Understanding accessibility to basic services for public housing in Milan: An open-source approach

Giulio Frey

Last update: August 30, 2023

Abstract

We propose a connectivity index built using fully open source to evaluate the accessibility to basic services of the public housing stock owned by Comune di Milano. Our approach is scalable to other cities, fully reproducible and has negligible costs of implementation. We cover the inner workings of the routing machine necessary to build the index, we qualitatively describe the housing stock and go over a comprehensive history of public housing institutions. Results of the connectivity index are analyzed using the Gini index, correlation and mutual information with distance from the city center. We find that most services are quite equally distributed among the public housing units when looking at the Gini index. All services are negatively correlated with distance from the city center and university buildings and cultural points of interest have the highest values of Mutual information.

1 Introduction

One house every ten in Milan is public. Public housing is not only highly widespread but also requested: just 31% of the target population is assigned to public housing (Comune di Milano 2023). Although Milan's housing market is classified as fairly valued by UBS 2022, a rapid change in the city's population is happening: in the last decade, 40% of the city population was replaced (Maran 2023). The economic attractiveness of the city may push out some of the most vulnerable parts of the population, which on the other hand may be the ones that necessitate the most form opportunities of the city (Chetty et al. 2017).

Public housing is thus a necessary policy tool to allow lower-income individuals and families to fully interact with the economic benefits coming from living in a highly productive environment. Efficient allocation of public housing is thus necessary, but in Milan, this does not always happen. The public housing stock, in fact, is not fully assigned. Many tenants, after the assignation of an apartment stay there for the rest of their life and thus when the apartment is freed (after 20-30 years) it is in need of restorations (Maran 2023). As resources are limited, it is not easy to prioritize which should be areas where the public investment for renovation of the house has a higher return for the tenants.

We propose an index for the evaluation of the connectivity of the different social housing buildings with necessary services around the city. The aim is to add another source of analysis in the decision-making processes of areas in need of renovation. We will highlight both those areas that are highly connected to services and thus most suitable for public housing development and renovation and also compare existing public housing stock to understand where services are missing. The approach for data acquisition to build the index is fully open source, thus it has very limited cost for implementation. It is also scalable and reproducible for other cities and uses.

We analyze the connectivity index with different statistical tools: Gini coefficient, Correlation and mutual information with geodesic distance from the city center. We find that most connectivity services are quite equally distributed and 9 out of 24 services are below the threshold of 0.1. All services are negatively correlated with geodesic distance from the city center implying that as distance increases the accessibility to all services decreases. Mutual information explores nonlinear types of correlation and reports that university buildings and cultural points of interest have the highest mutual information with distance from the city center.

This paper is structured as follows: section 2.1 provides an overview of the literature on urban analytics. Section 2 covers a comprehensive history of public housing institutions and buildings in Milan and a synthetic description of the public housing stock owned by Comune di Milano. Section 3 explains the data source and how the distance matrix is calculated using the Open Source Routing Machine. Section 4 goes over the design of the connectivity index used for the analysis. Section 5 explains the results obtained and provides some insights on the metric used for the analysis of the connectivity index. Section 6 draws conclusions and appendix A provides maps created using the tools described in this paper. Finally appendix B provides a guide to running OSRM backend locally on a PC and interacting with it in Python.

2 Background

2.1 Literature Review

Data science's tools are increasingly applied to urban planning, so much so that this process earned its own name in literature: urban analytics. Those tools see applications in many fields related to urban planning: from urban transport to energy, air quality, health, policing and transport management (Kandt and Batty 2021).

Multiple authors showed how spatial accessibility is an important factor to be considered in the policy-making process. Sharma and Patil 2022 shows how an unequal supply of educational opportunities across the city can further aggravate social inequality between neighborhoods in Mumbai, India. Yin et al. 2018 show how the variable is China's spatial accessibility to healthcare and how this is correlated with the socio-economical characteristics of the population. In Grubesic and Durbin 2017 spacial accessibility to breastfeeding support is used to assess policies addressing this issue in Ohio, USA

Those studies are only focused on one specific service and its easiness of access without considering an overall basket of services that any individual needs. According to Wang and Luo 2005 focusing on only one type of service may not consider the substitution effect of public service facilities and how the lack of easy access to one service may be compensated by another one.

Other issues of current spatial analysis research are highlighted by Li et al. 2021. Firstly previous research has been focused on cars as a standard mode of transportation, which does not apply correctly to dense urban environments and does not consider disadvantaged groups that do not have access to private mobility. Secondly, authors have tended to use threshold distances and district-level analysis rather than individual-based travel times that may better represent accessibility.

Our approach fully addresses all these issues as it is multiservice, individual-based and our index considers pedestrian travel time in parallel with variability of choice of the same service.

2.2 Historic background

Italy began the development of national public housing in 1903 with Legge Luzzati, before public intervention in the market for housing was almost nonexistent. This law was the direct consequence of two main factors affecting Italy at the turn of the century: first, a sociological change started in 1898 by popular uprisings all across the nation where the conditions of the most vulnerable were increasingly evident. Secondly, the installment of the second Giolitti term moved Italian politics towards reformism and socialism. The aim of this law was to create better housing conditions for the increasing amount of blue-collar workers moving to Italian cities (Istituto Autonomo Case Popolari - Milano 1972). In this legal framework, the institutions responsible for public housing were not directly responsible for development but were only regulators of private entities (Urbani 2010). In 1909 the City of Milan created the Istituto Autonomo per Le Case Popolari (Autonomous Institute for Public Housing). The major legislative initiative for public housing came from the local administration, this is rare in post-unitary Italy as most of the administrative power was centralized at the state level.

During the initial phase of the Mussolini dictatorship, no relevant change happened. The construction of public housing was still supervised by local entities all around the country. In 1926 new legislation (R.D.L. n. 386 of 10 March 1926) invested 100 million liras with a non-repayable loan to construct units for affordable rent. Those would be constructed by the local Istituti Autonomi Case Popolari. After the period of controlled rent, the units will be sold on the market. This law had the final objective of increasing the house ownership rate of the middle class, in line with the Fascist party objectives regarding housing. Later in the decade more and more the responsibilities of the Istituto Autonomo Case Popolari were shifted to the Ministero dei Lavori Pubblici (Minister of Public Works). The year 1933 signed a pivotal point for Fascism in Italy as the regime was becoming more and more a totalitarian one. Public and private life were becoming less and less separated and as a consequence of this shift, a new focus was brought on public housing. Public housing shifted under the provincial responsibility and a national council of public housing institutes was created. The target of private ownership for the middle class was abandoned in favor of the construction of residential districts for the lower and lowest-income populations. The directive was to create a public housing district with services that allowed the Fascist regime to spread at the family level. The new aim was synthesized in the motto "La Casa Fascista per la Famiglia Fascista" with obvious consequences to those that did not fit inside the ideals of the party such as political dissenters, religious and other minorities (Roberto Ferretti 2000).

Only during the 1950s, the State assume a more relevant but still indirect position by giving additional responsibility to the national insurance program to provide public housing. Between 1978 and 1988, in order to meet the increase in demand for housing that drove upwards prices, 2000 housing units per year were added all over Lombardy. Following this period of expansion, the supply of public housing cooled down to around 700 new housing units added per year in the period between 1989 and 1995. It reached 450 housing units per year in the period 1995-2001 (Istituto Regionale di Ricerca della Lombardia 2003). This reduction was mainly caused by two factors: a reduction of public funds and law 560 ("Norme in materia di alienazione degli alloggi ERP"), which asked for a reduction of the public housing stock of 50% in order to fund the renovation of the existing stock. Only one-third of the sold housing units were replaced by new constructions, far from a one-to-one replacement as initially planned (Cognetti 2021). Since December 2014 all the buildings owned by Comune di Milano have been maintained by MM s.p.a. replacing ALER which previously had this responsibility.

