Transportation Engineering 16 (2024) 100244

Contents lists available at ScienceDirect

Transportation Engineering

journal homepage: www.sciencedirect.com/journal/transportation-engineering

On the equity of the x-minute city from the perspective of walkability

Nadia Giuffrida [a,*], Anna Mölter [b], Francesco Pilla [b], Páraic Carroll [b], Michele Ottomanelli [a]

[a] Polytechnic University of Bari, Via Edoardo Orabona, 4, 70126, Bari, Italy
[b] University College Dublin, Belfield, Dublin 4, Ireland

A R T I C L E I N F O

Keywords:
Walkability
Transport equity
15-minute city

A B S T R A C T

Walkability and equity in transport are crucial aspects of sustainable mobility and social well-being. The x-minute city concept emphasizes the importance of walkability, by fostering the design of a city where people can easily access their daily needs aiming to reduce reliance on private cars. However, such approaches, which generally rely on the idea of an “average resident” can ignore inequalities amongst people and fail to achieve the goal of building urban environments where everyone can participate in city life regardless of their socio-economic characteristics and vulnerability. In this study we propose an approach to assess the equity of the x-minute city, highlighting the limitations of the current application of the concept. The approach includes the computation of x-minute thresholds based on the walkability of pedestrian paths and considering different users’ needs. Home to school trips and social trips are taken as a reference; equity metrics such as the Lorenz Curve and Gini Index are used to assess how the x-minute city concurs with the transport equity of a city. The results of the assessment can help identify potential disparities in access to key destinations among different user groups, and support evidence-based policy recommendations to promote equitable transportation options. The case study of Bari, Italy, is used to illustrate the application of the method; however, the proposed approach can be replicated in different contexts, contributing to the ongoing discourse on walkability and equity in transport.

Introduction

As concerns over environmental sustainability and public health continue to grow worldwide, decision-makers and planners are fostering new policies to promote active transport habits. Walking and cycling have emerged as effective alternatives to private transport offering numerous benefits from reducing carbon emissions and traffic congestion to improving physical fitness and mental well-being. In this context, Moreno [1] developed the 15-minute city concept, highlighting how urban planning can be used to build more sustainable cities; the idea is that all essential services, such as grocery stores, schools, healthcare facilities and entertainment venues should be reachable within a 15-minute walk or bike ride from one’s home. This would reduce the reliance on private cars for daily needs thus reducing negative externalities (such as greenhouse gas emissions, accidents and fuel costs), while increasing physical activity. Starting from the concept developed by Moreno, several cities have implemented measures to improve the walkability of their neighbourhoods, using different time thresholds (e.g. 20-minute, 30-minute), hence the more general term *x-minute city*. However, despite the validity of the simple concept that citizens should be “able to meet most of their needs within a short walk from their homes” [2], the advantages of walking are not equally accessible to everyone. Adopting the x-minute city model requires a holistic approach that considers not only mobility but also housing affordability and supply, as well as social and economic diversity. Aside from the fact that the choice of more extended x-thresholds has poor justification by adopters, using them to measure opportunities means that the benefits to residents who exceed the thresholds are ignored, generating the so-called edge effect [3]. Moreover, systemic issues such as unsafe pedestrian infrastructure, lack of sidewalks and crosswalks, and long distances between origins and destinations in certain areas can create significant barriers to the walkability of urban environments. On the other hand, it is important to note the significant advancements spurred by the COVID-19 pandemic, particularly in major European cities, where active mobility measures were swiftly implemented to adapt to changing travel patterns and meet social distancing requirements [4–6]; the development of such improved infrastructure may indeed enhance the walkability experience. Hence, accessibility related to active mobility plays a crucial role in enabling the realization of the x-minute city model and walking-friendly cities in general; however, there are

* Corresponding author.
E-mail address: nadia.giuffrida@poliba.it (N. Giuffrida).

https://doi.org/10.1016/j.treng.2024.100244
Received 16 May 2023; Received in revised form 11 March 2024; Accepted 12 March 2024
Available online 13 March 2024

several challenges in measuring the actual accessibility experienced by pedestrians, due to both the quality of the pedestrian environment and their own physical abilities, and decision-makers cannot rely exclusively on a generalized threshold that uses the city centre as the average origin of all trips and considers the average pedestrian accessibility on the network. Furthermore, a comprehensive examination of the equity of the x-minute city should encompass access to all services essential to the population, including recreational and shopping facilities; in the era of e-commerce and online purchasing, a holistic approach should not overlook the significance of access to urban delivery services, including active mobility options (see e.g. [7,8]). This puts into question the whole concept of the x-minute city and its effectiveness.

On the basis of this premise, in this paper we propose an approach to the assessment of the equity of the x-minute city, in order to explore the differences of an x-minute city approach for different trip purposes and different social categories. The assessment entails a set of scenarios accounting for different walkability conditions, diverse users' categories and their related variety of needs, in order to explore the equity implications. This will provide insights into how the x-minute approach performs in terms of connecting users to key destinations, and whether it promotes accessibility and inclusivity for all users. The final aim is to provide insights for policymakers and practitioners to inform decisions related to the interaction between transportation planning and the x-minute city approach, with the ultimate goal of promoting equitable accessibility for all users. The proposed approach is applied to the case study of Bari, a medium-sized city located in the South of Italy, to demonstrate its applicability in a real-world urban context, and provide understanding into the walkability and equity of transport in the city.

The remainder of the paper is structured as follows. Section 2 provides a literature review on the topic of the x-minute city, showcasing studies that elucidate its feasibility and potential impact on urban mobility and liveability. In Section 3, we introduce the novel approach developed by the authors, which aims to incorporate the influence of diverse social categories on the efficacy of the x-minute city model. Building upon this framework, Section 4 presents the application of our approach to the case study of Bari, focusing in particular on the case of the 15-minute city. Finally, in Section 5, we synthesize the findings and draw conclusions regarding the implications of our research for policymakers.

Literature review

Although it is not actually a recent concept [9], the x-minute city approach since its comeback has awakened the interest of several administrations and researchers who explored the potential benefits and challenges in its implementation. Travel time threshold accessibility is, indeed, the main and most intuitive approach used in the evaluation of the accessibility of the x-minute city. The main concern expressed by scholars is regarding the type of amenities that should be reachable within the threshold and the distribution of such amenities within the territory, aiming at analysing the "horizontal equity" of the x-minute city approach. In their main position paper, Moreno et al. [10] emphasized the need for six urban functions in the 15-minute city: living, working, healthcare, education, commerce/groceries and entertainment. Previously, Grodach et al. [11] evaluated the amenities of the 20-minute neighbourhood infrastructure, a concept similar to the x-minute city, highlighting the need for green spaces, education and religious institutions, sports facilities, local shops, post offices and health facilities. They analysed the case study of Mambourin in Australia; the results from their study show the lack of public spaces and facilities for public engagement, highlighting the varied interests and needs of the different individuals and households in the territory. Weng et al. [12] and Capasso Da Silva et al. [13] selected the amenities respectively for the case of the 15-minute and the 20-minute city, based on inputs from city resident surveys, assigning different weights to the facilities according to the importance assigned by the local dwellers. Weng et al. [12], analysed the case of Shanghai (China) and assessed the current impact of 15-minute walkable city, analysing its spatial distribution and the impact to different social categories. In order to assess weighted walking times, they used a modified Walk Score approach [14], providing different weights for the pedestrian infrastructure according to the presence of amenities that could satisfy the needs of the different social categories. Their results show that the most walkable communities are mainly located in the central area of the megacity; moreover, children-concentrated communities are more likely to have lower walkability, highlighting a greater need from the most vulnerable groups.

