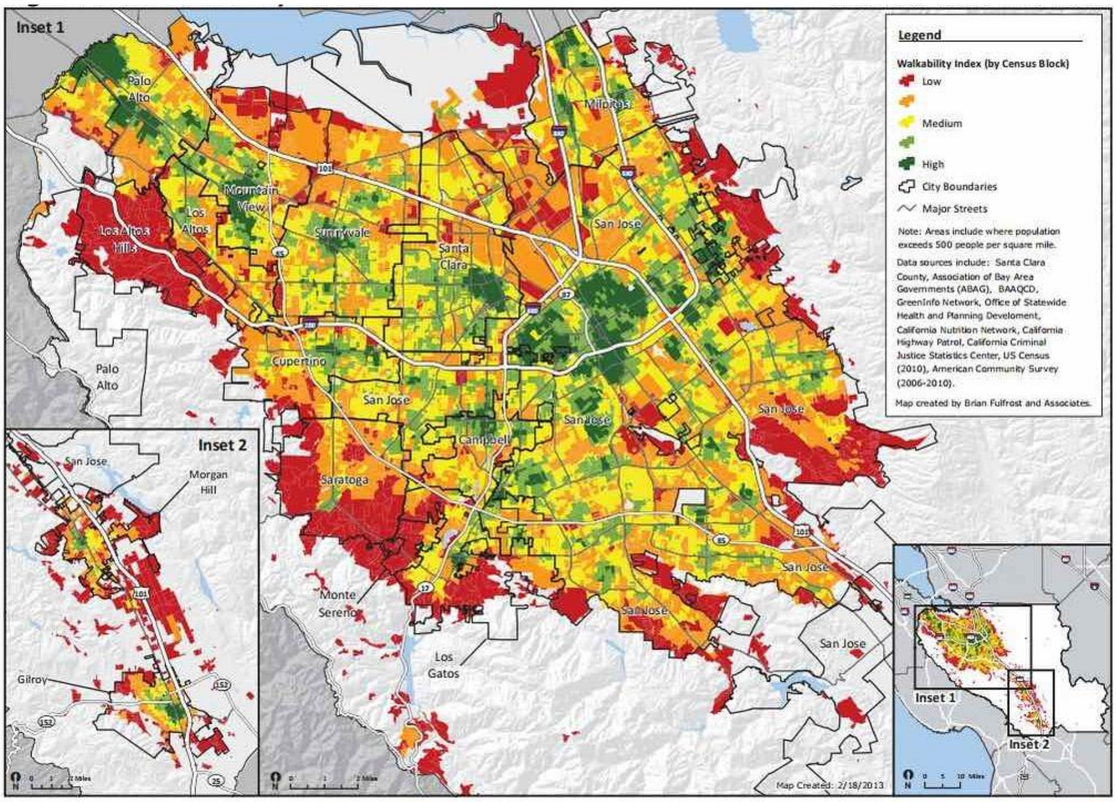

Figure 4-2. Walkability Index for Santa Clara General Plan Health Element, in existing conditions (https://www.sccgov.org/sites/dpd/DocsForms/Documents/HealthElement_Existing_Health_Conditions_FINAL_May_2013.pd)

Furthermore, an environmental impact assessment can be conducted to evaluate urban development's potential effects on the environment. If issues are found, the urban planner can then recommend ways to alleviate or mitigate negative outcomes.

Finally, GIS tools can help evaluate a building plan, monitor the project after completion, and even gather feedback to help make improvements. With remote sensing, GIS can help planners track if development is following the area's land-use plan. It can also help them evaluate the impact and suggest adjustments - if required.

In the light of the complexity and multidisciplinary nature of the concept of urban accessibility, GIS tools are a valuable support tool for running analyses and visualizing the results, even for different working scenarios. In recent years, webGIS platforms have been developed to support decision-makers choices and promote the engagement of users and citizens. A few examples are given below:

- The Collaborative Accessibility-based Stakeholder Engagement System (CoAXs) is an interactive planning tool developed by the Massachusetts Institute of Technology (MIT) to increase the active participation of stakeholders and citizens in solving problems related to the public transport system. Users can simulate different travel scenarios by examining the speed and frequency of different modes of transport and visualising the number of activities accessible through networked travel within a defined time frame. The tool has currently been implemented in several cities such as Atlanta, Bogotá, Boston, Concepción, London, New Orleans, Pretoria, San Francisco and Santiago (http://coaxs.scripts.mit.edu/home/);

- The WebCAT portal (powered by Transport for London) provides the calculation of public transport accessibility levels (PTALs) and access time to points of interest. The portal calculates the time needed to reach a certain node of the network by foot or by bicycle, waiting and onboard times. Moreover, it shows the number of services available in the catchment area, the reliability of the available transport modes, the functioning of public transport access points. It also measures the territorial extent reachable from a point in a given time interval and at different times of the day. The tool does not take into account the speed or usefulness of accessible services, the ease of interchange, crowding degree and the resulting accessibility to services (https://tfl.gov.uk/info-for/urban-planning-and-construction/planning-withwebcat/webcat?intcmp=25932);

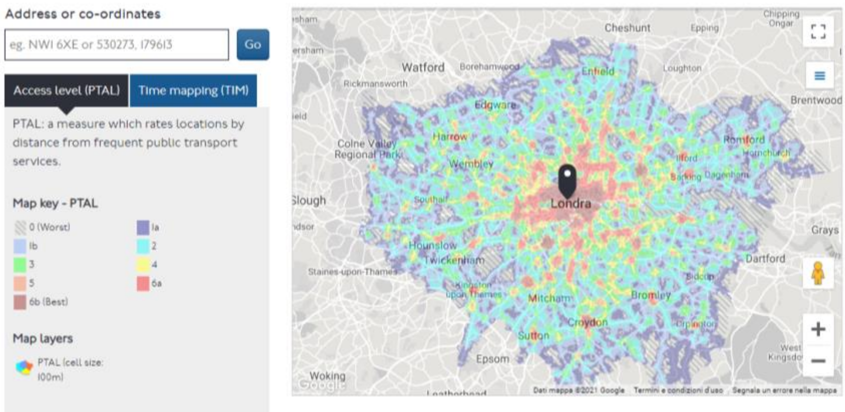

Figure 4-3. WebCAT by Transport for London

- Geo Open Accessibility Tool (GOAT) is an open-source web-based tool, developed at the Technische Universität München to measure and model cycling and walking accessibility in order to support not only the choices of planners but also those of citizens who can benefit from the interactivity, intuitiveness and flexibility of the tool in their daily travels. The project stems from the growing awareness of the role of active mobility in the development of transport systems on an urban and neighbourhood scale and the potential of cycling and walking for intermodal and sustainable mobility. The tool, using OpenStreet Map data, allows the calculation of different accessibility indicators, enabling the construction of isochrones or maps (heat-maps) based on gravity measurements, configuring different scenarios according to the decision-makers needs. For example, the model can simulate a new bridge or a new residential area's effects on accessibility. Interestingly, it is also possible to build travel scenarios for a person moving on a wheelchair, which testifies to the growing attention to the issue of urban accessibility for frail people or people with special needs (https://www.open-accessibility.org/);

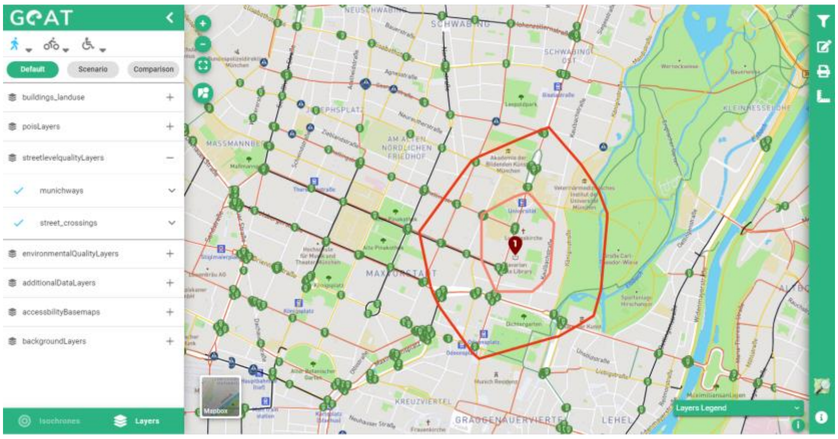

Figure 4-4. GOAT interface

- OpenRouteService was developed by HeiGIT - Heidelberg Institute for Geoinformation Technology. It offers a wide range of services based on OpenStreet Map data that can be used in different applications and scenarios. The Directions service provides routes and navigation information according to different criteria, designed for cars (fastest route, shortest route, recommended route), heavy vehicles, bicycles (customizable according to a vehicle - mountain bike, racing bike, e-bike), walking and wheelchair routes. The road network contains indications concerning the surface (i.e., asphalt or paved surface), type of route (i.e., road, pedestrian), steepness, depending on the mode of travel. The POIs Service helps find points of interest, specific services or products around a given point, with global coverage. The Isochrones Service measures the accessibility of a place by estimating the time or distance to be covered and constructing isochrones areas to display the catchment area served by services and infrastructures.

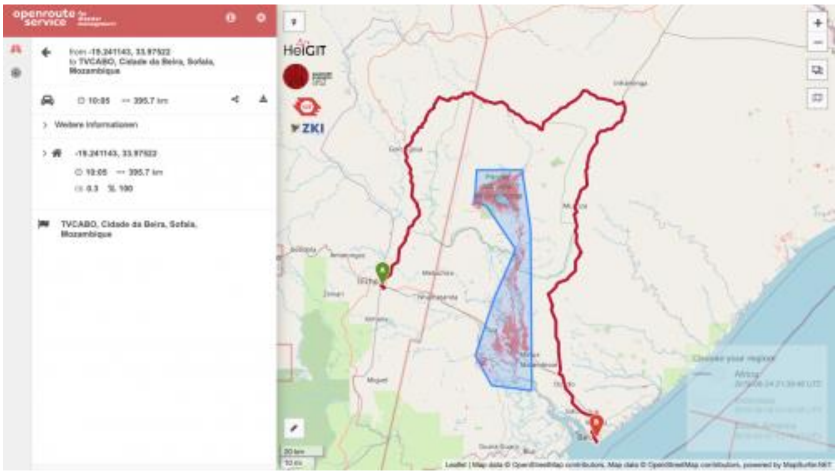

Figure 4-5. Screenshot from OpenRouteService platform

Openrouteservice also offers geocoding services. Of particular interest to public decision-makers is the disaster management service, developed to support the work of humanitarian and rescue workers in the most vulnerable and disaster-prone regions. In emergencies, it is possible to recalculate the routing graph once every hour based on the latest OSM data (https://maps.openrouteservice.org/#/);

- Wheelmap, developed by Sozialhelden e.V. and based on OpenStreetMap data, is a tool to facilitate the movement of disabled users in urban areas. The tool maps wheelchair accessible places, constantly updated thanks to the contribution of users who can vote for activities, services and destinations using a traffic light system (https://wheelmap.org).

Figure 4-6. A screeshot from Wheelmap platform

The above are just a few examples of webGIS applications for the study of land accessibility. The support of GIS technology for the development of a methodology to measure urban accessibility is undeniable. At the same time, I delved into the current offer of decision support tools for the governance of urban transformations developed with such technology. It emerged that most of the tools take into account a place-based or transport-based concept of accessibility, in which the measure becomes a sum of travel times or available services. At the same time, other fundamental factors such as the supply of services and the characteristics of the population users are neglected. Other tools develop measures at such a scale of detail that the dynamically complex system of the city is ignored.

This chapter is dedicated to the GIS-based methodology for measuring the accessibility of urban services. The methodology framework takes its cue from the scientific literature and, at the same time, from the gap between academic research and real-world practice. The methodology has evolved throughout the research programme through application to three different case studies – Naples, Milan and Nice – described in the next chapter.

4.2 GIS-based accessibility measures: Two Steps Floating Catchment Area

As highlighted in previous sections, several methods and approaches were developed to compute accessibility. The scientific and political interest in the topic is mostly due to a means for ensuring social equity. Depending on the application context, these measures vary significantly in terms of theoretical basis, operationalization, interpretability and communicability (Geurs & Van Wee, 2004). In the previous chapter, a framework from the scientific literature of the most commonly used methodologies to evaluate accessibility was defined and three major families of accessibility measures were identified: contour measures (Campbell, et al., 2019; Sahitya, & Prasad, 2020), gravity-based measures (Scheurer & Curtis, 2007), and utility-based measures (Domencich & McFadden, 1975).

Within scientific panorama, the floating catchment area (FCA) method is one of the most popular approaches for measuring spatial accessibility. The method is a special application of a gravity model, and it was proposed for the first time by Radke and Mu (2000). Since then, the FCA method has been modified and improved several times and has mostly been used in research on access to healthcare (Hu et al., 2012; Ahn et al., 2014; Ding et al., 2015; Tao et al., 2018), public transport (Langford et al., 2012; Kanuganti et al., 2016) and green areas (Dony et al., 2015). The method evaluates access to a service site in terms of provision (with variables describing the supply side) and need (considering the social features of the demand) — as well as the distance between them — to identify unserved areas. As a result, the method's limitations have yielded several developments and improvements thereof. This paragraph aims to state some of the main improvements after conducting a systematic literature review.

One of the most significant advances is awarded to Luo and Wang. In 2004, they proposed a two-step methodology (2SFCA – 2 Steps Floating Catchment Area) to define the service area of physicians. The method was first applied in the Chicago area.

$$R_j = \frac{S_j}{\sum_{i \epsilon [d_{i,j} < d_0]} P_i} \qquad \text{Equation 4-1}$$

$$A_i = \sum_{j \epsilon [d_{i,j} < d_0]} R_j \qquad \text{Equation 4-2}$$

It consists of two steps: the first (Equation 4-1) aims to evaluate the balance of supply (S_j) and demand (P_i, when the distance $d_{i,j}$ is lower than a set threshold d_o), quantifying the stress level of services (R_j), while the second estimates accessibility (A_i) as the sum of available services, weighted by their ratios and their distances from users.

From its first application, the method was differently developed in order to take into account additional elements of the urban environment, individual capabilities and limits and features of functional urban subsystem (services and activities). Table 4-1 below displays some of the studies selected because of the improvements they developed to implement the 2SFCA method, which this study sought to adopt and further develop for its age-based 2SFCA method.

First, several studies have focused on distance-decay functions and their parameters. Luo and Qi (2009) have proposed an enhanced 2SFCA (E2SFCA) method that discretises the weights obtained by a Gaussian function in order to divide the catchment area into multiple travel zones. Bauer and Groneberg (2016) have also introduced a variable distance-decay function in a 2SFCA method (iFCA). The decay function is shaped individually for every single population location by the median to consider the frictional effect of distance. Furthermore, Kiran et al. (2020) have worked on the introduction of multiple decay functions in order to better estimate actual accessibility levels to fire stations in the Brisbane area. Meanwhile, in their application of accessibility measurements to healthy food stores, Kuai and Zhao (2017) have introduced a Huff-core distance-decay function that considers the probability that certain populations visit certain groceries.

Second, some improvements have been explored in quantifying supplies and demands. Xing et al. (2020) have studied the accessibility to parks in Wuhan (China) from young people's perspective, introducing a quality index on the supply side in order to give due weight to the needs and expectations of younger people. Guo et al. (2019) have developed an age-based 2SFCA considering mobility behaviours of the elderly through mobile phone data, with Qiu et al. (2019) adopting a similar application for the region of Yichang (China).

Authors	Service Category	Demand feature	Context of application	Territorial scale	Improvement
Xing et al. (2020)	Parks	Young people	Wuhan, China	Regional	Introducing quality index on the supply side with respect to youth characteristics
Guo et al. (2019)	Urban parks	Elderly people	Beijing, China	Regional	New data sources: mobile phone data
Ma et al. (2019)	Hierarchical healthcare facilities	-	Wuhan, China	Regional	Three-step FCA: multiple travel modes; arithmetic mean-based Gaussian weight algorithm
Bryant & Delamater (2019)	Public parks	-	Washington D.C., USA	Metropolitan	Micro- and macro-level population representations: modifiable areal units
Qiu et al. (2019)	Green areas	Elderly people	Yichang, China	Urban	Spatial distribution of population using mobile phone call data
Kiran et al. (2020)	Fire stations	-	Brisbane, Australia	Urban	Multiple decay functions
Wang (2018)	Hospitals	-	Florida, USA	State	Inverted 2SFCA (i2SFCA): used to measure the scarcity of resources or intensity of competition
Kuai & Zhao (2017)	Healthy food providers	-	East Baton Rouge Parish, Louisiana, USA	Regional	Kernel Density 2SFCA for optimal threshold search
Bauer & Groneberg (2016)	Healthcare providers	-	Berlin, Germany	Urban	Variable distance-decay function (iFCA)
Fransen et al. (2015)	Day-care centres	Commuters	East Flanders, Belgium	Regional	Commuter-based 2SFCA to account for trip-changing behaviour
Luo & Qi (2009)	Primary care physicians	-	Illinois, US	State	The discretisation of Gaussian distance-decay function (E2SFCA)

Table 4-1. Main studies on the evolution of the FCA family of metrics.

Furthermore, Bryant and Delamater (2019) improved the 2SFCA method introducing micro and macro-level representations of the population through variable areal units. Their method was applied to compute accessibility to parks in the Washington, D.C. (USA) area. The inverted-2SFCA developed by Wang (2018) represents an outlier application since it uses the method to measure the scarcity of resources or intensity of competition for hospitals in Florida (USA).

Third, multiple travel patterns have been considered in some research. Ma et al. (2019) have differentiated the impacts of multiple travel costs on spatial accessibility outcomes, considering both private and public modes of transport. A commuter-based 2SFCA has been developed by Fransen et al. (2015) to estimate accessibility levels to day-care centres, taking into account changes in usual trip behaviours.

Given these limited considerations, my research proposes an age-based 2SFCA method that considers network characteristics and mobility attitudes to measure spatial accessibility to urban services.

Hence, this study aims to contribute to the scientific literature on the theme of urban accessibility by: introducing three different distance-decay functions, one per age group (people aged 65-69, 70-74 and 75 and over); developing a multimodal network for time travel analyses comprised of walkable roads and transit (bus and metro) lines; diversifying older people's walking speeds. Moreover, it also aims to support decision-makers in emergency conditions to provide a good level of accessibility to essential services for the elderly, the most vulnerable demographic.

Furthermore, the methodology was designed in a GIS environment in order to be easily integrated into a virtual decision support tool (webGIS), which overcomes the limitations of the current platforms summarized in the previous paragraph.

4.3 The Multimodal 2 Steps Floating Catchment Area (M2SFCA)

The study of scientific literature in the sector and technological advances in the field of spatial planning aimed at improving urban accessibility has allowed me to identify existing gaps, both in terms of methodology and its application into real-world practice.

Hence, an *ad hoc* GIS-based procedure was developed to evaluate the elderly's level of accessibility to urban services. The method contemplates the personal characteristics of potential users and multimodal transport services (i.e., walking in the street, the frequency of service and the localisation of urban transport stops) (Makarewicz & Németh, 2018; Wang & Cao, 2017).

One of the methodology's strengths is that it was designed to be replicated to different territories, with the use of only OpenData.

This section summarises the research design, which evolved throughout the Ph.D. programme thanks to the gained knowledge, application to various case studies (as further discussed in the next chapter), and the product's industrialisation into a decision support tool (further details are given in chapter 6).

The proposed GIS-based procedure is organised in the following three phases: data collection, GIS analysis and, finally, visualisation of results. This approach integrates spatial and alphanumerical open data and management, analysis and representation capabilities of GIS software. Figure 4-7 presents the geoprocessing workflow to execute operations of the proposed methodology.

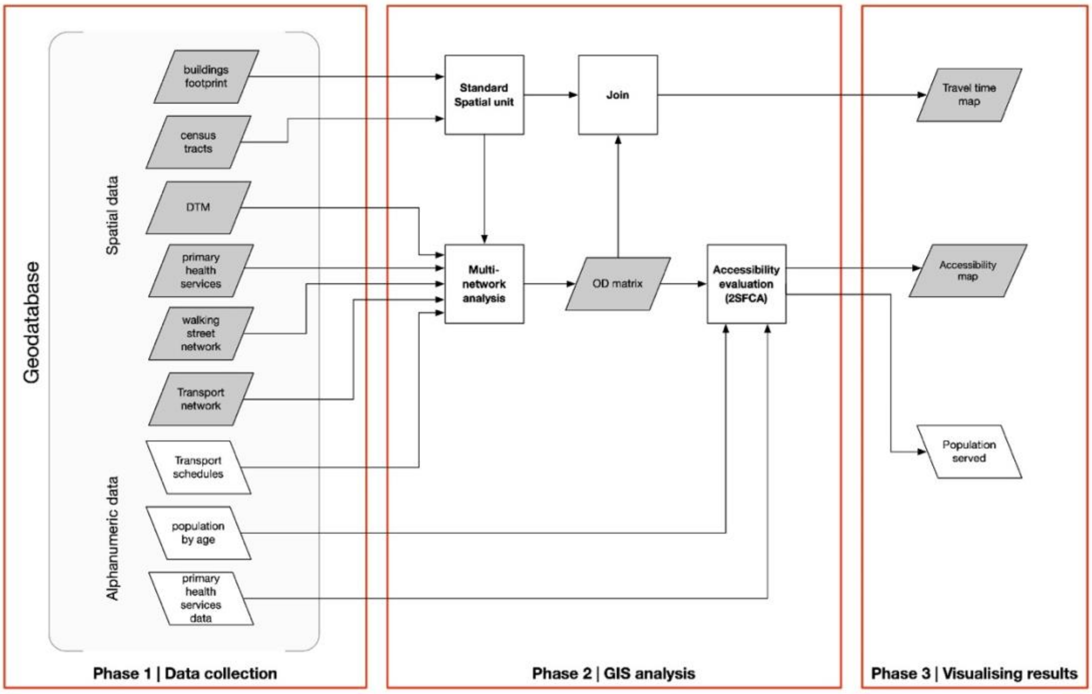

Figure 4-7. The conceptual GIS-based procedure for evaluating the accessibility of urban services to elderly people

In the procedure's first phase, creating a geodatabase using a GIS software that contains different types of data (spatial and alphanumeric) was necessary.

In the second phase, namely the geoprocessing stage, joint data and network analysis operations were run with input data and then evaluated for older adults' accessibility to urban services.

Finally, the methodology results are represented, in maps and tables, to allow easy interpretation and identify critical areas of the territory.

The black box of "Accessibility evaluation (2SFCA)" hides the following components (Figure 4-8) that have been developed within a trial-and-error procedure that involved the implementation of the methodology to three significant case studies. The decision to break down the enhanced 2sFCA method into four components is the result of systematic studies in the scientific literature: in order to guarantee a strong theoretical basis for the accessibility measure, it was decided to include the variables that describe each of the four components: land-use, transport, individual and temporal.

The following chapter exploits the evolutionary process that led to the final formulas of the methodology and the scientific results achieved during this process.