Owner	Occupied	Free	Free because of lack of maintenance
MM	21737	1021	3731
ALER	24333	394	3274

Table 1: Public Housing Stock by usage

2.3 Overview of Public Housing Owned by Comune di Milano

Breda 2016 and Breda 2021 provide a thorough description of the housing stock owned by Comune di Milano. We will cover the main insights.

The housing stock owned by Comune di Milano is spread all around the city. Although the acquisition of public housing started in the twentieth century, some buildings were constructed before and later acquired. For example, via Bergamini 1 was built before the eighteen century and acquired by Comune di Milano in 1938. This causes some of the units to be located very close to the city center, in locations with high property value.

The first public housing projects specifically constructed for this use were the two built by Società Umanitaria. Those projects are located in Via Andrea Solari 40 and Viale Lombardia 65. Here we can see how the increase in importance of the city center and the extension of the population forced those projects at what were then the city boundaries. From now on no major public housing project will happen inside the city center except for the postwar reconstruction of bombed buildings.

Three important wartime buildings were constructed between 1940 and 1941 by Istituto Fascista Autonomo per le Case Popolari (Autonomous Fascist Institute for Public Housing). The period after the Second World War can be defined as the "home for all" period, with standardized construction practices and housing units. In the years 1959 al 1979 Milan experienced the construction of the biggest projects in order to meet the increasing demand coming from a period of high economic growth. These projects are located in Baggio, Bruzzano, Gallaratese, Quarto Oggiaro and Quinto Romano. In the 1980s buildings were constructed in the city center to replace those that had been bombed. Until 1999 the development in the city outskirts. In between 2000 e il 2012, 14 housing projects were completed.

standardize decimal and thousand separators

Comune di Milano today owns 26'489 public housing units (Servizio Abitativo Pubblico-SAP) around the city of Milan. Those are administrated by the public-owned company MM s.p.a. Comune di Milano is not the only provider of public housing around the city, also Regione Lombardia with the public-owned company ALER provides 32.017 units, ALER housing units are in reduction due to budgetary needs. MM and ALER combined provide SAP units that amount to 10% of all housing units in the city of Milan. In comparison the national average is 4%, on the other hand, the European Union average is 20% (Comune di Milano 2023).

Demand for public housing is high. Comune di Milano administrates both the allocation of

MM and ALER housing units. In 2021 11916 applications were received, in 2022 17.785 and at the end of the year 16.468. The high demand does not allow the allocation of units to all the target population of public housing policies. On average the ISEE of tenants is 5,000 €, and the policy target is to provide public housing for all families below 16000€. Only a small fraction of the tenants that cannot receive SAP units will receive another type of rent protection, the others will be left to choices on the free market. (Comune di Milano 2023)

The main legal framework that norms public housing in Lombardy comes from two regional laws: 16/2016 and 4/2017. Those also highlight the prerequisites for accessing public housing services, which are:

- Citizenship requirement: Being an Italian or EU member state citizen or being a permanent resident
- Residency requirement: Being resident in Lombardy or working in the region
- No arrears that caused a removal from a previous assignation to public housing
- ISEE below 16000€

(Incorvaia 2021)

Future of public housing in Milan

3 Data

3.1 Services data

We combine data from the Open Data portal of Comune di Milano with administrative data from MM. Comune di Milano provides us with the location of services, and whether MM keeps track of all public housing buildings maintained by the company.

Locations of services can be extracted with many different methodologies. The most used in literature is extracting location from web-based map services such as Google Maps or the Open Street Map. Those services are not necessary for this application as the Open Data portal already provides coordinates of many services. More importantly many services targeted towards the most vulnerable will be not easily extracted from the web. Consequently, The acquisition of georeferenced data for services can be replicated in two different ways: by obtaining administrative data from similar portals as the one offered by Comune di Milano or by shifting to web-based map services. repetition

Services included in this analysis have the objective to represent the necessities of the users of public housing. We decided to include services that fall under five categories:

- Education and culture: schools, universities, libraries, public Wi-Fi, and cultural points of interest (such as museums and monuments).
- Retail and similar: stores, groceries, supermarkets, pharmacies, filtered water distribution points, newsstands and postal offices.
- Counselling: family and addiction counseling.
- Leisure: sports facilities and parks.
- Transports: bike lanes, trains and metro stations.

Most services have a function that is easily inferable, but some require a more detailed explanation. Water fountains are public fountains that filter and add carbon dioxide to water. They should not be mistaken for the famous "vedovelle" that are more diffused and smaller but do not provide filtered water. Family counseling (Consultorio familiare) is a public health service provided by Regione Lombardia that provides support for all citizens (individuals, families and children) on all issues regarding relationship, family and sexual life. Patients are followed by a multidisciplinary team of doctors, psychologists, paramedics, lawyers and social workers. Examples of services provided support regarding birth control, breastfeeding, menopause, psychological issues of individuals or families, family law and female cancer prevention. Cultural points of interests comprehend museums, public art and historical monuments. Postal offices have some additional responsibility compared to other countries. They also offer insurance and other financial products but most notably eligible citizens can withdraw pensions and state provided income support policies. Addiction counselling (Servizi per le Dipendenze patologiche or SERD) is a public service provided by the national health service that supports all individuals subjects to addiction. Like family counselling, professional form different background can support SERD patients. Services provided are prevention, treatments, social reintegration of individuals that suffer from any type fo addiction. All services are geoencoded as data points, also parks and bike lanes, where the area covered is converted into points. This allows for a large park or a long bike lane close to a public housing building to be have more importance in subsequent analysis compared to a smaller or shorter counterpart.

3.2 Open Source Routing Machine

In order to analyze the connectivity of each building of social housing with different services we need to create a matrix of distances. The distance matrix will be shaped as follows:

$$D_{m\times n} = \begin{bmatrix} d_{11} & d_{12} & \cdots & d_{1n} \\ d_{21} & d_{22} & \cdots & d_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ d_{m1} & d_{m2} & \cdots & d_{mn} \end{bmatrix}$$

Dataframe Name	Number of Services	Short Description
acqua	52	Water fountains
biblio	26	Public libraries
ciclabili	3722	Bike lanes (data points)
consu	21	Family counselling
cult	322	Cultural POI
distr	1027	Stores and Groceries
edicole	577	News-stands
farmacie	414	Pharmacies
metro	110	Metro stations
parchi	1065	Public parks (data points)
posta	82	Postal offices
serd	15	Addiction counselling
sinf	300	Kindergarten
sita	115	Italian schools
sport	1041	Sport facilities
sprim	1734	Elementary schools
ss2	174	High schools
ssec	1146	Middle schools
treni	24	Train stations
uni	711	University buildings

Table 2: Services data composition

With m representing the total number of social housing buildings owned by Comune di Milano and n representing all the services. Our distance matrix is quite big as we have 984 buildings and 13275 services. A total of $13,062,600$ distances needs to be calculated. This will indeed be a long and costly process using an API service like the ones offered by Google Maps, thus we moved to locally computable and open source alternatives. We implement the backend of The Open Source Routing Machine (Luxen and Vetter 2011) in our code in order to calculate the distance matrix [1].

The Open Source Routing Machine (OSRM) is a cross platform and open source routing engine. It is written in C++ and is highly optimized: it can process distances between two coordinates points in milliseconds[2].

Another advantage of this process as highlighted by Huber and Rust 2016 is that is a fully local method. This allows firstly to be implemented with data that is highly sensible and cannot be shared with API providers. Secondly reproducibility of research is improved by being fully detached from online services. Sometimes those services are preferred as they allow for traffic information to be included in travel time estimates, in a recent version, this feature was also added to the OSRM.