Capasso Da Silva et al. [13] presented the case of Tempe (Arizona, USA), a classical suburban city with wide roads; they evaluate 20-minute service areas by cycling, walking and transit, focusing on non-commute travel. Their results show that walking performs worst in terms of accessibility, in particular when considering the sidewalk network as exclusive infrastructure where pedestrians are allowed to walk. O'Gorman & Dillon-Robinson [15] developed a baseline for the 20-minute neighbourhood in Scotland and identified five dimensions: stewardship, including local community groups and resident association; civic, considering cultural and heritage assets, but also security infrastructure (e.g. street lighting); movement, mainly referred to public transport, active travel, traffic calming and parking; resources, including several type of opportunities, such as groceries shops, health facilities, job opportunities and restaurants; spaces for play and recreation and parks. Similarly, Olsen et al. [16] identified ten domains related to health, transport, education, social and recreational for a national wide equity-assessment of the Scottish context for the 20-minute neighbourhoods. Their study shows that a quarter of rural locations had access to zero domains and almost half to less than 3. Moreover, they showed that extending the 20 min definition to a 30 min gives a 95 % increase in residential locations that have access to all domains; this shows the variability of the concept if one does not consider the capabilities of individuals in traveling the design threshold distances. Graells-Garrido et al. [17] proposed the use of big data coming from mobile phone, census, and volunteered geographical information to measure the spatial variations in the relationship between origin-destination flows and local urban accessibility in the 15-minute threshold for the city of Barcelona; their study shows that people tend to visit other neighborhoods with better access to education and retail amenities than their own, while they travel less to other neighborhoods with better accessibility to professional and health amenities. Moreover, unequal access to food retailers emerges, probably due to a large concentration of food amenities in the center of the city. Wu et al. [18], analysed the 15-minute community life circle strategy promoted by the city of Shanghai, using the 2018 AutoNavi POI (Point of Interests), OSM (OpenStreetMap) road network data and LandScan population data set. They adopted kernel density estimation, service area analysis and other statistical models to analyse the coverage of points of interests based on the current network; the results show that although some of the basics services are covered, 15-minute access to facilities in Shanghai still needs to be optimized through functional replacement or urban renewal design, above all to respond to the needs of the population residing in the various areas. In 2022, Logan et al. [2] compared approaches to measure the x-minute city, assessed different urban areas in USA and New Zeland according to the concept and presented interactive visualizations. The results suggest that, instead of setting arbitrary "x" targets, policymakers should seek to minimise X by improving accessibility. Finally, Calafiore et al. [19] selected the relevant amenities according to the existing literature and focus their study of the 20-minute city on non-work-related amenities; they analysed the case of Liverpool City Region and explored the relationship between car ownership and accessibility; they found that people living in less walkable neighborhoods in general have low car ownership and low accessibility, while they also have to deal with higher transport costs, suffering a great transport inequality condition.

Table 1 provides an overview of the reviewed studies, summarizing key findings and highlighting their contributions to the discourse, based on key criteria, including the selected time threshold (e.g., 15-minute or 20-minute), transportation modes considered, and the methodologies employed.

The literature review shows that in general, the x-minute city design approaches are considered positively, since they promote the enhancement of active travel; however, several studies show how the socio-demographic conditions and the quality of the infrastructure can have a significant impact in the assessment of the threshold accessibility, particularly in the case where only walking is considered as a transport option. In particular, most of the studies are not able to assess the actual impact of the 15-minute cities on the different social categories, adopting a generic population, flat walkability conditions (hence, a generic walking time) and considering several urban functions as essentials for everybody; this does not reflect the variety of different road users and available infrastructure within the territory. Equity assessment, indeed, should include consideration based on both the need to evaluate whether all the population has the same accessibility to the services - i.e. the so-called horizontal equity - and the different level of needs due to socio-economic conditions - the vertical equity [20].

Starting from these concepts, in this paper we explore the different equity impacts of an x-minute city design for different trip purposes and social categories. The aim is to offer the following contributions to the discourse on the x-minute city topic: firstly, to advance the assessment beyond the traditional 'flat minute' concept currently used in literature, which relies on abilities and needs of an average individual; secondly, to introduce an approach capable of considering the multiplicity of social contexts and targeted opportunities/amenities, thereby enhancing the understanding of urban accessibility and equity.

In particular, in order to assess equity impacts, we will use the Lorenz curve [21] and Gini Index, which are economic measures commonly applied to evaluate the distribution of a particular attribute within a population. These measures have been successfully used to assess transport equity in previous studies, e.g. in the context of public transport services and shared mobility [20,22–24].

Method

This paper proposes an equity assessment which enables the exploration of the impact of the x-minute city in different scenarios. Threshold accessibility measures are computed for different scenarios involving users with different needs and scopes. The approach is based on the following steps:

- Spatial zoning, which can be conducted with different levels of detail.
- Modelling the characteristics of the road network, in order to compute the shortest path among origins and destinations.
- Scenario definition: different scenarios considering different trip purposes and users categories should be considered, in order to consider their own characteristics and behaviours.
- Walkability assessment: this is conducted considering the spatial characteristics of each link in the road network, according to a Walkability Index (*W*) previously developed [25]
- Threshold accessibility analysis: isochrones will be used to assess accessibility in the different scenarios; they are polygons that represent areas that can be reached within a specified travel time (e.g., x-minutes) from a given origin, on a transportation network; isochrones are evaluated considering the underlying walkability constraints and pedestrian walking speed.
- Equity assessment: using the Lorenz Curve and Gini Index, the equity of the distribution of opportunities across isochrones will be assessed to identify disparities or inequities in access.

The approach is summarized in Fig. 1. In the following sections more

Table 1
Overview of reviewed studies on the x-minute city approach.

References	X minutes	Mode	Method/ Approach	Highlights
Grodach et al. [11]	20 min	cycling, walking and transit	network buffer method to derive the catchment sizes	Dimensions: green spaces, education and religious institutions, sports facilities, local shops, post offices and health facilities
Weng et al. [12]	15 min	walking	modified Walk Score approach	Different behavior characteristics of pedestrian groups and facility attributes
Capasso Da Silva et al. [13]	20 min	cycling, walking and transit		focusing on non-commute travel
Moreno et al. [10]	15 min	walking, cycling	Position paper on the concept	urban functions: living, working, healthcare, education, commerce and entertainment
O'Gorman & Dillon-Robinson [15]	20 min	walking	physical assets within an 800 m zone	dimensions: stewardship (local community), civic (cultural assets), movement (public transport, active travel, traffic calming and parking), resources (opportunities), spaces (recreation and parks).
Graells-Garrido et al. [17]	15 min	walking	Gravity model and Geographically Weighted Regression	unequal access to food retailers
Wu et al. [18]	15-minute community		kernel density estimation, service area analysis	although some of the basics services are covered, 15-minute access to facilities in Shanghai still needs to be optimized through functional replacement or urban renewal design
Olsen et al. [16]	20/30 min (20-min return trip)	walking	physical assets within an 800 m zone	ten domains related to health, transport, education, social and recreational
Logan et al. [2]	10, 15, 20-minutes	walking	Comparison of different methods	instead of setting arbitrary "x" targets, policymakers should seek to minimise X by improving accessibility
Calafiore et al. [19]	20 min (20-min return trip)	walking	spatial clusters and equity analysis through	Focus on non-work-related amenities people

(continued on next page)

Table 1 (*continued*)

References	X minutes	Mode	Method/ Approach	Highlights
			OLS and Geographically Weighted Regression	living in less walkable neighborhoods have low car ownership and low accessibility, while they have higher transport costs, suffering a great transport inequality condition

details for each step are provided.

