EX— TRA experimenting with city streets to transform urban mobility

Accessibility by Proximity Tool, final version.

WP2b

Dr.-Ing. Benjamin Büttner

María José Zúñiga

Ulrike Jehle

URBAN EUROPE

To cite this report: Büttner, Zuñiga and Jehle (2023). Accessibility to Proximity Tool, final version. Published by: Technical University of Munich.

Contacts: benjamin.buettner@tum.de ; mariajose.zuniga@tum.de ; ulrike.jehle@tum.de

Academic Partners

Non-Academic Partners

Table of Contents

WP2: Objectives and aims stated in the funded EX-TRA proposal

WP2 aims at identifying conditions for accessibility by proximity in city districts by:

- operationalizing a citizen-centred, inclusive 'Accessibility by Proximity Index',
- developing and applying an 'Accessibility by Proximity Open Online Expert Tool' to assess accessibility impacts,
- creating Accessibility by Proximity policy guidelines to inform planning practitioners and decision-makers.

For archiving these goals, the WP2 is organized into four tasks as follows:

Task 2.1: Index operationalization _ Lead: PoliMi

An 'Inclusive Accessibility by Proximity Index' (IAPI) has been operationalized, measuring accessibility to opportunities for different users based on individual needs and abilities and use and transport conditions. The index provides the basis for tool development (task 2.2); tool application (task 2.3) has provided insights for index improvement.

The index has been informed by reviews of academic literature and planning guidelines, expert interviews, citizen surveys, and focus groups on the participating cities, to be carried out by local academic partners coordinated by PoliMi.

Task 2.2: Tool development _ Lead: TUM

An 'Accessibility by Proximity Open Online Expert Tool' to assess accessibility impacts of existing and planned transport and land use conditions has been developed based on the accessibility index (task 2.1) and the existing Geo Open Accessibility Tool (https://www.open-accessibility.org/). The tool relies on open data (e.g., OpenStreetMap) and can be applied in different contexts. Tool development is iterative, with refinement following the application (task 2.3).

The tool has been developed by TUM in collaboration with PoliMi and includes input from local academic partners.

Task 2.3: Tool application _ Lead: TUM

Currently, the tool has been applied in four partner cities to analyze the current conditions for accessibility by proximity and highlight options to make accessibility more inclusive. In successive iterations, evaluate the impacts on the accessibility of street experiments and other measures affecting land use and transport conditions. Local academic partners have applied the tool; TUM has collected and used the generated knowledge to improve GOAT.

Task 2.4: Guideline development _ Lead: PoliMi

Policy guidelines will be drafted based on the experiences gathered during the application of the tool (task 2.3). They will highlight the key points to consider in land use and transport planning to create citizen-centred, inclusive conditions for accessibility by proximity. Local partners will organize workshops to develop the planning and policy recommendations with stakeholders. Finally, PoliMi will collect and integrate the insights.

WP2b – TUM

The following pages serve as a theoretical supporting document to Deliverable D2.2, "Accessibility by Proximity Tool, first version".

Task 2.2: Tool development

This chapter explains how GOAT planning software (Geo Open Accessibility Tool) was further developed to suit the 'Accessibility by Proximity Open Online Expert Tool'.

About GOAT

GOAT is an open-source web tool designed for local accessibility analysis and mainly runs on OpenStreetMap (OSM) data (Pajares et al. 2021; Büttner, Jehle, and Linares Ramirez 2021). It contains different indicators (isochrones, multi-isochrones, and heatmaps) and includes several modes: walking (standard, senior), cycling (standard, pedelec), and wheelchair (standard, electric). The main aim of GOAT is to support cities and planners in making the right decisions in favour of sustainable mobility. The tool identifies shortcomings by visualizing current accessibility levels. In addition, scenarios on changes in ways, points of interest (POIs), and buildings can be modelled, and their effects on accessibility assessed. In addition, it can, e.g., analyze which accessibility benefits a new pedestrian bridge over a river or which location is the best suited to place a new bike-sharing station. Although many planners regard GOAT as a helpful tool, it lacks the temporal and individual components of accessibility. The first component reflects time constraints related to both availability of opportunities during the day and the availability of time for individuals to use such options. The individual component reflects individuals' needs, abilities, and opportunities that can influence access to transport and their ability to participate in opportunities (Geurs and van Wee 2004).

New functionalities

Including the IAPI in GOAT (see Chapter Integration of the IAPI in GOAT) can enrich the tool with a comprehensive analysis option on a neighbourhood scale that gives a good impression of how well different districts perform in terms of local accessibility. At the same time, GOAT gives a suitable "stage" to the IAPI and makes it easily accessible through the web interface. The IAPI and the existing indicators complement each other and can result in a comprehensive instrument for walking, cycling, and wheelchair users.

In addition, the streetscape quality in GOAT is enhanced by small-scale analysis options. To test it, GOAT was transferred to two study areas in Munich (Glockenbachviertel and Neuhausen city districts). Therefore, spatial data such as road type, max speed, surface, sidewalk width, parking, illuminance, street furniture, trees, and land use were gathered for the study areas (Büttner, Jehle, and Linares Ramirez 2021).

GOAT Transfer to Milano

GOAT was transferred to Milano to test the new functionalities in other local contexts. The study area is the "Comune di Milano" - municipality of Milan (see *Figure 1*). The GOAT setup process automatically downloads the OSM data and extracts the relevant objects, such as POIs, buildings, and ways. Similarly, GOAT expects to have a source of population data. In addition, land use data can be included to make the analysis more precise.

Figure 1. The study area of Milano for GOAT.

In Milan, the OSM data includes a wide variety of information for streets, buildings, and land use. Data is generally rich with detailed characteristics such as opening hours for POIs or the number of lanes for streets; this benefit results from the open-source functionality. OSM is built, maintained, and updated by the volunteers of the OSM community; however, this also translates into outdated and sometimes incomplete information. To overcome this issue, it is essential to compare the information available in OSM with the information reported in the open data portals from the official institutions. For the case of Milan, most of the information has been compared with the portal of "Comune di Milano", "Istituto Nazionale di Statistica" (National Institute of Statistics), and the "Sistema Statitistico Integrato" (Integrated Statistics System).

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

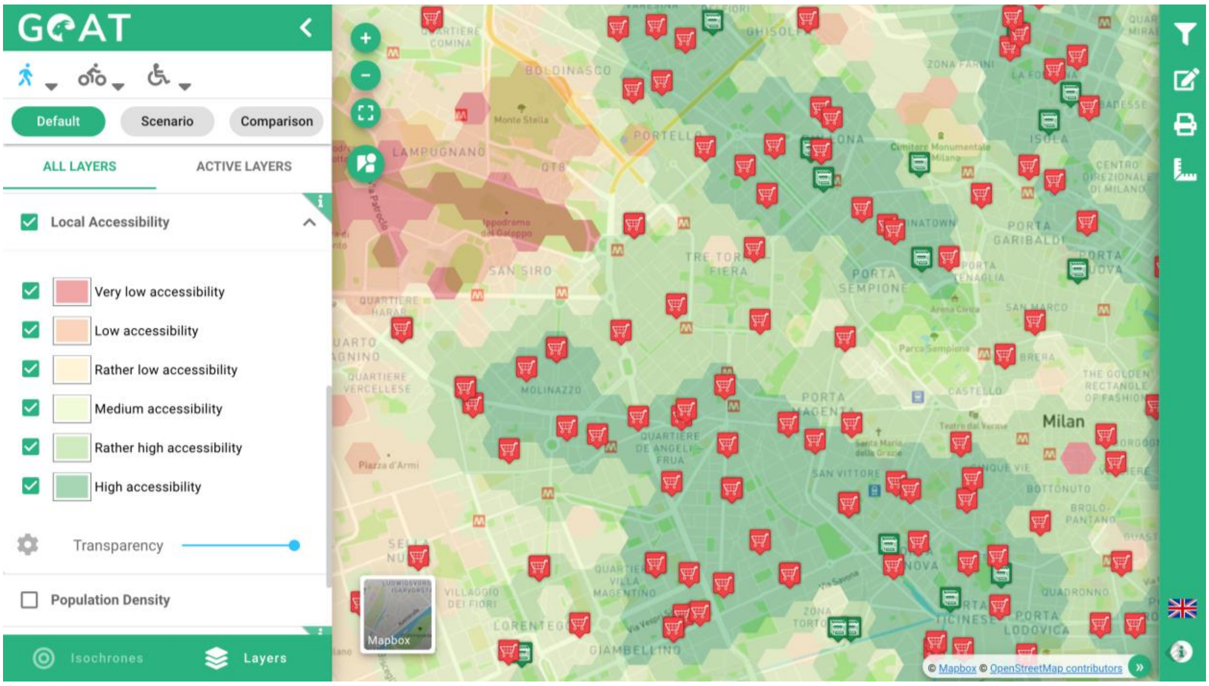

Figure 2. Heatmap with local accessibility to supermarkets and marketplaces in Milan.

Use of OSM Data

OSM data is the primary source of data for GOAT in Milan. The required data was organized into two datasets: 1) POIs, and 2) network information. For the POIs, the data are amenities that attract residents to develop their daily activities, such as schools, supermarkets, or gyms. Also, other places visited less frequently, such as museums, post offices, or government offices, were considered. In OSM, points usually represent this information; however, polygons with the shape of the building can also represent POIs. To overcome the disparity in element type, GOAT reorganizes all data from multiple shapes and types into new tables by establishing the information uniformly; this process facilitates the visualization and calculations. Although not all the attributes of the POIs are equally filled across all the amenities, GOAT's transferability features organize some attributes; furthermore, official information or mapping events are an alternative solution to the lack of detail in the information.

In the case of network-type entities, they also need to be organized into a clean and consistent dataset. Typically, the network dataset comprises line entities that represent streets or sidewalks. In addition, the network data has essential attributes (e.g., smoothness, surface) that help to improve accessibility calculation. Next, the features considered for the IAPI and the methodology to calculate it can be found in the chapter *Integration of the IAPI in GOAT*.

Points-of-Interest

The POIs selected in the GOAT version for Milan have been classified into six categories: public open spaces, commercial activities, and services to the public, gathering and cultural spaces, sports, healthcare and social care, education spaces, and public transport. Each category has a table with attributes considered, the OSM feature, and in some cases, the official source from the "Comuni di Milano" can match one or multiple attributes. In the following tables, the columns highlighted in grey represent the used source of each POI.

Public open spaces

For public spaces, three POI categories are defined in the IAPI: gardens, parks, and playgrounds. For all of them, the available information in OSM was reviewed and compared with the data sets from the municipality. In the case of gardens and parks, the file "localizzazione dei parchi e giardini" (location of parks and gardens) was compared with the OSM features "garden" and "park". For playgrounds, the file "Spazi verdi pubblici per attività ludiche" (Green public spaces for ludic activities) was compared with the OSM "playground" features. To summarize, for gardens and parks, the information from the city was more detailed; in the playgrounds, the locations were almost the same; thus, the data of OSM was used.

The columns highlighted in grey show the source that was used for this POI.