An OSRM running on all the planet is impossible to develop without the computing capabilities of a server, but a local version (in our case limited to Provincia di Milano) is more than accessible

[1] Source code and datasets available at `https://github.com/giuliofrey/mm_tesi`

[2] 15.7 seconds for 1000 requests with 8 GB of RAM and i7-8550U CPU @ 1.80GHz

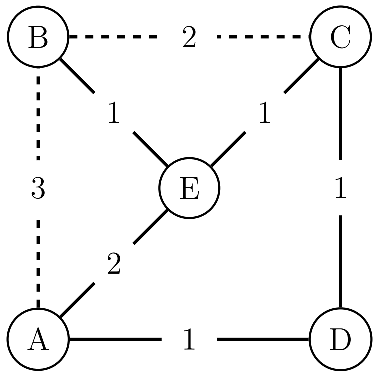


Figure 1: Contraction of node E. Shortcuts are indicated with dashed lines. After the contraction all edges of node E can be removed.

even to commercial PCs.

It is also important to understand not only the institutional setting but also how calculations are performed under the hood. We thus cover in this section the inner workings of OSRM. Routing is an example of application of shortest path problems, where the road network is modelled into a weighted and directed graph $G = (V, E)$. Junctions are represented by nodes and street segments by edges. All this information is extracted from OpenStreetMap, an open source mapping project that has now reached the same level of accuracy of private services. An impractical solution to this problems can be derived form Dijkstra's algorithm (Cormen 2009), but this approach necessitates to analyze an immense number of edges necessary to solve a routing problem.

OSRM uses a contraction hierarchy (CH) algorithm, a simple yet effective tool, to speed up the routing problem. CH algorithm preprocess the graph by exploiting the tendency of road network to be constructed by few important and many unimportant roads and junctions, this is known as an hierarchical structure: Local roads, for example, will be used only around the start and destination points and not along most of the route. Preprocessing is a time consuming process, but once completed allows for a single query to be run extremely fast. Note that it is not necessary for the algorithm to know in advance the type or roads, but it estimates that autonomously.

Node contraction is the process that aims at removing unimportant nodes from the calculation, by creating shortcuts. Shortcuts are edges that represents shortest path between nodes without the necessity to pass trough the contracted node. An example of the contraction process is illustrated in figure 1. The most important aspect for node contraction is to find witness paths. Those are the shortest paths that do not need to pass trough the contracted node (in our example path connecting C and A) and thus will not necessitate shortcuts. Local limit searches are an effective tool to find witness path (Geisberger et al. 2012).

Another important aspect of CH algorithms is node ordering, that is the sorting of which nodes to contract. Optimal node ordering is proved to be an NP-hard problem (Bauer et al. 2010). Geisberger 2008 shows how effective node contraction does not necessitate knowing all the complete order of nodes to be contracted: it can be achieved only by knowing the next node to contract. The next node to be contracted is selected using a linear combination of priority terms. The most important one is edge difference: edge difference is the number of shortcuts introduced by the contraction of a node minus the existing number of edges of that node. We want to keep this as low as possible otherwise the contracted graph will converge to the complete graph. Edge difference could be problematic as a contraction could change edge difference of close or distant nodes, reevaluating all the graph will prove counterproductive. This issue is solved by evaluating just a neighborhood of the contracted node. Edge difference may lead to contraction happening just in a small region, this could lead to slow routing. Uniformity across the graph is thus necessary and this is achieved with heuristics, the most powerful are: Deleted Neighborhoods, Original Edges Term and Voronoi Regions (Geisberger et al. 2012).

4 Empirical Design

Indexes used in evaluation of spacial accessibility are categorized by Marwal and Silva 2022 in isochrones, gravity or utility based. Isochrones provide a simple and broad view of accessibility, but count only the locations accessible when below a certain defined boundary. Gravity based measures weight opportunities using a functional form of travel time or costs, they can be also integrated with features of locations such as quality of treatment for hospitals or similar. Utility based models rely on random utility theory to evaluate locations, knowing that agents will select the ones that maximize their utility. They require low input data but still some is necessary in order to estimate parameters of the utility function (Ziemke, Joubert, and Nagel 2018).

We create an index for connectivity (CI) with main objective of facility of implementation. Thus we chose a gravity based model with a functional form that rewards locations that are closer to a specific distance. Note that still all locations are considered when calculating the index. The connectivity index satisfies the following conditions :

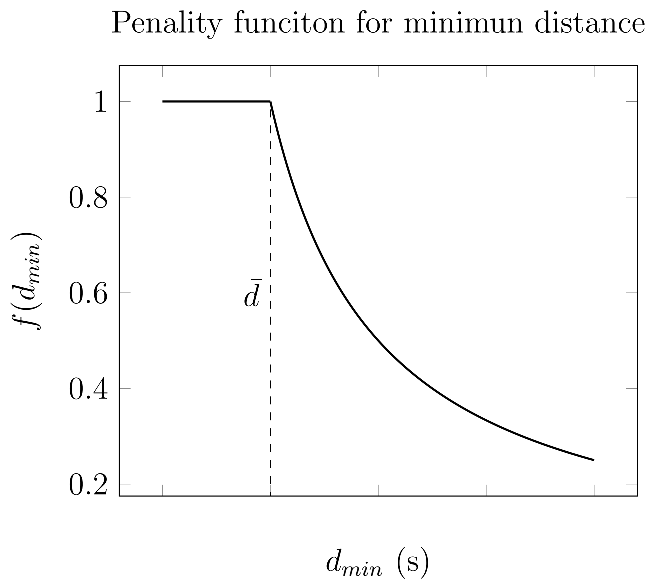
1. $0 < \text{CI} < 1$

2. CI depends on the minimum distance to the element of a given service (minimum distance or MD)

3. CI depends also on the total number of elements accessible in less than a threshold distance (number of elements in neighborhood or NEN). This value is relative to the building with the most elements of a given service inside the minimum threshold distance

4. It allows for a different weighting given to MD and NEN

5. It gives a "penalty" to all those services where the closest element is more distant than fifteen minutes.



We define $\boldsymbol{s}_i$ as the vector containing all distances to services in the city for building i. We denote $d_{min} \in \boldsymbol{s}_i : d_{min} \leq d_j \forall d_j \in \boldsymbol{s}_i$, that is the minimum distance for service i (MD). We set $\bar{d}$ as the threshold for close services. n will be the number of elements in the vector where $d < \bar{d}$ (NEN). n_{max} will be the maximum number of close services for any building, thus representing the best in class for number of services inside the threshold distance. We need this measure as some services are more frequent around the city than others. Our index will be:

$$\text{CI} = \alpha f\left(d_{min}\right) + \beta \left(\frac{n}{n_{max}}\right) \tag{1}$$

where:

$$f(x) = \begin{cases} 1 & x \leq \bar{d} \\ \frac{1}{x - \bar{d} + 1} & x > \bar{d} \end{cases}$$

Note that α and β must be chosen such that $\alpha + \beta = 1$

5 Results

We created the distance matrix for each service and each public housing building as presented in section 3. In order to extract insights form those data we applied our connectivity index to the distance matrix. We chose to implement a parametrization of CI that assigned equal value to closeness (α parameter) and variability of services (β parameter). This implies that $\alpha = \beta = 0.5$. Another parameter that needs to be exogenously determined is $\bar{d}$, that is the threshold distance for close services. Political and academic debate on the "15 minute city" was the main driver of parametrization choice for threshold distance of $\bar{d} = 900s$ (Khavarian-Garmsir, Sharifi, and Sadeghi 2023). Although this threshold is deterministic, in our index it is not the only mode of evaluation, as our index is not entirely based on this value.

