Resilience, proximity and the 15-minute City: A Case Study for Central Italy

Eleonora Cutrini, Federico Ninivaggi

Department of Economics and Law
Università degli Studi di Macerata, Italy

eleonora.cutrini@unimc.it

Abstract

This article develops a method for evaluating well-being and urban resilience based on the concept of the 15-Minute City. The approach relies on the use of georeferenced and open-access data drawn from OpenStreetMap and enables to ascertain proximity and density to essential services and recreational facilities according to the taxonomy introduced by Moreno et al., 2021. Our experimentation is applied to Ancona, a mid-sized city in Central Italy. After a mapping of different target groups (i.e., elderly, foreigners) to ascertain their spatial distribution within the city, the analysis identifies four clusters of areas based on selected socio-demographic indicators and reveals that they are also characterized by a different location within the city and a different mix of services and facilities. In line with previous studies, we confirm that peripheral neighborhoods are more in need of interventions compared to downtown areas which are instead well-connected to the public transport network and offer both essential services for daily needs and several amenities and facilities for outdoor activities. The article discusses the urban planning implications of the method and the usefulness of data-driven policies to improve well-being and inclusion in cities.

Keywords (up to 5): 15-Minute City, Resilience, Well-being, Proximity, Spatial segregation, OpenStreetMap

1. Introduction

In recent years, major cities have increasingly promoted urban policies to achieve a more sustainable environment, especially after the COVID-19 pandemic. In fact, during lockdowns, spending more time at home, and close to one's residence, has highlighted the centrality of the provision of neighborhood services for individual well-being. Hence, with the forced restrictions on people's mobility during the emergency phases, COVID-19 fueled the debate on how to radically rethink urban spaces, especially in metropolitan areas. The theme of redefining urban strategies for resilience has been at the center of deep reflections in various European cities and there are already many positive examples of implementing more sustainable urban model. After Paris, with its mayor Hidalgo that launched the slogan of "city 15 minutes away", it was also taken up by several Italian major cities, including Milan, Turin, Rome and Bologna.

The notion of Carlos Moreno's 15-minute city (Moreno, 2016; Moreno et al., 2021) refers to an area where citizens can easily reach essential services and amenities through a 15 minutes' walk (or bike ride). It is based on 8 key principles, namely proximity to services, proximity to public transport, mixed land use, density, place-making, ubiquity/affordability, walk- and cyclability, and inclusiveness. As for the latter principle, from a social justice perspective (Leventhal, 1980), it is worth noting that the 15-Minute City is an urban planning concept focused on groups of people who have historically been excluded from planning, such as women, children, people with disabilities, and the elderly. In this perspective, access to schools, green spaces, basic social infrastructures, and complementary activities for residents are considered essential to improve the well-being and social cohesion of local communities. Therefore, through the 15-Minute lens it is possible to address the emerging New Urban Question whereby social injustices are increasingly revealed in the form of spatial injustices, especially in large European metropolises (Secchi, 2010).

A major challenge of planning strategies based on the 15-Minute City is the transfer of the model to different spatial contexts. Not only the 15-Minute City should be adapted to individual cities based on their morphology and specific needs and characteristics (Moreno et al., 2021), but for some requirements it could be a model more easily attainable and viable for mid-sized urban centers or even in small towns. In fact, in mid-sized and small cities, due to their traditional mixed zoning practices, different land uses (such as residential, commercial, and industrial) usually tend to coexist, resulting in a variety of activities and services within the same area or neighborhood.

In Italy, the ongoing 2021-2027 structural funds programming and the National Recovery and Resilience Plan represent a unique opportunity for a sustainable redefinition of urban development models. However, to be successful, the new urban policies necessary to face the emerging environmental and social challenges need to be accompanied by specific tools to plan scenarios and decision-making, and to diffuse the practice of result-oriented monitoring, reporting and evaluation processes. Assessing the effects of interventions put in place on the territorial transformation dynamics is crucial to improve territorial governance and ensure accountability of all stakeholders. To this purpose, transparent and spatially detailed information is extremely important to support collective decision-making and to develop evidence-based policies. In this respect, satellite data and Volunteered Geographic Information (VGI) platforms, such as Google Maps and OpenStreetMap (OSM), are becoming increasingly popular among academics and practitioners as a precious source of knowledge, especially when official statistics are difficult or expensive to produce at a detailed spatial granularity (Bachtrögler-Unger et al., 2023).

The first essential step to translating the planning principles of the 15-minute city model into reality is a detailed assessment of the major areas of need where interventions should be prioritized. In Italy, most of the research in the context of the 15-minute cities and its variations[1] so far has investigated the possibility of constructing accessibility metrics (e.g., EnelX, 2022; Lanza and Carboni, 2023; Olivari et al., 2023), or they have been limited to the very essential services (Gaglione et al., 2022) disregarding a thoughtful analysis of all the amenities that make centers and suburbs more lively, like in the area of education, entertainment, living, as suggested by Moreno et al., 2021. Moreover, the different attempts to operationalize the concept with the use of urban georeferenced data usually adopt the concept of proximity as physical distance without the possibility of ascertaining relational proximity or social separation because of the lack of open socio-demographic data (Olivari et al., 2023). Furthermore, most of the experimentations examined so far usually overlooked the importance of considering not only a wide range of services for vibrant urban space and the density of such facilities, but also the spatial distribution of target groups.

We believe that the analyses based on proximity metrics, even when applied at the neighborhood scale, can hide significant heterogeneity in terms of equal access, density and diversity of key services that require a more narrative, detailed, and qualitative approach. We advocate that further experimentations and more comprehensive tools based on the notion of the 15-Minute City are needed to support informed urban planning decisions by municipal authorities, to improve mobility patterns and the livability of different neighboorhoods.

Against this backdrop, we contribute to the existing literature with a case study on the city of Ancona and a method to identify which of the different areas of a city already follow the 15-minute paradigm, in terms of density and proximity to essential services and amenities (Moreno et al., 2021). We start

[1] Two notable variations are 15-Minute Walkable Neighbourhoods (Weng et al, 2019) and the 20-Minute City model (Capasso Da Silva et al., 2020).

from the hypothesis that access to a wide range of services and amenities essential for a decent quality of life should be guaranteed without spatial and social inequalities. Hence, this work aims to provide a methodology based on OSM data to help evaluate well-being and progress in terms of accessibility to services related to basic needs and amenities, with a focus on two fragile urban groups: the elderly and the foreigners. In our proposal, after distinguishing between selected areas of the city according to their location and basic socio-demographic characteristics, we inspect them in terms of the proximity to several services related to all the six domains suggested by Moreno et al. (2021), namely, Entertainment, Healthcare, Public Transport, Commerce, Education, Living, Working).

We provide the results of an in-depth study where the graphical analysis combined with different statistical methods -clustering analysis and ANOVA - is applied to characterize different neighborhoods of Ancona, a mid-sized city in Central Italy. Results enabled us to determine the proximity to essential services by walking, cycling, and their density in the different clusters defined according to basic socio-demographic features. Moreover, the experimentation allows us to detect the urban environment in its current state and note how the spatial distribution of services is uneven, with some areas benefiting from an abundance of recreational and commercial facilities, while others appear to be less favored, with evident implications on residents' well-being and equity in access to essential services.

We argue that this article introduces a valuable methodological approach to guide targeted interventions for the development of accessible, sustainable and inclusive cities. In particular, it provides urban planners and policy makers with useful tools for operationalizing the principles of proximity, accessibility and density, thus offering the possibility to continuously support public decisions, by monitoring the effectiveness of interventions and eventually adjusting urban planning strategies.

The article is organized as follows. Section 2 introduces the context of the research and the background literature. Section 3 describes the data and the methodology. Section 4 illustrates and discusses the main results of the case study. Section 5 offers concluding remarks, policy implications and avenues for future research.

2 Background

From a long-term perspective there is more than one reason to be optimistic about urban resilience to natural disasters and many other forms of physical destruction (Glaeser, 2022). Nonetheless, it is well known that the COVID-19 pandemic has led to changes in people's mobility habits and lifestyle during periods when governments were forced to implement strict containment measures such as lockdowns. In a time of profound change in daily routines, the demand for parks and other public outdoor spaces has increased while travel to the workplace and travel for commercial and recreational activities has necessarily decreased.

It is not clear how and to what extent these contingent changes in mobility habits during lockdown will transform into permanent changes in mobility preferences. Still, recent planning policies are increasingly inspired by the idea that proximity is essential to promote urban well-being and adaptation to climate change. The concept of the 15-Minute city, according to its proponent, refers to an area with a 15-min radius, *"in which residents will manage to experience a higher quality of life as they will be required to travel less to access basic facilities such as public spaces, with increased time and opportunities to interact with other members of the community and accomplish other social functions, which are increasingly important but which have been lacking as a core function of contemporary urban planning models."* (Moreno et al, 2021, p. 105).

