Urban Network Analysis training in Rhinoceros3D

by
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TABLE OF CONTENTS

FOREWORD

Walking the streets: an approach to urban proximity through the analysis of pedestrian networks

Eulàlia Gómez-Escoda
Deputy Director of International Relations at ETSAB-UPC

This publication presents the academic experience "Urban Network Analysis training in Rhinoceros3D" held during the month of July 2022, as part of the *Summer Masterclass* program, which each year invites internationally renowned professors to provide specific disciplinary training to the ETSAB-UPC community. In an intensive 3-4-day format, participants learn about topics related to architecture, urbanism and landscape that complement the content taught in the core and elective courses offered in the school's undergraduate and master's degree programs. The masterclasses are either instrumental — oriented to the use of software tools; or to the deployment of representation and analysis systems — or theoretical — oriented to foster critical spirit around historical and contemporary issues.

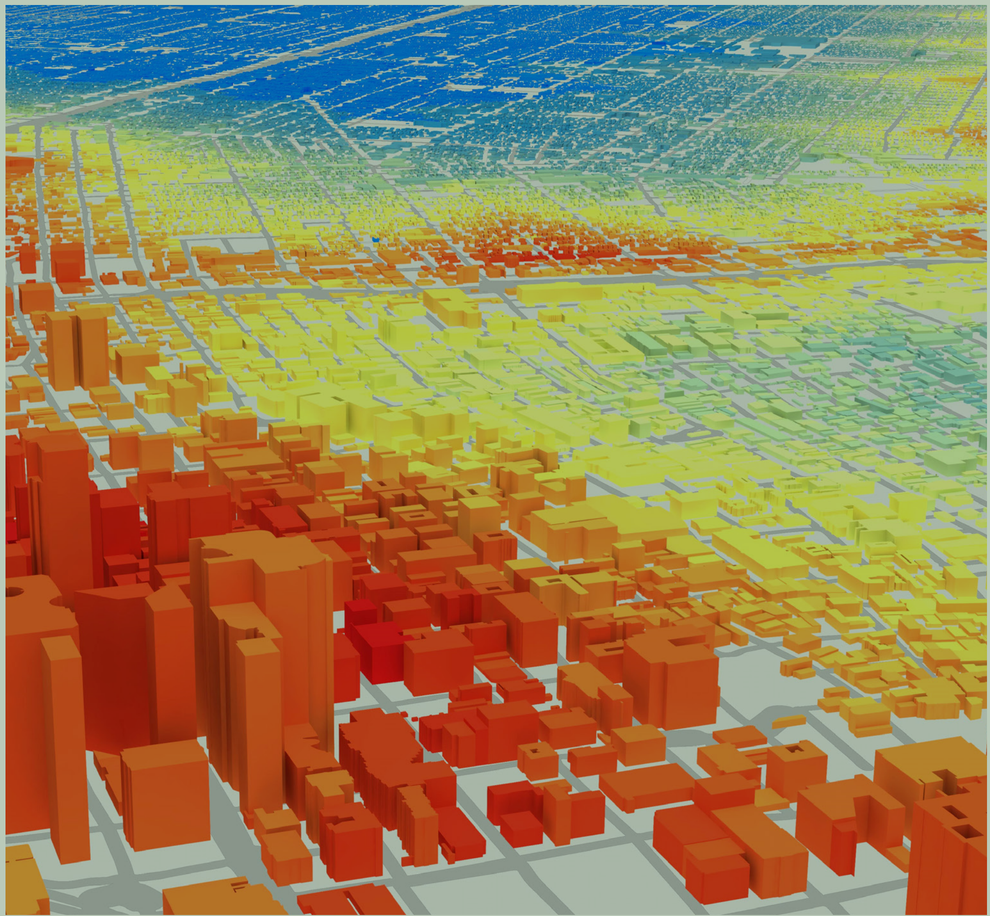
On this occasion, Andres Sevtsuk, Associate Professor of Urban Science and Planning at MIT and Director of the City Form Lab shared with a group of nine researchers UNA, a toolbox for Rhino aimed to the calculation of isodistances and minimum paths with Open Street Maps. The discussion on urban proximity proposed by Prof. Sevtsuk seemed very appropriate to close the course 21-22, the first one in which the restrictions derived from the pandemic were not felt in the classrooms, after two years of teaching online, keeping distances, and crossing glances behind masks.

The notion of proximity in the urban environment was the subject of numerous debates when, during the days of strictest closure, the behavior of cities was transformed.[1] In the case of Barcelona, since March 14, 2020 and for six weeks, only essential services were allowed to continue operating: food stores, pharmacies and health facilities were part, for eight weeks, of the few blinds that were raised at ground level in the city. The new "stay-at-home" routine radically changed urban performance, with an undisguised reduction in mobility and a radical shift from the social network to the digital scene.

Barcelona went from hosting 2,3M people on March 13, 2020 to 1,6M two days later. With most workplaces closed, the urban debate during the lockdown focused on households and streets. The drastic reduction in vehicle movements highlighted unprecedented air quality — both in terms of pollution and visibility — and an explosion of greenery in the city. The city went in a few hours from being a hyper-connected metropolis to relying exclusively on proximity services. In this dystopian scenario, the provision of commerce became as or more important than in the active city itself, because it turned the "additional value" represented by commerce into "essential value" in the exceptional context. From this perspective, understanding what citizens could find in the vicinity of their place of residence became a new way of understanding the urban layout.

The work deployed by students during tthe masterclass and explained in the following pages display a diversity of approaches to network analysis. All them are related to ongoing urban transformation projects in Barcelona and focus on walking relationships: between hospitality services and *Superblocks* (Berra-Sandin, Morera and Villavieja); between schools and squares in a neighborhood where most of the streets are pedestrian (Massana, Mata, Salazar and Sotomayor); and around the discussion of the optimal position of the L9 metro stations (Clua, Martí and Valls). The three works read together highlight the need to make the cities walkable and the concern to optimize the quality of daily pedestrian travel.

[1] Both this paragraph and the following one are part of an article published by the editor of this volume. Read the complete research at Crosas, Carles; Gómez-Escoda, Eulàlia. 2020. "Mapping Food and Health Premises in Barcelona. An Approach to Logics of Distribution and Proximity of Essential Urban Services", *ISPRS International Journal of Geo-Information 9*, n. 12: 746. Special Issue Measuring, Mapping, Modelling, and Visualization of Cities. https://doi.org/10.3390/ijgi9120746



CALL

The workshop introduces participants to the concepts of modeling pedestrian flows over spatial networks using UNA tools. The workshop will consist of an introductory lecture that describes the capabilities and application areas of UNA tools in urban design and planning, in person introduction of the different software functionalities available; a conduct of 2 hands on training exercises using pre-prepared datasets, as well as time to trouble-shoot issues and questions with participants.

Ahead of the training a few related articles will be shared with participants as optional background reading. At the workshop, participants also are introduced to both printed and digital copies of the UNA user guide as well as online training videos.

Schedule:
First Day, 11 July 2022:
13.30-14.30 | Introductory lecture.
14.30-17.30 | Software installation, introduction to setting up networks. Examining pedestrian or bike accessibility on networks. Exercise 1 handed out and completed in class (can be continued as homework). Teams formed and homework distributed for representing a chosen design scheme as a spatial network.
17.30-18.30 | Teams work independently on documenting the chosen scheme as a network in Rhino.

Second Day, 12 July 2022:
9.00-10.00 | Desk-crits with all teams to examine the network representations of their schemes. Team work time.
10.00-12.30 | Introduction to pedestrian flow modeling. Exercise 2 handed out and started in class (continued as homework).
13.30-16.30 | Introduction to spatial patronage estimation and analysis of pedestrian flow with multiple competing destinations.
17.30-18.30 | Desk-crits while teams work independently on the analysis of their schemes.

Third Day, 13 July 2022:
9.00-10.00 | Introduction of additional tools to model detours and “frustration points” for pedestrians in spatial networks.
10.00-12.30 | Desk-crits while teams work on the analysis of their schemes and presentation materials.
13.30-14.30 | Team work to finalize presentations. Faculty floating around for help.
14.30-16.30 | Team presentations.