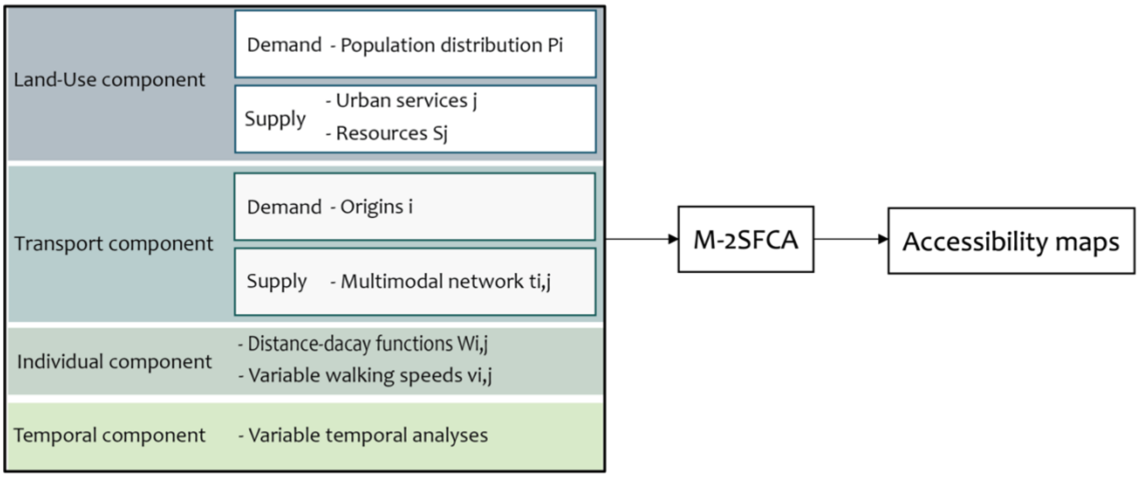

Figure 4-8. M2SFCA *black box* and its results (author's elaboration)

4.3.1 The Land-Use component

As concerns the components of the land-use system, both supply and demand-side features were considered since the level of accessibility in an urban environment depends on the interactions between supply and demand. In particular, the demand for healthcare provisions consists of population distribution P_i, where *i* refers to the smallest territorial unit, a 50-m-side hexagonal cell (Papa et al., 2018; Rossetti & Tiboni, 2020).

Using a hexagonal grid (rather than a square one or census track) is preferred when dealing with problems related to the connectivity of different space units (Burdziej, 2019). Due to geometric issues, the hexagonal grid provides a substantially better match between distances measured in grid units and straight-line (Euclidean) distances. This issue might make a coarse hexagonal grid more acceptable for modelling dispersal than a square or rectangular grid. Moreover, using a hexagonal grid improves the data output accuracy of the GIS-based procedure (Jin et al., 2007). For this GIS-based procedure, a six-sided cell was used as the spatial unit, with a side length of 50m that provides a greater aesthetic attraction — but above all, greater accuracy — in the calculation and visualisation of results. A proportional function was used to assign the census tracking socio-economic data to the hexagonal cells of the grid, taking into account the buildings' footprint located in each cell (Carpentieri & Favo, 2017).

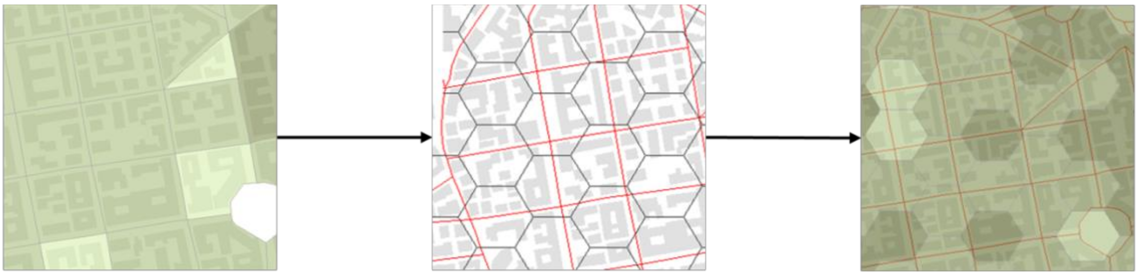

Figure 4-9. The census data from census tracks are proportionally distributed in hexagonal cells. c the proportionality factor is the footprint of the residential buildings in each census section

On the supply-side, the land-use component is described by combining the location of urban services (j) and their resources – S_j – described, for instance, by the surface of buildings (m^2), number of employees or users.

4.3.2 The Transport component

The second component of accessibility methodology concerns the transport system. Like land use, the mobility system consists of two sub-systems in connection with each other: supply and demand.

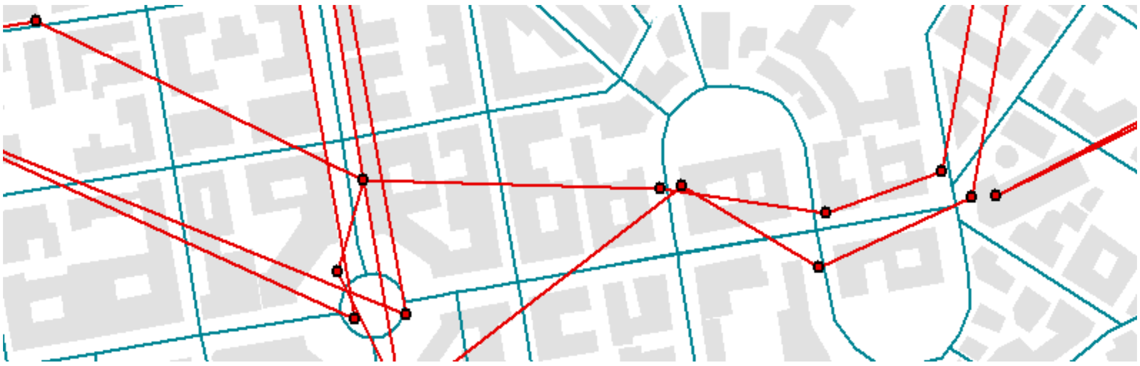

Figure 4-10. The multi-modal graph combines footpaths in blue (speedways and non-pedestrian roads have been excluded from the network) and public transport routes in red. Links at public transport stops connect the two networks. The image shows that the network in red is not real (its branches do not correspond to the route followed by public transport) but has only an analytical meaning: each arch is associated with commercial speeds due to the arrival and departure time at the respective start and end nodes, from GTFS data

A multimodal network was developed for the supply-side of transport facilities, including infrastructures, road and transit routes, and their operating performances. The network is made of walkable roads and transit (bus and metro) lines to include all the available transport modes for the elderly. The ArcGIS Network Analysis tool was used to compute the OD (Origin-Destination) travel matrix. The residential locations of dwellers approximated to the barycentre of hexagonal cells – i – were considered as origins of multimodal travel journeys to reach locations of urban services – j. The outputs of OD matrix analyses are travel times $t_{i,j}$, which are the combination of walking, waiting and onboard times on public transport.

4.3.3 The individual component

The most innovative aspect of the study is the introduction of variables that take into account the behaviours of the elderly, such as their dependence on public transport and their reduced use of private cars. In other words, the research introduced characteristics linked to the behaviour of the population, considering them essential to improve accessibility to places and services of the urban system.

Hence, Gaussian distance-decay functions – Wi,j – were introduced, one per age group, in order to consider the degressive mobility capital of older people while ageing (Kwan, 1998). Moreover, the pedestrian arcs have been matched with walking speeds for each age group (65-69; 70-74; ≥75) to measure travel time $t_{i,j}$ to get from i (origins) to urban service j. According to Lindemann et al. (2008) and Rydwik et al. (2012), the walking speed for each age group is 0.8 m/s for those aged 65-69; 0.7 m/s for people aged between 70-74; 0.6 m/s for the oldest (≥75).

As far as the Gaussian distance-decay functions, their main characteristic is that they quickly decrease when time travel increases and gets close to the maximum time that each elderly age category manages to hold (according to their physical capabilities) to access health services. Moreover, as people age, their mobility capital decreases. As further explained in the following chapter, different distance-decay functions have been used to test the methodology and its effectiveness (Bauer & Groneberg, 2016).

4.3.4 The temporal component

The last component relates to the variable accessibility perceived by dwellers due to temporal issues. Both the transport and the functional system undergo changes throughout the week or day. The same applies to the demand from the population.

The introduction of temporal dynamics within accessibility measurements represents one of the new fields of research (Geurs et al., 2015; van Wee, 2016), which may provide a valuable, previously hidden input for policymakers. Given that the level of accessibility (Farber et al., 2014) and its equity vary through the day (El-Geneidy et al., 2015), it is inequitable to include a temporal dimension into accessibility analysis (Baradaran & Ramjerdi, 2001).

Given the complexity of the accessibility issues, research interest has been extended to two dimensions: from spatial to temporal. Spatial disparities concern the distribution and availability of public transport and urban services. Additionally, the temporal equity in the analyses has been added.

The emergence of new, large datasets and progress in computational capacities offers have been crucial for studying this not a negligible component of urban accessibility. The rapid development of open databases has provided valuable open data sources, especially for transport analyses.

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CHAPTER 5. PILOT APPLICATIONS AND CASE STUDIES: URBAN ACCESSIBILITY TO PRIMARY HEALTHCARE SERVICES

5.1 Introduction

The results achieved by the research activities are manifold. One concerns the development of an innovative GIS methodology for spatial analysis and its implementation in a GIS-based web server. With reference to this first objective, the results are both theoretical and methodological. The previous chapter describes the main traits of the 2SFCA method and its component to evaluate holistically urban accessibility to services from the elderly perspective.

The way to arrive at an effective and robust methodology could not but pass through more than one phase of experimentation in order to reinforce its salient features: first, the application of the enhanced 2SFCA method to measure accessibility to health services in very different cities; the introduction of new variables and components; finally, the validation of the method for different emergency or time scenarios.

On the other hand, applying the methodology to different case studies highlighted its weaknesses, which were then taken into account for the subsequent implementation phase in a GIS map server, which is described in the following chapter.

Each of the following three paragraphs is devoted to one of the three case studies: Naples (Italy), Milan (Italy) and Nice (France). The succession of paragraphs follows the temporal evolution of the methodology, which got enriched at each step with new awareness. Weak points were then transformed into new variables, functions, formulas, representation techniques and outcomes. At the same time, the strengths have provided fertile ground for further research activities.

The GIS-based methodology described in the previous chapter was designed to be replicated and scaled to different contexts and adapted to measure urban accessibility to essential services for older people. In order to test its validity, the assessment of accessibility levels to local health services was chosen. The availability of accessible healthcare services for the elderly is essential for a high quality of urban life (Khalil, 2012; Moroke et al., 2019). With little evidence that older people today are healthier than the elderly of previous generations (WHO, 2018), ageing is dominated by poor health, isolation and a strong dependency on medical care. While ageing people get inevitably weaker due to hearing loss, cataracts and refractive errors, back and neck pain and osteoarthritis, chronic obstructive pulmonary disease, diabetes, depression, and dementia that can all contribute to mobility problems (Fredriksen-Goldsen et al., 2011; WHO; 2018; de Sousa Faria, 2020). For instance, some studies have considered older people as a group with substantial healthcare needs by describing the variables of access to medical care provision (Wang et al., 2020; Du et al., 2020; Koh et al., 2015). Other researchers have suggested that the quality of such services — in terms of the number of available beds or physicians or square meters — plays a major role when users have to cope with the choice of being in one healthcare structure rather than another (Bakimchandra et al., 2020; Cabrera-Barona et al., 2018). Hence, a good level of accessibility to healthcare services has significant positive effects on the quality of life of older people (Linchuan & Xu, 2020). Moreover, urban health services are characterised by an intrinsic and significant complexity, including administrative and management complexity. Yet, the availability of quality healthcare resources in the municipal area is among the incontrovertible rights of citizens, especially the weakest and the elderly.

The contribution of people over 65 to society will continue, if not increase, in the future, so long as mobility options are maximised, for example increasing the numbers of buses, improving ticketing policies for public transport use and introducing driverless cars. Some studies (O'Hern et al., 2015) proved that the car continues to be the prime mode of transport for older people, at least in high-income countries, including those across America and Europe. However, data suggest an increase in the prevalence of the numbers killed or seriously injured as a result of frailty: older people are more likely to be injured or killed if involved in a collision (MacLeod et al., 2014; Lee & Lee, 2019; Manning, 2019). In the light of this, more interventions that help older people move in cities are needed to try out new modes and new destinations and support a gradual process of giving up driving, potentially reducing its negative consequences (Musselwhite & Shergold, 2013; Musselwhite et al., 2015). The use of bus or transit, above and beyond walking, keeps people connected to their communities and essential urban services (Julien, 2015; Shergold, 2015). When dealing with the needs of social and healthcare assistance of older people, some studies have conceptualised accessibility of healthcare services by developing an integrated geospatial approach to model medical care use for the elderly supported by transport features, hospitals, and clinic proximity as other quality parameters. This approach represents important progress in multidimensionally estimating accessibility to one of the more essential supply systems for the elderly. The limited available data for supply-side variables represented a barrier for research in several cities. The contexts of analysis, methodological advances, results, and the evolution of the methodology itself are described for each case study.

Although the focus of this research concerns the measure of spatial accessibility to primary healthcare services for the elderly proposing some improvements and innovations, the methodology is suitable for measuring accessibility to other urban services (Wang et al., 2020; Carpentieri et al., 2019; Xu & Yang, 2019).

5.2 Naples[3]

The first case study is the city of Naples, Italy. The methodology has been applied to evaluate the urban accessibility to public primary health services for older people. This case study was selected because it represents one of the most interesting examples of a complex southern European city with high population density, non-uniform urban structure and the absence of a specific plan and urban planning tool to take into account the needs of older adults.
In addition, the choice of Naples as the first context of application is also due to a territorial link. Since it is a familiar and well-known context, the reading and interpretation of the results were easier and more reliable to test the robustness and validate the methodology.
The application to the city of Naples is the first real test of the 2SFCA method, which is described by the following formulas:

$$R_d = \frac{\sum_{k=1}^{n} S_{k|d}}{\sum_{65-69} P_i t_{travel\ i,j}^{-\beta} + \sum_{70-74} P_i t_{travel\ i,j}^{-\beta} + \sum_{>75} P_i t_{travel\ i,j}^{-\beta}} \qquad \text{Equation 5-1}$$

$$Acc_i = \sum_{65-69} R_d t_{travel\ i,j}^{-\beta} + \sum_{70-74} R_j t_{travel\ i,j}^{-\beta} + \sum_{>75} R_j t_{travel\ i,j}^{-\beta} \qquad \text{Equation 5-2}$$

The first step of the methodology (Equation 5.1) aims at computing a ratio between the supply of primary health services and the demand of older adults. The second formula aims at defining accessibility for each hexagonal cell of the grid, *i*; *d* identifies the healthcare district, which is the administrative boundary of the healthcare services; *j* identifies the healthcare building; P_i is the sum of older people dwelling in cell *i*; $t_{travel\ i,j}$ is the total travel time, which is the combination of pedestrian and transit movements to get from residence places (*i*) to healthcare buildings (*j*); β is the coefficient of the impedance function, equal to 1 for this first application; $S_{k|d}$ is the number of available services, also considering the kind of surgery (*k*) within each district (*d*). For what concerns the first formula, the denominator has

[3] This paragraph is part of the published scientific paper "Carpentieri, G., Guida, C. & Masoumi, H.E. (2020). Multimodal Accessibility to Primary Health Services for the Elderly: A Case Study of Naples, Italy. *Sustainability* 12, no. 3: 781. https://doi.org/10.3390/su12030781

three different elements. Each element refers to a different age group (people aged 65 and 69, 70 and 74 and over 75). This scheme was necessary since total travel time was differently computed for each age group, assuming that, while ageing, walking speed decreases (Papa, E. et al., 2018). Equation 5.2 presents a similar structure for the same reason. In detail, Equation 5.1 defines a ratio between the healthcare supply, the number of surgeries within the same district, and demand, which is the number of people per age group (65–69, 70–74, and over 75). This first measure is an indicator of the stress level of each district: the higher the number of older residents, and the fewer the healthcare buildings, the more stressed the district is. When considering the demand, the total (sum of pedestrian and transit components) travel time to the power of $-\beta$, where β is equal to 1, is considered an impedance factor. The total travel times are simulated with three different speeds for the three age groups since walking speed decreases with ageing. Equation 5.2 assesses the accessibility of each cell of the grid as the sum of three elements for the three age groups. Each element is the sum extended to the healthcare buildings that serve the generic cell *i* of the product of the supply/demand ratio of the district and impedance function to reach the *j* healthcare building from *i*.

Compared to the FCA-type accessibility measures described in detail in the first paragraph of the previous chapter, some innovative aspects have been introduced with this first application. First of all, the travel time to reach the health services from the centres of residence of the elderly is the sum of the trips on foot and the trips by local public transport. The walking time was calculated by assuming three different walking speeds for each age group (0.8 m/s for 65-69; 0.7 m/s for people aged between 70-74; 0.6 m/s for the oldest). Instead, the travel time by local public transport was estimated through analysis of the LPT network, built based on the GTFS data of the municipality of Naples.

The second element of innovation is the introduction of an exponential decay function to take into account the limited willingness to walk of the elderly: as travel time increases, the attractiveness of health services decreases.

The city of Naples has 970,185 inhabitants (ISTAT, 2018) within 117.27 km², and it is the fifth Italian city in terms of population density. In the last decade, the city was affected by a gradual increase in the elderly population (Map I-1): from 2008 to 2018, the elderly population of the city lifted to 20,052 inhabitants (ISTAT, 2018).

The Naples Local Health Agency (ASL – Azienda Sanitaria Locale) is responsible for the primary healthcare supply in the city boundary. It has a very complex structure due to the demand (nearly one million units) and the socio-economic and health heterogeneity within the competence area. The Naples ASL has eight hospital structures spread all over the city. However, health districts have a significant strategic role to better program and allocate resources to monitor and manage medical care and treatments. The Italian law (D.Lgs. 229/1999 Art. 3) regulates health districts functions and identify them as territorial joints of ASL, the closest health supply for citizens. A programmatic document of health services provision at the local level organizes the districts' activities and upper health general levels and equivalent private services.

Health Districts have a strategic role in the current welfare system to integrate this form of assistance to more institutionalized solutions, such as physicians and voluntary organizations. They represent an important tool in order to limit social exclusion in urban areas.

District	Neighbourhoods	Number of health buildings	Number of services	Total population	Population 65-69	Population 70-75	Population over 75
24	Chiaia, Posillipo, S. Ferdinando	2	14	82,161	5,368	4,247	9,146
25	Bagnoli, Fuorigrotta	2	13	95,682	6,607	4,977	10,453
26	Pianura, Soccavo	1	11	106,518	5,767	3,737	6,730
27	Arenella, Vomero	1	11	114,950	8,289	6,708	15,380
28	Chiaiano, Piscinola, Marianella, Scampia	1	11	91,818	4,320	3,027	5,472
29	Colli Aminei, San Carlo all'Arena, Stella	3	21	97,875	6,014	4,598	9,092
30	Miano, Secondigliano, S. Pietro a Patierno	2	17	79,271	3,980	2,922	5,384
31	Avvocata, Montecalvario, Pendino, Mercato, S. Giuseppe Porto	2	13	91,964	5,613	4,022	8,185
32	Barra, S. Giovanni a Teduccio, Ponticelli	2	12	110,709	5,509	3,867	7,299
33	Vicaria, San Lorenzo, Poggioreale	1	10	90,157	5,368	3,730	7,788
City	-	17	133	961,106	56,835	41,835	84,928

Table 5-5-1. District neighbourhoods and population.

The enhanced 2SFCA method was first applied to evaluate urban accessibility levels to local primary health services managed by Naples ASL. In particular, the municipality of Naples is divided into ten health districts whose administrative boundaries overlap one or more neighbourhood borders, as reported in Table 5-1. It is worth highlighting that district boundaries represent an administrative restriction to services availability since only neighbourhood dwellers can access healthcare within the district. Their structures are spread throughout the whole city. They offer the following primary services to the elderly: cardiology, geriatrics, dermatology, urology, neurology, pulmonology, orthopaedics, dentistry, otolaryngology, ophthalmology and diabetology. Map I-3 (see Annex I) highlights how healthcare services are spread within the city and within each district. It represents the supply component of the accessibility measure.

Map I-2 draws the Naples city multimodal transport network (pedestrian and transit) used to compute travel times, considering three different walking speeds for the three age groups (Arup, 2015). As discussed in more detail in paragraph 4.3 of the previous chapter, the mobility network used to compute travel times combines walkable roads and public transit lines (bus, railway, and tram). Firstly, OpenStreetMap data was used to create the pedestrian network, taking only walkable roads and their gradient. Then, GTFS data from the ANM (Azienda Napoletana Mobilità – Neapolitan Mobility Company) was used to add bus and railway routes and stops in the transport network. Since public transport is not a continuous service in space and time, additional modelling operations were needed to connect the pedestrian system to the public transit system. Once the network was ready, the ArcGIS Network Analyst tool computed an OD (Origin-Destination) matrix, containing in each cell the total travel time to get from a generic six-sided cell to the closest healthcare centre.

District	Very poor [%]	Poor [%]	Low [%]	Good [%]	Very good [%]
24	0,4	19,3	12,0	21,5	46,7
25	4,7	34,3	11,8	25,8	23,3
26	0,6	40,6	9,6	16,6	32,6
27	9,3	34,8	28,4	18,3	9,3
28	3,8	8,4	15,2	37,3	35,2
29	0,0	0,0	0,4	31,6	68,0
30	0,0	0,0	4,5	8,2	87,3
31	0,0	0,7	22,8	25,0	51,5
32	0,0	0,9	37,6	43,4	18,2
33	20,0	24,1	19,5	24,1	12,2

Table 5-2. 65-69 aged population per district per level of accessibility.

A preliminary reading of the data reported in Table 5-1 would suggest some interesting issues related to the spatial distribution of elderly and health services within the city of Naples. In Table 5-2, 5-3 and 5-4, the number of elderly (65-69, 70-74 and over 75) in Naples Districts have been reported. For what concerns the first age range (65-69), Districts 25 (Bagnoli and Fuorigrotta), 26 (Pianura and Soccavo), 27 (Arenella and Vomero), and 33 (Vicaria, San

Lorenzo and Poggioreale) need an in-depth evaluation. District 27 about 4,000 older people, aged between 65 and 69, suffer from very poor accessibility to primary health services. This percentage increases to nearly 70% if we also consider a low, poor and a very poor level of accessibility. Indeed, 87.3% of dwellers in District 30 (Miano, Secondigliano, S. Pietro a Patierno) have very good access to primary health services. This highlights the deep social and spatial inequity even for bordering neighbourhoods. Moreover, this analysis highlights no difference between core urban areas and suburbs: Vomero is one of the central neighbourhoods. Its dwellers have poorer accessibility compared with residents in district 33 that includes suburban areas. For the second age range (70-74), in District 27, more people suffer from a low accessibility level: in more detail, over 70% of the elderly suffer from a medium and low level of accessibility, which is about 5,000 people. Both Districts 25 and 26 show more or less the same results as for people aged between 65 and 69. For District 27 (Arenella and Vomero), about 2.500 (more than 40%) people have a low level of accessibility due to an access travel time above 30 minutes. District 33 (Vicaria, San Lorenzo, Poggioreale) is not the worst in this context. However, it could be further investigated since nearly 40% of its 70-74-aged dwellers suffer from a low level of accessibility.

District	Very poor [%]	Poor [%]	Low [%]	Good [%]	Very good [%]
24	0,5	20,7	11,3	20,2	47,3
25	4,1	33,2	11,7	26,5	24,5
26	0,5	37,0	8,6	19,9	34,0
27	10,5	35,1	27,7	17,7	9,0
28	2,7	6,9	14,1	38,7	37,6
29	0,0	0,0	0,5	36,2	63,3
30	0,0	0,0	3,1	7,8	89,0
31	0,0	0,7	23,8	25,5	49,9
32	0,0	0,9	35,4	41,7	22,1
33	19,3	22,0	19,5	25,9	13,3

Table 5-3. 70-74 aged population per district per level of accessibility.

Previous considerations are confirmed even for this last age range (over 75): districts 25, 26 and 27 still have the highest rate of dwellers with the poorest accessibility levels (37%, 31% and 42%). Due to the slowest walking speed considered for this elderly age range (0.5 m/s), in every district, the number of people with a low, poor and very poor level of accessibility increases.

Map I-4, in Annex I, highlights the accessibility levels and how Naples inhabitants differently access healthcare services. Maps and tables represent significant support in decision-making processes, especially when dealing with local restructuring welfare policies to better allocate resources.