Other urban planning concepts can easily be found in the past literature that has similarly focused on sustainable mobility to design more livable urban spaces. In this respect, the 15-Minute City model is not a radically new concept in city planning if we consider that, like previous similar urban planning concepts, it focuses on a neighborhood scale (Perry, 1929; Davis, 1979), it is based on the close proximity to essential services (Howard, 1902), and time-based urban planning where crucial facilities to the daily life of residents are all located within easy walking distance in compact and diverse areas (Hägerstrand, 1970, Asher, 1997; Calthorpe, 1993). To outline the historical development of the main concepts related to the 15-Minute City, one should highlight significant previous contributions from Perry's neighborhood unit (1929) to Jane Jacobs (1961), from the Time-Geography (Hägerstrand, 1970) to its development in the 1990s. Hägerstrand's Time-Geography represents the theoretical foundation for many studies on mobility and it is still a useful framework for studying how various constraints in space and time shape travel patterns. During the 1990s, thanks to the growing availability of GIS techniques and micro-level data on daily activities and travel behaviour, research has focused on refining spatio-temporal, geo-computational techniques to describe individuals' actual or potential spatial movement.

During the 1990s the theory has also evolved into Chronourbanism (Asher, 1997) or New Urbanism (Davis, 1979) with the fundamental Transit Oriented Development (TOD) model (Calthorpe, 1993). In particular, it is worth noting that the TOD concept, while encouraging more sustainable behaviours, maintains particular attention to the proximity to public transport. Hence, it refers to an organization of space designed to bring people, activities, and public space together to create an integrated urban environment and vibrant communities, with walking and cycling connections and near transit hubs (bus and rail lines) that make it easy for residents to travel around the city.

In this respect, as in the Perry's planning approach (Perry, 1929), in the 15-Minute City the neighborhood becomes the elementary unit from which to start to create many connected walkable areas whereby proximity is related to the basic functions of living, employment, healthcare, education, entertainment, and commerce (Moreno, 2016; Moreno et al., 2021).

Accessibility and proximity advanced in the 15-min concept are crucial principles because micro-mobility has several advantages on the environmental, social, and economic grounds. Not only urban residents can benefit from lower pollution and congestion, and increased green spaces, they can also benefit from better social interactions and health-related advantages for the opportunities to practice active mobility to enjoy activities that are necessary for daily life. On the economic ground, this model has the potential to reduce commuting costs and social costs and negative externalities due to excessive traffics, such as those related to road maintenance, pollution and other associated costs. Moreover, it can unlock numerous potential advantages such as employment, innovations, reputation of the whole city as a sustainable place.

Since its introduction in 2016 for the city of Paris, the concept attracted the interest of several international organizations including the C40 Cities Climate Leadership Group (2020), UN-Habitat (2020) and the Organisation for Economic Co-operation and Development (OECD, 2020), to improve the quality of life in the context of COVID-19 and beyond. Moreover, the concept has already applied to several cities, such as Portland, the city of Kirkland, Eugene and Tempe in the United States (City of Portland Bureau of Planning and Sustainability, 2012; EIT-Urban Mobility, 2022), Brussels (BSI, 2021), Melbourne, Ottawa, Milan, Buenos Aires, Utrecht, Edinburgh while other cities – e.g., Rome, Milan, Dublin - are scheduling to launch a similar experimentation (EIT-Urban Mobility, 2022).

Meanwhile, considering different cities as case studies the central question that empirical studies have attempted to address is "Which part of the town is already close to the 15-Minute City model?"

In Italy, there have been some attempts to introduce methodologies, usually based on proximity-based indicators, to characterize urban areas in different contexts. Case studies and practical applications are already available for the cities of Bologna (Olivari et al, 2023; Abdelfattah et al., 2021); Terni and Matera (Murgante et al. 2023) and Naples (Gaglione et al., 2022).

Olivari et al, 2023 introduce a new proximity index (NEXI) based on open data to determine the degree of proximity to essential services by walking. The implementation of the NEXI index is made available as an interactive map where the index is computed on a hexagonal grid and thematized according to its value. The main advantage of the NEXI index is that it can be replicated everywhere, but it is also granular enough to be able to evaluate the proximity at a small scale. Moreover, the index is also scalable and already available for the entire Italian territory. The authors illustrate the cases of Bologna and Ferrara and highlight how it is important that the index is combined with additional information (e.g. local population).

A case study of Bologna is also provided by Abdelfattah et al., 2023 who focus on the right to independent mobility within the city for children, as one of the most vulnerable road users (WHO, 2020). Their work is particularly interesting for our purpose because they emphasize the importance of adopting a user-centric approach – i.e., a different approach for different social groups - when evaluating accessibility to urban amenities. They consider a wide range of essential services and amenities (29) grouped by 8 macro-categories, and they study the coexistence of these macro-categories within a 15-minute walking timeframe. They also perform walk score analysis of neighborhoods for the whole resident population and for the target group, that is 11-14 years old children.

Sony CSL in collaboration with Sapienza University (Rome, Italy) developed an index of proximity based on open data (Ubaldi et al., 2021). Again, the aim is to derive algorithms to map how close different parts of a city are to the 15-Minute ideal. The index is available for some cities in Italy and France and its values depend on the time necessary to reach the different types of services. Another similar solution is the 15-minute city index developed by EnelX and the University of Florence (EnelX, 2022). The index is based on data drawn from institutional portals, satellite images and open-source communities and it is available for each Italian city.

Murgante et al. (2023) focus on density, proximity, and diversity for the town of Terni and Matera. They introduce a set of relevant, reproducible, and comparable indicators at the sub-municipal (district) level apt to measure levels of spatial inequality in the access to basic services. Based on open data retrieved from the Google Maps web service, they map the proximity and diversity of urban functions based on an index computed as a weighted sum of 9 categories of services, namely Education, Retail Activities, Cultural Services, Craft Stores, Institutional, Public Services, Recreational Activities, Healthcare, Civil Defence, and Financial Services. Their analysis highlights the gap in terms of access to basic services and facilities among central districts and areas on the outskirts of the city.

Gaglione et al (2022) propose a GIS-based methodology to identify which parts of an urban area can be defined as a 15-minute City. They investigate selected districts of the city of Naples according to geomorphological, physical (related to the spaces and the paths, functional (distribution and location of services), socio-economic (population) and settlement characteristics to verify services' accessibility in 15 minutes based on the users' willingness to walk and the characteristics of the areas. Their study, based on Google Maps data, focuses on the accessibility to essential services only in the domains of commerce and healthcare, namely grocery stores, supermarkets, post offices, banks, pharmacies, and clinics.

In their work, Lanza and Carboni (2023) introduce an Inclusive Proximity Accessibility Index (IAPI) that quantitatively measures and classifies, in a GIS environment and at an urban scale, cycle and pedestrian access within the neighbourhood, considering the quality of travel and mobility concerning the experience of different mobility profiles. Furthermore, the index indicates urban policies, detecting and mapping disadvantaged contexts in terms of access to services and the quality of cycle and pedestrian paths for which improvements are needed (e.g., pedestrianisation, improvements in cycle-pedestrian connections) and re-localization of local services.

Finally, Ubaldi et al. (2021) detect patterns of spatial inequalities and segregation in Rome through OpenStreetMap points of interest, i.e., the location-based and open-access data which are used in the present study. Their analysis shows that people mobility habits are strictly correlated to socioeconomic indicators of the area people live in.

On this background, moving from the 15-minute City model and the related TOD approach (Calthorpe, 1993) we examine the case of Ancona. Since in both planning strategies the objective is to promote sustainable urban growth by increasing walking, cycling and public transport and minimizing the use of private cars, in our experimentation particular attention is paid to the Public Transport domain of the Moreno's taxonomy (Moreno et al., 2021). Moreover, moving from a social justice view, our analysis adopts a notion of accessibility which refers to a mobility system and a spatial distribution of amenities and essential services capable of guaranteeing citizenship rights for all social groups.

2 Data and Methodology

Our methodology intends to be instrumental to a deeper understanding of the urban environment's potential to meet the needs of city residents. Moreover, by enabling the identification of inequalities in the spatial distribution of OSM Point of Interests (POIs) associated with essential services and facilities, the proposed tools facilitate informed decisions for planning and urban regeneration policies for inclusive, healthy, and safe neighbourhoods.

Our guiding question is "Starting from the 15-Minute City model, which part of the town of Ancona eventually needs significant improvements and in which domains"?