Selected Participant Researchers:
Albert Massana
Alejandro Salazar
Álvaro Clua
Didac Morera
Enric Villavieja
Francesc Valls
Joan Martí
Melissa Mata
Mikel Berra
Ricardo Sotomayor

PRESENTATION

Urban Network Analysis tools for modeling land use and transportation interactions for pedestrians and cyclists.

Andres Sevtsuk
City Form Lab Director, Massachusetts Institute of Technology

Design of the built environment – the spatial arrangement of buildings, blocks, streets, public spaces and the socio-economic functions they house — produces a variety of influences on urban mobility patterns and mode choices. Sprawling developments, where destinations are far apart and routes between them wide and fast, incentivize motorized trips. High density, mixed-use environments, with diverse destinations connected through a network of quality sidewalks, incentivize walking, biking and face-to-face encounter. City form and land-use patterns influence whether, how often and along which paths people choose to walk.

A robust body of planning literature has emerged to articulate the qualities that make urban environments walkable and bicycle friendly. Walkability is typically associated with the availability of useful and diverse destinations within walking distances (e.g., retail, service and employment establishments, transit stations), and the quality of the walking routes that connect to such destinations—their physical or psychological safety, their environmental comfort, as well as their cerebral stimulation. However, despite a rich literature on qualities of built environments that bring people out on foot or by bike, practical methods for measuring, analyzing, and modeling active mobility remain lacking in practice. Much of transportation literature on pedestrian mobility relies on rather crude proxy metrics to evaluate the walkability of a place — intersection density, block size, population or employment density and land-use mix at the census tract level are often used as predictors. While useful for characterizing walkability at the aggregate, whole neighborhood level, density metrics and neighborhood summary statistics do not capture the influence of built environments on mobility behavior at the individual trip scale, where decisions to undertake walks actually start.

The Urban Network Analysis (UNA) toolbox enables designers, planners and transportation scholars to measure accessibilities and predict flows of non-motorized urban movement at the individual trip resolution over networks. The software helps quantify how environmental design affects access to spatial opportunities and amenities, contributes to pedestrian flow on sidewalks, and influences the viability and patronage of amenities and public spaces in a city. These analyses not only enable us to capture the influence of urban form and land-uses on active mobility, but also inform us how planning and design decisions that shape future built environments, can be operationalized to achieve more accessible, walkable, bike-friendly and transit-oriented cities.

Quantitative approaches for predicting trip volumes, route choices and infrastructure utilization rates have been commonplace for motorized traffic modeling for decades. Cities use such analyses to inform transportation policy, land use policy, development rights as well as infrastructure investment decisions. However, most land-use and transportation interaction models operate with traffic analysis zones, zip codes, or Census tracts as spatial units of analysis, modeling travel patterns between them at the urban or even metropolitan scale. Land-use descriptions refer to the aggregate numbers of jobs, residents or firms located in these zones. Though technological improvements have brought several large land-use transportation interaction models to the scale of individual parcels (MatSim, SimMobility, Urban Sim) their transportation focus has largely remained on motorized trips, not walking and cycling. Albeit powerful for describing multi-modal mobility patterns between urban regions, most transportation models do not connect in their resolution or focus to the kinds of phenomena that urban designers concern themselves with — the buildings and their use patterns on specific sites, the quality and character of public spaces and infrastructure that connects them. Pedestrian network interaction models are unique in this aspect, establishing a direct analytic bridge between the work of an urban designer and the demand for mobility, particularly pedestrian mobility, that can ensue from a project or intervention.

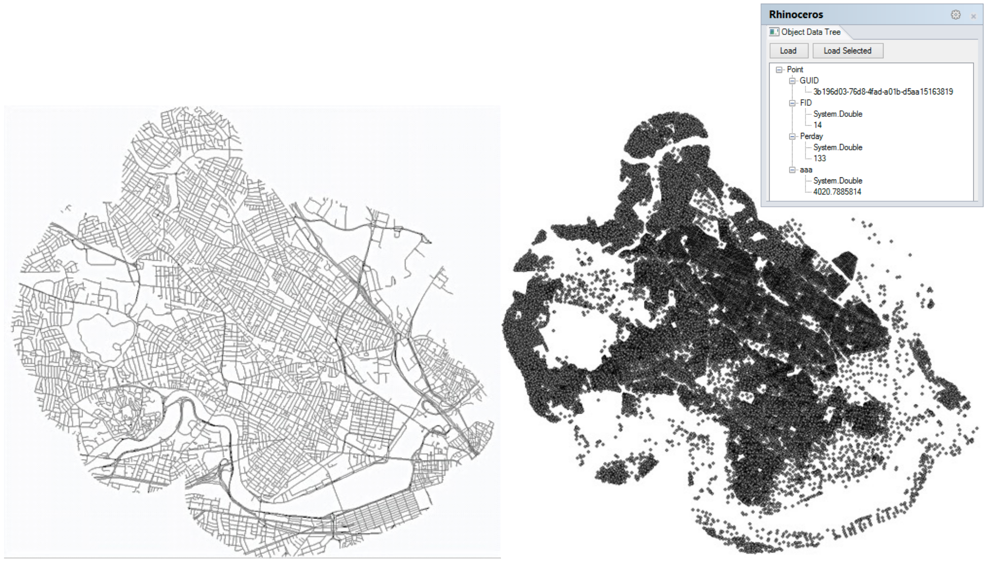


Figure 1. All UNA analyses require a network input, along which all trips are modeled, and point datasets to describe pedestrian origin and destinations. Each of these input elements can contain attribute information that can be used as 'weights' in analyses.

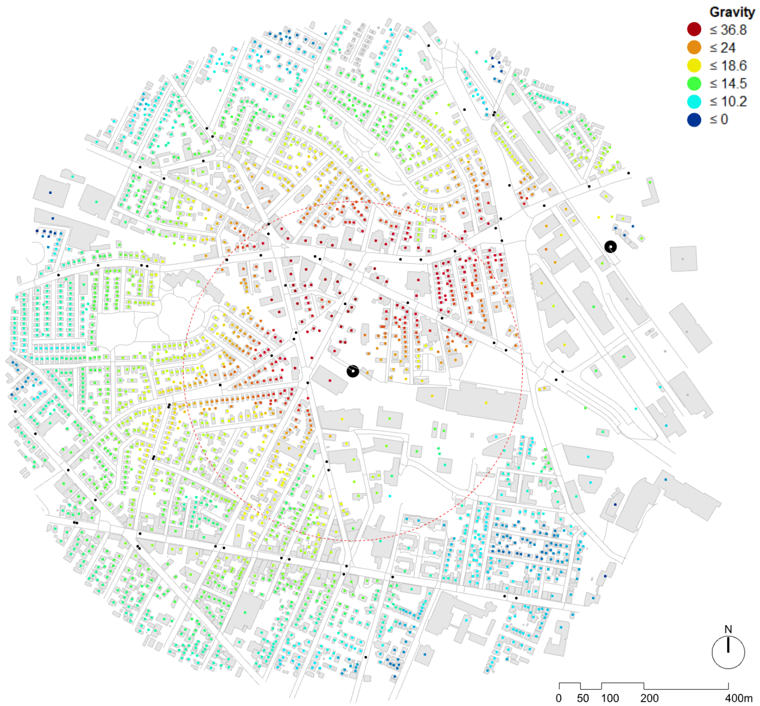


Figure 2. Map of gravity accessibility from all address points to bus and rail public transit station in Somerville, MA, where destination weights describe the level (departures per day) of service of each station. Each MBTA train station is considered 5X the weight of a bus stop. Search radius= 1,000 meters.

The UNA tools aim to make quantitative modeling accessible for pedestrian and bicycle mobility. As the name suggests, an overarching feature of UNA tools is that all spatial relationships are analyzed along networks. Whether an arrangement of rooms within a building, buildings along a street or streets within a district, the toolbox implicitly analyzes spatial relationships along circulation routes, corridors, streets or infrastructure links. Two elements of the built environment that may be close to each other along a straight-line, are not necessarily close in terms of network distance, as is the case, for instance, with buildings located on the opposite banks of a river with no bridge between them. Similarly, topological associations, such as contained or containing spaces in Euclidean geometry, do not necessarily imply access in network geometry, as exemplified by gated communities, where only limited members of society can enter. Representing spatial relationships along networks enables the UNA toolbox to describe built environments close to ways in which they are perceived by specific people or demographic groups on the ground.