5.1 Summary Statistics

Table 3 reports summary statistics for the connectivity index of each service. We aggregate the CI calculated for each building to the service that this refers to in order to have a city wide metric differentiated by type of service. This means, for example, that the average reported for train stations is the average CI across public housing buildings for the service of train stations.

From the average we see that 14 services out of 22 have average CI scores of 0.5 ± 0.15. Cultural points of interest, family and addiction counselling university buildings and train stations are the services that score on average lower than this range. Cultural points obtain an exceptionally low value of 0.058004 on average. This values could be a consequence of the tendency of cultural points of interest to be placed in the city center and thus away from the majority of public housing buildings. This view is also confirmed by metrics described in the following paragraphs. The median provides similar insights. We see from maximum and minimum that our index ranges exactly from 1 to 0 ± 0.00003 for all services. This was indeed expected from the design of the connectivity index.

It is also interesting to see how CI scores are distributed among public housing units. For this purpose we use skewness and kurtosis. Skewness estimates the third standardized moment of the population distribution and it is an index of the symmetry of the distribution. It ranges from $-\infty$ to $+\infty$, it is 0 when the distribution is perfectly symmetric and takes negative or positive values based on were the asymmetry lays. Kurtosis is an estimate of the fourth standardized moment of the population distribution and it is used to compare the peakedness (weaker or heavier tails and shoulders) of a distribution to the ones of the normal. It ranges from 1 to ∞ and for reference the normal distribution has a kurtosis of 3. Often to this metric is subtracted 3 (as in our case) to better highlight the relation with the normal distribution (Ho and Yu 2015). From table 3 we note that the most skewed distribution is the distance from Duomo with a value of 12.600432. This implies that the distribution of the geodesic distance from the city center is asymmetric and the right tail extends the most. This metric shows that there is a concentration of public housing units are placed close to the city center. Kurtosis is also high, implying that this metric is more has heavier tails compared to the gaussian distribution. A concentration of data has low value of distance from city center but outliers are quite frequent. Looking at results for the CI we see that the highest value of skewness is reached by cultural points of interest. Here the interpretation differs as a higher values imply better connectivity. This service has finds most of the data on the lower scores of CI implying that most public hosing is poorly connected with cultural points of interest. Kurtosis is also high showing that there are more outliers compared to the normal. We see that the services that come closest to having a symmetric distribution are metro stations, with a value of 0.384926. Notably, most of the services obtain a negative value of skewness, implying that most of the scores have high values. Store and groceries seem to be the most left with a value of -3.172366. Looking at kurtosis 12 out of 22 services have values higher than zero and thus tails heavier than the Gaussian distribution. Postal offices, Italian schools and water fountains come very close to 0 with values of -0.082454, -0.069862 and 0.074387 respectively. Those are the services that have distributions most similar to the normal.

Service	Mean	Median	Minimum	Maximum	σ	Skewness	Kurtosis
Water fountains	0.588909	0.666667	0.000038	1.000000	0.298981	-1.256788	0.074387
Public libraries	0.448982	0.666667	0.000035	1.000000	0.330759	-0.545798	-1.568690
Bike lanes	0.583804	0.581871	0.000043	1.000000	0.098156	-2.484344	18.249688
Family counselling	0.180754	0.000914	0.000032	1.000000	0.285379	1.013261	-0.832189
Cultural POI	0.058004	0.000417	0.000033	1.000000	0.183163	3.140419	8.898860
News-stands	0.579617	0.568966	0.000039	1.000000	0.094452	-1.154315	15.855984
Pharmacies	0.614192	0.612903	0.000040	1.000000	0.125522	-1.438254	10.073702
Metro stations	0.384926	0.550000	0.000043	1.000000	0.305534	-0.305707	-1.527592
Public parks	0.502103	0.531792	0.000036	1.000000	0.181710	-1.966817	3.413313
Postal offices	0.493276	0.562500	0.000039	1.000000	0.259047	-1.147095	-0.082454
Addiction counselling	0.191438	0.000843	0.000033	1.000000	0.291208	0.976176	-0.752664
Kindergarten	0.683411	0.678571	0.000039	1.000000	0.115460	-2.197506	12.323776
Italian schools	0.466289	0.535714	0.000038	1.000000	0.247952	-1.068808	-0.069862
Sport facilities	0.693574	0.676724	0.000040	1.000000	0.122241	-1.134635	8.502487
Elementary schools	0.708579	0.700000	0.000040	1.000000	0.134471	-1.730198	8.854016
High schools	0.422154	0.541667	0.000035	1.000000	0.281271	-0.668483	-1.149812
Middle schools	0.608370	0.593023	0.000039	1.000000	0.135834	-2.820057	11.689541
Train stations	0.222444	0.002111	0.000034	1.000000	0.304051	0.684745	-1.456602
University buildings	0.212721	0.001405	0.000037	1.000000	0.271683	0.630182	-1.281901
wifi	0.616373	0.603774	0.000039	1.000000	0.100988	-1.044054	10.986417
Stores and Groceries	0.509896	0.515695	0.000038	1.000000	0.108288	-3.172366	16.078387
All services	0.626734	0.613839	0.000043	1.000000	0.074860	0.992269	10.011883
duomo_dist	5213.334094	4933.363499	318.419822	61032.302044	2533.143374	12.600432	277.884758

Table 3: Summary statistics on the connectivity index for each service. σ denotes the standard deviation.

5.2 Gini Index, Correlation and Mutual Information

Table 4 reports three statistics that further evaluate the connectivity index across services. Those are the Gini coefficient, correlation with geodesic distance from the city center and mutual information.

The Gini coefficient adds a metric to estimate how equally the connectivity index is distributed among buildings. The Gini coefficient is calculated using the Lorenz curve, which is a polygonal line connecting points that have coordinates given by the cumulative relative frequency of a certain value and arranged increasingly. This curve is compared with the egalitarian line, that is the Lorenz curve where all variables have the same value. The index is the ratio of the area between the two curves and the area below the egalitarian line. The Gini coefficient ranges from 0 to 1. Note that the Gini coefficient is 0 when the Lorenz curve and the egalitarian line coincide, this corresponds to perfect equality. The converse is true when the Gini index is 1 (Giorgi 2020). Although the Gini coefficient is often applied to income and wealth inequality, it can provide insights also when applied to the connectivity index. In this case, the value 0 will represent a perfect equality of access to a specific service among the public housing buildings. We see that the lowest Gini coefficient is achieved when considering all services across the city. This implies that overall access to services with no differentiation is quite equally distributed across public housing units. Most services perform well with nine of them under the threshold of 0.1. Only four services performed more than 0.5. Those are university buildings, train stations, addiction and family counseling and cultural points of interest, the worst service when it comes to equality of scores.

We add a metric for geodesic distance in meters from the city center, that we identify with the coordinates of Duomo di Milano. Python's Geopy library allows us to calculate the geodesic distance between two points using the World Geodetic System model, the most used for this type of calculation. We also provide summary statistics for this metric and we see that on average, each public housing unit is 5968.278 meters away from the city center. The correlation column reports the Pearson correlation between each service connectivity index. We want to investigate if there is some correlation between the availability of services and the distance of the building from the city center. Notably, each service has a negative correlation between CI and distance from Duomo. This suggests that as the distance of public housing buildings from the city center increases, the availability of all services decreases. Although the previous insight is true for all services, we see a wide range of values of correlation. For example, overall services have the most negative correlation with a value of -0.596738. Notably for policy implications, elementary schools, middle schools and family counseling are quite negatively correlated with distance from the city center with values around -0.4. Public parks, public libraries, postal offices, Italian schools and addiction counseling have correlation values of -0.2 and -0.1. Train stations and water fountains have almost no correlation with distance from the city center, implying that those services are quite diffused around the city.