2.1 Data

We provide a set of analytical and graphical tools to analyze the urban environment at a high granularity. The characteristics of this approach allow municipal authorities to understand the complex structure of neighborhoods with their different availability and diversity of services. The methodology is based on urban georeferenced data, and it is applied to 74 selected districts of the city of Ancona which, due to their demographic, morphological and settlement characteristics, make them a significant set of areas for the experimentation.

To guarantee accessibility as a citizen's right, an effective methodology should be based on specific tools designed for analyzing urban contexts and identifying groups of areas with different densities of services and socio-demographic characteristics. The proposed method is based on the use of OMS data to determine the spatial distribution of facilities in six essential domains.

The first step was to use clustering techniques integrated with descriptive analyses to identify groups of areal units based on the relative concentration of the elderly and the foreigners within the city.

To this purpose, it was crucial to collect detailed data on the number of residents and their socio-demographic characteristics. These data were made available by the municipal office for real estate and urban planning of the city of Ancona which provides us with data on residential addresses and basic characteristics such as citizenship and age for all city inhabitants. With this information, the residents were calculated by age group and citizenship. From a user-centric approach, this additional information was particularly important to focus on specific targets of the population and evaluate their actual proximity to specific urban services, e.g., public transport for the elderly and the foreigners, green areas, and parks.

To operationalize the 15-Minute City we relied on a set of circles with a diameter of 1km - henceforth referred to as areal units - corresponding to what is commonly defined as the average distance that can be walked in approximately 15 minutes. Hence, the POIs counted within the areas with a diameter of 1km can be considered as the set of services and amenities which is accessible to residents within a 15-minute walk.

Figure 1 – Areas units included in the experimentation for the city of Ancona

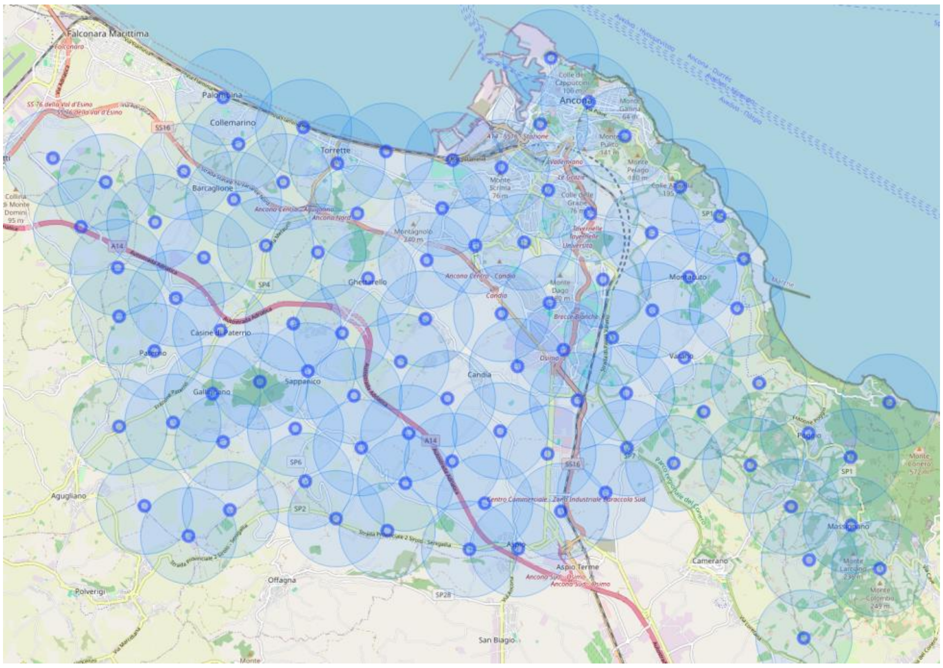


Figure 1 shows the distribution of the selected 74 areal units in the town of Ancona on which the experimentation was conducted. For each areal unit, POIs and the population within a radius of 500 meters were counted. Therefore, the *density* of each of the 26 categories of services and facilities - was computed as the count of each POI per thousand inhabitants in the surrounding areal unit.

The 26 categories identified by OSM cover the widest range of public and private services available in an urban area and that can be categorized into 6 domains according to the proposal of Moreno et al., 2021.

Following Moreno's taxonomy (Moreno et al., 2021), we map the locations' attributes of each areal units according to six well-defined domains:

1) *Commerce*: banks, ATM, and all the places where food and non-food goods are sold, e.g., shops, mall and supermarkets (Marketplace),
2) *Education*: all the schools, universities and kindergartens found in the area;
3) *Public transport*: the main train stations and bus stops (Platform) in the area;
4) *Health*: all the health buildings, such as hospitals, family care doctors, dentist, and pharmacies;
5) *Living*: recreational venues for sports and open-air activities, e.g., sport centres, parks, playgrounds, swimming pools;
6) *Entertainment*: the main cultural sites such as cinemas and theatres, and commercial places such as restaurants, bars, café, bars for leisure and social interactions.

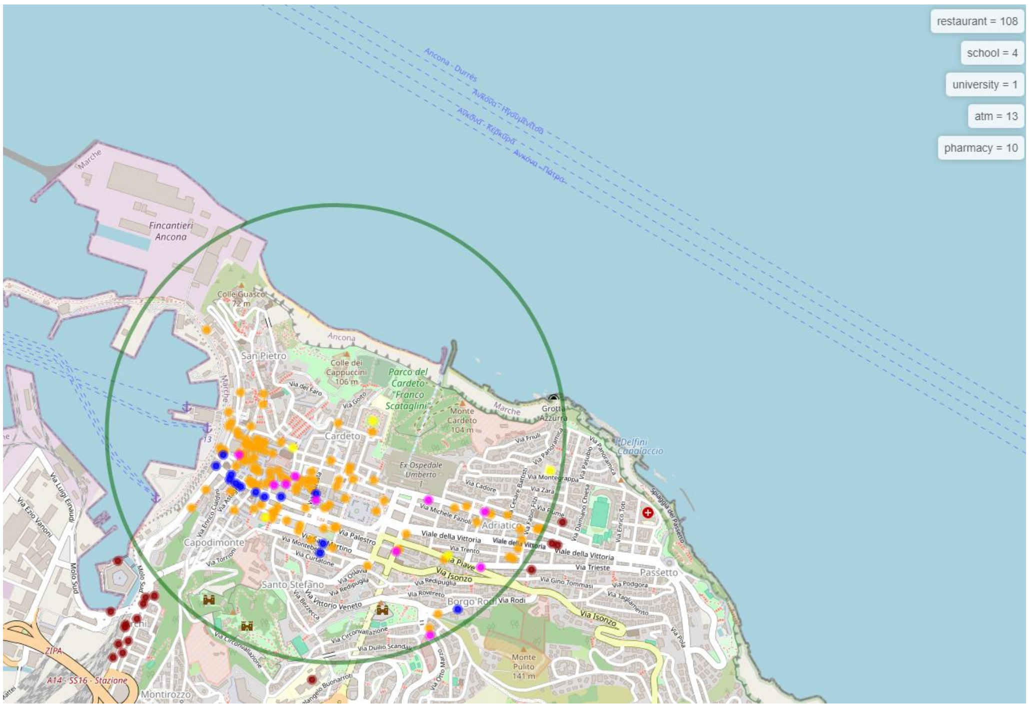
Table 2 provides the detailed list of POIs included in the analysis to scrutinize the presence and density of essential services and facilities needed to sustain a lively urban environment. The *osmdata_sf* function in R permits to consider each object according to different geometric attributes: point, polygon, multipolygon and line. For each identified key and value group, the geometry to be counted was chosen. Since point geometry is normally characterized by greater data availability than polygon geometry, in order to improve data quality, whenever practical, the point geometry was primarily selected, opting for the polygon geometry only in those cases when the categories are reported in OSM as extended areas (e.g., parks, playgrounds …).

Table 2- OSM categories included in the analysis by domains of essential services

	OSM Category	OSM Key	15-Minute City domain
1	atm	amenity	Commerce
2	bank	amenity	Commerce
3	marketplace	amenity	Commerce
4	post_office	amenity	Commerce
5	kindergarten	amenity	Education
6	school	amenity	Education
7	university	amenity	Education
8	bar	amenity	Entertainment
9	cafe	amenity	Entertainment
10	cinema	amenity	Entertainment
11	nightclub	amenity	Entertainment
12	pub	amenity	Entertainment
13	restaurant	amenity	Entertainment
14	theatre	amenity	Entertainment
15	clinic	amenity	Healthcare
16	pharmacy	amenity	Healthcare
17	social_facility	amenity	Healthcare
18	park	leisure	Living/Sport
19	pitch	leisure	Living/Sport
20	playground	leisure	Living/Sport
21	sports_centre	building	Living/Sport
22	sports_centre	leisure	Living/Sport
23	sports_hall	building	Living/Sport
24	swimming_pool	leisure	Living/Sport
25	platform	public_transport	Public transport
26	train_station	building	Public transport

For each areal unit, the count of the selected OSM category has been carried out by adding the number of POIs with point geometry and those with polygon geometry, for the latter the coordinates of the centroid were used for specification. In this way, considering both geometries, a more detailed description of the urban environment has been produced, mitigating possible concerns related to data completeness, a typical shortcoming of VGI data.