District	Very poor [%]	Poor [%]	Low [%]	Good [%]	Very good [%]
24	0,6	21,0	13,0	18,6	46,9
25	3,8	33,3	10,7	25,8	26,4
26	0,7	30,3	8,5	28,9	31,7
27	7,5	33,9	29,2	19,5	9,9
28	3,7	6,2	13,7	39,8	36,6
29	0,0	0,0	0,4	34,9	64,6
30	0,0	0,0	2,9	8,8	88,3
31	0,0	0,7	26,0	25,2	48,0
32	0,0	0,8	34,5	42,2	22,5
33	0,6	21,0	13,0	18,6	46,9

Table 5-4. Over 75 aged population per district per level of accessibility.

The methodology is based on the assumption that primary health buildings' locations are significant aspects as well as their resources, in terms of physicians, number of surgeries and operating hours, and they all contribute to these results.

The application to the selected case study suffers poor primary healthcare provision data and non-recent information concerning population (population data refers to 2011). Moreover, in order to analyze the overall urban services supply, future applications could be run for different timing intervals to estimate the accessibility level. The outputs show that the elderly population suffers from very poor accessibility to primary health services, whether they reside in suburban or central neighbourhoods.

In conclusion, Naples provided a representative study area for the first application of the enhanced 2SFCA methodology due to its morphology and socio-economic and demographic structure. Results confirm that entire neighbourhoods suffer a very poor accessibility level. An important implication of this issue is that local municipal authorities and healthcare institutions need to carry on their primary responsibility to plan and implement healthcare resources. In order to improve social justice and reduce disparity in the access to healthcare services, they must be cautious in the process of marketizing public hospitals. This necessitates more specific and holistic land-use planning policies, also considering the needs and availability of the elderly.

A further insight is that the healthcare provision system has a complex structure due to several agreements by private services that support public institutions. Due to the limitation of data availability, this study provides only a snapshot of spatial access to the public district healthcare structure in Naples, which is not sufficient to fully evaluate the effect/impact of the Healthcare Local Agency provision within Naples.

The methodology applied in Naples highlighted two key aspects for its implementation into a decision support tool for policymakers: first, it is imperative to take into account the whole primary health supply system, also considering its administrative rules; secondly, since the main objectives of this research are the elderly, variable distance-decay functions should be introduced to compute their mobility availability better.

5.3 Milan[4]

The proposed GIS-based methodology was secondly applied to the city of Milan to evaluate urban accessibility to primary public health services for the elderly. Milan is also the study area of the research project "MOBILAGE. Mobility and ageing: daily life and welfare supportive networks at the neighbourhood level", funded by the Fondazione Cariplo. Milan took part in the Healthy Cities Network launched by the WHO in 1987, there has not been a clear attempt in recent years to generate a multidisciplinary response to the societal and demographic changes that are currently engulfing the city. Thus, according to the last national census (2011), 25% of the residents of Milan are 65 years or older — against a national average of 20.8%.

The spatial and numerical analyses to measure accessibility to health services in Milan were conducted on the eve of the outbreak of the Covid-19 pandemic, which raised important new questions. Milan was the first major European city to experience the lockdown measures related to the limit the spread of the new coronavirus. Some health centres had been closed, the supply of public transport had been significantly reduced, and the mobility of the population was restricted.

The enhanced 2SFCA was further developed within the Covid-19 scenario to consider the limits of the provision of healthcare services: for instance, in some cases, ordinary hospitals were converted in order to treat Covid-19 patients, limiting other essential medical assistance. Moreover, further considerations were needed to take into account issues

[4] This paragraph is part of the published scientific paper "Guida, C., & Carpentieri, G. (2021). Quality of life in the urban environment and primary health services for the elderly during the Covid-19 pandemic: An application to the city of Milan (Italy). Cities, 110, 103038. https://doi.org/10.1016/j.cities.2020.103038"

related to the significant connection between urban characteristics and the transmission of the infection (Gargiulo et al., 2020; Liu, 2020). The urban environment provides a solid background for the virus' transmission. The high population density in the metropolitan area and the extensive levels of public transportation in the large cities have a "multiplier effect" for transmitting the virus. Therefore, one cannot ignore the urban context within the discussion of severe infectious disease transmission. At the same time, when dealing with urban planning matters, the new coronavirus and the still-uncertain ways (Holmdahl & Buckee, 2020) in which it can be transmitted cannot be disregard: territorial authorities at every level had to promptly react in the very first moments of the pandemic to strengthen healthcare provision and keep urban activities to a minimum standard, in order to limit the health emergency; now, and for the next months (or years), decision-makers will be more committed to preparing urban environments and services for a phase of coexistence with the virus, to reduce social and economic disparities and emergencies.

The enhanced 2SFCA methodology was applied to Milan to prove its effectiveness in supporting decision-making processes, enabling the optimisation of allocations and resources of healthcare and public transport services in policy-making — in ordinary conditions as well as during the spread of Covid-19. Minor changes have been made to the formulas, summarized below.

The supply of healthcare services is quantified by the number of available surgeons for each building (S_j); the demand is the sum of the population, potential users divided into three age ranges in location *i*, with Pi weighted to consider a time-distance-decay function, W_{ij}, which is a function of the total travel time. The travel times between residential locations *i* and healthcare structures *j* are estimated by Network Analyst and ArcMap, taking both walking and transit routes into account. Furthermore, in order to consider the limited supply of healthcare services during the spread of Covid-19, a *k* coefficient was introduced. It varies between 0 and 1 to highlight the variable availability of services for the elderly. The coefficient *k* was introduced to consider the variation of the number of available services in different scenarios. *k* represents the ratio between the available services S_j during emergency scenarios, instances when the supply of healthcare services could be reduced, and the number of services functioning ordinarily.

$$k = \frac{\sum_j^n S_j}{\sum_{j=1}^m S_j}$$ Equation 5-3

For the second step, A_i, the accessibility of each hexagonal cell was obtained (as reported in Equation 5-5) by summing the supply-demand ratios of the *j* health centres serving the *i* cell — multiplied for the impedance function coefficients W_{ij}, to take into account both the spatial distribution of health centres and the population.

$$R_j = \frac{S_j \cdot \left(\frac{S_j}{S}\right) \cdot k}{\sum_{65-69} P_i \cdot W_{ij}^{65-69} + \sum_{70-74} P_i \cdot W_{ij}^{70-74} + \sum_{>75} P_i \cdot W_{ij}^{>75}} \quad \text{Equation 5-4}$$

$$A_i = \sum_{65-69} R_j \cdot W_{ij}^{65-69} + \sum_{70-74} R_j \cdot W_{ij}^{70-74} + \sum_{>75} R_j \cdot W_{ij}^{>75} \quad \text{Equation 5-5}$$

The distance-decay function W_{ij} was introduced to reflect older people's mobility habits: a Gaussian impedance function, whose values vary between 1 and 0, was used; this function's main characteristic is that it quickly decreases when time travel is close to the maximum availability of minutes that each elderly age category requires (according to their physical capabilities) to access at the health service (Kwan, 1998).

$$W_{ij} = e^{-t_{ij}^2/\beta} \quad \text{Equation 5.6}$$

The coefficient β was set equal to 180 for people aged between 65-69, 160 for those between 70-74 and 140 for those aged 75 and over, in order to best represent mobility attitudes of different elderly age categories according to outcomes in the scientific literature (Bauer & Groneberg, 2016). Figure 5-1 below shows the Gaussian impedance functions used in our application.

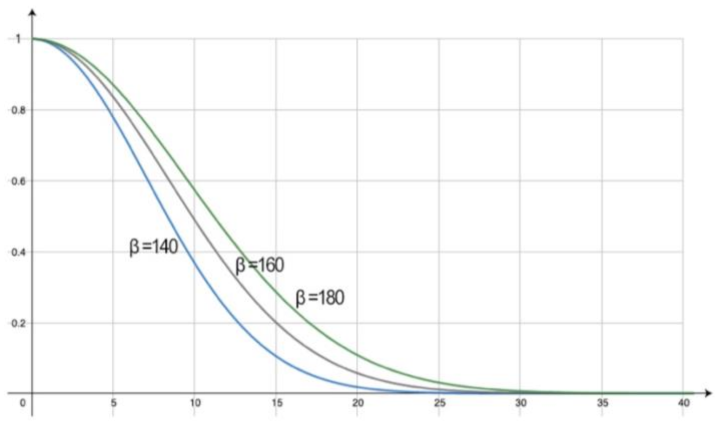

Figure 5-1. The three Gaussian distance-decay functions

The city of Milan has 1,242,689 inhabitants (ISTAT, 2020) within 181.67 km² — the second-largest municipality in Italy by population.

The city is divided into eighty-eight neighbourhoods and nine boroughs. The urban structure of Milan significantly changes from the city centre to the peripheral areas. The city has developed along radial axes and in concentric circles (the circle of Navigli, the ramparts, the trolley-buses ring, the railway ring, the ring road). In more recent decades, it has grown sporadically, incorporating and connecting pre-existing settlement areas — rich areas from both a physical and social point of view. Milan is one of the largest Italian cities to have implemented sustainable mobility (see Comune di Milano, 2015 for the Urban Plan for Sustainable Mobility – PUMS). The European Union awarded the 2016 Access City Award for being the most accessibility-friendly city, particularly for people with disabilities (Mariotti et al., 2018). For these reasons and the gradual increase in its elderly population — especially in suburban areas, as shown in Map I-5 — the city of Milan represents an interesting case study for further investigating the application in decision-making processes of the developed methodology. The application is based on 2011 census data (ISTAT, 2011). The network analyses are run differently for the three age groups of the elderly: people aged 65-69 years, 70-74 years and 75 and over the years, according to their variable walking speed.

The Health Protection Agency of Milan (ATS – Agenzia di Tutela della Salute) is responsible for the primary healthcare supply within the Metropolitan City of Milan. The ATS was set up in 2016, as part of the implementation of Lombardy (Northern Italy) Regional Law 23/2015, and covers the provinces of Milan and Lodi, with their 194 municipalities, for a total number of users equal to 3,464,423 (ATS Milano, 2018). The ATS of the metropolitan area of Milan was formed through the merger of four ex-ASLs (Local Health Agencies) and represents the administrative joints of Lombardy in making healthcare services available and operative for citizens in different and heterogeneous territories. Considering the differences between territories of the metropolitan area, the ATS is divided into six districts: Milan; North Milan; Rho Area; West Milan; Melagrano and Martesana; Lodi. They all have a significant role in the organizational logic of central and strategic management and have the same territorial extension of Territorial Healthcare and Social Agencies (ASST – Aziende Socio Sanitarie Territoriali). ASSTs are providers of primary healthcare services, including both public and private centres. The entire system of healthcare provision comprises both public structures and private contracted services: they share 50% of the total demand for healthcare assistance. Considering the regional scenario, the supply from the public side is greater than the contract facilities of a private nature. More particularly, in 2017, according to the Lombardy region’s statistics, the ATS of the Metropolitan City of Milan recorded 54.5% of access to private healthcare services, regardless of the number of available beds or the category of medical service provided.

The methodology was applied to evaluate the level of accessibility to both public and private healthcare facilities within the Milan Municipality District. Map I-7 in Annex I indicates that healthcare centres managed by ATS Milan are spread across the whole city's territory and offer the following primary services to the elderly: cardiology, diabetology, neurology, ophthalmology, orthopaedics, otolaryngology, pulmonology, urology, rehabilitation, dermatology and gynaecology. Table 5.5 shows the number of available surgeries within each structure. This application was useful to test the methodology's effectiveness during emergency scenarios: hence, accessibility to primary health services was assessed for the elderly before (base scenario) and during the Covid-19 pandemic emergency (Covid-19 scenario). In terms of transport and healthcare provision, the first scenario refers to February 2020, during a morning weekday. For the Covid-19 scenario, for the primary health services, the indications of the Lombardy region's decree (DGR Lombardy n° XI/2906 of 08/03/2020) were taken into account. The Region issued the closure of some primary health services located in main hospitals to devote employees and rooms to Covid-19 recovery. In Table 5.5, a comparison of the reduction in primary health services for each surgery between the two scenarios is proposed. For transport services in the Covid-19 scenario, we considered the reorganization by the company of public transport (ATM – Agenzia Transporti Milanesi s.p.a) that reduced the number of operating lines and their frequency on weekdays. This reduction of transport services is comparable to the holiday performing of base scenario, according to the indication of the ATM, as explained below.

Scenario	Card.	Diab.	Neuro.	Opht.	Ortho.	ORL*	Pulm.	Urology	Rehab.	Derma.	Gynec.	Total
Base	60	42	56	50	52	57	35	39	51	50	59	540
Covid-19	45	30	42	37	39	44	20	27	39	39	46	398
%	-25%	-29%	-25%	-26%	-25%	-23%	-43%	-31%	-24%	-22%	-22%	-26%

Table 5-5-5. Available surgeries for health structure (public hospitals and polyclinics and private health centres) in the two scenarios. (*ORL stands for Otolaryngology)

As soon as the first Covid-19 infection in the Milan area was confirmed, the ATM created a dedicated team that developed an action plan, scheduled on different levels and times, in order to promptly react during the emergency phase, for guaranteeing a certain level of service and getting ready for the ongoing phase of the virus consequently. In fact, during the lockdown weeks, the ATM maintained a level equal to 75% of ordinary operativity for those who needed to move for work or health needs — even though in Milan, as in every European city, the usage of public transport declined up to 90%, as shown in the following chart (Figure 5-2). The data in Figure 5-2 below refers to the period between 15th January 2020 (more than a month before the first Covid-19 infection was confirmed in Italy) and 4th May 2020, the first day of Phase 2.

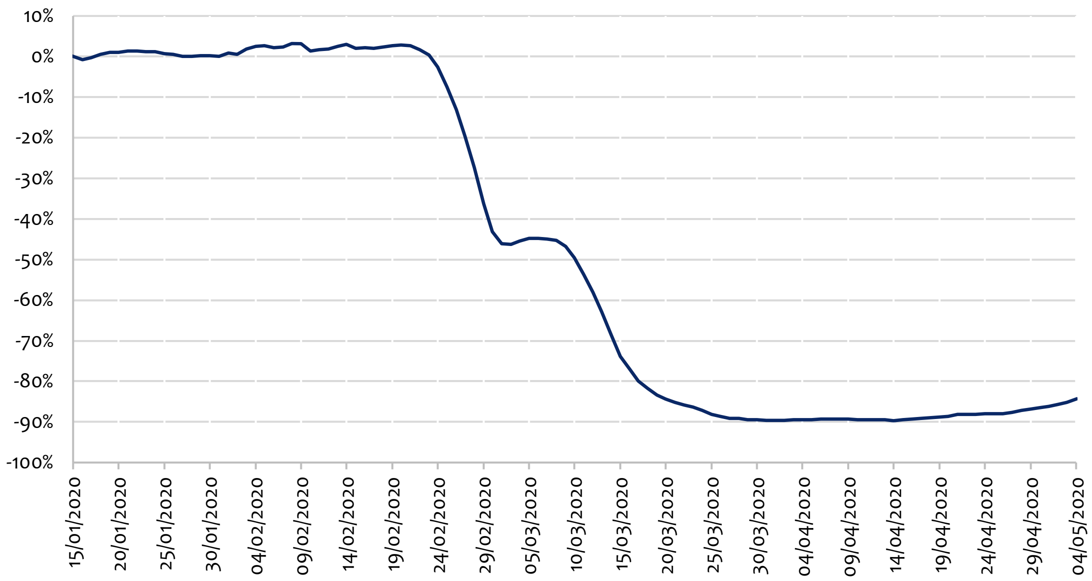

Figure 5-2. Decline of Public Transport usage from 15/01/2020 to 04/05/2020 in the city of Milan (Data source: Moovit Italia)

To encourage people's mobility in urban areas, the ATM worked to ensure a significant level of activity of public transport, as well as an intense and capillary cleaning of each vehicle. Among these safety measures, the company also provided travel tickets for people aged 65 and over for direct delivery to their residences (ATM, 2020). These policies show that transport companies provide a satisfactory level of service, especially for those whose demand for certain services and needs — such as for health facilities — is inflexible. On the other hand, the elderly could be seriously discouraged from using public transport due to the particularity of the present health emergency. As such, the enhanced 2SFCA methodology considers this aspect through its distance-decay functions, which are different per age group, to limit people's mobility capitals.

In terms of the supply side, as for Naples, a multimodal transport network of the city was created using ArcGIS tools to create a multimodal network dataset and to evaluate travel times. Map I-6 shows the structure of the multimodal network of the city of Milan. The variation of transport monetary costs was not considered since these are flat within the Milan municipality, as travel fares do not depend on physical distances and public transport modality.

The numerical values in Table 5-6 and Table 5-7 highlight the accessibility issue's multidisciplinary. Undoubtedly, it is scientifically advantageous, but it represents a drawback when dealing with real-world practices. To bridge the gap between rhetoric and real practice, the number of inhabitants and their location within each accessibility group can help identify the main urban field of action from a G2C (Government to Citizen) point of view, in terms of public transport network performance, health services supply distribution, and location of new health centres. For the Covid-19 scenario, measuring accessibility to essential urban services could be helpful for local authorities in keeping urban life as normal as possible during emergencies. The methodology presented in this paragraph mainly focuses on the differences between the accessibility to primary healthcare services in an ordinary scenario and during the first phase of the coronavirus pandemic (March 2020). It is worth highlighting that the Covid-19 scenario considers the moment immediately following the pandemic's outbreak.

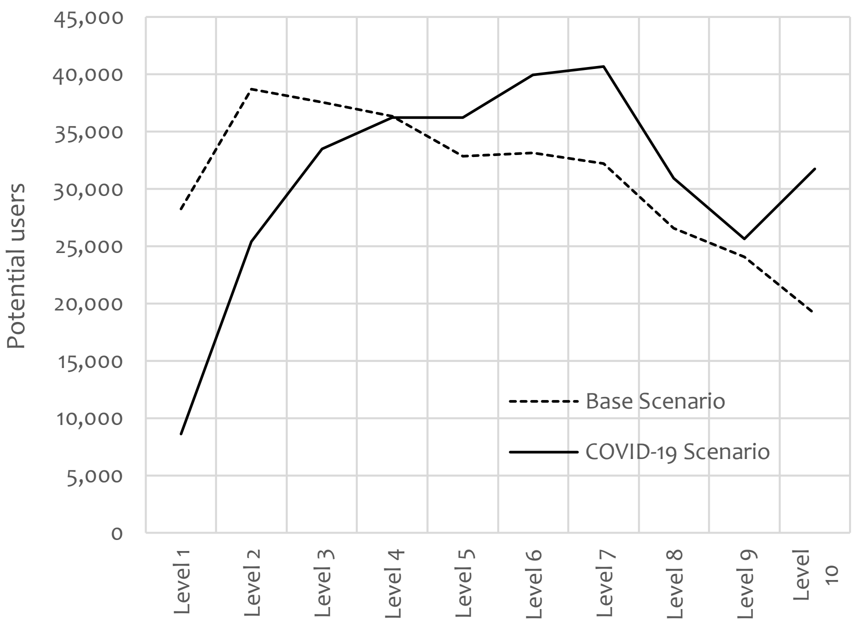

Figure 5-3. The comparison of accessibility levels for the elderly population (over 65 years old) in the two scenarios

Table 5-8 below represents the number of potential users (people aged 65 or above) per level of accessibility. The accessibility levels' thresholds were chosen according to the quantile classification — a data classification method that distributes a set of values into groups containing an equal number of values (Shah & Adhvaryu, 2016; Bauer et al., 2018; Zhu et al., 2018). This issue, connected to the representation of the results, is an innovative element concerning the application in Naples. A different gradation was chosen from the five levels of accessibility (from high accessibility level to poor), following some other methodologies, such as the PTAL (Public Transport Accessibility Level - https://tfl.gov.uk/info-for/urban-planning-and-construction/planning-with-webcat/webcat) of Transport for London. Hence, in this application, ten accessibility levels were considered, ordered from greater to poorer accessibility. Figure 5-3 shows that, due to healthcare services and transport restrictions, the people who benefit from higher accessibility levels (1, 2 and 3) are far fewer during the Covid-19 emergency than in ordinary working conditions. On the contrary, an inverse relation is highlighted for the lower accessibility levels.

Table 5-6 and 5-7 below highlight the number of potential users, divided per age group (65-69, 70-74 and 75 and over). Focusing on the main differences — also proven by the above chart — the medium levels of accessibility underwent no significant modification, at least in absolute terms. At the same time, there are considerable changes for both the high and low levels of accessibility. Bearing in mind that, between the two scenarios, the demand of potential users is unvarying, levels 1 and 2 demonstrate considerable decreases (from 9% and 13% to 3% and 8%). This means that all of these users were re-distributed in lower accessibility levels. Under the same quality-of-life standards, fewer people have had access to primary healthcare services during the Covid-19 disease outbreak in Milan.

Level of Accessibility	Percentage of inhabitants			Number of
	65-69	70-74	≥ 75	elderly people
Level 1 (Very good)	9.2%	9.1%	9.3%	28,268
Level 2	12.3%	12.2%	12.8%	38,700
Level 3	12.3%	12.1%	12.1%	37,536
Level 4	11.8%	11.7%	11.8%	36,367
Level 5	10.5%	10.4%	10.8%	32,861
Level 6	10.9%	10.8%	10.6%	33,142
Level 7	10.3%	10.7%	10.4%	32,226
Level 8	8.5%	8.8%	8.5%	26,574
Level 9	7.9%	7.8%	7.7%	24,074
Level 10 (Very poor)	6.3%	6.4%	6.0%	19,107
	72,869	78,002	157,984	

Table 5-6. Number of inhabitants per level of accessibility in the base scenario.

Level of Accessibility	Percentage of inhabitants			Number of
	65-69	70-74	≥ 75	elderly people
Level 1 (Very good)	3.0%	2.7%	2.9%	8,620
Level 2	8.0%	8.1%	8.4%	25,411
Level 3	10.6%	10.7%	11.0%	33,518
Level 4	11.6%	11.6%	11.8%	36,195
Level 5	11.6%	11.6%	11.8%	36,206
Level 6	13.1%	12.8%	12.9%	39,958
Level 7	13.2%	13.3%	13.1%	40,676
Level 8	10.1%	10.4%	9.8%	30,920
Level 9	8.4%	8.2%	8.3%	25,618
Level 10 (Very poor)	10.4%	10.6%	10.0%	31,733
	72,869	78,002	157,984	

Table 5-7. Number of inhabitants per level of accessibility in the Covid-19 scenario

The matrix shown in Table 5.8 focuses on how healthcare provision accessibility was rebuilt for the elderly. In the rows and the columns are the respective levels for the typical scenario and the Covid-19 scenario. Each matrix element represents the number of territorial units that changed their classification between the two conditions. On the diagonal are the percentages of cells that maintained the same level of accessibility. The matrix is an upper triangular matrix, meaning that the whole territory of Milan underwent a significant decrease in accessibility to primary healthcare services during the first days of the pandemic. No improvements in accessibility have been recorded, as there are no values in the lower triangle of the matrix.

The matrix representation was introduced to better evaluate how accessibility changed within the city of Milan due to the restrictions that deeply changed healthcare provision and the public transport system. The matrix focuses on how potential users were reallocated in terms of accessibility levels. Table 5-8 and Figure 5-4 represent these changes between accessibility classes.

