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Are Italian cities already 15-minute? Presenting the Next Proximity Index: A novel and scalable way to measure it, based on open data

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ABSTRACT

In recent years, the concept of proximity has gathered significant attention and the best-known model dealing with this concept is Carlos Moreno's 15-minute city, where citizens can easily reach any essential service through a 15 minutes' walk (or bike ride). This city model presents numerous advantages, including reductions in car traffic and carbon footprint, improvement in citizens' health and safety, enhancement of the economy in the whole city, improvement of accessibility and so on. However, transitioning to a 15-minute city is not a straightforward undertaking and we argue that for this process to succeed it is best to rely on data-driven assessments of its developments. Therefore, in this paper we present the NExt proXimity Index (NEXI), based on open data and capable of measuring the level of local proximity to services by walking, according to the principles of the 15-minute city. The goal of NEXI is to identify which of the different areas of a given territory already follow the 15-minute paradigm and its implementation is made available as an interactive map where the index is computed on a hexagonal grid and thematized according to its value. The NEXI is designed to be glocal: it is based on OpenStreetMap data so it can be replicated everywhere (global), but it is also granular enough to be able to evaluate the proximity at a small scale (local). Moreover, the index is designed to have a scalable computation and is in fact already available for the entirety of Italy. Finally, the NEXI can be combined with additional local data (e.g. population level) to gather additional insights, as was experimented in two use cases carried out in the cities of Ferrara and Bologna, Italy.

1. Introduction

The concept of sustainable mobility, initially associated mostly to the improvement of public transportation, has now expanded to encompass a variety of forms of mobility, including the so-called active mobility. Traditionally the goal of mobility has been to travel long distances fast (Rodrigue, 2020). However, in recent years, researchers and municipalities have begun to consider the concept from a different perspective. Instead of seeking fast ways to travel long distances to reach the services they need, citizens should find those services close to them. In such a perspective, fast mobility would be replaced by proximity.

The concept of proximity has always been an essential ingredient when it comes to planning cities. From Jane Jacobs in early '60s onwards, urban theorists consistently argue that bringing people and opportunities closer together allows neighborhoods to flourish (Tomer et al., 2019).

However, in the last few years, talking about proximity and particularly "x-minute-city" has almost become a fashion, sometimes even propaganda. The concept refers to cities where residents can access to most of their needs within a short walk or bike ride from their homes (Logan et al., 2022). Again, this idea is not entirely new as similar models, like Clarence A. Perry's "neighborhood unit" (1929), used in the architecture and urban planning competition of Chicago in 1923, have been around for almost a century.

In the framework of x-minute cities, many similar models were invented as the concept was molded to cities with different needs and structures. However, none of the previous examples of x-minute cities has become quite as popular as the "15-minute city" developed for the city of Paris, France. The concept owes its fame to the mayor of Paris, Anne Hidalgo, inspired by Professor Carlos Moreno, researcher and professor at IAE Sorbonne Business School in Paris, who, in 2016, theorized the concept by taking up previous studies. According to Moreno's definition, a 15-minute city is composed of accessible neighborhoods where

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1 https://www.dedanext.it/
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citizens can easily reach any necessary service through a 15 minutes' walk or bike ride (Allam et al., 2021). This paper focuses on the concept of proximity by walking, neglecting all the other forms of active mobility. Walking was selected as it is the most inclusive form of mobility because it does not require any means of transport.

In the year 2020, the notion of proximity has gained significant attention, particularly due to the COVID-19 pandemic. As Moreno et al. (2021) explain, the pandemic provided an unexpected boost to the concept, as the emergence of the pandemic exposed the vulnerability of cities in their current structure and the need for a radical rethinking. Many governments around the world indeed imposed restrictions about the maximum distance that people could walk from their home to prevent the spread of COVID-19. People were therefore compelled to experience life in their districts, interact with their neighbors, visit local parks for a breath of fresh air and make their purchases in local shops and supermarkets.

So, with the pandemic as a driver, the 15-minute model became more interesting (Abdelfattah et al., 2022) as a possible way of optimizing travel, reducing pollution, enhancing the economy, and transforming urban space to prioritize sustainability and giving new value to time. An urban center that brings services closer together, simplifies access, reduces inequalities and improves social cohesion by giving value to a new sustainable neighborhood dimension. In summary: it improves people's lives and aims to preserve the environment, in the short and long term.

However, while the idea of the 15-minute model is straightforward, its implementation poses significant challenges, requiring large investments and careful planning based on data, to make sure that the project undertaken will have a positive effect on the urban mobility and that no asset will be wasted on useless activities.

Fortunately, we now have an enormous amount of data, in particular spatial data and geolocation services, to allow planners and cities to measure and see how neighborhood design, transportation networks, and other factors influence travel patterns as well as how much a city is characterized by proximity and whether daily needs are easily accessible for citizens. The Index presented in this paper, the NExt proXimity Index (NEXI), exploits that data to answer the question "Which parts of your city or town already follow the 15-minute model?"

The NEXI is an open data-based methodology to measure the level of proximity by walking from households to "city services" (i.e. points of daily interest for residents and city users) according to the principles of the 15-minute city. The goal of the NEXI is to identify those areas within a given territory that follow the 15-minute model. The NEXI is available as an interactive map (currently covering the whole of Italy) where the index is computed on a hexagonal grid and thematized according to its value. The NEXI is intended as a support tool for municipalities that are implementing new mobility strategies and to help them make data-informed decisions. The index can be used by public administrations to plan land use and mobility infrastructures, identify less accessible areas, guide co-participation processes with citizens and monitor the impact of policies on territories.

The index was developed with two primary objectives: global replicability and granularity, making it a "glocal" index that can be scaled to big areas, such as entire countries, while also detecting the peculiarities of small areas, being based on a hexagonal grid as the smallest resolution unit, where the hexagons have a diameter of 250 meters. Its development has been possible thanks to the availability of freely accessible data about road networks and city services for the whole world and thanks to the application of a parallelizable algorithm.

This paper aims at reviewing the concepts of accessibility and proximity to fundamental services in cities as well as describing the various methods conceived to measure them, then introducing a new index and comparing it to the other approaches. More specifically, Section 2 provides examples of alternative indexes, highlighting their differences and clarifying the value added by the NEXI. Section 3 describes the algorithm behind the NExt proXimity Index, while Section 4 presents its applications to the cities of Ferrara and Bologna. In the Conclusions the strengths and weaknesses of the NEXI are discussed. Finally, the Future work section outlines potential advancement to the index.

2. Measuring proximity in cities

Walking is a simple health behavior with the potential to have a large public health impact due to its accessibility and its documented health benefits (Lee et al., 2008 and Song et al., 2013) and unlike other modes of transport, almost everyone is required to walk at some point during the day, although it should be noted that it is not necessarily an equitable activity as people's different abilities could influence the form and uses of public spaces. However, walking still represents one of the most democratic modes of transport, as long as appropriate infrastructures are in place (Claris and Scopelliti, 2016), and is also a profoundly social activity (Ingold and Vergunst, 2008) enabling, in comparison to other modes of transport, a greater diversity of social interactions (Middleton, 2018).

Therefore, due to its high accessibility and inclusivity, the paper specifically focuses on walking, starting from this section where an overview of the existing scientific literature on the concepts of proximity and accessibility is provided, together with an introduction to the novel concept of "x-minutes city", relevant examples of cities that have successfully implemented it and an overview of established 15-minute indices, all of which to offer an insight into the current state of the art in this field.

2.1. Accessibility and spatial proximity

Accessibility and proximity are two closely related concepts that are critical to the promotion of walking in urban areas. These concepts are of utmost importance to municipalities striving to establish a healthy, inclusive, and liveable city, as pointed out by Balletto et al. (2021). These terms are often used interchangeably to define approaches and models aiming at achieving high-quality public services and a balanced mix of important and central services and infrastructures. The current section of this paper will provide an overview of the definitions of accessibility and proximity, highlighting their distinct characteristics and clarifying the choice made for the design of the NEXI.