Figure 2 – POIs for different OSM categories for a 15-minute areal unit in the city of Ancona



As an example, Figure 2 visually displays relevant POIs based on OSM geo-referenced data for the city of Ancona. The map illustrates simple counts of the categories considered in the work within 500 meters of the point with latitude 13.52 and longitude 43.6. The points denoted by the red color fall outside the boundary of the 1 km radius circle, therefore, they are not considered in the count. This process was repeated for each of the selected 74 areal units. Similarly, the computation of the residents in the area required adding the residents of all the addresses that fell within each circle.

To derive metrics of density for each area and OSM category, the demographic data provided by the municipality of Ancona were then cross-referenced with the counts of the POIs. The number associated to each POI category was divided by the resident population in the circumscribed area, and the values are reported in Table 5 (Section 3.2) as counts per one thousand inhabitants.

In our analysis we paid particular attention to the OSM categories associated to public transport. The TOD concept refers to planning dense, walkable, and mixed-use space near transport hubs, to promote a sustainable urban growth (Calthorpe, 1993). In this perspective, we included the absolute number of bus stops of the local public transport service as a proxy of the connectivity of each areal unit with the rest of the city. Hence, for each cluster, the value associated to the OSM category "Platform" is the average value obtained from the simple counts of bus stops registered in the respective areal units included in the cluster (Table 5). For all the remaining OSM categories, we instead considered the density of the respective POIs relative to the resident population in the areal unit.

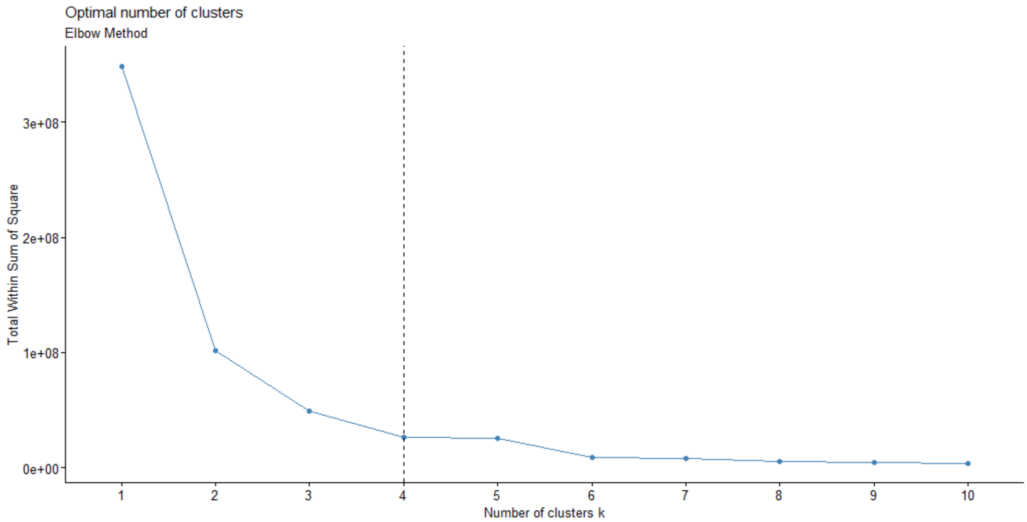
2.2 Methodology

To investigate the conditions of accessibility for different areal units we rely on methodology based on the following three steps. First, we provide a typology of areal units according to socio-demographic georeferenced data and through a k-mean cluster algorithm. Areal units are classified into different groups (clusters) in such a way that the data in each subset are similar in terms of certain distance measurements. Central to all the cluster analysis goals is the notion of the degree of similarity (or dissimilarity) there is between the individual units being clustered. In particular, the variables considered in the cluster analysis for profiling the different areas of the town were:

- V1: Total resident population in the areal unit;
- V2: Share of the resident population in the areal unit out of the total resident population in the city;
- V3: Share of foreign population in the areal unit over total foreign population in the city;
- V4: Share of population over 68 in the areal unit out of total population over 68 in the city;
- V5: Concentration of foreigners defined as the share of foreigners in the total population of the areal unit;
- V6: Concentration of elderly people defined as the share of foreigners in the total population in the areal unit.

The Elbow method was adopted to identify the optimal number of subsets by relating the number of to the within-cluster sum of squares (WSS) (Figure 3). The WSS calculates the sum of the squared distances between each centroid and the points of its cluster. The optimal number of clusters is the point at which the increase in WSS ceases of being significant (the “elbow”), suggesting that increasing the number of clusters will not lead to a significant improvement in the internal similarity of the clusters.

Figure 3 – Optimal number of clusters



As shown in Figure 3, the choice of the optimal number of clusters was four. Then, the K-means algorithm proceeds by randomly choosing a number of non-coinciding centroids, as many clusters as desired, and computes the distance of each point in the dataset with respect to each centroid. Each point in the dataset is connected with the cluster associated to the closest centroid. Thus, the position of each centroid is computed again and continues by averaging the positions of all the points of the associated cluster until there are any other observations that change clusters. With the aim of ensuring the minimization of intra-cluster variance and maximization of inter-cluster variance, we repeated the algorithm 25 times with different initial centroids.

The second step of the methodology proposed is to characterize the four clusters based on their density of relevant POIs associated with major domains of the 15-Minute model. To this purpose we provide average values for the 26 OSM categories to characterize the four clusters in terms of the relevant domains from the perspective of the 15-Minute model.

Finally, we complemented our results with an analysis of variance (ANOVA) for each OSM category considered. In the form adopted here, the ANOVA provides a statistical test of whether all the four clusters' means are equal, providing the value and the significant level of the associated F-statistics. In more detail, the F value indicates the ratio between the variance between the 4 clusters and the variance within the clusters. Hence, for each OSM category, a high F value suggests that the clusters' means are different enough from each other with respect to the variance within each cluster. The p-value - Pr(F>F-value) - is the probability value associated with the actual F-value. A low p-value (typically below 0.05) indicates that the difference between the clusters' means is statistically significant.

We advocate that the stepwise methodology described is particularly useful to eventually identify the need of planning interventions to improve the livability and resilience of certain parts of the city.

3 Results and discussion

3.1 Exploratory analysis based on socio-demographic georeferenced information

To evaluate inequalities in the quality of life within urban areas it is important to consider not only the distribution of essential services and facilities but also the possible separation of social groups into different neighbourhoods. Local institutions can promote policies apt to avoid exacerbating social inequalities and promote social inclusion in urban areas. In this respect, it is important to verify whether the distribution of disadvantaged groups within the urban space is coupled with a disproportion in density and accessibility to essential services and amenities for a decent life.

To this purpose, the methodology described in Section 2.2 is intended to jointly assess the density of services and the socio-spatial configuration of different areas of the city. As already pointed out in Section 2.1, the municipal administration provided microdata information for the whole resident population. In particular, from the information on citizenship and age we constructed georeferenced information able to distinguish between Italian and foreign population living in different areas of the city. Moreover, it was possible to distinguish residents of different age classes for each areal unit (Table 3). This additional information allows to investigate specific target groups on which to relate the territorial distribution of essential services for a decent quality of life, e.g., public transport for the elderly or the foreign residents or even green areas and parks for children. The age groupings were defined in the logic of different possible use of public transport: in the 0–12-year range it can be assumed that public services are not used independently, while it is assumed that between 13 and 18, users such as students of upper-secondary and high schools can use public transport independently. The 19-35 class encompasses and the university resident population and the younger working-age population groups, the 36-67 class considers the older working-age resident population. Finally, the 68-120 class represents the elderly population, a possible specific target for policies aimed at the well-being of the population which constitutes almost a quarter of the total residents in Ancona as 23% of the city population is over 68 years old. In contrast, 15% is between 0 and 18 years old.