Accessibility levels distribution Covid-19

Accessibility levels distribution pre-Covid-19

	Level1	Level2	Level3	Level4	Level5	Level6	Level7	Level8	Level9	Level10
Level1	30.5%	36.5%	14.2%	5.3%	3.6%	3.1%	2.1%	1.0%	0.1%	3.8%
Level2		39.0%	38.4%	8.3%	5.4%	3.4%	3.8%	0.8%	0.2%	0.8%
Level3			39.0%	41.6%	8.0%	5.8%	3.0%	1.9%	0.2%	0.6%
Level4				43.6%	39.1%	8.2%	6.4%	1.6%	0.1%	0.9%
Level5					48.5%	36.6%	8.1%	3.5%	1.5%	1.9%
Level6						61.9%	29.4%	2.8%	4.2%	1.8%
Level7							70.6%	19.0%	5.5%	4.9%
Level8								78.6%	12.2%	9.2%
Level9									77.1%	22.9%
Level10										100.0%

Table 5-8. Percentage variation of inhabitants per level of accessibility between base scenario and Covid-19 scenario

The results data are interesting in understanding how the accessibility paradigm could be implemented in base conditions and during emergencies. Local authorities could introduce smart decision-support tools in ordinary planning practices to better allocate and distribute resources from the supply side. At the same time, this data could be useful only if associated with the territory and, hence, the base locations of potential users of primary healthcare services. Images below represent the levels of accessibility for the whole city of Milan and how they were modified during Covid-19 restrictions.

In particular, Map I-8 shows the spatial accessibility of the elderly to primary healthcare services in the base scenario. Map I-9 refers to the Covid-19 pandemic scenario due to the changes made to healthcare provision at the beginning of the Covid-19 outbreak in Milan (according to DGR Lombardy n°XI/2906 of 08/03/2020) that designated some of the main healthcare centres "Covid hospitals" for detecting and hospitalising people affected by the coronavirus.

The third map highlights where the Covid-19 restrictions particularly changed the accessibility conditions for the elderly. It shows that due to the reduction of healthcare provision overall, the whole city reduced accessibility. Moreover, neighbourhoods where hospitals turned into Covid-19 hubs severely decreased their usual standards for the elderly.

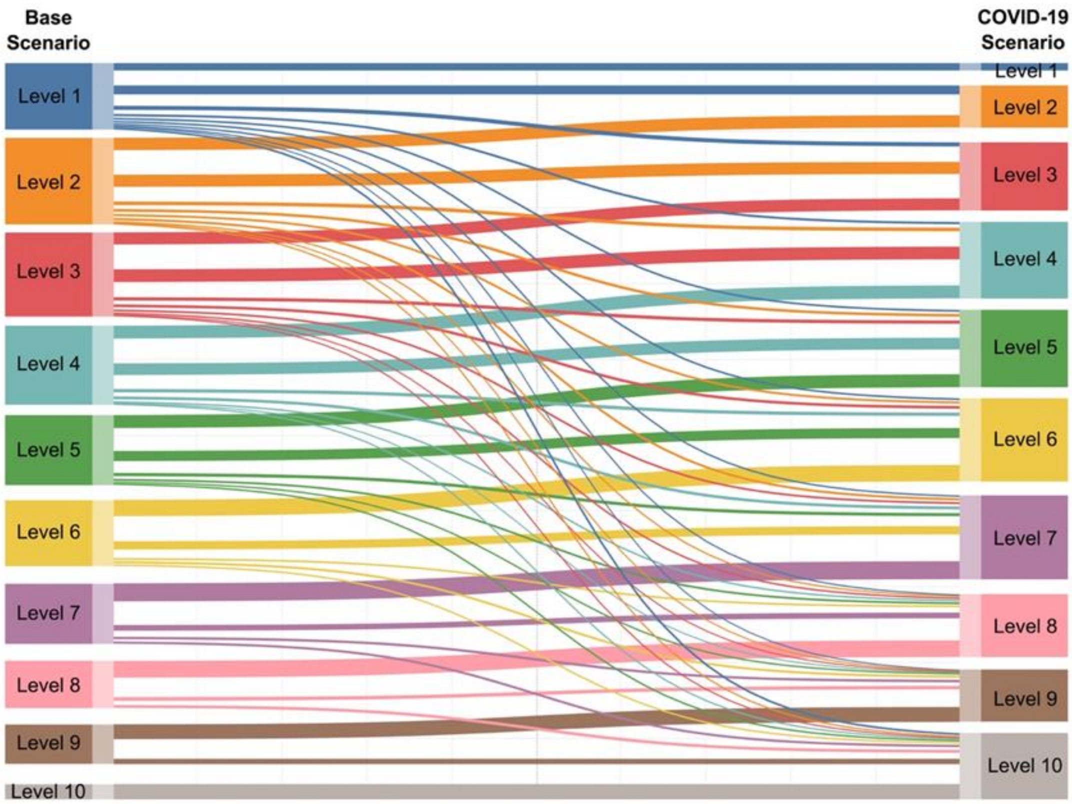

Figure 5-4. Sankey diagram of a variation of inhabitants per level of accessibility between base scenario (on the left) and Covid-19 scenario (on the right)

Although the results present some limitations due to the lack of reliable input data, their representations show that accessibility-oriented tools for decision-makers could be helpful in emergency conditions for guaranteeing high quality-of-life standards, especially for those who are more vulnerable and in need than others. On the supply and demand sides, a range of compatible solutions to manage both emergency (a health emergency, in this case) and ordinary performing scenarios can be identified to satisfy the essential needs of the more vulnerable users, limiting changes to the accessibility and, hence, the quality-of-life standards.

The procedure's application in Milan was useful for the former's validation and has led to some interesting and meaningful results. Also, the outcomes of a comparison between the two scenarios (base and Covid-19) could be useful to support the policymakers in planning the services by considering the spatial separation between users and primary health buildings and understanding the secondary impacts related to the health emergency of the Covid-19 pandemic and the reduction of accessibility. The results highlight that some districts need to improve their elderly inhabitants the accessibility to primary health services for the base scenario, most of which are located in peripheral areas. Results from the Covid-19 scenario show that a high reduction of accessibility is localised near the primary health centres closed in the peripheral areas, and in the central areas the reduction of accessibility is even more widespread. As shown, the application also allows technicians to provide policymakers with some meaningful and interesting suggestions related to the characteristics and locations of health services, the mobility supply system and the urban morphology. Such an approach needs a holistic and integrated attitude to the city context in order to take into account both the components of land use and transport systems defining urban accessibility.

For local planning practices, the urban structure and organisation of the Health Local Agency limit the range of actions to improve accessibility to healthcare services from the elderly perspective. Furthermore, the spread of the new coronavirus has reshaped the design of healthcare provision with specialised structures, limiting the number of available services dedicated to the elderly. The following measures represent feasible ways of enhancing the supply of essential services in dense-populated urban areas: as for the urban component, policymakers can design public transport routes and schedules according to the demands of healthcare services; from the perspective of local health agencies, the outputs of the model could be used to better allocate resources (such as number of physicians, number of beds or work schedules) within the existing structures.

In terms of international practices, the planning of healthcare services in urban areas — particularly for the elderly, the most vulnerable users — should follow two basic guidelines. The first is equity-oriented since the allocation of resources within cities should consider the varied socio-economic backgrounds of different groups. As noted in previous paragraphs, studies have shown that older people suffer from poor accessibility to essential services due to the lack of mobility capital. The trip mode has a significant influence when assessing accessibility as the availability of multiple choices is crucial to satisfying personal and social needs.

The Covid-19 virus raised new unforeseen questions related to perceived safety. Public transport companies are working on this issue, limiting the capacity of each vehicle while increasing the number of bus or railway routes, assuring intense and capillary cleaning, for instance. The second guideline is related to the equilibrium of supply and demand. Bearing in mind that the high density of structures in big cities cannot allow the reallocation of healthcare or transport structures, the balance of supply and demand can be achieved by improving the level of services designed for the elderly and their peculiar needs. For example, local health agencies can develop and implement strategic plans to promote healthy ageing in urban areas, with the partnership of local authorities and stakeholders, to provide specialized services to the elderly. On the other hand, policymakers can improve road and public transport networks so that the urban fabric could be accessible not only for an average adult but also for the weakest users, promoting special equity and social justice.

These are few examples of how healthy ageing policies could be implemented in ordinary urban planning tools to face today and tomorrow challenges for human development.

5.4 Nice[5]

The application of the enhanced 2SFCA methodology to the city of Nice is one of the results of the partnership established with the Université Cote-d-Azur and the Espace Laboratory (Étude des Structures, des Processus d'Adaptation et des Changements de l'Espace). This case study was useful to validate the methodology within a foreign city. Moreover, the enhanced 2SFCA method was run to evaluate the temporal variation of perceived accessibility within a weekday, thanks to greater data availability.

Hence, the 2SFCA formulas were enriched with reference to the time scenario for measuring accessibility to primary health care services.

Nice is the fifth French city for the number of inhabitants (over 340,000) and population density of 4.762 inh./Km2 (INSEE, 2017). The city is close to the France-Italian border, 20 Km away from the Monaco Principality. It stretches from the sea to the Alpes, with a 71.92 Km^2 surface and 520 m total ascent. It is divided into nine urban administrative districts, which are

[5] This paragraph is part of the in print scientific paper "Guida, C., Gargiulo, C., Caglioni, M. & Carpentieri, G. (2021). Urban accessibility to healthcare facilities for the elderly: evolution of the time-based 2SFCA methodology for the Nice case study (France). Lecture Notes in Computer Science, Springer".

named *cantons*. The share of elderly people in Nice, in the 2017, is over 24% (48,102 women and 32,819 men). Table 5-9 shows the distribution of older people in the nine city cantons, and Map I-10 displays in detail the localization of the elderly. The highest shares of people aged 65 and over live in T2, T4, T6, T5 and T9 cantons.

Like the other European Welfare States, France provides citizens with a system of universal health care, which the government largely finances through a national health insurance system. However, there are some major differences in the structure of the French healthcare system and its financing versus its European peers. Most crucially, France spends over 11% of GDP on health care, much higher than the EU average. The French healthcare provision is based on a Social Security system available to all. It comprises a fully integrated and capillary network of public hospitals, private clinics, doctors, and other health professionals. It is a multi-payer system that provides medical care for all citizens regardless of age, income or social status.

		Number of Primary health centre		
Districts	**Elderly**	**Morning**	**Afternoon**	**Evening**
T1 - Plaine du Var	6,823	2	2	0
T2 - Ouest Littoral & Coteaux	12,100	1	0	0
T3 - Collines niçoises	9,159	2	2	1
T4 - Centre Ouest	11,045	3	3	0
T5 - Centre Nord	10,081	3	3	0
T6 - Centre Est Trois Collines	10,254	4	4	1
T7 - Rives du Paillon	4,824	0	0	0
T8 - Coeur de Paillon	6,550	3	3	0
T9 - Est Littoral	10,085	2	2	1
	80,921	20	19	3

Table 5-9. older adults distribution and primary health centre in the city districts of Nice.

In a recent document published by the French Ministry of Healthcare and Solidarity, it turns out that 99,9 % of French citizens have access to a physician within 20 minutes. At the same time, the ministry highlights that it fails to meet the demand for care in some territories because of healthcare supply distribution. The Healthcare Regional Agency (l'Agence régionale de santé – ARS) of Provence, Alpes and Côte d'Azur developed in 2018 a regional strategy to strengthen and assure equal accessibility to territorial services, through the Territorial Plan of Accessibility (PTAS – Plan Territorial d'Accès aux Soins). The plan is mostly focused on the increasing share of people aged 65 and over, promoting higher accessibility to proximity healthcare facilities, in particular to polyclinic centres (Maisons de Santé

Pluriprofessionnelles, Centre de Santé and Communauté Professionnelle Territorial de Santé). The healthcare system of such services for the city of Nice and dedicated to older adults is made of 20 facilities. They were selected from the France OpenData database (2021). Each centre offers a variable number of primary health services, from 10 to 1. The data of health services located in each structure was collect consulting the open-access information available on the websites. Also, the opening hours are different for each centre. This feature was taken into account to assess temporal variation of accessibility within a weekday. Table 5.9 compares the number of open centres for each timeslot in the districts. For this application, we consider only the public primary health centres located in the city of Nice.

A multimodal network of Nice was created for the mobility component, using ArcGIS Pro tools to connect the walking roads network and GTFS data into a network dataset and evaluate the total travel times. First, OpenStreetMap data was used to create the walking network, taking only pedestrian roads and their slope. Then, GTFS data of 2020 from the Transit Company of Nice (Lignes d'Azur) were used to add bus and tram lines and stops in the local transport network. Map I-11 shows the multimodal transit network of the city of Nice.

For the application to the city of Nice, we evaluated the level of urban accessibility to 20 ambulatories that serve over 80,000 older adults in three different timeslots (Morning, Afternoon and Evening). The available health services of each healthcare centre were addressed as the number of surgeons of interest to the elderly, that are: cardiology, dentistry, urology, otolaryngology, ophthalmology, dermatology, orthopaedics, pulmonology, diabetology, rehabilitation, neurology.

We considered three different age groups (young elderly, medium elderly and old elderly) and three timeslots (morning, afternoon and evening). Map I-13, Map I-14 and Map I-15 present the results of evaluating the total accessibility for older people at primary health services in the selected city for the three-time scenarios. According to scientifically established and widespread practices (PTAL – Transport for London) and following previous methodological application to Milan, ten accessibility thresholds were chosen through a quantile classification. These accessibility values are represented in ten classes following a colour gradient from light grey (very poor accessibility) to red (very good accessibility). The primary health services are shown in Map I-12. As morning time, we considered 6 am to 12 pm, afternoon time from 12 pm to 6 pm, and evening time after 6 pm. Hence, the GIS analyses were run for 9 a.m., 4 p.m. and 8 p.m. scenarios.

Some specific spatial patterns are easy to identify in the three maps (I-13, I-14 and I-15). The historical centre of Nice always shows good accessibility during the day (characterized by green colour independently by the timeslot). In the morning and afternoon, the two main valleys in Nice show high accessibility towards the primary health services: the one in the middle with the Magnan river and the west with the Var river. Lower values of accessibility permanently characterize the hills of Nice to the primary health services due to the distinctive street network configuration and the difficulty for the public transport system to serve all low-density subdivisions on the separate hills.

Figure 5-5 shows the comparison between the three-time scenarios (morning, afternoon and evening) in the city of Nice. The frequency of each one of the ten accessibility levels is represented in a proportional staked bar histogram. The first five classes (from red to yellow) correspond only to 20% of total territorial units in the morning, which augment to 30% in the afternoon and 70% in the evening. It is interesting to note that the worst class does not increase significatively during the day: the travel time to join an open service increases, but this one remains accessible.

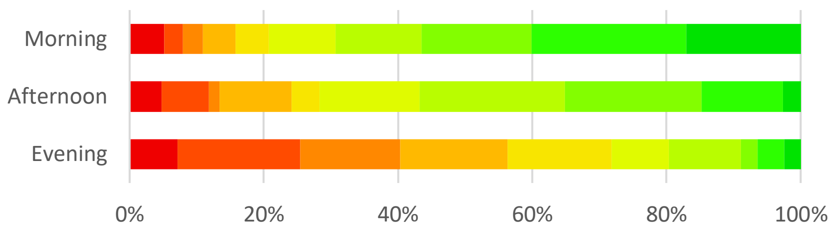

Figure 5-5. The comparison of accessibility at primary health services for the elderly in the city of Nice for the three-time scenarios

Figures 5-6, 5-7 and 5-8 show the variation of accessibility levels in each urban district of Nice in the morning, afternoon and evening scenarios.

For the morning scenario, the districts with a high share of elderly people living in the low accessibility level areas are T1 (Plaine du Var) and T2 (Ouest Littoral & Coteaux). The District T8 (Coeur de Paillon), T5 (Centre Nord) and T4 (Centre Ouest) have an adequate level of accessibility. What stands out in the afternoon scenario is a general reduction of accessibility levels in each district. It is mostly due to a poorer supply of public transport services because only one proximity health service centre closes within the afternoon timeslot.

There is a diffuse reduction of perceived accessibility due to a reduced provision of healthcare services during the evening timeslot: the number of available centres is only three.

The application of the methodology to Nice may be affected by some limits because of the lack of open and more recent data, concerning transport and healthcare provision features.

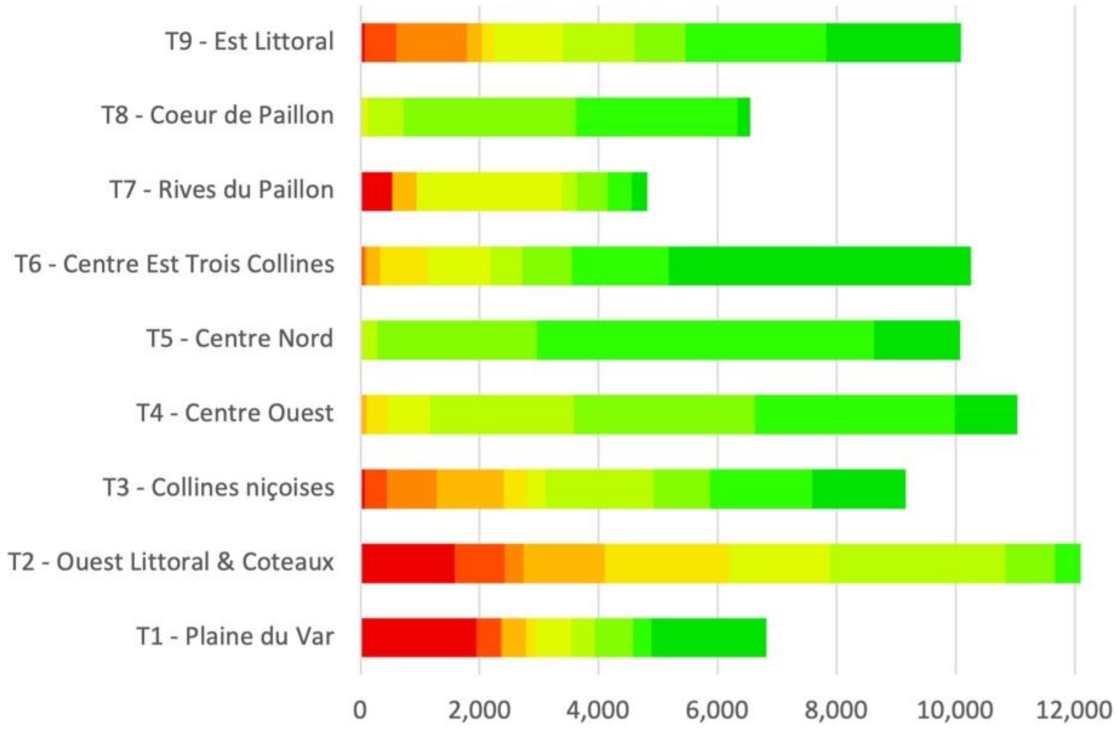

Figure 5-6. The levels of accessibility for the three elderly categories in the morning scenario for the city of Nice

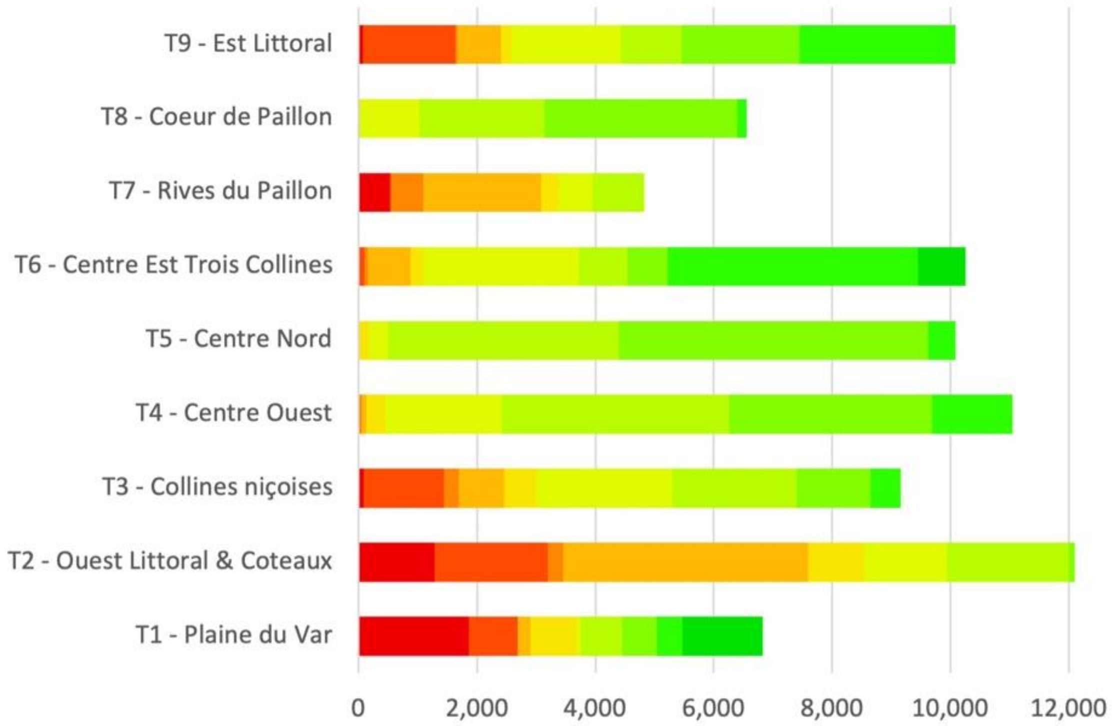

Figure 5-7. The levels of accessibility for the three elderly categories in the afternoon scenario for the city of Nice

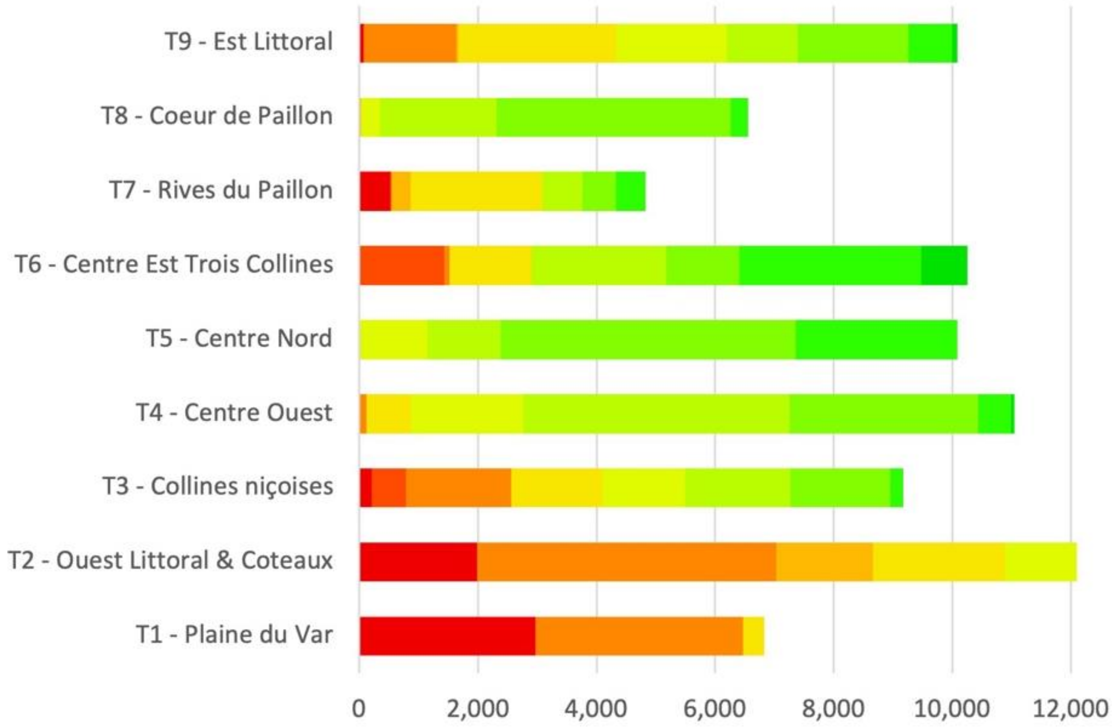

Figure 5-8. The levels of accessibility for the three elderly categories in the evening scenario for the city of Nice

Hence, the results refer to the measured accessibility only to a share of a wider healthcare provision system, particularly proximity facilities which are the focus of ARS for the elderly dwelling in Provence, Alpes and Cote d'Azur Region. At the same time, results show the methodology's effectiveness in evaluating spatial and temporal inequalities when assessing healthcare facilities, providing a state-of-the-art condition for decision-makers and involved stakeholders.