Zoning and modelling of the road network

Territorial zoning consists of dividing the study area into different zones based on relevant criteria such as geographic boundaries, administrative units, or socio-demographic characteristics, which can be achieved with various levels of detail. As depicted in Fig. 1, ZONING allows to get disaggregated information on USERS (such as travel speeds and behaviours, based on socio-demographic characteristics) and OD (main origin-destination trips). Within the scope of this study, we have employed two distinct zoning approaches, namely a more detailed zoning based on population data, and a census-based zoning which incorporates finer-grained socio-demographic data. In relation to the modelling of the road network, given that we are dealing with pedestrian trips, it is important to refer to a detailed network that enables one to identify as many routes as possible (including those using paths reserved for pedestrians, such as stairs) and the characteristics of the surrounding environment. As shown in Fig. 1, ROAD NETWORK MODELLING allows to evaluate shortest paths and get detailed information on geometric and functional characteristics of the infrastructure; a sufficient level of detail is also needed to calculate a more accurate WALKABILITY INDEX *W*, as shown in Sections 3.2 and 4.2. Detailed information on the data used for the case study are reported in Section 4.1.

Walkability assessment

In this work, we focused on walkable accessibility, since it can be considered the most cost-effective mode of transport in terms of health impacts and economic return; moreover, it is often taken into consideration by public administrations in the case of scarce resources since they can assign priority of interventions for the improvement of pedestrian infrastructure [26]. However, defining an actual walkable distance in the 15-minute assessment is not straightforward. For example, the Scottish Government uses 800 metres as the walkable distance taking accessibility for all (i.e. those without mobility challenges) into account [15], considering that they can be walked in about 10 min; this disregards the needs of those who might not be able to walk at the required speed and does not consider the differences in infrastructure quality.

In order to overcome these issues, in this paper a walkability assessment of the road network is performed considering a Walkability index (*W*, previously developed in [25]) as a constraint to a fluid pedestrian flow. The aim is to determine the extent to which the road network design supports safe and convenient pedestrian mobility.

The walkability index is based on a set of metrics that capture different aspects of the pedestrian environment. These metrics include the presence of signalized crossings (if available), navigation for people with visual impairment, presence of footpaths, presence of public seating, green spaces, and bus stop facilities (if present). The walkability index serves as a quantitative measure of the quality of the pedestrian infrastructure, providing insights into the extent to which the built environment supports and encourages walking as a mode of transportation.

The presence of signalized crossings (c) is an important factor in assessing walkability, as it indicates the presence of safe and designated areas for pedestrians to cross the road. Navigation for people with visual impairment (t), such as tactile paving and audible signals, can enhance the accessibility of the pedestrian environment for individuals with visual impairments, ensuring that they can safely navigate the city. The presence of footpaths (fs), or sidewalks (s), is a critical component of walkability, as it provides dedicated spaces for pedestrians to walk separated from vehicular traffic. Public seating (ps) can contribute to the comfort and convenience of pedestrians, providing resting areas and promoting walkability as a mode of transportation. Green spaces, such as parks and urban green areas (g), can enhance the aesthetic appeal and liveability of the pedestrian environment, making it more attractive for walking. Lastly, the presence of bus stop and related equipment (bs) can improve the accessibility and convenience of public transportation, which can complement walking trips.

The walkability index is computed as a combination of the aforementioned parameters, and it is estimated for each zone *i*; each of the parameters can be weighted according to the importance assigned by the decision-makers, as shown in Eq. (1):

$$W_i = \frac{w_c c_i + w_t t_i + w_{fs} fs_i + w_s s_i + w_{ps} ps_i + w_g g_i + w_{bs} bs_i}{n_m} \; \forall i \in I \quad (1)$$

Where w_{mc}, w_t, w_{fs}, w_s, w_{ps}, w_g and w_{bs} are the weights assigned to each parameter by decision-makers and $i \in I$ the set of links of the modelled network.

The walkability index aggregates the metrics into a composite measure that reflects the overall quality of the pedestrian environment.

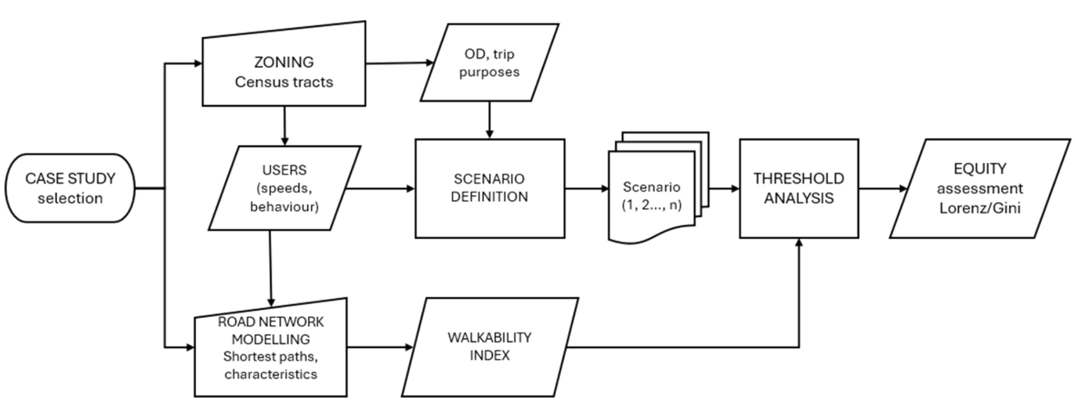

Fig. 1. Overview of the equity assessment approach for x-minute city scenarios.

By quantitatively assessing these different aspects of walkability, the index will provide a holistic evaluation of the pedestrian environment and inform decision-making efforts aimed at improving the walkability of the city. In our work, we will use the walkability index to provide a realistic differentiation of the quality of the road network, influencing the walking speeds of each link; as illustrated in Fig. 1, WALKABILITY INDEX is used to perform THRESHOLD ANALYSIS of the different scenarios.

Scenario definition

As depicted in the framework in Fig. 1, outputs of ZONING allow for SCENARIO DEFINITION: different scenarios are developed to account for varying trip purposes and user classes, ensuring that the unique preferences, needs, and behaviours of different population groups are taken into consideration. By delineating distinct scenarios, such as commuting, recreational activities, and shopping, as well as considering diverse user classes based on factors like age, mobility limitations, and socioeconomic status, one could capture the full spectrum of urban mobility demands and experiences. This allows for a more nuanced analysis of the equity implications of the x-minute city model, as it enables researchers to evaluate the accessibility and inclusivity of urban environments from multiple perspectives. Furthermore, by considering the specific characteristics and behaviours associated with each scenario and user category, policymakers and planners can better tailor interventions and infrastructure improvements to meet the diverse needs of urban residents and promote equitable access to essential services and amenities.