POIs	OSM feature	Official source
1.1 Gardens	leisure=garden	https://dati.comune.milano.it/dataset/ds89_infogeo_parchi_giardini_localizzazione_
1.2 Parks	leisure=park	
1.3 Playgrounds	leisure=playground	https://dati.comune.milano.it/dataset/ds724-aree-gioco-spazi-verdi-pubblici-per-attivita-ludiche/resource/5e5b89a1-20bb-4c0c-9182-a55f16af4dfb

Table 1. Sources for public open spaces.

As parks are extensive areas, they were kept as polygons, while points represented gardens and playgrounds (see *Figure 3*).

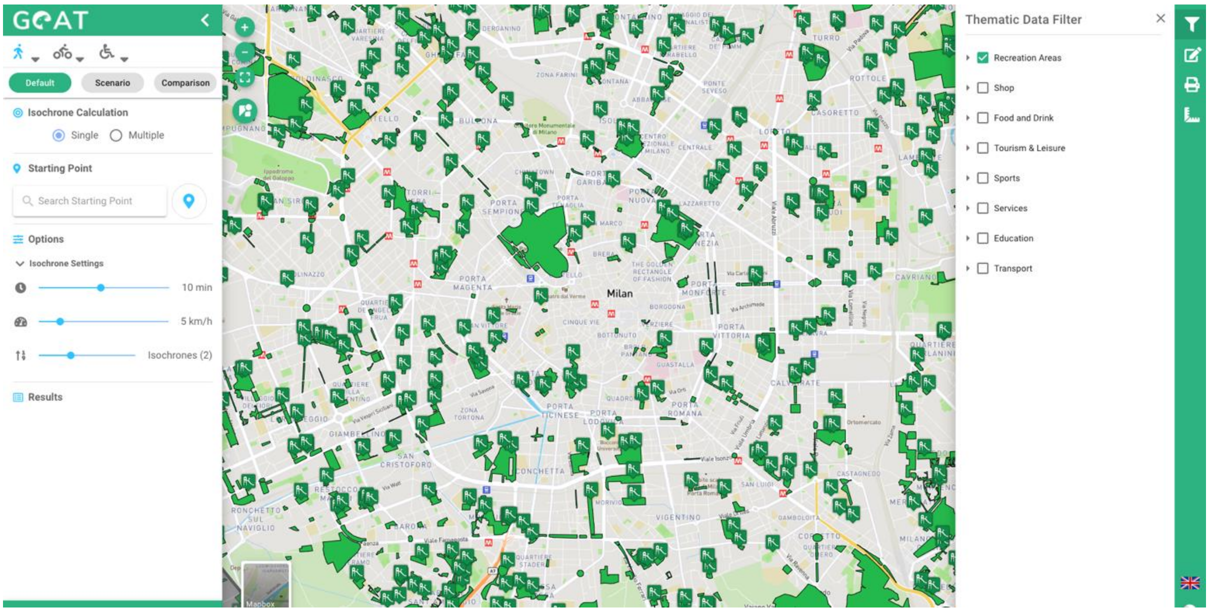

Figure 3. Screenshot of GOAT showing the public open spaces in Milano.

Commercial activities and services to the public

This category has been divided into stores, foods and drinks, and services. The POIs grocery stores, supermarkets, and street markets build the "stores" subcategories. When looking for the grocery stores in OSM, the official tag "shop=grocery_store" had no points in Milano; the most similar tag is "convenience_stores". In the case of the official source, it was compared with the "Attività commerciali: media e grande distribuzione" (Comercial activities: medium and large-scale distribution). Since the file contained multiple kinds of stores and businesses, it was necessary to filter the information. In the case of the grocery stores, most of the locations were tagged as "minimercati". For supermarkets in OSM, different tags were grouped under this category of POI; the tags "supermarket", "discount_supermarket", "international_supermarket," and "hypermarket" were collected to include multiple location types with a similar purpose.

The official source for grocery stores and supermarkets was the file "Attività commerciali: media e grande distribuzione". It was filtered by "supermercato". However, both grocery stores and supermarkets had a higher coverage along the city and a greater variety in the type of stores in the OSM data. In the case of street markets, the official source "Attività commerciali: mercati settimanali scoperti" was not georeferenced and only had the schedule and address of the street markets; for that reason, for street markets, the OSM data, which corresponds to the tag "marketplace", was used.

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

The columns highlighted in grey show the source that was used for this POI.

	OSM feature	**Official source**
Stores		
2.1. Grocery Stores	shop=convenience	https://dati.comune.milano.it/dataset/ds50-economia-media-grande-distribuzione (minimercati)
2.2 Supermarkets	shop=supermarket shop=discount_supermarket shop=international_supermarket shop=hypermarket	https://dati.comune.milano.it/dataset/ds50-economia-media-grande-distribuzione (supermercato)
2.3 Street markets	amenity=marketplace	https://dati.comune.milano.it/it/dataset/ds291-economia-mercati-settimanali-scoperti
Food and drinks		
2.4 Bars	amenity=bar	https://dati.comune.milano.it/dataset/ds58_economia_pubblici_esercizi_in_piano
2.5 Restaurants	amenity=restaurants	
2.6 Café	amenity=café	
2.7 Pub	amenity=pub	
Services		
2.8 Newsstand	shop=newsagent	https://dati.comune.milano.it/it/dataset/ds57-economia-edicole
2.9 Kiosk	shop=tobacco shop=kiosk	https://dati.comune.milano.it/it/dataset/ds619_dove_pagare_la_tassa_auto_nel_comune_di_milano (Tabaccheria)
2.10 Bank	amenity=bank	https://dati.comune.milano.it/it/dataset/ds619_dove_pagare_la_tassa_auto_nel_comune_di_milano (Filiale Bancaria)
2.11 Atm	amenity=atm	-

2.12 Post offices	amenity=post_office amenity=post_box	https://dati.comune.milano.it/it/dataset/ds555_uffici_postali_milano
2.13 Hairdressers	shop=hairdresser	https://dati.comune.milano.it/it/dataset/ds62_economia_parrucchieri_estetisti_centri_abbronzatura
2.14 Administration	government=* --amenity = public_building	https://dati.comune.milano.it/it/dataset/ds677_elenco_immobili_di_proprieta_del_comune_di_milano

Table 2. Sources for commercial activities and services to the public

In the subcategory of services, the data from the official source for newsstands and kiosks had better coverage around the city. Also, in the local context, a "Tabaccheria" (Tobacco shop) is a small store, and it could be mixed up with a store that sells just tobacco products, "tabaccherias" also have convenience items, such as magazines, newspapers, and sweets. In the case of financial services, the OSM data was as complete as the official information. In addition, it has ATMs located outside of bank locations. Post offices are also well-mapped with letterboxes throughout the city, although the letterboxes were not recorded in the official data.

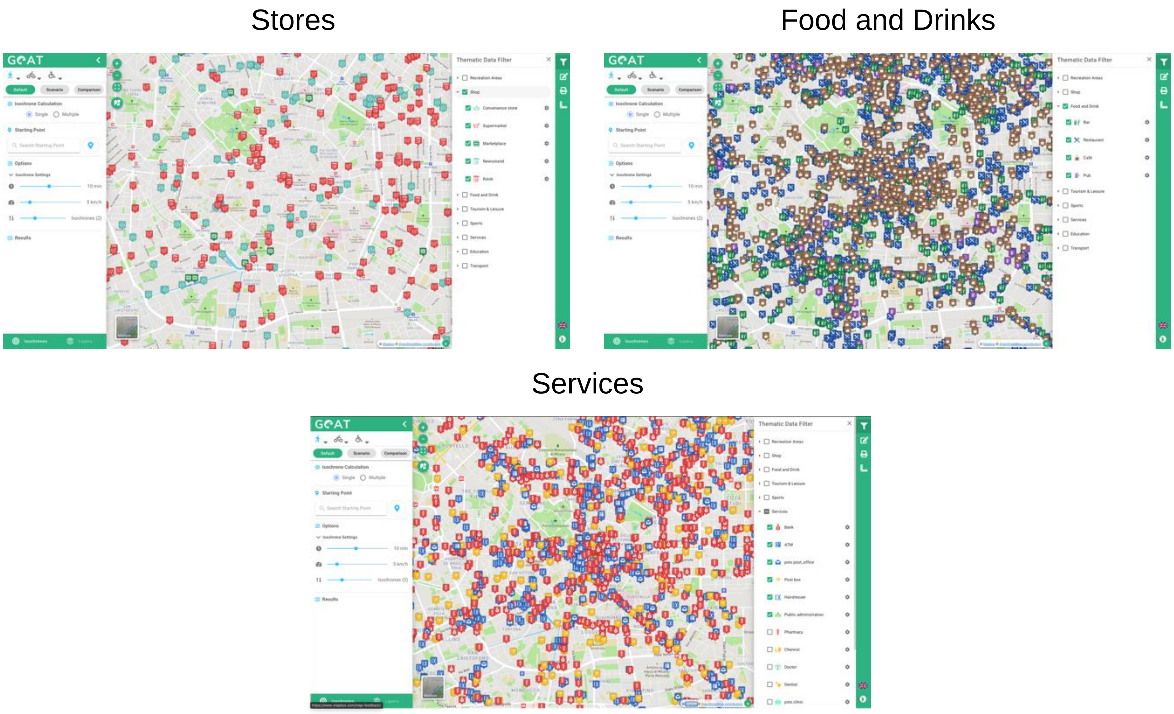

Figure 4. Commercial activities and services to the public

Regarding hairdressers, the official information is mixed with esthetic and tan salons. In contrast, the hairdresser tag from OSM covers most of the points from official sources and is already filtered. In addition, the administrative buildings of the local government are well-tagged in OSM, while all buildings and land of the public administration are included in the official data. The resulting implementation of GOAT can be seen in *Figure 4*.

Gathering and cultural spaces

All cultural places were selected from the OSM data, which is pretty much in line with the data from the official information (see ***Error! Reference source not found.***). The missing amenities were cultural facilities that do not necessarily allow public access and have an administrative purpose. The resulting implementation in GOAT can be seen in *Figure 5*.

The columns highlighted in grey show the source that was used for this POI.

