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Are essential services fairly distributed in Milan? Spatial Fairness Assessment with an Inclusive Accessibility by Proximity Index

Master's Thesis

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Declaration of Academic Honesty

I hereby certify that I have written my thesis independently and have not used any other sources and aids than those cited.

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List of Abbreviations

EX-TRA	-	Experimenting with city streets to transform urban mobility
GOAT	-	Geo Open Accessibility Tool
IAPI	-	Inclusive Accessibility by Proximity Index
ISTAT	-	Italian National Institute of Statistics
NIL	-	Nuclei di Identità Locale (Nuclei of Local Identity)
OSM	-	OpenStreetMap
PET	-	Physiological Equivalent Temperature
POI	-	Point of Interest
Polimi	-	Politecnico di Milano
PUMS	-	Piano Urbano per la Mobilità Sostenibile
SDG	-	Sustainable Development Goals
SWTCI	-	Street Walkability and Thermal Comfort Index
TUM	-	Technical University Munich

Abstract

Sustainable transport plays a key role in the development of more livable cities. Improving walking and cycling has an enormous effect on improving the urban conditions for cyclists. This research implements the Inclusive Accessibility by Proximity Index (IAPI) in Geo Open Accessibility Tool (GOAT), a web tool capable of modeling walking and cycling accessibility. The main outcome: to find which social groups have a better accessibility by active modes to the essential services in Milan. In a review of existing literature, this paper assigns impedance values to seven urban characteristics and calculates a modified gravity-based accessibility measure to six categories of amenities. This measure includes impedance factors that incorporate the positive and negative effect from the urban environment. Then, in combination of the accessibility results and the sociodemographic information, the spatial fairness assessment characterizes the distribution of the amenities in city through a horizontal equity (GINI Index and Lorenz Curves), vertical equity (correlation and multiple linear regression) and a Deprivation Index. By implementing the comfort-based measure IAPI is possible to visualize the positive effect of attractive are in walking. From the equity analysis, public transport and sports have the best accessibility of categories in the city; the worst, cultural amenities. From the households' perspective, groups with foreign background, young (18-35) and couples with children are the vulnerable groups of people. The deprivation index shows a high inequality between perimetral and central NILs; however, Milan is still a very equitable city. This study presents a future direction for the incorporation of comfort factor within a walkability index. It also reveals the importance of including sociodemographic data in walkability measures to focus efforts in improving the urban condition of those who need the most.

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1. Introduction

Sustainable mobility has been one of the key tools to improve the quality of life of people in cities around the world. In conjunction with the improvement of urban environment, it is part of the Sustainable Development Goals of the Unite Nations to fight poverty and inequalities by 2030. To develop sustainable mobility, cities around the world can implement Push-Pull measures to shift away from the car-oriented development (Yassin 2019). Pull measure have demonstrated better results and adoption by citizens, among many technological and high investment solution, promote better walking and cycling condition are one best low-budget high-impact practices to improve quality of life, while achieving sustainable goals. In fact, many street experiments and tactical urbanism experiences have pushed policymakers are implementing land use strategies as the 15-minute city, to improve accessibility and generate more equal societies.

Within this new planning concepts, accessibility planning is fundamental to ensure successful results. Accessibility is a wide concept, is the extent to which land-use and transport systems enable individuals to reach activities or destinations employing a combination of transport modes (Geurs and van Wee 2004). It has 4 components land use, transport, time, and individuals. This last one has been neglected by many accessibility measures, in consequence, the aim of this study is to include it in an accessibility evaluation in Milan. This situation motivated the main research question: "*Which social groups have a better accessibility by active modes to the essential services in Milan?"*

To answer this question, this research project has four outcomes. First, to develop the IAPI index in GOAT for the study area of Milan. The IAPI is under development by the Politecnico di Milano and the Technical University Munich, it is part of the EX-TRA project. For the implementation was necessary to define three main categories for the data collection: socio-demographic data, points of interest, and network data. For the socio-demographic data, Comune di Milano data the required data. In the case of points of interest and network data, the primary source is OpenStreetMap (OSM). This outcome also included the estimation of the impedance factors for the network characteristics and the inclusion of positive comfort from street elements. There's also a comparison between a comfort-based accessibility and a gravity-based accessibility calculation.

Therefore, the research analyses individual characteristics, especially sociodemographic features of the population and calculates accessibility to a set of amenities. The accessibility indicator is the Inclusive Accessibility by Proximity Index (IAPI). The IAPI is then implemented within the Geo Open Accessibility Tool (GOAT) an open-source web tool capable of modeling walking and cycling accessibility.

Second, to estimate the accessibility to the POIs and evaluate the differences in accessibility. With the IAPI running in GOAT, the comfort-based accessibility calculation was the base to the creation of accessibility heatmaps for all the amenities, and the categories that grouped them. Two methodologies of visualization of the results were tested, normalization of the data with a Z-Score methodology, and normalization with a min-max methodology and generating the breaks with natural breaks from QGis.

Third, to develop a spatial fairness assessment of the essential services, with measures on horizontal and vertical equity as well as the calculation of a deprivation index. For this analysis the sociodemographic characteristics were compared against the results form the last outcome. In the horizontal equity, accessibility is the resource that is distributed among the population, with the GINI index and the Lorenz Curves, is possible to determine how the resource is being distributed among the population. In the case of the vertical accessibility, the analysis consistent in a correlation evaluation between the expected accessibility of each category and the social characteristics defined. Later the analysis included a linear regression model to analysis the influence between the social characteristic in the estimate value of accessibility for each category. Finally, a deprivation index analysis finds the NILs whit the worst accessibility conditions, while most of the vulnerable groups live in those areas,

Finally, the research proposes a set of recommendations to improve the individual's component of the IAPI. It indicates where the suppositions can improve for the need in the network data and proposes changes on impedance factors suppositions, also describes the results of spatial fairness assessment to the understand the current situation of Milan and sets a group of recommendation to the EX-TRA partners for next steps in the project.

2. Background

2.1. Sustainable Mobility

In the last decades, many cities around the world started to shift their mobility from car-oriented toward active modes (Yassin, 2019). By the 70s, the first crisis of fossil fuels showed the early week spots of a system with a complete lack of sustainability (Gössling, 2020). With the years, cities around the world have realized about the problems and cost of the model of development and raised their interest on policies and action towards a more sustainable future. By March 2021, 156 countries had already developed such urban policies (United Nations, 2021). In the transport sector, they are reflected on prioritizing programs that encourage citizens to walk, bike, and use public transport (Lee et al., 2016; Weng et al., 2019; Yassin, 2019). Moreover, the actions have also included land use strategies as the 15-minute city, where citizens should be able to reach most of their daily destinations easily within a short period of time on a non-motorized mode of transport (Weng et al., 2019).

These actions are under national and world policy programs that seek to improve the three "dimensions" (Carter & Moir, 2012; Lehtonen, 2004; Mori & Christodoulou, 2012; Purvis et al., 2019; Stirling, 1999) of sustainability encompassing economic, social, and environmental (or ecological) factors or 'goals' (Purvis et al., 2019). From a global perspective since 2015 United Nations have adopted 17 goals that pursue to end poverty, and protect the planet targeted to 2030. They are known as the Sustainable Development Goals (SDGs), also known as the Global Goals. (United Nations, 2021) Goal 11 - Sustainable cities and communities, is focuses the global efforts in generate urban habitat where people can find business and career opportunities, affordable housing, high quality public transport and green environments to participate as an inclusive society.

To achieve structural results with the Global Goals, strategies may be aimed at making unsustainable practices (as indiscriminate car use) less attractive or feasible via so-called push measures (i.e., 'penalties'), while the use of more sustainable transport modes (as public transport, walking or cycling) may be stimulated by means of pull measures (i.e., 'rewards') (Steg, 2007). Eriksson et al. (2008) reported that "Pull" measures may be more effective in encouraging an increase in the use of sustainable modes of transport. However, "Pull" measures alone may be insufficient to effect a change in transport behavior. (Eriksson et al., 2008; Steg, 2007; Xia et al., 2017) A combination of both, can drive better results but the communication of the benefits on the "Push" measures is critical for their success. Within the pull measures, improving walking a cycling are among the top priorities on the cities' agenda for a sustainable development. They allow citizens to develop their transportation needs with the least resource consumption and environmental impact, while they experience better quality of life achieving the ultimate of sustainable urban development. (Yassin, 2019) The sustainable development have proven not only to improve the quality of life of people and a better future for the next generations, (Nundy et al., 2021) but provide a better resilience against natural and public health threats.

The COVID 19 pandemic showed us how cities that prioritized the development open spaces, parks, public transport, walking, and cycling had a better response and were more resilient to the pandemic. (Nundy et al., 2021) These cities permitted daily outdoor movement, that in combination with soft mobility allowed for social life even during lockdown periods. (Abdelfattah et al., 2022; Rajabifard et al., 2021) In Germany, for example, about 4% of transport users started using the bicycle during the lockdown period. In consequence, the bicycle may have attracted new user groups. (Eisenmann et al., 2021) As a result, the importance of walking and bicycle usage in a period of social distancing was relevant to maintain satisfactory health levels in society. (De Vos, 2020; Eisenmann et al., 2021)

2.2. Accessibility

Sustainable modes as public transport, cycling and walking play a fundamental role on achieving the goals of sustainable development. Nevertheless, the interaction between land use development and the transportation structure is important to evaluate strategy-making and scenario development towards sustainability (Wulfhorst et al., 2017). Furthermore, the characteristics of individuals and time constraints add layers of complexity that are usually overlooked when assessing sustainability objectives. An effective analysis on how to consider those complexities is to measure accessibility.

2.2.1. Definition of accessibility

When defining accessibility several authors have propose a mixture of alternatives. The classic from Hansen (1959) that establish accessibility as the potential of opportunities available for an individual (or groups) located at a certain location for interaction. Followed by Dalvi and Martin (1976) that defined accessibility as the capacity of a location to reach and be reached from different locations through the transport system. And the recent definition from Dong et al., (2006) where accessibility is the available opportunities that allow individuals to participate in one (or more) particular activities, considering travel purposes or larger activity-based travel. (Guzman et al., 2017)

Among multiple definitions one of the most complete, Geurs and Van Wee (2004) define accessibility as the extent to which land-use and transport systems enable individuals to reach activities or destinations employing a combination of transport modes. Furthermore, they define 4 components in the concept of accessibility: (Guzman et al., 2017)

- Land-use component, which refers urban space, and the distribution of opportunities e.g., jobs, education, healthcare, or recreational facilities at destination locations, and the demand for opportunities at origin locations.
- Transport component, the transportation system and the parts that compose it is expressed in terms of the "disutility" for an individual to travel between origins and destinations using a given mode of transport.
- Time component, meaning thee time constraints such as opening hours, or holidays seasons but also the availability of time for individuals to make use of such opportunities.
- Individual component, referring to the needs, abilities, and opportunities of individuals. e.g., sociodemographic characteristics, economic status, or physical disabilities.

All the components connected between each other. There are direct relationships, like how individual need, or abilities determine the accessibility to opportunities, or how travel time and cost determine the accessibility by public transport. On the other hand, there are indirect relationships, as how the land use distribution can affect the transport component by determining the travel demand. Figure 2-1 illustrates the complete maps of relationships between the components of accessibility.

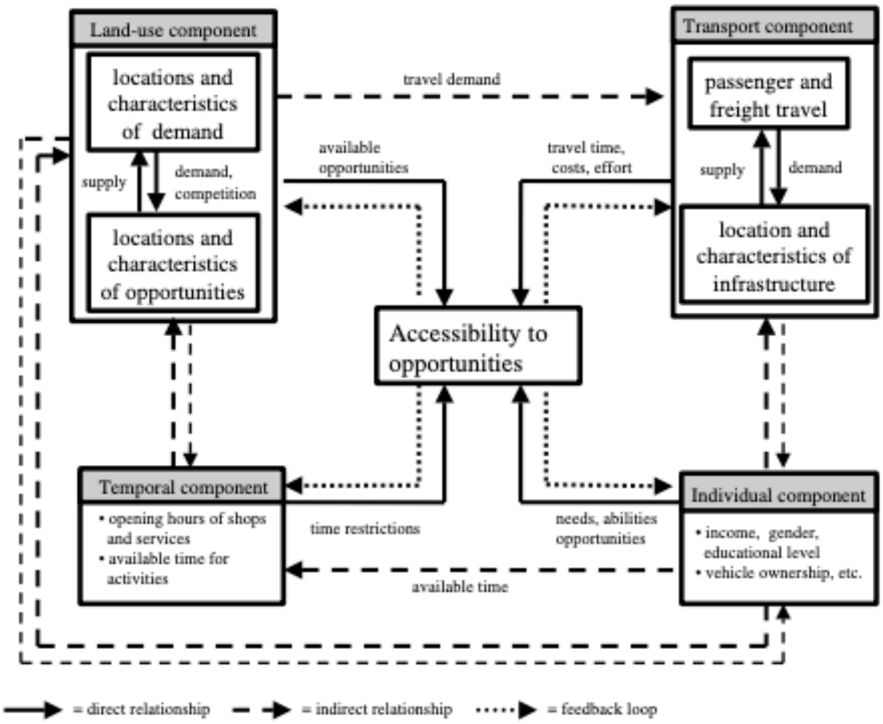


FIGURE 2-1. RELATIONSHIPS BETWEEN COMPONENTS OF ACCESSIBILITY.[1]

To measure accessibility, in general, is necessary to use spatial distribution of the urban components and the generalized cost of transport (distance, cost, time). (Kwan, 2010) These characteristics belong to the components of land use and transport can be grouped on the place-based perspective (i.e., from one geographical location to another), on the contrary individual and temporal components that are grouped on person-based measures (i.e., also considering personal characteristics, resources and capabilities, including time budgets, etc.) (Lucas et al., 2016). The person-based measures are not commonly implement in accessibility studies.

Accessibility measures are can be classified as distance measures, topological measure (Pirie, 1979), gravity-type and cumulative-opportunity. (Kwan, 2010; Pirie, 1979) The simplest of these is one which (Ingram, 1971) has called relative accessibility'. It refers to the physical separation between two points. The measure can be summarizes as: places far apart are mutually less accessible than closer places (Pirie, 1979) for topological measures, the links and network vertices set reference for measuring distances. (Pirie, 1979) the gravity-type accessibility indices, introduced by (Hansen, 1959), are derived by weighing the opportunities in an area by a measure of attraction and discounting each opportunity by a measure of impedance (Kwan, 2010). And cumulative-opportunity measures, also called isochoric indices, evaluate accessibility in

[1] (Geurs & van Wee, 2004)

terms of the number or proportion of opportunities that can be reached within specified travel distances or times from a reference location (Kwan, 2010).

2.2.2. Person-based accessibility

Person-based measures analyze accessibility form the viewpoint of individuals incorporating spatial and temporal constrains. (Geurs & van Wee, 2004) this constrains set the boundaries of opportunities that can be reached given predefined time constraints. Nevertheless, their application in accessibility studies is relatively rare (Geurs & van Wee, 2004). These measures are more conservative than place-based measures in terms of assessing the level of equity of service delivery (Lucas et al., 2016). As a result, accessibility instruments usually fall short on assessing individual variations, including gender and ethnic differences. (Geurs & van Wee, 2004) This fact has motivated multiple research projects to incorporate the individual characteristics, especially socioeconomic features of the population within the accessibility estimations. Guzman et al. (2017) assessed a vertical and horizontal equity analysis, by using Gini coefficients and Lorenz curves, to the accessibility to work and study places in Bogota. Similarly, Lucas et al. (2016) propose a method to assess the socially relevant accessibility impacts of policies, the method combines ethics principles with accessibility-based analysis, the Lorenz curve and Gini index and demonstrated their method by comparing three cities in the Netherlands.

Incorporating the social characteristics of individuals results challenging, in addition including the perspective of the individual about the land use or transport structure can be even harder. To set the context, passengers waiting at bus stops with the ability to see the excepted waiting time can use their waiting time more productively, select which route they would want to take, or choose to select an alternative mode of transportation. Empirical evidence shows that the time travelers spend outside the transportation vehicle of choice (e.g., waiting at a stop) is more onerous than the time they spend inside the vehicle in motion to their destination (Ben-Akiva & Lerman, 1985). This means that a person waiting for five minutes in the bus stop has the perception that the time lapsed is longer than if those same five minutes were within the bus. This is partly due to the higher degree of uncertainty associated with waiting for a transit vehicle. The same perception effect applies to the space, and studying this effect is fundamental motivation of walkability indicators.

2.3. Walkability and Comfort

Walking accessibility planning is a powerful approach towards sustainable mobility, it allows to shape the transport and space conditions according to the individual's needs, to facilitate the analysis of the urban areas, walkability indexes come handy to understand the relations and influence of the urban space and individuals. In fact, Walkability is defined as the extent to which the built environment has a positive effect on walking (Weng et al., 2019) this approach tries to overcome how many conventional approaches to the opportunity-based assessment of quality of life usually measure the distribution, population density and distances of different opportunities in space. But distance is not all there is. If we want to reason in terms of capabilities, we should also take into account the quality of accessibility (Blecic et al., 2015)

Nevertheless, quantifying quality of accessibility or the positive effect of the environment is such a challenging task. Is possible to consider a multiplicity of factors such as sidewalk width or quality, green areas, noise, pollution, traffic, or even the availability of street furniture. In fact, some authors (Blecic et al., 2015; El-Geneidy et al., 2014; Ewing & Handy, 2009; Landis et al., 1997; Maghelal & Capp, 2011; Páez et al., 2020; Ryan & Pereira, 2021) have organized and classified multiple walkability indicators according different factors A common ground is the definition of the unit of analysis, i.e. area, neighborhood, segment, intersection; the data source, so survey, geographical information, audits; and the data measured, subjective, objective or both. For the purpose of this study evaluating comfort is the priority, so, by comparing different methodologies, the purpose is to incorporate the positive effect or urban features. Then a set of 64 walkability indicators were filtered according to the characteristics of this study. Therefore, the unit of analysis corresponds to a city scale, the data source is geographical information and the data measured is objective. With this characteristics, walkability indicators as Walkability Index (Maghelal & Capp, 2011), Pedestrian Potential value (Vale et al., 2015), Microscale Audit of Pedestrian Streetscapes (MAPS – Global) (Cain et al., 2018), walkability explorer (Blecic et al., 2015), Pedestrian environmental Factor (Kuzmyak et al., 2006), Promethee II for Street Quality Street Walkability (Ortega et al., 2020) and Thermal Comfort Index (Labdaoui et al., 2021) had methodologies to incorporate comfort into the walkability calculation according to general needs of the study.

After reviewing the methodologies and the data required by the walkability measures to incorporate positive effect or urban features as comfort, Walkability Index, Pedestrian Potential value considered variables that were not considered for this study as residential or building density, density, and slope. walkability explorer and Pedestrian Environmental Factor did not consider differentiated factors for comfort but only variables related to land use and the network available. However, from the list, 3 methodologies had suitable inputs to incorporate comfort attributes into this study.

MAPS – Global (Cain et al., 2018) Developed a scoring system that summarized items into subscales at multiple levels of aggregation. Most sections included positive and negative scores based on the expected effect on physical activity. Then developing a scale of comfort with positive and negative values according to the expected effect would be an input for the methodology. From Promethee II for Street Quality Street Walkability (Ortega et al., 2020) the application of the method required: the determination of the type of criterion (maximum or minimum). Most of the factors considered (criteria) are maximized, as the objective is to rank streets and identify the most walkable. The criteria they refer are the factors of the walking needs defined (e.i. Green, Public transport, facilities, furniture) this approach is determining the impedance factor for the variable in this this study. Labdaoui et al. (2021) consider thermal comfort in assessing walkability by developing the Street Walkability and Thermal Comfort Index (SWTCI), which focuses on comfort facilities and Physiological Equivalent Temperature (PET) at the street scale. Here, pedestrian facilities had differences that affected the PET score for streets based on the presence or absence of the urban element. Where 0 meant the total absence of the element, and 1 meant the high presence. The indicators scores were used to estimate the PET scores, which is 1 in the desired PET range, and 0 in the uncomfortable thermal conditions.

2.4. GOAT

GOAT is an open-source web tool capable of modeling walking and cycling accessibility, it has special features that allow it to be interactive and flexible for accessibility planning. Due to its flexibility, it is highly transferable, and it has been implemented in multiple study case scenarios. Currently is working in Munich, Fürstenfeldbrück, Freising and Freiburg and has been implemented in many more locations around the world for research on accessibility. GOAT can be regarded as a middle ground between simple WebGIS-applications for every user and a fully-featured GIS desktop software. (Pajares et al., 2021a) Technically, GOAT a WebGIS-application and is built, as most of the web applications are, in line with the classical Server-Client-Architecture of the web. A spatial database using PostgreSQL with the PostGIS extension could be described as the back-bone of the application. (Pajares et al., 2021a) One of the key strategic aims of GOAT is easy transferability, an automatic set up process collects the data form OpenStreetMap or provided and filters it into a clean and ready to use table. For the routing algorithm

GOAT uses a custom implementation the classical Dijkstra shortest-path calculation (Pajares et al., 2021a)

In GOAT, accessibility can be visualized in two ways, with contour-based accessibility measure and gravity-based accessibility measures. (Pajares et al., 2021a). First, with the with contour-based accessibility there two possibilities, a single travel time isochrones as Figure 2-2 where the user selects the starting point in the map and with multi-isochrones which are interpreted as isochrones from several starting points. (Pajares et al., 2021a)

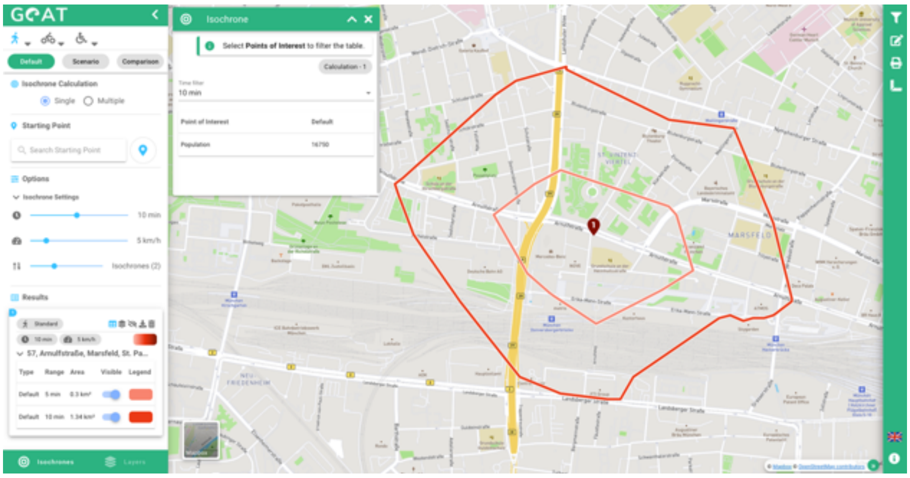


FIGURE 2-2 ISOCHRONES IN GOAT

For the gravity-based accessibility measure, GOAT uses a modified Gaussian function as an impedance function accessibility, for this function multiple sensibility values are available depending on the amenity type, users have the possibility to pick suitable sensitivity values. However, by default, the value is β = 300,000 (Pajares et al., 2021a). Accessibility is visualized in a hexagonal grid width a default grid width 150 m. the hexagon shape helps to reduce bias because of the edges in comparison with grid of squares, this is validated by the low perimeter-to-area ratio of the shape of the hexagon. Hexagons are the most circular-shaped polygon that can compose a uniform grid. (Birch et al., 2007)

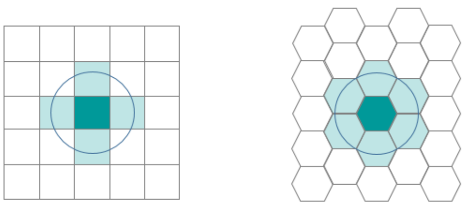


FIGURE 2-3 COMPARISON SQUARE AND HEXAGONAL GRID[2]

[2] Source: https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-statistics/h-whyhexagons.htm

Once the grid is defined, the centroid of each grid cell is used as the starting point for the accessibility calculation and the routing operation is set for a maximum travel time of 20 min walking. Then every point of interest is snapped to the closest edge and an interpolated travel time is derived from the link for each destination. Then for the visualization the accessibility values are braked using statistical quintiles for comparing the different grid cells. (Pajares et al., 2021a)

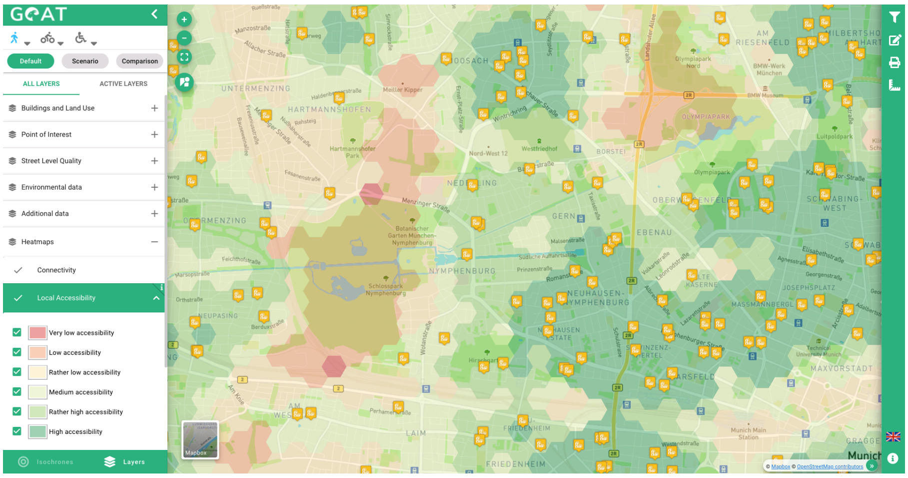


Figure 2-4 Heatmap Accessibility in GOAT

2.5. Spatial Fairness Assessment

Fairness, justice, equity, or equality are concepts that be easy confused. Their definitions cover a wide variety of areas from philosophical to economical. First, justice is broad moral and political idea related with the distribution of benefits or resources; second, and with a more procedural context, refers to the fairness of processes; third, the recognition and enforcement of rights or entitlements (Fraser, 1995; Kymlicka, 2002; Young, 1990). Then justice is related to morally created by the group of people that shares the same moral values. In the case of fairness, it is the subjective assessment events and whether the events were morally realized. (Goldman & Cropanzano, 2015) What is fair for one person, however, might not be fair for others (Duran-Rodas et al., 2020).