All analyses performed by the UNA toolbox require users to provide three key inputs — a network, along which movement is analyzed (optionally, with weights indicating segment costs), trip origin points (optionally, with weights indicating trip generation numbers) and trip destinations points (optionally with weights, indicating destination attractiveness), illustrated in Figure 1. Origin weights, for instance, can describe the number of residents in buildings, which can be used to determine how many trips each building generates, and network segments can include weights, which can be used as custom impedance costs when computing trips over the network instead of the default geometric costs.

The networks and origin-destination points can be either two- or three-dimensional, allowing analyses to range from interior building networks to large-scale planimetric urban networks. Networks can be created from any Rhino curve objects, including lines, polylines, arcs and splines. The data needed to set up networks can either be downloaded and imported to Rhino from existing sources, such as open GIS databases, CAD base maps and Open Streetmap files, or traced directly in Rhino by the users themselves. The UNA toolbox includes functions for importing and exporting data along with attribute information to geojson and table formats, which can be used for exchanging data with GIS, Excel, various Python libraries or other applications. Similarly, point and line attribute weights can be either edited directly within the Rhino drawing environment or joined from external table files, using Rhino objects' Globally Unique Identifiers (GUIDs) as join keys.

Having set up a network with Origins and Destinations, users can deploy a series of tools to describe and analyze pedestrian or bicycle mobility in built environments.

Accessibility tools can be used to analyze how accessible a given set of Destinations are from a given set of Origins along networks, which is key to understanding non-motorized trip demand to such facilities. The UNA toolbox offers two types of pedestrian accessibility indices, including a number of user-specified adjustments: the reach index and the gravity index. The reach index, also known as the cumulative opportunities type accessibility index, computes how many destinations can be reached from each origin within a given network radius. The gravity accessibility index not only counts destinations that are found within the specified network radius, but divides each destination (or destination weight) found with a travel cost required to reach it. The underlying assumption, grounded in travel behavior literature, is that the further the destination, the less likely people are to travel to it, and the less it contributes to accessibility (Figure 2).

Gravity accessibility forms a basis that is widely used in determining pedestrian trip generation and trip distribution outcomes in UNA pedestrian flow analyses. Typically, the more accessible certain types of destinations are to people, the more trips to such destinations are generated. Similarly, the more attractive certain destinations are (represented with their higher destination weights), the more trips they attract

Figure 3. Stochastic route assignment for 75 trips, which allocates an equal probability to all routes that are up to 20% longer than the shortest available path.

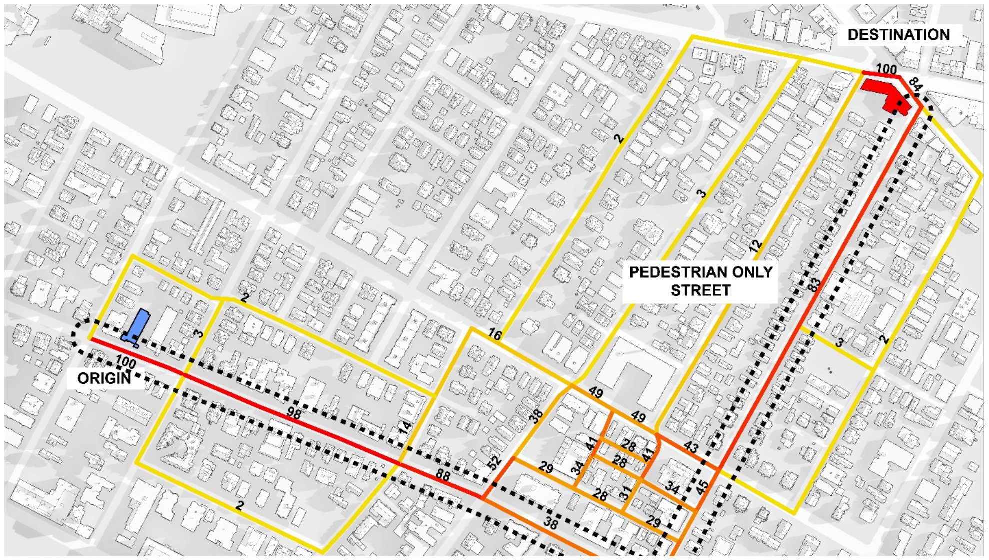


Figure 4. Stochastic route assignment for 75 trips, which allocates an equal probability to all routes (n=56) that are up to 20% longer than the shortest available path.

relative to other competing destinations around them.

Having determined the trip generation volumes to particular destinations, users can evaluate which street segments or walking paths are likely to be utilized on such trips using a customized Betweenness algorithm. The UNA betweenness tool offers powerful options to model pedestrian flows to competing destinations with accessibility-based probabilities, with customized distance decay rates, and along a range of competing route options.

A Detour Ratio variable in th3 Betweenness tool enables trips between origin-destination pairs to be routed along all "plausible" paths that are up to a certain percentage longer than the shortest path. The detour ratio is a ratio between an allowable route length and the shortest available route length. A Detour Ratio of "1.2", for instance, will find all routes that are up to 20% longer than the shortest route between given origin-destination pair (Figure 3). The total number of trips starting from an origin is split between each "plausible" path found and the betweenness values of individual path segments are cumulatively summed.

In order to allow for idiosyncratic route choice preferences among different walkers, we assign each of the routes found an equal probability. However, since many paths overlap on certain segments (Figure 3), parts of the route network, where most unique routes overlap, naturally obtain the highest probabilities. For instance, since the first and the last segment necessarily have to be used by all route alternatives, they obtain the maximum probability of 1, indicating that all trips that are generated between the O-D pair must use them.

A number of pedestrian route choice studies have demonstrated that pedestrians tend to be deterred by route complexity, captured by the number of turns along the route. Route impedance calculations in the UNA toolbox thus offer a Turn Penalty option to the user, where two settings can be used to determine how each turn along the route affects travel costs: a) a Turn Angle variable defines the minimum angular deviation between two segments to be considered a turn (e.g., 45 degrees), and b) the Penalty options defines the magnitude of the penalty incurred by each turn in the units of perceived distance (e.g., 30 meters). When activated, then lowest cost routes not only minimize distance, but simultaneously also turns.

When networks have been set up using custom-segment costs, then route-assignment also accounts for these custom segment costs. Figure 4 shows the same O-D pair as in Figure 3, but with reduced travel costs street segments that are highlighted with a dashed buffer line (i.e., pedestrian priority streets with no vehicular traffic). All segments along that route have been assigned a "perceived length" that equals half their actual geometric length. The route assignment algorithm still finds a number of different paths options, but due to the lower costs of highlighted segments, route distribution is now clustered around this lowest-cost path.

In addition to distributing trips spatially, the model can also output the total patronage volume to each destination type. This can be used for explaining how many total walking trips an urban area generates, or how much change in walking trips may result from development changes. These trip volumes are derived based on address-level location-specific relationships between origin-destination pairs, accounting for choice between multiple destinations and accessibility to each destination.

A number of additional tools for modeling pedestrian mobility offer additional analytic options. A clustering tool allows one to detect groups of closely spaced destinations on networks, highlighting which sets of facilities might work as agglomerations, attracting more visitors. The UNA Straightness index helps users detect 'frustration points' where pedestrians may be able to see their destination on 'as a crow flies' path but cannot actually walk to the destination without undertaking a significant detour. It illustrates how much longer actual network walks from origins to destinations are in comparison to "as a crow flies" distances and allows users to detect node-pairs, where the shortest network route is at least a given factor (e.g., three times) longer than a straight line. High straightness scores signify efficient routes to destinations, while a low straightness scores points to relatively long detours and potential frustration points for pedestrians.

These analyses can inform how likely people are to undertake pedestrian trips in built environments, model how such pedestrian trips could distribute over walking networks, inform what locations in a city are better or worse for particular land uses or activities, how many and what types of users public spaces or infrastructure investments are likely to benefit, or how a change in built form or land-use patterns in one location might influence pedestrian activity and facility patronage at others around it. By offering hands-on and simple-to-use software tools for modeling trips on foot or by bike, the UNA tools aim to contribute to over-due efforts in rebalancing urban transportation policy from its historic biases favoring car-oriented and capital-heavy systems, towards giving more priority, specificity and quantitative rigor to urban movement that takes place on foot, by bike and other personal mobility devices.