POIs	OSM feature	Official source (Second Source)
3.1 Museum	tourism=museum	https://dati.comune.milano.it/dataset/ds76_infogeo_associazioni_localizzazione
3.2 Gallery	tourism=gallery	
3.3 Arts centre	amenity=arts_centre	
3.4 Cinema	amenity=cinema	
3.5 Theatre	amenity=theatre	

Table 3. Sources for gathering and cultural spaces

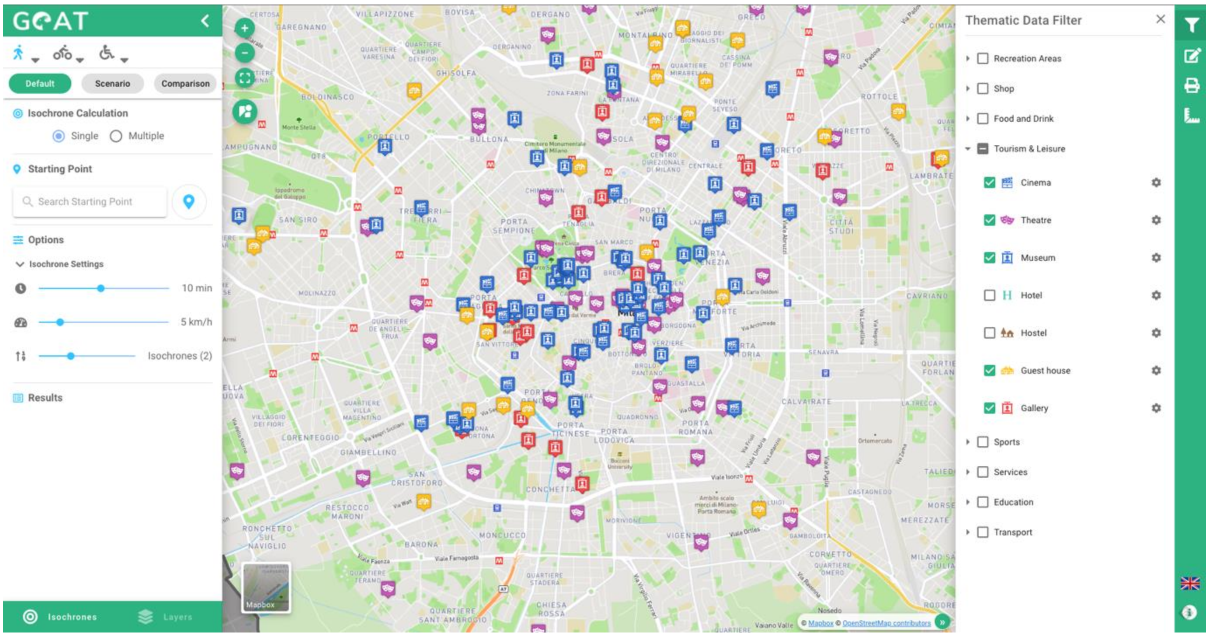

Figure 5. Gathering and cultural spaces.

Sport

For sports locations, it was necessary to cover multiple sports scenarios, such as football fields and indoor activities like bouldering and gymnasiums where people play volleyball or basketball. The official information was taken from the file "Sport: localizzazione degli impianti sportivi"; compared to the OSM data, both were very similar. Since the OSM data was already filtered in the categories needed, in both categories, 4.1 and 4.2, OSM data was selected (see

Error! Reference source not found.). The resulting implementation in GOAT can be seen in *Figure 6*.

The columns highlighted in grey show the source that was used for this POI.

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

Table 4. Sources for sports facilities.

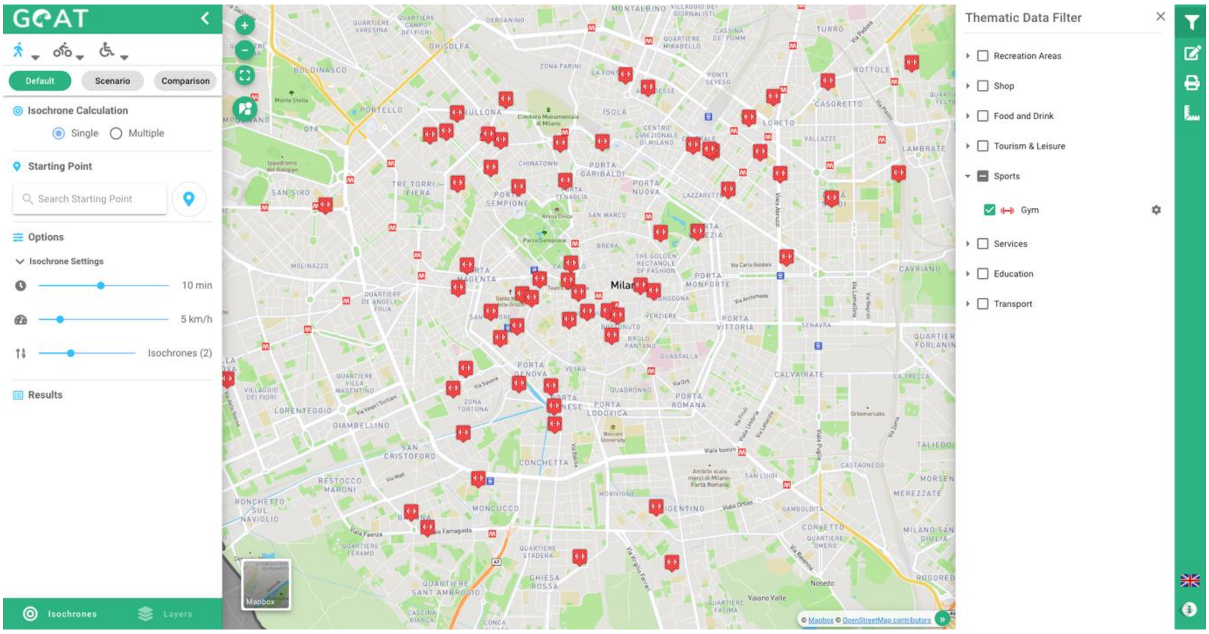

Figure 6. Fitness centres.

Healthcare and social care

The OSM data has good coverage of the amenities related to health (pharmacies, drugstores, chemists) compared to the official information (the information available was listed with health professionals but was not georeferenced). The OSM data was complete for clinics and hospitals and already filtered according to the needs. In contrast, in community centres and social facilities, OSM data did not cover the city or the data from the city's source. The used data sets are summarized in ***Error! Reference source not found.***. The resulting implementation in GOAT can be found in *Figure 7*.

The columns highlighted in grey show the source that was used for this POI.

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

Table 5. Sources for health and social services.

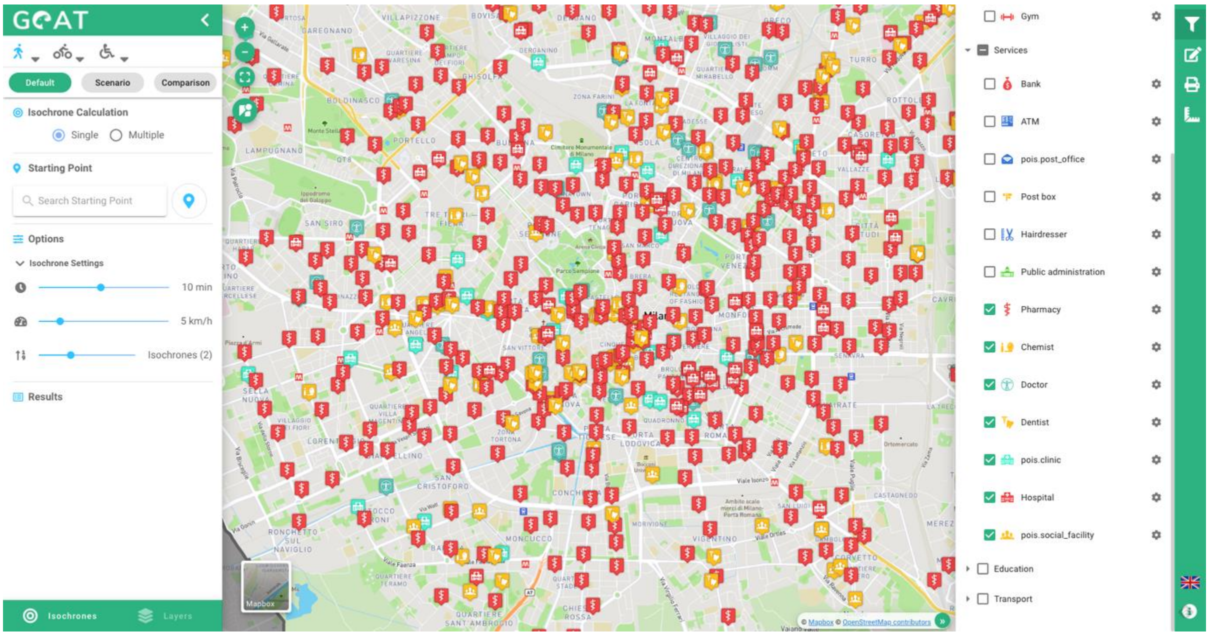

Figure 7. Health and social services.

Educational facilities

The educational amenities were generally incomplete in OSM data; only libraries and universities were similar to the official information. For primary and secondary schools, the lack of mapped amenities may be due to the difficulty in the tagging system. Therefore, all educational POIs were taken from the official source (see ***Error! Reference source not found.***).

The columns highlighted in grey show the source that was used for this POI.

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

Table 6. Source for educational facilities.

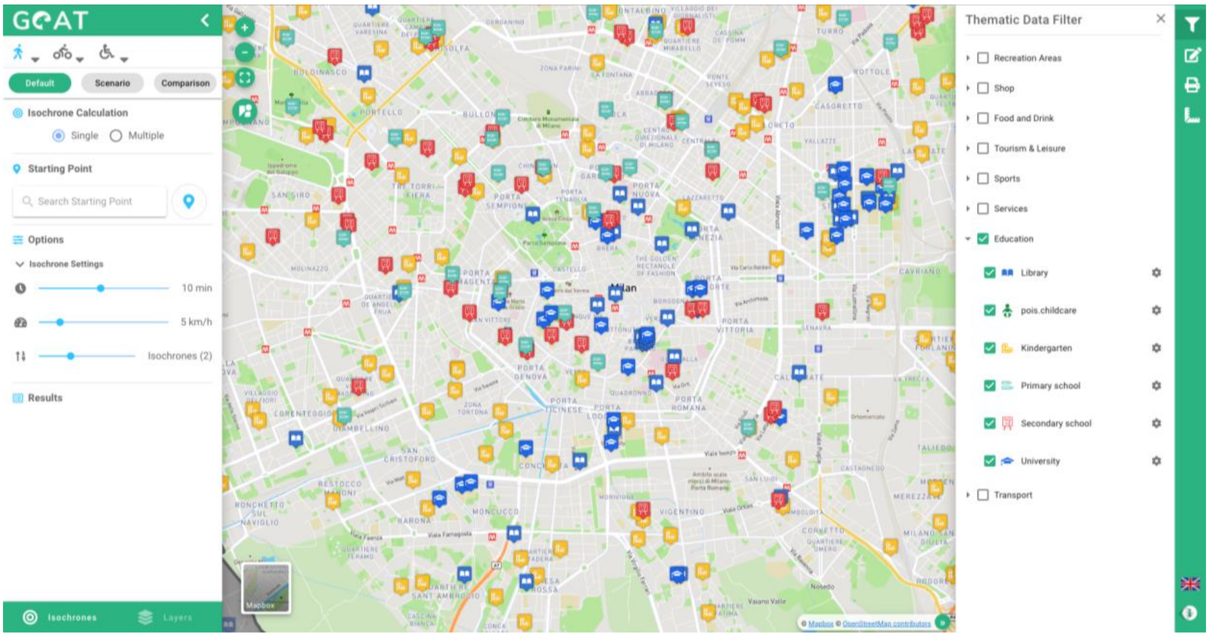

Figure 8. Education spaces.

Public Transport

For public transport analysis, our analysis focused on the location of the stops rather than the lines. In the official data, stops are assigned to a route, and it was not clear how to differentiate them by type of transport, while in the OSM data set, they are divided by type of transport (see

Error! Reference source not found.). The information mapped in OSM was incomplete for shared mobility, and the official sources show coverage across the city.

The columns highlighted in grey show the source that was used for this POI.

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

Table 7. Source for public transport.