The case-study approach was adopted to allow a deeper insight into the enhanced 2SFCA methodology. The first application to Naples highlighted how the healthcare management by local authorities may be a key issue to improve accessibility within urban environment. The second application to Milan showed how almost zero altimetric differences and the combination of public and private healthcare facilities improve the overall accessibility of the city. Moreover, the Milan application was run for an ordinary and an emergency scenario, due to the outbreak of Covid-19 infection and consequent restrictions. Hence, it has proved the effectiveness of the methodology to support decision-makers in urban planning practices in ordinary as well as in emergency scenarios.

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CHAPTER 6. RESEARCH PRODUCTS

6.1 Introduction

The research project of the Ph.D. program of which this thesis represents a final result has been funded by PON Ricerca e Innovazione 2014-2020 - Asse I "Investimenti in capitale umano" of the Italian Ministry of Education, University and Research (MIUR – Minitero dell'Istruzione, dell'Università e della Ricerca), with D.D. 4th May 2018, n.1090, as an Innovative doctorate with industrial characterization.

In the first phase of the research work, my activities focused on a systematic literature review and the design of a GIS methodology for measuring urban accessibility to services for the elderly population. Then, the methodology was innovated, tested and validated through applications to different case studies: the results for Naples, Milan and Nice have been published in scientific journals in the field of urban planning. Thus, in order to effectively contribute to the improvement of the urban life of older adults, it is necessary to provide public decision-makers and citizens with reliable but easy-to-interpret results. The joint work with the IT industry has been oriented in this direction.

This chapter is fully dedicated to the research and development activities carried out with the industrial and technological partner of Ph.D. programme, Energent S.p.A.

My work was hybrid: in developing the two products, I took part in the whole process both as a customer, a product owner and a team member. This privileged perspective has allowed me to enrich both products with ideas I would never have experienced otherwise.

The knowledge acquired as part of the doctoral course was useful to immediately define the priorities of the two products from the outset. However, the heterogeneous skills of the entire team were the key to fleshing out all the elements of the design, highlighting the strengths and limiting the weaknesses of the work.

The first product is a Research to Business (R2B) tool, a WebGIS that allows policy-makers and stakeholders to identify priority domains and areas for actions and visualize potential scenarios (Ratcliffe & Krawczyk, 2011).

The second one is a Research to Users (R2U) tool. Urban accessibility and age-friendliness result from providing both tangible and intangible services and reliable information and support rather than only interventions in built environments (Turner & Tomer, 2013). A considerable part of the work carried out with Energent S.p.A. concerned the design and development of a mobile application to bridge the gap between the offer of opportunities and services in cities and the perception of accessibility from the elderly. Particular attention was paid to the graphic design and the implementation of elderly-friendly functionalities, so it can be easy to use by a population segment that is not digital natives.

The research problem underpinning the entire programme was designed to make an innovative contribution to academic research in the field as well as find solutions that met the needs of the industrial partner. The systematic literature review, the development of the accessibility measurement methodology, and its validation to several case studies contributed to the product architecture design.

Due to Covid-19 restrictions, all the activities were performed remotely, and the AGILE methodology was implemented to achieve the desired tasks (Cohen et al., 2003; Dyba & Dingsoyr, 2009).

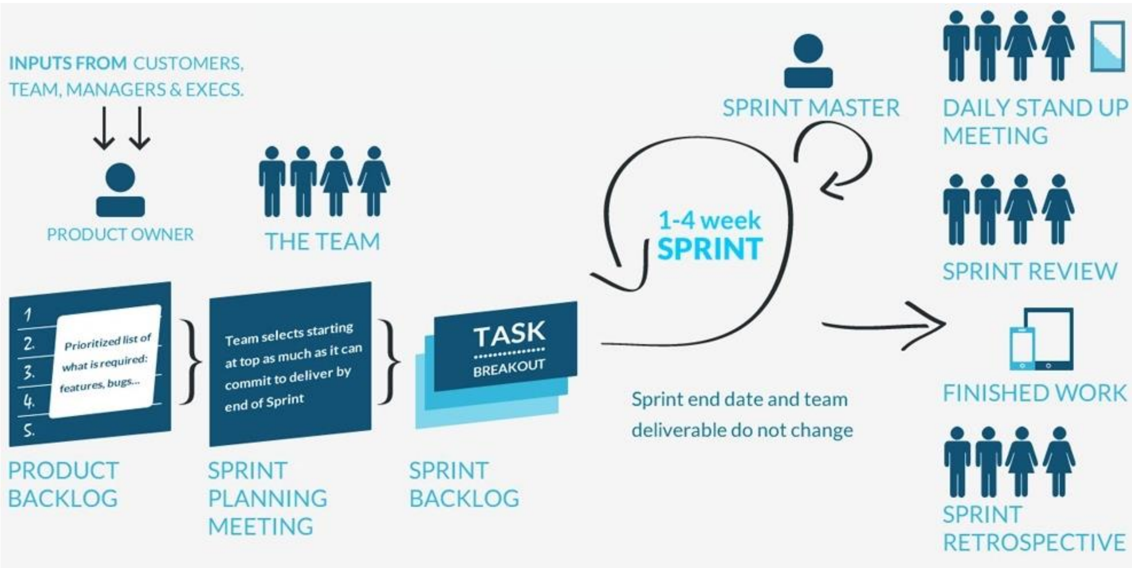

Figure 6-1. AGILE methodology structure

That choice was motivated by the need to get results within a short period and, at the same time, to produce high-quality software. Moreover, the AGILE methodology has been chosen to allow frequent changes to requirements and constant reassessment of priorities needed during the design phase of the product architecture and its development. It was possible to guarantee a prompt reaction capable of managing changes reactively and proactively by adopting the methodology.

In brief, the AGILE software development process has the following characteristics:

- Iterative: several development cycles (iterations or 'sprints'), each consisting of a complete cycle (analysis, development, testing and release);
- Incremental: the system grows progressively in characteristics iteration by iteration;

- Evolutionary: incremental development with particular attention to the feedback following the consolidation of each iteration for the development of the next one;
- Adaptive: development adapts as a result of feedback from previous work (greater attention to the evolution of adaptation to feedback).

The following image (Figure 6-1) explains the developing procedure that was applied.

To date, the architecture of the two tools has been fully implemented and tested on a case study: the city of Naples. Future developments will concern the possibility of industrialising the prototypes of the two products.

The following paragraphs thoroughly describe the essential traits (and limits) of the two innovative accessibility-oriented tools.

6.2 Laocoonte: Research2Business product

The first is a R2B (Research to Business) product. The aim is to provide policymakers with a user-friendly tool to identify areas of the territory with the greatest critical problems in terms of accessibility to urban services for the elderly population and suggest priority areas for intervention.

The tool was implemented on a web platform owned by the partner Energent S.p.A., Laocoonte, which aims to study and define a classification and prediction model to optimise industrial processes. The Laocoonte project places its application in the information and communication technologies (ICTs) sectors. It introduces an interesting element of novelty in the Machine Learning field. Its performance can be adapted according to the data source, standardize input data according to the result to be obtained, and select the best classification and prediction algorithms.

Starting from the characteristics of this powerful platform and the architecture of the R2B product, I worked to implement the M2SFCA (Multimodal 2 Steps Floating Catchment Area) methodology within the Laocoonte platform. This work of mutual contamination had two significant advantages: on the one hand, it was possible to exploit the platform's extraordinary and innovative computing capabilities in analysing huge amounts of data; on the other hand, the design of the R2B tool, with the integration of thematic maps for visualising the results, demonstrated the further potential of the platform.

The R2B product has been designed with two separate access roads. The first interface is dedicated to professionals (technicians and planners) who upload the dataset through a guided procedure. A second customized access is provided to policymakers and stakeholders to easily visualise analysis results in graphs, tables, and maps.

Figure 6-2 summarises the platform's workflow and functioning. It shows the interface offered to planners and spatial researchers and that offered to decision-makers. The first interface is the back end of the results and maps displayed in the second one. The tool has been designed to be as user friendly as possible, so no advanced data analysis and management skills are required.

Figure 6-2. R2B platform workflow. Green circles identify actions and steps dedicated to non-expert users. The blue circle refers to the front-end visualization for policymakers and stakeholders

The first step of the workflow is to load a dataset containing information about accessibility, calculated using the M2SFCA methodology, and about the urban environment. For the first test of the platform, carried out in the city of Naples, the dataset reported in the following Table 6-1 was implemented.

ID	Unique identification number of the hexagonal cell
Longitude	Longitude of the centroid of the hexagonal in the WGS84 Global Reference System (Google Maps)
Latitude	Latitude of the centroid of the hexagonal in the WGS84 Global Reference System (Google Maps)
Acc_tot	Accessibility to healthcare services, calculated using 2SFCA methodology
Acc_65-69	Accessibility to healthcare services, calculated using 2SFCA methodology, 65-69 years old people
Acc_70-74	Accessibility to healthcare services, calculated using 2SFCA methodology, 70-74 years old people
Acc_over75	Accessibility to healthcare services, calculated using 2SFCA methodology, 75 and older people
Pop_ov65	Elderly population (aged 65+) years residing in the hexagonal cell
Pop_65-69	The elderly population aged 65-69 residing in the hexagonal cell
Pop_70-74	The elderly population aged 70-74 residing in the hexagonal cell
Pop_over75	The elderly population aged 75 and over residing in the hexagonal cell
Ttravel_65_69	Total time for the population aged 65-69 (walking plus waiting and onboard local public transport time) to reach the nearest health centre

Ttravel_70-74	Total time for the population aged 70-74 (walking plus waiting and onboard local public transport time) to reach the nearest health centre
Ttravel_over75	Total time for the population aged 75 and over (walking plus waiting and onboard local public transport time) to reach the nearest health centre
N_Stops	Number of Local Public Transport stops within 100 m of the centroid of the hexagonal cell
N_intersections	Number of conflict points of the road network and pedestrian network within 100 m of the centroid of the hexagonal cell
Roads	Length of the road network per hexagonal cell [m].
Pavements	Pavement length per hexagonal cell [m]
Building_ratio	Coverage ratio of the single hexagonal cell [m2].

Table 6-1. Dataset attributes for testing R2B tool in Naples

The second step involves preliminary cleansing analysis. Users are asked to select a target variable and eventually exclude variables from the analysis. In the case of the decision-support tool under investigation, the target variable to be maximised will be accessibility (Acc_tot, Acc_65-69, Acc_70-74 or Acc_over75). If variables are to be excluded (because they are strongly correlated or considered not useful for the analysis, for instance), the user can do so at this stage.

The third step introduces statistical analyses to investigate the correlation between the variables involved, the sample's significance and identify a model that relates the target variable to the others. This module uses an open-source engine called Weka. Weka stands for "Waikato Environment for Knowledge Analysis" and it is a machine learning software developed at the University of Waikato in New Zealand.

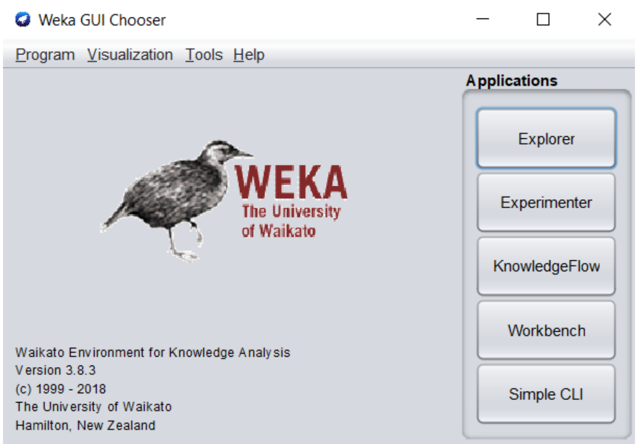

Figure 6-3. WEKA interface

It is open source and is distributed under the GNU General Public License. The Weka workbench is a software system written entirely in Java and consists of an advanced collection of algorithms and techniques for pre-processing machine learning. Weka is designed to test existing methodologies on different datasets quickly and flexibly. It supports the whole experimental process of data mining: preparation of input data, statistical evaluation of learning schemes, graphical visualisation of input data and learning results. The advantage of using this technology is that it is not necessary to define the algorithm for identifying the model beforehand. In contrast, it is possible to use the one that best suits the database on a case-by-case basis.

This last interface provides maps, tables and graphs that are useful to decision-makers and stakeholders. It is possible to select the variable and mode of representation, employing drop-down menus. Users can save developed models, export results and also go back to test different scenarios. Figure 6-4 and 6-5 show the Laocoonte interface for policymakers.

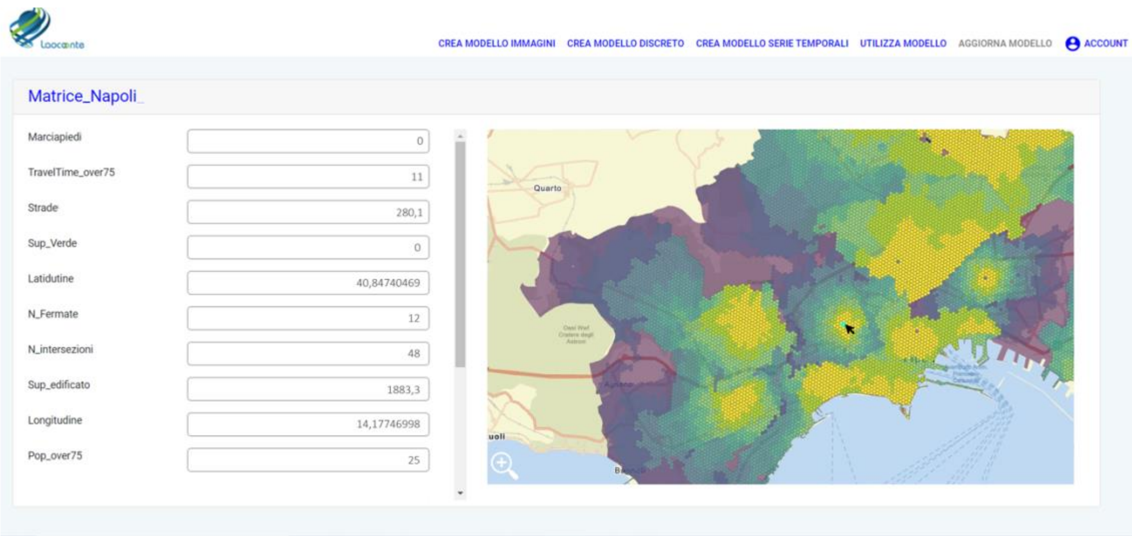

Figure 6-4. Example interface of the Laocoonyr platform

On the right, there is the map of accessibility to primary health services in the city. On the left, the variables most highly correlated with the M2SFCA accessibility measure are shown in descending order. By selecting one of the cells, users can read the values of the most significant attributes.

Compared to other web GIS tools available online (some have been analysed in section 4.2), the adaptation of Laocconte to the objective of the research work proposes significant innovations. First of all, integrating a holistic approach to accessibility in a single tool supports the governance of spatial transformations. The characteristics of the built environment, mobility supply and urban services are brought together in a single work-frame.

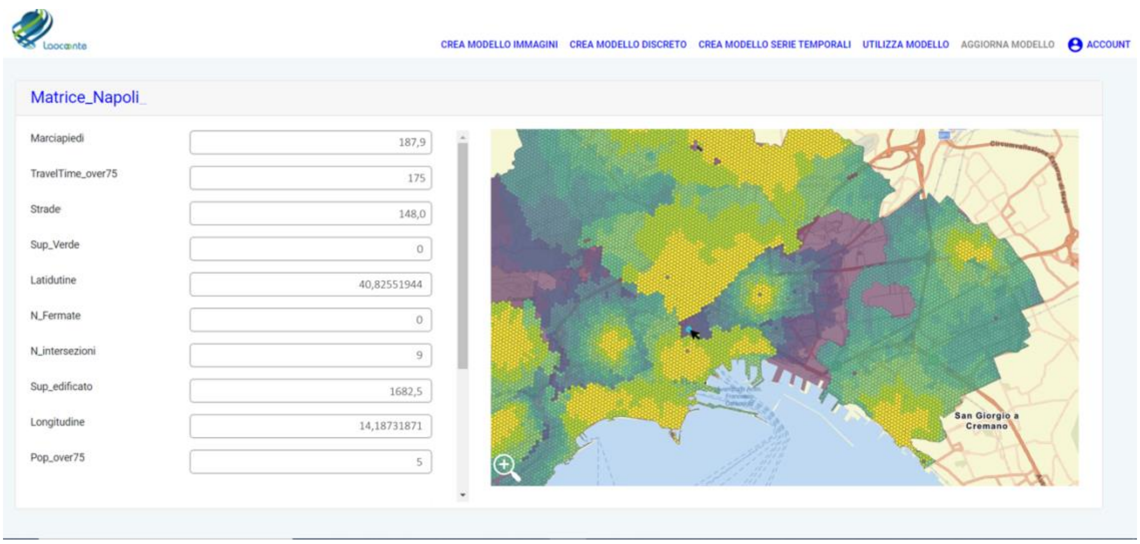

Figure 6-5. Example interface of the Laocoonte Platform

A further aspect of innovation is the introduction of user behaviour, both in the accessibility calculation model and through the interoperability of the R2B and R2U tool, as discussed in more detail in the following paragraph.

6.3 Enea: Research2User product

The second objective of the work is a R2U (Research2Users) product, whose goal is to improve the quality of life of the elderly in urban environments by enhancing the perceived accessibility to essential services and activities.

The study of best practices implemented around the world (paragraph 2.4), of accessibility measures developed within the academic panorama (chapter 3) and of tools to support policy makers (chapter 4) shows that the socio-anthropic component is an essential part to build (and/or adapt existing cities to) more age-friendly environments. Such individual component depends on several variables, such as mobility capital, health status, socio-economic conditions of the elderly.

Taking into account the users' perspective is undoubtedly the key to fulfill the desired objectives at the basis of the research project. Hence, when designing the architecture of research products, the active component of citizens could not be omitted.

While innovative technologies and methods provide the measurement, the representation and the interpretation of spatial and temporal accessibility to urban services, the actual perception from users is more difficult to quantify, because it brings together countless variables and a significative rate of accessibility linked to the intangible services offered by cities.

The collaboration with Energent S.p.A., an expert company in the developing of ICT - Information Communication Technologies - has enabled the development of a second industrial-oriented product: a mobile app to inform, guide and support the daily journeys of older people, on foot and on board local public transport, and to communicate with the decision support tool.

The app is configured as a virtual assistant, named Enea.

Figure 6-5. Raffaello (1483-1520) - Giulio Romano (1499-1546) and workshot - The Fire in the Borgo (1514) - Room Fire in the Borgo- Raphael Rooms - Vatican Museums

The name of the app and the virtual assistant with whom the older adults talk their way around the city refers to Aeneas, the hero of Virgil's Aeneid, son of Anchises and the goddess Aphrodite.

"Ergo age, care pater, ceruici imponere nostrae;
ipse subibo umeris nec me labor iste grauabit;
quo res cumque cadent, unum et commune periclum,
una salus ambobus erit. mihi paruus Iulus
sit comes, et longe seruet uestigia coniunx.
uos, famuli, quae dicam animis aduertite uestris"

"Come, then, dear father, to lay upon our neck;
I will climb on my shoulders, nor will this labor burden me;
where and when things will fall, one and common danger
there will be one salvation for both.
My little Iulus
let him be a companion, and a wife shall keep his footsteps afar off.
You, servants, take heed to your minds what I shall say"

Virgil, Aeneid II.857–863

The hero of Troy is remembered not only for his vicissitudes after escaping the fall of his city at the hands of Ulysses and for the conquest of the Latium coast, but also for one episode which precedes the fleeing of Troy. At the same time, Aeneas carries his old father on his back. The following verses from Book II of the Aeneid refer precisely to this scene.

As Aeneas saved his father and got out of the burning city, the app's virtual assistant, like a modern Aeneas, guides and supports the elderly so that they can have easier access to the life of their city and the services it offers. In particular, the assistant:

- Notifies users of the presence of points of interest with respect to the area in which they are geolocated; of possible exposures to hazards (discontinuity points on pedestrian routes, inaccessible crossings, but also heat waves or extreme climatic events); of information relating to local public transport, in the vicinity of shelters and stations; of potential tools to digitise ticketing procedures (to access postal services, for example), thus offering digital literacy services;
- It guides users like a navigator from a list of activities to be carried out for a certain time interval (defined by the users), suggesting the best succession of activities, the most accessible locations and the most suitable routes, on the basis of waiting times, perceived;
- It allows the collection of reports and small reports on potential hazards found along pedestrian routes (unmarked construction sites, uneven pavement, etc.). User input of this information will allow the creation of a community as well as the collection of useful data to give ad hoc navigation suggestions to users on how to reach the activities and services they are interested in.

Considering the users to whom the app is dedicated, it was necessary to design an elderly-friendly interface as well as to integrate text-to-speech and speech-to-text options. As for the R2B product, the city of Naples was chosen as background for the testing phase.

As well as for the support-decision tool, also the mobile app has been designed following the AGILE methodology.

The first task of this process focused on the writing of *user stories*. They are informal, general explanations of the mobile app features written from the perspective of the end user. Its purpose was to articulate how a software feature would provide value to the final customer (Lin et al., 2014). The template of user stories is given below:

As [user description],

I want [functionality or action],

So that [goal or value for the user].

Figure 6-6. User story template

The first versions of the user stories were revised several times, reviewed with the members of the team working on the development of the app (both from server and back-end sides) and enriched by the points of view of older people in the area, who were informally interviewed.

The following user stories have been selected as example deliverables of this first task.

1.	**As an** [*elderly user (over 65)*], **I want to** [*get an overview of the app with "Hi, I'm Enea, your digital assistant to improve your walking in Naples. Plese, tell me you are going out or your destination*"], **so that** [*I can get to know all the features of Enea*].
2.	**As an** [*elderly user (over 65)*], **I want to** [*get an overview of the app with "Hi, I'm Enea, your digital assistant to improve your walking in Naples. If you want to report a problem on your route, please tell me "Enea there is a problem"*], **so that** [*I can learn about all the features of Enea*].
3.	**As an** [*elderly user (over 65)*], **I want to** [*launch the app and listen to Aeneas ("Good morning/Good afternoon/Good evening User, I am ready to guide you around town")*], **so that** [*I can get feedback on the app's activity status*].
4.	**As an** [*elderly user (over 65)*], **I want** [*Enea to read the alerts from an ad hoc section by saying "Enea, read today's alerts*"], **so that** [*I can be aware of current alerts I might have missed*].
5.	**As an** [*elderly user (over 65)*], **I want to** [*start navigating to one or more services in the city, knowing their crowding rate, route, walking time and possible waiting time for LPT*]. **so that** [*I can choose the most accessible service among those available*].
6.	**As an** [*elderly user (over 65)*],

	I want [*Enea to track my movements in the city ("Enea, I'm going out") so that it can suggest how to improve them (digitisation of procedures, waiting times, alerts for exposure to dangers, etc.)*], **so that** [*I can make use of all the information available*].
7.	**As an** [*elderly user (over 65)*], **I want to** [*warn Enea of reaching the destination*], **so that** [*he can stop navigating*].
8.	**As an** [*elderly user (over 65)*], **I want** [*Enea to assist me in reporting problems related to the urban environment and perceived safety, through the choice of certain options*], **so that** [*I can suggest to other users the possible exposure to dangers and dialogue with public decision-makers*].
9	**As an** [*elderly user (over 65)*], **I want** [*Enea to call national emergency numbers and/or favourite numbers saved in the phonebook] so that [he can call for help, in case he makes an alert related to perceived safety*], **so that** [*I can call for help, in case I make a report regarding perceived safety*].