Table 3 Basic demographic information on the population of Ancona

Residents by nationality

	N.	%
Italian citizens	84918	84.6
Other citizens	15405	15.4

	100323	

Residents by age classes

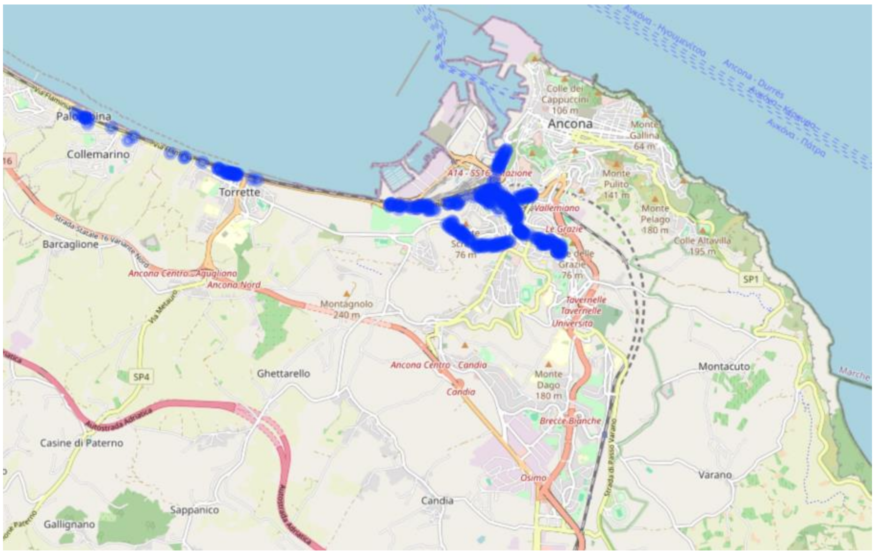
	N.	%
0-12	9328	9.3
13-18	5512	5.5
19-35	18282	18.2
36-67	44205	44.1
68-120	22996	22.9
	100323	

Source: Statistical Office of the municipality of Ancona

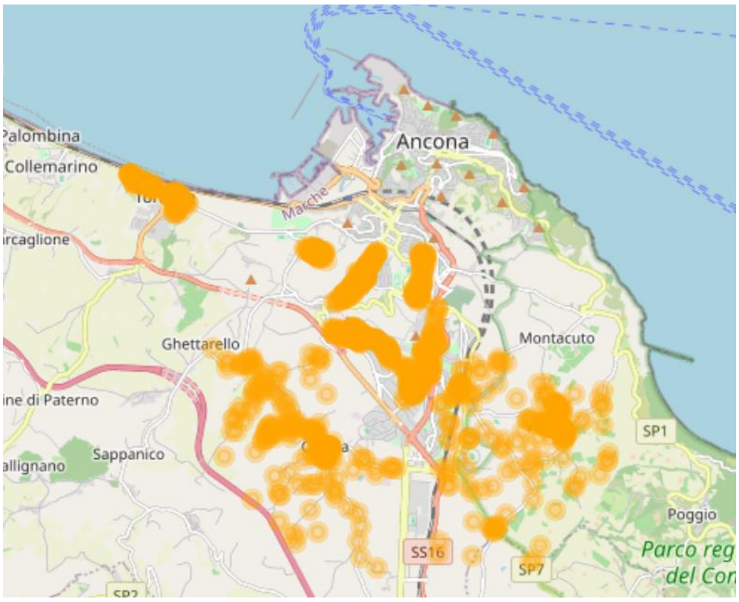
Foreign residents represent the 15% of the entire city dwellers (Table 3). Thanks to the georeferenced information on citizens, their age, and their nationality it was possible to delineate the spatial distribution of potential target groups, verifying whether they tend to settle uniformly or rather they are concentrated in certain neighborhoods.

Figure 4 – Spatial distribution of target population groups

Panel A: Spatial distribution of 20% of foreign population - Seven streets



Panel B: Spatial distribution of 20% of the elderly - Eight streets

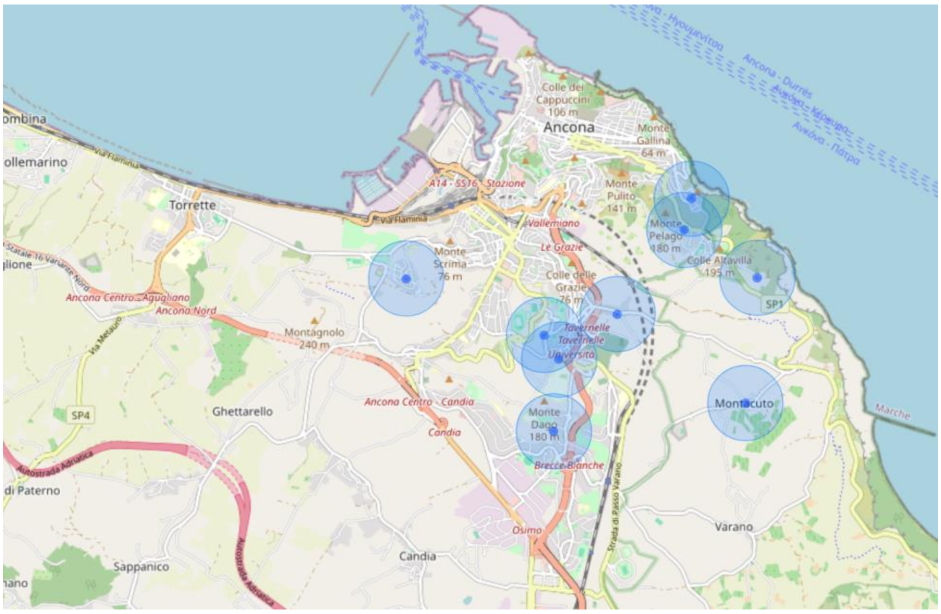


Panel (a) and panel (b) of Figure 4 sketch the spatial distribution of foreign citizens and elderly people, respectively. In the first case, the first seven streets with the highest quotas represent 20% of the total foreign residents in the city, indicating a notable concentration in some areas of the municipality. The same share, i.e. 20%, of the total reference population, for residents over 68 years of age is populated in eight streets, and in two of them the population is spread out over a larger surface area because it refers to hamlets and peripheral areas at the outskirts of the municipality.

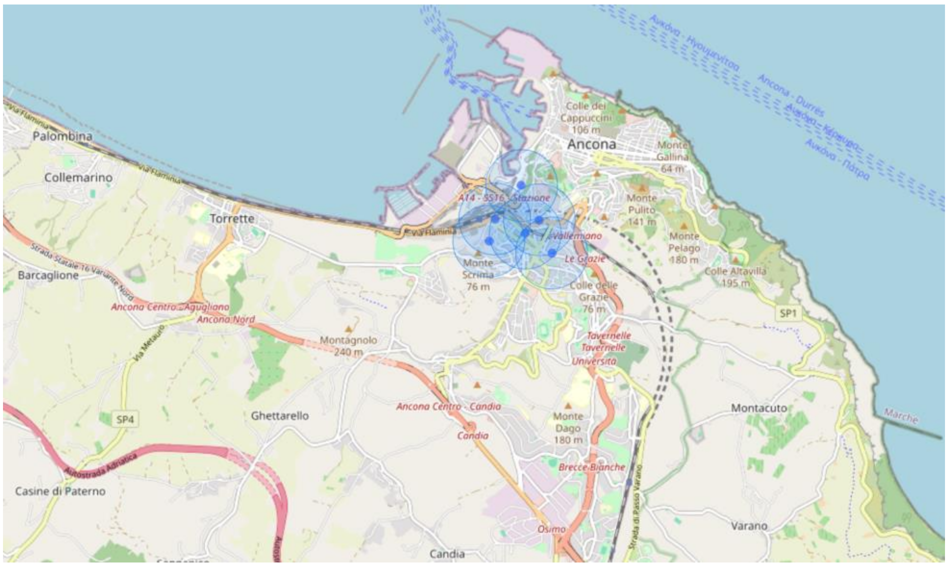
The clear difference in the settlement patterns of the two target groups is evident when comparing the panels of Figure 3 and indicates a spatial division that may raise social issues. A high concentration of certain segments of the population must be taken into consideration by local administrations that aim to design public services inspired by principles of social justice in a fair and effective way. For this purpose, it is useful to further examine the socio-demographic characteristics of all 74 territorial units (Figure 1) to reveal even more clearly how elderly people and foreign citizens tend to group together in different neighborhoods. Figure 5 shows where elderly people exceed 30% of the total resident population in the respective areal unit (panel A) and where foreign citizens exceed 30% of the total residents in the respective areal unit (panel B).