Pearson's correlation investigates linear relationships between variables. A more general measure comes from mutual information that observes also monotonic and non-monotonic relationships. We replicate the same analysis for the correlation investigating the relation between distance from the city center and connectivity index. Mutual information as described in Cover and Thomas n.d. is "a measure of the amount of information that one random variable contains about another random variable". We see that the results here change substantially compared to the ones shown previously. This was expected as mutual information investigates more complex types of relations between variables. Mutual is equal to 0 when no information is provided and is maximum when the two random variables are the same. This relationship is described by the following equation

$$I(X;Y) = H(X) - H(X|Y)$$

Where $H(X)$ is Shannon's entropy of the random variable X and $H(X;Y)$ the conditional entropy of X and Y. From the previous, we get that:

$$I(X;X) = H(X)$$

Thus in our case, the upper bound is 5.553744, which is the mutual information of the same variable (distance from Duomo). We see that the cultural points of interest come very close to this bound, although they obtained a lower correlation. The same can be said about university buildings and all services. On the other hand, middle, elementary and Italian schools, public libraries, postal offices, kindergarten and water fountains perform the lowest value of mutual information (less than 3.000).

Service	Gini	Correlation	Mutual Information
Water fountains	0.240346	-0.053253	1.913922
Public libraries	0.367927	-0.193059	2.533260
Bike lanes	0.071857	-0.376415	4.534293
Family counselling	0.721401	-0.382185	4.458782
Cultural POI	0.910358	-0.351438	5.394022
News-stands	0.069450	-0.512833	3.071575
Pharmacies	0.091634	-0.470427	2.875015
Metro stations	0.415849	-0.276610	3.318674
Public parks	0.154304	-0.196006	3.898988
Postal offices	0.253366	-0.162762	2.340985
Addiction counselling	0.703958	-0.124862	4.360059
Kindergarten	0.083242	-0.375858	2.330676
Italian schools	0.255305	-0.140015	2.651912
Sport facilities	0.089091	-0.280608	3.641130
Elementary schools	0.095642	-0.428292	2.814154
High schools	0.342531	-0.304161	3.529942
Middle schools	0.092428	-0.395775	2.565271
Train stations	0.657674	-0.076874	4.122878
University buildings	0.635098	-0.276371	4.844099
Public Wi-Fi	0.079492	-0.478185	3.303520
Stores and Groceries	0.065545	-0.338781	3.333871
All services	0.057605	-0.596738	5.038962
Distance from Duomo	0.188589	1.000000	5.553744

Table 4: Statistics on the connectivity index for each service. Correlation column reports the Pearson correlation between the connectivity index and geodesic distance in meters from the city center (identified with Duomo di Milano). Gini column reports the Gini coefficient of each service. MI column reports the mutual information between the connectivity index and distance from the city center

consu				serd				sinf			
Max	ID max	Min	ID min	Max	ID max	Min	ID min	Max	ID max	Min	ID min
1.000000	10004301	0.000155	20002703	1.000000	30000601	0.000141	10002701	1.000000	20000804	0.000941	10002701
1.000000	51015501	0.000155	20002605	1.000000	30000504	0.000141	10003901	1.000000	51010701	0.000951	10003901
1.000000	10004201	0.000155	20002606	1.000000	51016301	0.000158	41010201	0.964286	20000805	0.002360	51012601
0.800000	20001102	0.000155	20002607	1.000000	30003701	0.000187	10003203	0.964286	20003501	0.002491	51016001
0.800000	10003001	0.000155	20002701	1.000000	30000801	0.000187	10003204	0.928571	10003801	0.003155	30001402
0.800000	10004101	0.000155	20002702	1.000000	30000701	0.000187	10002101	0.928571	10003802	0.004664	51038101
0.800000	20001001	0.000155	20002801	1.000000	30003402	0.000195	10002601	0.928571	51023601	0.005708	41018505
0.800000	20001101	0.000155	20002604	1.000000	30003401	0.000195	10002602	0.928571	20000801	0.005708	41018504
0.800000	20001103	0.000155	20002603	1.000000	30000503	0.000195	10002604	0.928571	20000803	0.006098	41023301
0.800000	20000301	0.000155	20002602	1.000000	30000502	0.000195	10002605	0.892857	51017501	0.535714	20001813
sita				sprim				ss2			
Max	ID max	Min	ID min	Max	ID max	Min	ID min	Max	ID max	Min	ID min
1.000000	30003701	0.000159	51016001	1.000000	20000801	0.000455	41021801	1.000000	10004201	0.000327	10002701
1.000000	30000601	0.000164	51038101	1.000000	51023601	0.000455	41021802	1.000000	10004301	0.000329	10003901
1.000000	30000502	0.000182	51013001	1.000000	20000201	0.000455	10003301	0.916667	20000805	0.000386	41010201
1.000000	30000503	0.000307	10004501	1.000000	20000804	0.000455	41021901	0.916667	51013901	0.000408	41021801
1.000000	30000501	0.000490	41019402	1.000000	20000805	0.000455	41021902	0.916667	20000804	0.000408	10003301
1.000000	30000504	0.000490	41019401	1.000000	51010701	0.001782	30001402	0.916667	20000201	0.000408	41021901
0.964286	20000401	0.000519	51023702	0.987500	10003802	0.002147	51016001	0.916667	20000801	0.000408	41021802
0.928571	20000101	0.000519	51023701	0.987500	51014901	0.002849	51012601	0.916667	20000802	0.000408	41021902
0.928571	20000102	0.000519	51023703	0.987500	41019101	0.003587	51038101	0.916667	20000803	0.000448	41018505
0.928571	20000103	0.000526	51023705	0.987500	41019102	0.003922	41018801	0.916667	51010701	0.000448	41018504
ssec				distr				all			
Max	ID max	Min	ID min	Max	ID max	Min	ID min	Max	ID max	Min	ID min
1.000000	41019802	0.000354	41021801	1.000000	10004301	0.000547	41021902	1.000000	10004301	0.502790	41021901
1.000000	10004301	0.000354	10003301	0.986547	10004201	0.000547	41021801	0.980469	20000401	0.502790	41021902
1.000000	41019801	0.000354	41021802	0.919283	20000401	0.000547	41021802	0.974330	10004201	0.502790	41021802
0.906977	10004201	0.000354	41021901	0.883408	30000601	0.000547	41021901	0.952567	20000201	0.502790	41021801
0.906977	10001801	0.000354	41021902	0.831839	30003701	0.000547	10003301	0.938058	20001001	0.502790	10003301
0.872093	51015501	0.000473	51016001	0.820628	20001001	0.000573	10002701	0.921875	20000101	0.504464	30001402
0.825581	20000802	0.000518	51038101	0.784753	30000501	0.000577	10003901	0.920201	20000103	0.506138	51016001
0.825581	51013801	0.000668	41019602	0.748879	30000502	0.000743	30001402	0.914062	20000102	0.507254	51038101
0.825581	20003801	0.000668	51017101	0.748879	30000504	0.001018	51012601	0.904576	30000601	0.515067	10002701
0.825581	51010801	0.000668	51017103	0.733184	30000503	0.002304	30001901	0.901786	51013801	0.515625	10003901

Table 5: best and worst performers for a selection of services. Max (Min) reports the top (bottom) 10 scores and ID max (min) the associated ID of the housing buildings associated with the score

5.3 Best and Worst Performers

Table 5 reports the best and worst performers in a selection of the services analyzed. We note that the public housing building 10004301 scores the best connectivity index in Family counseling, Stores and Groceries and overall services with all scores of 1. Notably, it also scores second for high schools and middle schools connectivity. This public housing building is located in Via Bergamini 1, the most central unit in our dataset with a geodesic distance from Duomo of 318.4 m. Build between the XVIII and XIX centuries, it was acquired by the city of Milan with an esproprio con determinazione amichevole dell'indennità (expropriation with compensation that was agreed upon) on the third of February 1938. In this building, the real estate registry indicates that there should be 51 apartments (Breda 2016).