This first phase defined the general architecture of the product which includes three main sections:

- Alerts and warnings;
- Navigation;
- Problem reports.

For the first section, from a series of interviews held with councillors and technicians of the Municipality of Naples to promote the research activity, *ad hoc* RSS feeds (Really Simple Syndication or Rich Site Summary) were created for the Enea app, containing warnings concerning weather conditions (heat waves, heavy rainfall, for instance) and related to public transport, welfare activities and to the public offices of the municipality. These RSS streams were then integrated into the app server.

Text-to-speech options are provided for this section to quickly inform users of the validity date of the warning or alert and a summary of its content. The second section aims at providing users indications regarding the route to be followed to reach a destination, the degree of crowding at arrival and the possibility of choosing alternative solutions.

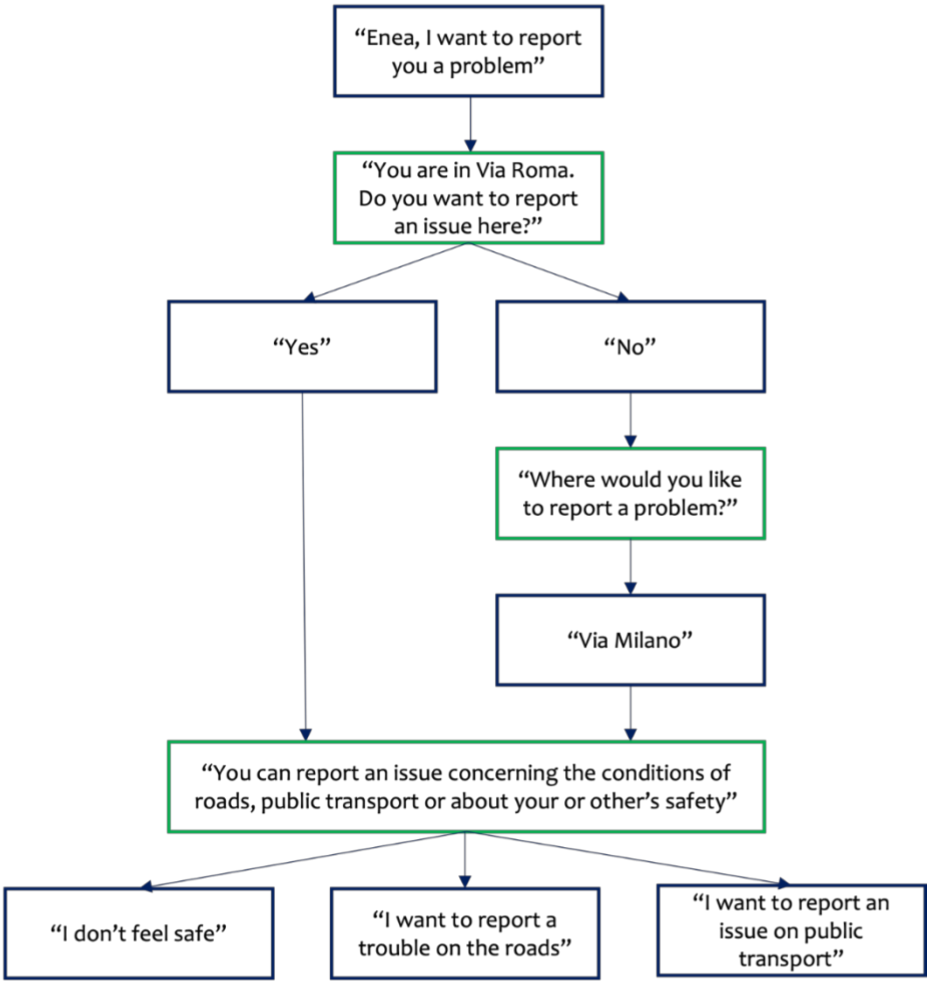

Figure 6-7. Enea guided problems report

For implementing this functionality, Directions API by Google were introduced in the app server. The third and last section allows users to report any problems encountered along the route that threaten general urban accessibility. Through a flow of guided questions and answers (Figure 6-4), Enea collects the reports in a server and allows them to be viewed by other users. In this way, Enea users would be part of a community that can make more conscious choices of destinations to reach and routes to follow. In addition, this section is configured as a bridge between users and decision-makers. Users' reports will also be displayed in the tool to support decision-making processes and identify priority intervention strategies.

Then, according to the AGILE methodology, the app's graphics were designed before the app and server programming activities. Below there are some of the app prototype pages.

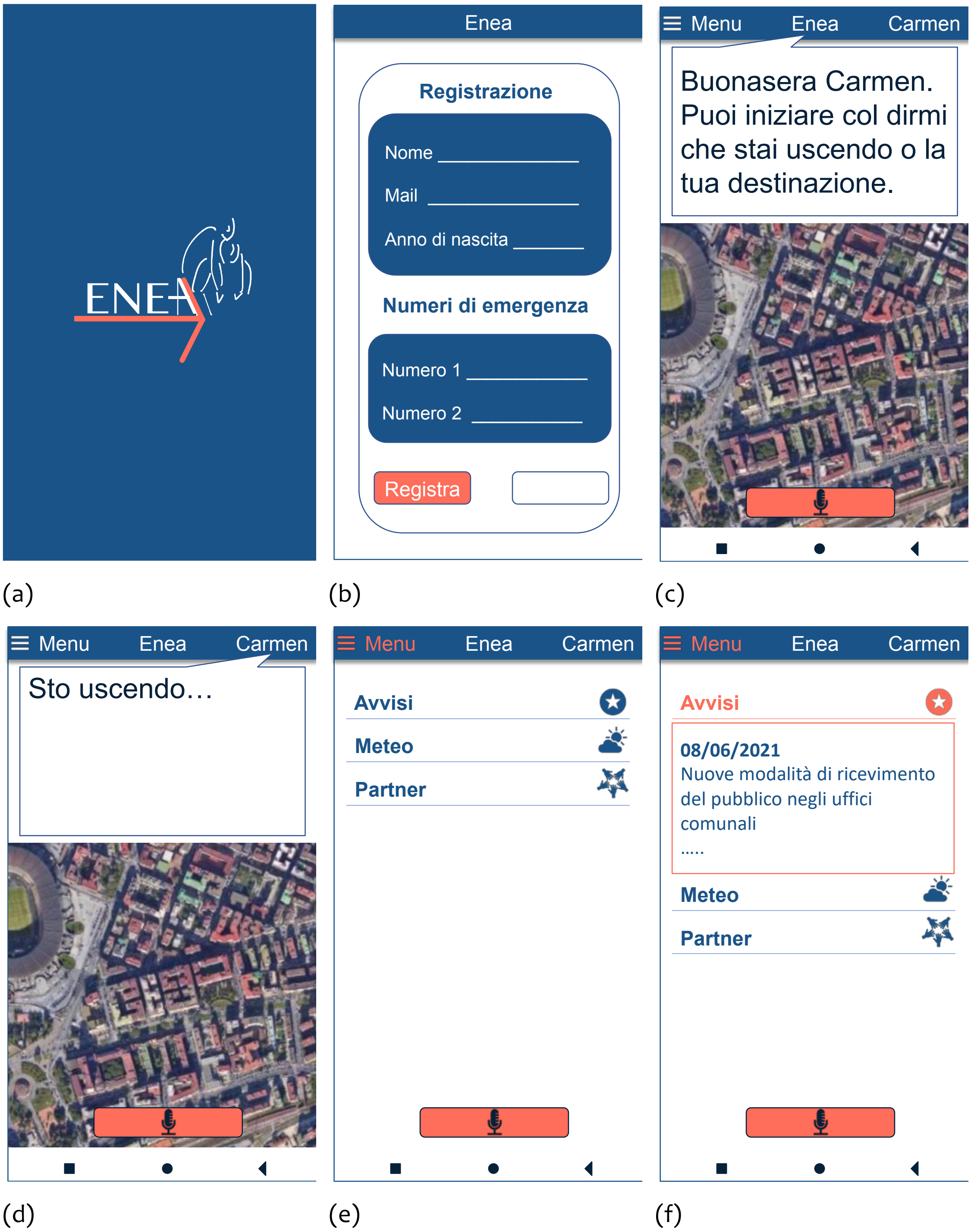

Figure 6-8. Graphic design for the app pages. (a) is the start-up screen, with the logo, designed by the author. (b) is the registration page, which the user can choose to skip; on this page it is possible to enter two emergency contact numbers, which the app can call in case the user makes a security alert. (c) is the first dialogue screen of the app, where the user can interact with enea by clicking on a clearly visible button at the bottom. (d) shows a type of user-Enea interaction ("Enea, I'm leaving"). (e) is the summary screen of the menu, which also contains a section dedicated to the project partners. In (f) is an example of display of alerts collected by Enea through the RSS feed

Although Enea is now only a prototype, there are plans to strengthen the back-end server, test it with a larger and more heterogeneous sample of users and start the industrialisation phase of the app.

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CHAPTER 7. CONCLUSIONS

7.1 Conclusions

This dissertation is the final result of a research project carried out as part of the Ph.D. programme in Civil Systems Engineering at the Department of Civil, Building and Environmental Engineering of the University of Naples Federico II.

The activities carried out and summarised in this thesis are based on various conceptual and methodological assumptions, which are based on sound scientific ground and concern the need to apply an integrated approach to urban and territorial systems, capable of coordinating the spatial and functional organisation of the urban system and the implementation of transport systems, in order to limit age-inequalities (and everything that follows such as isolation, ageism, depression, healthcare issues, etc.) and promote age-friendly approaches to the development of more inclusive and sustainable cities and communities.

The Ph.D. programme has been funded by PON Ricerca e Innovazione 2014-2020 - Asse I "Investimenti in capitale umano" of the Italian Ministry of Education, University and Research (MIUR – Minitero dell'Istruzione, dell'Università e della Ricerca), with D.D. 4th May 2018, n.1090, as an Executive doctorate with industrial characterization. Therefore, the research activities were designed, carried out and validated, with the supervision of my tutor, Prof. Arch. Carmela Gargiulo, and the project partners, in order to achieve not only theoretical-methodological results, but also so that they could be implemented in technological and innovative tools, supporting both public decision-makers and stakeholders and, not least important, users.

The problem underlying the research relates to the ongoing ageing of global population: almost every country in the world is experiencing growth in both the size and share of older adults. Today 728 million persons are 65 years and over in the world and in the next 30 years this number is expected to increase to more than double its present value (Sanderson & Scherbov, 2010) and it is worth noting that this number has more than doubled since 1980 (382 million) and is projected to reach nearly 2.1 billion by 2050 (United Nations, 2020). A second and inexorable trend is in the spotlight of 21st century and it is already intersecting demographic turn-over: today, more than 4 billion people live in urban areas (Zhang, 2016; Bodo, 2019). This means that over half of the world (55%) live in urban settings. The demographic turn-over and the expected urbanization mandate that urban areas adapt an intergenerational view of growth and development (Bloom et al., 2010). According to the

OECD report (2015), ageing trends seem to be different between metropolitan areas and non-metropolitan areas. In the large urban areas, the older population is growing faster than the total population. This means that the challenges are greater to overcome, but also that, again, cities have more and better resources and offer greater opportunities to develop more sustainable environments.

In the light of these phenomena, because of their temporal and spatial evolution and their almost global reach, the research was set up in order to define innovative methods and tools, capable of supporting decisions relating to territorial and urban transformations, so that cities can prepare for the challenge of demographic change, in terms of their physical and spatial management. Hence, although my research is grounded in the scientific field of governance of urban and territorial transformations, it is contaminated and enriched by the fields of transport planning, information and communication technology and sociology.

The results achieved by the research work and described in this volume are manifold.

The identification of the improvement of accessibility to built spaces and urban services as a key for increasing the quality of life of the elderly in the city is a first result. In more detail, after summarising current and future trends in population ageing, the second chapter discusses key considerations for elderly people related to social isolation and urban life participation.

Population ageing and urbanization are the culmination of successful human development during last century. They also are major challenges for this century. Living longer is the fruit of critical gains in public health and in standards of living. On the other hand, urban growth is associated with a country’s technological and economic development. Vibrant cities benefit a country’s entire population – urban and rural. Because cities are the centre of cultural, social, and political activity, they are a hothouse for new ideas, products and services that influence other communities and therefore the world. Yet to be sustainable, cities must provide the structures and services to support their residents’ wellbeing and productivity as well as a good level of accessibility to such urban facilities. Though today's elderly population is healthier than past generations, older people still require supportive and enabling living environments to compensate for physical and social changes associated with ageing.

Improving spatial, temporal and personal accessibility to urban services and environments is one of the keys to improve quality of life, limit age inequalities and ageism and enable an active social life for older adults.

Historically, nobody has been responsible for ensuring that people can get to key services, employment sites, places of interest, etc. and, as a result, services have been developed with inadequate attention to accessibility (Farrington J. & Farrington C., 2005). At the same time, accessibility has been often seen as a problem for transport planners to solve, rather than one that concerns and can be influenced by other organizations, for example by locating, designing and delivering services that are easily and conveniently available (Social Exclusion Unit, 2003).

The third chapter of my dissertation defines the scientific frame of paradigms, definitions and measures of urban accessibility, in order to point out the main trends and gaps. The systematic literature review gives a comprehensive overview about urban accessibility literature and its current research status, in order to introduce its assessment in an accessibility-oriented urban planning tool, to improve elderly's quality of life within urban areas.

The development of such methodology, its revision and validation are the third result of my research activities: the systematic study of scientific literature, as well as of technological advances in the field of spatial planning aimed at improving urban accessibility, has allowed me to identify existing gaps, both in terms of methodology and its application into real-world practice. Hence, an *ad hoc* GIS-based procedure was developed to evaluate the elderly's level of accessibility to urban services, considering the personal characteristics of potential users and multimodal transport services (i.e., walking in the street, the frequency of service and the localisation of urban transport stops) (Makarewicz & Németh, 2018; Wang & Cao, 2017).

The methodology was designed to be replicated and scaled to different contexts and adapted to the measurement of urban accessibility to essential services for older people. In order to test its validity and to improve the whole method, the evaluation of accessibility levels to local health services was performed for three significant case studies: Naples and Milano, in South and Northern Italy, and Nice (France). The results and maps of these activities have been collected in chapter 5 and Annex I respectively.

The third result of research activities is the outcome of joint work with the industrial partner of the Ph.D. programme, Energent S.p.A. Two innovative and technological products have been designed and programmed.

The first is a R2B (Research To Business) product: a GIS-based decision-support tool that helps policy-makers and stakeholders to know the level of spatial accessibility to urban services in their city, to identify a ranking of priority areas and types of intervention and, finally, to monitor, by creating intervention scenarios, the benefits of the developed actions. The platform on which the tool was integrated and tested is owned by the partner Energent S.p.A., whose aim is to study and define a classification and prediction model for the optimisation of industrial processes and for Business Process Management with the implementation of a pilot system determined on databases referring to the insurance and health sectors. The Laocoonte project places its application in the ICT technology sector in information and communication technologies (ICT) and introduces an element of novelty in the Machine Learning area in that it allows the application to be adapted to the type of data source, regularize the data itself according to the result to be obtained and select the best classification and prediction algorithms in the industrial sector and in the banking and insurance sector.

Starting from the characteristics of this powerful platform and the architecture of the R2B product, I worked to ensure that the two tools could offer a valid support tool for local decision-makers, making the most of their potential.

The second objective of the industrial-oriented work is a R2U (Research2Users) product, whose goal is to improve the quality of life of the elderly in urban environment, by enhancing the perceived accessibility to essential services and activities.

Taking into account the users' perspective is undoubtedly the key to fulfill the desired objectives at the basis of the research project. Hence, when designing the architecture of research products, the active component of citizens could not be omitted. While innovative technologies and methods provide the measurement, the representation and the interpretation of spatial and temporal accessibility to urban services, the actual perception from users is more difficult to quantify, because it brings together countless variables and a significative rate of accessibility linked to the intangible services offered by cities.

The result is the prototype of a mobile app to inform, guide and support the daily journeys of older people, on foot and on board local public transport, and to communicate with the decision support tool. It has been configured as a virtual assistant named Enea.

Research and development activities could not fail to take into account the ongoing Covid-19 pandemic. Mobility restrictions and lockdown forced me to revise the planning of the activities envisaged in the project phase (the training activities at the company and at the foreign academic partner were conducted in telematic mode) but they also gave me an opportunity.

The social and anthropic nature of the research I conducted prompted me to think carefully about the inequalities that Covid-19 has further emphasised, especially in urban settings. Therefore, part of the methodological research as well as the development of the industrial tools took this historical moment into account.

The work has some methodological and applicative limitations that can be overcome in future research work. First of all, the M2SFCA method developed could be enriched with additional components that take into account the quality of the built environment and thus return a pedestrian graph enriched with information relating to the presence of pavements, albedo, and elements of roads and pavements that can limit elderly people mobility capital, such as coexistence of different modes of mobility, kerbs, height differences, visibility, acoustics, etc. Similarly, the individual component could be calibrated on the actual mobility capital of the elderly, due to the territorial context. Other segments of the population to which significant attention should be devoted in the development of inclusive communities and cities could also be taken into account: children, ethnic minorities, disabled people.

Moreover, the two products of the industrial collaboration are now available as prototypes and only for the city of Naples. The next activities include testing them to a large and significant sample of potential users, as well as the start of technology transfer phase.

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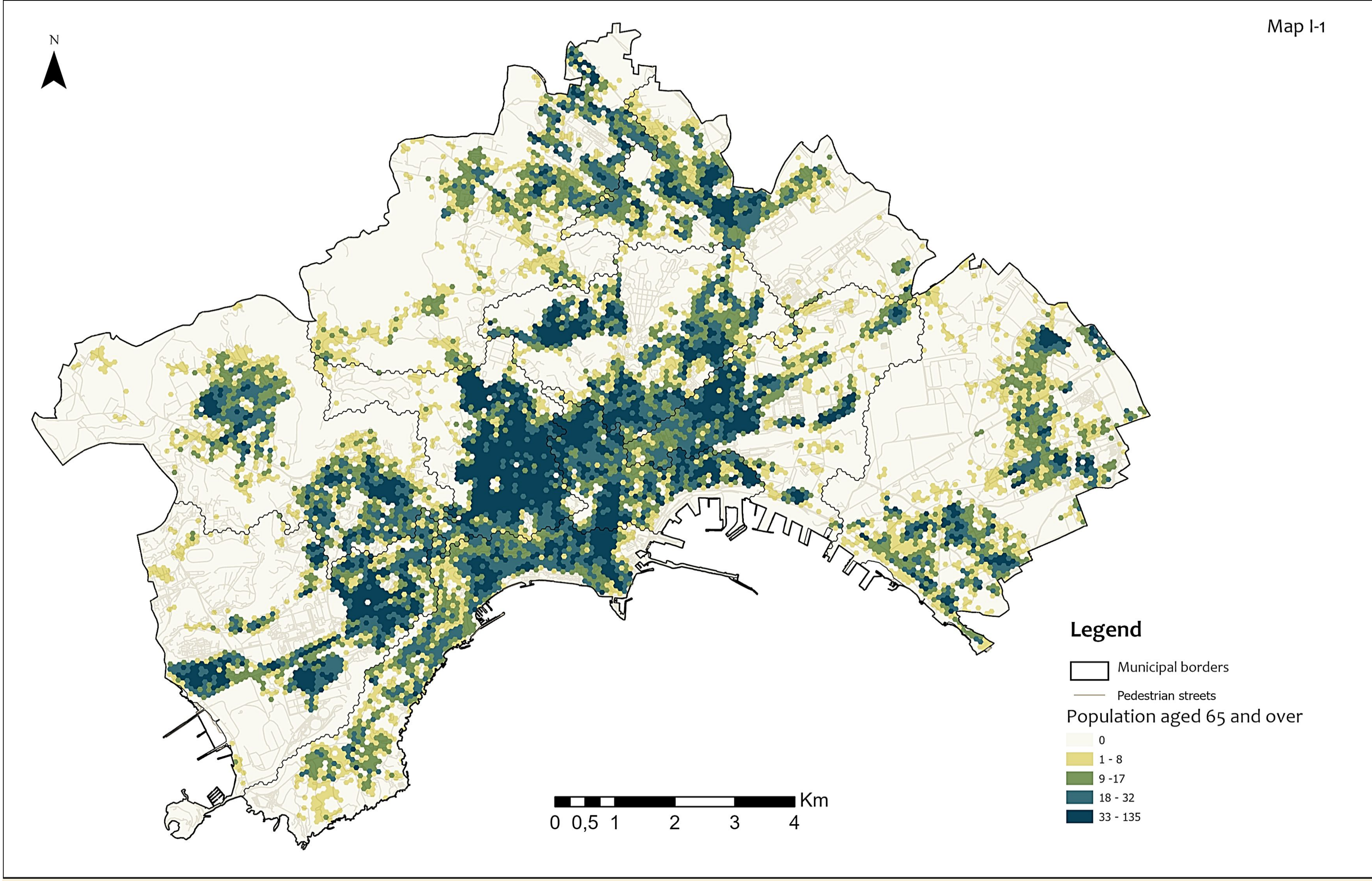
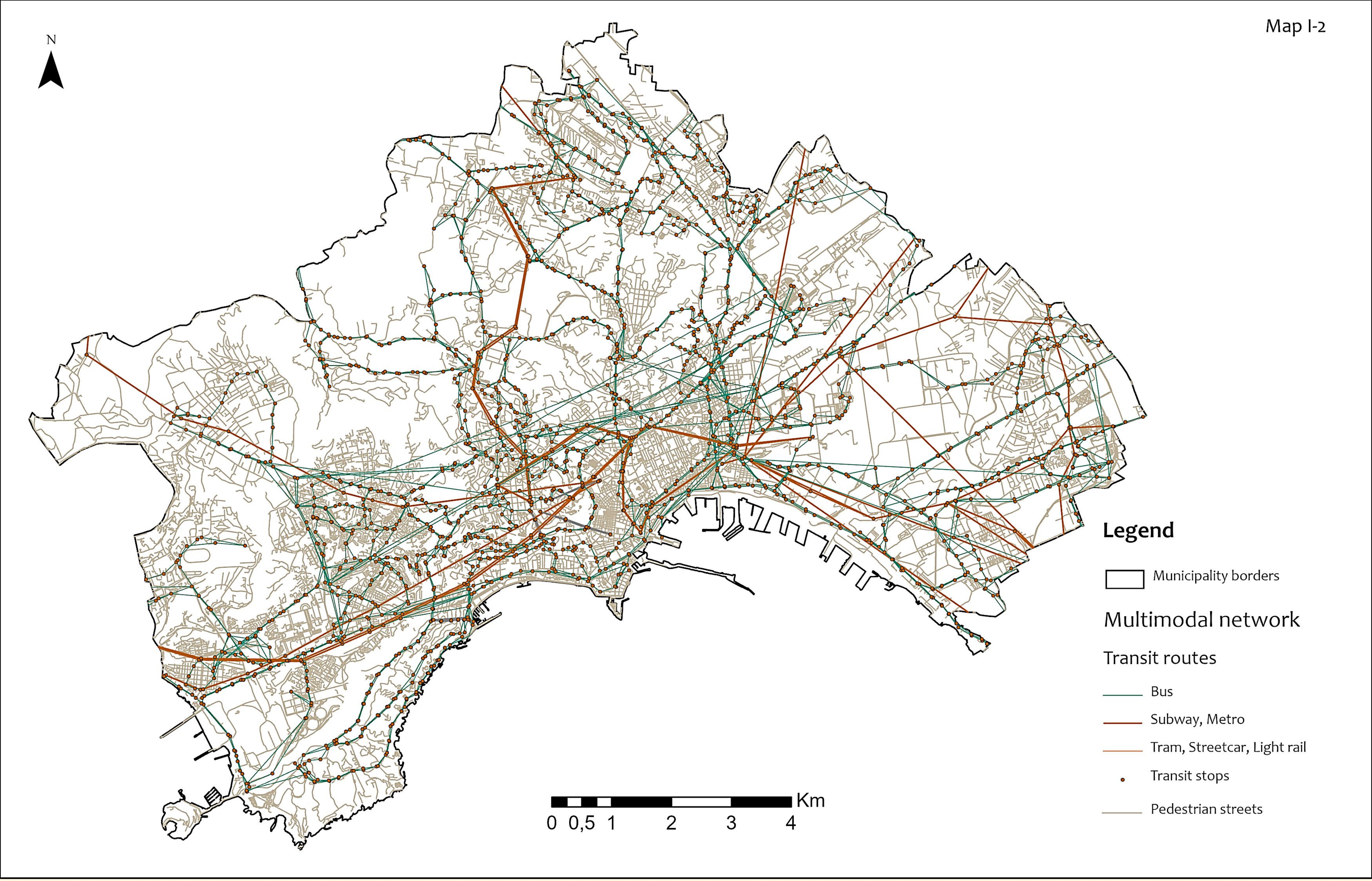
ANNEX I. MAPS