Threshold analysis

As part of the proposed approach, isochrones are computed to analyse trips. Isochrones are geographic representations that depict areas that can be reached from a specific location within a given x-time threshold using a particular mode of transportation (in our case walking). The computation of isochrones is performed within a geographic information system (GIS) using the QGIS software (version 3.28.3) and the modelled road network adopting the reduced speeds due to the walkability assessment. This provides a spatial representation of the areas that can be reached within a certain time frame on foot from each zone. Moreover, although cycling is typically included in the x-minute cities threshold evaluation, we will only consider the walking option for this study to evaluate the worst-case scenarios (i.e. with lower trips speeds), to stay on the safety side. However, the approach can be reproduced introducing cycling as a further option. The computation of isochrones for home to school trips and social trips, provides a first insight into the spatial distribution of opportunities for different user groups to identify potential disparities in access to key destinations. Fig. 1 shows that the output of THRESHOLD ANALYSIS is then used to perform the final EQUITY assessment, as described in Section 3.5.

Equity assessment

The assessment of equity aided by the computed isochrones is conducted using the Lorenz Curve and Gini Index approaches, which provide quantitative measures that can help assess the extent to which the benefits and burdens of transportation accessibility are distributed among different user groups.

The Lorenz Curve is a graphical representation of the cumulative distribution of a quantity (in our case the threshold accessibility) across different user groups. We use it to plot the cumulative percentage of accessible opportunities against the cumulative proportion of the population. A perfectly equitable distribution of accessibility would result in a diagonal line, indicating that each proportion of the population has an equal share of accessibility. The relationship between the Lorenz Curve and the straight line of equal distribution is called Gini Index and it considers the area (A) between the Lorenz Curve and the line of perfect equality (the diagonal line) or the area below the Lorenz curve (B). which are calculated using integration or numerical methods (as illustrated in Fig. 2).

When the entire Lorenz curve is not known, and only values at certain intervals k are given, the curve can be approximated on each interval as a line between consecutive points; then the area B can be approximated with trapezoids. X_k is the generic interval of the cumulative percentage of the population variable and Y_k is the corresponding interval of the quantity cumulative percentage (in our case the threshold accessibility), for $k = 1, \ldots,$ n intervals with known values; the Gini Index (G) can be mathematically calculated using the following formula:

$$G = 1 - \sum_{k=1}^{n} (X_k - X_{k-1})(Y_k + Y_{k-1}) \quad (2)$$

The Gini Index provides a concise measure that summarizes the inequality depicted by the Lorenz Curve; it ranges from 0 to 1, with 0 indicating perfect equity and 1 indicating complete inequality.

Results from the application

Case study

The proposed approach is applied to the case study of the city of Bari in Italy, taking into consideration its territorial framework. The city of Bari is located in the southern region of Italy and has a population of approximately 320,000 people. The city is known for its historic centre with narrow streets and limited road infrastructure, which includes a medieval castle and numerous churches. In recent years, the city has also invested in improving its walkability infrastructures to encourage more active modes of transportation and reduced reliance on cars. The decision to close the main central street of Bari (via Sparano) for the first time was taken in 1973 by the municipal administration, and since then, the city has implemented various measures to improve walkability. The recent Sustainable Urban Mobility Plan (SUMP) [27] also provides for the increase in the closures to traffic of some roads and central areas, in order to limit air pollution and improve the local economy. However, the current modal share of walking and cycling in the city is still relatively low.

The analysis will consider the specific road network constraints and walkability challenges in Bari, such as the presence of historic areas and limited pedestrian infrastructure, which may affect the accessibility and mobility of different user groups. In particular, for this case study, we decided to focus on the 15-minute city approach ($x = 15$) due to its prevalence and frequent utilization in existing literature.

Zoning and modelling of the road network of the city

In relation to population data, we relied on two different sources, in

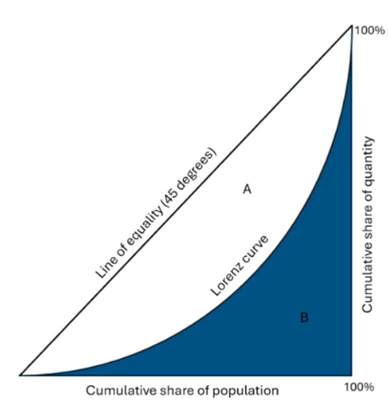

Fig. 2. Example of generic Lorenz curve with A and B areas depicted.

order to be able to take advantage of the most up-to-date information. Specifically, we used the Italian Statistic Institute data [28] in the scenarios regarding home to school trips. We decided to opt for this source in these cases, since we wanted detailed information on the age of the population and their current occupation status and the information provided by ISTAT, even if referring to the year 2011, is the most comprehensive. In the case of sociality score scenarios, we preferred to select a more up-to-date and detailed source; in particular, we utilised the WorldPop Open Population Repository [29] which enables the download of gridded data on the number of people per pixel in Geotiff format at a resolution of 3 arc (approximately 100 m at the equator) and projected in GCS WGS84 [30].

Fig. 3 shows that from both databases one can see that the most densely populated area is that of the historic center of the city, and the residences extend southwards along the axis that goes from the Viale dell'Unità street to Viale della Costituzione street. Other populated areas are the neighbourhood of San Girolamo in the northwest, and the neighbourhood of San Paolo in the west of the city.

Schools data and locations have been retrieved from a free webservice [31], which provides the name and the address of the facility. Addresses have been geocoded using HQGIS, a python-based plugin for QGIS that offers access to the HERE API and allows to geocode multiple addresses on the basis of an address field within a CSV database. Results from the geocoding is displayed in Fig. 4, which shows that locations of schools are quite in line with density of population. Finally, the road network was retrieved by Open Street Map (OSM) using the QGIS plugin QuickOSM.

Walkability Index in Bari

The methodology involves the computation of the W index, conducting a detailed assessment of the road network in Bari. The compatibility of each road network link with pedestrian trips is evaluated taking into account the existing infrastructure with the related parameters as presented in Section 3.3. The OSM road network and the other spatial data used for the W have been retrieved using the QGIS plugin QuickOSM; a summary of the metrics based on OSM data with related key and attributes in OSM and the simplified scores are reported in Table 2.

W was then computed for each link of the road network according to Eq. (1). In this study, for the sake of simplicity, it was decided to apply an equal value of 1 to all the weights. A mapping of the index is reported in Fig. 5 and shows that most of the pedestrian-friendly infrastructure is located in the central neighbourhoods of the city, while the most peripheral areas are disregarded.

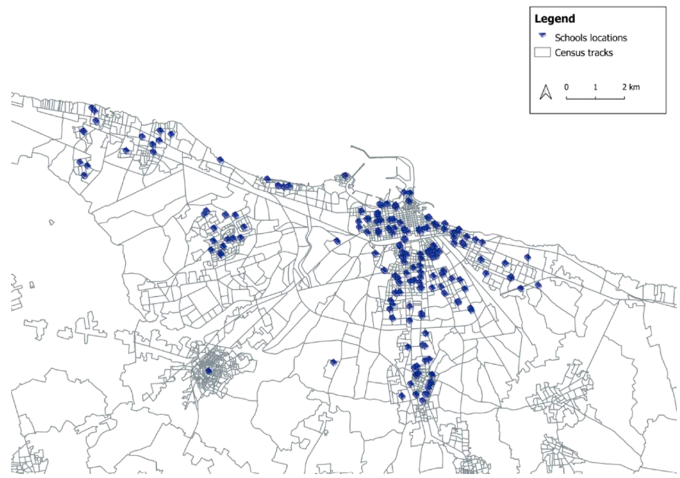

Fig. 4. Schools locations in Bari.