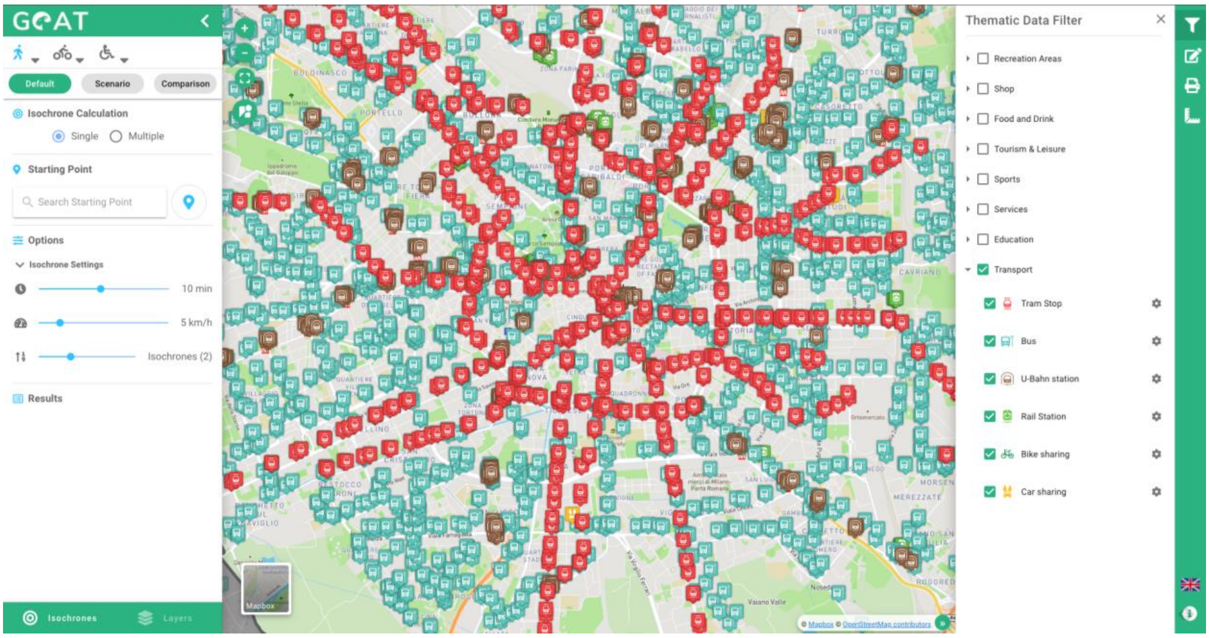

Figure 9. Public transport locations.

Integration of the IAPI in GOAT

The first version of the IAPI, developed by POLIMI (Pucci, Lanza, and Carboni 2021), was transferred into the 'GOAT logic' (i.e., comfort factors translated into resistance factors and

OSM syntax). The developed code can be found on GitHub () and is available under GPL-3.0 License.

Time-based accessibility

After defining the POIs (which were already chosen according to the needs of the IAPI), the network analysis for the IAPI must be prepared. We, therefore, obtained the network from OSM. This source contains a very detailed characterization of the streets in Milan. For the IAPI, it was necessary to define the features of the roads and streets that are important for the calculation. Since the characteristics of the paths highly influence perceived pedestrian and cyclist accessibility, a set of indicators was defined by Pucci, Lanza, and Carboni (2021); see *Figure 10*.

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

Figure 10. Indicators and basic attributes of the street network and different profiles of users (Pucci, Lanza, and Carboni 2021).

The indicators and associated attributes were matched with the OSM objects and tags to fit the network data set used in GOAT. In addition, the absolute speeds defined in Figure 10 were transformed into relative values (impedance factors) to hold the GOAT logic.

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

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

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

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

The opportunity value is 1 if the destination is within the defined area or boundary and 0 if it is not inside. The impedance factor is usually time-based, corresponding to the time needed to travel from origin to destination. This time depends on the distance and speed. First, distance depends on the network available. Second, in GOAT, speed can be dynamically assigned and depends on the user profile; as explained before, GOAT defines three user profiles (pedestrian, cyclist, and wheelchair users). In addition, the speed of the cyclist or pedestrian can be altered depending on the specific conditions of the network. For the cycling mode, GOAT already considered two factors that could reduce the speed of the users when using a particular path or street: surface and smoothness. They were not initially thought in the categories from Figure 10 but already implemented in GOAT to calculate the travel time more realistic.

As part of the IAPI integration, these impedances were expanded to the modes of walking and wheelchair. To estimate the impacts on travel time, an impedance value from 0 to 1 was assigned, representing the impact of the quality and type of infrastructure; ***Error! Reference source not found.*** summarizes the values for the qualitative assumptions.

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

Table 8. Impedance factors scale.

Surface type

In OSM, many types of surfaces were defined. For the accessibility calculation, we selected the group of characteristics that can influence the user's speed and assigned them an impedance factor value based on the speed impact they could have on the users. For that reason, they were grouped considering similarities and had the same impedance factors. Paving stones, unpaved, compacted, and fine gravel were the surfaces that had less impact on the speed. Walking has no effect on speed, and for cycling and wheelchair, minor irregularities on the surface may be uncomfortable and barely reduce the speed. The next group has a medium impact on the pace for the different users; the types of surfaces are set, unhewn-cobblestone, cobblestone, and pebble stone. These types are very similar, and usually, they have a flat rock shape, then the surface is hard, but the excess of cracks can cause a bumpy experience for cyclists and wheelchair users. Finally, gravel, sand, grass, and mud have the highest impact on the speed. Where the surface is soft, and it is easy for users with wheels to lose traction, walking users can also be significantly affected depending on environmental conditions. In ***Error! Reference source not found.***, the impedance factors representing the described impact on the travel speed can be found.

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

Table 9. Impedance values for surface type.

Smoothness

Another important characteristic that influences the speed is the condition of the path, also known as the smoothness of the surface. Sometimes, even if the surface material is pavement, external elements such as branches, construction errors, or poor maintenance can make it impossible to pass to specific users. In this case, the highest impedance factors from the scale were assigned to wheelchair users (***Error! Reference source not found.***). For bicycle users and pedestrians, it was assumed that they are not as much affected by the smoothness as wheelchair users, but still, bicycles need to slow down. For pedestrians, additional attention is required in case of uneven ground. The resulting impedance factor that represents the smoothness is listed in ***Error! Reference source not found.***.

Attribute	**OSM tag**	**Walking**	**Cycling**	**Wheelchair**
Paths in poor conditions	intermediate	0	0	0.05
	bad	0	0.05	0.15
	very_bad	0	0.1	0.3
	horrible	0.1	0.3	0.5
	very_horrible	0.15	0.35	0.75

Table 10. Impedance values for smoothness.

Comfort-based accessibility

The type of surface and the smoothness are characteristics of the streets that can directly influence the user's speed. However, many other path characteristics influence the accessibility of places but are instead related to comfort than speed. To include the relevant attributes from the network, instead of modifying the speed of each user profile according to the present characteristics, we had an extra impedance factor within the calculation called the 'comfort impedance factor'. The purpose of this value is to include all the comfort characteristics within the measure of accessibility. For the methodology to do so, we took the approach by Labdaoui et al. (2021) as a reference. Labdaoui et al. (2021) consider thermal comfort in assessing walkability by developing the Street Walkability and Thermal Comfort Index (SWTCI), which focuses on comfort facilities and Physiological Equivalent Temperature (PET) at the street scale. Here, pedestrian facilities had differences that affected the PET score for streets based on the presence or absence of the urban element. 0 meant the total lack of the component, and 1 represented the high presence. The indicators scores were used to estimate the PET scores (*Figure 11*), 1 in the desired PET range and 0 in the uncomfortable thermal conditions.

Table 5
PET scores according to the Thermal sensation and PET range in Csa Climate (Labdaoui et al., 2021).

PET range	PET scores
>8 °C	0
8 °C–12 °C	0.25
12.1 °C–15 °C	0.5
19.1 °C–26 °C	1
26.1 °C–28 °C	0.5
28.1 °CC–34 °C	0.25
34.1 °CC–40 °C	0

Figure 11. PET scores for different PET ranges (Labdaoui et al. 2021)

To implement the SWTCI methodology in the accessibility calculation, we defined a scale based on the existing scale for speed impedance factors. In this case, 0 will be the desired condition, meaning no impedance value for the indicator, and 1 to the greatest impedance value, meaning that the road's characteristic is less preferred. Comfort impedance values were added to the characteristics of road type, peak hour traffic, cycle paths, sidewalk width, and obstacles. It is critical to consider that since road conditions can have multiple characteristics from different categories, the final comfort impedance may have a total value greater than one.

Road type

Most of the roads in OSM have a key called 'highway'. This key is a primary classification that determines the hierarchy of the roads within the network. Although the key represents function and importance rather than physical characteristics, both are usually highly correlated. Roads were grouped into four categories. Roads where motorized vehicles have a higher distribution of the space; particular streets where the transit of motorized vehicles may be allowed, but the priority is the transit of cyclists and pedestrians; paths that have a higher prioritization in pedestrian traffic, and connections, that refer to tunnels and bridges (see ***Error! Reference source not found.***).

Attribute	OSM tag	Walking	Cycling	Wheelchair
Roads (highway)	Motorway	1	1	1
	trunk	1	1	1
	Primary	0.8	0.3	0.8
	Secondary	0.6	0.2	0.7
	Tertiary	0.2	0.1	0.3
	Unclassified	0.2	0.1	0.3
	Residential	0.2	0.1	0.3
Special Road (highway)	Living streets	0	0	0
	Service	0.05	0.05	0.05
	Pedestrian	0	0.5	0
	Track	0.1	0	0.1
Path	Footway	0.1	0.2	0
	Corridor	0	1	0
	Path	0	0.1	0
Connections (tunnel and bridge)	Tunnel	0.3	0.4	0.5
	Bridge	0.3	0.4	0.4

Table 11. Impedance values for road type.

Peak Hour Traffic

Traffic volume can affect the comfort level of a street; even if there is segregated infrastructure available for each traffic mode, roads with high traffic volumes can impact the noise and air quality in the surrounding street. Therefore, the number of available traffic lanes is the indicator to determine the traffic that can go through a road.

Attribute	OSM tag	Walking	Cycling	Wheelchair
Traffic Lanes	Local traffic survey/lanes	0.2	0.1	0.3

Table 12. Impedance values for Peak Hour Traffic.

Cycle paths

Cycle paths are the infrastructure that generates a safe and comfortable space for cyclists to make their daily trips. They have multiple typologies; they can be segregated or combined from other modes, at a road or sidewalk level, among other characteristics. In this case, it is essential if the infrastructure is segregated from vehicles and pedestrians or if it is shared with pedestrians or cars, where it can be slightly uncomfortable for cyclists due to the different speeds. *Table 13* shows the impedance for cycle paths.

Attribute	OSM tag	Walking	Cycling	Wheelchair
Reserved	cycleway bicycle = designated	0.5	0	0.3
Shared with cars or pedestrians	cycleway = shared_lane	0	0.1	0

Table 13. Impedance values for cycle paths.