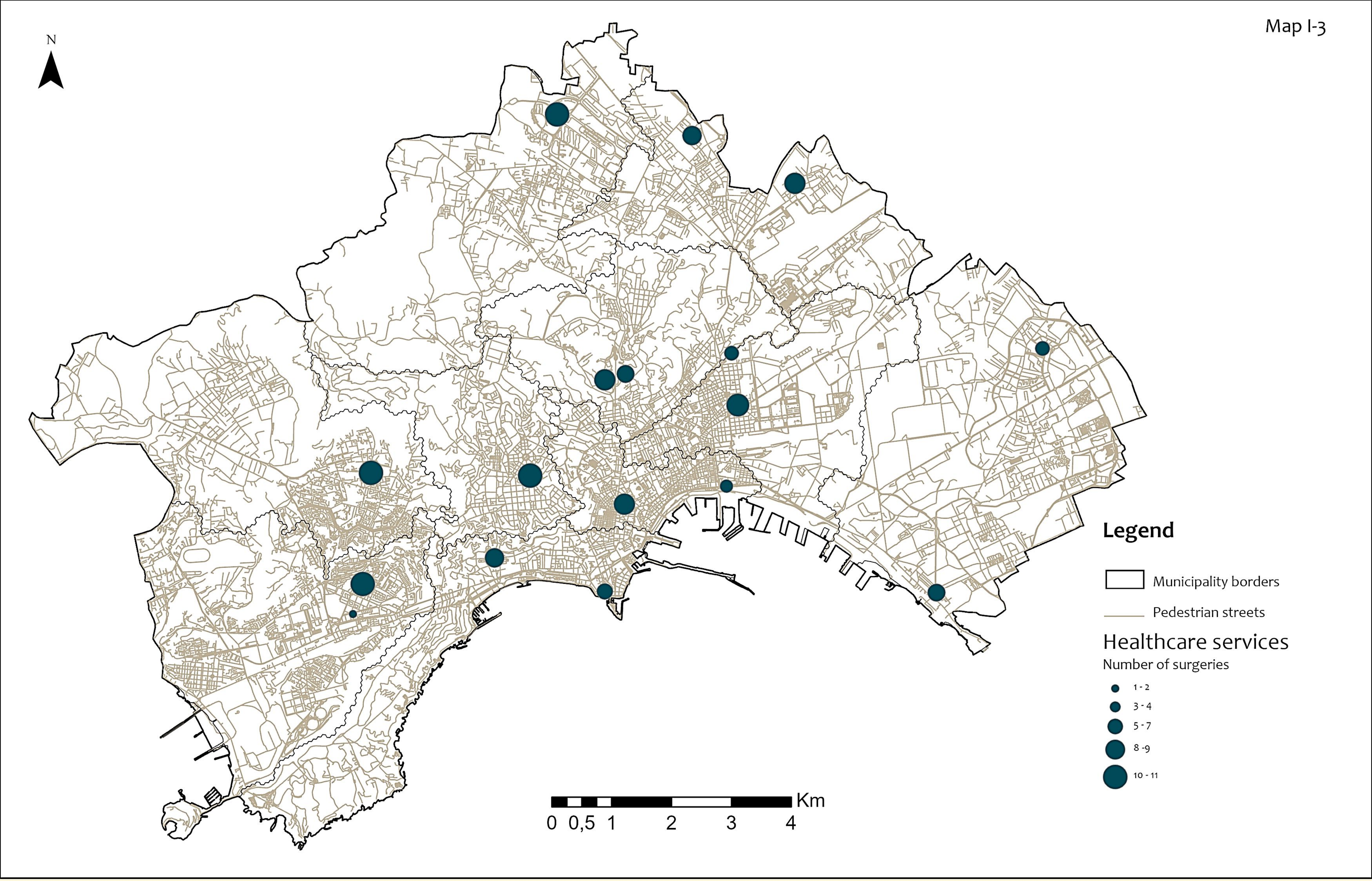
List of Maps



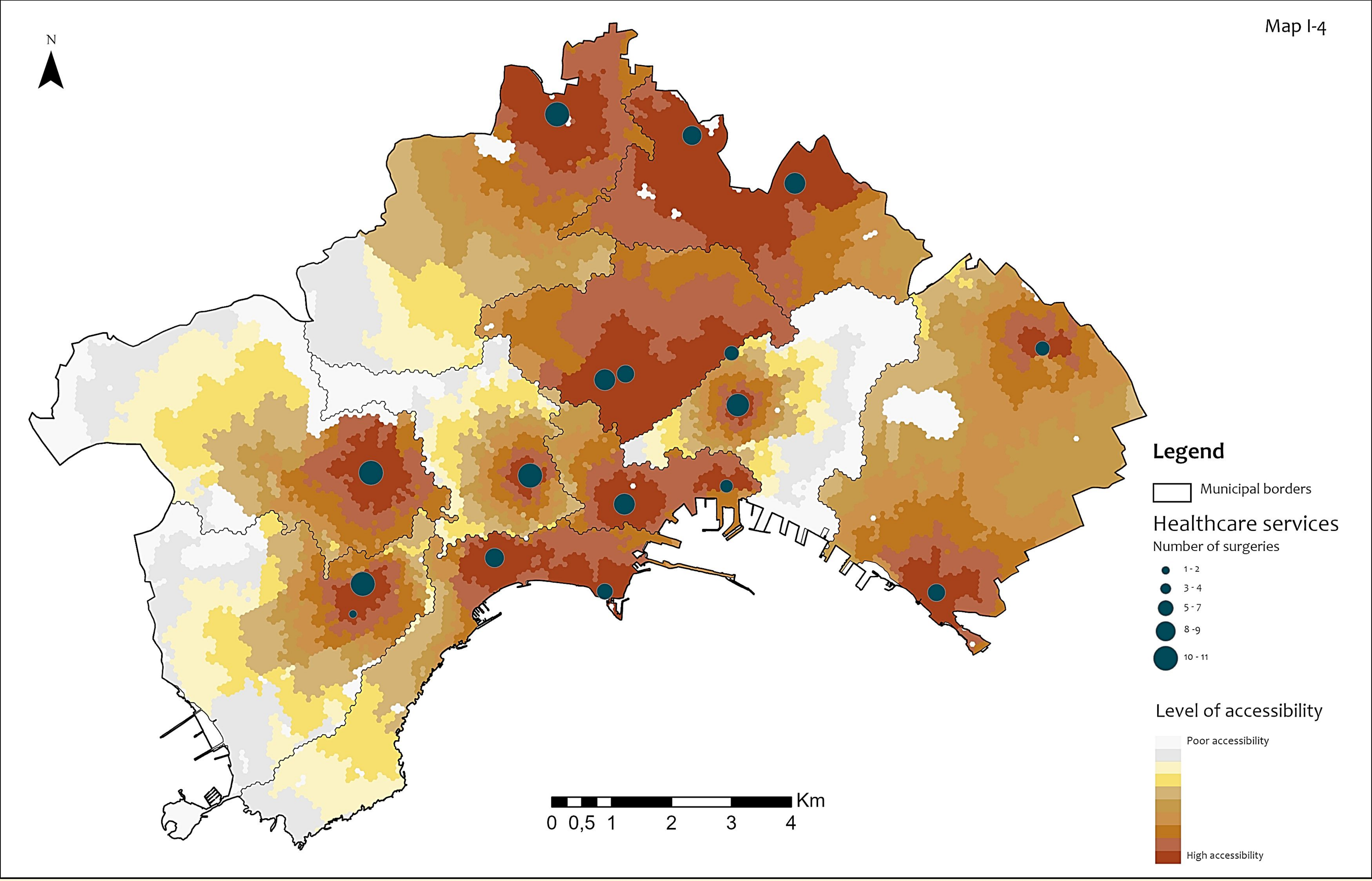
Distribution of people aged 65 and over – Naples (Italy)



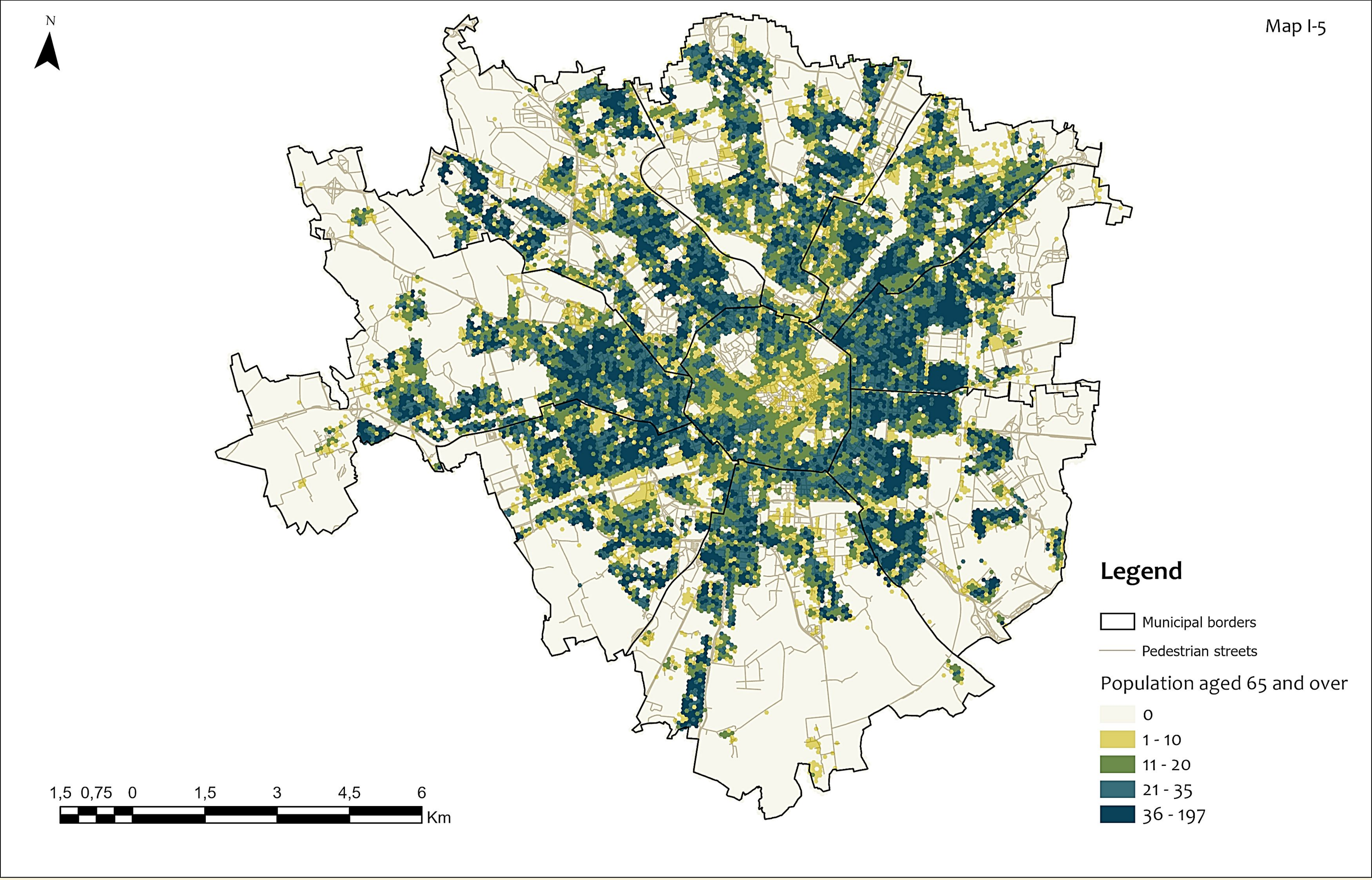
Multimodal mobility network - Naples (Italy)



Healthcare provision - Naples (Italy)



Urban accessibility to healthcare services for the elderly - Naples (Italy)



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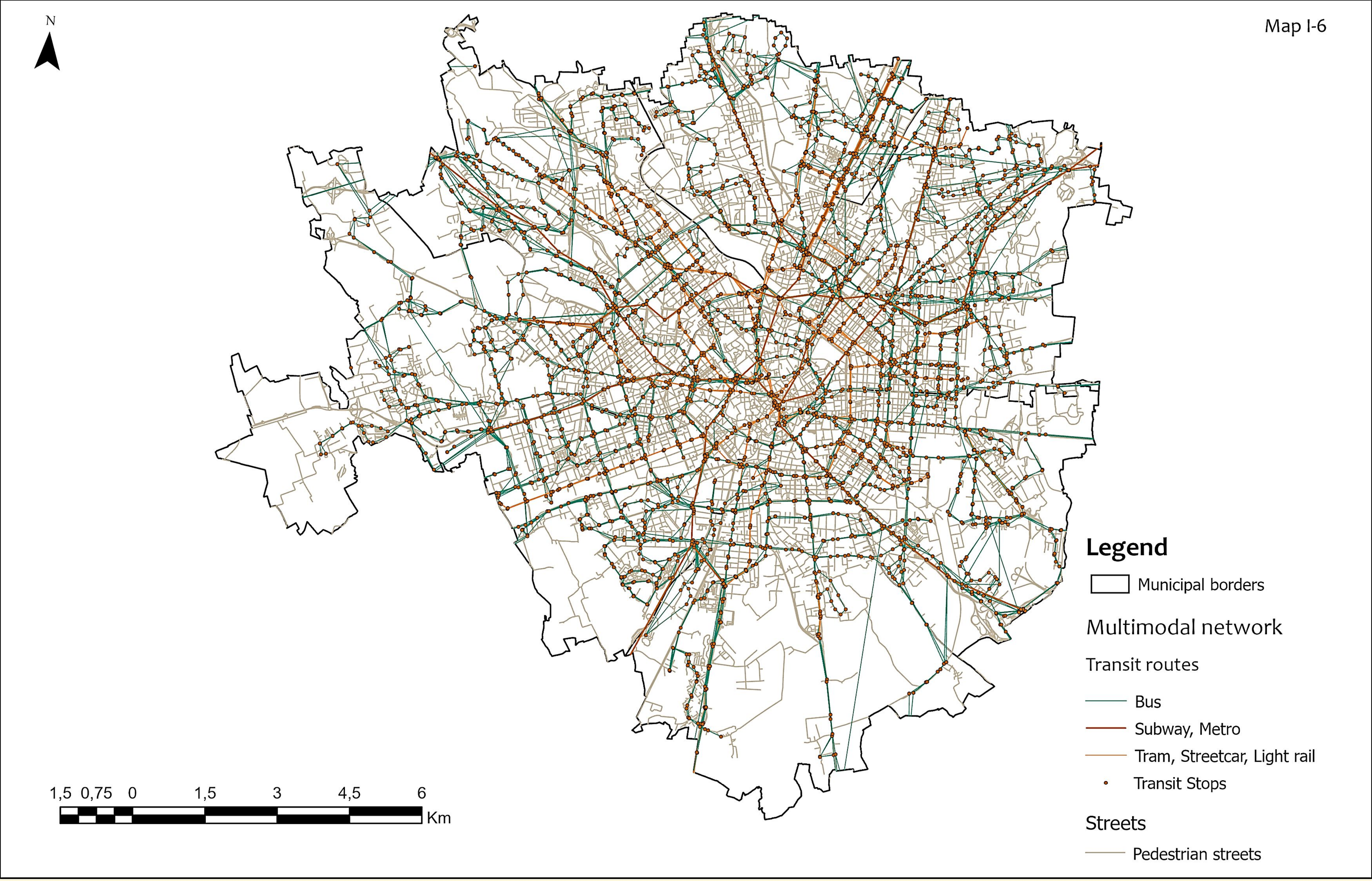
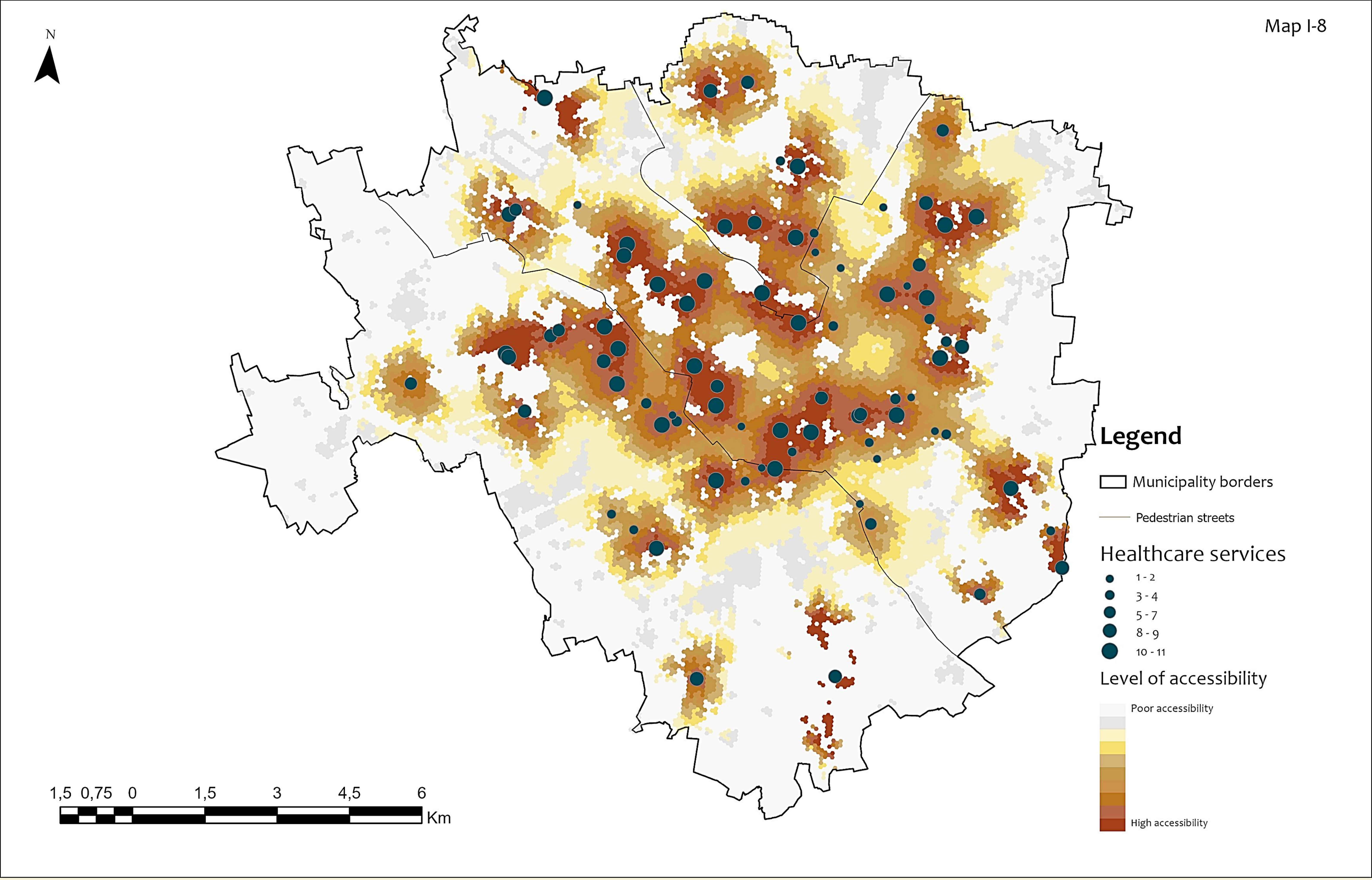
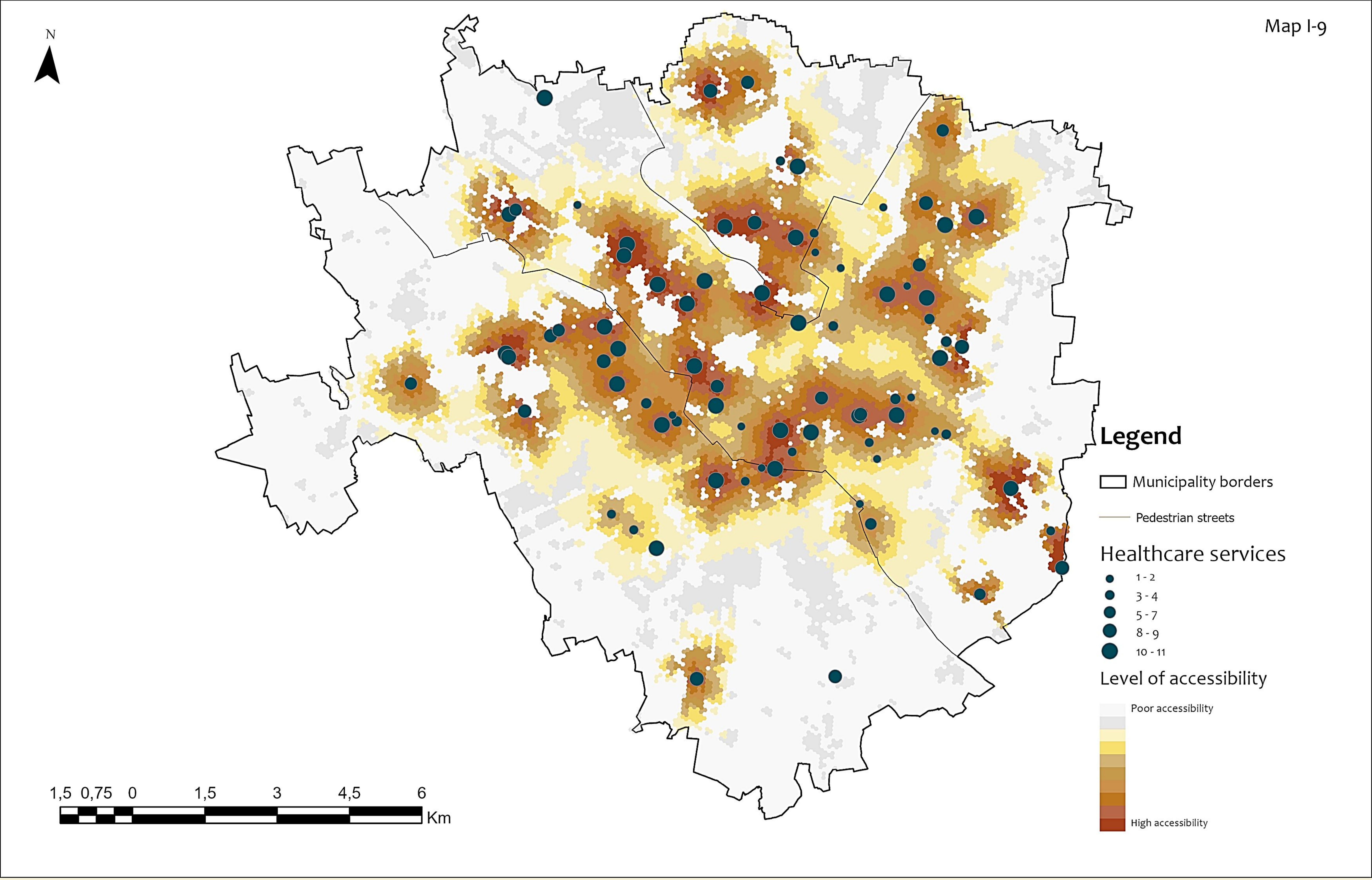