Unit 10002701 on the other hand, is the worst performer in Addiction counseling, kindergarten and high schools connectivity with scores of 0.000141, 0.000941 and 0.000327 respectively. It also scores in the worst ten units for groceries and stores and overall services. This unit is located in Via Guido Ucelli di Nemi 58, in the Ponte Lambro district, at the city limits. It was built in 1956 with the style of Case Minime (minimal hoses) that were built with common structures and materials. Building 10002901, Via San Mamete 8, is the first one to be built according to those standards, in total there are 25 examples of this type of building around the city. In Uccelli di Nemi 58 there are 35 apartments of 40 m^2 with one or two rooms. The ceiling height is 2.8 meters. It was poorly maintained and until 2008, was a renewal program of the Comune di Milano that included also other buildings in this district completely renovated this building, with the objective of increasing the capacity of users of 20% (Breda 2016).

Unit 41021801 has the lowest connectivity for elementary (0.000455) and middle school (0.000354). It is also in the worst 10 for connectivity with stores and groceries and high schools. It is also the fourth worst performer for overall connectivity with a score of 0.502790. This building is located in Via San Bernardo 48, close to the Abbazia of Chiaravalle, in the agricultural countryside at the southern city limits (Breda 2016). Built in 1985, this building was renovated in recent years using EU-GUGLE founds [3]. This project was an experiment to demonstrate the feasibility of net zero districts in different urban areas across the Union. Practices implemented across cities will be useful to implement similar objectives in other cities. Vienna (Austria), Aachen (Germany), Milan (Italy), Sestao (Spain), Tampere (Finland) and Bratislava (Slovakia) obtained a total of € 16,785,372 for the renovation of 226,000 m^2. Specifically for Via San Bernardo 48, the building undergone an envelope retrofitting, installation of heat recovery on exhaust air, photovoltaic and energy management systems. Additional renovations were made at the district level with the installation of a bike path connecting with the city center (planned but not yet constructed) and renovations made to the district's kindergarten (Neri and Pezzetti 2020). Other buildings obtained the EU-GUGLE founds, namely via Feltrinelli 11 and 16 (41039901) and via San Bernardo 50 (Morishita et al. 2017).

The worst performers of overall services are buildings 41021901 and 41021902, both located

[3] European Cities Serving as Green Urban Gate Towards Leadership in Sustainable Energy

in via San Bernardo 29/A, very close to the previously covered via San Bernardo 48. These buildings obtained an identical score of 0.502790, and performed poorly also in connectivity to schools and stores and groceries. Similarly to via San Bernardo 48, they also received another European found named Sharing Cities. This fund allocated 500 million euros to Bordeaux (France), Burgas (Bulgaria), Lisbon (Portugal), London (the United Kingdom), Milan (Italy), and Warsaw (Poland). Milan used the funds to implement building retrofit, improve shared e-mobility, install sustainable energy management systems and smart lamp posts. Funds were allocated using co-design principles, involving all stakeholders of the districts that were affected.

Additional qualitative insights can be drawn from maps that report the connectivity index scores of units across the city. Those reported in appendix A. We services such as kindergarten, elementary and middle schools and all services that have connectivity scores that gradually decrease when the distance from the city center increases. But we see other services that seem to be targeted to the city periphery, such as addiction and family counseling, that are both highly connected with specific sectors of the city that do not overlap with the city center.

6 Conclusion

This paper was intended as an explorative study of public housing and accessibility to fundamental services across the city of Milan. Many future developments are possible, first of all by adding more cities to the analysis. Although the principal objective of the connectivity index is to be easily interpretable, more insights can be drawn by changing methodology in the evaluation of distances, mainly by applying random utility models. Interesting insights may be drawn from the analysis of the relation between additional data not included in our datasets: accessibility to schools and grades, health rates and accessibility to sport facilities or pollution and accessibility to parks.

Our methodology is an easy to implement and open-source alternative with similar functionalities to more expensive private tools. This allows for funding to be directed towards different data sources for future research. The code used in this paper is also published in Github in order for future research to build on what has already been achieved here. Interesting improvements in the code may integrate public transport as a mode of transportation, which is implementable but tricky as highly time-dependent. Another factor that could be included is traffic, especially important for the analysis of cities where cars are still the dominant transport type.

We showed how there exists a high correlation between distance from the city center and connectivity to different services. This correlation is explored with different statistical methods. We also looked at the distributional differences in accessibility between public housing units and interestingly we found that accessibility is quite equally distributed.

All this information is important for two reasons: firstly by identifying areas of intervention, such as the southern agricultural periphery, that has units with the lowest scores. Another important aspect is to highlight best in class, that may have the best returns for the families that inhabit those units. Knowing all of this will be an important factor in the allocations of funding that is limited

Public housing is important as it can be seen not only as a policy tool that allows for the poorest to obtain affordable housing. Additionally, it may provide them with accessibility to fundamental services that will never be accessible to them without public support. Public housing thus could ideally become a social elevator that brings in vulnerable families and provides them with better services and schooling that was previously impossible. Understanding how this accessibility is spread around the city is thus not only a question of current standards of life for the current generation that access those, but also how this service could provide a social ladder to those who access it.

References

Bauer, Reinhard et al. (2010). "Preprocessing Speed-Up Techniques Is Hard". In: *Algorithms and Complexity*. Ed. by Tiziana Calamoneri and Josep Diaz. Vol. 6078. Series Title: Lecture Notes in Computer Science. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 359–370. ISBN: 978-3-642-13072-4 978-3-642-13073-1. DOI: 10.1007/978-3-642-13073-1_32. URL: http://link.springer.com/10.1007/978-3-642-13073-1_32 (visited on 08/21/2023).

Breda, Maria Antonietta (2016). *La tua casa. Atlante del patrimonio residenziale pubblico del Comune di Milano*. ISBN: 978-88-908224-1-4. URL: https://www.mmspa.eu/wps/portal/mmspa/it/home/media/pubblicazioni.

— (2021). "La Storia della Casa Popolare Milanese". In: *Report Milano. La casa popolare* 6, pp. 26–37.

Chetty, Raj et al. (2017). "The Impacts of Neighborhoods on Intergenerational Mobility I: Childhood Exposure Effects *". In.

Cognetti, Francesca (2021). "Lo Scenario Attuale Dell'Edilizia Residenziale Pubblica". In: *Report Milano. La casa popolare* 6, pp. 16–21.

Comune di Milano (Mar. 2023). *Una Nuova Strategia per La Casa*. URL: https://www.forumabitaremilano.it/wp-content/uploads/2023/03/Una_nuova_strategia_per_la_casa.pdf.

Cormen, T.H. (2009). *Introduction to Algorithms, 3rd Edition:* MIT Press. ISBN: 9780262033848. URL: https://books.google.it/books?id=0BoNBQAAQBAJ.

Cover, Thomas M and Joy A Thomas (n.d.). "ELEMENTS OF INFORMATION THEORY". en. In: ().

Geisberger, Robert (2008). "Contraction Hierarchies: Faster and Simpler Hierarchical Routing in Road Networks". en. In: *Experimental Algorithms*. Ed. by Catherine C. McGeoch. Vol. 5038. Series Title: Lecture Notes in Computer Science. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 319–333. ISBN: 978-3-540-68548-7 978-3-540-68552-4. DOI: 10.1007/978-3-540-68552-4_24. URL: http://link.springer.com/10.1007/978-3-540-68552-4_24 (visited on 08/21/2023).

