Understanding and modelling accessibility to public green in large urban centers using OpenStreetMap data

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As of 2020, around 55% of the worldwide population lives in urban areas and the World Bank estimates forecast an increase of around 1.5 times in the urban population by 2045. Cities are also major contributors to the climate-change, with a consumption of about 78% of the worldwide energy and a production of 60% of greenhouse gas emissions.

A transition toward greener cities is often called as one of the solutions to reduce the environmental impact of cities, but also to make the urban environments more liveable, with positive spillovers on the mental and physical health of their population. In this context, the United Nations' Sustainable Development Goals 11.7 [1] indicates the need to make cities more inclusive and safe, but also environmentally sustainable, calling for the universal provision of safe, inclusive, and accessible, green and public spaces. A proper evaluation of this target requires complementing standard average metrics, looking for instance at the surface of green areas per capita within an urban area, with more sophisticated metrics, that are able to capture the interplay between the spatial distribution of both the population and green areas within a city.

A few studies on selected cities worldwide highlighted the importance of considering this interplay [2–7]. Among these, a recent study on the city of Seoul [3] shows that vast portions of the parks in the city are located in outer areas so that frequent opportunities to visit them are relatively minimal. In general, urban green areas in Seoul are inadequately distributed in relation to population, land use, and development density. By contrast, in the case of Shanghai [6], the degree of accessibility to green areas appears to decrease as we move from the city core to the urban periphery. Using multiple regression and spatial lag regression analysis, the authors also found that housing price is negatively correlated with travel time to green space. This negative association translates directly into a large environmental inequality, wherein wealthier communities benefit more from green spaces than disadvantaged communities. A similar socio-economic, but also ethnic, stratification is observed in the city of Chicago, where white-majority census tracts generally enjoy a

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significantly higher degree of accessibility to green areas than minority-dominated census tracts [7]. The former ethnic group also presents a lower income-based green-areas accessibility inequity compared to the other racial-ethnic groups.

Efforts to move beyond case studies and provide more accurate cross-country indicators have led to the construction of the 'generalised potential access to green areas' from the European Commission, which is provided as one of the city-level indicators of the Global Human Settlement (GHS) - Urban Centers Database [8]. The metric measures the proportion of the urban population for urban centers included in the atlas living in high green areas. Based on satellite data on the Normalized Difference Vegetation Index, the metric is however agnostic with respect to the characteristics of these high green areas - for instance, whether these are public or private green areas - and any accessibility notion, since the metric does not consider that people can move from their residential location to nearby areas. These limitations are accounted for in a recent study for the European Environmental Agency [9], whose geographical coverage is however limited to specific urban hotspots in Europe, for which high-resolution land use data from the Urban Atlas [10] is available.

With its worldwide coverage and detailed mapping, the use of land use and street network data from OpenStreetMap (OSM) [11] allows to expand the analysis beyond the European boundaries. Our study provides a threefold contribution in this direction. First, we compare detailed high-resolution land use data on green uses for European hotspots included in the Urban Atlas [10] with green-related key-value pairs in OpenStreetMap for similar geographical areas. We use similarity indices to assess the degree of completeness of the OSM tags of natural land uses in urban environments and show how the quality varies according to the type of natural use and the size as well as the geographical area of the urban center under consideration. Second, we propose a framework for the monitoring of the target for large urban centers worldwide. In particular, by leveraging data from OSM and population estimates from the Global Human Settlement [12], we develop a framework to measure accessibility to public green in large urban centers worldwide at a high resolution. Our sample include more than 2500 cities, whose boundaries are extracted from the GHS Urban Center Database [8]. In particular, for each country, we include in our study the 50 largest urban centers by population, provided that the urban center has at least a population of 100.000 inhabitants. We identify natural green areas in each urban center using relevant OSM keys on *landuse*, *natural* and *leisure* (e.g.: *leisure=park*) and extract the walkable street network to measure walking distances using the OSM-based routing service Open Source Routing Machine (OSRM) [13]. Accessibility indices are then constructed for each populated cell of the population grid. Following the academic literature on urban accessibility, we build several accessibility indices, from a minimum distance index to exposure metrics. Figure 1A reports the walking distance (in minutes) to the closest public green area of at least three hectares from residential cells in the city center of Paris. The chart, instead, displays the proportion of the population with access to a green area of at least three hectares as a function of walking distance, for the cities of Tokyo, Paris, New York and Turin. The framework will also be also used to build an interactive tool to navigate our results, which can be customized to select the type of green of interest, as well as the size of the green area. The constructed indices and resulting database represent a valuable source of information for policymakers to identify cities that are missing out and direct attention to those subareas within otherwise well-performing cities where the degree of accessibility is still insufficient. The developed indices are then used to study the relationship between the measured level of accessibility and the structural characteristics of the cities and unveil the role of small green areas as accessibility enhancers, particularly in densely inhabited urban centers (Figure 1B, for the city of Paris). As a third contribution, we demonstrate how the framework can be used to simulate the impact of different urban interventions, from the addition of a new public green area to infrastructural interventions to the street network, to help policymakers to shape transitions toward more sustainable and accessible urban environments. Along this line, Figure 1C shows the impact of adding up to five new public green areas in the urban centers of Paris in terms of population (count and fraction) with access to a public green area of at least three hectares within 10 minutes from the residential location. The count reports the new population (in thousands) meeting the target, while the fraction is cumulative and include the entire population meeting the target for the different scenarios. The locations of the new public green areas are chosen to maximize the share of the population with access to green within the selected thresholds (10 minutes walking). The maps display in green residential cells meeting the target in the current scenario and after the implementation of the selected policy (addition of 1, 2 or 5 new public green areas). All Python code and materials developed for this project are made available at the GitHub repository: https://github.com/alibatti/AccessToGreenOSM.