The UNA Rhino toolbox was developed with a particular intent to make pedestrian modeling tools available to architects, designers and planners who not only investigate existing built environments, but also actively contribute to creating new ones. Most existing spatial analysis approaches are mainly used retrospectively to study existing urban developments. But the link to prescription is critical if spatial analysis is to have a meaningful effect on planning and design practice. Impact on design and planning can only be achieved if spatial analytic methods are applied in a normative way to synthetic, open-ended future design scenarios. In developing the UNA tools for Rhino — an increasingly popular and accessible software platform for designers — we have striven to incorporate measurement and analyses into a fast and iterative feedback loop, where spatial configurations can be designed, evaluated and redesigned in seamless cycles to rapidly improve the outcome. We hope the users of the tools take advantage of this functionality and not only investigate existing, but also proposed built environments.

More detailed information about the UNA tools can be found at https://unatoolbox.notion.site

Attribution:

City Form Lab team:
Andres Sevtsuk, Lab director
Raul Kalvo, Lead developer
Kevin Chong, Justin Kollar, Daniel Pratama, Help Documentation

Related papers:

Sevtsuk, A., Basu, R., & Chancey, B. (2021). We shape our buildings, but do they then shape us? A longitudinal analysis of pedestrian flows and development activity in Melbourne. *PLOS ONE*. https://doi.org/10.1371/journal.pone.0257534

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TEAM 1:

Mikel Berra-Sandín
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Barcelona's Superblocks under the spotlight: evaluating expected impact of green axes in pedestrian route choice and retail footfall

Mikel Berra-Sandín and Enric Villavieja Martinez

1. Introduction

In the past decade, increasingly more cities are transforming part of their streets in order to prohibit car traffic and convert them into pedestrian-only spaces. Such transformations influence the route choice of pedestrians, and consequently they affect the footfall on retail locations both in transformed streets and surrounding non-transformed streets. The research aims to quantify the effects of the planned transformation under the Superblocks plan in Barcelona, by using the Urban Network Analysis toolbox to evaluate changes in route choice and footfall in ground floor activities.

1.1 Walkability and effects on retail

Such transformations tend to generate disparate reactions among affected retailers. In many cities, retailers have opposed pedestrianization proposals, on the grounds that such projects reduce accessibility to their premises (Castillo-Manzano et al., 2014). However, recent research has proved that in Spain retail in pedestrianized streets has greater income and is more resilient than retail in streets with car traffic (Berra-Sandin, 2022; Yoshimura et al., 2022).

In addition, the fact of pedestrianizing some streets while maintaining others with car traffic can affect the kind of retail and other premises that appear in each of them. An example of it can be found in the city of Savannah (Georgia, USA) where the 1730 plan established a grid of car-oriented streets with mainly pedestrian inner streets. This scheme produces a relevant difference between the premises on main streets, more related with a bigger scale and car use, and inner streets and plazas, where there are smaller premises that depend more on pedestrians. Therefore, it remains to be seen whether pedestrianization projects can cause similar effects in other cities.

1.2 Pedestrianizations and perceived distance

Pedestrianization can alter route choices of pedestrians, as the changes in the physical and environmental conditions of pedestrianized streets reduce the perceived distance of pedestrians (Montgomery, 1998; Moudon et al., 1997). Therefore, this renders pedestrianized routes more attractive, changing the walkability patterns and ultimately affecting footfall in retail locations.

There is a large body of analysis in route choices in relation to the physical conditions of streets, mainly in North America and Asia (Al-Azzawi & Raeside, 2007; Cerin et al., 2007; Giles-Corti et al., 2005; Grant, 2002; Sevtsuk, Basu, & Chancey, 2021; Sevtsuk et al., 2016; Sevtsuk & Basu, 2022). To do so, previous research uses 'willingness-to-walk' as the measuring metric: different physical conditions such as turns, amenities, sidewalk width, or greenery can increase or reduce willingness to walk.

However, the effects of each of such elements on the willingness-to-walk is very different in analyzed cities. For example, each 3-meter increase in sidewalks increases the willingness-to-walk by 13.2 meter in Boston, but it does so by 83.7 meter in San Francisco, 46.7 meter in a previous study in Boston, or 35.3 meter in New York City (Basu & Sevtsuk, 2022; Guo & Loo, 2013; Sevtsuk, Basu, Li, et al., 2021).
Consequently, all studies agree that an increase in sidewalk width increases willingness-to-walk, yet the extent to which it does so differs largely among studies. However, such studies have led to the possibility of modelling projected pedestrian flows on streets, as a tool to guide urban planning (Sevtsuk, 2021).

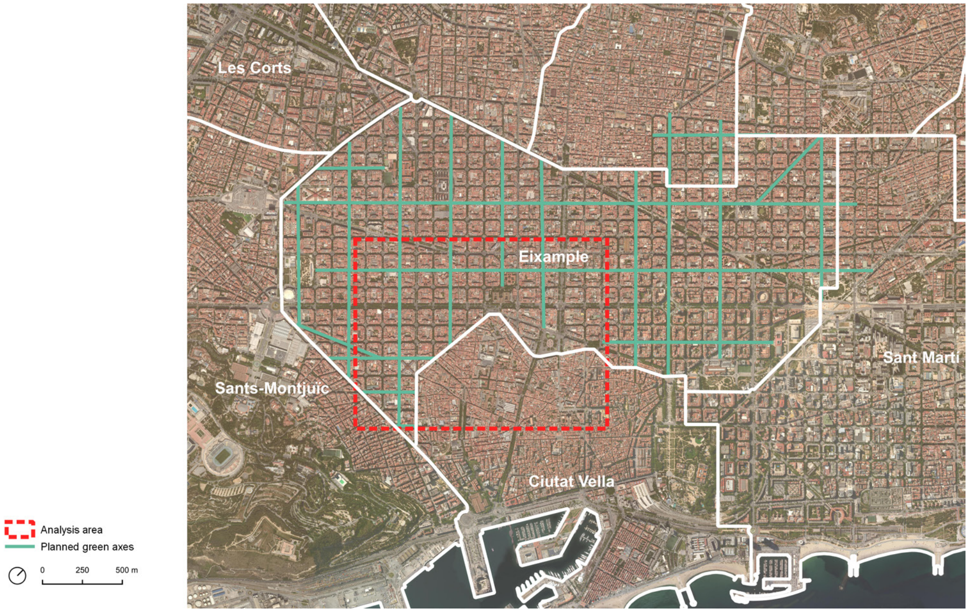

Figure 1. Green axes plan and analysis area. The chosen analysis area takes part of the Eixample district, characterized by its grid structure, and part of the Ciutat Vella district, in order to analyze different street structures and show differences between an area where the Superblock plan will transform streets and an area not affected by it.

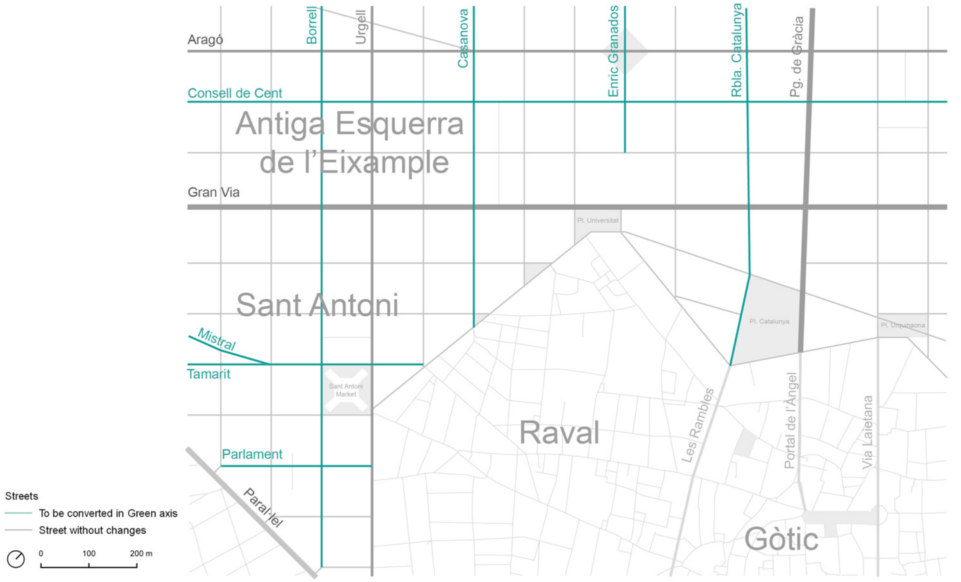

Figure 2. Street layout at the analysis area. The analysis area is heterogeneous not only form wise, but also in terms of uses: the areas at the right of the image, along the Rambla de Catalunya and Ramblas corridor, or the Passeig de Gràcia-Portal de l'Àngel corridor, are very tourist- and business-focused. The areas at the left side of the image instead are more local-focused: both the Raval area and the Sant Antoni area are popular neighborhoods.