Figure 5 – Areal units with a significant concentration of elderly and foreign citizens

Panel A: Areal units with elderly representing over 30% of resident population



Panel B: Areal units with foreign citizens representing over 30% of resident population



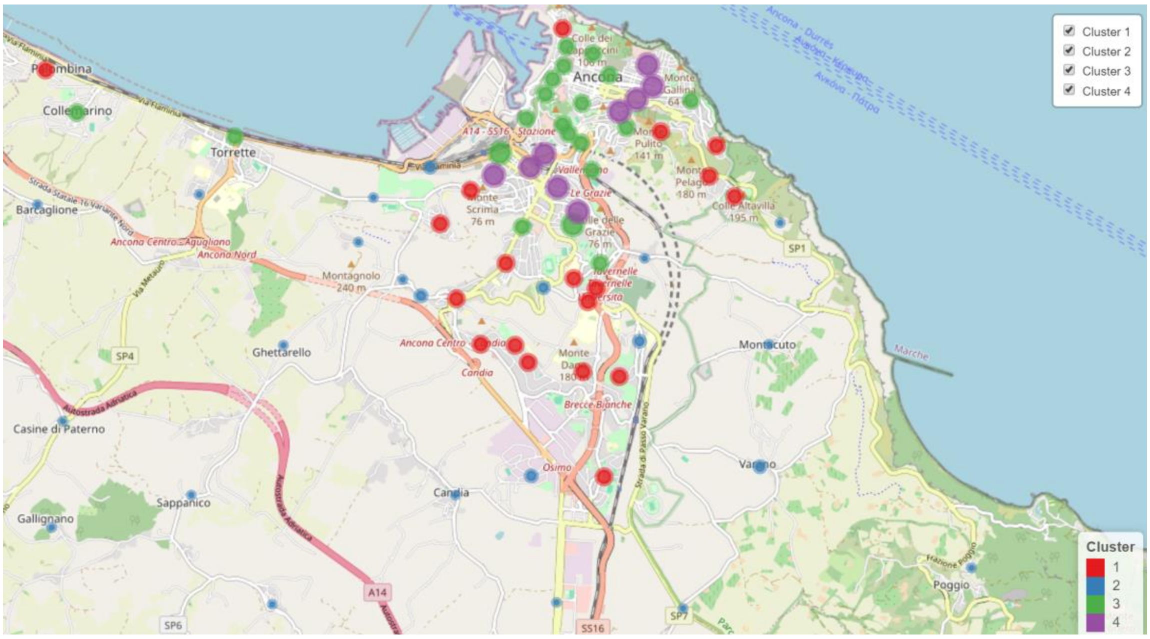
In this perspective, it is also important to carry out a detailed analysis of neighborhoods with different socio-demographic composition to understand whether and to what extent everyone has the possibility to reach -by walking or biking- all essential services within 15-minute distance, both in the central areas and in the suburbs.

3.2 Cluster analysis based on socio-demographic characteristics of areal units

The cluster analysis based on the k-means algorithm allowed to classify areal units into four groups, according to the six georeferenced socio-demographic attributes described in Section 2 (V1, …, V6).

In Section 3.3 we scrutinize for the identified clusters whether the availability of different services is guaranteed in all contexts or whether it is necessary to improve some facilities in some suburbs. Figure 6 reports the territory of the municipality of Ancona and the 74 areal units analyzed, whereby the different colors refer to the different clusters.

Figure 6 - Spatial distribution of areal units by cluster defined according to socio-demographic features



Note: the size of the circles is proportional to the average dimension of the areal units in terms of population.

Table 4 reports basic information on the subsets identified, namely the number of areal units included in each cluster, the average resident population (V1), the average share for residents (V2), elderly (V2), and foreigners (V3) over the city respective totals for the whole city. In addition, Table 4 displays, for each cluster, the average concentration of foreigners (V5) and elderly (V6) as a percentage of the population of the areal units.

Table 4 – Socio-demographic features of clusters, *average values*

Cluster	N. of areal units included	Population (V1)	Share of city's residents (V2)	Share of city's foreigners (V3)	Share of city's elderly (V4)	Concentration of foreigners (% on the areal unit) (V5)	Concentration of elderly (% on the areal unit) (V6)

(1) Residential neighborhoods on the outskirt of the city centre	19	1958	2,0%	1,1%	2,2%	8,1%	26,3%
(2) Peripheral suburbs	26	339	0,3%	0,1%	0,3%	6,0%	23,4%
(3) Highly populated central and semi-central districts	20	3912	3,9%	5,0%	3,7%	19,4%	22,0%
(4) Most densely populated central and semi-central districts with a high concentration of foreigners	9	6654	6,6%	10,9%	6,2%	23,7%	22,1%

The information provided in Table 4 and Figure 6 highlight the salient characteristics of each cluster. Cluster 1 is composed by 19 areal units reported in red on the map. They are mainly located in semi-peripheral residential neighborhoods of the city areas even if also some areal units belonging to the historic town center are comprised in this cluster. These are mainly neighborhoods with a relatively low concentration of foreign residents (8.1%) over the total residents in the same areas and the highest concentration of elderly people (26.3%) among the four clusters.

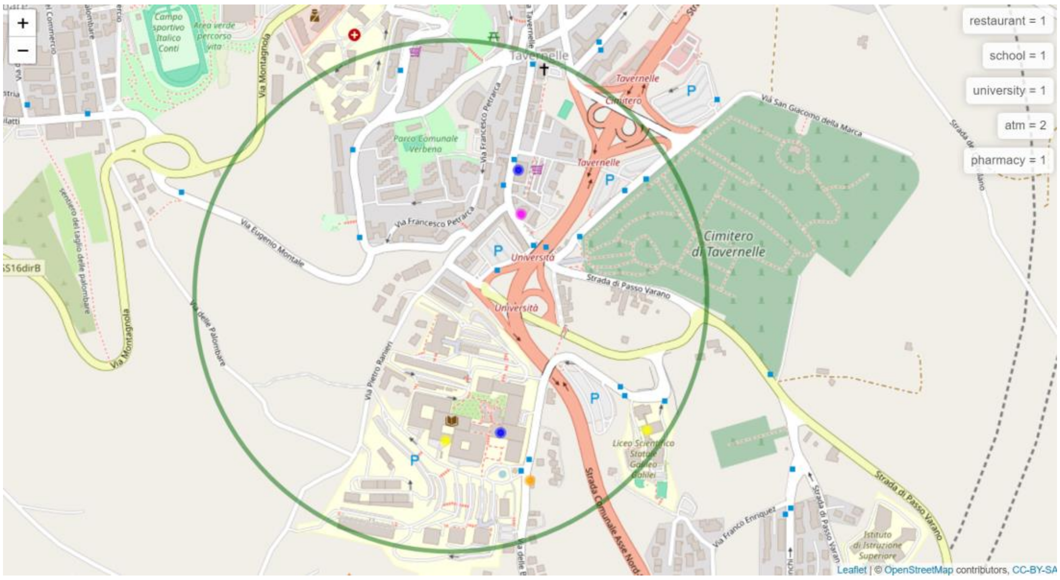
The second cluster, in blue, consists of 26 observations, almost entirely represented by suburbs and peripheral areas at the outskirt of the city. Given their location and the inevitably scattered population, it is not surprising that they are characterized by the lower average number of residents. The minimum average concentration of foreign residents (6%) is recorded in this cluster while the share of elderly people on the resident population in this group of districts is relatively high on average (23.4%).

The third (in green) and fourth clusters (in purple) include 20 and 9 areal units, respectively. These are central and semi-central districts as well as the main suburban agglomerations of Torrette and Collemarino. The majority of the city population lives in these two clusters, but the fourth group of areal units is characterized by a higher population density, double compared to the average population of areal units belonging to cluster 3. What distinguishes the two groups of neighborhoods is also the share of the city foreign population. Foreign residents in the city settled in the fourth group represent the 10.2 % while those living in the third group represent the 5% of the entire foreign population registered in the city.

Figure 7 illustrates four exemplary cases, one for each of the four clusters identified, with POIs associated to the domains of education, commerce, entertainment and healthcare, namely restaurant, school, university, atm, pharmacy. In the Appendix, we report details on the socio-demographic features of the selected areas (Table A1), and the complete list of the OSM categories for the 15-Minute City domains with their simple counts for each POIs (Table A2).