Scenarios definition

In this study, two different trip purposes are analysed:

- Social trips. This first set of trips can be considered equally valid for the entire population of the reference area. In particular, in this study we will refer to the accessibility index of the Sociality Score developed by Biazzo et al. [32]. Sociality score is a concept which quantifies the number of people one can meet from a specific area. The relevance of this metric is associated with the fact that densified cities promote social capital and social cohesion, thus guaranteeing community resilience [33]. This is particularly important in the case of walkability analysis, since pedestrian-oriented neighborhoods have proven to improve the quality of life of vulnerable users and cities sustainably [34,35]
- Home to school trips. We decided to explore this trip purpose since children can be considered among the most vulnerable road users, due to their age and the fact that they generally do not have access to private transport, aside from being a passenger. Moreover, school trips (more specifically, school drop-offs) are proven to be among the main causes of vehicular traffic during peak hours. In fact, many administrations are adopting school-streets requalification and organizing walking-buses initiatives, precisely with the aim of reducing the impacts of such trips [36].

Furthermore, each trip purpose is analysed according to different walkability conditions, considering different quality values for each link

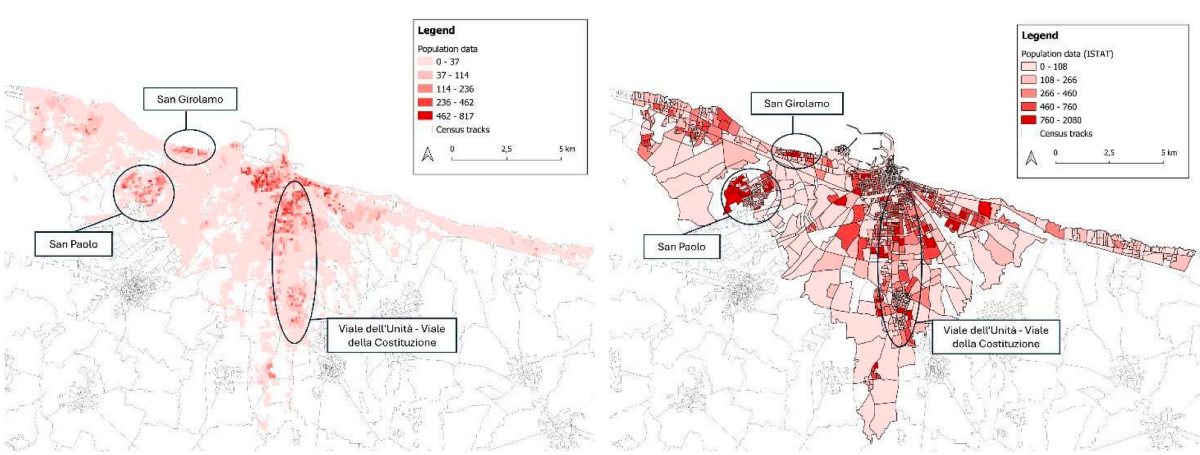

Fig. 3. Left: Population data by WORP [30]; Right: Population data by ISTAT [28].

Table 2
OSM metrics, key, feature, attributes and scores.

Name	Description	OSM key	Feature	OSM attribute	Score 1	0
m_c	presence of signalized crossing (if at crossing)	Highway	Point	Crossing	If present	If not present
		Footway	Lines	Crossing		
		Railway	Point	Crossing		
m_t	Navigation for people with visual impairment	crossing	Point, Lines	tactile	If present	If not present
m_{fs}	Presence of footway	footway	Lines	Surface	paved	unpaved
m_s		highway	Lines	Footway, pedestrian, steps, path	If present	If not present
		footway	Lines	Sidewalk		
m_{ps}	Presence of public seating	amenity	Points	bench	If present	If not present
m_g	Green spaces	Leisure	Areas	Park	If present	If not present
		natural	Points	Tree		
			Lines	Tree_row		
m_{sl}	Presence of streetlamp	highway	Points	street_lamp	If present	If not present
m_{bs}	Bus stop equipment (if present)	Public_transport	Areas, Points	All keys	If equipped	If not equipped

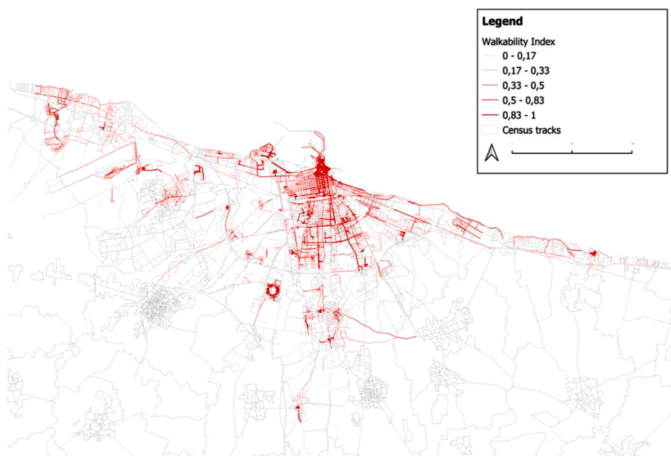

Fig. 5. Walkability index.

of the road network, overcoming approaches that provide for a unique speed for the entire pedestrian network. Furthermore, we design two scenarios for each of the two trip purposes: one considering the sociality score evaluated with speeds at each link adjusted by *W*; the speeds range from 3 km/h for the links with the lowest walkability conditions (hence, the lowest *W*) to 4 km/h (for the highest *W*). For a comparison with a flat-speed approach, we considered a second scenario with a value of speed of 4 km/h at each link. The chosen scenarios aim to assess the distribution of accessibility within the 15-minute city, analyse the effects of varying levels of walkability, and examine their correlation with the categories most affected by such accessibility. This enables a subsequent evaluation of vertical equity, aiding in reflecting the social needs of specific user categories.

A summary of the designed scenarios is reported in the table (Table 3).

Threshold analysis

The threshold accessibility was computed considering a 15- minute time interval for each of the four scenarios shown in Section 4.4. The

Table 3
The 6 explored scenarios.

Scenario name	Description
Sociality score (W)	Sociality score with speeds adjusted by W
Sociality score (W = 1)	Sociality score with speed = 4 km/h
School accessibility (W)	Schools accessibility with speeds adjusted by W
School accessibility (W = 1)	Schools accessibility with speed = 4 km/h

threshold within the road network has been computed for each zone using the Service Area tool in QGIS. More in detail, for the sociality score we computed the threshold for the 11.629 zones deriving from the WorldPop zoning, while for the Schools' Accessibility threshold we computed it for the 1501 ISTAT zones. Maps of the threshold accessibility at each zone for the 6 scenarios are shown in Figs. 6 and 7. A first look at the maps shows how, as expected, a reduction in speed due to a worse quality of the pedestrian infrastructure leads to a reduction in accessibility, especially in areas where it already assumes low values, i.e. in the suburbs.

Descriptive statistics analysis was performed for the four scenarios and results are shown in Table 4. The results confirm that the scenarios with $W = 1$ are those which allow to reach higher (Max) and average (Mean) values of accessibility; furthermore, even if the standard deviation values (σ) differ slightly among the couple of scenarios, the coefficient of variation (Cv) demonstrates greater variability for the scenarios in which the speed is adjusted by the *W*, proving the importance of considering different walkability conditions.