In urban planning, accessibility is the ability to reach relevant activities, individuals or opportunities, which might require traveling to the place where those opportunities are located (Handy, 2005), and it can be measured according to a mix of different factors, such as spatial distribution of destinations, the ease to reach them and the quality and character of the activities found at destination (Handy and Niemeier, 1997). Silva and Larsson (2018) explain that the term "accessibility" is often associated with the term "mobility", and in some contexts the latter becomes the proxy of the former. In reality, accessibility is the goal and mobility is one of the possible means to reach it, but not the only one. In fact, the authors present an alternative view to "accessibility by mobility", which is "accessibility by proximity", specifying its importance in achieving accessibility when slower modes, such as walking and cycling, are involved. Similarly, according to Vale et al. (2016), measures of active accessibility (i.e. accessibility by active travel: walking and cycling) can be grouped into 4 categories: activity-based, topology-based, distance-based and utility-based measures. The third type mentioned, distance-based accessibility, considers accessibility simply as a function of the spatial separation between places, i.e. accessibility is a synonym of spatial proximity. Therefore, spatial proximity concerns the location of areas relative to one another (Roberto, 2018). According to this definition of spatial proximity, higher separation implies lower accessibility and proximity. This concept is well described by Tobler's first law of geography: "everything is related to everything else, but near things are more related than distant things" (Tobler, 1970, p. 236).

The definition of spatial proximity as merely the distance between two locations may be limiting. In reality, spatial proximity is linked to and can be evaluated according to numerous other factors, one of them being social inclusion. Pucci et al. (2023) suggest that proximity can be also evaluated through different metrics as a generator of communities of places, practices, and project where forms of "relational proximity" serves as a resource for the emergence of new forms of social capital, interaction, and collective collaboration within communities. However, for the purpose of this paper, spatial proximity will only refer to physical distance: the reason of this choice is strictly related to the actual availability of detailed data at global scale. Indeed, high resolution data regarding other important factors (i.e. socio-demographic, orography, urban patterns) are not broadly available as open data. However, open datasets having a proper spatial resolution are emerging for demography[3] and orography[4] and these datasets might soon be included in future evolutions of the current indexes.

According to our definition of spatial proximity, the concept is strictly dependent on the distance of locations, making it crucial, when developing an index, to define a measure of distance. Many different types of distance are available in mathematics and some of them can be used to measure a geographical distance, such as Euclidean or Manhattan distance (Apparicio et al., 2008). A metric in this context can also be computed using the road network, by measuring the network distance (Aultman-Hall et al., 1997) or network time (Mavoa et al., 2012).

A second key aspect to consider when measuring proximity is the land use (Geurs and Ritsema van Eck 2001) as it is essential to define what activities or services are to be reached and which ones can be excluded by the calculus. In literature we can find various indexes focused on different types of points of interest (hereinafter referred to as PoI), including grocery stores, retails, healthcare, education or recreational facilities as well as a wider set of amenities (Larsson, 2022). Moreno identifies six essential urban social functions to sustain a decent urban life: living, working, commerce, healthcare, education and entertainment (Moreno, 2021). Whereas Pozoukidou (2021) mentions healthcare facilities, preschools and schools, social services, commercial services, leisure, cultural and entertainment amenities, parks and natural areas in the list of essential everyday needs for citizens.

The final list of eight categories of services included in the NEXI (commerce and retail, education, entertainment, grocery shops, healthcare, post/bank offices, public parks, restaurants) is mainly inspired by the Walk Score methodology (Walk Score, 2011), but considers also social services, such as post offices and banks. However, it should be noted that proximity preferences are understood as being personal, since the destinations to which we need or wish to have access are not the same for everyone (Haugen, 2011) and therefore the NEXI is open to include different services categories. Indeed, Geurs and van Wee (2004) identify another crucial component when measuring accessibility, the individual component: accessibility is not just about space, but also about people, their need, abilities and opportunities.

2.2. X-minute cities

Our definition of proximity is strictly connected to the relatively new concept of x-minute city, being it a model that promotes accessibility by proximity. The x-minute city is a type of design aimed at reducing car dependence by enabling urban residents to walk or cycle to essential amenities within x minutes from their home (Logan et al, 2022). Hereafter, we will present some examples of how the concept was implemented by different cities around the world.

In the city of Melbourne, Australia, in 2017 a new urban plan (Plan Melbourne 2017–2050) was presented pursuing the aim of shaping the city into "20-minute neighborhoods", where residents can meet their daily (non-work) needs within a short, non-motorized, trip from home (Thornton, 2022). The 20-minute neighborhood has been promoted also by the city of Portland, USA. The City of Portland Bureau of Planning and Sustainability defines this as a place with convenient, safe, and pedestrian-oriented access to the places people need to go to and the services people use nearly every day: transit, shopping, healthy food, school, parks, and social activities (City of Portland Bureau of Planning and Sustainability, 2012). Finally, the Greater Sydney Commission, the planning agency for the Sydney region, came up with the term "30-Minute City", referring to a new plan that should make Sydney region more interconnected and should allow its citizens to reach one of the three main metropolitan centers in less than 30 minutes walking, bike riding or by public transport. Therefore, the concept of 30-minute city presented for Sydney (Levinson, 2019) is more focused on public transports and intermodal connections. Even the well-known Barcelona's superblocks fall into the set of polycentric urban solutions that enhance active mobility and give back space to pedestrians. Superblocks are constructed cells transforming the city into sustainable and healthy, compact and connected neighborhoods with a mixed land use, and high potential for social capital (Mueller, 2020).

The concept of x-minute city adopted by the solution of this paper adheres to the 15-minute city presented by Carlos Moreno in 2016. Moreno's 15-minute city is based on the concept of "chrono-urbanism", which states that the quality of urban life is inversely proportional to the amount of time invested in transportation. According to Moreno (2021), locals should be able to access all their basic needs by walking or cycling for no more than 15 minutes. The 15-minute city model outlines how it is necessary to "repair" urban and social fragments, moving towards a polycentric city, driven by four major components: proximity, diversity, density, ubiquity (Moreno, 2016). The NEXI index presented in this paper is based on Moreno's concept of 15-minute city, focusing mainly on the component of proximity.

In its report, EIT Urban Mobility (2022) identifies opportunities as well as challenges brought by redesigning a city according to the 15-minute city model. The report separates the benefits of the model into four areas of impact: 1) social, with the regeneration of a social cohesion and a sense of place; 2) health, by promoting active mobility; 3) environmental, reducing the use of cars; 4) economic, reducing, for instance, the cost of roads maintenance and public health. The report identifies challenges especially for the suburban context, where the implementation of the 15-minute paradigm would be slower and could increase the inequalities between city centers and peripheral areas. In this regard, O'Sullivan (2021) states that social segregation would represent one of the main risks. Bike lanes and parklets are not enough to connect by active mobility all those neighborhoods that are already marginalized. Preventing the use of cars in cities, without carefully planning adequate interventions and implementing appropriate policies, could exacerbate already problematic situations. Policies should focus on removing potential barriers, improving active mobility infrastructures, strategically planning public transportation trips, promoting local businesses and increasing street safety. However, even in an urban context the paradigm presents some issues such as the consequent gentrification process that could derive from the transformation of the city center. Moreover, establishing a 15-minute city requires overcoming the challenging propensity for businesses to relocate from town centers to major commercial hubs.

2.3. Existing proximity indexes

Many algorithms have already been implemented for the automatic computation of measures of walkability, accessibility or proximity to daily services in the logic of x-minute city. In fact, as highlighted also by Knap et al. (2023), there can be many variations in the definition of the metric to create such an index: for instance, using different threshold travel times and alternative modes (i.e. pedestrian, bike, public transport). In the last few years, some indexes have also been developed to provide online access to results through interactive maps, dashboards and Application Protocol Interfaces (APIs).

[3] https://data.humdata.org/dataset/kontur-population-dataset?https://ghsl.jrc.ec.europa.eu/

[4] https://tinitaly.pi.ingv.it/

One of the best known is the Walk Score methodology, implemented in early 2007 by the company bearing the same name and measuring the proximity of any address using a patented system. Walk Score calculates a score by mapping out the walking distance to amenities in 9 different amenity categories (Walk Score, 2011): for each address, Walk Score analyzes hundreds of walking routes to nearby amenities. Points are awarded based on the distance to amenities in each category. Amenities within a 5-minute walk (0.25 miles) are given maximum points. A decay function is used to give points to more distant amenities, with no points given after a 30-minute walk.