Equity and equality are distributive rules together with efficiency. (Leventhal, 1980; Talen & Anselin, 1998) Equity means treatment of people according to their differences (Rawls, 1999), naturally this concept always implies a moral judgement, while equality does not have to imply a normative posture when is used to indicate full equality or sameness (Pereira et al., 2017; Wee & Geurs, 2011). To close the definitions, the latest introduced concept efficiency is defined as the distribution of the resources are according to people's contributions (Leventhal, 1980) Thus, a spatial fairness assessment determines if the spatial allocation of resources follows a rule of spatial equity, equality, efficiency, or a mix of the three (Duran-Rodas et al., 2020)

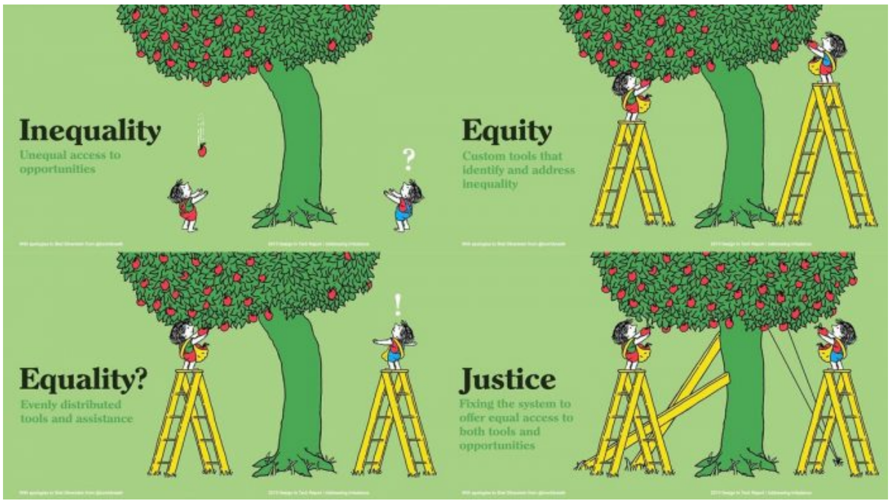


FIGURE 2-5 GRAPHIC SUMMARY OF JUSTICE RULES[3]

Equity involves the equal distribution of resources, regardless of the different needs or abilities of people (Leventhal, 1980; Talen & Anselin, 1998)._To measure the degree of inequality, the Gini index, together with Lorenz curve are the best metrics of equality. This indicator, is very popular measuring the distribution of income over the population of a country (Weymark, 1981). The Gini index is defined as the ratio of the area between the Lorenz curve and the equality line. It takes values of 0 for absolute equality and of 1 for absolute inequality. In addition, Lorenz curve are the graphical representation showing the cumulative proportion individuals in terms of the cumulative of the resource of analysis (Chatterjee et al., 2017)

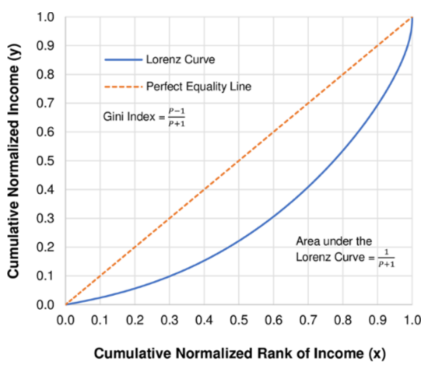


FIGURE 2-6 LORENZ CURVE[4]

[3] (Heeks, 2021)
[4] (Sitthiyot & Holasut, 2021)

Then, the main focus of accessibility studies by socio-economic groups is equity: evaluating opportunities between or within groups, and whether particular groups have higher costs to reach services. (Smith et al., 2020) In the transportation context, that means to give to the vulnerable people higher accessibility and a wider option of mobility. Then, by definition, equity or vertical equity refers to how resources are distributed according to the people's needs (Duran-Rodas et al., 2021). In other words, equal treatment for equals and unequal treatment of unequal's (Rescher, 1966) Transport connects services and opportunities with people, however, all services within an area do no need the same level of accessibility. Therefore, is necessary to define essential opportunities to allow the participation in society, such as employment, education, trade and social, when transport can serve this basic services, it links a lack of mobility to social disadvantage and exclusion. (Guzman et al., 2017; Lucas, 2012)

The definition of essential needs is very wide, and cover definitions, from universal drivers rooted in our most basic and primate beings to merely subjective cultural constructs (Ian Gough & Len Doyal, 1991). But in general, there are requirements to live a satisfactory life and participate in society (Cardoso et al., 2021). With social component for basic needs Maslow (1943) develops his famous research, where he established a pyramid in which satisfying basic needs is a prerequisite to attain higher levels of satisfaction. However, many authors (Cardoso et al., 2021; Max-Neef, 1991; Tay & Diener, 2011) have critics with this approach because the theory is purely academic and not realistic, and these theories should be social and able to be appropriated by policymakers and communities as work-in progress tools to improve lives (Max-Neef, 1991) In the urban context, is necessary to connect the basic needs with the basic services. In that case, Max-Neef (1991) with some modifications by Cardoso et al. (2021) provides a framework (see Figure 2-7) where cities can create their unique list of services according to local cultural needs.

Needs	Definition
1. Subsistence	Subsistence entails survival, including the availability, affordability and accessibility of prerequisites for bodily functions such as air, water, food and energy, living space providing shelter, and the ability to move from place to place for different purposes
2. Protection	Protection concerns the ability to deal with physical and mental health threats, and to live in a safe environment with few risks, with some level of preparedness
3. Affection	Affection means the ability to express and experience emotions of liking, loving or fondness, towards people or in relation to the environment
4. Understanding	Understanding is the ability to gain the knowledge, information, capacities and skills required to take actions, make decisions and communicate with others
5. Participation	Participation refers to the creation of communities that allow their members to live with dignity and in harmony with each other, and collaborating with others for communal goals
6. Leisure	Leisure is about feeling excited, surprised, relaxed, having pleasurable experiences and taking relief from mental pressures through relaxation and joyful activities
7. Creation	Creation concerns applying creative abilities and producing material requirements of life, earning income and contributing to feeling needed and significant
8. Identity	Identity is about deserving recognition for one's beliefs, values and preferences and the ability to act according to feelings of belonging to a place or a community
9. Freedom	Freedom addresses the ability to make decisions and take actions, to have control over life and property and to live in societal conditions which enable personal rights

FIGURE 2-7 DEFINITION OF UNIVERSAL NEEDS

To include the classification of essential services to equity calculation, Duran-Rodas et al. (2020) define the equity index rate of low status population with the average accessibility to essential services. Where the average accessibility is calculated by a gravitational-based accessibility measure of the selection of service defined with needs on Figure 2-7, and the low social status population can be determined with most common methodologies to asses spatial equity such as descriptive statistics and statistical tests, correlation, regression, and maps an plots. (Duran-Rodas et al., 2020)

EQUATION 2-1 DEPRIVATION INDEX

$$Deprivation\ index_{(area)} = \frac{\%\ low\ social\ status\ population}{average\ accessibility\ to\ essential\ services}$$

3. Methodology

This master thesis developed a spatial fairness assessment of essential services in Milan. For this purpose, the analysis used the Inclusive Accessibility by Proximity Index (IAPI). The index measures accessibility to opportunities for different users based on individual needs, abilities, land use, and transport conditions. To further deep into the person-based perspective, the following research question was proposed: *Which social groups have better accessibility by active modes to the essential services in Milan?*

To provide an answer, this work developed the IAPI in the study area of Milan using GOAT and developed a spatial fairness assessment of the services considered within the EX-TRA project. Based on this analysis, this thesis provides recommendations to the IAPI and delivers a methodology on how to improve the study of the individual's component in an accessibility analysis.

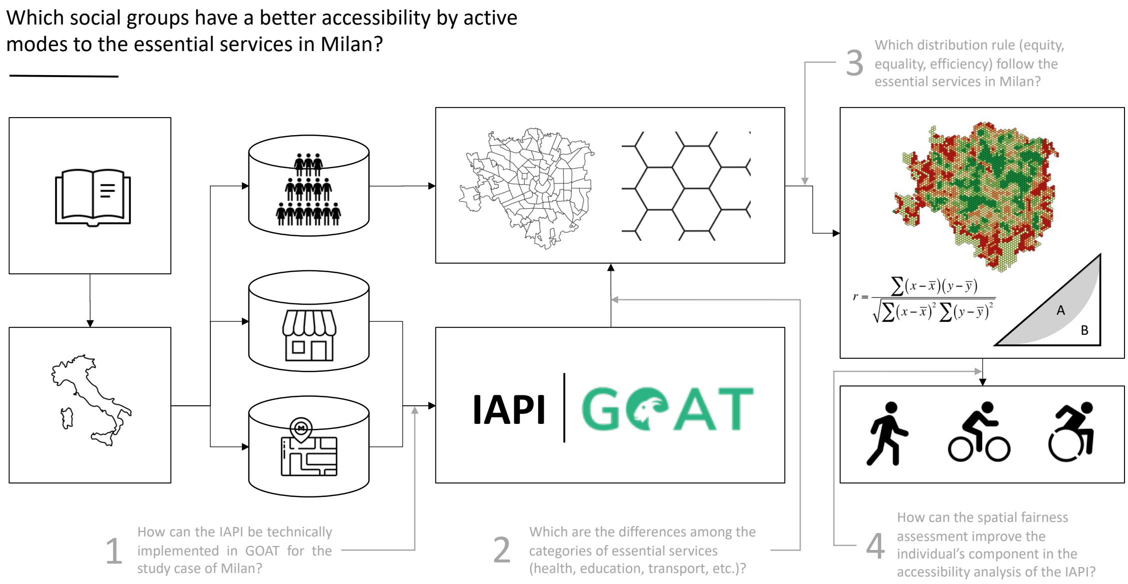


FIGURE 3-1. METHODOLOGY AND RESEARCH QUESTIONS

After the background information and following an academic procedure to answer the research question, Figure 3-1 shows the components of the research and the dependencies and connections between them. At this point, the background information has already set the theoretical and scientific bases to develop the study. Then come five parts: analysis of the study area, data collection, implementation of IAPI in GOAT, spatial fairness assessment, and conclusions.

The study's area analysis begins with a review of the principles that had guided the city's urban planning, land use, and transportation development. As a result, it is easier to understand and develop the analysis and assessment of later steps within a local context. This analysis is fundamental to transferring GOAT's functionalities, improving the data's quality, implementing the IAPI, and understanding the research results.

Subsequently, there are three main categories for the data collection: socio-demographic data, points of interest, and network data. For the socio-demographic data, it was necessary to search official databases (Comune di Milano, n.d.-b). The information available for population includes data such as age, gender, nationality, and family type divided by Nuclei di Identità Locale (NIL) for the last eleven years. Since this research does not consider a time component within its scope the information of reference is for 2020. In the case of points of interest and network data, the primary source is OpenStreetMap (OSM). These data reflected the place-based perspective of accessibility: types of roads, sidewalks measurements, public open spaces, commercial places, health and education locations, and public transport stops. In some cases, local data from the official sources (Comune di Milano, n.d.-a) had better coverage across the city, consequently preferred for the analysis.

Points of interest and the network data were the input to implement the IAPI within GOAT. For the points of interest, they were grouped into six categories: commercial activities and services to the public, gathering and cultural spaces, sports, health care and social care, education spaces, and public transport. In the case of the network data, it was classified according to the influence of speed depending on the surface and smoothness of the road. In addition, and as the comfort-based analysis's main component, they were classified into roads, peak hour traffic, cycle paths, sidewalks, and obstacles.

The comfort-based analysis is the main characteristic of the IAPI. Therefore, to include the comfort perception within the accessibility calculation, the impedance function $f(t_{ij})$ from the accessibility equation was changed to include comfort-based impedance factors from the characteristics of the network. However, this methodology did not include the positive effect of urban elements of the public space (benches, trees, streetlights). In consequence, the methodology of Labdaoui et al. (2021) was used to estimate "negative impedance factors". His methodology considers thermal comfort in assessing walkability by developing the Street Walkability and Thermal Comfort Index (SWTCI).

EQUATION 3-1 CHANGE TO ACCESSIBILITY BASED ON PERCEIVED TIME

$$A_i = \sum O_j * f(t_{ij}) \quad \Rightarrow \quad A_i = \sum O_j * f(t^*_{ij})$$

with: $A_i = Accessibility\ at\ origin\ i$
$O_j = \ Opportunity\ value\ at\ destination\ j$
$f\left(t_{ij}\right) = impedance\ function\ from\ i\ to\ j$
$f\left(t_{ij}^{*}\right) = impedance\ function\ with\ perceived\ time$

With the impedance factors estimated for all the city roads, it is possible to calculate the accessibility to the POIs. To visualize the accessibility calculation, the temporal-based isochrones helped to evaluate and validate the results at a street and neighborhood level. At the same time, the grid-based heatmaps allowed for the city-scale analysis. In addition, the heatmaps were the indicator to combine with sociodemographic information and develop the spatial fairness assessment.

The last segment of the research, the spatial fairness assessment, has four parts: first, the accessibility calculation for the different POIs comparing the visualization of two normalization methods; second, the horizontal equity analysis, in which the Gini indicator was used to measure and compare accessibility across the city; third, the vertical equity analysis, where a correlation and simple regression analysis helped understand the distribution of accessibility among the social groups. From the equity analysis, it is possible to classify the distribution of the POIs according to the theories of distributive justice; finally, the deprivation index took the essential services and, with the social groups classified as vulnerable groups, allowed to identify neighborhoods with poor accessibility to the essential services.

The research project has four outcomes. First, to develop the IAPI index in GOAT for the study area of Milan. This outcome includes collecting and implementing the geographical and sociodemographic data to assess the calculation of the index, as well as the estimation of the impedance factors to include a comfort-based perspective. Second, to estimate the accessibility to the POIs and evaluate the differences in accessibility. As a result, it is possible to do a deeper analysis of how the population has access to the essential services. Third, to develop a spatial fairness assessment of the essential services defined by the partners of the EX-TRA project for the study area. This outcome allows identifying the distributive justice rule that the essential services follow. Finally, accessibility tools tend to fall short on the individual component; then, this research proposes a set of recommendations to improve the individual's component of the IAPI.

4. Study Area

The study area of the research is Milan. This city was selected to develop the implementation of the IAPI in GOAT due to its participation in the EX-TRA Project. The city is the capital of the region of Lombardia in the North-West part of Italy and is the center of the “Città Metropolitana di Milano”, where it groups 133 communities with an extension of 1574 km^2. Within this area, 3.2 million inhabitants develop their daily activities, making it the third-largest metropolitan region in Europe after London and Paris (Città Metropolitana di Milano, 2022). The following chapters will present specific socio-demographic characteristics; the principles that guide the city's planning process; and the land use and transportation distribution. This information sets the context for further accessibility and fairness analysis.

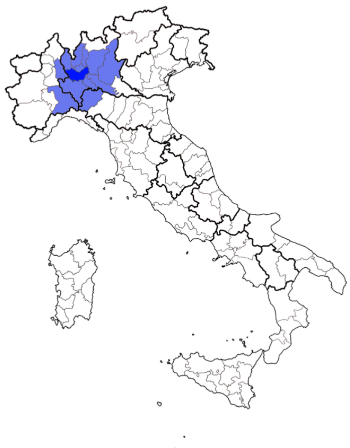


FIGURE 4-1 LOCATION OF MILAN IN ITALY[5]

4.1. Milan 2030

For this decade, Milan has a vision of development that goes beyond its borders. The integration with the metropolitan area plays a crucial role in the city's development, with significant projects along the axis of the northwest and northeast. Public transport and the connection between the airport and the railway station project the new urban development in the transport area. Moreover, the ecological green belt, which finds significant points in the stopovers, becomes the urban threshold of the Metropolitan Park, a merger of the North Park and the South Agricultural Park. (Comune di Milano, 2019)

[5] Source: https://it.wikipedia.org/wiki/Area_metropolitana_di_Milano

Water is a critical player in the city's development. There is a high priority in urban regeneration by turning railway yards into public spaces. Also, the design of a wide pedestrian network enhances the squares, streets, neighborhoods, and local identities the city is made of, which are the backbone of urban life. (Comune di Milano, 2019)

Milan is an international city; this means it has a deep connection, both material and immaterial, that creates a strong interdependency and complements the urban and territorial structure. (Comune di Milano, 2019) For that reason, with the responsibility of being a regional node, Milan proposes a highly functional level of accessibility and a concentrated urban structure for its future development. Never forgetting to offer high quality reach public transport for its inhabitants, and reducing the use of private mobility. (Comune di Milano, 2019)

For housing and land use, the plan of Milan 2030 does not expect to generate new urban areas, according to the PGT 2012. It expects to protect 1,7 million m^2 by downsizing the settlement forecasts and limiting 3 million m^2 to agricultural use, thus reducing land consumption by 4%. (Comune di Milano, 2019) In addition, they want to encourage the quality of mixed-use and preserve the variety of public and private services. Other strategies seek to penalize abandoned buildings to incentivize the recovery of the properties and to develop the potential of the neighborhoods. (Comune di Milano, 2019)

4.2. Urban planning

The heart of the metropolitan area is represented by the City of Milan, which is administratively divided into nine districts; each one has a local council, elected at the same time as the mayor and the city council. This structure is established in the "Piano di Governo del Territorio (PGT)" (Territory Government Plan). (Comune di Milano, 2019) Here, The city (2019) has developed "*Il PUMS – Piano Urbano per la Mobilità Sostenibile*" (The PUMS – The urban plan for sustainable mobility). It is an instrument of strategic planning for a middle-long term that expects to satisfy the existing and future mobility demand in the urban and metropolitan areas. The plan contains:

- The territorial and socio-economic structure of the reference context.
- The state of the supply of infrastructures, services, and policies for private and public mobility.
- The overall picture of the demand for mobility of people and goods which are(?) is expressed in the area.

- The interactions between transport supply and demand, with their criticalities.
- The environmental impacts generated by the transport system affect air quality, energy consumption, and noise.
- The reference scenario of the interventions envisaged and planned independently of the SUMP itself.

For this research, the following subchapters develop a summary of the socio-economic structure; supply of infrastructure and services; and demand for people's mobility.

4.3. Transportation

4.3.1. Transportation offer

In the territory of Milan, there are more than 1,100 km of roads. Milan's authority manages more than 770 km (about 70% of the total). Depending on the purpose, there are different classification criteria for the road network: administrative, technical-functional, and hierarchical. In the case of public transport, Milan and some close-by municipalities are served by underground and tram lines. There are four underground lines and a fifth under construction for a total of almost 95 km and 113 stops. The tramways account for 18 lines with a total extension of about 120 km. (Centro Studi PIM, 2019)

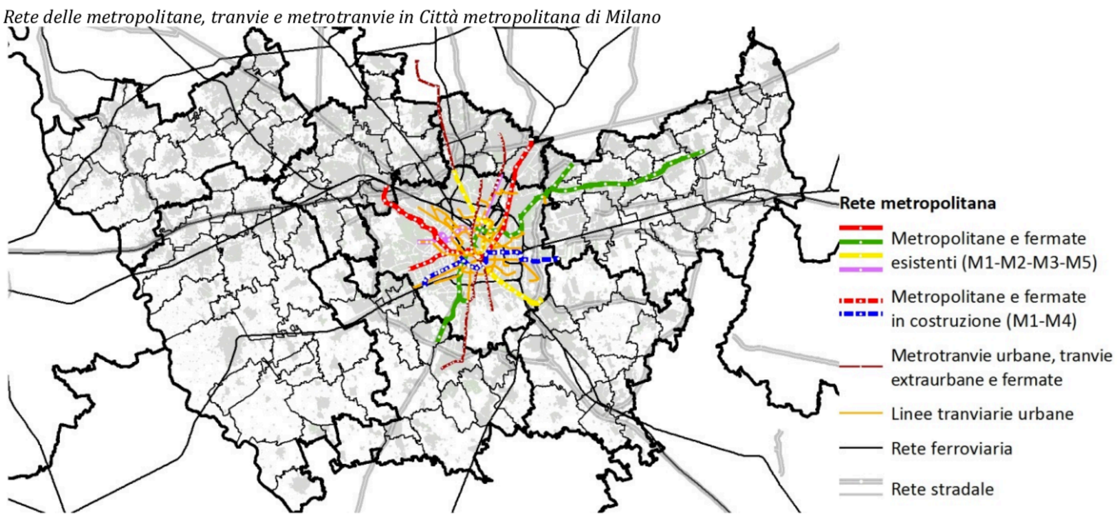


FIGURE 4-2 NETWORK OF SUBWAYS, TRAMWAYS, AND LIGHT RAILWAYS IN THE METROPOLITAN CITY OF MILAN[6]

[6] Source:(Comune di Milano, 2019)

In the case of bicycle infrastructure, the information is generally poor and inconsistent. Within the PUMS (2019), the information is fragmented and heterogeneous. It even states that a more precise examination of the situation may derive following the preparation of the so-called Biciplan - Urban Plan of Cycling Mobility (SUMP sector plan), which, among other things, will have to define the networks of cycle routes.

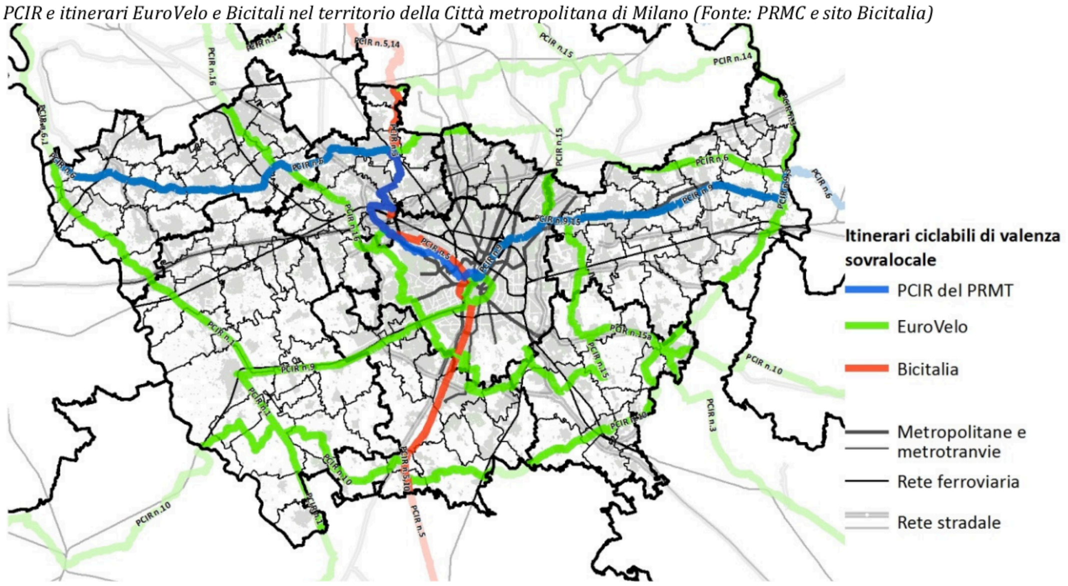
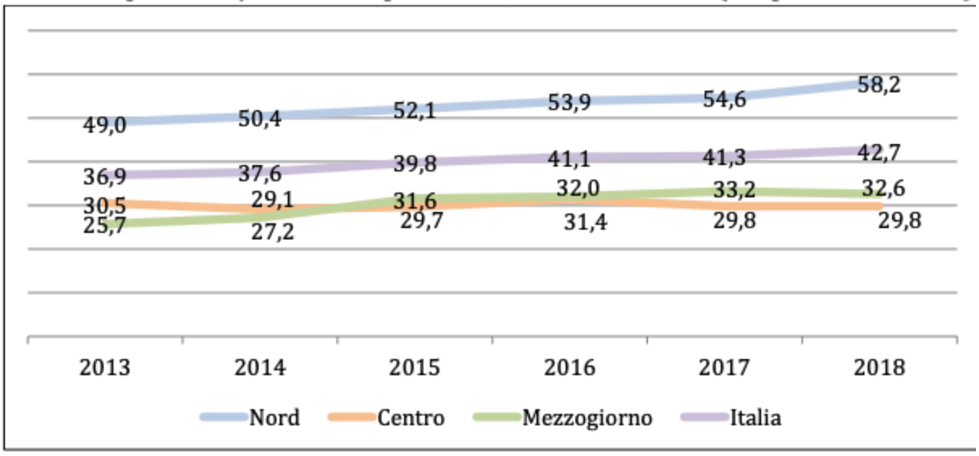


FIGURE 4-3 PCIR AND EUROVELO AND BICITALIA ROUTES IN THE TERRITORY OF THE METROPOLITAN CITY OF MILAN[7]

In the case of pedestrian infrastructure, there was no available information in the PUMS. However, the monitoring of the Environmental Observatory on the cities of ISTAT has some information available on the pedestrian infrastructure. This data is not particular for the city of Milan, but shows a time change in the infrastructure of the region, which is a good estimator for the city. Moreover, it is possible to compare it with other parts of the country. Figure 4-4 confirms that some progress is being achieved in the provincial capital municipalities. Compared to pedestrian areas in 2018, the average value of all the capitals was 42.7 square meters per 100 inhabitants, which shows an increase of 15.7% in the last five years. Finally, there is an evident gap between the cities of the North (58.2) and that of the cities of the South (29.8)

[7] Source:(Comune di Milano, 2019)

Graf. 67 – Disponibilità di aree pedonali[(a)] nei Comuni capoluogo di provincia/città metropolitana[(b)], Anni 2013-2018 (m2 per 100 abitanti)



(a) Superfici nette (escluse le aree di sedime degli edifici eventualmente compresi nel perimetro delle aree pedonali)
(b) Valore riferito all'insieme dei Comuni capoluogo per i quali i dati sono disponibili nell'anno di riferimento
Fonte: Elaborazioni Isfort su dati Istat

FIGURE 4-4 AVAILABILITY OF PEDESTRIAN AREAS IN THE PROVINCIAL CAPITAL / METROPOLITAN CITY MUNICIPALITIES, YEARS 2013-2018 (M2 PER 100 INHABITANTS)[8]

In recent years, the culture of shared mobility has become increasingly popular which sees the presence of the following services: car sharing, managed by six operators, with almost 3,400 vehicles made available (about 23% electric) and over 1 million users; scooter sharing, offered by five operators, which make available almost 2,000 vehicles with about 140,000 users, often also enrolled in a car and bike-sharing services; bike-sharing, with traditional or pedal-assisted bikes, active in Milan, where it is more widely spread and managed by two different operators and shared electric micro-mobility, initially introduced in the Municipality of Milan, but subsequently withdrawn due to some critical issues, including the absence of specific legislation that regulates its safe circulation. (Centro Studi PIM, 2019)

4.3.2. Transportation demand

The Metropolitan City of Milan is a high motorized area. In 2017, the area had 2.3 million vehicles circulating the roads, and this number has been continuously increasing since 2013. Nevertheless, within the urban area, 956.121 cars had circulated in the streets, and as shown in Figure 4-5, that has seen a significant reduction in the motorization rate. (Centro Studi PIM, 2019) The main hypothesis for this behavior is the available public transport and other modes to solve the mobility needs.

[8] Source: (ISFORT, 2020)

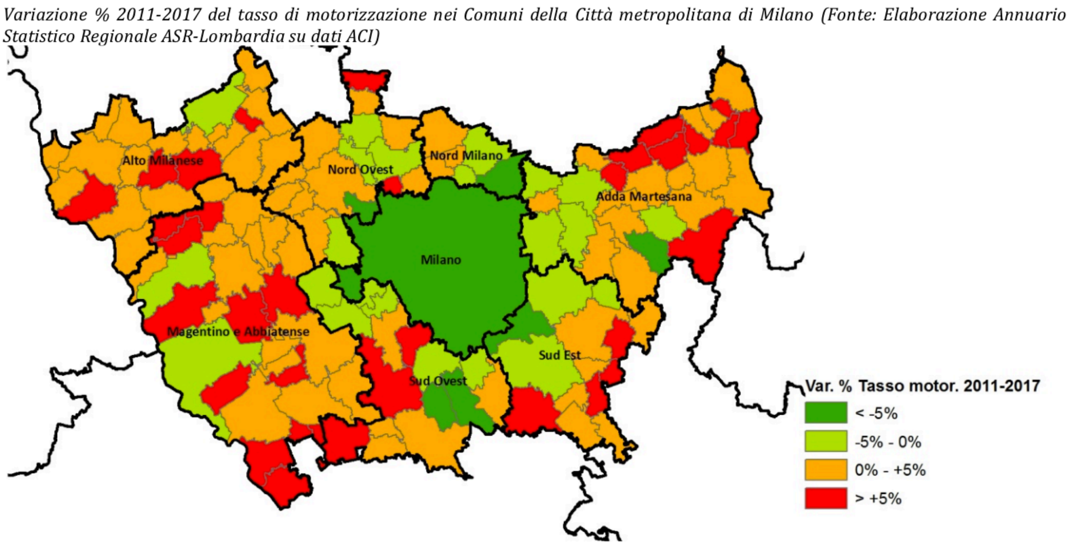


FIGURE 4-5 % VARIATION 2011-2017 OF THE MOTORIZATION RATE IN THE MUNICIPALITIES OF THE METROPOLITAN CITY OF MILAN[9]

This behavior is seen in detail in Figure 4-6: the graph on the left shows the modal partition of the internal trips in the Comune di Milano, while the graph on the right shows the partition of trips between the city and the region. In the city, automobile trips take 24% of the trips, while public transports take 41% of the pie. The active modes take 28% of trips, having a more significant share than trips by automobile, and they are distributed 10% by bicycle and 18% by pedestrian trips.

The picture is entirely different for the trips between the Commune and the region, where the majority of the trips are done by car with 55%, followed by 36% of the trips by public transport and closing with a shy 3% for the active modes. It is interesting to notice that motorcycle is 5% of the trips in both situations.

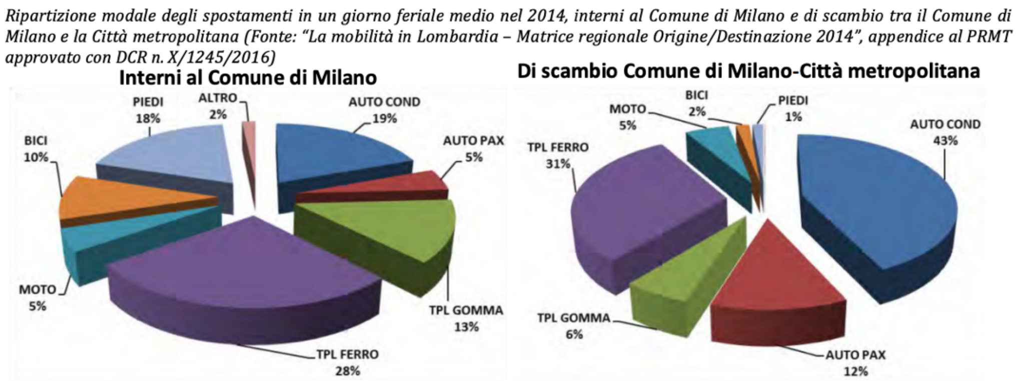


FIGURE 4-6. MODAL PARTITION IN MILAN IN 2014[10]

[9] (Comune di Milano, 2019)
[10] Source: (Comune di Milano, 2019)

4.4. Population and working places

Milan's resident population is now 3,2 million inhabitants, which has grown steadily in the last ten years. It has multiple differences especially in the central districts, where people develop their daily activities and work or study. In Figure A-2, high-density areas are highly towards the city's center. However, the partition of the NIL areas shows parks from the city center as low-density areas.