Figure 7 Examples of 15-minute areal units of the four socio-demographic clusters, POIs for different OSM categories

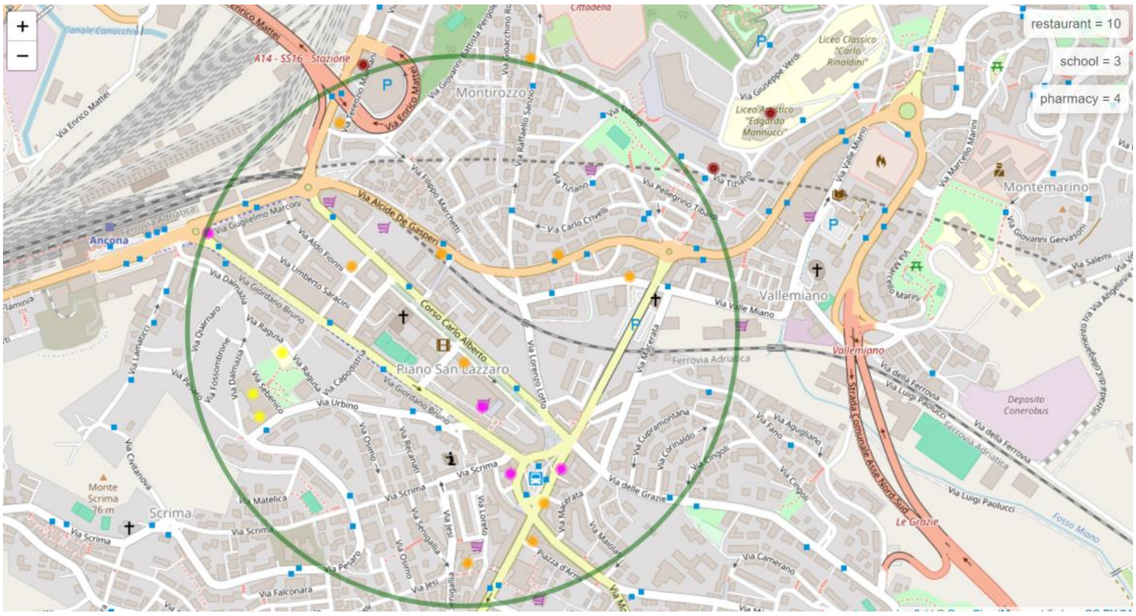
Via P. Ranieri - Cluster 1



Strada della Madonnetta - Cluster 2

Via T. Frediani- Cluster 3

Corso Carlo Alberto di Savoia - Cluster 4



The different location and socio-demographic characteristics of the four clusters suggest that they can be classified as “Residential neighborhoods on the outskirt of the city center” (Cluster 1), “Peripheral suburbs” (Cluster 2), “Highly populated central and semi-central districts” (Cluster 3) and “Most densely populated central and semi-central districts with a high concentration of foreigners” (Cluster 4).

Table 5 describes the four clusters in terms of the presence and density of essential services grouped according to a set of domains usually considered in the literature on the 15-Minute City

(Moreno, 2016; Moreno et al., 2021). At the bottom of table 5, we report, the average Location Quotient (LQ) for each cluster and the two social groups analysed. In this context, the LQ is an indicator of their relative concentration within the city and offers insights into their residential segregation in specific city areas.

Concerning the proximity to essential services and amenities, we first notice that in each cluster at least one OSM category for each domain is present. However, a look at Table 5 suggests that the availability, diversity, and density of some domains and some specific categories of services are highly heterogeneous across the four socio-demographic clusters.

Table 5 –Density of essential services in the socio-demographic clusters by 15-Minute City domains

	Cluster 1 - Residential neighbohroods on the outskirt of the city center	Cluster 2 - Peripheral suburbs	Cluster 3 - Highly populated central and semi-central districts	Cluster 4 - Most densely populated central and semi-central districts with a high concentration of foreigners	Average density for the whole city
PUBLIC TRANSPORT					
Train station	0.02	x	0.1	0.04	0.06
Platform	16	3	39	48	8.66
ENTERTAINMENT					
Bar	0.5	0.17	1.21	0.12	0.63
Cafe	1.51	4.02	3.85	1.96	2.65
Pub	0.03	x	0.23	0.18	0.16
Restaurant	1	1.52	3.43	1.25	2.05
Cinema	0.06	x	0.14	0.12	0.11
Theatre	0.03	ò	0.15	0.05	0.08
EDUCATION					
Kindergarten	1.26	0.07	0.06	x	0.27
School	2.1	0.25	4.34	1.81	2.83
University	0.67	0.06	0.99	x	0.58
HEALTHCARE					
Dentist	0.05	x	0.13	0.11	0.1
Hospital	1.88	0.96	0.65	0.35	0.94
Clinic	0.02	0.13	0.03	0.11	0.06
Pharmacy	0.49	1.09	0.86	0.63	0.69
Social facility	0.09	0.1	0.39	0.25	0.28
COMMERCE					
ATM	0.16	x	0.07	0.07	0.09
Bank	0.2	0.06	1.63	0.77	0.97
Post office	0.24	0.14	0.27	0.16	0.21
Marketplace	0.03	x	0.11	0.1	0.09
LIVING/SPORT					
Sport hall	0.19	0.11	0.16	0.06	0.14
Sport centre	0.43	19.86	0.68	0.29	0.65

Park	27.04	10.12	25.86	12.36	21.62
Pitch	2.29	8.43	1.61	1.43	1.74
Swimming pool	0.16	0.19	0.07	X	0.06
Playground	0.31	0.06	0.39	0.38	0.36
LQ - Foreigners	**0.55**	**0.33**	**1.28**	**1.65**	
LQ - Elderly	**1.10**	**1.00**	**0.95**	**0.94**	
N. of areal units	**19**	**26**	**20**	**9**	

As already clarified in Section 2.1, the values reported in Table 5 for the OSM category "Platform" refers to the simple average of the count of bus stops available in the areal units that compose each cluster. It is therefore not, like the other categories, the number of POIs per thousand inhabitants. Hence it is clear that resident living in the city centre (clusters 3 and 4) enjoy the greatest transit connections (clusters' averages are 48 and 39, respectively) to the rest of the town, while the residential suburbs are undoubtedly less transit oriented (16 bus stops on average). Not surprisingly, the peripheral areas, and sparsely inhabited hamlets included in Cluster 2 are very poorly served by local public transport (3 bus stops on overage).

"Highly populated central and semi-central districts" (Cluster 3) presents high average density of POIs per thousand inhabitants for most categories, usually higher than the city average in most of the cases. These areas are well-equipped with essential amenities, such as shops, markets, banks, post offices, pharmacies, specialist doctors, social facilities, schools, and public transport. They are central districts or neighborhoods close to the city center and offer a plenty of recreational services and cultural amenities, such as cafés, bars, pubs, restaurants, cinemas, and theatres. They are also livable areas in that they are endowed with a high density of green zones, sport facilities and parks. However, less than average density is recorded for kindergartens that are, instead, particularly concentrated in Cluster 1.

"Residential neighborhoods on the outskirt of the city center" (Cluster 1) displays also optimal conditions in terms of diversity and density for POIs belonging to the domains Commerce, Education and Living. However, despite their relatively central location and residential function, these areas are in shorter supply compared to the other neighborhoods for most of the essential services in the sphere of Healthcare and they have a very low density of supermarkets, and amenities for cultural activities and leisure, such as cinemas, theatres, restaurants and pubs.

In "Peripheral suburbs" (Cluster 2), which includes areas with a very limited concentration of foreign citizens, less populated (Table 4), and more distant from the city center (Figure 6), we found the lowest densities in the domains of Education, Commerce and Entertainment relative to the other clusters, Public Transport is also extremely scarce so that it can be inferred that residents are forced to use private car to reach the city center. In particular, for these peripheral districts, no POIs are registered in OSM for the categories of ATM, marketplace, pub, cinema, theatre and dentist. Furthermore, few playgrounds and parks are located nearby.

Similarly, in “Most densely populated central and semi-central districts with a concentration of foreigners” (Cluster 4), we found that the provision of services belonging to Education and Living/Sport are in short supply. Overall, the density and variety of facilities included in the domains of Commerce and Entertainment can be considered acceptable since the respective values are generally slightly lower than the city averages. Given their central or semi-central locations (Figure 6), dwellers settled in these suburban areas can reach the city centre rather easily either by walking, cycling or using public transport (Table 5). Like the first cluster, the areal units included in Cluster 4 have, on average, a medium-low degree of diversity, especially in some domains, e.g., no POIs are registered in OSM for the categories of kindergarten, university, and swimming pool.

Finally, it is worth noting that the diversity of different facilities within some domains are very limited. For example, cluster 2 – peripheral suburbs with sparse population – displays a very low diversity in facilities within two domains, namely entertainment and commerce (Table 5).

Our results are in line with previous experimentations in the cities of Matera and Terni (Murgante et al., 2023) in that we also found for the city of Ancona that proximity and density of POIs associated with essential services and facilities show quasi-optimal conditions in central and semi-central districts (mainly Cluster 1 and 3) while in central and semi-central neighbourhoods (Cluster 4) with significant presence of foreign population, diversity and proximity to essential services and amenities tend to be lower. In edge and sub-urban areas (Cluster 2) diversity are very low and also accessibility to basic urban functions is scarce.