Geisberger, Robert et al. (2012). "Exact routing in large road networks using contraction hierarchies". In: *Transportation Science* 46 (3), pp. 388–404. ISSN: 15265447. DOI: 10.1287/trsc.1110.0401.

Giorgi, Giovanni (2020). "Gini Coefficient". en. In: *SAGE Research Methods Foundations*. 1 Oliver's Yard, 55 City Road, London EC1Y 1SP United Kingdom: SAGE Publications Ltd. ISBN: 978-1-5264-2103-6. DOI: 10.4135/9781526421036883328. URL: https://methods.sagepub.com/foundations/gini-coefficient (visited on 07/10/2023).

Grubesic, Tony H. and Kelly M. Durbin (Nov. 2017). "Breastfeeding Support: A Geographic Perspective on Access and Equity". In: *Journal of human lactation : official journal of International Lactation Consultant Association* 33 (4), pp. 770–780. ISSN: 1552-5732. DOI: 10.1177/0890334417706361. URL: https://pubmed.ncbi.nlm.nih.gov/28602120/.

Ho, Andrew D. and Carol C. Yu (June 2015). “Descriptive Statistics for Modern Test Score Distributions: Skewness, Kurtosis, Discreteness, and Ceiling Effects”. en. In: *Educational and Psychological Measurement* 75.3, pp. 365–388. ISSN: 0013-1644, 1552-3888. DOI: 10.1177/0013164414548576. URL: http://journals.sagepub.com/doi/10.1177/0013164414548576 (visited on 07/16/2023).

Huber, Stephan and Christoph Rust (2016). *Calculate travel time and distance with OpenStreetMap data using the Open Source Routing Machine (OSRM)*, pp. 416–423. URL: http://project-osrm.org/..

Incorvaia, Giuseppina (2021). “Normativa Dell’Edilizia Residenziale Pubblica”. In: *Report Milano. La casa popolare* 6, pp. 12–13.

Istituto Autonomo Case Popolari - Milano (1972). *Origini dell’ Istituto Case Popolari a Milano.*

Istituto Regionale di Ricerca della Lombardia (2003). *Verso l’ edilizia sociale: Le politiche abitative in Lombardia tra nuovi bisogni e ridefinizione dell’azione pubblica.* Consiglio regionale della Lombardia. ISBN: 9788883355928.

Kandt, Jens and Michael Batty (Feb. 2021). “Smart cities, big data and urban policy: Towards urban analytics for the long run”. In: *Cities* 109, p. 102992. ISSN: 0264-2751. DOI: 10.1016/J.CITIES.2020.102992.

Khavarian-Garmsir, Amir Reza, Ayyoob Sharifi, and Ali Sadeghi (Jan. 2023). “The 15-minute city: Urban planning and design efforts toward creating sustainable neighborhoods”. en. In: *Cities* 132, p. 104101. ISSN: 02642751. DOI: 10.1016/j.cities.2022.104101. URL: https://linkinghub.elsevier.com/retrieve/pii/S0264275122005406 (visited on 07/11/2023).

Li, Yongling et al. (Dec. 2021). “Accessibility-Based Equity of Public Facilities: a Case Study in Xiamen, China”. In: *Applied Spatial Analysis and Policy* 14 (4), pp. 947–968. ISSN: 18744621. DOI: 10.1007/s12061-021-09387-2.

Luxen, Dennis and Christian Vetter (2011). “Real-time routing with OpenStreetMap data”. In: *Proceedings of the 19th ACM SIGSPATIAL International Conference on Advances in Geographic Information Systems*. GIS ’11. Chicago, Illinois: ACM, pp. 513–516. ISBN: 978-1-4503-1031-4. DOI: 10.1145/2093973.2094062. URL: http://doi.acm.org/10.1145/2093973.2094062.

Maran, Pierfrancesco (Feb. 2023). *Casa mia, quanto mi costi? – Per un mercato immobiliare inclusivo.* Talk by Assessore alla Casa Pierfrancesco Maran organized by Tortuga Think-Tank.

Marwal, Aviral and Elisabete Silva (Mar. 2022). “Literature review of accessibility measures and models used in land use and transportation planning in last 5 years”. en. In: *Journal of Geographical Sciences* 32.3, pp. 560–584. ISSN: 1009-637X, 1861-9568. DOI: 10.1007/s11442-022-1961-1. URL: https://link.springer.com/10.1007/s11442-022-1961-1 (visited on 07/11/2023).

Morishita, Naomi et al. (2017). "EU-GUGLE: A sustainable renovation for smarter cities from a pilot project". In: *Smart and Sustainable Planning for Cities and Regions: Results of SSPCR 2015 1*, pp. 353–382.

Neri, Raffaella and Laura Anna Pezzetti (2020). "Slow Mobility, Greenways, and Landscape Regeneration. Reusing Milan's Parco Sud Decommissioned Rail Line as a Landscape Cycle Path, 2019". en. In: *Regeneration of the Built Environment from a Circular Economy Perspective*. Ed. by Stefano Della Torre et al. Research for Development. Cham: Springer International Publishing, pp. 149–158. ISBN: 978-3-030-33256-3. DOI: 10.1007/978-3-030-33256-3_15. URL: https://doi.org/10.1007/978-3-030-33256-3_15 (visited on 08/16/2023).

Roberto Ferretti (2000). "Le case per il popolo. L'edilizia popolare a Bologna tra liberalismo e fascismo". it. In: *Contemporanea* 2, pp. 233–260. DOI: 10.1409/10109. URL: https://doi.org/10.1409/10109 (visited on 08/16/2023).

Sharma, Gajanand and Gopal R Patil (2022). "Spatial and social inequities for educational services accessibility-A case study for schools in Greater Mumbai". In: *Cities* 122, p. 103543. DOI: 10.1016/j.cities.2021.103543. URL: https://doi.org/10.1016/j.cities.2021.103543.

UBS, Chief Investment Office (Oct. 2022). "UBS Global Real Estate Bubble Index". In.

Urbani, Paolo (May 2010). *L'Edilizia Residenziale Pubblica Tra Stato e Autonmie Locali*. Conference on Foundamentals Rights and Policy in the EU after Lisbon. Pescara, Italy. URL: www.pausania.it.

Wang, Fahui and Wei Luo (2005). "Assessing spatial and nonspatial factors for healthcare access: towards an integrated approach to defining health professional shortage areas". In: *Health & place* 11.2, pp. 131–146.

Yin, Chaohui et al. (Mar. 2018). "Inequality of public health and its role in spatial accessibility to medical facilities in China". In: *Applied Geography* 92, pp. 50–62. ISSN: 0143-6228. DOI: 10.1016/J.APGEOG.2018.01.011.

Ziemke, Dominik, Johan W. Joubert, and Kai Nagel (June 2018). "Accessibility in a Post-Apartheid City: Comparison of Two Approaches for Accessibility Computations". en. In: *Networks and Spatial Economics* 18.2, pp. 241–271. ISSN: 1566-113X, 1572-9427. DOI: 10.1007/s11067-017-9360-3. URL: http://link.springer.com/10.1007/s11067-017-9360-3 (visited on 07/11/2023).

A Maps

This section shows two different types of maps: figure 2 shows all services that were extracted from the Open data portal of Comune di Milano. Figure 3 plots the locations of the social housing buildings owned by Comune di Milano and the associated connectivity index for that specific service.