BSI Brussels, together with KU Leuven, developed the 10-minute city for the city of Brussels (BSI, 2021). BSI and KU Leuven considered the limits of state of the art solutions, such as single mode (pedestrian), single time (15 minutes), fixed and limited number of urban facilities (PoI), newly collected ad hoc data, same needs for all citizens and neighborhoods; researchers created several heat maps, one for each theme of interest (economy, mobility, environment, living together, and so on) and then calculated a 10-minute city score to assign to each neighborhood.

Sony CSL, together with Sapienza University (Rome, Italy) developed a 15-minute city platform showcasing an index of proximity based on open data about the use of city venues, historical data about individual people movements derived from GPS tracks (Ubaldi et al., 2021) and routing algorithms to map how close different parts of a city are to the 15-Minute ideal. The index is available for some cities in Italy and France and its values are provided on a regular hexagonal grid and thematized basing on the time necessary to reach the different types of services.

Another similar solution is the 15-minute city index developed by EnelX and the University of Florence (EnelX, 2022). The index is available for each Italian city and its values are provided on a regular orthogonal grid. The index is based on data from institutional portals, satellite images and open-source communities.

CITYACCESSMAP is a web application for global scale urban accessibility insights. It uses open data from OpenStreetMap (hereinafter referred to as OSM) and the Global Human Settlement Layer (GHSL) by the European Commission, to quantify and visualize walking accessibility to a variety of services for different cities in the world. Planners can use this tool to obtain both high-level and granular insights into how access to different services is distributed across their city and its population, and how close they are to achieving the 15 Minute City (Nicoletti et al., 2022).

Considering the solutions presented in this section, the added value of NEXI consists mainly in the ability to be replicated almost everywhere on the globe and its sole use of open data. The peculiarities of the NEXI will be further described in the concluding section.

3. The NExt proXimity Index

The NEXI was designed in 2021 within the Landscape Metropolis project[5] and then improved and finalized within the Air Break project (co-funded by UIA program)[6]. The index was developed as a tool to facilitate the goals of the projects, both having the same city – Ferrara, Italy – among their pilots, by helping to identify the criticalities in terms of service accessibility and the areas where an intervention was most needed.

The city of Ferrara lays in one of the most air-polluted areas in Europe[7] – the Po Valley – and it is severely affected by serious environmental and health problems, including cancer mortality and acute myocardial infarction rates among the highest in Italy (Khomenko et al., 2021). In addition to this, peripheral areas of the city are undergoing a process of depopulation, leading to social disaggregation and paving the way for economic impoverishment, also due to the lack of services – mainly an efficient mobility network - in those areas. This is why, today, even though nearly 30% of the inhabitants of Ferrara move by bike (the city is also known as "the city of bikes") and despite great efforts by relevant mobility actors, private cars are still largely used for reaching the city from the peripheral areas.

Therefore, there are clear and manifold benefits in developing an index capable of driving improvements in terms of bringing services close to where they are missing and incentivizing the use of active mobility in place of a polluting one. This section describes how NEXI is defined as well as the details of its implementation.

3.1. Index definition

The NEXI has been created to answer the question "Which areas of the region of interest meet the requirements of the 15-minute model?". Therefore, it is important to define how to measure the conformance to the requirements.

Beforehand, we will define the category of services used in the computation. Table 1 lists the service categories used to compute NEXI and provides for each one the reference to the category:feature tags defined in Open Street Map (OSM) [8].

The smallest elements involved in the index calculation are the nodes of the road network (the intersection points of the network geometries) and the points of interest (the geographical location of the various services). For each node the algorithm computes the time needed to reach – at an average walking speed - the closest PoI of any given category, being constrained to move only on roads accessible to pedestrians.

More in details, the time needed to reach the PoIs is computed as $t = l/s$, where:

- l is the length of the shortest route to the PoI, on a road network made only of walkable roads,
- s is the approximate walking speed of an average person, that is 5 km/h.

If all the categories can be reached within 15 minutes, the node is considered to be a 15-minute node. Using a 5 km/h speed, the maximum reachable distance in 15 minutes is 1250m.

Having defined how to establish if a node is a 15-minute one, we can now easily extend the concept to an entire area. The algorithm computes the level of proximity of a given area as the mean of the levels of proximity of the nodes inside that area. Therefore, an area is 15-minute if the average time to reach all the categories from the nodes in that area is lower or equal to 15 minutes.

However, the aim of the index is not just to identify the so called 15-minutes areas among the others, but rather to provide a spectrum of different levels of proximity. In fact, many factors can influence the time a person is willing to walk, including personal traits, such as age, health condition or even external aspects, such as the weather and some people can be willing to walk more than 15 minutes. Moreover, in order to be able to evaluate both the detail of the area accessibility per service category and the global accessibility level, we decided to develop two different proximity indexes:

1 The NEXI-Minutes assigns to each category for each area a value of time which is the average time to reach each category, measured using the speed of 5 km/h;
2 The NEXI-Global takes inspiration from the Walk Score methodology, measuring the global proximity to all service categories on a scale that goes from 0 to 100, where 0 means that none of the categories is at least within a 30-minute walk, while 100 means that all categories are within a 15-minute walk and all values in between describe an intermediate situation. Following the approach of the Walk Score, the categories are not weighted uniformly but proportionally

[5] https://italy.climate-kic.org/projects/landscape-metropolis-paesaggio-come-infrastruttura/
[6] https://www.uia-initiative.eu/en/uia-cities/ferrara
[7] https://isglobalranking.org/ranking/#air
[8] https://wiki.openstreetmap.org/wiki/Main_Page

Table 1
Categories and included amenities

NEXI category	OSM category	OSM feature
Education	amenity	college, driving school, kindergarten, language school, music school, school, university
Entertainment	amenity	arts centre, brothel, casino, cinema, community center, conference centre, events venue, fountain, gambling, lovehotel, nightclub, planetarium, public bookcase, social centre, strip club, studio, swinger club, theatre
Grocery	shops	alcohol, bakery, beverages, brewing supplies, butcher, cheese, chocolate, coffee, confectionery, convenience, deli, dairy, farm, frozen food, greengrocer, health food, ice-cream, pasta, pastry, seafood, spices, tea, water, supermarket, department store, general, kiosk, mall
Health	amenity	clinic, dentist, doctors, hospital, nursing home, pharmacy, social facility
Posts and banks	amenity	atm, bank, bureau de change, post office
Parks	amenity	park, dog park
Sustenance	amenity	restaurant, pub, bar, cafe, fast-food, food court, ice-cream, biergarten
Shops	shops	department store, general, kiosk, mall, wholesale, baby goods, bag, boutique, clothes, fabric, fashion accessories, jewelry, leather, watches, wool, charity, secondhand, variety store, beauty, chemist, cosmetics, erotic, hairdresser, hairdresser supply, hearing aids, herbalist, massage, medical supply, nutrition supplements, optician, perfumery, tattoo, agrarian, appliance, bathroom furnishing, do-it-yourself, electrical, energy, fireplace, florist, garden centre, garden furniture, gas, glaziery, groundskeeping, hardware, houseware, locksmith, paint, security, trade, antiques, bed, candles, carpet, curtain, doors, flooring, furniture, household linen, interior decoration, kitchen, lighting, tiles, window blind, computer, electronics, hifi, mobile phone, radio-technics, vacuum cleaner, bicycle, boat, car, car repair, car parts, caravan, fuel, fishing, golf, hunting, jet ski, military surplus, motorcycle, outdoor, scuba diving, ski, snowmobile, swimming pool, trailer, tyres, art, collector, craft, frame, games, model, music, musical instrument, photo, camera, trophy, video, videogames, anime, books, gift, lottery, newsagent, stationery, ticket, bookmaker, cannabis, copy node, drycleaning, e-cigarette, funeral directors, laundry, moneylender, party, pawnbroker, pet, pet grooming, pest control, pyrotechnics, religion, storage rental, tobacco, toys, travel agency, vacant, weapons, outpost

to the perceived relative importance of the different categories (i.e., grocery stores are more necessary then banks).