1.3 Pedestrianizations in Barcelona: the Superblocks plan

The Superblock plan is a strategy to pedestrianize a large number of streets in Barcelona. Even though the plan affects streets in all districts of the city, its main intervention takes place at the Eixample district: an area shaped as an orthogonal grid of streets, resulting in equally sized 113x113 meter blocks and 20m wide streets, and characterized by a great mix of uses (Gomez-Escoda et al., 2022). The original plan, as drafted back in 2014, planned that 1 in 3 streets would keep car traffic, thus creating 400 x 400m superblocks comprising 9 traditional blocks. In the streets inside the superblocks, no through traffic would be allowed, creating more space for pedestrians and civic uses (Rueda Palenzuela, 2017).

However, as the implementation has developed since 2016, the Superblock model has shifted to an easier to implement, less ambitious plan. In the model in implementation as of 2023, on average one in four streets of the Eixample will be converted into 'green axes' (Figure 1): single-graded streets with car traffic only limited to local access, and with improved greenery, thus enhancing walkability (Ajuntament de Barcelona, 2021).

The proposal creates a stark contrast between such green axes, which become pleasant walking routes, and the rest of the streets, which keep having car transit. Nonetheless, the evaluation of the first implemented superblocks suggests that transit is reduced both in the transformed streets and in the rest of the streets, thus improving the urban realm.

However, the impact of the Superilles plan in retail is still unclear. The existing studies, all done in the Sant Antoni Superblock, show contradictory results with regard to the income of retailers: while a study by the Barcelona Oberta retailer association (Benvenuti, 2021) claimed that revenue fell after the Superblock implementation, data by the Barcelona City Council shows that post-covid revenue recovery was much faster in the Sant Antoni superblock area compared to the rest of the city (Márquez, 2021).
Come what may, Superilles are on the route to implementation, and so does a new 'Use plan' for the Eixample district, which will limit the number of 'high impact activities' such as bars, restaurants or convenience stores in the green axes so as to avoid a radical change of uses. There will be a limit of 5 high impact activities in a 50-meter radius in green axes, aimed to mitigate the change of character and preserve existing retail in green axes (Benvenuti, 2023).

Despite the control in activities and the ambition of the plan, it remains to be seen whether the Superblock plan will affect the types of activities in each kind of street, and may result in a specialization of activities in each kind of street: more pedestrian-focused on green axes, and more car-oriented in the rest of streets. Consequently, it is worth analyzing how pedestrian routes may change upon complete implementation of the Superblock plan, and how this affects footfall in retail.

2. Goal and object of study

The goal of this study is to evaluate the impact of the implementation of the Barcelona superblocks in the walking accessibility to retail, public facilities and transit stops from houses. To do so, the research analyzes an area of 1,6x1,2km comprising parts of the Eixample district, where the Superblocks plan will be implemented, and parts of the Sants-Montjuïc and Ciutat Vella districts, where the Superblocks plan will not affect the street layout (Figure 2). The area goes from Calàbria to Pau Claris — west to east — and from Aragó to Aldana — north to south. It is worth noting that the research area also includes the Sant Antoni Superblock, which was implemented between 2017 and 2020. In that city fragment, the research models pedestrian routes both in the existing state in 2017, without any superblocks executed yet, and in a future scenario with superblocks implemented. In doing so, the research aims to dissect the change in retail footfall, variation in proximity to facilities, and change in perception of retail clusters.

3. Methodology

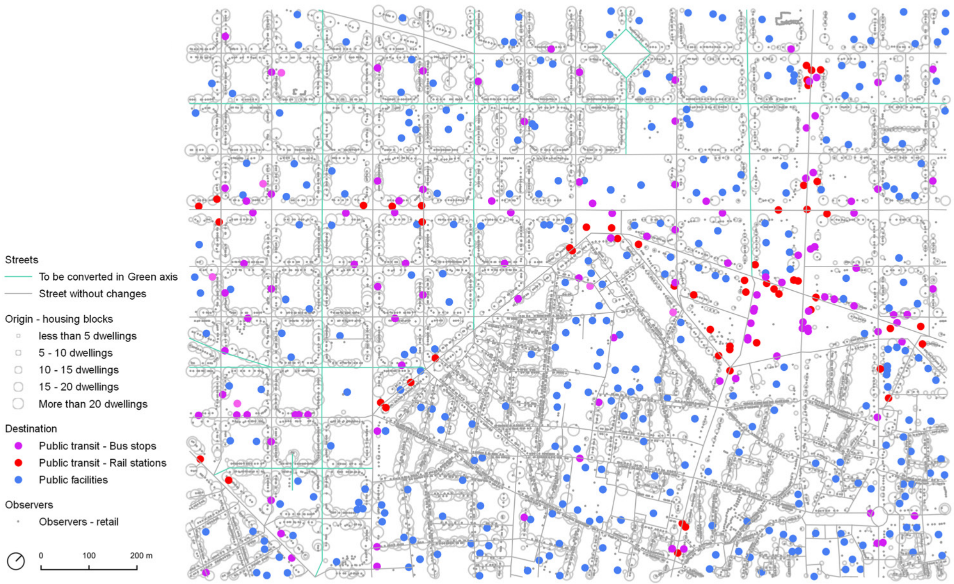

Figure 3. Location of origins (dwellings), destinations (transit stops or public facilities) and observers (retail) used for the analysis.

3.1. Data collection

The analysis uses a variety of openly accessible data provided by public institutions, in order to determine the location and type of activities and dwellings, and establish the location of destinations such as public transit stops and public facilities. In addition, noise maps also provide reliable information in order to evaluate existing environmental conditions in streets, prior to the Superblock implementation.

Street centerline graph: OpendataBCN, 2022
Activities: ground-floor space census, Barcelona City Council, 2019
Public facilities: facilities database, AMB, 2022
Dwellings: Land registry, Catastro, 2022
Public transit stops: OpendataBCN, 2022
Noise: OpendataBCN, 2017

3.2. Analysis

The study is conducted through the Urban Network Analysis toolbox (Sevtsuk, 2018). In all analyses, there are two scenarios:

Scenario 1: all Eixample streets are physically equal, willingness-to-walk is factored by noise.
Scenario 2: in green axes, physical and noise conditions improve, affecting willingness-to-walk.

The evaluation of the improvement is done as follows:

Sidewalk width: in green axes, sidewalk width will increase from 10m (5 meters in each side) to 20m (full street width). Therefore, the net increase will be 10m. Following most restrictive values from aforementioned studies in willingness-to-walk, it is determined that such increase in sidewalk width will cause a reduction of 40% in perceived length.
Noise: taking 70dBa as a reference value, a 10dBa change causes a 10% change in perceived length.

In order to determine the possible routes, in each of the analysis's parameters required by the Urban Network Analysis have been fixed.

Radius (maximum distance walked): 400m
Detour ratio (maximum length of alternative routes): 1.1
Beta: 0.001

The walkable distance chosen answers to the extent of three Eixample's blocks, which is the distance between the green axes.

The Detour ratio is used to calculate the extra distance that pedestrians are willing to walk from origin to destination. Choosing a path even though it is not the shortest one could answer to the quality of the street or the premises that can be found along it. In this case, a Detour ratio of 1.1 represents an extra 10% of distance.

The Beta index qualifies the walkability of the city according to the weather, the topography and the urban quality of the streets. In the case of Barcelona, the 0.001 Beta represents a high willingness to walk longer distances for pedestrians.