Equity assessment

The Lorenz Curve and Gini Index are computed for a systematic assessment of equity in the different isochrones for home to school trips and social trips in Bari. Figs. 8 and 9 depicts the Lorenz curve for the Sociality score scenarios and the Schools' Accessibility Threshold scenarios respectively.

For a vertical assessment of the equity of the accessibility measure, in the scenarios related to home to school trips, we computed Lorenz Curve using as reference the school – age population residing in each area of origin according to ISTAT [28], as shown in Fig. 10. Table 5 shows the Gini index for all scenarios.

Discussion

Some considerations arise from these analyses:

- In the two scenarios of the sociality scores, the Lorenz Curve and Gini Index depicts a situation of almost perfect equity; a small difference can be appreciated within the two scenarios, with the "$W = 1$″ scenario performing slightly better than the other.
- The Schools' Accessibility Threshold findings offer totally different insights, with values that differ widely from the equity line; as expected, the scenarios in which the speeds adjusted by *W* values are considered to perform worse. Moreover, when considering the school-age population, the graph indicates that almost 20 % of students have no access to educational facilities in the 15-minute city, while around the 70 % experience accessibility of less than half of the highest value.

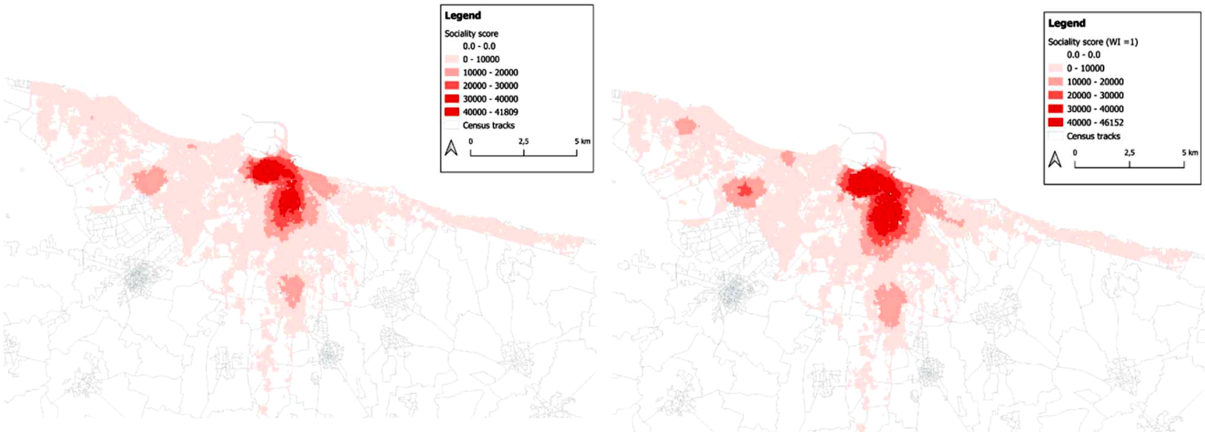

Fig. 6. Left: Sociality score with reduced speeds according to WI; Right: Sociality score with WI = 1.

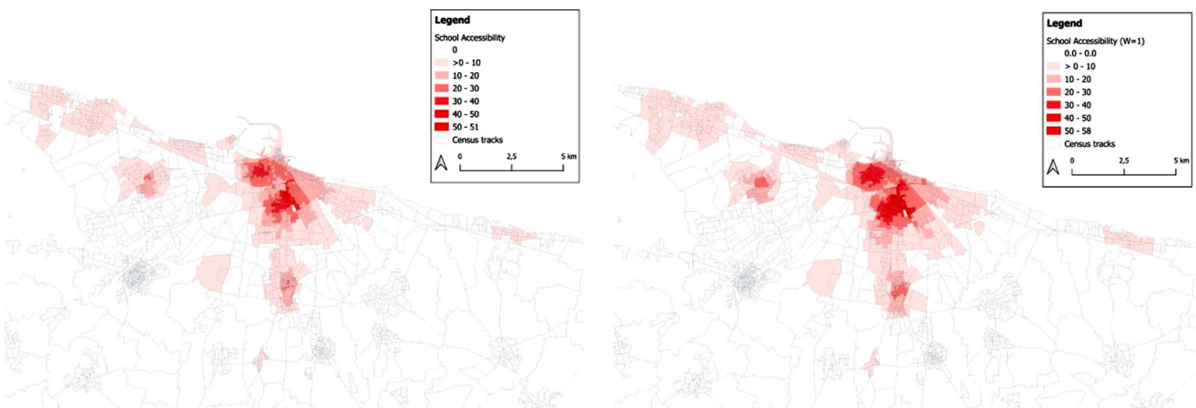

Fig. 7. Left: School Accessibility with reduced speeds according to WI; Right: Sociality score with WI = 1.

Table 4
Basic statistics for the four scenarios.

Trip Purpose	Scenario	Max	Mean	σ	Cv
Sociality score	$W = 1$	46,151.522	6749.141	9604.152	1.423
	W	41,808.817	5242.732	8065.179	1.538
School Threshold Accessibility	$W = 1$	58	16.136	13.176	0.817
	W	51	13.062	11.116	0.851

- These results are corroborated by the Gini Index evaluation in Table 5: while indices for the sociality score are close to 0, all the Schools' Accessibility Threshold scenarios assume higher values, with the ones related to school-age population assuming the highest ones. This is in line with the findings by Weng et al. [12].

The results show that the walkability of the infrastructure influences the x-minute city performance, highlighting the need for policymakers and urban planners to prioritize investment in pedestrian infrastructure in underserved communities and to create walkable environments that

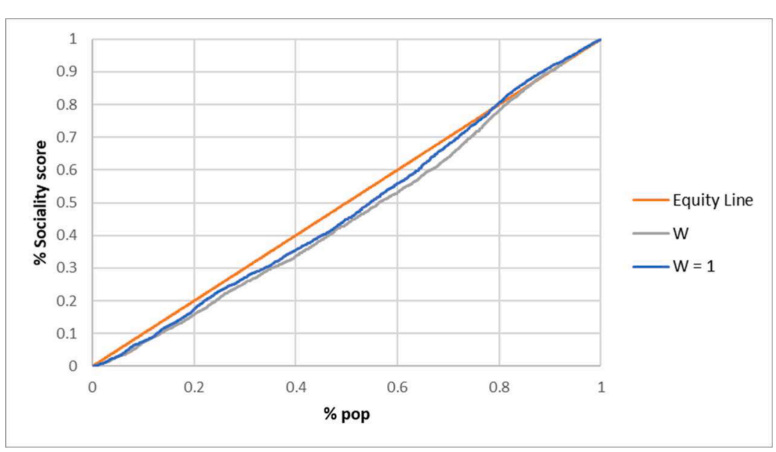

Fig. 8. Lorenz curve for the two different scenarios of the Sociality Score.