When developing a proximity index, many other factors can be taken into account to enrich the analysis in addition to the ones already considered. One very interesting parameter is the population of the area of analysis, that is a key information to assess how many people are affected by the degree of service proximity available in the same area. To consider this aspect we developed the NEXI-Discomfort index according to the following formula, considering both the difference from the ideal situation and the number of residents affected:

$$Discomfort = (100 - Global) * Population$$

Therefore, high levels of discomfort are assigned to those areas that are highly populated, but where proximity is low. Of course, the discomfort index is assessable only in the areas where population data with such a small granularity is available.

Up until this point we have referred to a generic “area of interest” to which the level of proximity is assigned. Given a geographical extension of land, the NEXI algorithm must partition it in smaller areas before classifying them according to how x-minutes they are. There are many possible ways to do it, from geopolitical borders to geometric tiling. As one of the objectives of the NEXI is to be easily replicable on any territory, a choice was made to use a tiling that is independent from the area of analysis: with this choice it is always possible to partition the extension on interest, even when data about administrative borders are not available. Even when it comes to tiling, there are many possible choices of regular geometrical shapes, e.g. squares, triangles and hexagons. The choice fell on a grid of regular hexagons because of the remarkable property of equidistance between the centers of adjacent cells that it upholds which, in turn, guarantees that the analysis of the index trend in space will have no bias dependent on the direction of evaluation. The diameter of hexagons is fixed at 250m as it was the best trade-off between an acceptable computational time and a spatial resolution small enough to allow the NEXI to be glocal.

3.2. Replicability with OSM data

For the NEXI to be an index with worldwide replicability it needs to be based on data that is available for every part of the world. Getting the required data from local administrations worldwide would be too challenging, if not impossible, and it would also require complicated activities to integrate such datasets with mutually inhomogeneous structures. Therefore, the choice as source for both road network and PoIs data, has fallen to Open Street Map (OSM).

The OSM project is a knowledge collective that provides a user-generated geographic database of the world and follows the peer production model created by Wikipedia (Haklay and Weber, 2008). The data collected is distributed as open data (with ODbL license[9]) and reused in many sectors (Mooney and Minghini, 2017), mainly due to accuracy and high update rate of the dataset offered, global coverage of the world and uniformity of the collected attributes.

The size and reliability of OSM is also responsible for a positive feedback effect regarding data coverage: so many public and private actors rely on it that they are stimulated to keep it updated and expand its coverage, so to maintain the benefits they have from using it. Recently, for example, large corporations including Apple, Microsoft, and Facebook hired editors to contribute to the OSM database to increase data coverage in specific areas of interest (Anderson et al., 2019 and Schröder-Bergen et al., 2021). Similarly, local administrations interested in a more locally accurate version of the NEXI (or any other OSM-related index, of course) could be incentivized to update OSM with their own more accurate datasets and this of course would be also beneficial for the whole community of OSM users.

The most direct way to access to OSM data is via the Overpass-API service[10] that allows to download its data on the fly. The access to this web service is included in a lot of different packages for geospatial data analysis, such as Pandana, a Python library for network analysis that uses contraction hierarchies to calculate travel accessibility metrics and shortest paths (Foti and Waddell, 2012) and that is also the library of choice for the computation of the NEXI.

3.3. Scalability by design

The algorithm implementing the index is designed to be scalable and parallelized and is structured in four main steps (see Figure 1), all of which have been implemented in Python[11].

Tiling

9 https://opendatacommons.org/licenses/odbl/
10 http://overpass-api.de/
11 https://www.python.org/

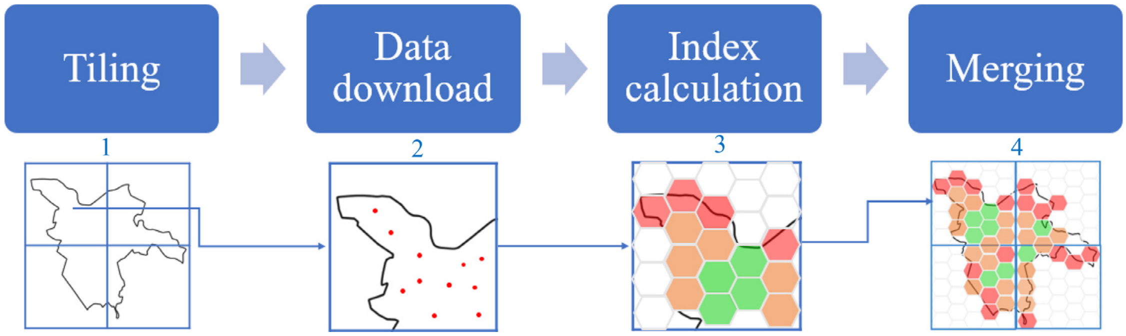

Figure 1. Macro-steps of the algorithm

As mentioned, one crucial requirement for the algorithm is to make it scalable. To do so the area of interest is subdivided into rectangular tiles (of configurable dimension) that will be processed independently in the two following steps. This approach offers three main advantages:

- If the processing of a tile fails, the results of all the previously processed tiles are still safe and the algorithm can safely restart just from the last one before the mistake.
- OSM download API has a limit on the amount of data that can be requested per day, so working on tiles overcomes the limit by downloading the area of interest a bit at a time.
- Tiles allow for the parallel computation of the two following steps and thus for a globally faster processing.

Data download

The data for each tile is downloaded using Pandana[12] for Python. More in details, two types of data are requested: the road network (composed by nodes, edges and their length) and the PoIs which are subsequently assigned to the eight categories defined in sub-section 3.1. Road network data is requested with the filter for “network type” set to “walk”, with the effect of downloading only walkable street.

This step can be replaced with a custom alternative process in case the user plans to use data from a source different form OSM.

Index calculation

The index is computed over the tile as described in in sub-section 3.1.

Merging

Once all tiles have been downloaded and processed, the results are merged in one final textual output that can be used for any downstream application. One impactful application is certainly the creation of a visual interactive map, like the one already available for Italy.

4. Index applications

This section presents two practical applications of the NEXI in the cities of Ferrara and Bologna, both located in Italy. In the former use case, we show how to build on proximity and demography to identify the areas of the city that are most impacted by the lack of close-by basic services, while in the latter use case we show the impact of enriching and extending the OSM information base behind the NEXI with additional information from the local administration.

4.1. Service discomfort analysis in Ferrara

As previously stated, the development of the NEXI started on the area of Ferrara, Italy, within Landscape Metropolis project which allowed for an in-depth analysis of the index and its potential future developments, like service discomfort analysis.

Starting by examining the visual representation of the NEXI-Minutes over the city (Figure 2), the map shows for each cell the average NEXI-Minutes value over all service categories. It should be noted that not the whole area of interest is covered with the hexagon tiles: the missing hexagons correspond to the portion of area where the network has no node and it is therefore not possible to compute the algorithm.

This visualization of the average index is suitable just for a quick evaluation of the spatial trends and is not suitable for analysis at cell level since there is no way to highlight the cases of cells where one or more of the service categories is not present at all within the cell. Instead, NEXI-Minutes shows its real potential when is used to investigate the proximity of a specific category. As an example, Figure 3 shows a comparison of three categories: it is evident that sustenance services are much more homogeneously diffused and dense than the services of the other two categories and that education category has rather few service points and located predominantly in the central areas of the city.

Moving on, Figure 4 displays the NEXI-Global index for the area of Ferrara. This representation is not affected by the incompleteness of the NEXI-Minutes averaged over (available) categories and instead gives an accurate and clear perception of the overall service proximity situation. For example, the index is highly effective in highlighting the 15-minute zone (green) within the area of analysis, which roughly corresponds to the center of the city. All the cells other than the 15-minutes ones are thematized with a discrete gradient ranging from yellow to red, corresponding to ever decreasing values of proximity. A red cell means that there are few (or no) services close to the area, while a yellow cell may either mean that services of all categories are present but are on average a little far or that some of the service categories is completely missing or is very far.

Overlaying the NEXI-Global with the extent of the urban settlements (available as open data from the Italian National Statistical Institute, ISTAT[13]), in Italian: “località”, clearly highlights a typical feature of the Italian context: Ferrara, as most of Italian cities, is surrounded by numerous tiny centers (Figure 5). Moreover, it is apparent that the choice of cell size is suitable to represent the diversity of proximity even in such small areas.