Three types of analyses are conducted:

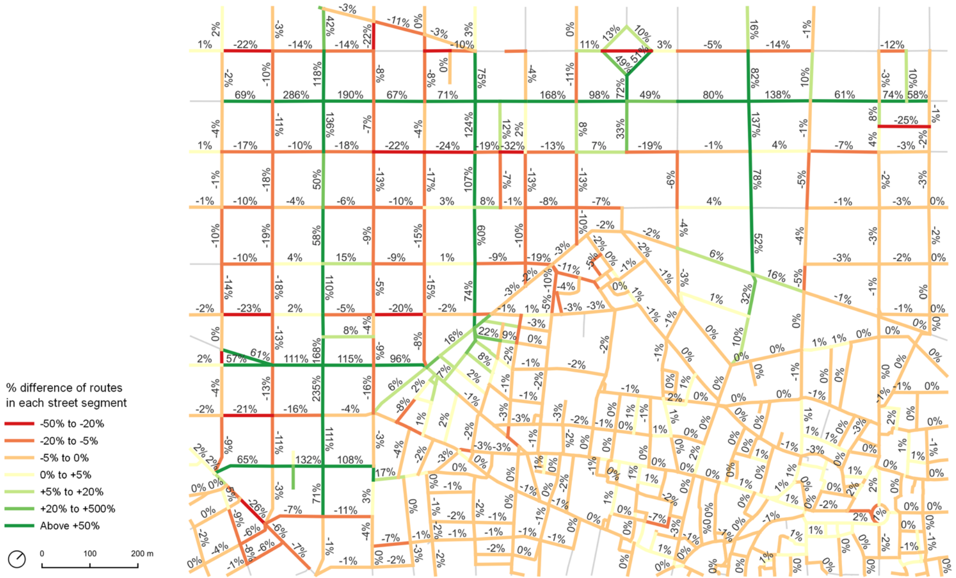

Figure 4. Footfall change of each street between scenario 1 and 2, according to the routes from dwellings to public facilities in 400m max walking distance. Green axes sharply increase the number of routes passing by, while the rest of the streets at the Eixample neighborhood slightly reduce the routes passing by.

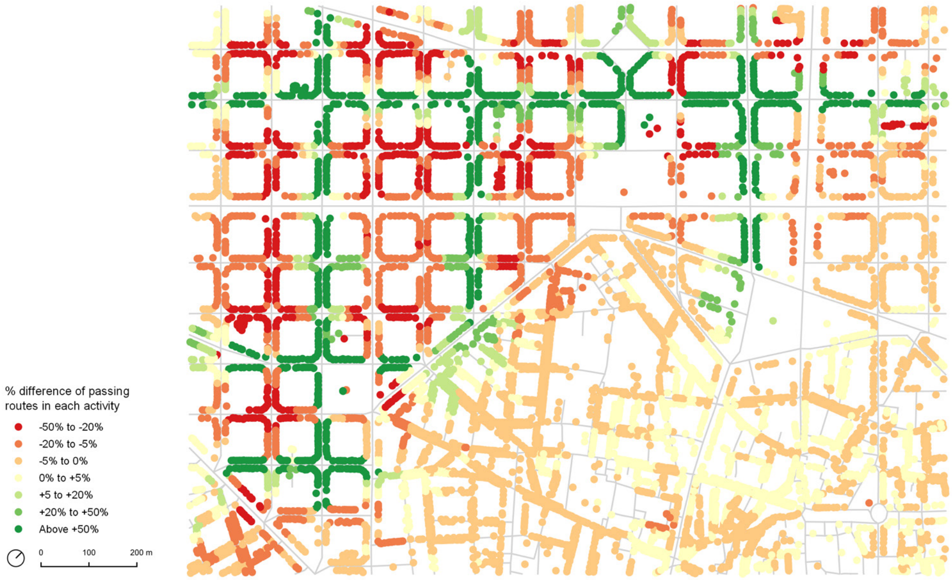

Figure 5. Footfall change in each ground floor activity between scenario 1 and 2, according to the routes from dwellings to public facilities. It depicts a clear distinction between stores at the green axes and the rest of stores: the first ones increase footfall drastically, while the second ones lose footfall. Consequently, this could transform the theoretically even distribution of activities in the Eixample into a two-tiered district, with prime locations and not so desirable streets.

3.2.1. Betweenness analysis

The betweenness analysis counts the amount of footfall passing from given points, when determining origin-destinations. In this analysis, dwellings are set as origins, and destinations are either public facilities or public transport stops. The analysis counts how many routes pass in front of each ground floor activity.

3.2.2. Gravity analysis

The gravity analysis identifies every point on a given walking distance from an origin.
The aim of this analysis is to study the accessibility to both public facilities and public transport stations from dwellings. The used criteria is as follows: the walking distance from any origin to destination (dwellings) is 400 meters following the street's axis.

3.2.3. Cluster analysis

The cluster analysis looks for groups of similar ground floor activities. The researched activity types are bars and restaurants, clothing retail, and food retail.
In order to establish if there is a cluster of any such activities, the following criteria is used: the minimum number of activities is 10, and the maximum distance of nearest neighbor is 50m.

4. Betweenness analysis: how many pedestrians walk along retail?

The betweenness analysis is set to show the change in footfall in every stretch of streets, and thus in existing retail activities (Figures 4 and 5). As expected, the research shows a sharp increase in footfall along the green axes, where in some stretches it would even duplicate. This comes at the expense of routes passing on the rest of streets, where footfall would slightly decrease — sharpest declines are up to 32%, while the average decline in non-Superblock streets is 15%.

These results happen in either routes from dwellings to public facilities or from dwellings to public transport. Therefore, both analyses depict that the distribution of current walking routes in the Eixample neighborhood will shift to green axes as busy walking corridors and other streets will see their pedestrian traffic dwindle. Even though the decrease in footfall in non-transformed streets is not drastic, it may affect the viability of retail activities. Nonetheless, activities located in green axes will see their footfall sharply increase, thus rendering them much more attractive.

5. Gravity analysis: how many facilities are at walking distance from dwellings?

Gravity analysis allows the research to compare between Ciutat Vella and Eixample grids, both presented in the city fragment chosen for this study. Furthermore, the variation in perceived distance due to the implementation of the superblocks extends the perception of accessibility from dwellings to public facilities and public transport stations.

On the one hand, in the Ciutat Vella fragment, on scenario 1 every dwelling has access to 13,25 public transport stops, while it has access to 11,88 public facilities within 400 meters. On scenario 2, such figures raise slightly to 13,89 and 12,27, respectively. On the other hand, at the Eixample grid on the fragment, every dwelling has an average of 16,39 public transport stations and 9,28 public facilities within 400 meters in scenario 1. After the Superblock transformation, though, there is a steep increase in accessibility: dwellings have 20,83 stops and 12,75 facilities within reach (Figure 6).

Therefore, as a consequence of the reduction in perceived distance, the number of public interest points accessible from any dwelling changes drastically. While in the Ciutat Vella the increase is a 4,84% on access to public transport stations and a 3,27% on public facilities, in the case of Eixample's grid the increase is up to 27,13% and 37,47%. As a result, even if in scenario 1 dwellings at Ciutat Vella have greater accessibility to public facilities, in scenario 2 dwellings at Eixample have more public facilities withing a 400m perceived

CIUTAT VELLA							EIXAMPLE					
	PUBLIC TRANSPORT			PUBLIC FACILITIES			PUBLIC TRANSPORT			PUBLIC FACILITIES		
Scenario	1	2	**Change**	1	2	**Change**	1	2	**Change**	1	2	**Change**
From dwellings to ...												
MIN	1.57	1.58		2.15	2.15		1.39	1.54		2.45	2.89	
AVG	**13.25**	**13.89**	**4.84**	**11.88**	**12.27**	**3.27**	**16.39**	**20.83**	**27.13**	**9.28**	**12.75**	**37.47**
MÁX	49.69	49.70		19.20	20.86		63.31	67.76		19.45	26.32	

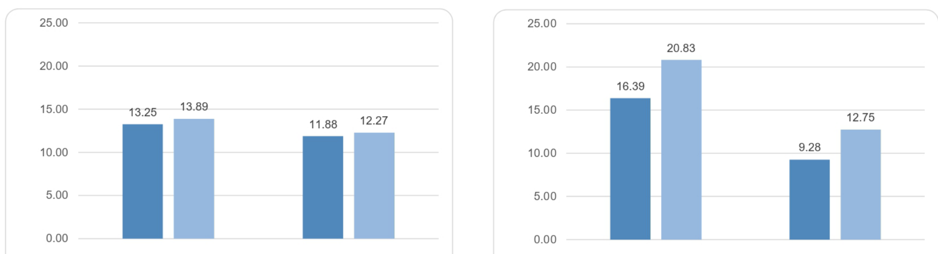

Figure 6. Comparison of the number of public facilities and transit stops accessible from each dwelling block, in scenarios 1 and 2. Ass graphics show, accessibility increases slightly in Ciutat Vella, where there are no green axes, yet the increase in the Eixample is remarkable.

distance range.