Sidewalk width

The width of the sidewalk is critical to the comfort of walking trips; wider sidewalks allow for a more significant and varied number of activities. Unfortunately, the information available in OSM for the sidewalk width was too incomplete to represent the infrastructure for pedestrians in Milan. However, in 2020, Transform Transport (a non-profit research foundation focused on innovation in mobility and transport planning) and Systematica (a transport planning and mobility engineering consultancy) developed a study of the current state of Milan's sidewalk infrastructure. The study shows how the current width would allow pedestrians to maintain the recommended social distance necessary for the COVID-19 pandemic containment. In this study, Transform Transport (2020) estimated the sidewalk width of the city from the georeferenced polygons of the sidewalks taken in the geoportal of Milan (see *Figure 12*). The impedance values for the sidewalk's width are shown in ***Error! Reference source not found.*** by following the same classification.

Figure 12. Sidewalk classification in Milan (Transform Transport 2020).

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

Table 14. Impedance values for sidewalk width.

Obstacles

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

On the other hand, fixed obstacles were easier to consider and divided into three categories. First, street furniture is usually an excellent feature in the streets, but they become an obstacle when the sidewalk lacks enough space. Second, GOAT had a wheelchair classification for roads, and it defined the characteristics that allow wheelchairs to use them comfortably. Finally, the highway key "steps" are assumed to be the most substantial obstacle a pedestrian cyclist or wheelchair user can find in the city.

Attribute	Source	Walking	Cycling	Wheelchair
fixed street furniture (Only sidewalk Uncomfortable or Acceptable)	stop street_lamp traffic_signal benches	0.1	0.1	0.2
Freedom from barriers	wheelchair	0.2	0.3	0.6
Stairs (highway)	steps	0.3	0.7	0.9

Table 15. Impedance values for obstacles.

Comfort Street Elements

All the characteristics listed before are attributes of the street network that influence the speed or comfort of road users. However, individual elements can improve the perception and ease of street use. These elements are street furniture, nature, and urban decoration, and they are additional attributes of the street network. Street furniture includes street lighting, benches, bicycle parking, and wastebasket. The elements for nature and urban decoration are parks, flowerbeds and green areas, trees, and fountains. Including them in the impedance comfort calculation is necessary to create a scale like the speed and network characteristics but with a "negative impedance" because a street with these additional elements may be more attractive than other streets with the same features but without the different attributes (see ***Error! Reference source not found.***).

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

Table 16. Impedance Scale for additional network attributes.

To add the impedance comfort to the accessibility calculation, it was checked if a road is within a radius of 10 meters from street furniture. If this is true, then the road takes the additional value for the calculation. Subsequently, the qualitative characteristics to assign the impedance values for street furniture are that street lighting has the highest impact on people's comfort, which is a fundamental element for walking or cycling at night. In the case of benches and wastebaskets, the presence on the street improves walking and wheelchair users; on the contrary, bicycle parking benefits cyclists but not walking or wheelchair users.

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

Attribute	**OSM tag**	**Walking**	**Cycling**	**Wheelchair**
Street furniture	Street lighting	-0.2	-0.2	-0.2
	Benches	-0.1	0	-0.1
	Bicycle parking	0	-0.2	0
	Wastebasket	-0.1	0	-0.1
Nature and urban decoration	Flowerbeds and green areas	-0.2	-0.1	-0.2
	Trees	-0.2	-0.2	-0.2
	Presence of fountains	-0.2	-0.1	-0.2

Table 17. Impedance factors for additional street elements.

Integration of impedance factors

To incorporate all the impedance values from the different road characteristics, the accessibility equation must be enriched, in this case, by including the comfort impedance factors.

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

With: $f(t_{ij}, ic_{ij}) = x_{ij} * (1 + ic_{ij(surface\ type)} + ic_{ij(smoothness)}$
$+ ic_{ij(road\ type)} + ic_{ij\ (peak\ hour)}$
$+ ic_{ij\ (cyclelanes)} + ic_{ij\ (sidewalk)}$
$+ ic_{ij\ (obstacle)} + ic_{ij\ (street\ lights)}$
$+ ic_{ij\ (benches)} + ic_{ij\ (bicycle\ parking)}$
$+ ic_{ij\ (waste\ basket)} + ic_{ij\ (flowerbeds)}$
$+ ic_{ij\ (trees)} + ic_{ij\ (fountains)})$

$x_{ij} = travel\ time\ from\ i\ to\ j$

$ic_{ij} = impedence\ comfort\ from\ i\ to\ j$

From the equation, it was relevant to notice that the road characteristics are unique, and a road cannot have multiple attributes for the same characteristic. For example, a street cannot be pedestrian and primary simultaneously or a sidewalk with an acceptable and ideal width. Nevertheless, it is possible to have trees and benches on the same road or streetlights and a fountain for the additional street elements. For that reason, each impedance comfort must be considered individually.

Walking impedance

After adding up the impedance factors for each of the streets in Milan, it is possible to identify the characteristics of the roads for the user types: walking, cycling and wheelchair. *Figure 13* shows the total impedance factors for walking. It was possible to identify that the streets next to the historic centre have a negative or very low impedance. It could reflect a high density of additional elements and groups of characteristics of the roads that reflect livable streets. On the other hand, in the outskirts, the comfortability of the streets for walking reduces; however, very few roads were classified as having a horrible or impassable comfort level.

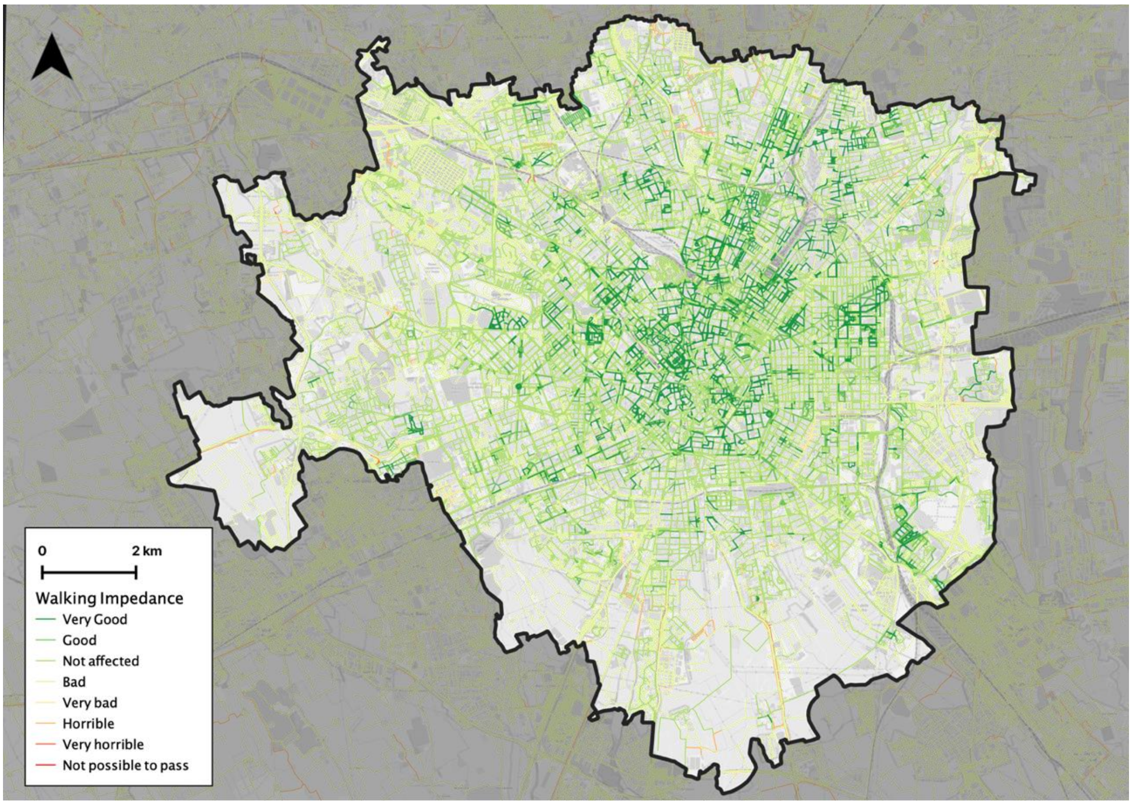

Figure 13. Walking impedance for the network in Milan.

Cycling impedance

Regarding the impedance factors for cycling, the distribution was very similar to the pedestrian comfort levels. The city centre also presents the highest comfort levels for cyclists, and as the streets are farther from the historical centre, the comfort level decreases. Contrary to the walkability conditions, more roads are classified with a bad or worst comfort level; the sensibility of cycling trips to the type or smoothness of the surface could explain this.

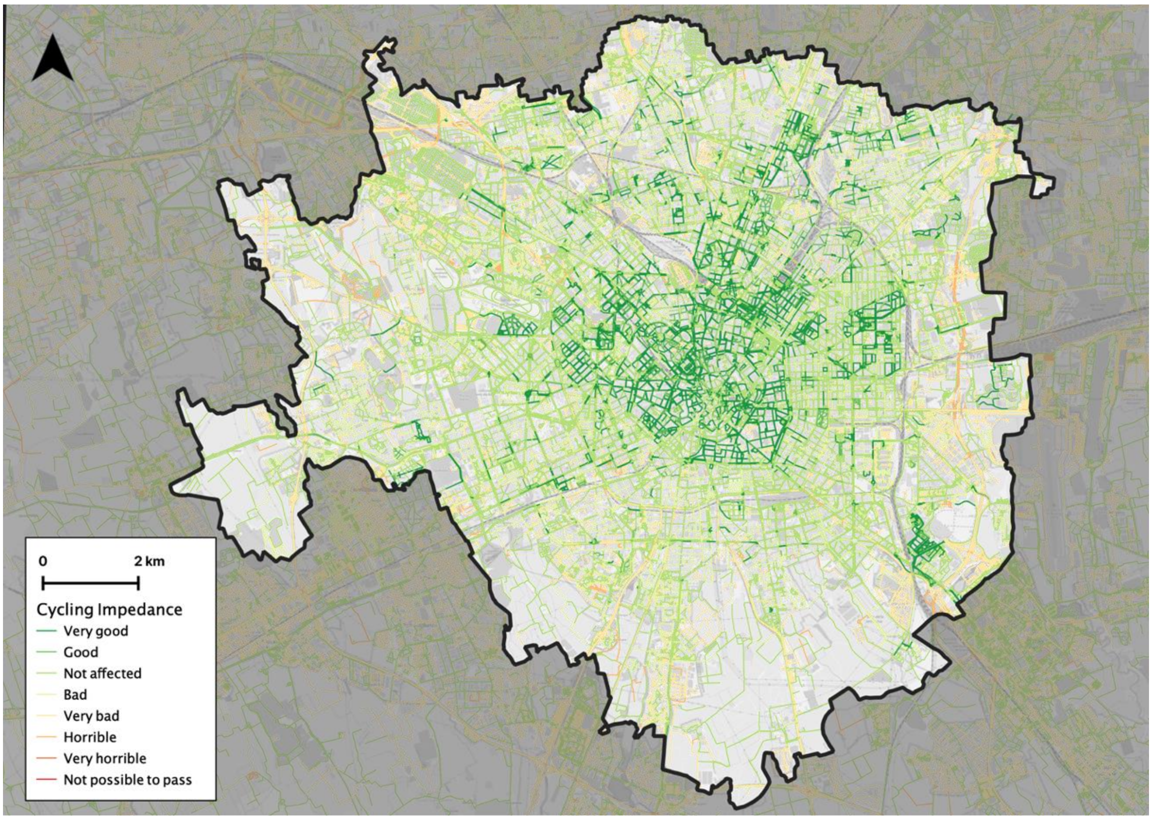

Figure 14. Cycling impedance for the network in Milan.