Another interesting insight that we can derive from the overlay in Figure 5 is that we can see how the proximity index effectively provides the information on what service is missing in all cells, however it does not take into account that there could be few or no people living in some of the areas it evaluates, thus making it useless to build new services or infrastructures there. To get past this situation a possible solution could be to develop the NEXI-Discomfort index, deriving it from data on population distribution.

Therefore, thanks to the GIS department of the Municipality of Ferrara, the NEXI-Global was composed with data on population distribution derived from the municipal registry (updated at the end of 2021) to derive the NEXI-Discomfort. Figure 6 shows the spatial distribution of population using the same hexagonal grid adopted by the NEXI and it clearly portrays a situation of high inhomogeneity.

[12] https://pandas.pydata.org/

[13] https://www.istat.it/it/archivio/104317

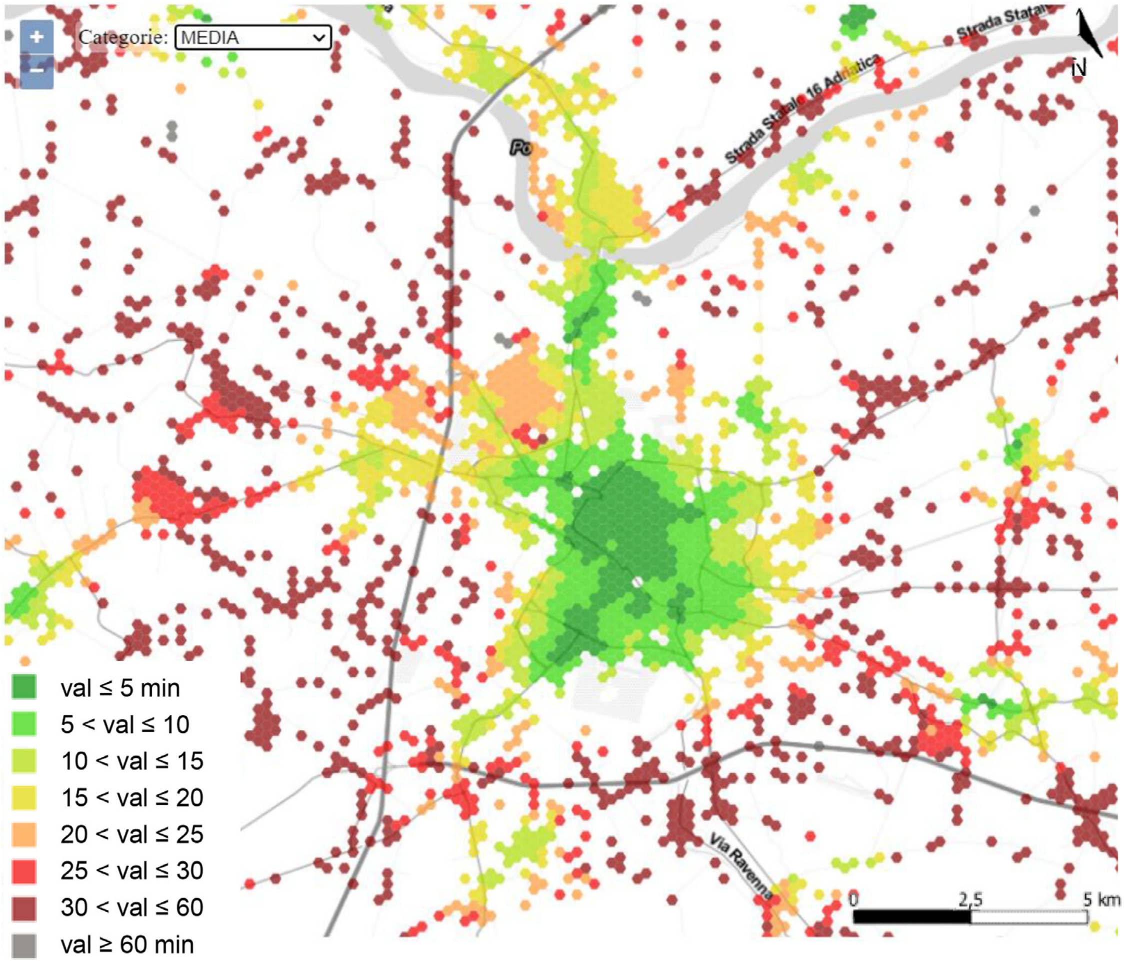

Figure 2. NEXI-Minutes index - Average over category - Ferrara

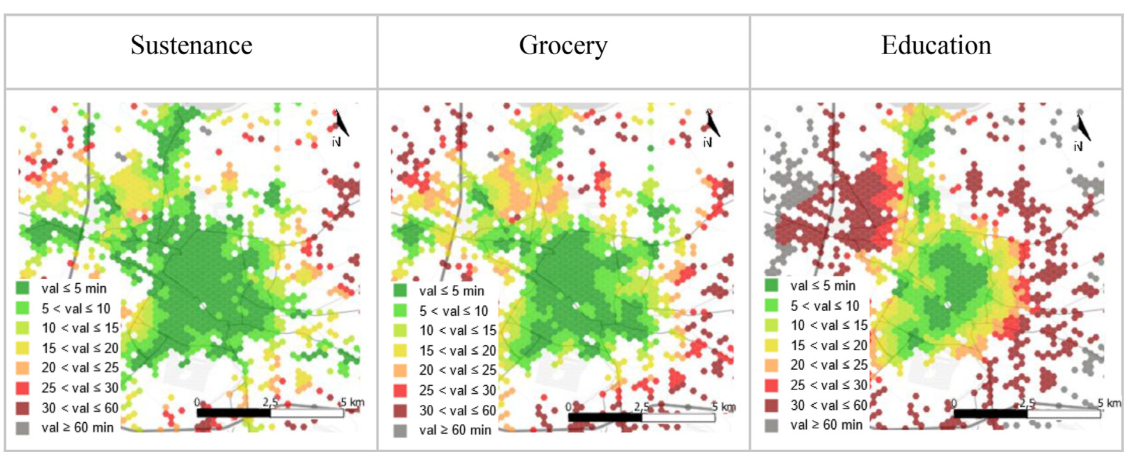

Figure 3. NEXI-Minutes index - Categories comparison - Ferrara

By simply joining the data about population and proximity it was possible to provide a quantitative answer to the question: "how many people in the city of Ferrara live in a 15-minute area?" (Figure 7).

Finally, by computing the NEXI-Discomfort index as described in sub-section 3.1, it is possible to identify the areas that are more affected by a lack of basic services, as they are characterized by being highly populated and at the same time having a low proximity value. The resulting map is shown in Figure 8.

The NEXI-Discomfort provides a new way of looking at the territory, one that clearly highlights the areas where it is necessary to intervene to build new polarities, to strengthen neighborhood services and to create the conditions for citizens to live in a neighborhood that is really 15-minutes.