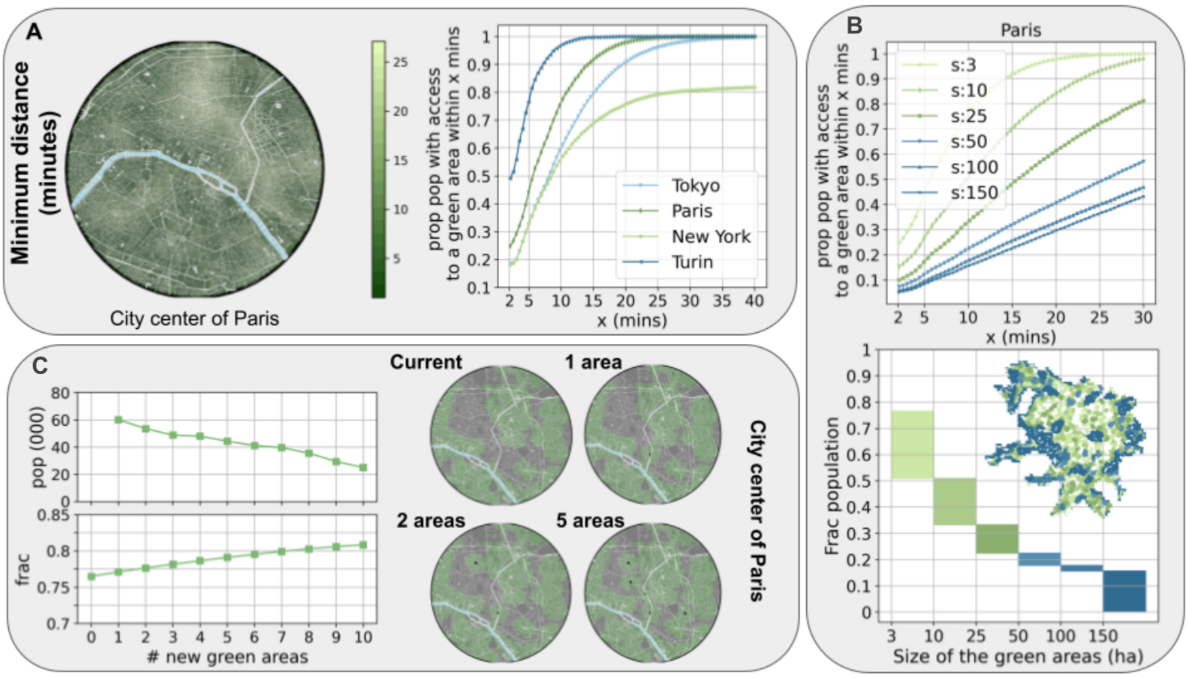

Figure 1. A: Walking distance (in minutes) to the closest public green area of at least three hectares for the city center of Paris (map) and the proportion of the population with access to a green area of at least three hectares as a function of walking distance, for the cities of Tokyo, Paris, New York and Turin (chart). B: The proportion of the population with access to a green area of at least s hectares as a function of walking distance in Paris, for increasing minimum park size thresholds s (top). The contribution of public green areas of different size to the overall fraction of the population with access to a public green area of at least 3 hectares within 10 minutes from their residential location (bottom). C: The impact of adding up to five new public green areas in Paris.

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