Wheelchair impedance

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

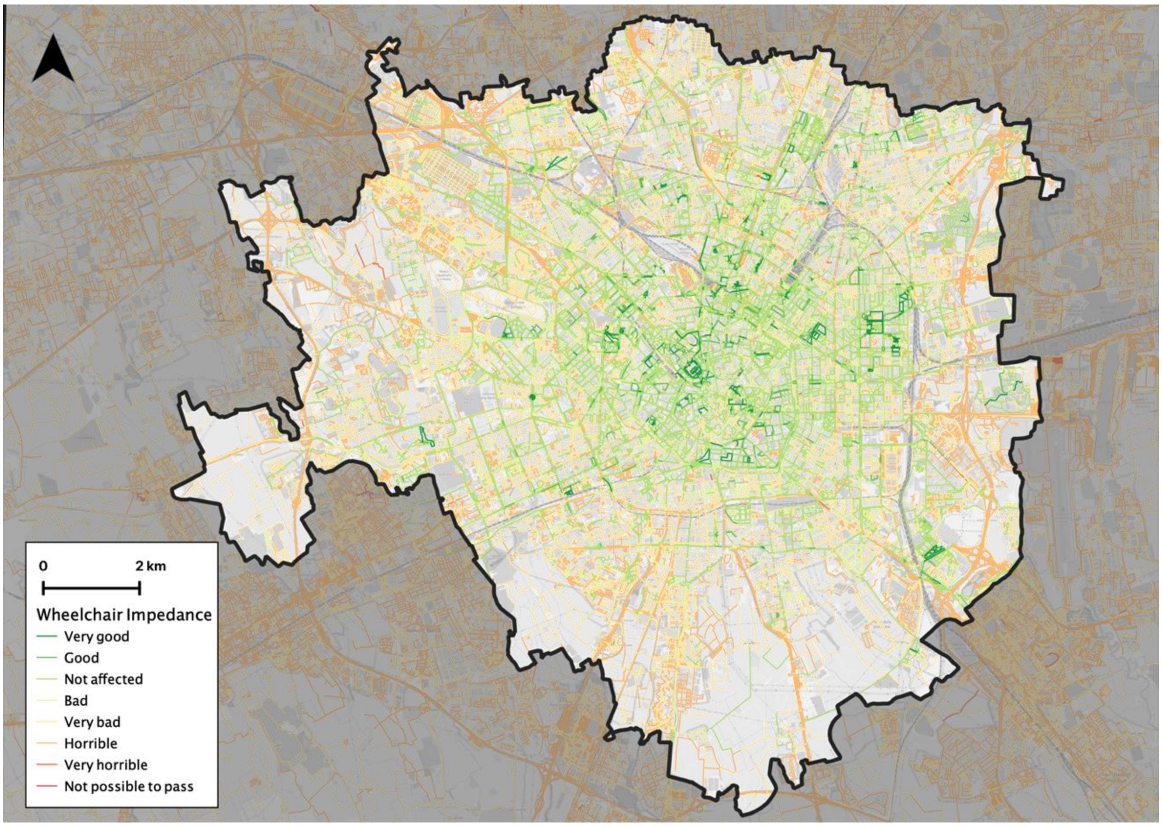

Figure 15. Wheelchair impedance for the network in Milan.

Accessibility Indicators

Isochrones

Once the impedance factors are estimated, it is possible to calculate the accessibility for different points in the city. To visualize the accessibility calculation, multiple indicators are available; we used distance-based isochrones and heatmaps. The isochrones are isolines representing the farthest distance that can be reached from a specific point. This distance depends on the infrastructure, the network, and the travel time. For example, in *Figure 16*, the isochrones for the three user profiles show the difference between standard accessibility, calculated only considering the distance, and comfort accessibility, including all the estimated impedance factors.

Figure 16. Perceived Comfort Isochrones.

Heatmaps

The second indicator to visualize accessibility is the heatmaps. With this indicator, accessibility is calculated to multiple points on the space by defining a grid; each cell is assigned the value of accessibility for the point of interest being analyzed. For example, *Figure 17* shows the perceived accessibility estimation for supermarkets, similarity, *Figure 18* shows the accessibility for all supermarkets on a calculation based only on the distance. In comparison, perceived accessibility increases in the area close to the city's historic centre while decreasing in the city's outskirts. This behaviour matches the estimation of the impedance factors shown in *Figure 13*.

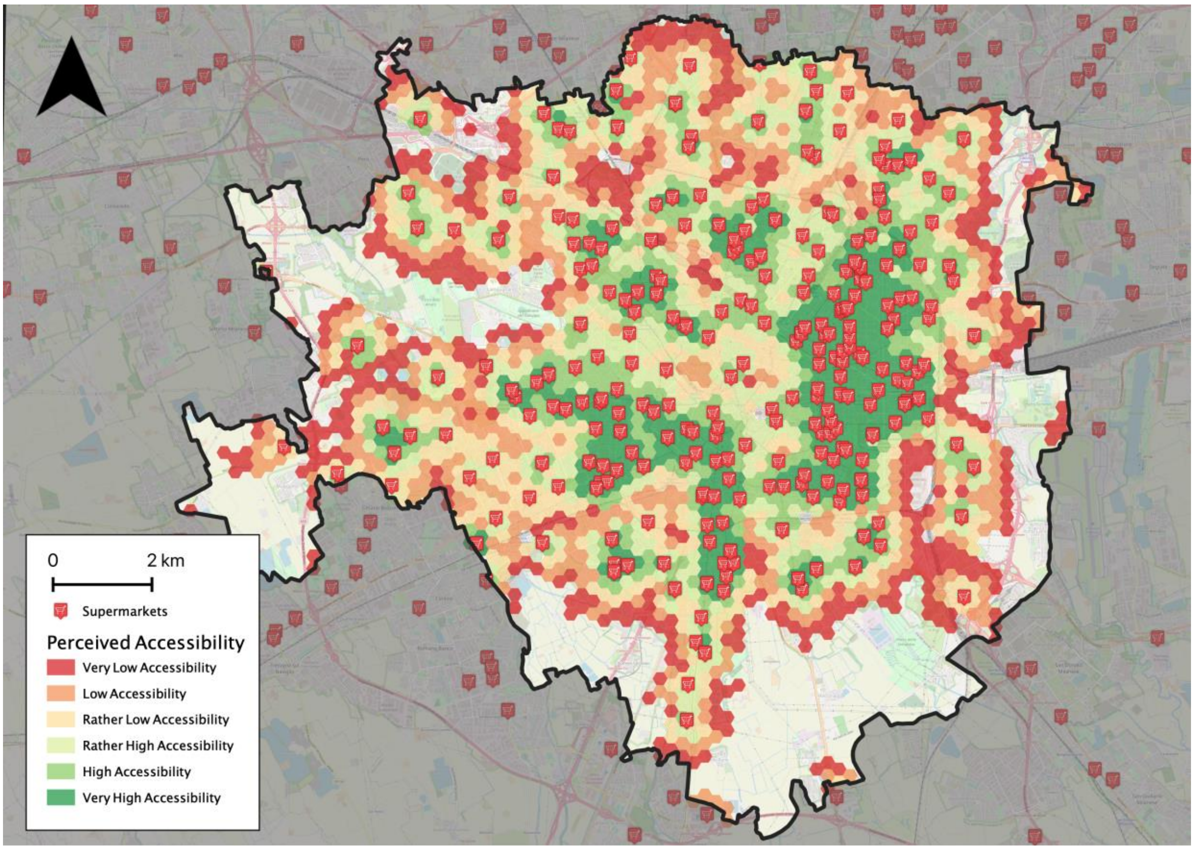

Figure 17. Perceived accessibility for supermarkets.

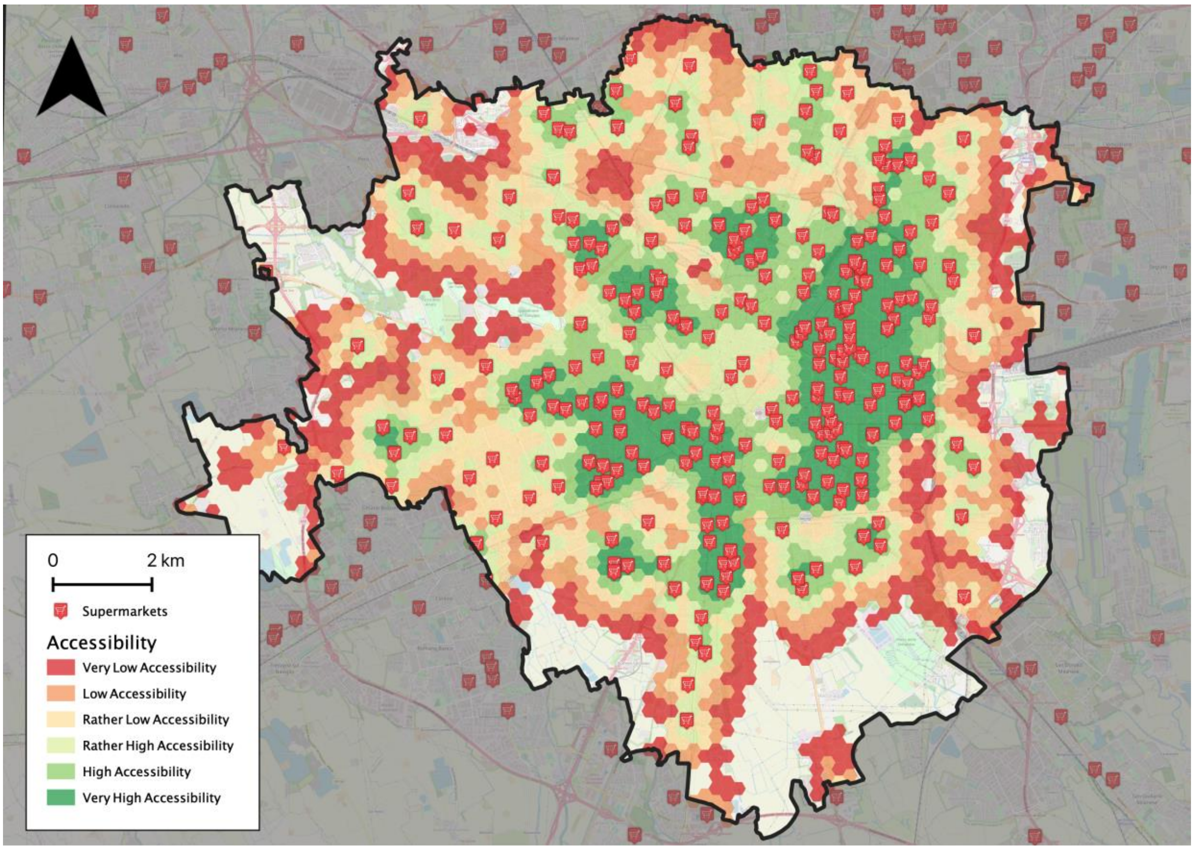

Figure 18. Accessibility for supermarkets.