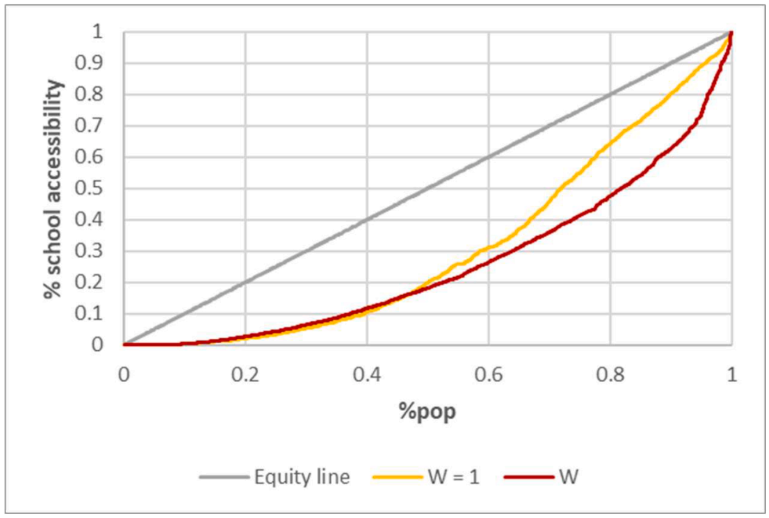

Fig. 9. Lorenz curve for the four different scenarios of the Schools' Accessibility Threshold.

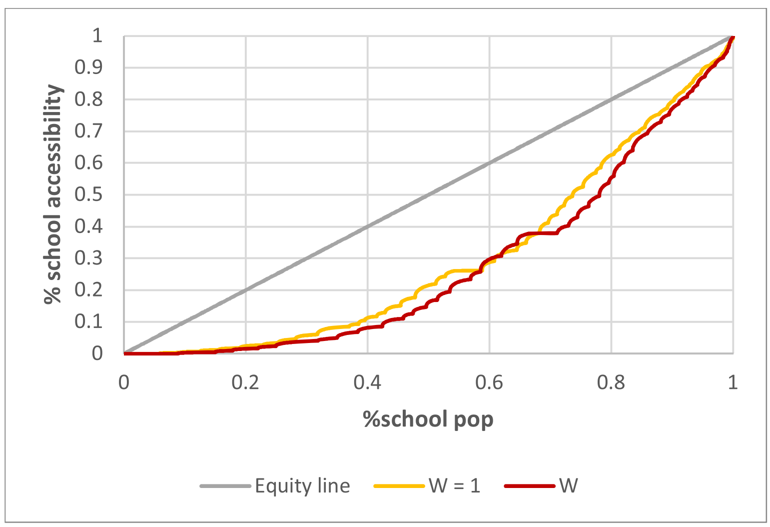

Fig. 10. Lorenz curve for the school – age population in the two different scenarios of the Schools' Accessibility Threshold.

Table 5
Gini Index for the six scenarios.

Scenario	Gini Index
Sociality $W = 1$	0.079
Sociality W	0.045
School $W = 1$	0.386
School W	0.404
School (age) $W = 1$	0.395
School (age) W	0.445

address the needs of diverse populations. Moreover, vulnerable categories such has children do not achieve equal access to school facilities: almost 20 % of students have no access to educational facilities in the 15-minute city, while around the 70 % experiences of less than the half of the highest accessibility condition, highlighting evident disparities in access to their core destinations. This is further exacerbated by the fact that this study does not consider that not all the educational services are equal [37], i.e. schools are generally identified as a key public amenity, disregarding the quality of the school in question and the maximum number of students that can be accommodated. As a further limitation, this study considered generic starting speed values for all users. However, the constraints arising from the mobility abilities of users might play a pivotal role in shaping the speed at which isochrones are calculated. The velocity used in these calculations is contingent upon a range of factors, including but not limited to the specific characteristics of the users under consideration, such as travel preferences and demographic information.

The results corroborate the imperative for decision makers to enhance the quality of paths for active mobility to schools. Students, indeed, face different challenges when commuting to school, mainly due to the fact that parents frequently opt to drive them to the educational facilities, contributing to increased traffic volumes and associated externalities, such as air pollution and safety hazards, near school entrances. By promoting active mobility options such as walking and cycling, improving the quality of paths and infrastructure (hence the walkability), and guaranteeing equity among the different city areas, policymakers might play a role not only alleviating traffic congestion and reduce emissions but also fostering healthier and more environmentally friendly school journeys.

Conclusion

In recent years, the x-minute city approach emerged as a solution to foster sustainable mobility and improve the quality of life of our cities. However, for the sake of simplicity, city administrators often rely on very general approaches for the design of this concept, considering a generic population, a flat walking time and seeing several urban functions as essentials for the whole population, often disregarding the need of the vulnerable categories. In this paper we presented an approach to explore the equity impact of the x-minute city in urban areas, applied a set of scenarios accounting with different social categories and needs. The approach considers different walkability conditions, based on the current quality of the infrastructure and uses Lorenz Curve and Gini Index as assessment tools to enhance the understanding of equity in accessibility within the context of the computed isochrones. The case study of the city of Bari is used to validate the suitability of the approach. The findings underscore the significant impact of infrastructure walkability on the effectiveness of the x-minute city concept, emphasizing the imperative for policymakers and urban planners to prioritize investments in pedestrian infrastructure, particularly in underserved communities. Additionally, creating walkable environments tailored to the diverse needs of various population groups is crucial to enhancing the overall success and inclusivity of urban mobility initiatives.

While the proposed approach offers a comprehensive framework for assessing the equity implications of the x-minute city concept, it is important to acknowledge some limitations in our application. Firstly, it was limited to school and social trips, thereby not fully capturing the range of trip purposes that individuals undertake in urban environments. We assumed uniform walking speeds for all students, overlooking potential variations in travel modes and speeds based on age and individual preferences. For example, students may opt for alternative active modes of transportation (such as cycling), potentially resulting in faster travel times. Furthermore, different trip purposes may entail varying degrees of flexibility or specific needs, which were not explicitly accounted for in our analysis. These limitations highlight the need to explore a wider range of trip purposes and consider individual-level factors to provide a more nuanced understanding of the equity implications of x-minute city initiatives. Future research might consider other age groups (e.g. elderly people) and trip purposes or users' needs (e.g. facility to receive online products) as determinants that influence the computation of isochrones thus generating different analysis scenarios. It is clear that the x-minute city concept should be linked to the citizens' actual needs and capacities, regardless of their socio-economic background, and avoiding the gentrification processes; conversely cities should prioritize local accessibility to promote economic benefits by boosting small businesses located within residential communities, since people's daily needs can all be met easily.

In summary, the proposed approach can support evidence-based decision-making and policy recommendations to promote equitable transportation options and help to ensure that all users, regardless of their socio-economic background, have fair and equal access to important destinations within the city.

CRediT authorship contribution statement

Nadia Giuffrida: Writing – review & editing, Writing – original draft, Visualization, Supervision, Methodology, Data curation, Conceptualization. **Anna Mölter:** Writing – review & editing, Writing – original draft, Validation, Methodology, Conceptualization. **Francesco Pilla:** Writing – review & editing, Writing – original draft, Validation, Methodology, Conceptualization. **Páraic Carroll:** Writing – review & editing, Writing – original draft, Validation, Methodology, Conceptualization. **Michele Ottomanelli:** Validation, Methodology, Conceptualization.

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.

Data availability

Data will be made available on request.