Further support on the heterogeneity in the functional conditions conducive to urban vitality in the different clusters identified is provided by the ANOVA results. As clarified in Section 2.2, the ANOVA analysis is here used to test the difference between the four clusters’ means in each of the OSM category considered to ascertain significant differences in the density to essential services. The differences in clusters’ means are higher and statistically significant in a variety of OSM categories belonging to different domains, namely Platform, Bank, Pub, Theatre, Dentist, Cinema, Playground, Marketplace, and School.

The clustering analysis based on the k-mean algorithm also revealed significant variations across clusters, which are particularly evident for certain categories (Table 5). The ANOVA results further confirm these spatial disparities, with Platform, Bank, Theatre and Pub with highly significant differences (p-values lower than 0.001), signaling a notable heterogeneity across clusters. In particular, it is worth noting that public transport records the higher spatial variation between the four clusters with a F value of 86.8 In contrast, kindergartens, post offices, pharmacies, clinics, social facilities, bars, sport centres, parks, swimming pools, do not show significant differences between urban clusters. This result may reflect a more uniform distribution of essential services and recreational venues for sports and open-air activities (Table 6).

Table 6 –ANOVA results

OSM category	F-value	Pr(F> F-value)	Sign
Bar	3.253	0.027	
Cafe	0.643	0.590	
Pub	6.861	0.000	***
Restaurant	2.625	0.057	
Kindergarten	2.209	0.095	
School	4.742	0.005	**
University	1.570	0.205	
Dentist	5.182	0.003	**
Hospital	0.604	0.615	
Atm	3.244	0.027	
Bank	16.020	0.000	***
Post_office	0.610	0.611	
Clinic	0.723	0.542	
Marketplace	6.437	0.001	**
Pharmacy	0.404	0.750	
Social_facility	1.564	0.206	
Cinema	4.342	0.007	**
Theatre	6.983	0.000	***
Train_station	3.429	0.022	
Sports_hall	0.591	0.623	
Sports_centre	0.842	0.476	
Park	2.586	0.060	
Pitch	1.889	0.139	
Swimming_pool	0.282	0.839	
Playground	4.221	0.008	**
Platform	86.836	0.000	***

Note: 0.001***, 0.05, **, 0.1*

The present study enables a deep understanding of which services and amenities should be improved to stimulate a lively environment based on the 15-Minute model. Converging evidence from k-mean clustering and ANOVA analysis highlights a discernible pattern in the urban environment, where specific services and amenities related to public transport, education, commerce, cultural activities, and leisure are subject to greater spatial variance, potentially influencing the socioeconomic dynamics of different areas of the city. The risk is that the social composition of the areas of residence, together with the unequal spatial distribution of services and resources, may perpetrate the structure of constraints and opportunities for individuals, fueling the reproduction and the intergenerational transmission of inequalities.

In particular, we highlighted that peripheral areas face major challenges in implementing the 15-Minute City model, as evidenced in other case studies (e.g., Zakariasson, 2022 for the city of Munich, Murgante et al., 2023 for the towns of Terni and Matera in Italy). Instead, the central and semi-central districts are the best places to imagine more liveable, human-centred neighbourhoods, according to the planning principles of the 15-Minute City model.

Finally, the results of our analysis revealed that the districts belonging to Clusters 1 and 3 in the town of Ancona perform very well in terms of proximity to services, with a more diversified service supply compared to the other suburbs. Instead, there is room for work towards making some other districts more livable, by ensuring a more balanced offering, such as peripheries included in Cluster 2 and the more densely populated downtown districts with a significant presence of foreign residents included in Cluster 4.

4 Concluding remarks, policy implications and avenues for future research

The changes in people's mobility habits during the COVID-19 pandemic has indicated the path to strengthening urban policies for sustainable mobility, the development of green areas and resilience to climate change. Meanwhile, in the context of the New Urban Question (Secchi 2010), residential segregation in urban spaces can easily become a threat to the social inclusion of disadvantaged groups if it is associated with an unequal spatial distribution of services and resources. In this context, promoting territorial policies for the well-being of the whole resident population requires an in-depth knowledge not only of the spatial distribution of basic infrastructures and services but also of the socio-economic and demographic characteristics of the urban environment.

In particular, to promote an inclusive and sustainable city and avoid gentrification and ethnic segregation in some neighborhoods, urban design should foster a distributed accessibility of local services. Spatial analyzes and advanced statistics on georeferenced open data can be used to monitor the distribution of essential services and amenities relative to specific targets of the population, and it is therefore fundamental in order to define a planning strategy oriented towards the needs of all citizens.

This article provides the first evidence on whether Ancona, a mid-sized city in Central Italy, is already 15-minute. The clustering approach enabled to identify groups of areal units with similar socio-demographic characteristics, allowing to recognize spatial patterns and areas of abundance or lack of services. The ANOVA analysis complements these results by determining the statistical significance of the observed variations, giving an empirical basis to evidence-based planning decisions. For example, if a lack of essential services emerges from the ANOVA analysis, urban development policies could be directed towards an increase in investments in such services in the specific areas identified by the cluster analysis.

Since the distribution of services can influence the social structure and urban fabric, the urban design should follow principles of social equity with interventions aimed at improving accessibility and quality of life of urban environment for all. We believe that our findings represent a remarkable example of how different statistical and graphical tools may help detect invisible spatial inequalities in the urban landscape. Hence, the methodological approach introduced in this article provides urban planners and policy makers with useful tools to guide targeted interventions for the development of accessible, sustainable, and inclusive cities.

The experimentation for Ancona made it possible to test the applicability and validity of the approach, with encouraging results on the effectiveness and sensitivity of the tools to evaluate spatial transformations. Thanks to the use of open data, the ease of computation, and the possibility of adapting the tools to specific aims and target-oriented approaches, the methodology is easily transferable to other cities without any significant adjustment. Continuous assessment through this approach can improve the effectiveness of interventions to be monitored over time, offering the possibility to timely adjust planning strategies.

While we provide arguments on the viability and usefulness of the proposed approach to detect which parts of an urban settlement fulfil the requirements of the 15-Minute City model, we also propose avenues for future research. First, extending the analysis to other mid-sized cities from different European countries as case studies could unveil variations or further confirm the observed spatial regularities. Second, to monitor and evaluate conditions for an inclusive well-being at an intra-urban level, it could be important to complete the analysis with a more comprehensive measurement of the diversity of services, both between and within the six domains suggested by Moreno et al. (2021), with statistical methods used in some previous studies such as Olivari et al. (2023). In this vein, we also suggest that our inquiry and the qualitative narrative presented in this article could be further enriched with a deeper analysis of the association between the services' availability and further indicators capturing socio-economic conditions, thereby facilitating comparative analyses. We leave further investigation along these possible extensions and improvements for future work.

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Appendix

Table A1 - Socio-demographic features of exemplary areal units

Cluster	Example	Population	Share of city's residents	Share of city's foreigners	Share of city's elderly	Concentration of foreigners (% on the areal unit)	Concentration of elderly (% on the areal unit)
1	Via P. Raneri	2043	2,04%	1,73%	2,68%	13,07%	30,25%
2	Strada della Madonnetta	840	0,84%	0,47%	1,02%	8,57%	28,10%
3	Via T. Frediani	4951	4,94%	5,16%	5,27%	16,06%	24,58%
4	Corso Carlo Alberto di Savoia	9717	9,69%	27,39%	6,35%	43,42%	15,10%

Table A2 - 15-Minute City domains: POIs of OSM categories for exemplary areal units, *simple counts*

	Via P. Raneri (Cluster 1)	Strada della Madonnetta (Cluster 2)	Via T. Frediani (cluster 3)	Corso Carlo Alberto di Savoia (Cluster 4)
PUBLIC TRANSPORT				
Train station	-	-	-	-
platform	19	3	58	56
ENTERTAINMENT				
Bar	-	-	3	1
Cafe	5	1	29	17
Pub	-	-	1	2
Restaurant	1	1	9	10
Cinema	-	-	2	1
Theatre	-	-	1	-
EDUCATION				
Kindergarten	-	-	1	-
School	1	1	2	3
University	1	-	1	-
HEALTHCARE				
Dentist	-	-	1	1
Hospital	17	-	-	-
Clinic	-	1	-	-
Pharmacy	1	1	6	4
Social facility	-	-	-	1
COMMERCE				
ATM	2	-	-	-
Bank	-	-	3	10
Post office	-	-	1	1
Marketplace	-	-	1	1
LIVING/SPORT				
Sports hall	1	-	1	1
Sports centre	1	-	1	5
Park	163	-	155	15
Pitch	5	1	2	5
Swimming pool	-	-	-	-
Playground	1	-	1	1