Natural Environment Visualization

Natural environments have a higher impact on human well-being. Therefore, with the accessibility indicators, it is possible to visualize the effect of green and attractive streets on the trip experience for people. For example, *Figure 19* shows two isochrones, yellow representing the isochrones from a ten and a 20-minute walk with a standard calculation based only on distance. The purple lines are also ten and 20-minute walks, but with the perceived comfort methodology. In addition, the map shows trees represented by green dots. Isochrones reveal how depending on the characteristics of the streets, perceived time can change and allow one to reach farther distances in streets with a higher density of trees. However, the comfort accessibility calculation has many variables besides trees that may diminish the impact of some clusters of trees on the reach of the isochrones.

Figure 19. Environmental benefits.

The final decision to not integrate IAPI in GOAT

After assessing and testing the first version of the IAPI integration in GOAT, in close coordination with our partners from POLIMI, it was decided not to continue integrating IAPI in GOAT. The reasons for this are two-fold. First, both tools are currently in different development stages, which makes it challenging for the practitioners to give individual feedback on both. Second, the use cases are seen as distinct. The tools are instead seen as complementary. Therefore, we decided to use Bologna as a test bed to implement both tools to understand and gather insights on how they could complement each other.

Task 2.3: Tool application

This task aims to transfer GOAT to all EX-TRA cities within selected districts to analyze the current conditions for accessibility and evaluate the impacts on the accessibility of street experiments. The implementation includes locally available data sets. If available, the results from the Commonplace surveys (conducted by the project partners from the University of Westminster, see Emilia and Enrica (2022)) will also be included.

The overall aim of this task is that the tool assists the local partners in identifying areas that have low perceived accessibility and, in addition to that, highlights where StreetExperiments can improve the situation. Those shortcomings can either be due to the network – changes in the streetscape (e.g., adding street trees, adding street furniture, allocating more space for active mobility) that could improve the situation – or due to the land use (e.g., unequal distribution of POIs). Here, the location of new POIs (e.g., street food markets and pop-up stores) could help to improve the situation.

Figure 20. GOAT implementation process.

GOAT has been implemented irregularly in each city due to the different municipalities' availability. The implementation process is organized into four stages. The first one consists of Requirement Workshops. This stage aims to gather the needs and requirements of the local city to implement them into GOAT. The second phase embraces the Onboarding Workshops, where practitioners of each municipality get introduced to the (new) features of the tool. With this workshop, the application phase starts. The third step consists of the Evaluation Workshop, organized once per city. The aim is to gather final valuable feedback on the usefulness of GOAT and its functionality. Finally, a Synthesis Workshop will be held with all five EX-TRA cities to exchange international experiences. *Figure 20* shows the timeline and the process of GOAT implementation. The current status of GOAT implementation through the five EX-TRA cities is detailed per city below.

GHENT

For the city of Ghent, the Requirement Workshop was skipped due to the opportunity to hold a face-to-face workshop as part of the bi-annual EX-TRA meeting in Ghent on the 11th of October 2022. Thus, a basic GOAT version was already prepared for this session. Both implementation stages were condensed into one workshop. Below, the process and results of the Onboarding Workshop are described.

Onboarding Workshop

The first GOAT version developed for the city of Ghent was provided to the local planners to assist them in conducting an accessibility analysis. Eighteen participants were part of this session. The photos below capture the workshop process.

Figure 20. Face-to-face Onboarding Workshop for the City of Ghent.

The session was held in two phases. Firstly, the GOAT team presented the tool functionalities and requested them to test the features in groups of two people. The topics practitioners analyzed are the following:

- Connectivity: finding a suitable location for a new tunnel to cross the railway tracks.
- Connectivity: adding a new bridge over the river.
- Access to supermarkets (to identify the potential for pop-up markets).
- Access to green areas.
- Access to playgrounds (with scenario creation).
- Access to carsharing (coverage of the catchment areas within 4min walking).
- Access to social amenities.
- Access to doctors.

- Compare population density and accessibility.
- Removal of bus stops and evaluating accessibility effects (a real-world example).

Secondly, an open round of feedback was held after exploring the tool. Participants gave positive feedback on the instrument, mentioned improvements, and shared future features. The main results are the following:

Positive feedback

- The recalculated indicators and the interactive scenarios are helpful features.
- The open-source data strategy was named a big plus.

Need for improvement

- Clarify in the heatmaps the concepts of "connectivity" and "local accessibility".
- Make the data sources clearer and the tool features more transparent.
- Improve the dynamic of the tool navigation.
- Clarify which network is fetched for the ways scenario (walking or cycling).

Future functionalities

- Include information about bike-sharing systems (cargo, e-bike) and parking.
- Update heatmaps in coordination with network changes.
- Allow an option to upload shapefiles as helpful information.

As a relevant point, practitioners were particularly interested in including public transport analysis. The Onboarding Workshop allowed for gathering the needs of practitioners to include them in the following version. The GOAT team has been improving the tool to enable local planners to use it until the end of 2023.

Feedback on GOAT in Ghent

An online workshop was organized on the 13th of December 2022 to follow up on and monitor the implementation of GOAT. The session comprised an open discussion between the local planners and the GOAT team to exchange comments and discuss the tool's functionality. Miro was used as an interactive tool where participants could write down their observations, giving them a general graphic picture of the session. The workshop embraced four main topics: use cases, functionalities, data, and improvement ideas. Below, there is a detailed description of the results.

Use cases

Currently, practitioners have been using GOAT to analyze connectivity and accessibility to different amenities and to compare population density and accessibility. Besides, the tool is used to evaluate accessibility effects in real-world examples; precisely when bus stops are removed. On the other hand, local planners mentioned future use cases to implement in GOAT. Those are the analysis of the accessibility to parking places for disabled people, accessibility to loading zones (by car), the interaction between vehicles and bike-sharing systems, and wheelchair accessibility.

Functionalities

For Ghent local planners, GOAT has been more useful regarding local accessibility analysis. They mentioned the information and the results obtained could be used for policy updates and recommendations.

Data

Practitioners highlighted that some information should be included for better accessibility analysis. The data should consist of the combination of car and bike sharing, loading zones as POIs, API, and disabled parking (requested vs public parking areas).

Improvement ideas

After using the tool for two months, the follow-up workshop helped gather future functionalities for GOAT. Practitioners mentioned that it is helpful to implement options to share their datasets between team members. It would include the month of the timestamp, enable data export in GIS extensions to use later the maps in programs such as QGis, ArcGIS and ArcGIS and FME, and implement the routing network. Plan4Better is improving the data sets based on the planner's feedback. GOAT for the City of Ghent is currently in the application phase.

MUNICH

The city of Munich is a particular case. GOAT has been implemented in other projects such as GOAT 1.0 (2019-2021), the Innovation Phase between Plan4Better and the City of Munich (2021) and GOAT 3.0 (2021-2024). During the development of the latter, Requirement Workshops were conducted. Therefore, the needs and requirements of local practitioners have already been fully collected. Also, GOAT is already implemented in Munich since 2019.

Consequently, it was decided not to rerun the Requirement Workshops but to set up an Onboarding Workshop with the practitioners specifically for the EX-TRA project. Currently, it is foreseen to have the Onboarding Workshop together with the GOAT 3.0 project during mid-2023. It will use the last version of GOAT for Munich. However, it is crucial to show the development and results of the previous Requirement Workshops. Below, the process and its outcomes are described.

Requirement Workshop GOAT 1.0 and Innovation Phase

GOAT was tested by more than 20 local practitioners, among others from the Mobility Department of the City of Munich, within four workshops. In the following, the results are summarized. The workshops started with a short discussion about the planning questions the participants deal with in their work life and which tools they use. The main topics local planners handle are:

- Analyse bike-sharing accessibility to existing infrastructure and study scenarios for potential new sites.
- 15-Minute city: understanding how well the destinations for daily needs are distributed across the city.
- Giesinger Berg and Klenzesteg: analysis of possible scenarios for new bridges implementation.

After hearing the general planning needs, Plan4Better presented GOAT's current development state to introduce participants to the potential tool applications. They prepared four exemplary planning issues to be used by the participants while testing the tool. However, it was a free option also to develop their planning questions. Local planners were asked to solve one of the questions using GOAT and to record their results in writing. The planning questions were the following:

- Deal with planning issues of the bicycle and pedestrian bridge at Giesinger Berg.
- Analyze the accessibility of bike-sharing stations.
- Analyze the potential implementation of new bike-sharing stations.
- Deal with planning challenges to close the gap in public transport services.

After the end of the tool exploration, participants discussed their outcomes and challenges and provided valuable feedback, which helped further the tool's development. The main results of the workshops are the following:

Positive feedback

- For participants, GOAT had a simple and easy interface, completed with helpful tutorials.
- Problems and solutions were easily understood and struck because they were visually perceptible.
- The tool would benefit transport planning and committees in taking on planning tasks and evaluating critical scenarios.
- The visualization and export options are high quality, making it possible to share the results visually appealingly.

Need for improvement

- Even though the tool was visual enough, more quantitative statistics and statements should be included. Currently, Plan4Better has improved this requirement.
- There was some confusion regarding using the term "walkability" as a qualitative indicator in the data analysis. It was suggested to expand its research with qualitative results. This point has also been implemented.
- Classify bike-sharing stations and (bus) stops better according to the quality or size of mobility stations. This classification has been partially implemented with the "ÖV-Güteklassen".
- A clarification of speeds on the individual routes was needed, complementary with adding the personal travel time as an additional layer, especially for bicycle traffic. The development of this part is still open.
- Concerning the template, participants suggested readjusting the colours used to represent the walkability-population index. It has already been fixed by changing the colour scale and terms.
- Adaptation of the user interface depending on the screen size. It has also been arranged.

Future functionalities

- Participants suggested including the option to search for a specific location or POI. The examples mentioned were to find the ideal location to place sharing bike stations to achieve the maximum benefit and to analyze the number of stations needed to close all gaps in coverage.
- Include the analysis of the population percentage represented in each study and scenarios to know the scope benefit of implementing some infrastructure. It has been implemented.
- It would be helpful if GOAT enabled them to create their polygons (implemented), adjust attributes on existing routes based on specific needs (partially implemented) and select the same point several times to compare the exact location with different analyses (implemented).
- Enable to export or copy the results table and isochrones. This has been implemented.
- Implement a background layer with elevation differences (to identify slopes for cyclists) and show a map for cycling as a background map (to include cycling facilities). Both features have been implemented.
- Introduce a "diversion" factor, a systematic comparison between walking and air speeds, to find places with poor connectivity. The "connectivity" heatmap has been implemented to solve this requirement.

By now, for the City of Munich, GOAT version 1.4 has been developed. The integration of analyses and scenarios for multimodal mobility with different spatial levels is currently under development. It will provide new features such as a 15-Minute score and open space planner to process other use cases for GOAT 3.0.

AMSTERDAM

For the City of Amsterdam, we implemented both workshops online. The Requirement Workshop was carried out on the 1st of September, and the Onboarding Workshop on the 15th of March 2023. Throughout both, participants used interactive activities and tools to promote active interaction. Below, the process and outcomes of both sessions are detailed.

Requirement Workshop

The workshop was the first meeting between the EX-TRA partners and the City of Amsterdam. The session held ten participants. The session started with a presentation of the current functionalities of the tool. The next step consisted of an interactive activity using Miro-Board, where the participants discussed prepared questions. The questions and each result are described below.