Multimodal mobility network - Milan (Italy)

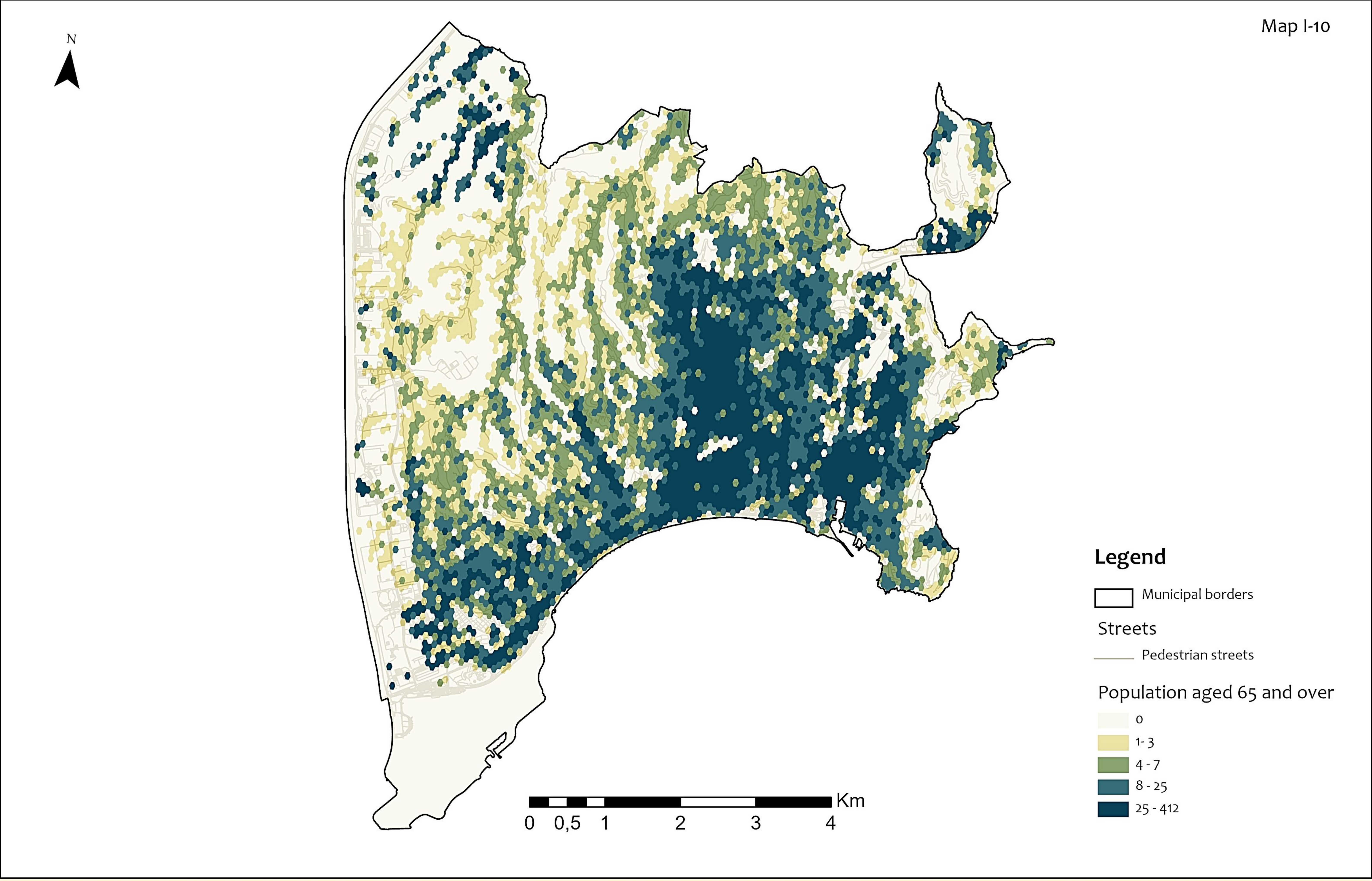
Healthcare provision - Milan (Italy)



Urban accessibility to healthcare services for the elderly, ordinary scenario - Milan (Italy)

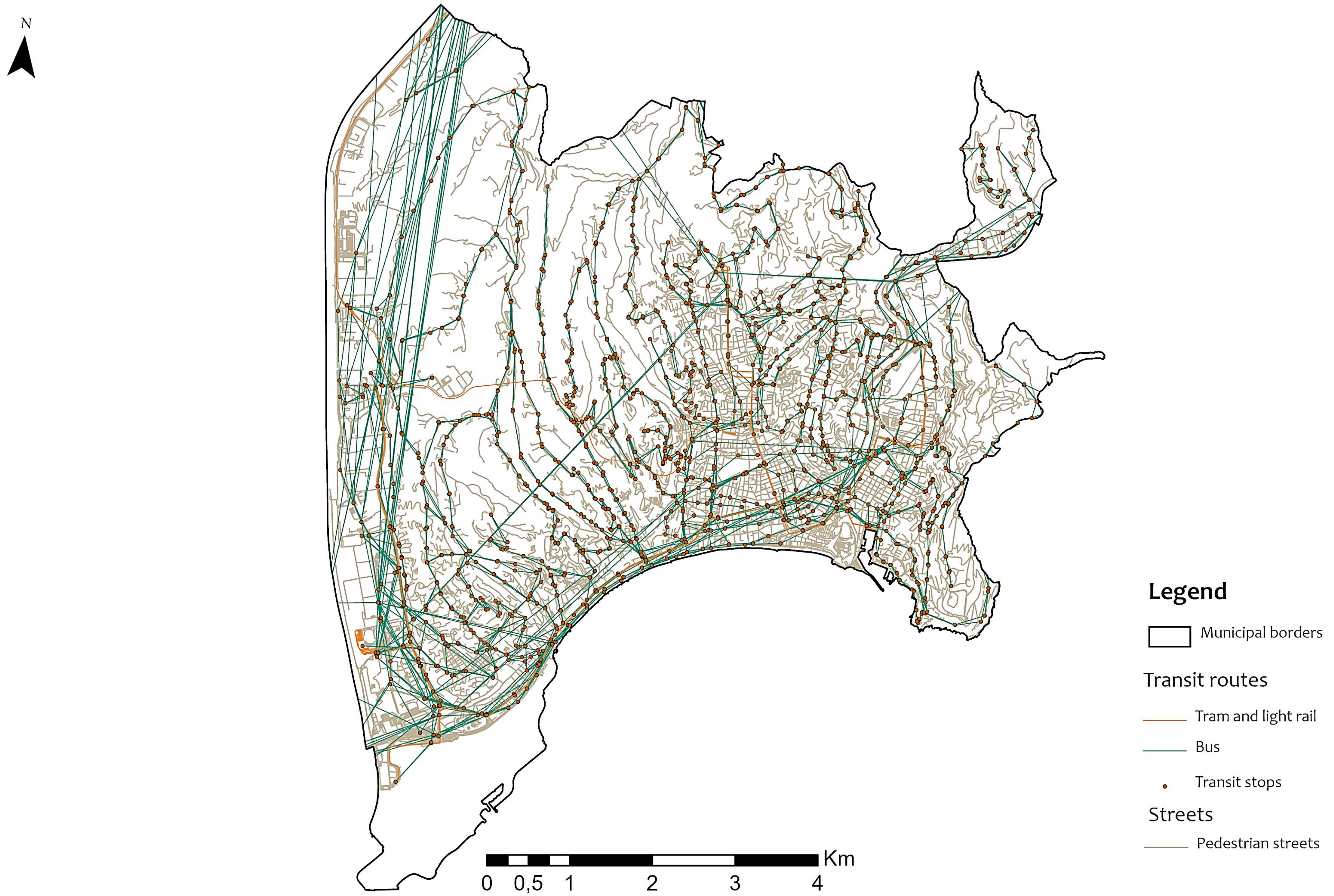


Urban accessibility to healthcare services for the elderly, Covid-19 scenario - Milan (Italy)

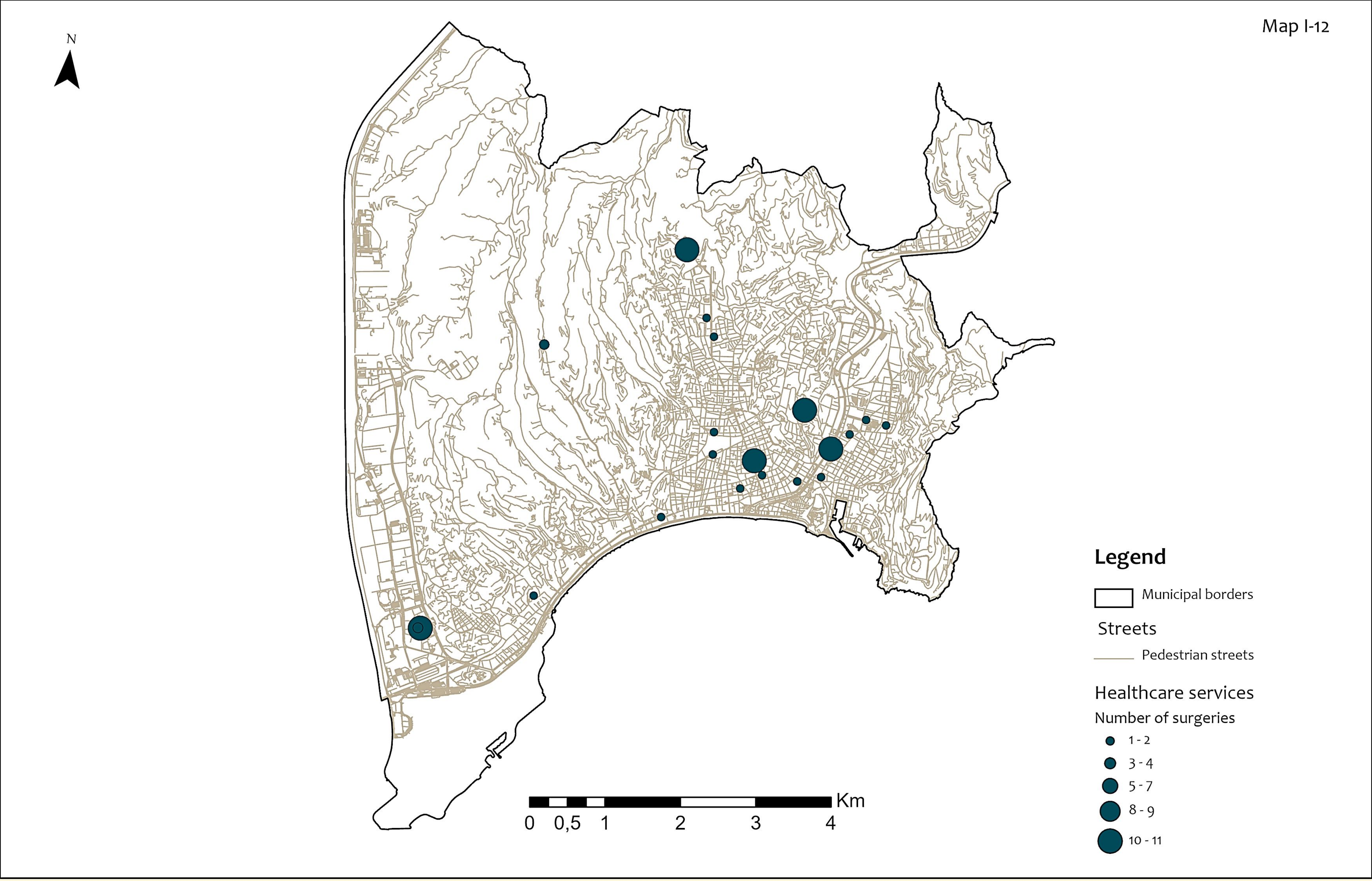


Distribution of people aged 65 and over - Nice (France)

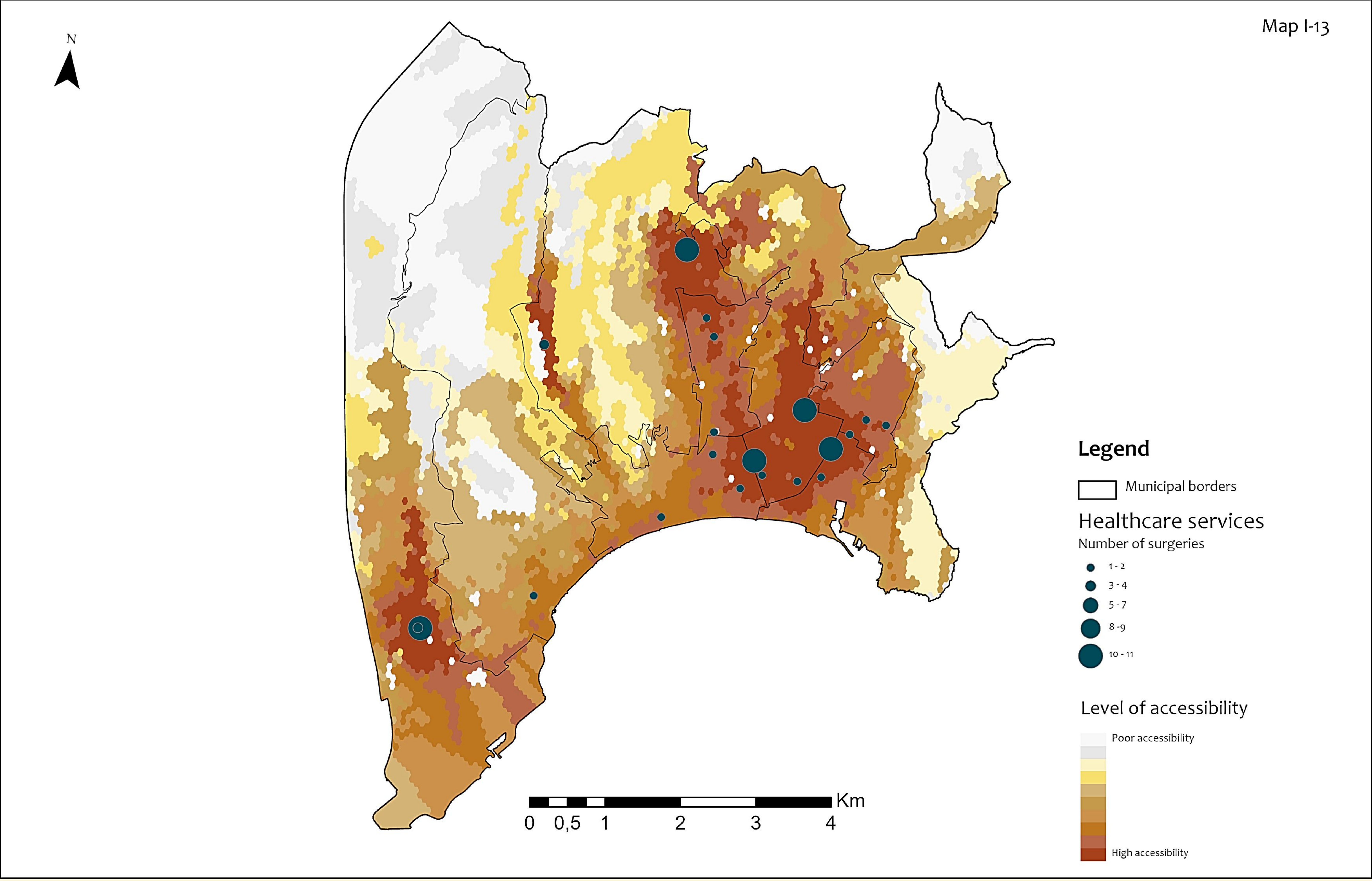
Map I-11



Multimodal mobility network - Nice (France)

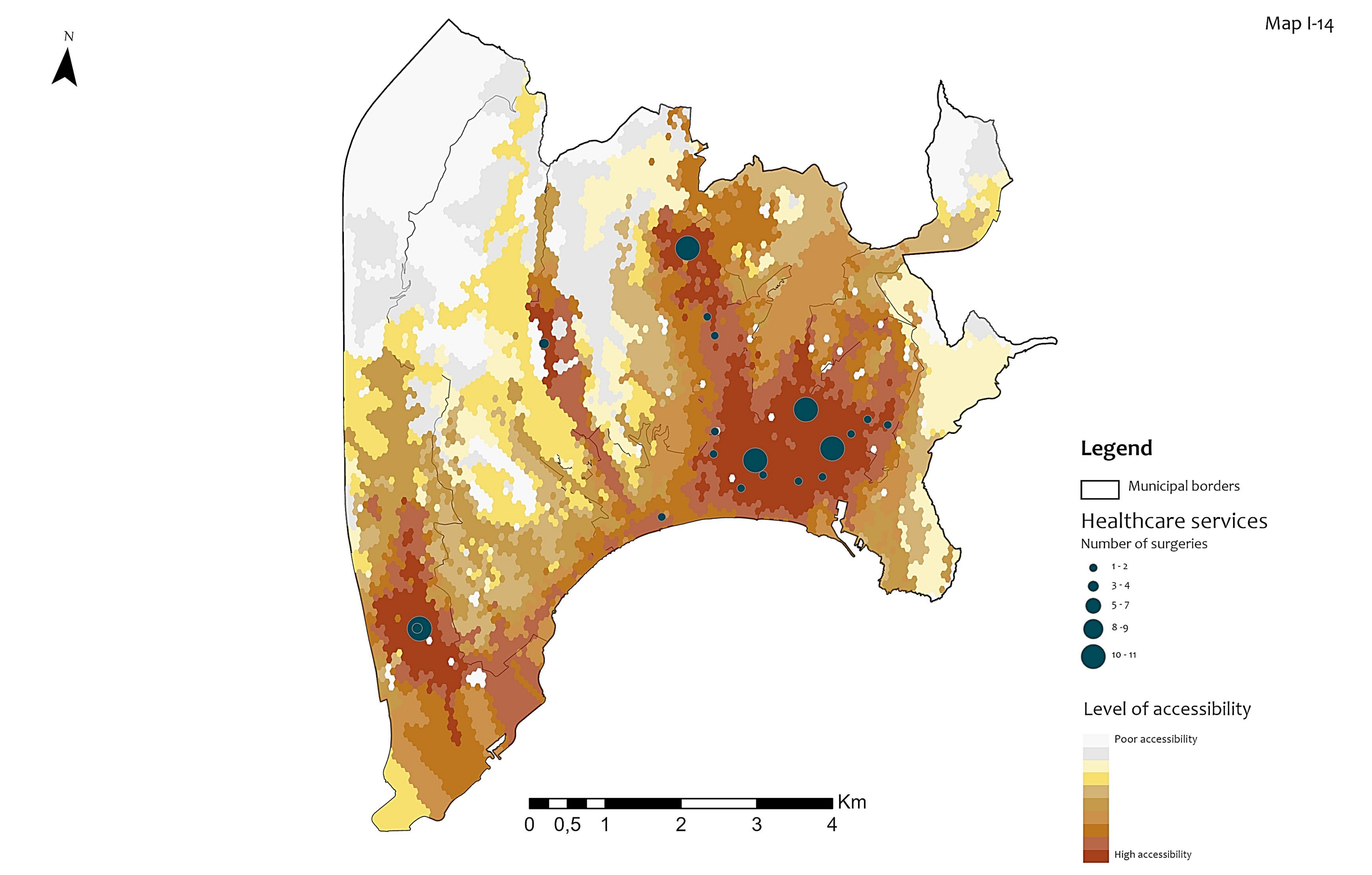


Helathcare proximity services - Nice (France)

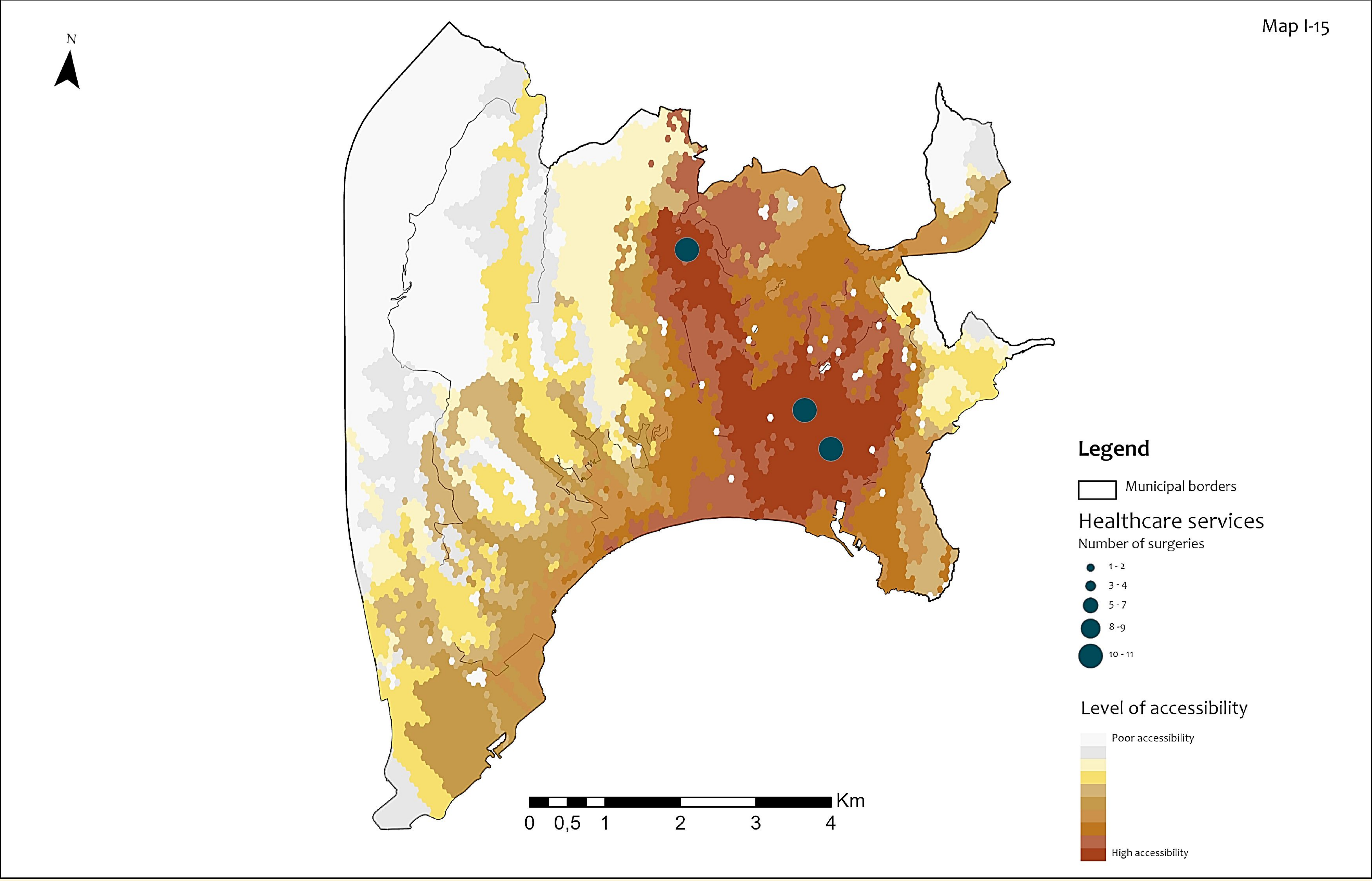


Urban accessibility to healthcare services for the elderly, morning scenario - Nice (France)

Map I-14



Urban accessibility to healthcare services for the elderly, afternoon scenario - Nice (France)



Urban accessibility to healthcare services for the elderly, evening scenario - Nice (France)

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Chapter 4

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