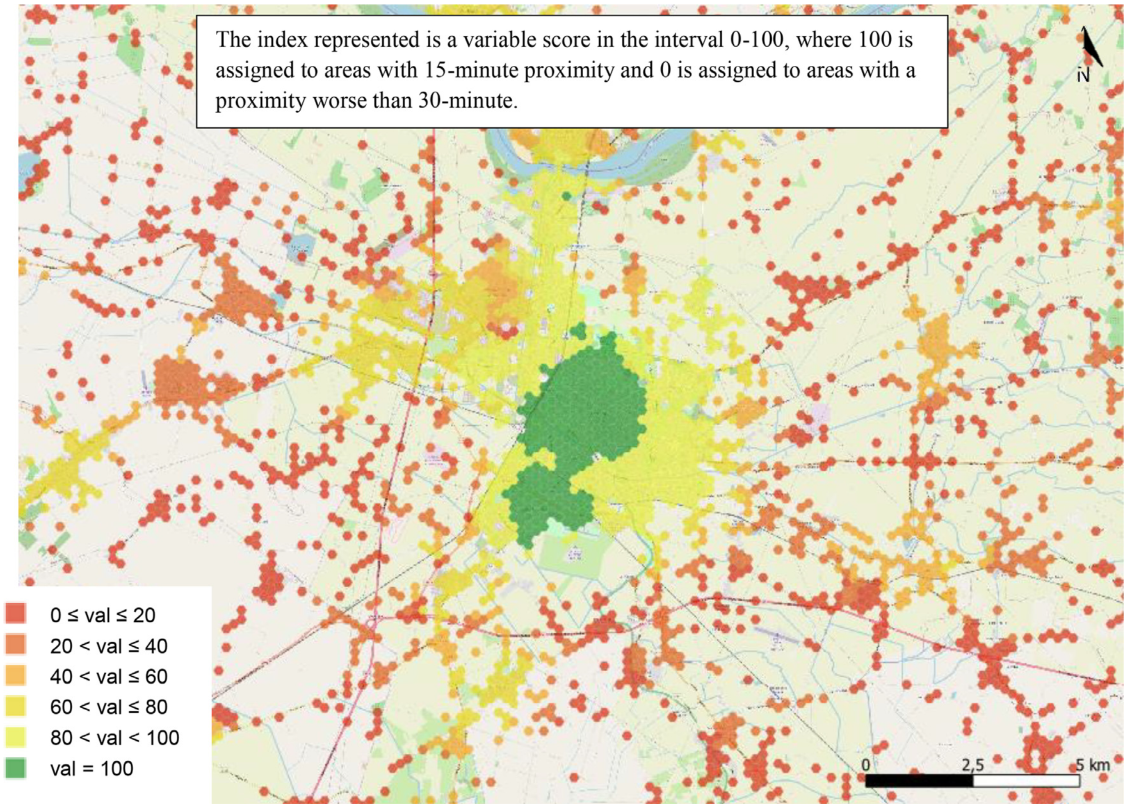

Figure 4. NEXI-Global index – Ferrara

4.2. Integrating NEXI with local data in Bologna

The municipality of Bologna was interested in analyzing the proximity related to some new categories of services: “community services” (such as services for young people and citizen helpdesks) and “access to public transport” (basically represented by the distribution of public transport access points - stops - within the city). Therefore, these two categories were added alongside the eight categories of the standard implementation of NEXI, so that the corresponding levels of proximity could be analyzed. The results are shown in Figure 9 and Figure 10.

Regarding the “access to public transport” category we would like to clarify that a high proximity score does not mean that from that cell it is possible to reach any service by public transport. It just represents the proximity of stops without considering transport destinations and service frequencies.

Another customization of the NEXI was requested concerning the parks category. The municipality was not satisfied by the corresponding OSM data as it included, in addition to the actual public parks, also some very small patches of green that could not be considered as parks. Therefore, OSM parks data were replaced by municipalities data.

5. Conclusions

As discussed in Section 2, there are currently several methods already available to measure proximity. And for limited areas, such as neighborhoods or cities, an in-depth analysis can be performed by collecting official or otherwise accurate data for that specific area, as it happened for the 10-minute city study implemented for the city of Brussels (BSI, 2021). However, the purpose of the NEXI is a different one. We aim to design a data-based tool that can be replicated globally, providing a reliable foundation for decision-making by local administrations.

In general, the added value of NEXI compared to the other indexes presented in the literature review can be characterized by the following main features:

- Scalability - the NEXI computation algorithm can process runs at different scales without relevant performance issues: i.e. the run for the whole Italian territory requires the same processing capabilities (CPU, RAM) that are needed for a run at the regional scale or at the municipal one, the only difference being the execution time which, without recurring to parallelization, increases proportionally with the scale of the area of interest.
- Replicability - the NEXI is easy to replicate in different areas and regions: data related to PoIs (facilities) and road network are already available from global projects like OSM or can be accessed from local open data portals; this also implies the possibility to customize the NEXI, by adding new categories of urban services (like in the case of Bologna, with “community services” and “access to local public transport).
- Interoperability - the NEXI index is not only accessible as interactive web map, but its values are also available through interoperable web protocols, as required by the European Directive 2007/2/CE (INSPIRE), with endpoints offering WMS (ISO19128) and WFS (ISO19142) access for viewing and analysis to a plethora of standard-compliant GIS and webmap clients.

The attention to scalability and replicability does not imply that the index is meant only to provide a global perspective. In fact, the NEXI is also capable of detecting changes in small areas up to the size of its hexagonal cells, making it a glocal tool. The index was developed to measure the level of proximity of any territory, even small towns and municipalities that are often overlooked by traditional measures of this type. Small-sized municipalities are quite common in Italy and other European countries and promoting proximity (or proximity by public transport) in these areas could bring new value to them.

Furthermore, the NEXI is not intended to be an unalterable solution but can be customized to meet the requirements of public administrations. In particular, it is possible to customize the categories of services to be considered in the computation and how they are considered, as