In the working sector, with almost 1.5 million employees and over 300,000 working places in the private sector alone, 41% of the working places are in the City of Milan and 38% of the Metropolitan area. Due to the high concentration of work, the city has the most significant increases; moreover, since 2014, it has affected the private economic system of the metropolitan city (with a particularly significant growth between 2015 and 2016).

The distribution of the territory of the working places by type shows that the manufacturing sector, which represents 7.2%, has its greatest concentration in the municipalities next to Milan. This characteristic is also seen in the band that goes from the southeast to the west, where traditional services are more concentrated (wholesale trade and logistics). On the contrary, mainly business services, the services sector is located within the city’s first and second municipalities belt.

4.5. Land Use Distribution

The data for the land-use distribution was obtained from OSM. The information available had 35 different categories. However, some categories belonged to very few areas and were not relevant for the land-use map. In consequence, Figure 4-7 shows the ten land-use categories with the most areas, and all the remaining categories were grouped under the category “other”.

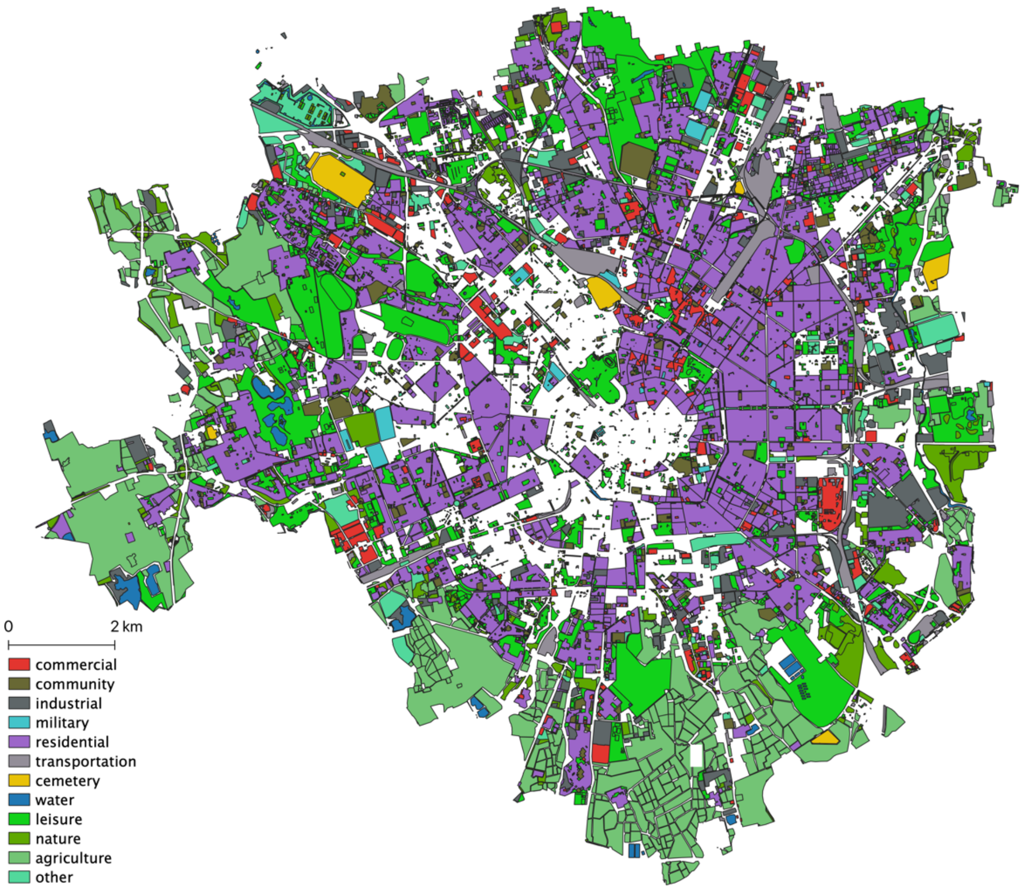


FIGURE 4-7 LAND-USE DISTRIBUTION[11]

The most common use in Milan is "nature," with 46% of the zones, followed by residential with 15% and agriculture with 7%. Nevertheless, a big area in the city has not been mapped in OSM, so the percentage is subject to change. Regarding the distribution, most of the agricultural and nature areas are on the city's outskirts. In the case of the residential areas, they count for most of the inner city. Furthermore, commercial areas seem to be clustered in different areas in the city, and the infrastructure area is widely arranged in the city, particularly for the train infrastructure.

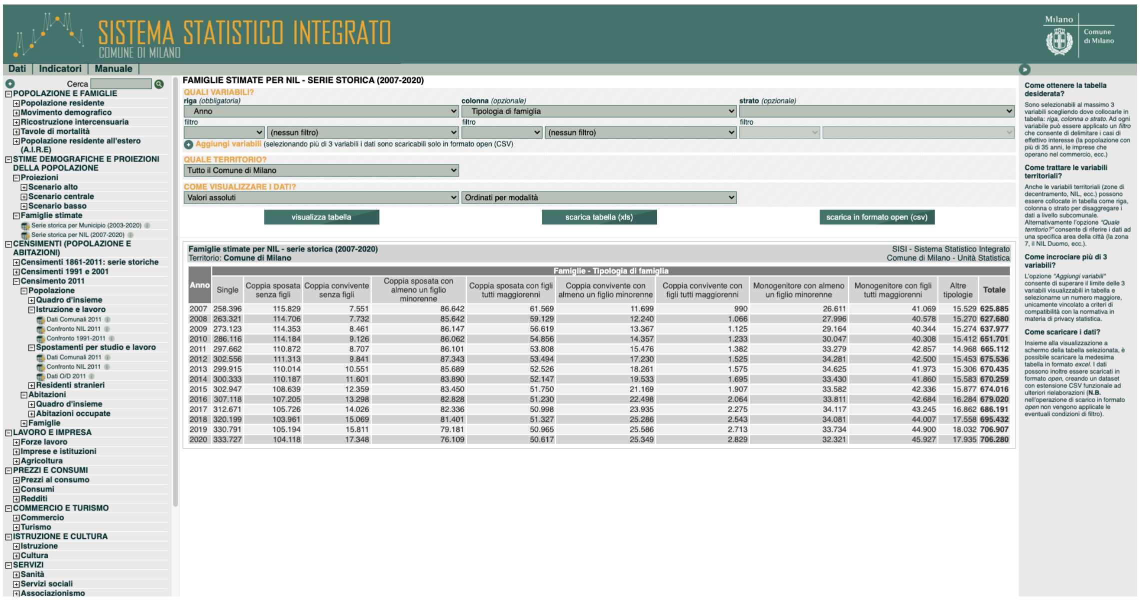
[11] Source: OpenStreetMap

5. Data Collection

For the implementation of the IAPI in GOAT, accessibility calculation, and spatial fairness assessment it was necessary to collect, verify and process multiple datasets. The required data belong to three types, socio-demographic, POIs, and network data. This chapter presents the source of the information, the processing procedure to organize the information, and the final output that was used as an input in later stages of the research.

5.1. Socio-demographic data

The information regarding the individual characteristics of people was found on the "Sistema Statistico Integrato" (Integrated Statistical System). The platform (Comune di Milano, n.d.-b) allows to create multiple kind of dynamic tables depending on the information of interest. For this research, it was important to identify the vulnerable social groups, so the available characteristics selected were family type, age groups, and nationality.



[12]

FIGURE 5-1 PORTAL OF THE "SISTEMA STATISTICO INTEGRATO"

The portal had a drawback when exporting the information. First, the number of characteristics were limited to two per table because the year component was mandatory and a dynamic analysis over a period of time was not part the scope of this research, therefore only the information for 2020 was taken. Second, the table could

[12] (Comune di Milano, n.d.-b)

only be exported for one location at a time, and since the entire city of Milan was available, the information was required in a more atomized form. The smallest administrative division available was "Nuclei d'Identità Locale" NIL (Nuclei of local identity), and the tables had to be exported individually for the 89 NILs in the city. The data was later processed and organized in the R-file "csv_together.R".

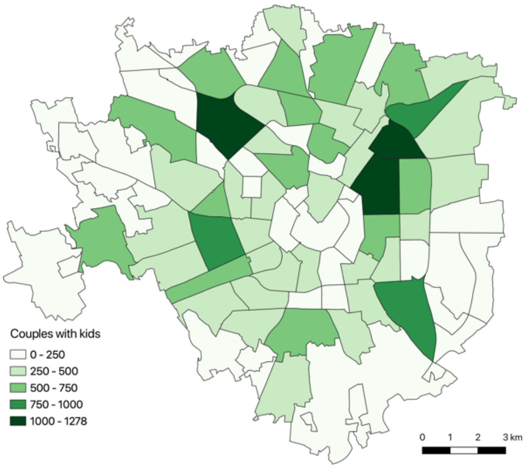
5.1.1. Family Type

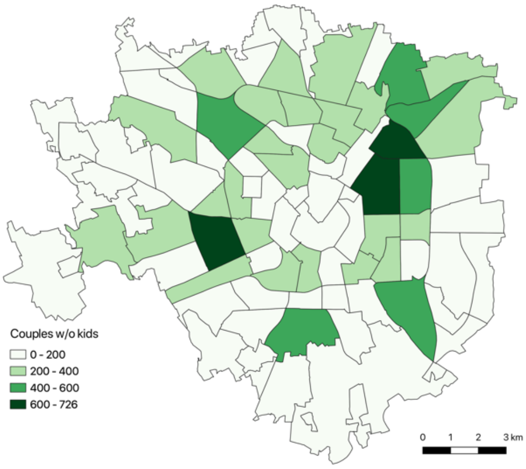
For the information regarding family type, households were classified into seven groups: couples with and without children, married couples with and without children, singles with and without children, and other family types. The purpose of keeping couples that have not gotten married is to assume that married couples have been together for a longer period, therefore, the location of their home may have been affected by the compromise. For the category *other*, no further information was available to identify the characteristics of this social group. Table 5-1, shows the total amount of families by each type. The majority are families of single persons, and the minority are couples without children.

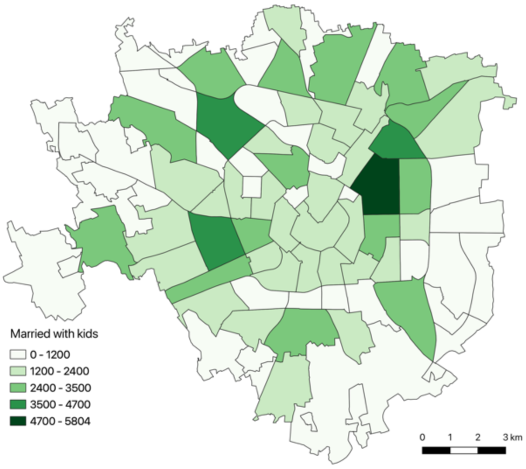
TABLE 5-1 NUMBER OF HOUSEHOLDS PER FAMILY TYPE

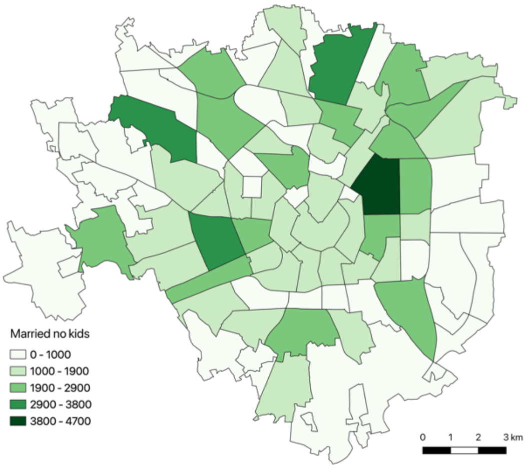
Family	With children	Without children
Couple	27.709	17.009
Married	124.347	102.128
Single	76.901	328.003
Other	17.687	

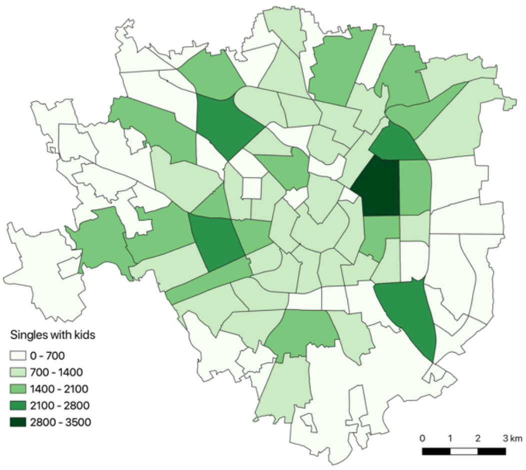
Regarding the location, all the groups have their highest presence on the northeast part of the city center, particularly in the NIL Buenos Aires-Venezia. And perimetral areas in the south tend to have low presence of families. For the type of families with children, the areas in the west part of the city have a higher presence compared to the areas in the east part. When comparing family types, it is important to highlight that couples do not live in the city center, and married couples seem to prefer northern areas of the city.

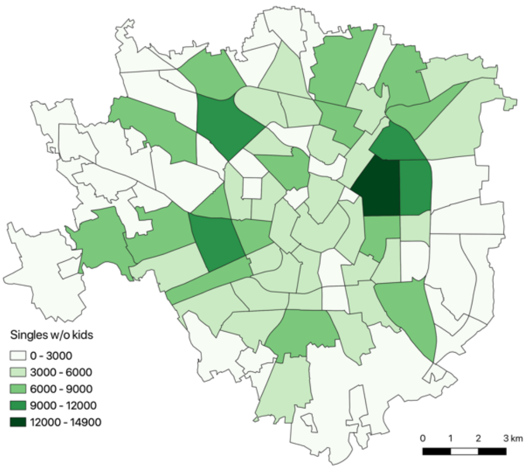

Couples with kids
0 - 250
250 - 500
500 - 750
750 - 1000
1000 - 1278
0 1 2 3 km

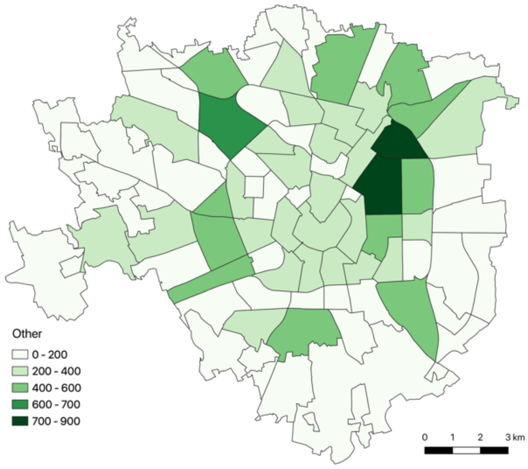

Couples w/o kids
0 - 200
200 - 400
400 - 600
600 - 726
0 1 2 3 km


Married with kids
0 - 1200
1200 - 2400
2400 - 3500
3500 - 4700
4700 - 5804
0 1 2 3 km


Married no kids
0 - 1000
1000 - 1900
1900 - 2900
2900 - 3800
3800 - 4700
0 1 2 3 km

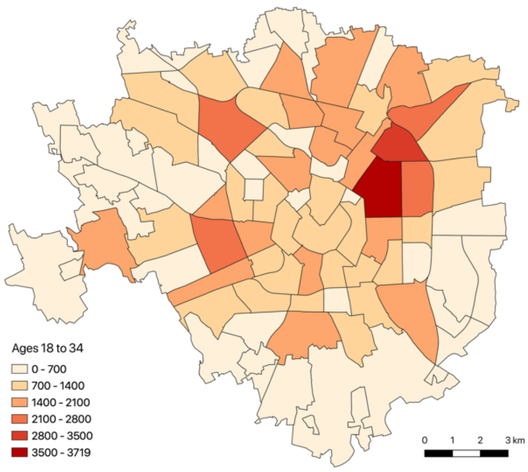

Singles with kids
0 - 700
700 - 1400
1400 - 2100
2100 - 2800
2800 - 3500
0 1 2 3 km

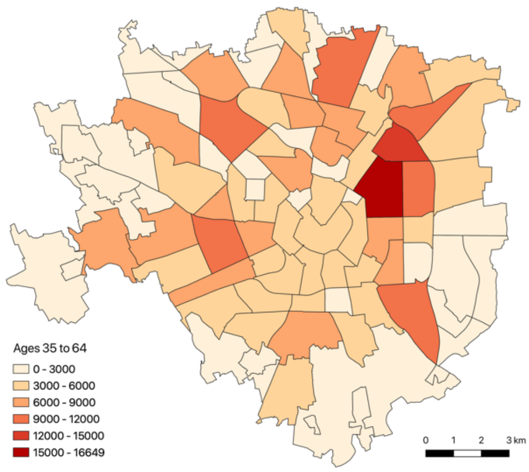

Singles w/o kids
0 - 3000
3000 - 6000
6000 - 9000
9000 - 12000
12000 - 14900
0 1 2 3 km

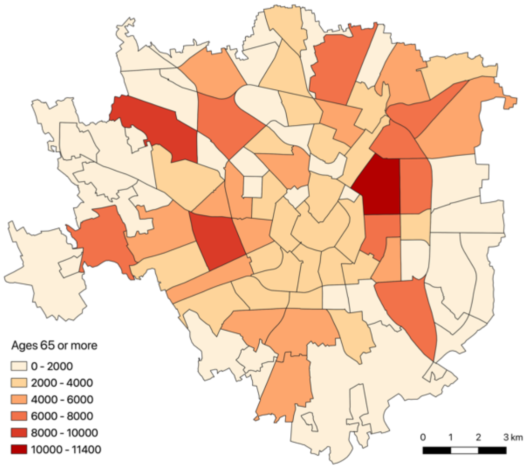


5.1.2. Age Groups

For the information regarding age, households were classified into three groups: from ages 18 to 34 years old, 35 to 64 and older than 65 years old, for this research they will be called young adults, adults and seniors. The original data has an extra classification for a group of older than 80 years, but for the purpose of this research it was merged into the group of 65 years and older. The group of young adults has a total of 73.321 households, the group of adults has 368.050, and the group of seniors has 246.413. Regarding the location, the distribution between groups of young adults has a very similar distribution compared to the group of adults. The main difference is a higher presence of the second group in the southwest of the city. In the case of the seniors, they have a higher presence on the west and south of the city. All the groups have their highest presence on the NIL Buenos Aires-Venezia in the northeast part of the city center.

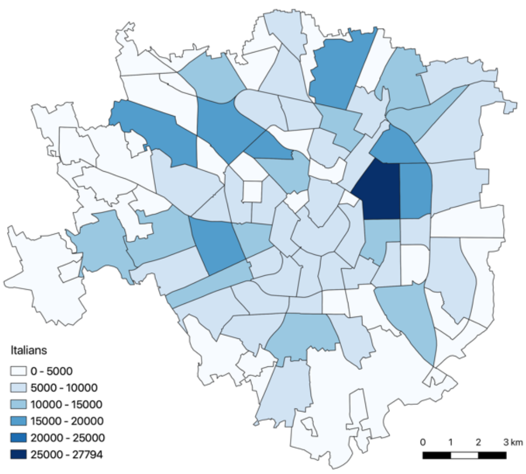


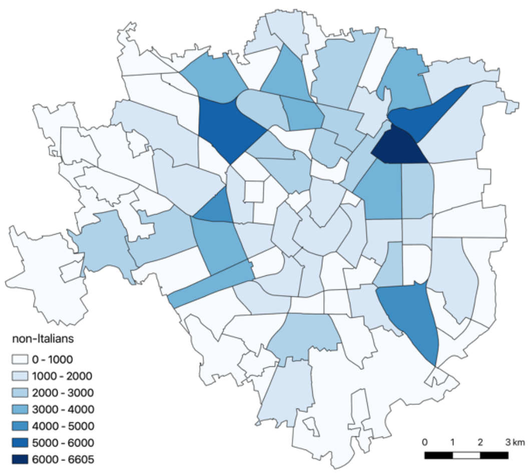




5.1.3. Nationality

For the nationality, the original information had available data for the categories of Italians, Peruvians, Ecuadorians, Chinese, Egyptian, Filipinos, Sri Lankans, and other nationalities. The information was organized to have only two groups, Italians, and non-Italians. In total, the number of households for Italians is 588.657 and for non-Italian 126.869. For the distribution in the territory, Italians follow the same behavior as many of the other categories analyzed. Most of them are located in the NIL Buenos Aires-Venezia and the northern part of the territory; They also have a higher presence in central zones. In contrast, the non-Italian have a lower presence in the central areas, and they are mainly located in NIL of Loreto.





5.2. Points of Interest

For the selection of the Points of Interest (POIs), this research took the list of services considered for the implementation of the IAPI in the early stages in Crescenzago. From the EX-TRA project Pucci et al., (2021) indicated that "the list of the daily services considered in this test has been selected based on similar experiences carried out at the local scale, and considering information derived from the interaction with the Local Authority". Consequently, Table 5-2 has the list of services considered for the first test of the IAPI.

TABLE 5-2 BASKET OF SERVICES FROM IAPI TEST IN CRESCENZAGO[13]

Items	Attributes
1. Public open spaces	1.1 Gardens
	1.2 Playgrounds
2. Commercial activities and services to the public	2.1 Grocery stores 2.2 Supermarkets
	2.3 Street markets
	2.4 Bar restaurants and cafes
	2.5 Newsstand
	2.6 Tobacco shops
	2.7 Banks with ATM
	2.8 Post offices
	2.9 Hairdressers
	2.10 Administration
3. Gathering and cultural spaces	3.1 Cultural and creative spaces
	3.2 Theatres and cinemas
4. Sport	4.1 Sport fields
	4.2 Gyms
5. Healthcare and social care	5.1 Pharmacy
	5.2 GP
	5.3 Healthcare clinics
	5.4 Social services
6. Education spaces	6.1 Libraries 6.2 Nurseries 6.3 Kindergartens 6.4 Primary schools 6.5 Middle schools

Indicator	Attribute	<OSM feature: or source
Public transport	Metro Station	<PT= platform; sto area>
	High frequency stop	Input from loca transit authoritie (GTFS…)
	Low frequency stop	
	Service frequency from stop (peak/ calm hours)	
	Number of lines serving the stop	
Sharing mobility	Bike sharing station	Input from loca transit authoritie (Open data)
	Car sharing station	

For this research, the POIs selected in the version of GOAT for Milan are classified in five categories: commercial activities, and services to the public, gathering and cultural spaces, sport, healthcare and social care, education spaces, and public transport. Each category has a table with attributes considered, the OSM-feature and in some cases the official source from the "Comuni di Milano". The official source can match one or multiple attributes. In the tables the final source of each POI is highlighted. The list is almost the same, but the changes made included: gardens were not considered as POIs, but as element for improving comfort, this will be explained in chapter 5.3.7**Error! Reference source not found.**; playgrounds were moved to the sports category; and a

[13] (Pucci, Carboni, et al., 2021)

few more attributes were added to the categories of gathering and cultural spaces, and healthcare and social care.

5.2.1. Commercial activities and services to the public

This category is divided into stores, foods and drinks, and services. The POIs grocery stores, supermarkets, and street markets are the “stores” subcategory. When looking for the grocery stores in OSM, the official tag “shop=grocery_store” had no points in Milano; the most similar tag is “convenience_stores”. In the case of the official source, it was compared with the “Attività commerciali: media e grande distribuzione” since the file contained multiple kinds of stores and businesses, it was necessary to filter the information. In the case of the grocery stores, most of the locations were tagged as “minimercati”. For supermarkets in OSM, different tags were grouped under this category of POI; the tags “supermarket”, “discount_supermarket”, “international_supermarket,” and “hypermarket” were collected to include multiple location types with a similar purpose. Like the grocery stores, the official source was the file “Attività commerciali: media e grande distribuzione” It was filtered by “supermercato”. However, both grocery stores and supermarkets had a higher coverage along the city and a greater variety in the type of stores in the OSM data. In the case of street markets, the official source “Attività commerciali: mercati settimanali scoperti” was not georeferenced and only had the schedule and address of the street markets; for that reason, street markets use the OSM data, and it corresponds to the tag “marketplace”.

TABLE 5-3 SOURCES FOR COMMERCIAL POINTS

POIs	**OSM feature**	**Official source**
Stores		
2.1. Grocery Stores	shop=convenience	https://dati.comune.milano.it/dataset/ds50-economia-media-grande-distribuzione
2.2 Supermarkets	shop=supermarket shop=discount_supermarket shop=international_supermarket shop=hypermarket	https://dati.comune.milano.it/dataset/ds50-economia-media-grande-distribuzione
2.3 Street markets	amenity=marketplace	https://dati.comune.milano.it/it/dataset/ds291-economia-mercati-settimanali-scoperti
Food and drinks		
2.4 Bars	amenity=bar	

2.5 Restaurants	amenity=restaurants	https://dati.comune.milano.it/dataset/ds58_economia_pubblici_esercizi_in_piano
2.6 Café	amenity=café	
2.7 Pub	amenity=pub	
	Services	
2.8 Newsstand	shop=newsagent	https://dati.comune.milano.it/it/dataset/ds57-economia-edicole
2.9 Kiosk	shop=tobacco shop=kiosk	https://dati.comune.milano.it/it/dataset/ds619_dove_pagare_la_tassa_auto_nel_comune_di_milano (Tabaccheria)
2.10 Bank	amenity=bank	https://dati.comune.milano.it/it/dataset/ds619_dove_pagare_la_tassa_auto_nel_comune_di_milano (Filiale Bancaria)
2.11 Atm	amenity=atm	
2.12 Post offices	amenity=post_office amenity=post_box	https://dati.comune.milano.it/it/dataset/ds555_uffici_postali_milano
2.13 Hairdressers	shop=hairdresser	https://dati.comune.milano.it/it/dataset/ds62_economia_parrucchieri_estetisti_centri_abbronzatura
2.14 Administration	government=* --amenity = public_building	https://dati.comune.milano.it/it/dataset/ds677_elenco_immobili_di_proprieta_del_comune_di_milano

In the second category, “foods and drinks”, we consider local differences in OSM data's naming/mapping habits. For example, in international use, a *bar* is a commercial establishment that sells alcoholic drinks to be consumed on the premises. Nevertheless, in the Italian context, a *bar* is a location where people go to in the morning to have breakfast; at lunch, they serve simple meals (if not closed after lunch) or people use them to get a quick coffee, and in the evening it is a meeting place to get an aperitif before dinner. (OpenStreetMap, 2022) In addition, all the other tags were similar to the information available on the file “Attività commerciali: pubblici esercizi in piano”. In consequence, based on the quality of the data and considering the local context, it is better to use the information from the official source.

In the subcategory of services, the data from the official source for newsstands and kiosks had better coverage around the city. Additionally, in the local context, a "Tabaccheria" (Tobacco shop) is a small store, and it could be confused with a store that sells just tobacco products. "Tabaccherias" also have convenience items, such as magazines, newspapers, and sweets. In the case of financial services, the OSM data was as complete as the official information; additionally, it has located ATMs outside of bank locations. Post offices are also well mapped with letterboxes throughout the city, although the letterboxes were not recorded in the official data. Regarding hairdressers, the official information is mixed with esthetic and tan salons. In contrast, the hairdresser tag from OSM covers most of the points from the official sources and is already filtered. In addition, the administrative buildings of the local government are well tagged in OSM, while all buildings and land of the public administration are included in the official data.

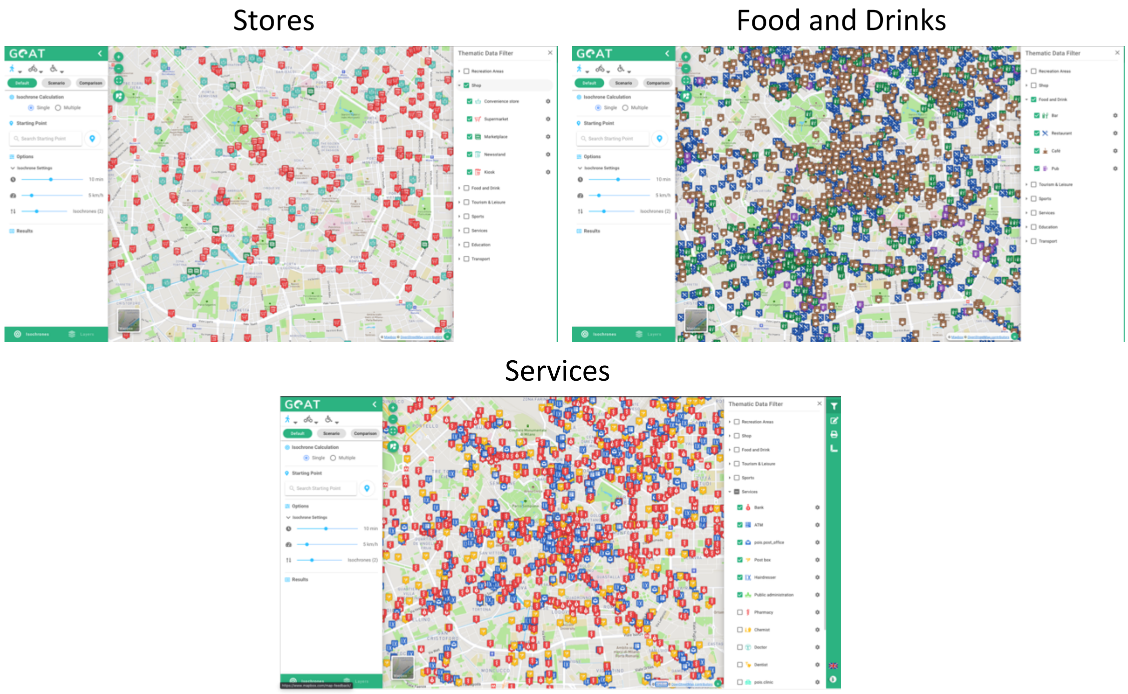


FIGURE 5-2. COMMERCIAL ACTIVITIES AND SERVICES TO THE PUBLIC

5.2.2. Gathering and cultural spaces

All cultural places are selected from the OSM data, which is very nearly in line with the data from the official information. The missing amenities are cultural facilities that do not necessarily allow public access and have an administrative purpose.