The following drawings depict the distribution of this gravity increase both towards public facilities and public transport stops (Figures 7 and 8). The increase is mainly around the green axes and their surroundings. The implementation of the superblocks in the Eixample produces an increase on the first streets of Ciutat Vella closest the green axes.

6. Cluster analysis: how do businesses gather?

The clusters identification that analyzes three types of ground-floor activities: bars and restaurants, clothing retail, and food retail. The minimum number of activities is 10, and the maximum distance of the nearest neighbor is 50m.

The reduction in perceived distance increases the perception of clusters. According to this analysis, the impact of superblock's implementation on clothing retail and food retail is slightly lower than on bars and restaurants. The first two categories increase their clusters only around Sant Antoni superblock and the transformation of Consell de Cent has only an impact on Passeig de Gràcia (Figure 9). On the other hand, the category of bars and restaurants experiences a bigger increase than the other categories, especially along Consell de Cent, which would become a bar and restaurant cluster almost through the whole length of the analyzed area (Figure 10).

As mentioned above, the city council has established a limitation on the new premises in order to avoid the reinforcement of clusters of high impact activities. However, it is likely that the proposed limit of 5 high impact activities in a 50-meter radius in green axes is already surpassed in many parts of such streets.

7. Conclusions

7.1. Research outcomes

The Superblock model in Barcelona will pedestrianize one in every three streets at the Eixample district, thus affecting walkability patterns. Pedestrianized streets, known as 'green axes', will have improved physical and environmental conditions, which according to previous research should increase the willingness-to-walk through such axes. In order to model such effect, we have modeled walking routes in two scenarios: one prior to the implementation of superblocks, where the only physical difference between streets is the level of noise, and one after the implementation of superblocks, where transformed streets will be pedestrian and have more greenery. In such scenarios, we have modeled routes from dwellings to public facilities and to transit stops.

The three types of analysis have shown the effects on footfall, on the accessibility from dwellings, and on activity clustering. Through the betweenness analysis, models have shown a sharp increase in footfall in green axes, where walking routes increase between 49% and 235%. In the meantime, footfall outside green axes decreases slightly, with decreases averaging 15%. These results show that activities may adapt to new walking patterns: activities in green axes will have more footfall, while activities outside green axes will see their footfall decrease, thus endangering their consumer base or possibly attracting more car-centric activities.

As for the proximity from dwellings to public facilities and transit stops, the gravity analysis shows that dwellings will have greater accessibility to such destinations, as the improvements in green axes will reduce the perceived distance to facilities and stops. This impact will be prominent in dwellings at the Eixample district, yet it will also be felt at Ciutat Vella dwellings, as they will more easily access facilities and stops outside the boundary of their district.
Lastly, the implementation of the green axes will also impact on the creation and expansion of activity clusters. Among the analyzed activities, the superblock plan will consolidate a bar and restaurant cluster along Consell de Cent street, while the surroundings of the Sant Antoni Market will become food and fashion retail clusters.

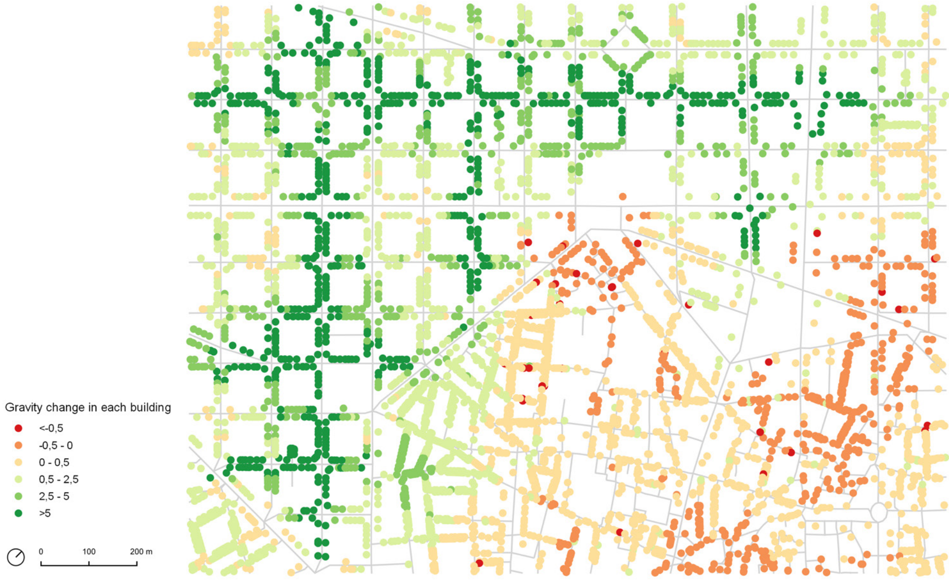

Figure 7. Gravity change in routes from dwellings to public facilities. All dwelling blocks in the Eixample district improve their accessibility – especially in areas along or close by green axes, but also in the rest of the district.

Figure 8. Gravity change in routes from dwellings to public transit stops.

7.2. Policy recommendations

In light of the expected impact of the superblock plan in footfall, and consequently in the viability of retail and other ground floor activities, the Superblock plan should be accompanied by economic policy to mitigate possible negative impacts in activities. The conducted research shows that activities outside green axes may see their footfall decrease, and thus may be in need of economic support in order to adapt to the new walkability patterns after the implementation of the Superblock plan.

In addition, the Superblock plan may result in the overconcentration of some types of activities along the green axes, be it as a result of an increased cluster effect, or as a result of the displacement of existing activities due to rising rents and the appearance of new activities substituting these. In this case, the Use plan drafted by the City council is already trying to regulate this overconcentration, by imposing more strict conditions to avoid the concentration of activities of a given type in green axes. As shown in the research, this concentration may especially happen in the bars and restaurants, where streets such as Consell de Cent can shift to an almost monofunctional use. Therefore, the regulation of uses should especially tackle the implementation of new hospitality activities along green axes.

Last but not least, the research shows that physical improvements in cities may have negative effects or cause gentrification. Consequently, improvement plans should evaluate possible effects beforehand, while design should be accompanied by economic and social policy to make sure that positive impacts are multiplied while negative impacts and displacements are mitigated.

Acknowledgments

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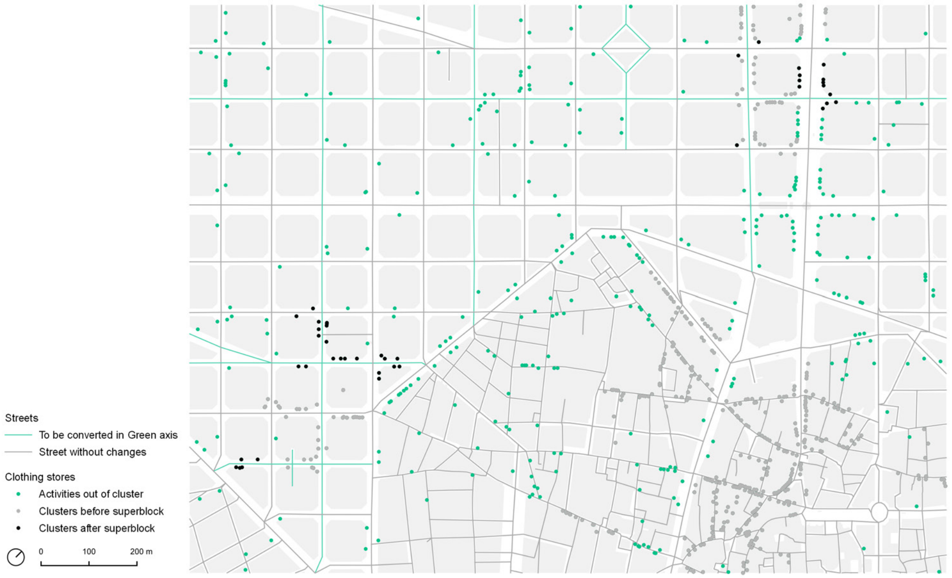

Figure 9. Clothing store cluster change between scenario 1 and 2. Clusters change slightly after the implementation of the Superblock plan, strengthening the concentration around Sant Antoni Market and Passeig de Gràcia.