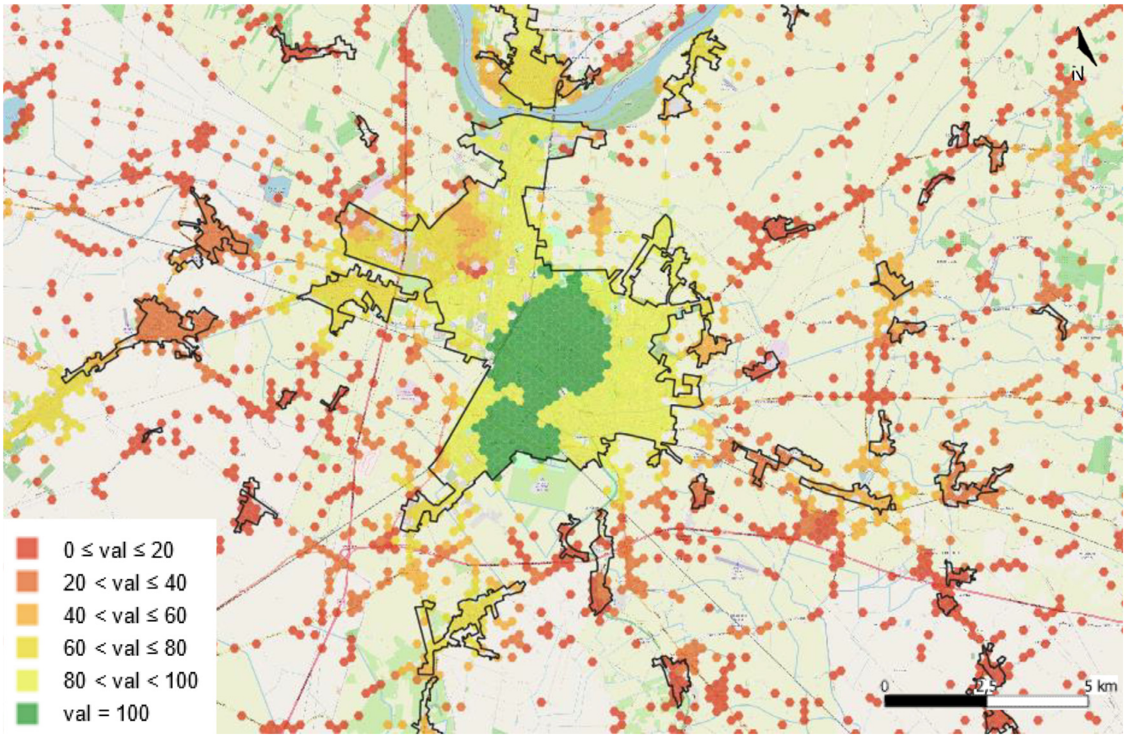

Figure 5. NEXI-Global index with borders of "località" – Ferrara

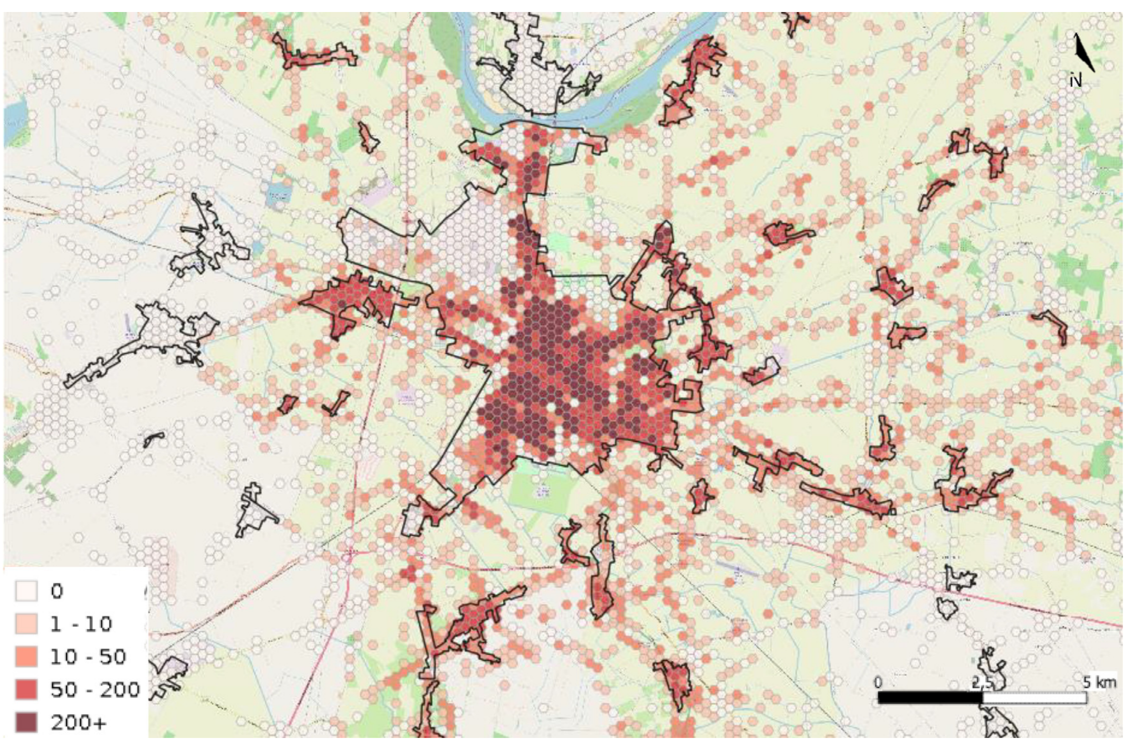

Figure 6. Population distribution with borders of "località" - Ferrara

well as include custom data to enrich the OSM base so to turn the computed index from realistic to real.

Of course, the NEXI does also have limitations, mainly related to the use of OpenStreetMap (OSM). Although OSM brings many advantages to the index, it also has some issues such as the non-uniformity of the data around the globe: since OSM data are updated on a voluntary basis, we cannot expect to have perfectly up-to-date data everywhere all the time. This means, for example, that some of the service PoIs might be missing or not up to date or that walking infrastructures (such as sidewalks and crosswalks) might not be correctly surveyed.

Moreover, the index only takes into account the physical distance between two points (the node of origin and the PoI of destination) and does not consider other aspects, such as how this distance can be covered (i.e. using which type of transportation?) and the path's characteristics (i.e.

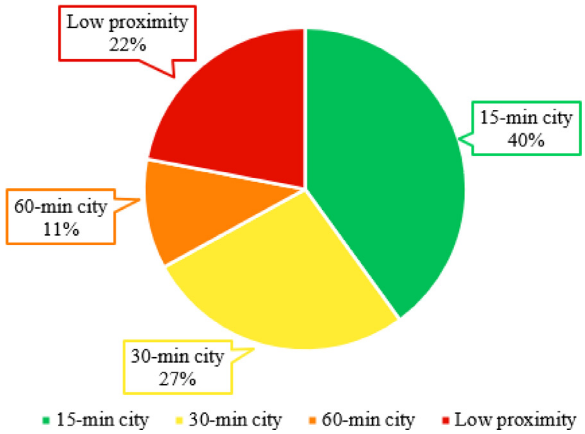

Figure 7. Percentage of population living in the different proximity levels in the city of Ferrara

is it smooth, uneven? Does it have a steep slope?). The NEXI currently focuses on walking, considering it to be a sustainable and inclusive way of moving around. However, it should be noted that walking is an activity that cannot be performed equally by all the people moving along a city's street network and that the personal experiences of mobility and access can be very different among individuals with unequal capabilities.

The next and final section will highlight how some of these limitations could be overcome, envisioning future evolution activities.

6. Future work

Improvements and new applications to the NEXI are currently in progress on various fronts:

What-if scenario tool with interactive adjustments to service types and their spatial distributions.

The NEXI in its current form allows a city to identify critical areas, evaluate missing components, and assess possible interventions to services or road network to improve the situation. Therefore, we think that it would be even more useful if the impact of such interventions could be estimated and visualized to the user in a quick and interactive way by a dedicated tool. Actually, this tool has already been prototyped in selected areas and we plan to test it in co-design processes with citizens and stakeholders to verify ideas and compare their effects on the territory.

Extend the index to additional modes of mobility other than walking.

Moreno's concept of 15-minute city is not limited to walking, it can also be applied to other forms of active mobility for accessing services. Biking, for example, provided that a safe infrastructure is in place, allows people living in peripheral areas to access various services that would be otherwise out-of-reach. For the same reasons, the NEXI algorithm was developed having also cycling in mind: it is therefore possible to have an approximated measure of the level of "bikability" just by changing the speed parameter from 5 km/h to 10 km/h. However, to build a more comprehensive index for "bikability" it would be useful to consider other factors, such as the road slopes which can have an even more relevant impact on biking then on walking.

However, there are instances where attaining accessibility solely through active mobility is unfeasible. For instance, as shown in the case of Ferrara, in rural areas, proximity to services is often limited due to low settlement density, making it more important to investigate the level of accessibility through public transportation instead of trying to improve the density of services. An analysis of public transportation has already been conducted in the case of Bologna, as described in the previous section. In that case, however, we only considered the location of the bus stops and their pervasivity in the city. We plan to extend this analysis by taking into account the routes and scheduled timetables, so to be able to measure accessibility of services by means of public transportation.

Include road morphology and time-dependent service availability in index determination.