TABLE 5-4. SOURCES FOR GATHERING AND CULTURAL SPACES

POIs	OSM feature	Official source (Second Source)
3.1 Museum	tourism=museum	https://dati.comune.milano.it/dataset/ds76_infogeo_associazioni_localizzazione_
3.2 Gallery	tourism=gallery	
3.3 Arts center	amenity=arts_centre	
3.4 Cinema	amenity=cinema	
3.5 Theatre	amenity=theatre	

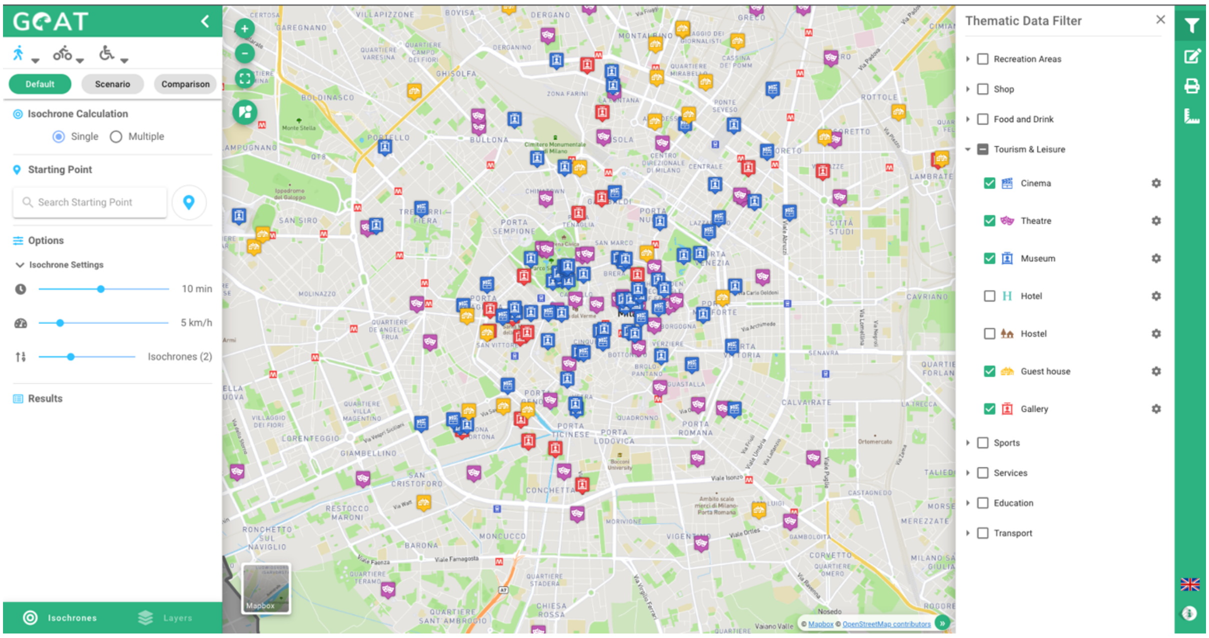


FIGURE 5-3. GATHERING AND CULTURAL SPACES

5.2.3. Sport

For sports locations, it is necessary to cover multiple kinds of sports scenarios, such as football fields and indoor activities as bouldering and gymnasium, where people play volleyball or basketball. The official information was taken from the file "Sport: localizzazione degli impianti sportivi", which in comparison with the OSM data, were both very similar. Since the OSM data was already filtered in the categories needed, in both categories, 4.1 and 4.2, the OSM data was selected. The file "Spazi verdi pubblici per attività ludiche" (Green public spaces for ludic activities) was compared with the OSM "playground" features. In the case of gardens and parks, the information from the city was more detailed, in the case of the playgrounds, the locations were almost the same, thus the information of the OSM was used.

TABLE 5-5. SOURCES FOR SPORTS FACILITIES

POIs	OSM feature	Official source

4.1 Sports facilities	sport=*!(leisure=fitness_centre)	https://dati.comune.milano.it/dataset/ds34_infogeo_impianti_sportivi_localizzazione_
4.2 Fitness Centers	leisure=fitness_centre --outdoor-fitness_station --discount_gym --gym --yoga	https://dati.comune.milano.it/dataset/ds32-infogeo-centribalneari-localizzazione

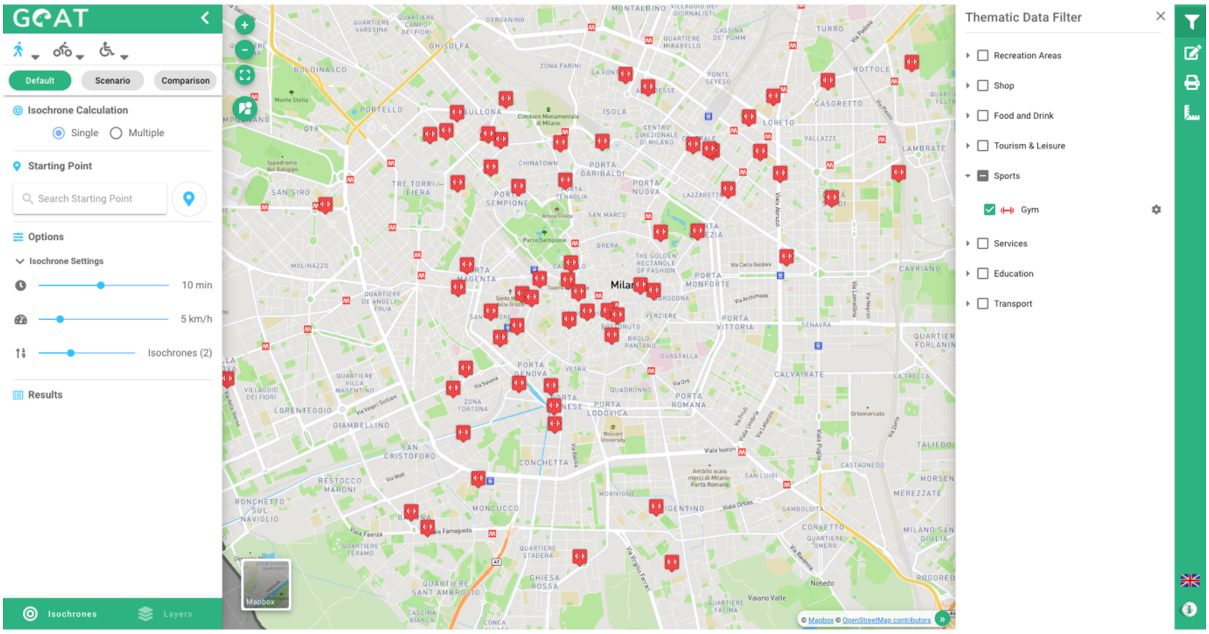


FIGURE 5-4. SPORT FACILITIES

5.2.4. Healthcare and social care

The OSM data has good coverage of the amenities related to health (pharmacies, drugstores, chemists) compared to the official information (the information available was listed with health professionals but was not georeferenced). For clinics and hospitals, the OSM data is complete and already filtered according to the needs. In contrast, in community centers and social facilities, the OSM data did not cover the city, nor the data from the city's source.

TABLE 5-6. SOURCES FOR HEALTH AND SOCIAL SERVICES

POIs	OSM feature	Official source

5.1 Pharmacy	amenity=pharmacy	https://dati.comune.milano.it/it/dataset/ds501_farmacie-nel-comune-di-milano
5.2 Chemist	shop=chemist	https://dati.comune.milano.it/dataset/ds50-economia-media-grande-distribuzione (drogheria)
5.3 Doctors	amenity=doctors amenity=dentist	
5.4 Clinic	amenity=clinic	https://dati.comune.milano.it/it/dataset/ds229-sociale-ambulatori-libera-scelta
5.5 Hospital	amenity=hospital	
5.6 Community Center	amenity=community_centre	https://dati.comune.milano.it/dataset/ds313-sociale-servizi-sociali-2014
5.7 Social Facility	amenity=social_facility	

Some forms of community centres might overlap with social facilities. When the centre is open to general audiences (sometimes of a specific age group or with specific interests) who gather for activities, it should be tagged amenity=community_centre. When it addresses an audience with specific problems, and/or is staffed with professional helpers (social workers, nurses), amenity=social_facility would be preferred.

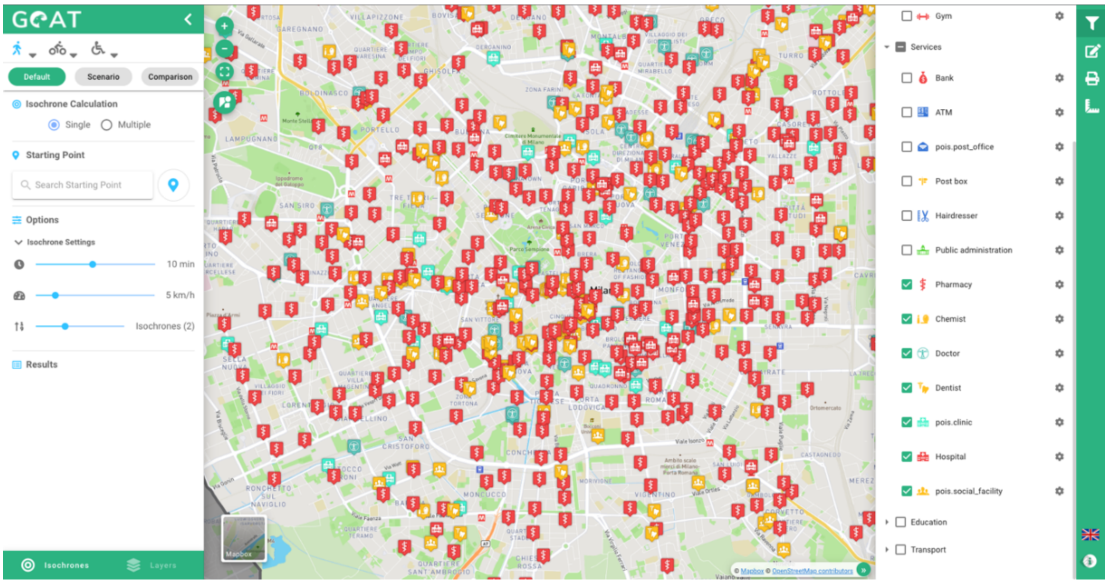


FIGURE 5-5. HEALTH AND SOCIAL SERVICES

5.2.5. Education spaces

In general, the educational amenities are incomplete in OSM data; only libraries and universities were similar to the official information. For primary and secondary schools, the lack of mapped amenities may be due to the difficulty in the tagging system. For that reason, all educational POIs are taken from the official source.

TABLE 5-7. SOURCE FOR EDUCATION SPACES

Attributes	OSM feature	Official source
6.1 Libraries	amenity=library	https://dati.comune.milano.it/dataset/ds41_infogeo_biblioteche_localizzazione_2007
6.2 Nurseries	amenity=childcare	https://dati.comune.milano.it/dataset/ds47-istruzione-asili-nido-localizzazione-delle-strutture/resource/a91230b8-0307-447d-bec3-9e8af2f3e426
6.3 Kindergartens	amenity=kindergarten	https://dati.comune.milano.it/dataset/ds671-infogeo-scuole-infanzia-localizzazione
6.4 Primary schools	amenity=school and isced:level=1	https://dati.comune.milano.it/dataset/ds40-infogeo-scuole-primarie-localizzazione
6.5 Secondary schools	amenity=school and isced:level=2,3	https://dati.comune.milano.it/dataset/ds46-infogeo-scuole-secondarie-i-grado-localizzazione/resource/e037a4b3-1f99-4fce-b511-df3d33e5766f
6.6 Universities	amenity=university	https://dati.comune.milano.it/it/dataset/ds94-infogeo-atenei-sedi-localizzazione

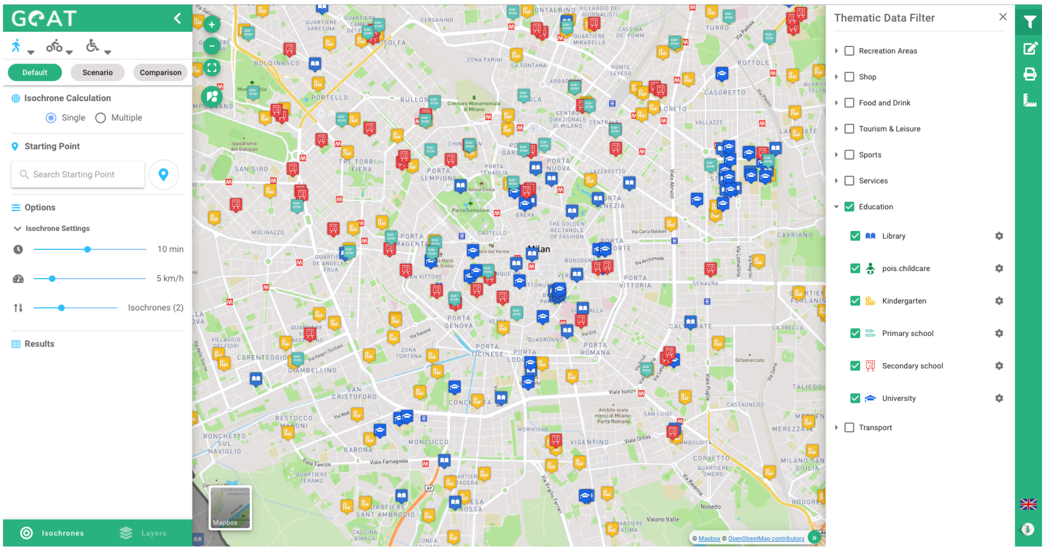


FIGURE 5-6. EDUCATION SPACES

5.2.6. Public Transport

For public transport analysis, the focus is on the location of the stops rather than the lines. In the official data, stops are assigned to a route, and it was not clear how to differentiate them by type of transport, while in the OSM data it was already divided by type of transport. For shared mobility, the information mapped in OSM is incomplete, and the official sources show coverage across the city.

TABLE 5-8. SOURCE FOR PUBLIC TRANSPORT

Attributes	OSM feature	Official source
Tram Stop	railway=tram_stop	https://dati.comune.milano.it/dataset/ds534-atm-fermate-linee-di-superficie-urbane https://dati.comune.milano.it/dataset/ds532-atm-composizione-percorsi-linee-di-superficie-urbane https://dati.comune.milano.it/dataset/ds535_atm-fermate-linee-metropolitane
Bus Stop	highway=bus_stop	
Metro Station	station=subway	
Bike sharing station	amenity=bicycle_rental	https://dati.comune.milano.it/dataset/ds65_infogeo_aree_sosta_bike_sharing_localizzazione_
Car sharing station	amenity=car_sharing	https://dati.comune.milano.it/dataset/ds79_infogeo_aree_sosta_car_sharing_localizzazione_

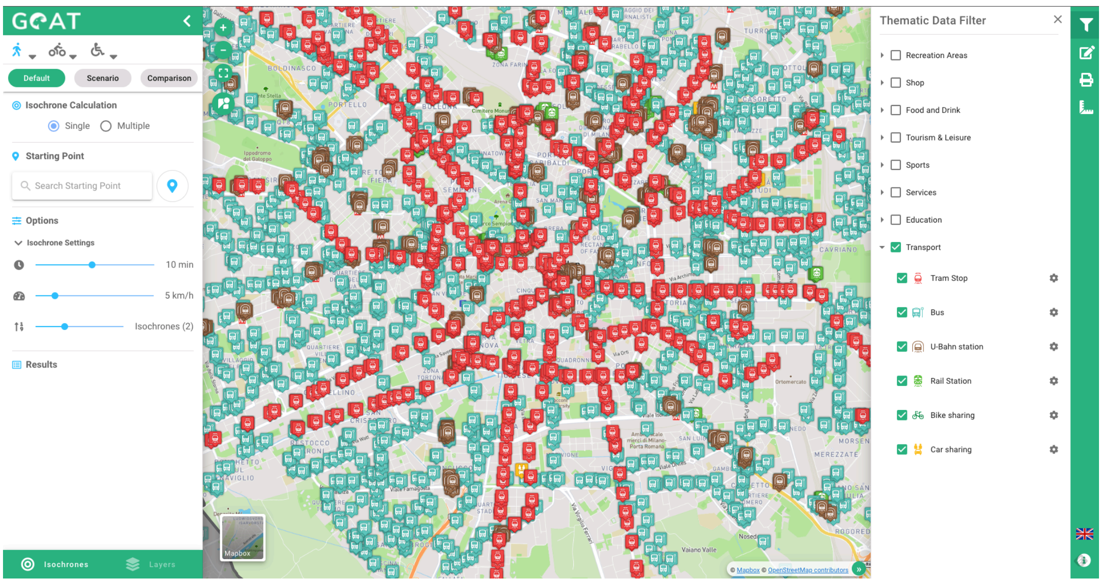


FIGURE 5-7. PUBLIC TRANSPORT LOCATIONS

5.3. Network Data

5.3.1. Roads

Most of the roads in the OSM have a key called highway. This key is a primary classification that determines the hierarchy of the roads within the network. Although the key represents function and importance rather than physical characteristics, both are usually highly correlated. Roads were grouped into four categories: roads, where motorized vehicles have a higher distribution of the space; special roads, where the transit of motorized vehicles may be allowed, but the priority is the transit of cyclists and pedestrians; paths, which have a higher prioritization in pedestrian traffic; and connection, which refers to tunnels and bridges.

TABLE 5-9 EXAMPLES IN MILAN OF ROADS CLASSIFICATION

Motorway

Image by https://www.mapillary.com/app/user/marcuscalabresus

Trunk

Image by https://www.mapillary.com/app/user/lvl5

Primary

Image by https://www.mapillary.com/app/user/ICT4Society

Secondary

Image by https://www.mapillary.com/app/user/namuit

Tertiary

Image by https://www.mapillary.com/app/user/adirricor

Residential

Image by https://www.mapillary.com/app/user/adirricor

TABLE 5-10 EXAMPLES IN MILAN OF SPECIAL ROADS CLASSIFICATION

Living streets

Service

Image by https://www.mapillary.com/app/user/ICT4Society

Image by https://www.mapillary.com/app/user/adirricor

Pedestrain

Image by https://www.mapillary.com/app/user/mikal

Track

Image by https://www.mapillary.com/app/user/ICT4Society

Footway

Image by https://www.mapillary.com/app/user/marcuscalabresus

TABLE 5-11 EXAMPLES IN MILAN OF CONNECTIONS CLASSIFICATION

Tunnel

Bridge


Image by https://www.mapillary.com/app/user/adirricor


Image by https://www.mapillary.com/app/user/ICT4Society

5.3.2. Peak Hours Traffic

Traffic volume can affect the comfort level of a street. Even if there is available segregated infrastructure for each traffic mode, streets with high traffic volumes can have an impact on the noise and air quality in the environment of the street. For that reason, the number of traffic lanes available is the indicator that determines the traffic that can go through a street. On OSM the key is lanes.

5.3.3. Cyclepaths

Cycle paths are the infrastructure that generate a safe and comfortable space for cyclists to make their daily trips. They have multiple typologies; they can be segregated or combined from other modes, at a road or sidewalk level, among other characteristics. In this case, it is essential if the infrastructure is segregated from vehicles or pedestrians, which may not be comfortable for pedestrian or wheelchair users to walk, or if the infrastructure is shared with pedestrians or cars, which could be slightly uncomfortable for cyclists due to the different speeds.

TABLE 5-12 EXAMPLES OF CYCLING INFRASTRUCTURE IN MILAN

Reserved


Image by https://www.mapillary.com/app/user/adirricor

Shared with cars or pedestrians


Image by https://www.mapillary.com/app/user/ adirricor

5.3.4. Sidewalks

The width of the sidewalk is key to the comfort of walking trips; wider sidewalks allow for a more significant and more varied number of activities. Unfortunately, the information available in the OSM for the sidewalk width is incomplete and does not allow to use the key to represent the infrastructure for pedestrians in Milan. However, in 2020 Transform Transport (a non-profit research foundation focused on innovation in mobility and transport planning) and Systematica (a transport planning and mobility engineering consultancy) developed a study of the current state of Milan's sidewalk infrastructure. The study shows how the current width would allow pedestrians to maintain the recommended social distance necessary for the COVID-19 pandemic containment. In this study, Transform Transport (2020) estimated the sidewalks' width of all the city from the georeferenced polygons of the sidewalks taken in the geoportal of Milan.

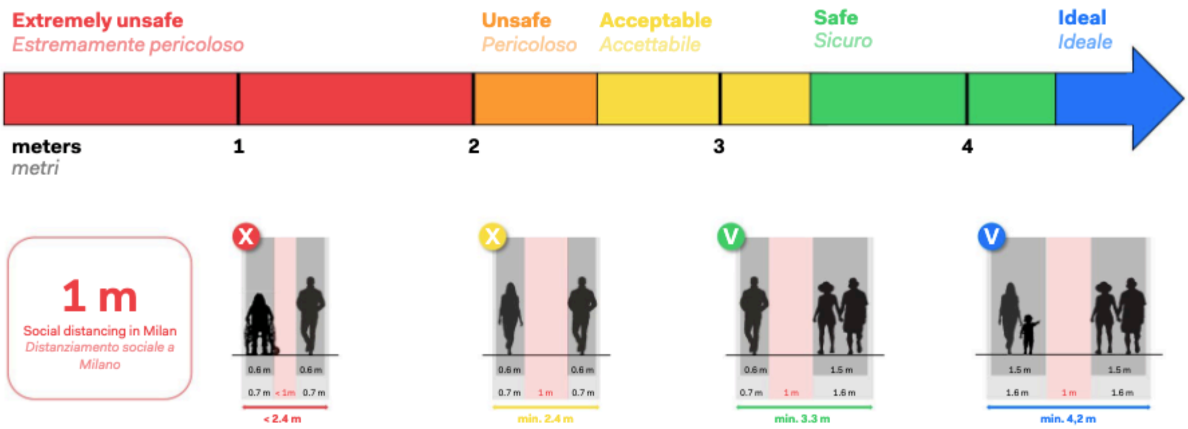


FIGURE 5-8. SIDEWALK CLASSIFICATION IN MILAN (TRANSFORM TRANSPORT, 2020)

After trying to estimate the sidewalks' width following the Transform Transport's methodology, posted on the repository "*sidewalkwidths-nyc*" by (meliharvey, n.d.) the script could not run the complete network of sidewalks for Milan. Then a mathematical approach was attempted to estimate the widths. It began with the assumption that sidewalks could be approximated to long skinny rectangles, and two could be calculated by QGIS the area and the perimeter. Then the width had to be estimated in function of the known variables, this approach had also the benefit that the orientation or location of the polygon was not relevant since such Euclidean motions do not affect the area nor the perimeter.

EQUATION 5-1 CALCULATION OF SIDEWALK WIDTH

$$P = 2L + 2w$$
$$A = w * L$$

$$2w^2 - P * w + 2A = 0$$
$$w = \frac{P - \sqrt{P^2 - 16A}}{4}$$

Under these assumptions, Equation 5-1 shows the basic equations for the area and perimeter and the product of replacing each formula in each other to have the quadratic formula. At this point, all polygons where $P^2 - 16A$ was less than zero were not considered. As a validation process of this methodology, the estimation was compared with the results from the study by Transform Transport (2020).

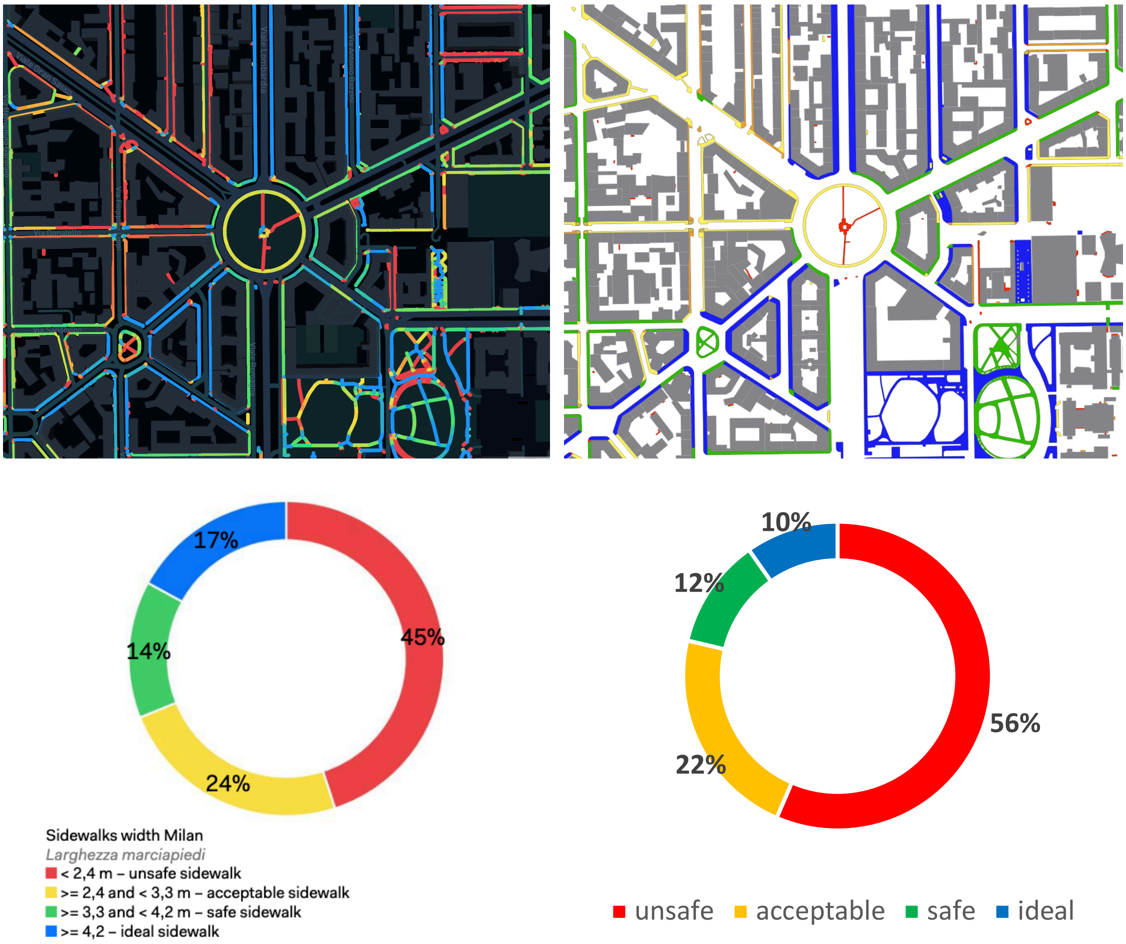


FIGURE 5-9 COMPARISON SIDEWALKS MILAN VS MATHEMATICAL FORMULA

From the visual inspection (see Figure 5-9) the results showed some consistency between the mathematical approach and the methodology of the Sidewalks Milan study. However, since the web application had a continuous grade of color, it was not easy to be compared with the discrete categories used. Then, the general distribution of the results was contrasted between the categories of both methodologies. Here, the acceptable and safe distribution had almost the same share of all sidewalks in the city for both methodologies, in the case of the categories of unsafe and ideal, the shares were not as closed as the others, but the proportions were correct being unsafe the majority in the city. From this analysis, the classification was added to the intersecting ways in the GOAT-database and the names of the categories were changed to fit the purpose of this reach.

TABLE 5-13 EXAMPLES OF SIDEWALK INFRASTRUCTURE IN MILAN

Ideal (>4,2m)

Image by https://www.mapillary.com/app/user/gorica7

Comfortable (3,3 – 4,2)

Image by https://www.mapillary.com/app/user/mapeadora

Acceptable (2,4 – 3,3)

Image by https://www.mapillary.com/app/user/ marcuscalabresus

Uncomfortable (< 2,4m)

Image by https://www.mapillary.com/app/user/ marcuscalabresus

5.3.5. Obstacles

Obstacles can dramatically affect the comfort of cyclists and pedestrians when they are using the roads. Obstacles can be classified as temporary and fixed. Temporary obstacles refer to objects, things, or vehicles, that do not allow a smooth transit through a particular infrastructure. For example, they can be service vehicles picking up the trash or the public bicycles out of a docking station waiting to be rented. Since these obstacles are hard to map, they were not considered for the calculation.