References

[1] C. Moreno, La Ville du Quart D'heure: Pour Un Nouveau Chrono-Urbanisme, 2016. https://www.latribune.fr/regions/smart-cities/la-tribune-de-carlos-moreno/la-ville-du-quart-heure-pour-un-nouveau-chrono-urbanisme-604358.html.
[2] T.M. Logan, M.H. Hobbs, L.C. Conrow, N.L. Reid, R.A. Young, M.J. Anderson, The x-minute city: measuring the 10, 15, 20-minute city and an evaluation of its use for sustainable urban design, Cities 131 (2022) 103924.
[3] J. Fortney, K. Rost, J. Warren, Comparing alternative methods of measuring geographic access to health services, Health Serv. Outc. Res. Methodol. 1 (2000) 173–184.
[4] F.M.M. Cirianni, A. Comi, A.S. Luongo, A sustainable approach for planning of urban pedestrian routes and footpaths in a pandemic scenario, TeMA 15 (1) (2022) 125–140.
[5] A. Möllers, S. Specht, J. Wessel, The impact of the Covid-19 pandemic and government intervention on active mobility, Transport. Res. Part A 165 (2022) 356–375.
[6] D. Nalmpantis, F. Vatavali, F. Kehagia, A review of the good practices of active mobility measures implemented by European cities due to the COVID-19 pandemic, in: IOP Conference Series: Earth and Environmental Science 899, IOP Publishing, 2021 012057.
[7] A. Arranz-López, L.M. Mejía-Macias, J.A. Soria-Lara, E-shopping and walking accessibility to retail, Transport. Res. Procedia 60 (2022) 298–305.
[8] P. Mateos-Mínguez, A. Arranz-López, J.A. Soria-Lara, M. Lanzendorf, E-shoppers and multimodal accessibility to in-store retail: an analysis of spatial and social effects, J. Transp. Geogr. 96 (2021) 103198.
[9] J. Stanley, S. Davis, Connecting Neighbourhoods: The 20-minute City, 2015. https://trid.trb.org/view/1375138.
[10] C. Moreno, Z. Allam, D. Chabaud, C. Gall, F. Pratlong, Introducing the "15-Minute City": sustainability, resilience and place identity in future post-pandemic cities, Smart Cities 4 (1) (2021) 93–111.
[11] C. Grodach, L. Kamruzzaman, L. Harper, 20-Minute Neighbourhood: Living Locally Research, 2019. https://www.monash.edu/_data/assets/pdf_file/0011/2045396/Monash-20-Min-Neighbourhood-Final-Report-29-11-19.pdf.
[12] M. Weng, N. Ding, J. Li, X. Jin, H. Xiao, Z. He, S. Su, The 15-minute walkable neighborhoods: measurement, social inequalities and implications for building healthy communities in urban China, J. Transp. Health 13 (2019) 259–273.
[13] D. Capasso Da Silva, D.A. King, S Lemar, Accessibility in practice: 20-minute city as a sustainability planning goal, Sustainability 12 (1) (2019) 129.
[14] Walk Score, Walk Score, 2024. <, https://www.walkscore.com/. Last access: 20/02/2024.
[15] S. O'Gorman, R. Dillon-Robinson, 20 Min Neighbourhoods in a Scottish Context. Ramboll, 2021. https://era.ed.ac.uk/bitstream/handle/1842/37524/CXC%20-%2020%20minute%20neighbourhoods%20in%20a%20Scottish%20context%20March%202021.pdf?sequence=3&isAllowed=y.
[16] J.R. Olsen, L. Thornton, G. Tregonning, R. Mitchell, Nationwide equity assessment of the 20-min neighbourhood in the scottish context: a socio-spatial proximity analysis of residential locations, Soc. Sci. Med. 315 (2022) 115502.
[17] E. Graells-Garrido, F. Serra-Burriel, F. Rowe, F.M. Cucchietti, P. Reyes, A city of cities: measuring how 15-minutes urban accessibility shapes human mobility in Barcelona, PLoS ONE 16 (5) (2021) e0250080.
[18] H. Wu, L. Wang, Z. Zhang, J. Gao, Analysis and optimization of 15-minute community life circle based on supply and demand matching: a case study of Shanghai, PLoS ONE 16 (8) (2021) e0256904.
[19] A. Calafiore, R. Dunning, A. Nurse, A. Singleton, The 20-minute city: an equity analysis of Liverpool City Region, TTransport. Res. Part D 102 (2022) 103111.
[20] N. Giuffrida, F. Pilla, P. Carroll, The social sustainability of cycling: assessing equity in the accessibility of bike-sharing services, J. Transp. Geogr. 106 (2023) 103490.
[21] M.O. Lorenz, Methods of measuring the concentration of wealth. Publications of the American Statistical Association 9, 1905, pp. 209–219.
[22] L. Caggiani, R. Camporeale, M. Ottomanelli, Facing equity in transportation Network Design Problem: a flexible constraints based model, Transp. Policy 55 (2017) 9–17.
[23] L. Caggiani, A. Colovic, M. Ottomanelli, An equality-based model for bike-sharing stations location in bicycle-public transport multimodal mobility, Transport. Res. Part A 140 (2020) 251–265.
[24] Y. Rofè, K. Martens, B.E. Eran, N. Mednik, Accessibility and Social Equity in Tel-Aviv Metropolitan Area - Examination of the Current Conditions and Development Scenarios, 2015. Technical Report.
[25] N. Giuffrida, A. Molter, F. Pilla, P. Carroll, Feasibility of a simplified index to improve active mobility infrastructure based on digital survey: the case of Dublin, Transport. Res. *Procedia* 72 (2023) 2309–2316.
[26] M. Ignaccolo, G. Inturri, G. Calabrò, V. Torrisi, N. Giuffrida, M. Le Pira, Auditing streets' pedestrian compatibility: a study of school sites' requalification. Pedestrians, Urban Spaces and Health, CRC Press, 2020, pp. 30–34.
[27] PUMS Bari, Sustainable Urban Mobility Plan for the Metropolitan City of Bari, 2024. <, https://www.pumscmbari.it/team-pums/. >Last access: 20/02/2024.

[28] ISTAT, Basi Territoriali e Variabili Censuarie, 2011. https://www.istat.it/it/archivio/104317.
[29] WOPR, WorldPop Open Data Repository, 2024. <, https://hub.worldpop.org/. >Last access 20/02/2024.
[30] M. Bondarenko, D. Kerr, A. Sorichetta, A.J. Tatem, Census/Projection-Disaggregated Gridded Population Datasets For 189 Countries in 2020 Using Built-Settlement Growth Model (BSGM) outputs. WorldPop, University of Southampton, UK, 2020, https://doi.org/10.5258/SOTON/WP00684.
[31] Puglia.indettaglio.it, 2024. <https://puglia.indettaglio.it/ita/comuni/ba/bari/scuole/scuole_di_bari.html>(Last access: 20/02/2024).
[32] I. Biazzo, B. Monechi, V. Loreto, General scores for accessibility and inequality measures in urban areas, R. Soc. Open. Sci. 6 (8) (2019) 190979.
[33] T.M. Logan, S.D. Guikema, Reframing resilience: equitable access to essential services, Risk Anal. 40 (8) (2020) 1538–1553.
[34] C.A. Celis-Morales, D.M. Lyall, P. Welsh, J. Anderson, L. Steell, Y. Guo, J.M. Gill, Association between active commuting and incident cardiovascular disease, cancer, and mortality: prospective cohort study, BMJ 357 (2017) j1456.
[35] F. Gaglione, C. Gargiulo, F. Zucaro, Elders' quality of life. A method to optimize pedestrian accessibility to urban services, TeMA 12 (3) (2019) 295–312.
[36] Cleancities, School Streets to Shape Child-Friendly Cities, 2022. https://cleancitiescampaign.org/wp-content/uploads/2022/05/School-Streets-to-shape-child-friendly-cities.pdf.
[37] R. Dunning, A. Calafiore, A. Nurse, 20-minute neighbourhood or 15-minute city?. Town and Country Planning, 2021.