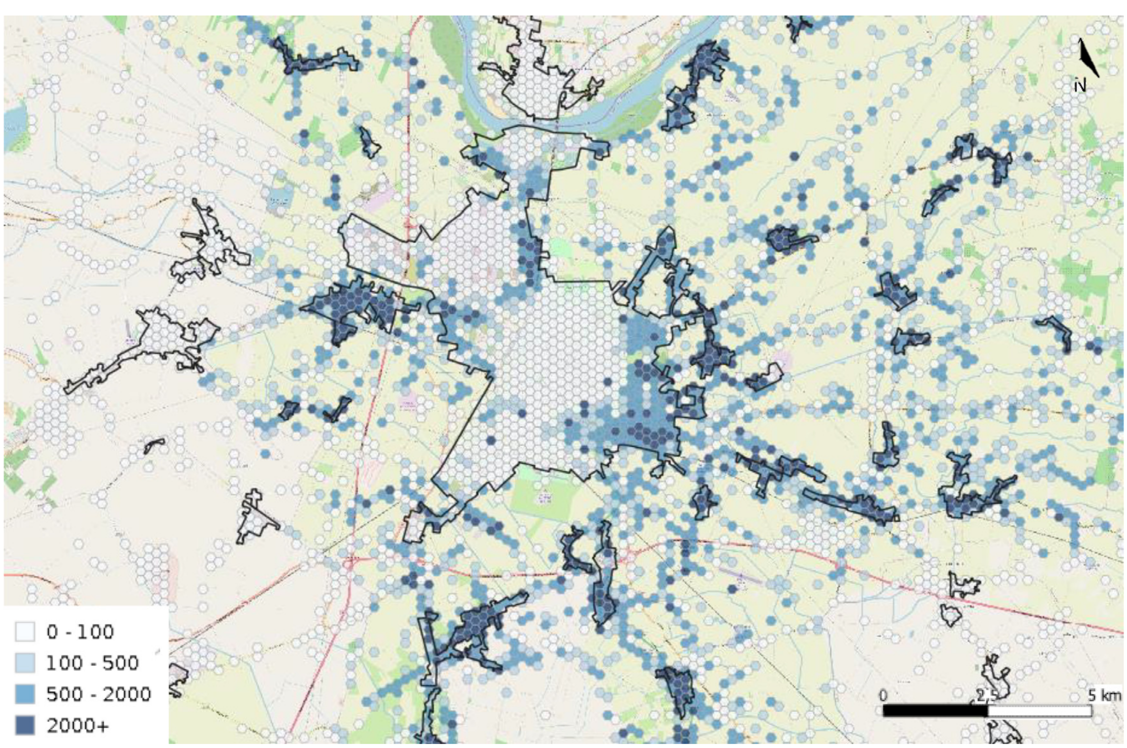

Figure 8. NEXI-Discomfort index and most affected areas - Ferrara

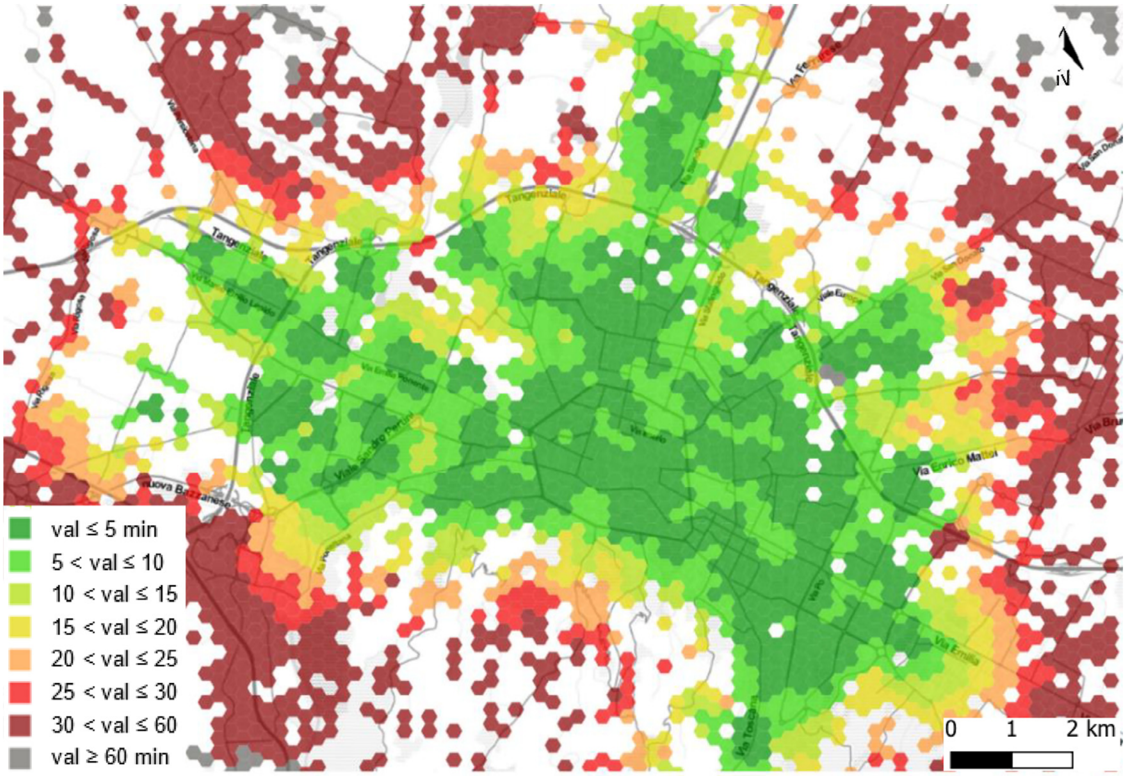

Figure 9. Bologna - Proximity Minutes Index - Community Services

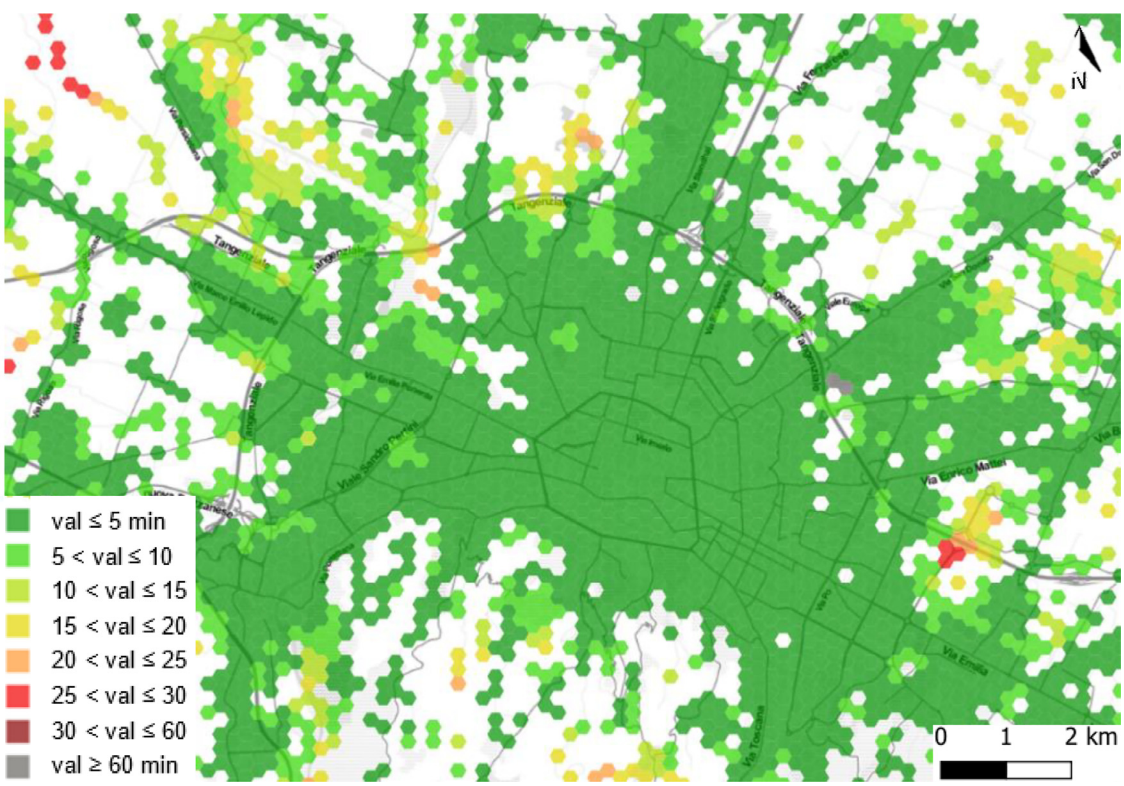

Figure 10. NEXI-Minutes index - Public transportation stops

The morphology of a territory can deeply affect the walkability (or cyclability) of an area. For instance, in areas with significant altitude differences, such as San Francisco, slope becomes an important parameter for measuring proximity. However, OSM does not provide sufficient information about the road's slope, with the incline tag only available for a small percentage of OSM roads (around 0.01%). Solutions such as intersecting the road network with a digital terrain model to assign slope values to each road could improve the NEXI. Other factors such as the materials composing sidewalk paving can also influence walking activity. The information on slopes and materials could then be used to adjust the average speed, as it was done by Pajares et al. (2021), or to assign a penalty to the path, as was done by Pucci et al. (2023).

Another factor exerting a considerable influence on proximity assessments is time. For instance, depending on the purpose of the walking, some neighborhoods may be more walkable during weekends rather than weekdays, or vice versa, as shown by J. Gao et al. (2020). A meaningful example is the presence of marketplaces during some days of the week: in those areas where supermarkets or shops are not present, a marketplace can completely modify the proximity level. Even during a single day, the proximity value can change; business activities, such as shops and supermarkets, but even parks sometimes, have specific opening hours out of which an area can become completely non walkable.

Reassess service types and categories to be included in index computation.

Finally, further research could be conducted to refine the choice of categories and the list of services included within each category.

The addition of new categories, such as "access to public transportation", raises the challenge of assigning appropriate weights to these categories, which are not currently considered in the walk score methodology. To address this the best approach would probably be to discuss directly with the local authority requiring the index about the priority of these categories for their analysis.

Regarding the types of services that should be included in each category there is also room for improvement with respect to the current inclusion of broad OSM categories, as some of the services included can hardly be considered essential. Therefore, it could be beneficial to keep in the list only essential services. Moreover, some of the categories, such as "shops", contain a variety of services that should all be present in the area to make it a 15-minute zone. However, the current version of NEXI only looks for one element of each category, regardless of the nature of the service. It would be beneficial to check instead for the presence of all the different shops that are essential in the daily life.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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