On the other hand, fixed obstacles are easier to consider, and they were divided into three categories. First, light obstacles defined by street furniture on narrow sidewalks. Normally, street furniture is an excellent feature in the streets, but where the sidewalk lacks enough space, they become an obstacle. Second, medium obstacles, which were identified by GOAT's wheelchair classification for streets, and defined the characteristics that allow wheelchairs to use them in a comfortable way. Finally, for strong obstacles, the highway key "steps" is assumed to be the most substantial obstacle a pedestrian cyclist or wheelchair user can find in the city.

TABLE 5-14 EXAMPLE OF OBSTACLES IN MILAN

Light (Only sidewalk Uncomfortable or Acceptable)	Medium (GOAT's wheelchair classification)
	
Image by https://www.mapillary.com/app/user/ marcuscalabresus	Image by https://www.mapillary.com/app/user/keren235
Strong (steps)	

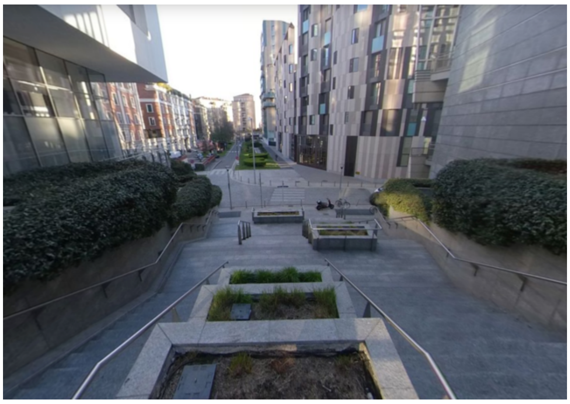



Image by https://www.mapillary.com/app/user/edo4tmapillary	

5.3.6. Surface and smoothness

In the OSM many types of surfaces are defined; for the accessibility calculation, twelve different types of surfaces were selected because they can influence the speed of the user and assign them an impedance factor value based on the speed impact they could have on the users. Another important characteristic that influences the speed is the condition of the path, also known as the smoothness of the surface. Sometimes, even if the surface material is pavement, external elements such as branches, construction errors, or poor maintenance can make it impossible for specific users to pass.

Table 5-15 Surface and smoothness indicators

Attribute	OSM - feature	Attribute	OSM - feature
Surface type	Paving Stones	Paths in poor conditions	intermediate
	Sett		bad
	unhewn-cobblestone		very_bad
	cobblestone		horrible
	pebblestone		very_horrible
	unpaved		
	compacted		
	fine_gravel		
	gravel		
	Sand		
	grass		
	Mud		

5.3.7. Comfort Street Elements

All the characteristics listed before are attributes of the street network that influence the speed or comfort of the users who use the road network. However, individual elements can improve the perception and comfort of using a particular street. These elements are street furniture, or nature and urban decoration, and they are additional attributes for the street network. Street furniture includes street lighting, benches, bicycle parking, and wastebasket. The elements for nature and urban decoration are parks, flowerbeds and green areas, trees, and fountains.

Table 5-16. Elements for additional street elements

Attribute	OSM - feature
Street furniture	Street lighting
	Benches
	Bicycle parking
	Wastebasket
Nature and urban decoration	Parks and gardens
	Trees
	Presence of fountains

6. Inclusive Accessibility by Proximity Index

The first version of the IAPI, developed by POLIMI (Pucci, Lanza, et al., 2021), was transferred into the 'GOAT logic' (i.e., comfort factors translated into resistance factors and OSM syntax). Therefore, the code that was developed can be found on GitHub (https://github.com/goat-community/goat/tree/feature/ex-tra) and is available under

GPL-3.0 License. The Index is part of the EX-TRA Project (Experimenting with City Streets to Transform Urban Mobility). Currently, the Technical University of Munich is working on the component of accessibility by proximity; the objective is to generate insights into which transport, and land use conditions can enable accessibility by walking and cycling through the IAPI. The project is being developed with multiple partners from Munich, Amsterdam, Ghent, Milan, and London.

After defining the POIs and network data, the analysis network for the IAPI was prepared. For the IAPI, a set of indicators was defined by Pucci, Lanza, and Carboni (2021); see Figure 6-1. These indicators have a high influence in the perceived pedestrian cyclist and wheelchair accessibility. Therefore, the indicators and associated attributes were matched with the OSM objects and tags to fit the network dataset used in GOAT. In addition, the absolute speeds defined in Figure 6-1 were transformed into relative values (impedance factors) to fit the GOAT logic.

Indicator	Attribute	«OSM feature» or *source*	(3km/h)	(2km/h)	(10km/h)
Type of road	Footways and Pedestrian streets	«Highway = pedestrian ; footway»	4,5 km/h		
	Underpasses (stairs)	«Tunnel = YES»	1,5 km/h	deleted	1,5 km/h
	Bridges and ramps (stairs)	«Bridges = YES»	1,5 km/h	deleted	1,5 km/h
Peak hour traffic	High	*Local traffic survey / plans*			5 km/h
	Low				15 km/h
Cycle paths	Reserved	*Local plans / Open data*			15 km/h
	Shared				
Sidewalk width	Low	*Direct on-site survey / automated collection (?)*		1 km/h OR arc deleted	
Obstacles	Sidewalks in poor conditions, steps, fixed street furniture	*Direct on-site survey / automated collection (?) /* «Highway = steps»		1 km/h OR arc deleted	
	No ramps in crossing points / steps			Interruption	
Slopes		*Direct survey / altimetry data*	< km/h	< km/h OR arc deleted	< km/h
Limites speed areas	Based on traffic policies of the Context of analysis	*Local plans / Open data /* «Highway = living street»	> km/h		> km/h

FIGURE 6-1. INDICATORS AND BASIC ATTRIBUTES OF THE STREET NETWORK AND DIFFERENT PROFILES OF USERS[14]

6.1. Distance-based accessibility

To estimate accessibility (either isochrones or heatmaps), GOAT calculates accessibility as the sum of all the opportunity values to destinations j, within a specified reach, multiplied by the impedance factor between i to j. Then, accessibility is calculated with the following formula:

[14] (Pucci, Lanza, et al., 2021)

Equation 6-1 Accessibility based on distance

$$A_i = \sum O_j * f(t_{ij})$$

with: $A_i = Accessibility\ at\ origin\ i$

$O_j = Opportunity\ value\ at\ destination\ j$

$f(t_{ij}) = impedance\ function\ from\ i\ to\ j$

$$f(t_{ij}) = e^{\frac{-t_{ij}^2}{\beta}}$$

with: $t_{ij} = time\ between\ i\ and\ j$

$\beta = sensitivity\ parameter$

The opportunity value is 1 if the destination is within the area or border defined and 0 if it is not inside. The impedance factor is usually time-based, and the time corresponds to the time between the origin and the destination. This time depends on the distance and speed. First, distance depends on the network available. Second, in GOAT, speed can be dynamically assigned and depends on the profile user; as explained before, GOAT defines three profile users, pedestrian, cyclist, and wheelchair users. In addition, the speed of the cyclist or pedestrian can be altered depending on the specific conditions of the network.

Table 6-1 Impedance factors scale

How affected?	**Not affected**	**Bad**	**Very bad**	**Horrible**	**Very horrible**	**Not possible to pass**
Impedance Factor	0	0.15	0.3	0.5	0.75	1

GOAT considers two factors that could reduce the speed of the users when using a specific path or street. They are type of surface and smoothness of the surface. They were not initially considered in the categories from Figure 6-1, but they are essential to be considered within the accessibility calculation. To estimate them, an impedance value from 0 to 1 represents the impact of the quality and type of infrastructure; Table 6-1 summarizes the values for the qualitative assumptions.

6.1.1. Surface type

The types of surfaces that had less impact on the speed are paving stones, unpaved, compacted, and fine gravel. Walking has no impact on speed, and for cycling and wheelchair, the minor irregularities on the surface may be uncomfortable and barely reduce the speed. The next group has a medium impact on the speed for the different profile users; the types of surfaces are sett, unhewn-cobblestone, cobblestone, and pebblestone. These types are very similar and usually they have a flat rock shape, then the surface is hard, but the excess of cracks can cause a bumpy experience for cyclists and wheelchair users. Finally, the highest impact on the speed comes from gravel, sand, grass, and mud. Where the surface is soft and easy to lose traction, in the case of the users that have wheels, walking users can also be significantly affected depending on environmental conditions. Table 6-2 has the impedance factors representing the speed's described impact.

TABLE 6-2 IMPEDANCE VALUES FOR SURFACE TYPE

Attribute	OSM - feature	Walking	Cycling	Wheelchair
Surface type	Paving Stones	0	0.1	0.1
	sett	0.05	0.15	0.15
	unhewn-cobblestone	0.05	0.15	0.15
	cobblestone	0.05	0.15	0.15
	pebblestone	0.05	0.15	0.15
	unpaved	0	0.1	0.1
	compacted	0	0.1	0.1
	fine_gravel	0	0.1	0.1
	gravel	0.1	0.2	0.3
	sand	0.1	0.2	0.3
	grass	0.1	0.2	0.3
	mud	0.1	0.2	0.3

6.1.2. Smoothness

For the smoothness of the road, the highest impedance factors from the scale (Table 6-1) were assigned to the wheelchair users; for the bicycle users, the impedance factor was barely reduced because they have more flexibility in their movement and can always walk with the bike by hand. Moreover, since walkers have the highest flexibility, they were only affected in case the smoothness was either horrible or very horrible. Table 6-3 has the impedance factor that represents the smoothness.

TABLE 6-3 IMPEDANCE VALUES FOR SMOOTHNESS

Attribute	OSM - feature	Walking	Cycling	Wheelchair
Paths in poor conditions	intermediate	0	0	0.05
	bad	0	0.05	0.15
	very_bad	0	0.1	0.3
	horrible	0.1	0.3	0.5

	very_horrible	0.15	0.35	0.75

6.2. Comfort-based accessibility

The type of surface and the smoothness are characteristics of the streets that can directly influence the speed of the profile user. However, some other characteristics are related to the environment. The environmental features may not directly impact the speed; however, they can create adverse conditions to prevent people from using specific paths or roads. To include the relevant characteristics from the network, instead of modifying the speed of each of the user profiles according to the present characteristics, we included an extra impedance factor within the calculation called comfort impedance factor.

As indicated in the literature review, Labdaoui et al. (2021) developed the To implement the SWTCI methodology in the accessibility calculation, we defined a scale based on the existing scale for speed impedance factors. In this case, 0 will be the desired condition, meaning no impedance value for the indicator, and 1 will be the greatest impedance value, which translates that the road's characteristic is less desired. Comfort impedance values were added to the characteristics of road type, peak hour traffic, cycle paths, sidewalk width, and obstacles.

To consider the impedance values within the accessibility calculation, they were added to the accessibility the sum of all the impedance values for a certain profile user, to the distance between the origin and the destination. If the sum of the impedance factors was positive, this would mean that the perceived distance is larger, thus the travel time too, as a result the accessibility to that point would be less. On the contrary, if the sum of the impedance factors is negative, that implies that the route has a number of enough comfort elements to overcome any of the negative characteristics of the road, therefore, making the perceived time shorter. It is important to consider that since the road conditions can have multiple characteristics from different categories, the final comfort impedance may have a total value greater than one.

EQUATION 6-2 PERCEIVED ACCESSIBILITY BASED ON COMFORT

$$A_i = \sum O_j * f\left(t_{ij}^*\right)$$

with: $A_i = Accessibility\ at\ origin\ i$

$O_j = \ Opportunity\ value\ at\ destination\ j$

$f\left(t_{ij}^*\right) = impedance\ function\ with\ comfort$

with: $t^*{}_{ij} = perceived\ time\ between\ i\ and\ j$

$$f(t_{ij}) = e^{\frac{-t^{*2}_{ij}}{\beta}}$$ $\beta = sensitivity\ parameter$

$d_{ij} = distance\ between\ i\ and\ j$

$$t^*_{ij} = \frac{d_{ij} * (1 + \sum_k ic_{kp})}{v_p}$$ with: $ic_{kp} = impedance\ comfort\ of\ category\ k$ $to\ profile\ user\ p$

$v_p = speed\ of\ profile\ user\ p$

6.2.1. Road type

To determine the impedance factors for the road types following the same scale from Table 6-1, the following table has the impedance values for each attribute depending on the profile user. For the roads, it is possible to identify 3 groups: motorways and trunk ways, where the transit of pedestrians or cyclist is not allowed and physically very dangerous, so they have a value of 1; primary and secondary, where it is still dangerous for pedestrians because of the high vehicle volumes this type of streets can have, for cycling the relative is lower with the vehicles, thus, the comfort is better than for pedestrians (Llorca et al., 2014); Tertiary, unclassified and residential, which have very similar urban characteristics, as maximum 2 lanes, or high presence of on-street parking, still have some vehicle traffic, which represents a bad walking experience on these roads.

For special roads, most of them have a pedestrian function, so the comfort of the profile user is not usually affected; however, the exceptions are pedestrian and footway roads, normally known as sidewalks, where the high volume of pedestrian, objects and urban design, can result uncomfortable for cyclist. The special streets that still have some low impedance values still allow for very little traffic.

For connections, which refers to bridges and tunnels, these kinds of infrastructure are delimited for the traffic of vehicles in most cases for Milan; however, in some cases, where active modes are allowed to use them, the impedance factor reflects the slope in the case of the bridges and the dark environment in the case of the tunnel. In case the way to access a tunnel or bridge was through stairs, it is considered by the "strong obstacle" category from the chapter 6.2.5.

TABLE 6-4. IMPEDANCE VALUES FOR ROAD TYPE

Attribute	OSM - feature	Walking	Cycling	Wheelchair
Roads	Motorway	1	1	1
	trunk	1	1	1

	Primary	0.8	0.3	0.8
	Secondary	0.6	0.2	0.7
	Tertiary	0.2	0.1	0.3
	Unclassified	0.2	0.1	0.3
	Residential	0.2	0.1	0.3
Special Road	Living streets	0	0	0
	Service	0.1	0.1	0.1
	Pedestrian	0	0.5	0
	Track	0.1	0	0.1
	Footway	0	0.5	0
	Path	0	0.1	0
Connections	Tunnel	0.3	0.4	0.5
	Bridge	0.3	0.4	0.5

6.2.2. Peak Hour Traffic

As describe in chapter 0, the indicator that determines the traffic that can go through a street is the number of traffic lanes available. For that reason, if the number of lanes is greater than 2, these impedance factor will apply.

TABLE 6-5. IMPEDANCE VALUES FOR PEAK HOUR TRAFFIC

Attribute	**OSM - feature**	**Walking**	**Cycling**	**Wheelchair**
Traffic Lanes	Local traffic survey/lanes	0.2	0.1	0.3

6.2.3. Cyclepaths

Cyclepaths were classified in reserved and shared with pedestrians or cars. In this case, reserved are cycleways which may not be comfortable for pedestrian or wheelchair users to use; and shared with pedestrians or cars, where it can be slightly uncomfortable for cyclists, due to the different speeds with pedestrians.

TABLE 6-6. IMPEDANCE VALUES FOR CYCLEPATHS

Attribute	**OSM - feature**	**Walking**	**Cycling**	**Wheelchair**
Reserved	cycleway	0.5	0	0.3
Shared with cars and pedestrians	cycleway = shared_lane	0	0.1	0

6.2.4. Sidewalk width

To determine the impedance factor of sidewalks according to the width, the rule is, the narrower the sidewalk the more uncomfortable it is. This effect applies more strictly to wheelchair users due to the lack of flexibility in case of an encounter with another person that needs to be avoided.

TABLE 6-7. IMPEDANCE VALUES FOR SIDEWALK WIDTH

Attribute	Walking	Cycling	Wheelchair
Ideal (>4m)	0	0.1	0
Comfortable (3 - 4)	0	0.2	0.2
Acceptable (2 - 3)	0.3	0.4	0.5
Uncomfortable (< 2m)	0.5	0.6	0.7

6.2.5. Obstacles

To determine the impedance factors for obstacles, the higher categorized the obstacle, the higher the impedance factor. Also, the impedance values for wheelchair user are higher due to the lack of flexibility to avoid the obstacles if necessary, for example, a streetlight pole in the middle of a narrow sidewalk, or the presence of stairs with an available ramp.

TABLE 6-8 IMPEDANCE VALUES FOR OBSTACLES

Attribute	Walking	Cycling	Wheelchair
Light (Only sidewalk Uncomfortable or Acceptable)	0.1	0.1	0.2
Medium (GOAT's wheelchair classification)	0.2	0.3	0.6
Strong (steps)	0.3	0.7	0.9

6.3. Comfort Street Elements

Including comfort street elements in the impedance comfort calculation is necessary to create a scale like the speed and network characteristics, as done in the walkability indicator MAPS – Global (Cain et al., 2018), a “negative impedance” represents a street with these additional elements is more attractive than other streets with the same characteristics, but without the additional attributes.

TABLE 6-9. IMPEDANCE SCALE FOR ADDITIONAL NETWORK ATTRIBUTES

How affected?	Not affected	Good	Very Good
Impedance Factor	0	-0.1	-0.2

To add the impedance comfort to the accessibility calculation, following Promethee II for Street Quality Street Walkability (Ortega et al., 2020) if a road is within a radius of 10 meters from a street furniture, the road takes the additional value for the calculation. Subsequently, the qualitative characteristics to assign the impedance values for street furniture are that street lighting takes the highest impact on people's comfort, which is a fundamental element for walking or cycling at night. In the case of benches and wastebaskets, the presence on the street generates an improvement for walking and wheelchair users; on the contrary, the presence of bicycle parking benefits cyclists, but not walking or wheelchair users.

In the case of nature and urban decoration, flower beds, green areas, and the presence of fountains, impact the comfort of walking and wheelchair users significantly as there are more contemplative points, which would require cyclists to slow down or completely stop. Furthermore, trees have the highest impact on all users because they bring benefits such as better landscape, provide greenery, and better air quality; they also have practical functions providing shadow or shelter on rainy days.

TABLE 6-10. IMPEDANCE FACTORS FOR ADDITIONAL STREET ELEMENTS

Attribute	OSM - feature	Walking	Cycling	Wheelchair
Street furniture	Street lighting	-0.2	-0.2	-0.2
	Benches	-0.1	0	-0.1
	Bicycle parking	0	-0.2	0
	Wastebasket	-0.1	0	-0.1
Nature and urban decoration	Parks and gardens	-0.2	-0.1	-0.2
	Trees	-0.2	-0.2	-0.2
	Presence of fountains	-0.2	-0.1	-0.2

7. Implementation of IAPI in GOAT

7.1. Transfer to Milan

The heart of GOAT is its open-source functionality, and the main source of data for its development in Milan is OSM. To begin, the calculation in GOAT requires the definition of a study area, in the case of Milan, it is the political boundary of the "Comune di Milano" - municipality of Milan, that contains the 9 districts of the city, without considering the neighbors of the metropolitan region. Then, GOAT automatically downloads the OSM-data and extracts the relevant data, such as points of interest, buildings, ways, etc. Similarly, GOAT expects to have a source of population data for the setup and sometimes land use data is handy to structure a new location.

The process of transferring GOAT to a new location is easy and convenient; however, Open Street Map is built, maintained, and updated by the voluntaries of the community, which translates in outdated and sometimes incomplete information. To overcome this issue, it is important to compare the information available in OSM to the information reported in the open-data portals of the official institutions. For the case of Milan, most of the information has been contrasted with the portal of "Comune di Milano", "Istituto Nazionale di Statistica" (National Institute of Statistics) and the "Sistema Statitistico Integrato" (Integrated Statistics System).

GOAT was transferred to Milan to test the new functionalities and assess local accessibility. The study area is the "Comune di Milano" - municipality of Milan, not be confused with the Metropolitan area of Milan. The GOAT setup processes automatically, downloads OSM-data and extracts the relevant data, as points of interest (POIs), buildings, ways, etc. Equally, GOAT expects to have a source of population data and land use data that can also be provided to make the analysis more precise.

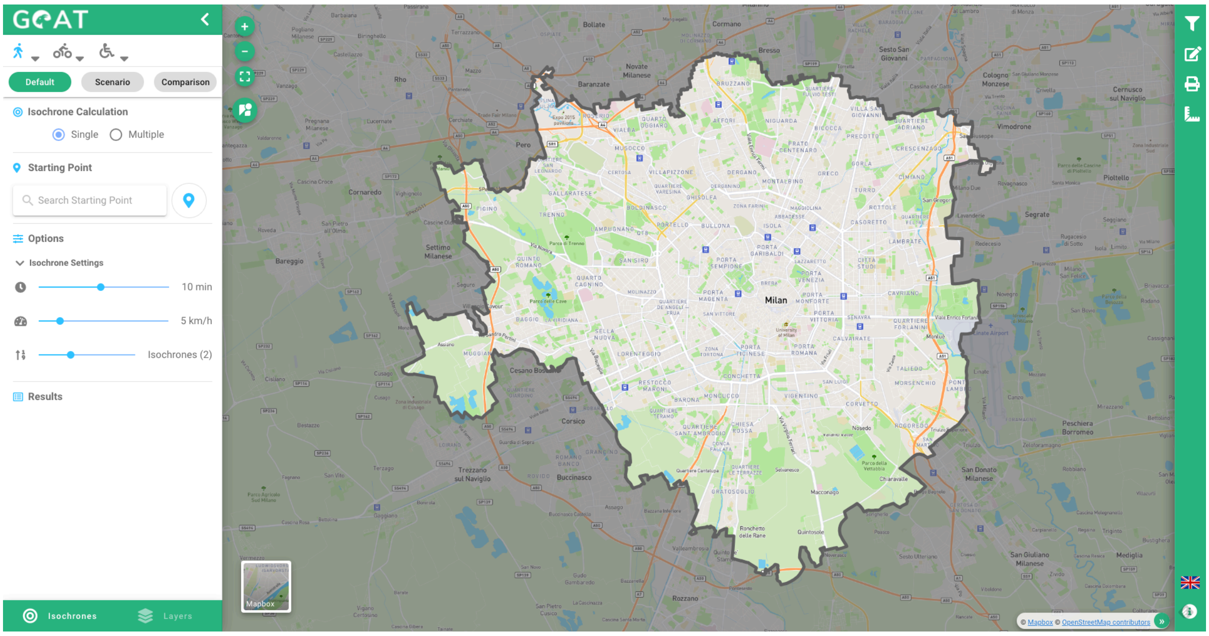


FIGURE 7-1. STUDY AREA OF MILANO IN GOAT

In Milan, the OSM data include a wide variety of information for streets, buildings, land use, among others. In general, the data is rich with detail characteristics as opening hours for POIs or number of lanes for streets. This benefit is the result of the open-source functionality.

After testing the transferability capabilities and organizing the available data in Milan, GOAT was used to calculate, understand, and analyze the local accessibility in Milano. For the local accessibility calculation, GOAT produces a predefined grid. The grid is divided into hexagonal grid-cells where each cell takes an accessibility value for a group of amenities based on a gravity-based procedure. (Pajares et al., 2021b) The result is a heatmap that shows the level of accessibility. For example, Figure 7-2 shows the heatmap with local accessibility for supermarkets and marketplaces; the grid-cells in dark red show areas with low accessibility, and the dark green show areas with high accessibility to supermarkets.

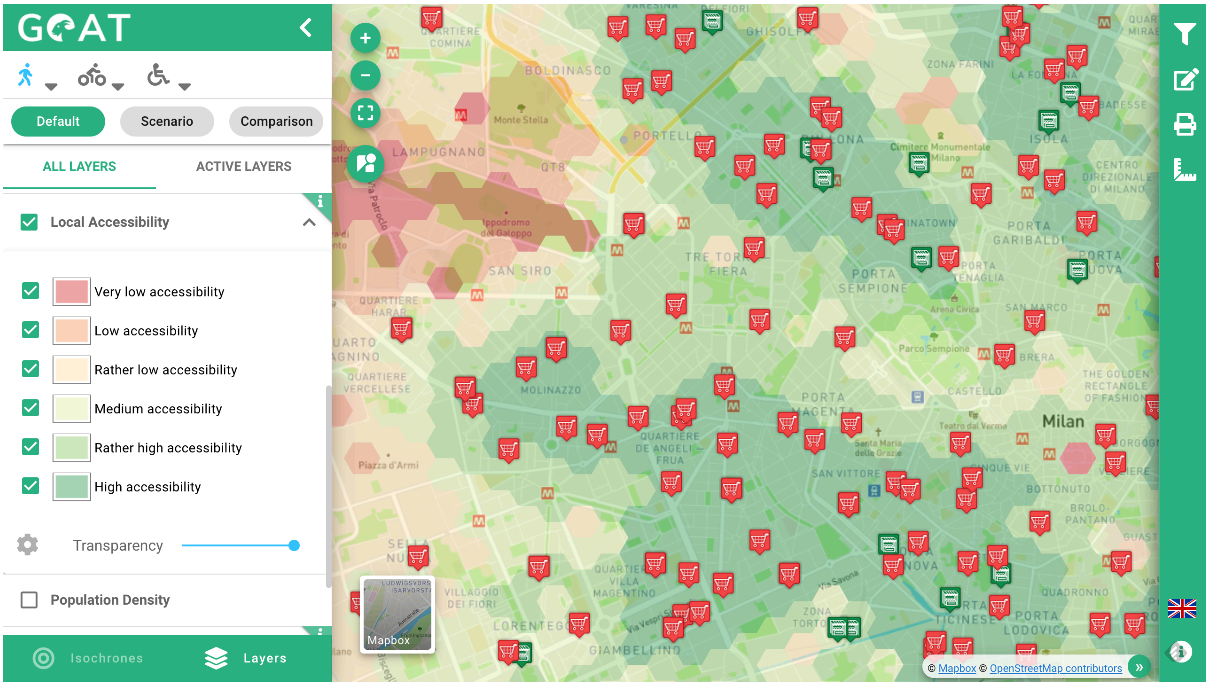


Figure 7-2. Heatmap with local accessibility to supermarkets and marketplaces in Milan

7.2. Points of Interest

As indicated in the chapter before, GOAT automatically downloads the OSM-data and extracts the relevant data, such as points of interest. It has already set a base of points that cover multiple categories, even more than the categories considered for this study. However, there were some points that were not originally considered by the algorithm and that need to be added. In other cases, the points were grouped according to the needs of this project, and for some points the OSM-data was incomplete, so it was necessary to add the data from the open-data portal of Milan.

To add the new POIs that were extracted from the OSM-data, it was necessary to modify three files: *goat_config.yaml,* where the POIs are selected to be added in the new table of POIS; *pois.sql*, where the points are further filtered, and organized according to the original characteristics and the needs; and *app-config.json, which* communicates with the frontend giving it the required information to show and to calculate GOAT's accessibility tools as the heatmaps.

goat_config.yaml

```
DATA_REFINEMENT_VARIABLES:
  #extrapolation ==> census.shp + landuse.shp needed as input
  #disaggregation ==> landuse.shp needed as input + high-resolution population input data + building data
  #distribution ==> landuse.sho need as input + high-resolution population input data
  #custom_population ==> population.shp custom population data needed
  POPULATION: "custom_population"
  #"yes" if you want to add these layers
  ADDITIONAL_WALKABILITY_LAYERS: "yes"
  OSM_MAPPING_FEATURE: "no"
  variable_container:
    heatmap_sensitivities: [150000,200000,250000,300000,350000,400000,450000]
    pois_one_entrance: ["kindergarten","nursery","primary_school","secondary_school","grundschule","hauptsch
      "car_sharing","bicycle_rental","cargo_bike","charging_station","bus_station","tram_station","subway_st
      "l-station_ffb","s-station_prio1_ffb","s-station_prio2_ffb","hairdresser","atm","bank","dentist","doct
      "bakery","butcher","clothes","convenience","general","fashion","florist","greengrocer","kiosk","mall",
      "hypermarket","international_supermarket","chemist","organic","marketplace","hotel","museum","hostel",
    ]
    pois_more_entrances: ["bus_stop","tram_stop","subway_entrance","rail_station","community_sports_center",
```

pois.sql

```
-- Add kiosks
SELECT osm_id,'polygon' as origin_geometry, a
tags -> 'origin' AS origin, tags -> 'organic'
operator,public_transport,railway,religion,ta
FROM planet_osm_polygon
WHERE (shop = 'kiosk' OR shop = 'tobacco')
```

app-config

```
{
  "name": "Shop",
  "categoryValue": "shop",
  "children": [
    {
      "name": "Kiosk",
      "value": "kiosk",
      "icon": "kiosk",
      "weight": 1,
      "sensitivity": 300000
    },
```

FIGURE 7-3 EXAMPLE OF IMPLEMENTING KIOSK IN GOAT

As detailed in the chapter 5.2, some of the POIs were not well mapped in the OSM and the information from the official source of Milan had better coverage and quality. To add these POIs, it was necessary to filter the information, organize it, and add it to the variable container. First, to filter the information according to the needs of the research, Table B-1 shows how the data was processed to set the POIs for each category. Once the data was filtered, it was necessary to define an "amenity" field. This is the field that is later used for all the calculations. Next, all shapes were merged under a single shape called "*custom_pois.shp*". Later, this table was added to the variable container and modified the "*pois.sql*" to add them to the POIs table. With this procedure the official data from Milan was loaded into GOAT-database.