- *For which use cases could GOAT be useful?*

  Participants mentioned it would be helpful if the tool provided an accessibility indicator (mainly for daily needs) for long-term monitoring to have later the correct information to develop policies (e.g., pedestrian policies). Besides, the prominent cases proposed were the development of pedestrian networks, street crossings, street objects on the micro-level and housing (re-densification). Practitioners would like to have an analysis of safety (how routes should be), the attractiveness of paths, connectivity limitations, new destination locations, multimodal connections and transport poverty. On the other hand, they also highlighted the analysis of walking accessibility and how it could be improved in the district of Nieuw West.

- *Which data can be provided?*

  The digital data that can be provided were pedestrian network, road network (traffic model), employment data (jobs per location), population data (individual, households), amenities location (including green areas), land use and functional arrangement of public space map.

- *Which functionalities are the most interesting for you?*

  Participants were more interested in a comprehensive accessibility analysis of specific areas and regions.

- *Which study areas are the most interesting for you?*

The most critical areas to analyze were new residential developments, specifically the Nieuw West area. Practitioners remarked on improving the area's accessibility, especially by public transport.

The workshop gathered many insights which helped the development of GOAT for Amsterdam. After the discussion, the City of Amsterdam decided to have an internal conversation to see how GOAT can complement the existing tools. They wanted to discuss the possibility of implementing GOAT to develop the Nieuw West district.

Feedback on GOAT in Amsterdam

An online workshop was organized on the 1st of September 2022 as a recap of the Requirement Workshop. During the first workshop, the City of Amsterdam mentioned that GOAT could be practical to implement in the Nieuw West district as a potential study area. Therefore, this session started with a brief description of the district, concretizing the needs and possibilities of the tool implementation. The session brought out the following valuable functionalities which are already part of the tool portfolio:

- Implement isochrones and multi-isochrones for walking and cycling.
- Create connectivity, local accessibility, and population density heatmaps.
- Incorporate interactive scenarios that combine new paths, POIs, and buildings.
- Include quality of walking paths.
- Enable to include public transport and cycling analysis.
- Participants also highlighted the importance of including analysis of different target groups, such as the elderly (zonal data) and children (access to schools).

Onboarding Workshop

Plan4Better have worked on including the needs and suggestions in developing the tool for the City of Amsterdam. This Onboarding Workshop was the second meeting between the City of Amsterdam and the EX-TRA team. Seven practitioners were part of this session. It aimed to test the current version of GOAT for Amsterdam. The workshop started with a short welcome and a presentation of the status of the tool function functionalities. Afterwards, the practitioners individually used the tool for their chosen planning questions. However, the following topics were suggested to analyze:

- 15-Minute City: performance of neighbourhoods regarding the connectivity of daily destinations.
- New building areas: assessment of population access to daily needs.
- Connectivity: evaluation of the network connection and effects of a new path connection.

- Street Experiments: identification of potential locations for new street experiments and how the access to the current ones is.

The primary outcomes of the session were classified into positive feedback, the need for improvement and future functionalities. The description of each section is detailed below.

Positive feedback

- The most used feature was the creation of scenarios. It allowed practitioners to analyze real-world examples, such as the accessibility effects of a new bridge.
- The analysis of the proximity of amenities, such as supermarkets and schools, was clear regarding where they are and for whom.
- Participants mentioned that it is helpful to visualize multi-isochrones from different amenities analysis.
- It was highlighted that GOAT could give many opportunities regarding mobility analysis.

Need for improvement

- The use of the interface regarding the functionality of some features and icons meaning needed to be clarified, and practitioners needed further explanations.
- Some doubts about the data accuracy were mentioned because each POIs group could be interpreted differently.
- The study areas in Amsterdam are based on a neighbourhood scale, meaning it would be helpful to have higher area aggregation.

Future functionalities

- Participants mentioned that it would be helpful to incorporate more recreational networks (e.g., data for people running and accessibility to nature).
- Including a breakdown of where physical obstacles in the street network are, especially for the outskirts, walking quality, traffic safety and accessibility by public transport would help perform a better mobility analysis. However, the EX-TRA project focuses on active mobility, so the study by public transport is not primordial at this stage of development.
- Adding more datasets is imperative for practitioners because the City of Amsterdam has detailed street network data at the pedestrian level.

At the end of the session, participants mentioned the potential of the implementation of GOAT in Amsterdam. However, they noted that more practice is needed to explore the tool deeply.

LONDON

For London, the Requirement workshop was held online on the 12th of September 2022, and the Onboarding workshop was carried out in person during the bi-annual EX-TRA meeting in London on the 21st of March 2023. Below, the process and outcomes of both sessions are detailed.

Requirement Workshop

The session was the first meeting between the EX-TRA team and the City of London, with eight participants. It followed the same structure as the Amsterdam Requirement Workshop. It means that it started with a brief introduction for each participant, followed by a short presentation of the current functionalities of GOAT. It aimed to gather insights for the potential implementation of the tool in London. Using Miro-Board, participants were asked to answer four main questions. The results are detailed below.

- *For which use cases could GOAT be useful?*

  Participants mentioned using GOAT to analyze micro-mobility, the extent of the 15-Minute City in London neighbourhoods, low traffic connectivity, walking and cycling connectivity to stations, and the implementation of EVs charge points. Besides, the tool could help develop street school programs and borough LIP projects.

- *Which data can be provided?*

  The data available during the workshop were population estimates, land use maps, LAEI, NO2, NOx, PM10, PTAL, and micro-mobility and cycle docks stations.

- *Which functionalities are the most interesting for you?*

  The creation of real-time interactive scenarios was the most used feature. Participants explored strategies related to public transport and planning new residential areas. Besides, they perceived the involvement of the travel time catchment in the analysis as attractive.

- *Which study areas are the most interesting for you?*

  Participants mentioned that an excellent initial focus could be the previous areas of opportunity and improvement identified by PTAL, besides Lambeth and Redbridge, the places where the EX-TRA and Commonplace projects have already collected the data. Similarly, they mentioned that retail centres needed intervention.

After the activity, a short discussion was opened. Practitioners mentioned that if GOAT is used as a self-service tool by spatial planners in TfL, there would be great potential for the tool implementation for the entire city. It would include setting GOAT up for a large scale with accessibility analysis to various POIs by walking, cycling and public transport. Besides, the study on a district scale would be interesting, focusing on walkability and cyclability analysis.

Onboarding Workshop

This Onboarding Workshop was the second meeting between the City of London and the EX-TRA partners. The first GOAT version developed for the city of London was presented to assist participants in conducting an accessibility analysis, where 15 planners were part of this session.


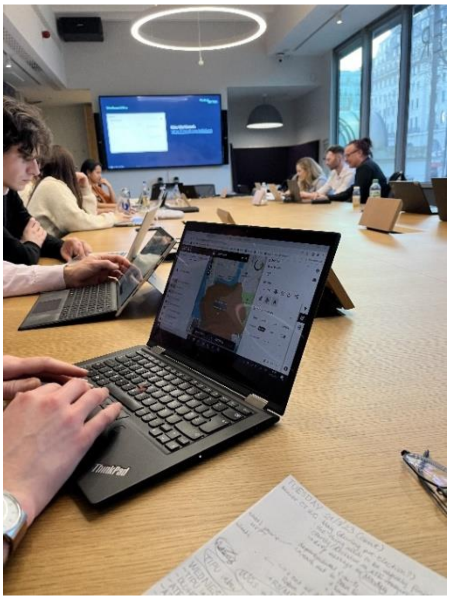

Figure 22. Face-to-face Onboarding Workshop for the City of London.

The workshop started with a presentation of the current functionalities of the tool, including strategic planning. Participants were grouped into teams of 3-4 people to work on planning questions using GOAT. The following questions were analyzed:

- Can we better understand development sites using tools to get a measure of walking access?
- How might an additional entrance at Hackney Downs station improve accessibility?
- How much further can you walk with Rotherhithe Bridge in place?
- Would a bridge between Canary Wharf and Canada Water be viable regarding walking accessibility?

The groups explored the tool and tried to solve their questions using GOAT. Later, they used a Miro-Board to present their work and results. The primary outcomes of the activity are divided into positive feedback, the need for improvement and future functionalities. Below there is a detailed description.

Positive feedback

- Participants mentioned practical accessibility analysis to amenities displayed in isochrones and various walking times.
- The scenarios help provide new facilities and the potential implementation results (e.g., new bridge, bike hire point).

- Through the isochrones feature, it is possible to analyze the demand for new facilities. It is helpful for policy analysis and decision-making processes.

Need for improvement

- It would be helpful to have the quality of the walking route incorporated (street lighting, path quality for wheelchair users).

Future functionalities

- It would be interesting to upgrade links. Participants gave the following real example: a road with >10,000 AADT, if it is placed a modal filter and analyze how that could change accessibility for various groups, e.g., a parent and child might not be able to use the main roads so their current 10 minutes isochrone would be reduced as they use longer routes. But, if the main street had less traffic and better facilities access, they could use it, thus increasing their 10 minutes isochrone.

BOLOGNA

The Requirement and Onboarding Workshop dates are being organized. Plan4Better and TUM are in contact with the municipality entity to set a potential date for developing the first workshop.

Conclusions

Up to this point, many of the expected workshops have been implemented. They have been a fundamental piece in the development and improvement of GOAT for the EX-TRA cities. The following step will evaluate the tool based on its usefulness and usability. The evaluation workshops will be held at the end of Autumn. It is planned to have a Synthesis workshop in Winter between the five EX-TRA cities to gather global insights and exchange ideas. Those will be the last steps of working package two. A summary of the current status of GOAT application per city is synthesized in *Figure 23.*

Figure 21. Current status of GOAT implementation per city.

Table of Tables

Table of Figures

References

Büttner, Benjamin, Ulrike Jehle, and Santiago Linares Ramirez. 2021. 'Theoretical and Methodological Framework'.

Emilia, Smeds, and Papa Enrica. 2022. 'Online Engagament and Usage Interim Monitoring Report. Deliverable 1.1, EX-TRA Project.' London: University of Westminster.

Geurs, Karst T., and Bert van Wee. 2004. 'Accessibility Evaluation of Land-Use and Transport Strategies: Review and Research Directions'. *Journal of Transport Geography* 12 (2): 127–40. https://doi.org/10.1016/j.jtrangeo.2003.10.005.

Labdaoui, Kahina, Said Mazouz, Mehdi Moeinaddini, Mario Cools, and Jacques Teller. 2021. 'The Street Walkability and Thermal Comfort Index (SWTCI): A New Assessment Tool Combining Street Design Measurements and Thermal Comfort'. *Science of The Total Environment* 795 (November): 148663. https://doi.org/10.1016/j.scitotenv.2021.148663.

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

Pajares, Elias, Benjamin Büttner, Ulrike Jehle, Aaron Nichols, and Gebhard Wulfhorst. 2021. 'Accessibility by Proximity: Addressing the Lack of Interactive Accessibility Instruments for Active Mobility'. *Journal of Transport Geography* 93 (May): 103080. https://doi.org/10.1016/j.jtrangeo.2021.103080.

Pucci, Paola, Giovanni Lanza, and Luigi Carboni. 2021. 'Inclusive Accessibility by Proximity Index, First Version. WP2.'

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