Figure 2: Map of the city of Milan showing all services used for the analysis

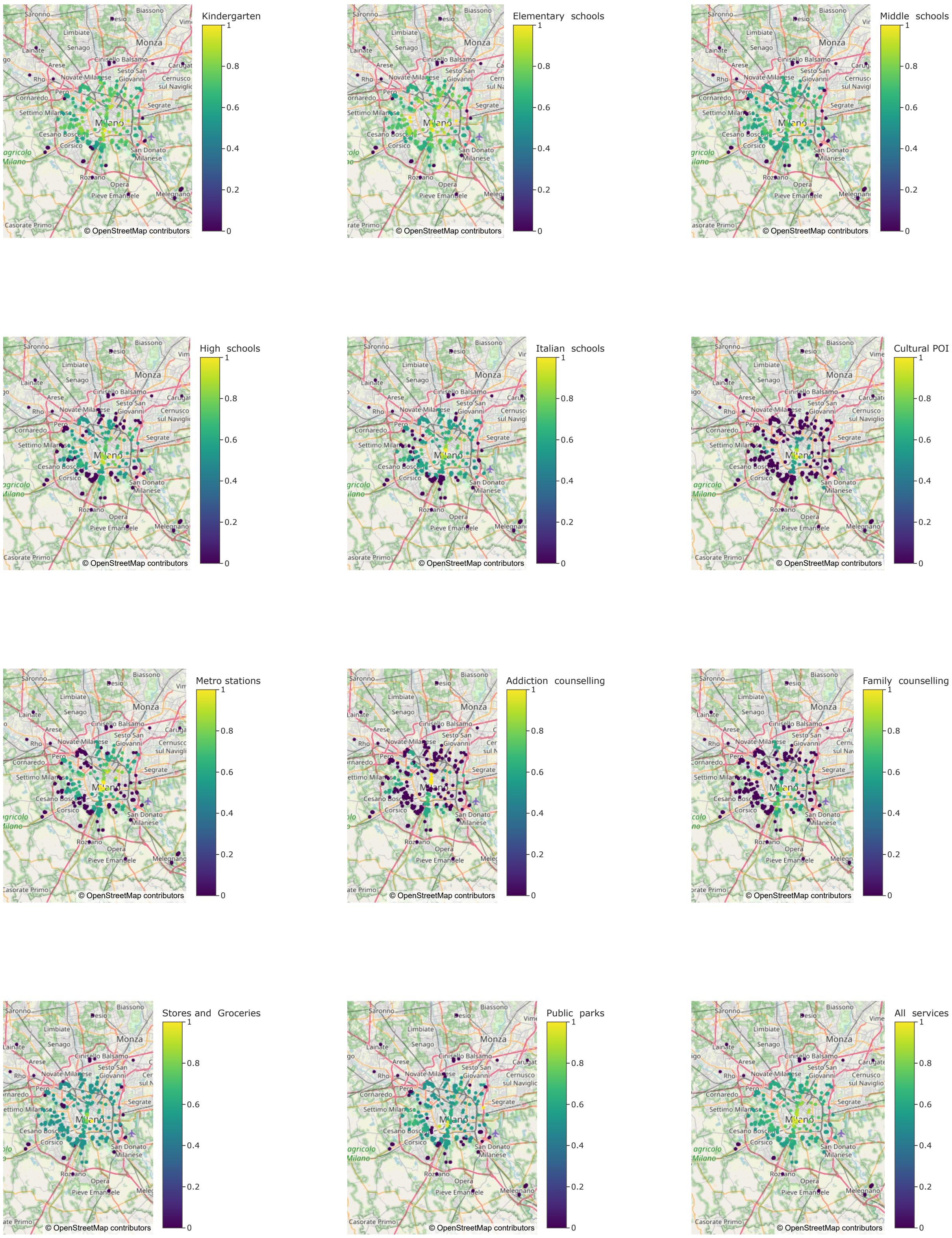


Figure 3: Plots of connectivity index for a selection of the services analyzed. Each dot corresponds to one public housing building

B Code overview

In this section, we will cover how to run OSRM backend locally on a PC and interact with it in Python. We will demonstrate the process of running it on Windows with WSL installed, but the process is similar to other operating systems. Other than WSL is also necessary to have installed Docker Desktop. This is necessary because OSRM is installed as a docker image, thus removing any OS compatibility problem that may arise.

First of all, start a WSL session and navigate to your directory. In this example the directory folder is called "dir" and the user is "myuser"

```
cd "/mnt/c/users/myuser/dir/"
```

Now we need to download the Open Street Map of the desired area. We will use the Geofabrik service (that can be called directly from the command line). Here we will demonstrate an example using the Nord ovest area of Italy, but a section of all the world can be downloaded.

```
wget http://download.geofabrik.de/europe/italy/nord-ovest-latest.osm
    .pbf
```

Note that if the resources of the PC are limited, especially RAM, a larger area may prove impossible to run on OSRM. An alternative is to select a smaller area on Geofabrik or to manually process the OSM file using Osmconvert.

Now we move to the actual computational part. We are preprocessing the map downloaded above. Note that this is transportation type specific: here we are running the preprocessing part with a foot.lua profile. If you want to change to a car or bike transportation type you will have to change this part with either car.lua or bike.lua. Subsequent changes of transportation profiles will need a new preprocessing.

```
docker run -t -v "${PWD}:/data" ghcr.io/project-osrm/osrm-backend
    osrm-extract -p /opt/foot.lua /data/nord-ovest-latest.osm.pbf ||
    "osrm-extract failed"
```

By running the command above docker will realize that the OSRM image is not installed, by showing the following output:

```
Unable to find image 'ghcr.io/project-osrm/osrm-backend:latest'
    locally
latest: Pulling from project-osrm/osrm-backend
```

This will trigger an automatic pull from the latest version if docker is correctly installed on your PC.

The following commands start the OSRM local version with a Multi-Level Dijkstra (MLD) algorithm.

```
docker run -t -v "${PWD}:/data" ghcr.io/project-osrm/osrm-backend
    osrm-partition /data/nord-ovest-latest.osrm || "osrm-partition 
    failed"

docker run -t -v "${PWD}:/data" ghcr.io/project-osrm/osrm-backend
    osrm-customize /data/nord-ovest-latest.osrm || "osrm-customize 
    failed"

docker run -t -i -p 5000:5000 -v "${PWD}:/data" ghcr.io/project-osrm
    /osrm-backend osrm-routed --algorithm mld /data/nord-ovest-latest
    .osrm
```

Alternatively to run OSRM with Contraction Hierarchies (CH) run the following code must be used instead:

```
docker run -t -v "${PWD}:/data" ghcr.io/project-osrm/osrm-backend
    osrm-contract /data/nord-ovest-latest.osrm || "osrm-partition 
    failed"

docker run -t -i -p 5000:5000 -v "${PWD}:/data" ghcr.io/project-osrm
    /osrm-backend osrm-routed --algorithm ch /data/nord-ovest-latest.
    osrm
```

The process above needs to run only the first time or when you want to change the transportation mode, algorithm or area of routing. The only command that needs to run every time is the last one.

After all of this, we can make a simple request of routing to test that everything runs.

```
curl "http://127.0.0.1:5000/route/v1/driving
    /13.388860,52.517037;13.385983,52.496891?steps=true"
```

To interact with OSRM in Python we use the following code[4]:

```
import requests

def get_route(pickup_lon, pickup_lat, dropoff_lon, dropoff_lat):
    loc = "{},{};{},{}".format(pickup_lon, pickup_lat, dropoff_lon,
        dropoff_lat)
    url = "http://127.0.0.1:5000/route/v1/driving/"
    r = requests.get(url + loc)
    if r.status_code!= 200:
        return {}
```

[4]Full code available on the Github repository

```
    res = r.json()
    duration = res['routes'][0]['duration']
    distance = res['routes'][0]['distance']

    return duration

get_route(9.1930893, 45.5053767 ,9.23444555, 45.49610165)
```