7.3. Integration of impedance factors

To integrate impedance factors into the GOAT-database it was necessary to add them into the variable container, then apply the filter and conditional for the characteristics of the infrastructure that had assigned a specific impedance factor, and finally add it to the ways table. First, to add the impedance factors to the variable container, they were added to the file goat_*config.yaml.* Then, each of the impedance factor was added to the ways table in the file *network_preparation2.sql.* To do so, the script first filters the data according to the parameter defined in chapter 6. Then, each category had a specific column for the respective impedance factor. At the end, all impedance factors were summed up for each profile user as shown on.

Equation 7-1.

Equation 7-1 Sum of impedance values for walking

$$
\begin{aligned}
ic_{(walking)} = {} & ic_{(surface\ type,walk)} + ic_{(smoothness,walk)} + ic_{(road\ type,walk)} \\
& + ic_{\ (peak\ hour,walk)} + ic_{\ (cyclelanes,walk)} + ic_{\ (sidewalk,walk)} \\
& + ic_{ij\ (obstacle,walk)} + ic_{ij\ (street\ lights,walk)} + ic_{ij\ (benches,walk)} \\
& + ic_{ij\ (bicycle\ parking,walk)} + ic_{ij\ (waste\ basket,walk)} \\
& + ic_{ij\ (flowerbeds,walk)} + ic_{ij\ (trees,walk)} + ic_{ij\ (fountains,walk)}
\end{aligned}
$$

It is important to highlight, the difference between the comfort-base categories and the comfort street elements. While the comfort-base categories are grouped under the categories name (e.g., road type, cyclepaths), for the comfort street elements each attribute has its own column with impedance values. The reason was that attributes from comfort-base categories are unique to every street; for example, a street that is residential, cannot be also tertiary. In the case of comfort street elements, one or multiple attributes can coexist in a street so they must have different impedance values; for instance, if a street has benches, it does not mean it cannot have street lights or wastebaskets.

To include both, the effect of impedance factor on the network for the accessibility calculation, together Equation 6-2 and Equation 7-1 for each profile user, was added to the file *fetch_and_extrapolate.sql*. Here, they were added and the sql_cost of Equation 6-2.Later, this function will be part of the calculation of the heatmaps.

```
sql_cost = jsonb_build_object(
'cycling','CASE WHEN crossing IS NOT NULL THEN (''%2$s''::jsonb ->> (''delay_'' || crossing_delay_category))::integer + (
            ELSE (length_m*(1+COALESCE(s_imp,0)+COALESCE(impedance_surface,0))::float)/%1$s END AS cost,
            CASE WHEN crossing IS NOT NULL THEN (    ''%2$s''::jsonb ->> (''delay_'' || crossing_delay_category))::integer
            ELSE (length_m*(1+COALESCE(rs_imp,0)+COALESCE(impedance_surface,0))::float)/%1$s END AS reverse_cost',
'walking', 'length_m/%1$s as cost, length_m/%1$s as reverse_cost',
'ebike', 'CASE WHEN crossing IS NOT NULL THEN (''%2$s''::jsonb ->> (''delay_'' || crossing_delay_category))::integer + ((
            ELSE (length_m*(1+COALESCE(impedance_surface,0))::float)/%1$s END AS cost,
            CASE WHEN crossing IS NOT NULL THEN (''%2$s''::jsonb ->> (''delay_'' || crossing_delay_category))::integer + (
            ELSE (length_m*(1+COALESCE(impedance_surface,0))::float)/%1$s END AS reverse_cost',
'walk_comfort','length_m*(1+COALESCE(impedance_walking_comfort,0))::float/%1$s AS cost,
                length_m*(1+COALESCE(impedance_walking_comfort,0))::float/%1$s AS reverse_cost',
'cyc_comfort','CASE WHEN crossing IS NOT NULL THEN (''%2$s''::jsonb ->> (''delay_'' || crossing_delay_category))::integer
            ELSE (length_m*(1+COALESCE(impedance_cycling_comfort,0))::float)/%1$s END AS cost,
            CASE WHEN crossing IS NOT NULL THEN (''%2$s''::jsonb ->> (''delay_'' || crossing_delay_category))::integer + (
            ELSE (length_m*(1+COALESCE(impedance_cycling_comfort,0))::float)/%1$s END AS reverse_cost',
'whe_comfort','length_m*(1+COALESCE(impedance_wheelchair_comfort,0))::float/%1$s AS cost,
                length_m*(1+COALESCE(impedance_wheelchair_comfort,0))::float/%1$s AS reverse_cost'
->> cost_function;
```

Figure 7-4 Inclusion of comfort in the cost equation for the accessibility calculation

7.4. Analysis impedance factors

After adding up the impedance factors for each of the streets in Milan, it is possible to identify the characteristics of the streets for profile users walking, cycling and wheelchair. Figure B-2 shows the total impedance factors for walking. It is possible to identify that the road next to the historic center has a negative or very low impedance. It could reflect a high density of additional elements and groups of characteristics of the streets that reflect livable streets. On the other hand, in the outskirts, the comfortability of the streets for walking is reduced; however, very few streets were classified as having a horrible or worst comfort level.

In the case of the impedance factor for cycling, the distribution is very similar to the pedestrian comfort levels. The city center also presents the highest comfort levels for cyclists, and as the streets are farther from the historical center, the comfort level decreases. Contrary to the walkability conditions, more roads are classified with a bad or worst comfort level; this could be explained by the sensibility of cycling trips to the type or smoothness of the surface.

For the comfort levels related to wheelchair, the differences are notorious compared to the walking or cycling levels of the streets. Similarly, the historic center seems to have a set of conditions that facilitate the mobility of all profile users; still, for wheelchair users it is worst, and even in the city center there are multiple roads with a very bad or worst comfort level. In the outskirts, the comfort situation is deplorable when most of the streets have a very horrible or worst level of comfort.

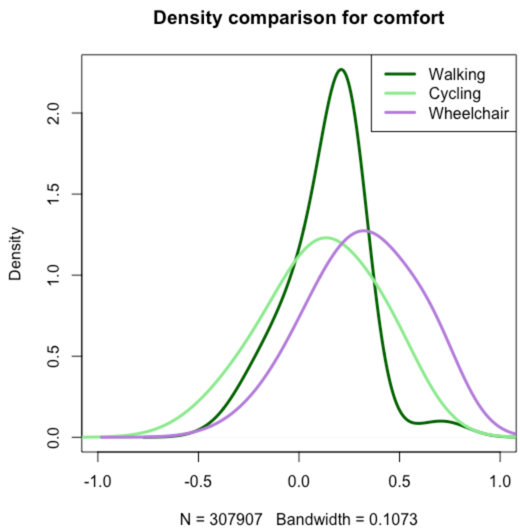


FIGURE 7-5 DENSITY COMPARISON OF COMFORT THE PROFILE USERS

To compare the distribution of the profile users, Figure 7-5 shows the density function that adjusts the histogram distribution for each user. In this graph, it shows that most of the characteristics for all users have an impedance factor between 0 and 0.5, (no effect to bad, from Table 6-1). In the case of walking, the comfort if highly concentrated in average and has a bigger tail towards a good comfort. For cycling, in average, the streets may have even better characteristics to ride a bicycle; however, as the distribution is wider, the probability to find streets with a bad or horrible comfort condition is higher than to walk. Finally, for wheelchair users the street comfort is shifted to a worst perception in comparison with walking and cycling.

7.5. Isochrones

Once the impedance factors are estimated, it is possible to calculate de accessibility for different points in the city. To visualize the accessibility calculation, there are multiple indicators available; For this study, two indicators where used: temporal-based isochrones and heatmaps. The isochrones are lines that represent the farthest distance that can be reached from a specific point; this distance depends on the infrastructure, the network, and the traveling time.

To execute the isochrones from GOAT, the function *isochrones_api* creates a table called *isochrones* where it is possible to compare scenarios by changing the input parameter of the function. For example, Figure 7-6**Error! Reference source not found.** shows the isochrones for walking trips where input parameter *routing_profile* was changed to compare the difference between distance-based accessibility, which was calculated only considering the distance and comfort accessibility, including all the estimated impedance factors.

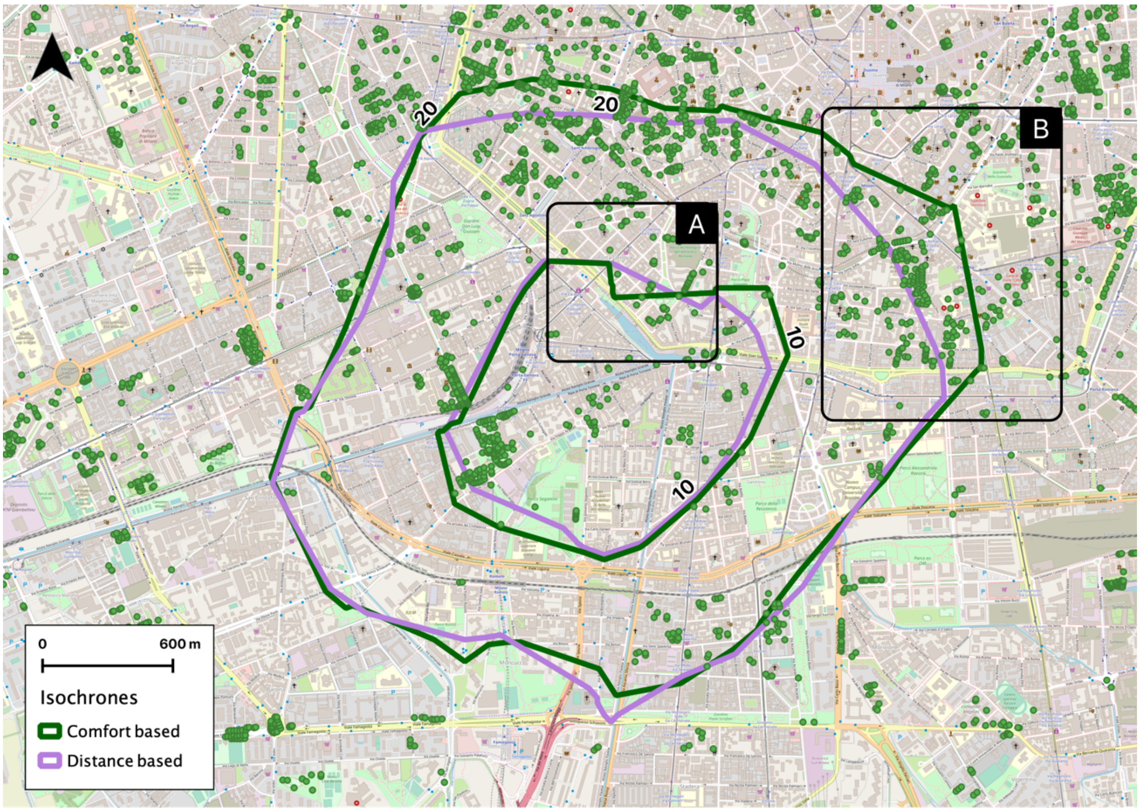


FIGURE 7-6 COMPARISON OF A DISTANCE-BASED AND A COMFORT-BASED ISOCHRONES

Natural environments have a higher impact on the quality of life. Therefore, with the isochrones it is possible to visualize the impact of green and attractive streets on the walkability experience for people on a street/neighborhood scale. For instance, Figure 7-6 shows two isochrones with trees represented by the green dots. Isochrones reveal that depending on the characteristics of the streets, perceived time can change and allow to reach farther distances where the urban conditions are more comfortable, which translates to a higher presence of trees in this example. "Square A" shows how the comfort-based isochrone shrinks next to the river; this could be caused by the impedance value of a bridge. On the contrary, "Square B" shows how streets with a higher density of trees influence the comfort of area, reducing the perceived travel time.

7.6. Heatmaps

The second indicator to visualize accessibility is the heatmaps. With this indicator, accessibility is calculated to multiple points on the space by defining a grid; each cell is assigned the value of accessibility for the point of interest being analyzed. Within GOAT, this operation requires multiple functions and tables. First, to define the *routing_profile* it was originally done by *pgrouting_edges_heatmap.sql;* however, to call this function properly, it must be done from the file *precalculate_heatmap.py*. This file generates the tables and calls the functions that will further on allow heatmap calculation. All the details on the functions and tables required are summarized in Figure A-1. After modifying the *routing_profile* for walking comfort, and running the pre-calculation of heatmaps, GOAT is ready to estimate the heatmaps for the walking trips using the comfort-based methodology.

Afterwards, it is necessary to indicate which is the point of groups of points of interest to which accessibility is calculated. This input is given in the function *heatmap_dynamic*, where the amenity and the sensibility parameter from Equation 6-2 are set. The sensibility index was defined as 300.000, which comes from the default value for GOAT. This can be translated into approximately 74.1% accessibility after 5 min, 30.1% accessibility after 10 min and 6.7% accessibility after 15 min of travel time to the respective amenity. (Pajares et al., 2021a)

As a result, Figure B-1 shows the perceived accessibility estimation for supermarkets; similarly, Figure B-2 shows the accessibility for all supermarkets on a calculation based only on distance. In comparison, perceived accessibility may show lower levels of accessibility across the city, due to the high number of impedance values that are being considered within the calculation. Next, the results of the accessibility calculation for all services using the comfort-based methodology are presented.

8. Spatial Fairness Assessment

8.1. Normalization

When calculating accessibility as shown in Equation 6-2, it is function of the number of POIs within the determined area. However, the result of accessibility is a non-dimensional number that is hard to understand. In addition, accessibilities between different POIs cannot be compared directly because some POIs do not require the same density to achieve a certain level of accessibility. For example, a city does not require the same number of universities and kindergartens to have the same level of accessibility for both. In the second case, the β- parameter helps to face this problem. However, to overcome these issues, it is possible to normalize the results.

One methodology to normalize the accessibility is with maximum and minimum values. As the name indicates this methodology encloses the data between the maximum and minimum value, having as a result a normalized number between 0 and 1. As a result, it is easier to understand the accessibility for a certain POI because the scale is pragmatic; 1 will mean the highest accessibility and 0 the least. However, this methodology still does not correct the distribution of the accessibility to allow direct comparison.

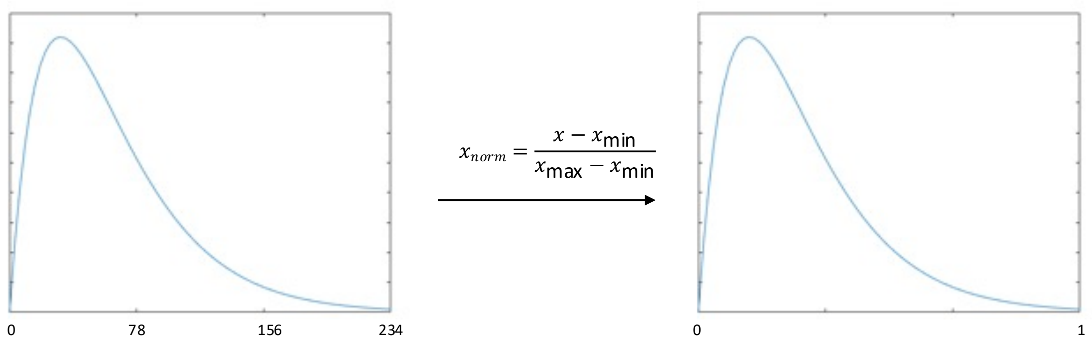


FIGURE 8-1 NORMALIZATION MIN-MAX

The other methodology is the Z-Score. With this normalization procedure the original distribution is adjusted to a normal distribution with an average of 0 and standard deviation of 1. When all the POIs have the same distribution, then it is possible to compare their accessibility because categories have the same breaks and ranges. Both normalization procedures are in the file *grid_access.sql.*

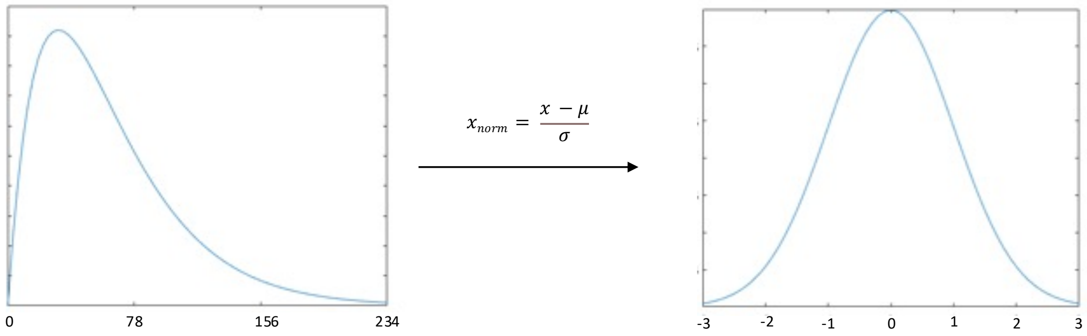


FIGURE 8-2 NORMALIZATION Z-SCORE

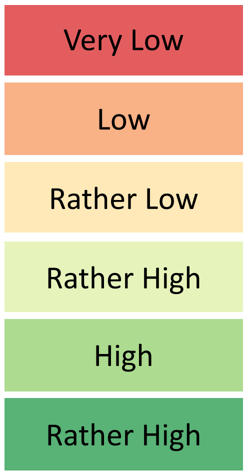


FIGURE 8-3 ACCESSIBILITY SCALE

The accessibility scale is a discrete and qualitative classification of the accessibility calculation. It is divided into 6 categories to avoid a middle category that does not describe the accessibility conditions. This code of color will be used for all the visualizations to facilitate a uniform analysis of the accessibility results among the different methodologies.

8.2. Social demographic data and accessibility

To integrate the social demographic data with the results from the accessibility calculation, the information from every NIL containing the details of the social data needed to be linked to each grid from the accessibility calculation. The aggregation procedure consisted in assigned the centroid of the grid cell to the NIL where it was located. The figure below shows a graphic representation of the colored centroids matching the zone where they are assigned.

FIGURE 8-4 AGGREGATION PROCEDURE

8.3. Horizontal Equity

8.3.1. Z-Score Results

The purpose of the horizontal analysis is to understand the spatial distribution of the POIs across the city. To compare them, the accessibility for each group of POI had a normalization by Z-Score methodology, the results are in Figure C-1. From the general distribution, the scale of the normalization is very short, the breaks in the accessibility scale are a quarter of standard deviation, otherwise it would not be possible to have extreme values of accessibility.

The visualization of this kind of analysis overestimates the reach of the points and is not very useful to analyze the spatial distribution. However, it helps to understand the statistical distribution of the data in the space. The maps that highlight from the rest is the cultural map, where most of the city seems to have a consistent “low accessibility”; nevertheless, it shows the super concentration of the POIs in the center of the city and shows how the mode and the mean are so close that they outweigh the lack of cultural offer in the rest of the city, shifting the whole scale towards better accessibility on average.

Similarly, as in the effect of the cultural POIs, from the maps it is possible to indicate that in all the categories the mode is skewed to the left of the mean, this explains the barely existent transition from “rather high accessibility” to “very high accessibility”. Also from the maps, since they are representing the distribution of the data, they are a good tool to identify clusters of POIs. To wrap up, the graphical representation of a normalization by Z-Score allows for a statical analysis rather than a spatial analysis. Consequently, a histogram graph (see Figure 8-5) fits as a better tool to understand the accessibility distribution of the POIs.

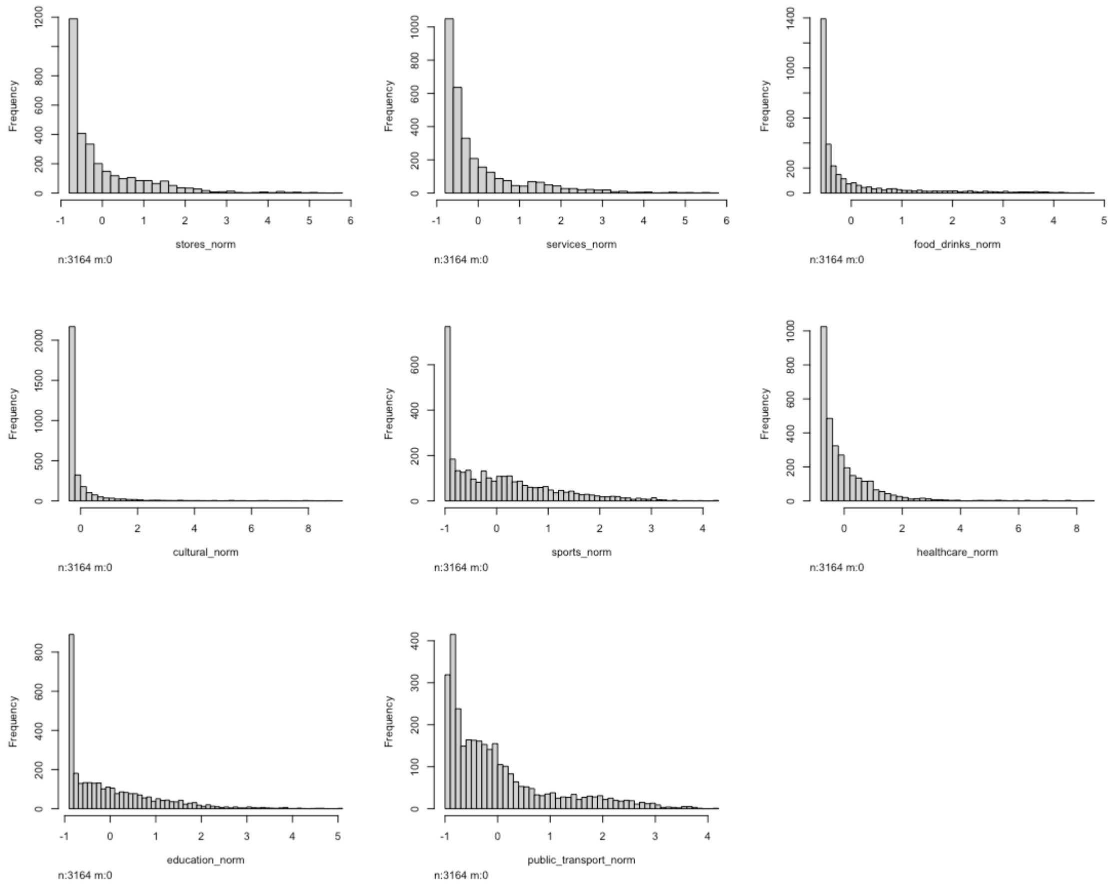


FIGURE 8-5 HISTOGRAM OF NORMALIZED ACCESSIBILITY

8.3.2. Lorenz Curve and Gini Coefficient

The Lorenz Curves reveal the differences on the distribution of the POIs among the population. Public transport and sports locations are the less unequally distributed services in the city, they are followed by education and healthcare and social care services. To close, the most unequally distributed categories area commercial and cultural points. Later, each category will be further analyzed following the order from the less unequal to the most unequal.

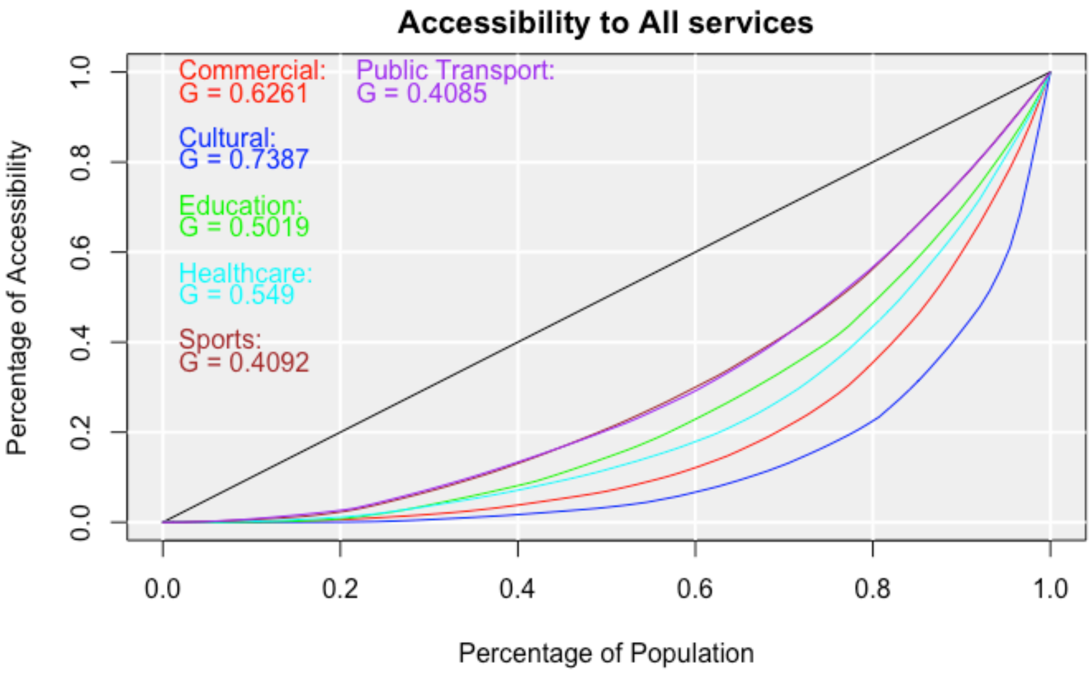
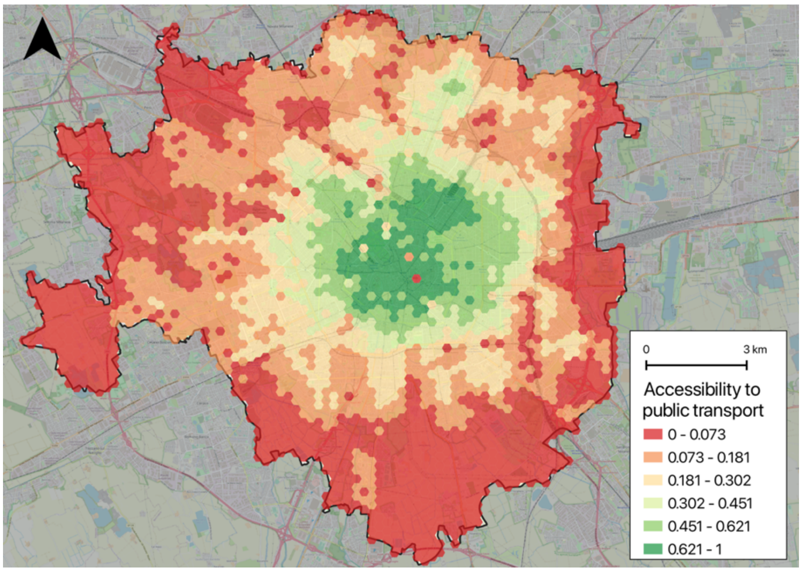


FIGURE 8-6 ACCESSIBILITY TO ALL SERVICES

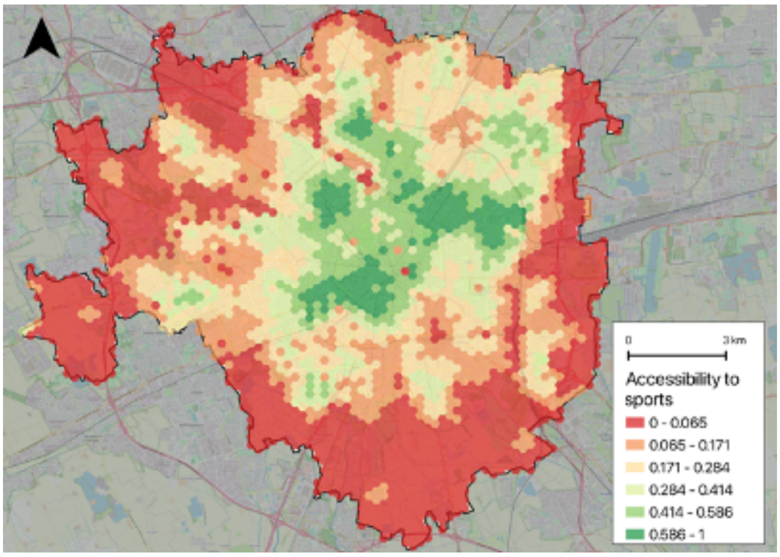
Public transport is the service with the least GINI index among all the POIs analyzed. The result is highly influenced by the distribution of the bus stops along the city. Also, the tram and metro network have a high-density service after the first ring that dived the city center; this allows people to access public transport, even without living in the city center. Car sharing and bike sharing systems are the least equally distributed services since cars have a larger range of travel. The distribution of the car sharing point is slightly larger than bicycles, which have a higher concentration in the middle neighborhood were, as seen in chapter 7.4, they have a better comfort perception of the space.



Category	GINI
Bus	0.3395
Tram	0.6141
Metro	0.6175
Car sharing	0.655
Bike sharing	0.6916

TABLE 8-1 ACCESSIBILITY TO PUBLIC TRANSPORT

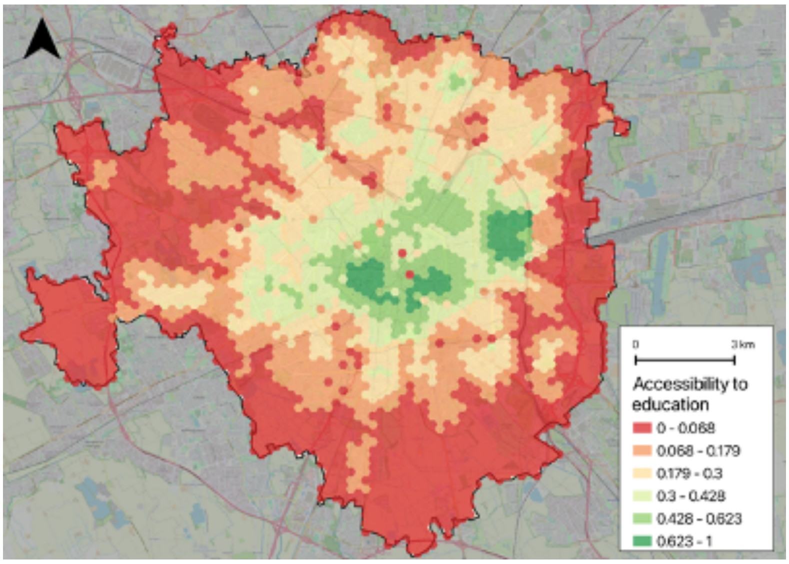
Following with sports, playgrounds played a major role on the distribution of this category, as they cover most of the area of the group. However, both fitness center and sport locations, are placed on areas with high density population, which allows them to have a higher catchment of people even with low number of points. The distribution in the city shows a different cluster of the category sports, and since most of these activities require green or open areas, the density in the city center is lower in comparison to other kinds of POIS.



Category	GINI
Playgrounds	0.3532
Fitness Center	0.7096
Sport location	0.7212

TABLE 8-2 ACCESSIBILITY TO SPORTS

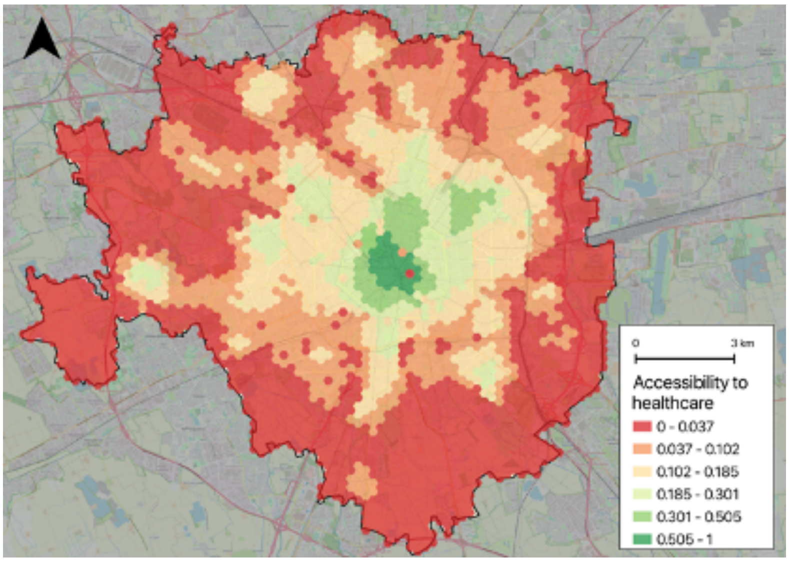
The education GINI coefficients reflect the expected distribution of the POIs by the classification. (See Figure C-8) Kindergartens have a low inequality across the city. Since they do not have big buildings, and have a low number of students, they respond to local demands. In the case of nurseries and primary schools they both practically have the same GINI index. In the case of nurseries, it was expected to be distributed at a more similar level to kindergartens than to primary schools, which could point to a lack of nurseries in the city. Secondaries still have a similar level of aggregation of students to primary schools and even the location seems to be similar, but the number in secondary school indicates a higher inequality. Libraries and universities are highly concentrated in Duomo and Bovisa (Milan Business School and Polimi) and Città Studi (University of Milan); they influence the accessibility calculation for the education category on those NILs. The main difference is that universities have presence in the northern part of the city between Bicocca and Greco, where the University of Bicocca has its campus.



Category	**GINI**
Kindergarten	0.3912
Primary	0.4231
Nursery	0.4256
Secondary	0.4846
Library	0.7659
University	0.8325

TABLE 8-3 ACCESSIBILITY TO EDUCATION

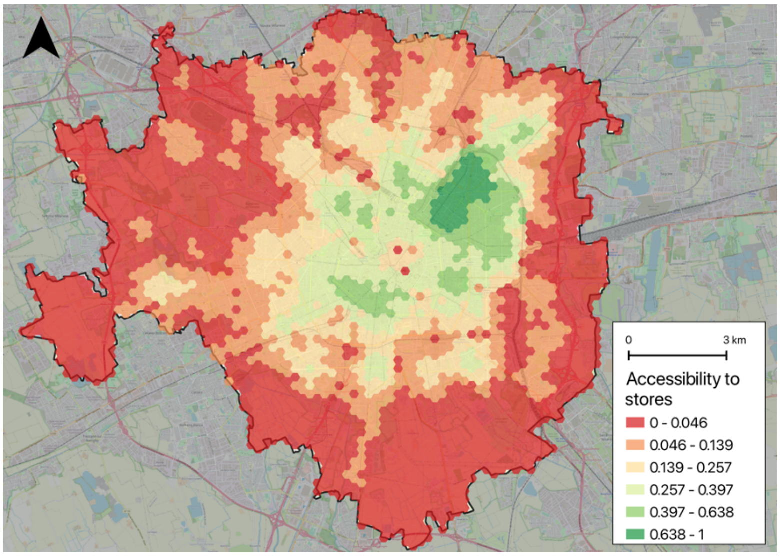
In the case of healthcare and social care (see Figure C - 7), there is a high concentration towards the center of city. Community center had the lowest Gini value for this category, being the most equitably distributed, while chemist where the least. Hospitals are well distributed across the city avoiding specific clusters. Some areas in the south and northwest may be lacking coverage, and doctor’s offices are highly concentrated in populated NILS as Buenos Aires-Venezia or Loreto.



Category	GINI
Community center	0.4687
Pharmacy	0.5447
Social Facility	0.6501
Hospital	0.6747
Doctors	0.6966
Clinic	0.7211
Chemist	0.7485

TABLE 8-4 ACCESSIBILITY TO HEALTH

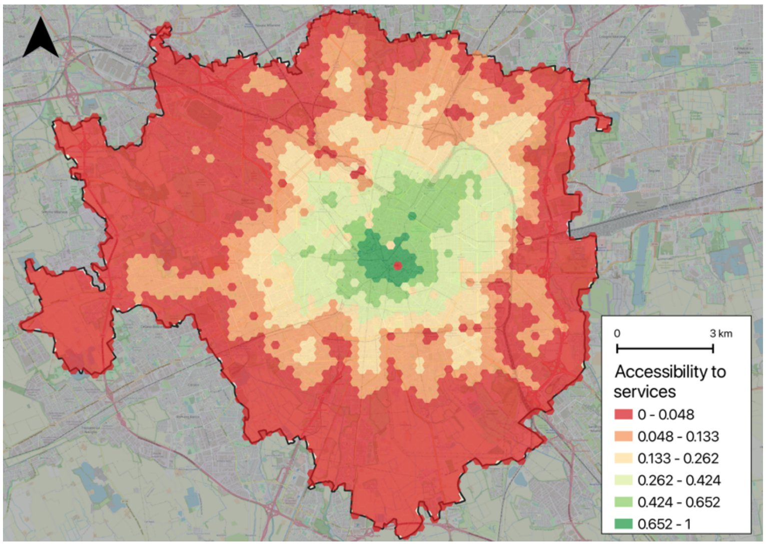
In the case of commercial points, in general Supermarket had the best Gini index while administration had the worst. Within each subcategory, the Stores do not follow the pattern of high concentration in the city center, rather they are in the NILs populated areas NILS as Buenos Aires-Venezia or Loreto.



Category	GINI
Supermarket	0.4889
Groceries	0.6282
Street market	0.7036

TABLE 8-5 ACCESSIBILITY TO STORES

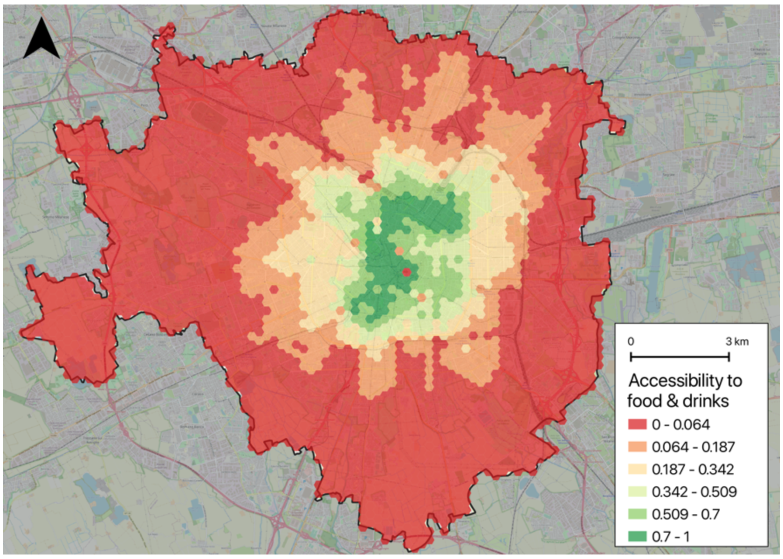
In case of services, they Kiosks had the best Gini index, however, this subcategory of commercial services is highly concentrated in the city center including the area around the Central Station.



Category	GINI
Kiosk	0.5177
Newstand	0.5637
Post office	0.5673
Hairdresser	0.5909
Bank	0.6738
ATM	0.7341
Administration	0.8333

TABLE 8-6 ACCESSIBILITY TO SERVICES

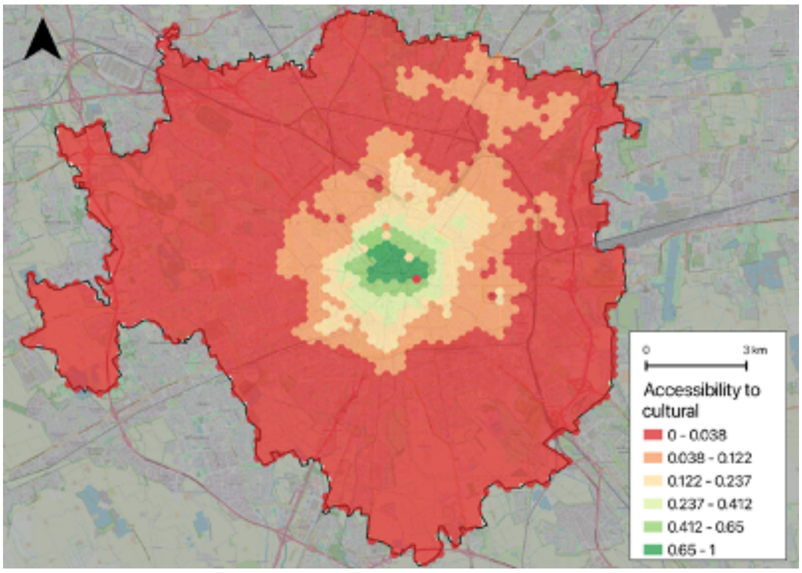
The Food and Drinks category did not have many difference between the POIs, and the location show a concentration in the city center, probability in the surrounding of the tourist attraction of the city.



Category	GINI
Café	0.5934
Bar	0.6092
Restaurant	0.6669
Pub	0.6718

TABLE 8-7 ACCESSIBILITY TO FOODS & DRINKS

Finally, the cultural offer (see Figure C-6) had the worst Gini value of all the categories. The points are located mainly in the NILs Duomo and Magenta, San Vittore in the center of the city, the exceptions are the arts centre that have a cluster in surrounding of Corsica, Ortomercado, Umbria-Molise and XXII Marzo. From the Lorenz curve it is possible to identify that 40% of the population had nearly zero access to cultural locations and by 65% the possibility barely increases to 10%.



Category	**GINI**
Theatre	0.6823
Arts Centre	0.7671
Cinema	0.7913
Gallery	0.8344
Museum	0.8464

TABLE 8-8 ACCESSIBILITY TO CULTURE

8.4. Vertical Equity

For the vertical equity, the evaluation is a correlation analysis between accessibility to all categories of POIs, and the sociodemographic characteristics of nationality, age group, and family type. First, to interpret the results, it is necessary to define a scale. In general, the correlation analysis goes from -1 to 1, where the closer to each of the extremes the stronger the correlation. In the case of this study, none of the general or detailed results is higher than 0.4 or less than -0.4. Then, as reference, the results will be analyzed by the next scale. The analysis will be done following each of the sociodemographic characteristics.

TABLE 8-9 CORRELATION CATEGORIES

Streng of relationship	**Absolute correlation value**
No relation	0 - 0.1
weak correlation	0.1 -0.25
strong correlation	0.25 - 0.4

First, the nationality characteristic reveals there is a strong negative correlation between Italians and cultural places, while for the other categories there is basically no relation. Similarly, cultural places have a strong negative correlation with non-Italians; in addition, all the other categories are also strong negatively correlated with them. The immigration background indicates that the higher the number of foreigners, the lesser the number of amenities and services of all categories. In the case of Italians this relation only applies for cultural spaces.

Continuing with age groups, overall, young adults have a weak negative correlation with all categories, and the strongest negative correlation is sport amenities. In the case of adults, the behavior of the correlations is very similar to young adults; however, correlations are slightly stronger. This means that for this groups the higher the amount of young and adults in an area, the fewer available services due to the correlation. However, it is important to remember that it is a weak correlation. Finally, for the group of seniors, they have a weak positive correlation with all the categories of amenities, except with cultural spaces. It is interesting to highlight that the highest correlation of this group is with education services, when the assumption would be that these services target younger age groups. A possible assumption is that the central location of education services makes it harder for young households to acquire or rent a property in central locations.

Finally, for the family types the results could be grouped in two major clusters: couples and singles. For couples, either married or not, but with the condition of not having children, there is no correlation with any of the categories of amenities, just a weak negative correlation with cultural places. More interesting is that couples with children have a strong negative correlation to all the categories. This finding indicates that having children is related to having worst accessibility to all services in the city. In the case of singles or other types of families, there is no correlation with any of the categories of the amenities.

TABLE 8-10 CORRELATION RESULTS FOR ALL CATEGORIES

term	commercial_mean	cultural_mean	sports_mean	healthcare_mean	education_mean	public_transport_mean
p_italia	-0.05	-0.24	0.02	-0.08	0.05	-0.02
p_altre_nazioni	-0.22	-0.25	-0.2	-0.21	-0.26	-0.28
p_youngs	-0.13	-0.19	-0.2	-0.16	-0.15	-0.18
p_adults	-0.14	-0.18	-0.2	-0.18	-0.19	-0.19
p_seniors	0	-0.1	0.12	0.06	0.16	0.07
p_coh_no_ch	-0.02	-0.06	-0.05	-0.11	-0.11	-0.08
p_coh	-0.28	-0.28	-0.33	-0.32	-0.35	-0.34
p_mar_no_ch	-0.09	-0.16	0.01	-0.04	0.05	-0.03
p_mar	-0.23	-0.25	-0.25	-0.24	-0.2	-0.24
p_ot	-0.05	-0.11	-0.07	-0.05	-0.02	-0.07
p_sing_no_ch	-0.03	-0.13	-0.03	-0.04	-0.02	-0.06
p_sing	-0.02	-0.05	-0.07	-0.04	-0.06	-0.06

To further analyze the relations between the socio demographic characteristics of the population and the accessibility to the categories of amenities, a multiple linear regression model analyses the significance of the variables when estimating the level of accessibility. In the correlation analysis, each variable is evaluated separately. With the multiple regression model, the variables influence each other and the relation with independent variable can change from the original correlation analysis.

To evaluate the results of the multiple linear regression models it is necessary to determine which variables are significant to estimate accessibility because for the model, the variables are influencing each other. The first run of the model with all the variables had a problem of singularity to calculate the estimators of all the social characteristics (see Figure C-11). This occurs due to the strong correlation between the independent variables. To solve it, the variable *p_ot* was removed from all models because it was the variable with highest P-value. As a results, Figure 8-7 shows how some of the variables that were significant in the first model, no longer had the noise from this variable and were not significant anymore.

	commercial			cultural			sports		
	Estimate	P-value		Estimate	P-value		Estimate	P-value	
(Intercept)	0.6376	0.000354	***	0.58388	3E-09	***	0.45997	0.00519	**
p_italia	-0.4261	0.038975	*	-0.54875	1.1E-06	***	-0.18517	0.33321	
p_altre_nazioni	-1.1274	0.002133	**	-0.79267	3.7E-05	***	-0.49528	0.14037	
p_youngs	1.8751	0.485163		0.30271	0.82491		0.54213	0.82932	
p_adults	2.5457	0.399775		0.71333	0.64314		1.59622	0.57284	
p_seniors	0.3802	0.898124		-0.842	0.5787		0.65523	0.81398	
p_coh_no_ch	-6.6585	0.092474	.	-3.89634	0.05428	.	-3.93331	0.28638	
p_coh	-10.5934	0.006017	**	-5.32394	0.00676	**	-6.9321	0.05218	.
p_mar_no_ch	-0.7357	0.831061		1.214	0.49069		-1.04212	0.74724	
p_mar	-3.5832	0.23637		-1.46555	0.34159		-2.10619	0.45659	
p_ot	-	-	-	-	-	-	-	-	-
p_sing_no_ch	-0.8824	0.767303		0.22924	0.88018		-0.46095	0.86901	
p_sing	1.2453	0.737377		2.11833	0.26524		0.08172	0.98127	
R-square	0.3668			0.5078			0.2496		
R-square ajusted	0.2751			0.4366			0.141		

	healtcare			education			public_transport		
	Estimate	P-value		Estimate	P-value		Estimate	P-value	
(Intercept)	0.37575	0.000079	***	0.4232	0.00307	**	0.7149	7.4E-05	***
p_italia	-0.29231	0.0079	**	-0.2135	0.19868		-0.4406	0.03307	*
p_altre_nazioni	-0.47346	0.0136	*	-0.6744	0.02174	*	-1.1322	0.00206	**
p_youngs	0.15007	0.9156		1.5128	0.48781		1.3838	0.60646	
p_adults	0.61773	0.6984		1.9604	0.42428		2.3518	0.43682	
p_seniors	-0.61499	0.6952		1.1597	0.63072		0.5493	0.85337	
p_coh_no_ch	-4.74417	0.0243	*	-4.734	0.13971		-6.5499	0.09805	.
p_coh	-5.02955	0.0131	*	-8.0138	0.01022	*	-10.1293	0.00853	**
p_mar_no_ch	0.76168	0.676		-1.8309	0.51358		-0.9925	0.77368	
p_mar	-1.31573	0.4093		-2.1912	0.37141		-3.1114	0.30365	
p_ot	-	-	-	-	-	-	-	-	-
p_sing_no_ch	0.37213	0.8132		-0.8845	0.71483		-0.6676	0.82294	
p_sing	1.73579	0.3773		-0.2729	0.92783		0.6817	0.85442	
R-square	0.3884			0.3169			0.3687		
R-square ajusted	0.3045			0.218			0.2773		

FIGURE 8-7 MULTIPLE LINEAR REGRESSION OF ALL AMENITIES

The significant variables are those whose P-value is less or equal than the significance level; in this case, it was 0.1. These variables are represented by a star (*) or a point (.). When a variable is not significant, it means that the estimator of the variable could be zero and the variable has no influence in the accessibility. In every model, the non-significant variables were removed one by one, always removing the variable with the highest P-value until all the remaining variables were significant for the model. A few exceptions applied.

	commercial			cultural			sports		
	Estimate	P-value		Estimate	P-value		Estimate	P-value	
(Intercept)	0.6376	0.000298	***	0.58388	3.1E-09	***	0.45997	0.00433	**
p_italia	-0.4366	0.029446	*	-0.52922	1.7E-06	***	-0.17102	0.347	
p_altre_nazioni	-1.1173	0.001854	**	-0.75409	5.2E-05	***	-0.56271	0.05688	.
p_youngs	1.6654	0.04002	*	-	-	-	-	-	-
p_adults	2.3451	0.000751	***	1.03802	0.00029	***	1.34765	0.00382	**
p_seniors	-	-	-	-0.19919	0.07665	.	0.07411	0.69555	
p_coh_no_ch	-6.8949	0.027287	*	-3.50864	0.02687	*	-4.46021	0.10907	
p_coh	-10.2625	4.21E-05	***	-5.08999	1.3E-05	***	-5.81017	0.00263	**
p_mar_no_ch	-	-	-	-	-	-	-	-	-
p_mar	-3.5697	0.000316	***	-1.39191	0.00152	**	-2.07642	0.00567	**
p_ot	-	-	-	-	-	-	-	-	-
p_sing_no_ch	-0.6617	0.073777	.	-	-	-	-	-	-
p_sing	1.6885	0.112358		0.9308	0.06852	.	-	-	-
R-square	0.3656			0.4827			0.2412		
R-square ajusted	0.2927			0.4303			0.1748		

	healtcare			education			public_transport		
	Estimate	P-value		Estimate	P-value		Estimate	P-value	
(Intercept)	0.37575	7.49E-05	***	0.27462	1.6E-05	***	0.7149	5.5E-05	***
p_italia	-0.32058	0.002328	**	-	-	-	-0.426	0.02493	*
p_altre_nazioni	-0.43431	0.019933	*	-0.48312	0.03725	*	-1.1368	0.00047	***
p_youngs	-	-	-	-	-	-	-	-	-
p_adults	-	-	-	1.43789	0.00028	***	2.0503	3E-05	***
p_seniors	-0.57145	0.003171	**	-	-	-	-	-	-
p_coh_no_ch	-2.30625	0.050945	.	-5.58753	0.02229	*	-6.9758	0.01967	*
p_coh	-5.14262	1.38E-06	***	-5.99834	0.00018	***	-7.9275	7.2E-05	***
p_mar_no_ch	-	-	-	-	-	-	-	-	-
p_mar	-	-	-	-2.07116	0.0015	**	-2.8925	0.00036	***
p_ot	-	-	-	-	-	-	-	-	-
p_sing_no_ch	0.69685	0.000314	***	-	-	-	-	-	-
p_sing	1.864	0.000286	***	-	-	-	-	-	-
R-square	0.3568			0.3168			0.3488		
R-square ajusted	0.3005			0.2281			0.3005		

Once the final models were estimated, it is possible to interpret the results. First, the intercept is significant for all models, this means that if all the variables were to take the value of zero, the intercept is the expected value of the accessibility for each model. Here, the accessibility is using the normalized value, then as expected from the Lorenz curves and Gini calculations, public transport has the highest accessibility expected value, however, here the expected value for cultural is the third largest of all and education has the lowest expected value of accessibility with variables that were significant for the corresponding model.

Second, in comparison with the correlation analysis, for the foreign background, household with Italian background went from having no relation, to being significant in almost all the models with exception of education. For foreigner, the results are consistent for both analyses. In the case group ages, young are significant for commercial accessibility, while the strongest correlation was sports. More importantly, the sign of the estimator changed, which means that with influence of all the other variables, now young have positive correlation with commercial accessibility. This behavior replicates for adults with all the amenities where they are significant. In the case of seniors, for cultural and sports amenities, they are consistent, but for healthcare, the sign changes in comparison with the individual correlation. To finish the comparison, the main outcome from the correlation analysis is still valid for the linear regression models. Couples with children have a strong negative correlation to all the categories. By comparing couples without children, only those that are not married are significant in the accessibility estimation and have a negative correlation. In the case of singles, those who do not have children are significant for commercial and healthcare amenities, while those with children are also significant for the accessibility of cultural places, for these last, is important to highlight that the correlation changed from negative in the individual analysis to positive in linear model.

8.5. Deprivation Index

After analysis the distribution of the amenities in the space, the accessibility distribution across the households, and influence of the sociodemographic characteristics in accessibility, a deprivation analysis was done to identify the NILs that lack accessibility to the essential services describe in chapter 2.5, particularly for those NILs with higher proportion of vulnerable groups. To develop this analysis is necessary to define the variables of the Equation 2-1. Based on the analysis from the literature review, following refer to the basic needs in conjunction with the amenities evaluated for this study:

- Food: grocery, supermarket, street market;
- Health: doctors, clinic, and hospital;
- Basic education: kindergarten, primary school, and secondary school;
- Transport: bus, tram, and metro.

For the calculation, the accessibility for the basic needs was the simple average of the amenities selected. In the case of the vulnerable groups of people and considering the results from the vertical equity analysis for the defined basic needs, the following characteristics determine them: Foreign nationality and Young and couples (non-married or married) with children. To include the percentages of the vulnerable characteristics, it was not correct to do a simple average to calculate the vulnerable group it was necessary to estimate the union of the groups of interest.

Equation 8-1 Estimation of vulnerable groups

$$F \cup Y \cup C = F + Y + C - (F \cap Y) - (F \cap C) - (Y \cap C) + (F \cap Y \cap C)$$

with: $F = \%\, foreigners$

$Y = \%\, young$

$C = \%\, couples\ with\ children$

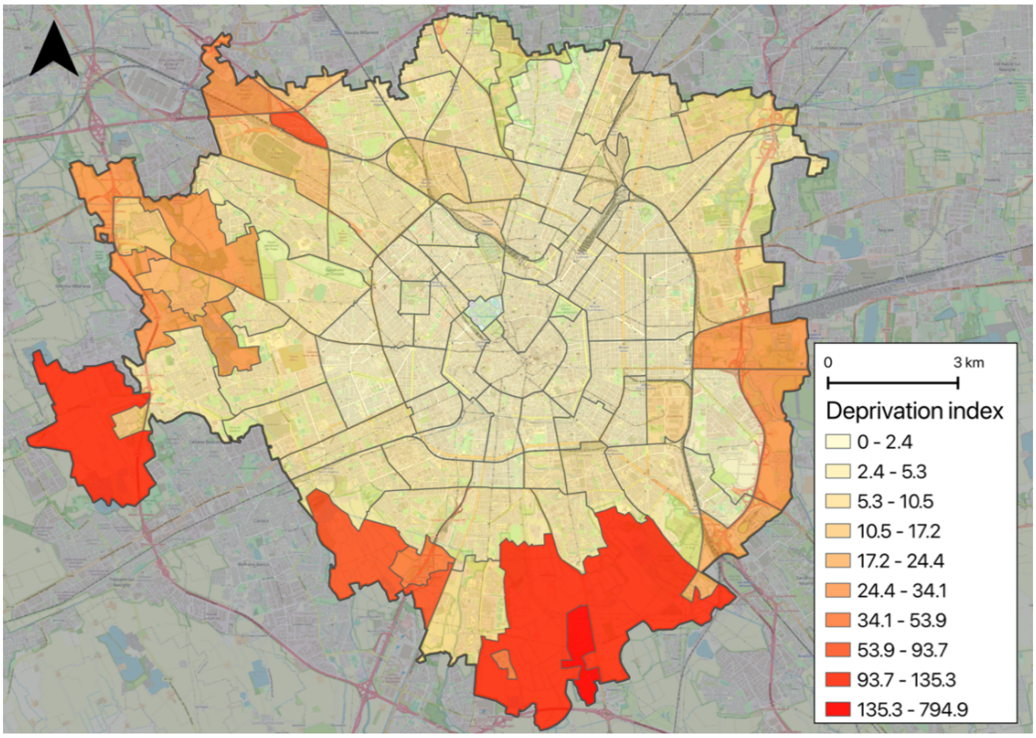


Figure 8-8 Deprivation index for vulnerable groups

The results were assigned to each the NILs (see Figure 8-8), as expected, the most vulnerable groups are located on the outskirts of the city. The highest deprivation value is for Quintosole, the small NIL in the south of the city, other NILs with high deprivation index are in the south, east, and west perimeter of the city. In general, the city has a good equality of accessibility, if considering Quintosole as an outsider (the deprivation index is almost 6 times greater than the next NIL), 10.3% of the NILs are within the highest quintile of the deprivation index (see Figure C-12), and in general they are areas with a high rural percentage. Table 8-11 shows the NILs within the highest quintile of the deprivation index.

Table 8-11 NILs with the highest Deprivation Index

NIL	Name	Deprivation Index
39	Quintosole	794.89
87	Parco Agricolo Sud	135.34
85	Parco delle Abbazie	107.35
86	Parco dei Navigli	93.74
75	Stephenson	69.63

47	Cantalupa	53.88
40	Ronchetto delle Rane	44.30
31	Parco Monlué - Ponte Lambro	34.15
73	Cascina Triulza - Expo	31.74
24	Parco Forlanini - Ortica	29.19
88	Parco Bosco in Città	26.62

Following the methodology of the deprivation index, and according to the results of the vertical equity, families with children have a strong negative correlation with accessibility to multiple amenities; for that reason, a second deprivation analysis was done for amenities that are attractive or necessary for the kids in the city. However, within the age groups, the information available did not have information for populations younger than 18 years old. To overcome this issue, the vulnerable group was assumed to be the couples, either married or not, and singles with children that belong to the age group of young (18-35). In this way, the filtered group would represent young parents with kids. For amenities considered, they were kindergartens, nurseries, primary, secondary, playgrounds and sport locations. Figure 8-9 shows the results of the deprivation index for kids.

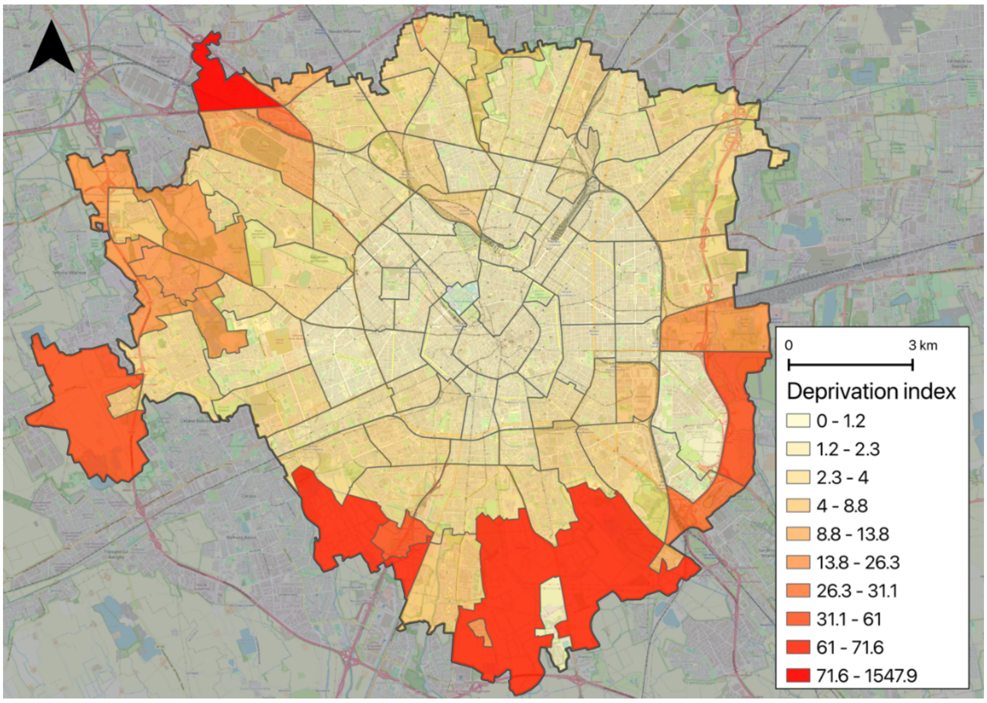


FIGURE 8-9 DEPRIVATION INDEX FOR KIDS

The deprivation index was very similar to the calculation for the vulnerable groups; the most vulnerable groups of kids are located on the outskirts of the city. The highest deprivation value is for Cascina Triulza - Expo, a limit NIL in the northwest of the city.

Other NILs with high deprivation index are in the south, east, and west perimeter of the city. In comparison with the vulnerable groups, the city still has a good equality of accessibility to amenities for kids but is worse than the original calculation.

Table 8-12 NILs with the highest Deprivation Index Kids

NIL	Name	Deprivation Index Kids
73	Cascina Triulza - Expo	1547.93
85	Parco delle Abbazie	71.63
86	Parco dei Navigli	66.45
87	Parco Agricolo Sud	61.00
47	Cantalupa	37.69
31	Parco Monlué - Ponte Lambro	37.61
75	Stephenson	31.09
32	Triulzo Superiore	30.64
40	Ronchetto delle Rane	26.32
24	Parco Forlanini - Ortica	19.72
62	Quinto Romano	17.57
88	Parco Bosco in Città	16.74

Once again, the NIL with the highest deprivation index can be considered an outsider. In this case, Cascina Triulza - Expo had a deprivation index 21 times greater than the next NIL. If taken out, 12.5% of the NILs are within the highest quintile of the deprivation index (see Figure C-13), and in general they are areas with a high rural percentage, which are located within the highest quintile of the deprivation index.

9. Conclusion

9.1. Findings

This master thesis developed a spatial fairness assessment to essential services in Milan. For this purpose, the analysis will be done using the Inclusive Accessibility by Proximity Index (IAPI). From the implementation of the IAPI in GOAT for the study are in Milan, is important to highlight the methodology to evaluate comfort of the urban area within a gravitational-based accessibility measure. By including the comfort as factor that influences the perceived time in walking trips, and using the accessibility tools as the isochrones, it is possible to visualize the impact of green and attractive streets on the walkability experience for people on a street/neighborhood scale. From the heatmap comparison, is significant to notice that perceived accessibility may show lower levels of accessibility across the city, due to the high number of impedance values that are being considered within the calculation. This result is aligned with Lucas et al. (2016) when they refer to the person-based measures as more conservative than place-based measures in terms of assessing the level of equity of service delivery.

Before analyzing the results from the spatial fairness assessment is critical to conclude on the comparison between the Z-Score and the Min-Max. The graphical representation of a normalization by Z-Score allows for a statical analysis rather than a spatial analysis. Because the Z-Score visualization overestimates the reach of the points and is not very useful to analyze the spatial distribution. Consequently, a histogram graph is a better tool to understand the accessibility distribution of the POIs.

The spatial fairness assessment had three parts, the horizontal analysis, with results from the accessibility calculation for walking trips using a Min-Max normalization; the vertical analysis, calculating the a correlation between the sociodemographic characteristics of the households and the average accessibility of all the categories of POIs; and, the estimation on the deprivation index, to find which areas of the city have the most vulnerable population with the lowest accessibility levels to essential services.

First, the horizontal analysis, revealed that public transport is the most equitable category of POIs in the city (Gini = 0.4085), the least equitable is cultural POIs (Gini = 0.7387). The results show a very high concentration of the POIs in the city center for most of the categories, this characteristic highlights for the categories of public transport, highly influenced by car and bike-sharing systems, healthcare, influenced by community center and social facilities, commercial services, food and drinks, and culture. Since the city center, NIL Duomo, does not have a particular high population living there, the concentration of this points may be induced by the tourism the city attracts. A similar behavior, but in another location, occur in the surroundings of NILs 21-Buenos Aires – Venezia and 22-Città Studi, where multiple POIs have generated a secondary center of concentration and categories like Stores and education, are mainly concentrated there.

In the vertical equity, the correlation analysis was calculated form all socio demographic characteristic, the first group, nationality, household with foreign background have a strong negative correlation with all the categories. This means, that the higher the percentage of non-Italians, the lower the accessibility to all POIs. In the case of group age exist a negative correlation between young, and adults with the accessibility to all POIs. However, it is important to remember that it is a weak correlation. Also, It is interesting to find that the highest correlation seniors is with education services, when the assumption would be that these services target younger age groups. And for type of families, the main finding is that couples with children have a strong negative correlation to all the categories. This finding indicates that having children is related to having worst accessibility to all services in the city.

The vertical analysis had a second part, a multiple linear regression was calculated having the average accessibility as the dependent variable and having the sociodemographic characteristics as the independent variables. In comparison with the results from the correlation analysis, for the nationality characteristic, households with Italian background went from having no relation, to being significant and positively correlated with accessibility in almost all the models with exception of education. For foreigner, the results are consistent for both analyses. In the case of the age groups, the results did not show a clear consistency for any of the categories, so the influence of the other variables changed the original weak negative correlation with of young and adult groups. Finally, for types of households, couples with children still have a strong negative correlation to all the categories.

Finally, for the deprivation index, it was necessary to define the essential services, and the vulnerable populations. In the first place, the categories to define essential were food, health, basic education, and transport. In the other hand, from the results of the verticals analysis the vulnerable groups were foreign nationality and young and couples (non-married or married) with children. The highest deprivation value is for Quintosole, the small NIL in the south of the city. In relation with the rules of justice, the essential services in Milan follow a mix between equitable and efficiency. The equitable result is reflected on the 10.3% of the NILs are within the highest quintile of the deprivation index, it is a low number, considering that these areas have a rural context where normally accessibility is higher. But the horizontal analysis reveals a high concentration of some of these services in areas with high population as the NILs 1 – Duomo and 21 – Venezia – Buenos Aires. The second analysis, the deprivation index for kids, shows a similar result as the calculation for vulnerable populations, but is important to highlight that the equity conditions, are worst in comparison with the first analysis. This is reflected in the 12.5% of the NILs are within the highest quintile of the deprivation index.

9.2. Recommendations

As part of the outcomes for this master's thesis, next is the set of recommendations to be for the IAPI and its application in Milan and the other partner cities from the EX-TRA project. This section also reflects the point of improvement for future research.

First, the IAPI is originally conceived as quantitative tool that expresses the actual levels of accessibility to selected destinations at the neighborhood scale (Pucci, Carboni, et al., 2021). With this research is proven that it has the potential to be escalated to a city level, nevertheless the requirements on the network data are suggested to change.

The IAPI requires six categories of indicator (network categories in this research), type of road, peak hour traffic, cyclepaths, sidewalks width, obstacles, slopes, and limited speed areas. To facilitate both the transferability and scalability of the IAPI, is recommended to change them into more open data friendly category. For example, in this research, the road category did not limit to footpaths, sidewalks, tunnels and bridges. It covered the complete spectrum of categories from OpenStreetMap. In this sense, the indicator Limited speed areas, was moved within the roads category as Living Streets.

In the similar sense, depending on information such as peak hour traffic, or sidewalks width even for a neighborhood scale can be challenging. In the case of peak hour, it can include other negative externalities as noise or pollution to include the effect of traffic. In the case of sidewalk width, it is a hard indicator to build, so may be the presence or absence of sidewalk can be enough.

For the implementation of comfort within the gravity-based accessibility calculation, the impedance factors were estimated following methodologies and analysis from the literature review, however, from the experts meeting (see Table A-4) and with the results from the project "Access to Rail", making a local survey can have better results on the estimation of the impedance factors and even improve the weighting system of the characteristics for the accessibility calculation.

Finally, one on the main motivations for this research, was to improve the person-based perspective into the accessibility calculation. This perspective is currently being consider by the Inclusive part of the index, pedestrians, cyclists, and wheelchair users. However, other characteristics as foreign background, or having children play can have similar effects on the accessibility of essential services. To overcome it, from the definition of the basket of services can include a person-based analysis as the essential services defined in the literature review. Also, including the calculation of equity indexes can have a higher impact on the results of the IAPI.

References

Abdelfattah, L., Deponte, D., & Fossa, G. (2022). The 15-minute city: Interpreting the model to bring out urban resiliencies. *Transportation Research Procedia*, *60*, 330–337. https://doi.org/10.1016/j.trpro.2021.12.043

Ben-Akiva, M., & Lerman, S. R. (1985). *Discrete Choice Analysis*.

Birch, C. P. D., Oom, S. P., & Beecham, J. A. (2007). Rectangular and hexagonal grids used for observation, experiment and simulation in ecology. *Ecological Modelling*, *206*(3), 347–359. https://doi.org/10.1016/j.ecolmodel.2007.03.041

Blecic, I., Cecchini, A., Congiu, T., Fancello, G., & Trunfio, G. A. (2015). Evaluating walkability: A capability-wise planning and design support system. *International Journal of Geographical Information Science*, *29*(8), 1350–1374. https://doi.org/10.1080/13658816.2015.1026824

Cain, K. L., Geremia, C. M., Conway, T. L., Frank, L. D., Chapman, J. E., Fox, E. H., Timperio, A., Veitch, J., Van Dyck, D., Verhoeven, H., Reis, R., Augusto, A., Cerin, E., Mellecker, R. R., Queralt, A., Molina-García, J., & Sallis, J. F. (2018). Development and reliability of a streetscape observation instrument for international use: MAPS-global. *International Journal of Behavioral Nutrition and Physical Activity*, *15*(1), 19. https://doi.org/10.1186/s12966-018-0650-z

Cardoso, R., Sobhani, A., & Meijers, E. (2021). The cities we need: Towards an urbanism guided by human needs satisfaction. *Urban Studies*, 004209802110455. https://doi.org/10.1177/00420980211045571

Carter, K., & Moir, S. (2012). Diagrammatic Representations of Sustainability – a Review and Synthesis. *Proceedings 28th Annual ARCOM Conference, 3-5 September 2012, Edinburgh, UK.*, 1479–1489.

Centro Studi PIM. (2019). *Piano Urbano Mobilità Sostenible*. Città metropolitana di Milano.

Chatterjee, A., Ghosh, A., & Chakrabarti, B. K. (2017). Socio-economic inequality: Relationship between Gini and Kolkata indices. *Physica A: Statistical Mechanics and Its Applications*, *466*, 583–595. 12. https://doi.org/10.1016/j.physa.2016.09.027

Città Metropolitana di Milano. (2022, February 22). *Territorio e comuni*. https://www.cittametropolitana.mi.it/portale/territorio/index.html

Comune di Milano. (n.d.-a). *Open Data*. https://dati.comune.milano.it/

Comune di Milano. (n.d.-b). *Sistema Statistico Integrato*. http://sisi.comune.milano.it/

Comune di Milano. (2019, October 14). *Milano 2030—PGT VIGENTE*. https://www.pgt.comune.milano.it/

Dalvi, M. Q., & Martin, K. (1976). The measurement of accessibility: Some preliminary results. *Transportation*, *5*(1), 17–42.

De Vos, J. (2020). The effect of COVID-19 and subsequent social distancing on travel behavior. *Transportation Research Interdisciplinary Perspectives*, *5*, 100121. https://doi.org/10.1016/j.trip.2020.100121

Dong, X., Ben-Akiva, M. E., Bowman, J. L., & Walker, J. L. (2006). Moving from trip-based to activity-based measures of accessibility. *Transportation Research Part A: Policy and Practice*, *40*(2), 163–180. 18. https://doi.org/10.1016/j.tra.2005.05.002

Duran-Rodas, D., Villeneuve, D., Pereira, F. C., & Wulfhorst, G. (2020). How fair is the allocation of bike-sharing infrastructure? Framework for a qualitative and quantitative spatial fairness assessment. *Transportation Research Part A: Policy and Practice*, *140*, 299–319. 21. https://doi.org/10.1016/j.tra.2020.08.007

Duran-Rodas, D., Wright, B., Pereira, F. C., & Wulfhorst, G. (2021). Demand And/oR Equity (DARE) method for planning bike-sharing. *Transportation Research Part D: Transport and Environment*, *97*, 102914. 4. https://doi.org/10.1016/j.trd.2021.102914

Eisenmann, C., Nobis, C., Kolarova, V., Lenz, B., & Winkler, C. (2021). Transport mode use during the COVID-19 lockdown period in Germany: The car became more important, public transport lost ground. *Transport Policy*, *103*, 60–67. https://doi.org/10.1016/j.tranpol.2021.01.012

El-Geneidy, A., Grimsrud, M., Wasfi, R., Tétreault, P., & Surprenant-Legault, J. (2014). New evidence on walking distances to transit stops: Identifying redundancies and gaps using variable service areas. *Transportation*, *41*(1), 193–210. https://doi.org/10.1007/s11116-013-9508-z

Eriksson, L., Garvill, J., & Nordlund, A. M. (2008). Acceptability of single and combined transport policy measures: The importance of environmental and policy specific beliefs. *Transportation Research Part A: Policy and Practice*, *42*(8), 1117–1128. https://doi.org/10.1016/j.tra.2008.03.006

Ewing, R., & Handy, S. (2009). Measuring the Unmeasurable: Urban Design Qualities Related to Walkability. *Journal of Urban Design*, *14*(1), 65–84. https://doi.org/10.1080/13574800802451155

Fraser, N. (1995). Recognition or Redistribution? A Critical Reading of Iris Young's Justice and the Politics of Difference*. *Journal of Political Philosophy*, *3*(2), 166–180. https://doi.org/10.1111/j.1467-9760.1995.tb00033.x

Geurs, K. T., & van Wee, B. (2004). Accessibility evaluation of land-use and transport strategies: Review and research directions. *Journal of Transport Geography*, *12*(2), 127–140. 15. https://doi.org/10.1016/j.jtrangeo.2003.10.005

Goldman, B., & Cropanzano, R. (2015). "Justice" and "fairness" are not the same thing. *Journal of Organizational Behavior*, *36*(2), 313–318. https://doi.org/10.1002/job.1956

Gössling, S. (2020). Why cities need to take road space from cars—And how this could be done. *Journal of Urban Design*, *25*(4), 443–448. https://doi.org/10.1080/13574809.2020.1727318

Guzman, L. A., & Bocarejo, J. P. (2017). Urban form and spatial urban equity in Bogota, Colombia. *Transportation Research Procedia*, *25*, 4491–4506. https://doi.org/10.1016/j.trpro.2017.05.345

Guzman, L. A., Oviedo, D., & Rivera, C. (2017). Assessing equity in transport accessibility to work and study: The Bogotá region. *Journal of Transport Geography*, *58*, 236–246. 2. https://doi.org/10.1016/j.jtrangeo.2016.12.016

Hansen, W. G. (1959). How Accessibility Shapes Land Use. *Journal of the American Institute of Planners*, *25*(2), 73–76. https://doi.org/10.1080/01944365908978307

Heeks, R. (2021). *From Digital Divide to Digital Justice in the Global South: Conceptualising Adverse Digital Incorporation*.

Ian Gough & Len Doyal. (1991). *A Theory of Human Need* (1st ed.). Red Globe Press London. https://doi.org/10.1007/978-1-349-21500-3

Ingram, D. R. (1971). The concept of accessibility: A search for an operational form. *Regional Studies*, *5*(2), 101–107. https://doi.org/10.1080/09595237100185131

ISFORT. (2020). *17° Rapporto sulla mobilità degli italiani*.

Kuzmyak, J. R., Baber, C., & Savory, D. (2006). Use of Walk Opportunities Index to Quantify Local Accessibility. *Transportation Research Record: Journal of the Transportation Research Board*, *1977*(1), 145–153. https://doi.org/10.1177/0361198106197700117

Kwan, M.-P. (2010). Space-Time and Integral Measures of Individual Accessibility: A Comparative Analysis Using a Point-based Framework. *Geographical Analysis*, *30*(3), 191–216. 36. https://doi.org/10.1111/j.1538-4632.1998.tb00396.x

Kymlicka, W. (2002). Multiculturalism and minority rights: West and East. *JEMIE - Journal on Ethnopolitics and Minority Issues in Europe*, *4*, 24.

Labdaoui, K., Mazouz, S., Moeinaddini, M., Cools, M., & Teller, J. (2021). The Street Walkability and Thermal Comfort Index (SWTCI): A new assessment tool combining street design measurements and thermal comfort. *Science of The Total Environment*, *795*, 148663. https://doi.org/10.1016/j.scitotenv.2021.148663

Landis, B. W., Vattikuti, V. R., & Brannick, M. T. (1997). Real-Time Human Perceptions: Toward a Bicycle Level of Service. *Transportation Research Record: Journal of the*

Transportation Research Board, *1578*(1), 119–126. https://doi.org/10.3141/1578-15

Lee, J., Choi, K., & Leem, Y. (2016). Bicycle-based transit-oriented development as an alternative to overcome the criticisms of the conventional transit-oriented development. *International Journal of Sustainable Transportation*, *10*(10), 975–984. https://doi.org/10.1080/15568318.2014.923547

Lehtonen, M. (2004). The environmental–social interface of sustainable development: Capabilities, social capital, institutions. *Papers of the Eight Meeting of the International Society for Ecological Economics; Montreal, Ont. Canada; July 11-14, 2004*, *49*(2), 199–214. https://doi.org/10.1016/j.ecolecon.2004.03.019

Leventhal, G. S. (1980). What Should Be Done with Equity Theory? In K. J. Gergen, M. S. Greenberg, & R. H. Willis (Eds.), *Social Exchange: Advances in Theory and Research* (pp. 27–55). Springer US. https://doi.org/10.1007/978-1-4613-3087-5_2

Llorca, C., Angel-Domenech, A., Agustin-Gomez, F., Ferrer, V., & García, A. (2014). Motor vehicles overtaking cyclists on two-lane rural roads: Analysis on relative speed and lateral clearance. *Safety Science*, *92*. https://doi.org/10.1016/j.ssci.2015.11.005

Lucas, K. (2012). Transport and social exclusion: Where are we now? *Transport Policy*, *20*, 105–113. https://doi.org/10.1016/j.tranpol.2012.01.013

Lucas, K., van Wee, B., & Maat, K. (2016). A method to evaluate equitable accessibility: Combining ethical theories and accessibility-based approaches. *Transportation*, *43*(3), 473–490. 10. https://doi.org/10.1007/s11116-015-9585-2

Maghelal, P. K., & Capp, C. J. (2011). *Walkability: A Review of Existing Pedestrian Indices*. *23*(2), 16.

Maslow, A. H. (1943). A theory of human motivation. *Psychological Review*, *50*(4), 370–396. https://doi.org/10.1037/h0054346

Max-Neef, M. A. (1991). *HUMAN SCALE DEVELOPMENT*. The Apex Press.

meliharvey. (n.d.). *Sidewalkwidths-nyc*. Sidewalkwidths-Nyc. https://github.com/meliharvey/sidewalkwidths-nyc

Mori, K., & Christodoulou, A. (2012). Review of sustainability indices and indicators: Towards a new City Sustainability Index (CSI). *Environmental Impact Assessment Review*, *32*(1), 94–106. https://doi.org/10.1016/j.eiar.2011.06.001

Nundy, S., Ghosh, A., Mesloub, A., Albaqawy, G. A., & Alnaim, M. M. (2021). Impact of COVID-19 pandemic on socio-economic, energy-environment and transport sector globally and sustainable development goal (SDG). *Journal of Cleaner Production*, *312*, 127705. https://doi.org/10.1016/j.jclepro.2021.127705

OpenStreetMap. (2022). Tag:amenity=bar. In *Wiki OpenStreetMap*. https://wiki.openstreetmap.org/wiki/Tag:amenity%3Dbar

Ortega, E., Martín, B., De Isidro, Á., & Cuevas-Wizner, R. (2020). Street walking quality of the 'Centro' district, Madrid. *Journal of Maps*, *16*(1), 184–194. https://doi.org/10.1080/17445647.2020.1829114

Páez, A., Anjum, Z., Dickson-Anderson, S. E., Schuster-Wallace, C. J., Martín Ramos, B., & Higgins, C. D. (2020). Comparing distance, time, and metabolic energy cost functions for walking accessibility in infrastructure-poor regions. *Journal of Transport Geography*, *82*, 102564. https://doi.org/10.1016/j.jtrangeo.2019.102564

Pajares, E., Büttner, B., Jehle, U., Nichols, A., & Wulfhorst, G. (2021a). Accessibility by proximity: Addressing the lack of interactive accessibility instruments for active mobility. *Journal of Transport Geography*, *93*, 103080. https://doi.org/10.1016/j.jtrangeo.2021.103080

Pajares, E., Büttner, B., Jehle, U., Nichols, A., & Wulfhorst, G. (2021b). Accessibility by proximity: Addressing the lack of interactive accessibility instruments for active mobility. *Journal of Transport Geography*, *93*, 103080. https://doi.org/10.1016/j.jtrangeo.2021.103080

Pereira, R. H. M., Schwanen, T., & Banister, D. (2017). Distributive justice and equity in transportation. *Transport Reviews*, *37*(2), 170–191. 20. https://doi.org/10.1080/01441647.2016.1257660

Pirie, G. H. (1979). Measuring Accessibility: A Review and Proposal. *Environment and Planning A: Economy and Space*, *11*(3), 299–312. https://doi.org/10.1068/a110299

Pucci, P., Carboni, L., & Lanza, G. (2021). *Inclusive Accessibility by Proximity Index, first version*. 38.

Pucci, P., Lanza, G., & Carboni, L. (2021). *Inclusive Accessibility by Proximity Index, first version. WP2.*

Purvis, B., Mao, Y., & Robinson, D. (2019). Three pillars of sustainability: In search of conceptual origins. *Sustainability Science*, *14*(3), 681–695. https://doi.org/10.1007/s11625-018-0627-5

Rajabifard, A., Foliente, G., & Paez, D. (2021). *COVID-19 Pandemic, Geospatial Information, and Community Resilience: Global Applications and Lessons* (1st ed.). CRC Press. https://doi.org/10.1201/9781003181590

Rawls, J. (1999). *A Theory of Justice*. Harvard University Press; JSTOR. https://doi.org/10.2307/j.ctvkjb25m

Rescher, N. (1966). *Distributive Justice a Constructive Critique of the Utilitarian Theory of Distribution*. Bobbs-Merrill.

Ryan, J., & Pereira, R. H. M. (2021). What are we missing when we measure accessibility? Comparing calculated and self-reported accounts among older people. *Journal* *of Transport Geography*, *93*, 103086. https://doi.org/10.1016/j.jtrangeo.2021.103086

Sitthiyot, T., & Holasut, K. (2021). A simple method for estimating the Lorenz curve. *Humanities and Social Sciences Communications*, *8*(1), 268. https://doi.org/10.1057/s41599-021-00948-x

Smith, D. A., Shen, Y., Barros, J., Zhong, C., Batty, M., & Giannotti, M. (2020). A compact city for the wealthy? Employment accessibility inequalities between occupational classes in the London metropolitan region 2011. *Journal of Transport Geography*, *86*, 102767. 31. https://doi.org/10.1016/j.jtrangeo.2020.102767

Steg, L. (2007). SUSTAINABLE TRANSPORTATION. *IATSS Research*, *31*(2), 58–66. https://doi.org/10.1016/S0386-1112(14)60223-5

Stirling, A. (1999). The appraisal of sustainability: Some problems and possible responses. *Local Environment*, *4*(2), 111–135. https://doi.org/10.1080/13549839908725588

Talen, E., & Anselin, L. (1998). Assessing Spatial Equity: An Evaluation of Measures of Accessibility to Public Playgrounds. *Environment and Planning A: Economy and Space*, *30*(4), 595–613. https://doi.org/10.1068/a300595

Tay, L., & Diener, E. (2011). Needs and subjective well-being around the world. *Journal of Personality and Social Psychology*, *101*(2), 354–365. https://doi.org/10.1037/a0023779

Transform Transport. (2020). *Milan Sidewalks Map*. https://issuu.com/systematica/docs/milan-sidewalks-map

United Nations. (2021). *The Sustainable Development Goals Report 2021*.

Vale, D. S., Saraiva, M., & Pereira, M. (2015). Active accessibility: A review of operational measures of walking and cycling accessibility. *Journal of Transport and Land Use*. https://doi.org/10.5198/jtlu.2015.593

Wee, G., & Geurs, K. (2011). Discussing Equity and Social Exclusion in Accessibility Evaluations. *European Journal of Transport and Infrastructure Research*, *11*. https://doi.org/10.18757/ejtir.2011.11.4.2940

Weng, M., Ding, N., Li, J., Jin, X., Xiao, H., He, Z., & Su, S. (2019). The 15-minute walkable neighborhoods: Measurement, social inequalities and implications for building healthy communities in urban China. *Journal of Transport & Health*, *13*, 259–273. https://doi.org/10.1016/j.jth.2019.05.005

Weymark, J. A. (1981). Generalized gini inequality indices. *Mathematical Social Sciences*, *1*(4), 409–430. https://doi.org/10.1016/0165-4896(81)90018-4

Wulfhorst, G., Büttner, B., & Ji, C. (2017). The TUM Accessibility Atlas as a tool for supporting policies of sustainable mobility in metropolitan regions.

Transportation Research Part A: Policy and Practice, *104*, 121–136. 26. https://doi.org/10.1016/j.tra.2017.04.012

Xia, T., Zhang, Y., Braunack-Mayer, A., & Crabb, S. (2017). Public attitudes toward encouraging sustainable transportation: An Australian case study. *International Journal of Sustainable Transportation*, *11*(8), 593–601. https://doi.org/10.1080/15568318.2017.1287316

Yassin, H. H. (2019). Livable city: An approach to pedestrianization through tactical urbanism. *Alexandria Engineering Journal*, *58*(1), 251–259. https://doi.org/10.1016/j.aej.2019.02.005

Young, I. M. (1990). *Justice and the Politics of Difference*. Princeton University Press.