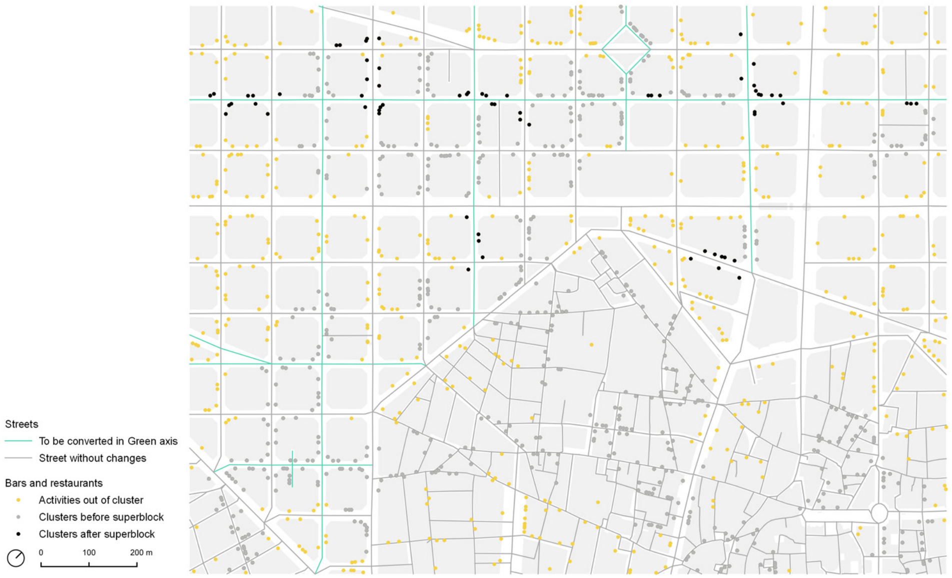

Figure 10. Bars and Restaurants cluster change between scenario 1 and 2. As shown in the image, clusters enlarge upon implementation of the Superblock plan, as a consequence of shorter perceived distances. In the case of bars and restaurants, the main change will happen along Consell de Cent street, which will become a long cluster of hospitality venues.

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TEAM 2:

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The walking routes of the children in Vila de Gràcia

André Salazar and Ricardo Sotomayor

1. Introduction

Barcelona is a walkable city. This is not a myth, is a fact supported by data because according to the city hall, around 35% of the journeys are made on foot, despite the fact that more than half of the road space is dedicated to vehicular movement (when the intensity of traffic is measured by the use of public road space in Barcelona, the results show that each citizen has 4m2 of sidewalk while each vehicle has 12m2 of road space). Inclusive mobility has been incorporated as a priority in European cities in recent years, and Barcelona is a clear example, because it has a long history of constantly trying to improve the city's walkability with projects such as the Superblocks, widening of sidewalks, by protecting school environments and by improving the accessibility of its citizens to the public space based on the idea that the ease, autonomy, and security that people need to access different places of socialization make daily mobility play a fundamental role for the vitality and resilience of the urban social fabric. Furthermore, boys and girls, especially the youngest (between 0 and 4 years old) are more sensitive to the conditions of daily mobility because they usually need the presence of caregivers and/or strollers to move from one point to another.

In this study, we analyzed the daily mobility of the children of Gràcia by modelling the pedestrian flows over the neighborhood with the Patronage Betweenness Tool from the UNA toolbox to measure the betweenness in three different scenarios: Home to School, School to Plaza and from the Plaza's back Home. The tool calculates and visualizes how many trips are likely to pass different network edges, given a set of trips between Origins and Destinations in a network.

2. La Vila de Gràcia neighborhood

The city of Barcelona is recognized around the world for its distinctive grid, originally proposed by the Catalan engineer Idelfons Cerdà, in what was the most important urban reform of the city during the 19th century, being the turning point between the transition of Barcelona as a medieval city surrounded by walls towards the contemporary city that we know today. However, there is an area to the north of the city whose scale contrasts with that of the Eixample , as it is full of low-rise buildings and narrow streets (mostly pedestrian) that connect a series of small squares scattered throughout the neighborhood and that each one has its own identity and are generally the meeting point for people of all ages and social strata for recreational, political, and social purposes.

Gràcia had its origins as a dependent territory to the north of Barcelona, it was a rural area and had a small population. During the 16th and 17th centuries, three convents were installed near the existing masías and a series of towers promoted by the Barcelona bourgeoisie were built. By the first half of the 19th century, the small agricultural nucleus had become the most important town on the Barcelona plain due to its progressive industrialization and because it possessed what Barcelona lacked so much: space in which to grow. In 1850 Gràcia was established as an independent municipality, but this did not last long, since in 1859 Barcelona finally managed to tear down its walls to begin carrying out the Cerdà plan, for which it eventually ended up being integrated into the city, connecting through the Paseo de Gràcia, which linked the town with the big city following the old path. When Gràcia finally joined Barcelona in 1897, it had 62,000 inhabitants, but it lacked facilities and services nevertheless little by little the streets that connected the neighborhood internally and externally were built, although the urbanization was being carried out autonomously by the owners of the land, for this reason there are some streets with multiple names or discontinuous streets and the numerous plazas, which were originally planned to be one plaza for each property. Nowadays the neighborhood is

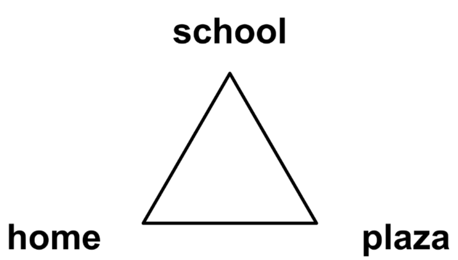

Fig 1. From home to the school to the plaça to home

surrounded with civic institutions, cultural, recreational, artistic, and sporting venues that are popular within the local community.

3. Methodology

When walking through Gràcia, it is not difficult to notice the constant flow of pedestrians in its streets and the variety of activities that take place in the small plazas that usually welcome the children of the neighborhood in the afternoons. Gràcia has 25 schools of which 15 are primary and secondary and 18 plazas with different dimensions and characteristics. According to data from the town hall, 12.6% of the population of Gràcia are children from 0 to 15 years of age and this group constitutes our study objective. In order to carry out the exercise, we analyzed the critical walking routes using the UNA toolbox with the following values:

3.1. From Home to the School

The first journey of children's daily mobility is usually the journey from home to school, therefore here we analyze the "betweenness" between homes (Origin points) and schools (Destination points) in a 500-meter radius. For the Origin points we had data from the city council on the approximate population per building and from this we calculated 12.6% (percentage of children aged 0-15 years) to have the data of kids that leave their homes and to this we added a plus one to each of the kids in order to have the data of the parents that escort them because according to the study "Infants i famílies a Barcelona" (Children's Institute, 2010), it is most likely that the accompaniment is done by a mother with one or two children and a stroller.

3.2. From the School to the Plaça

The second tour of the day takes place in the afternoons because it's when the children leave school, are picked up by a family member and go to the squares to walk, play, or eat something. In this exercise, the Origin points are the schools and to calculate the Destination points, we drew the four corners of each plaza and assigned them a patronage value to estimate their weight according to the proximity and dimension of the plaza.

3.3. From the Plaça to Home

The final journey of the daily schedule is taken at the end of the afternoon when the children return home and for this, we marked the squares as the Origin points and the buildings that we previously mapped as homes, as the Destination points, using the patronage value that we had also used in the second study.

By analyzing these three scenarios, we were also able add patronage data from the plazas because we assigned a value to the attractiveness index in two of the scenarios so this showed us which plazas were more inviting for the families in relation to proximity (from schools and homes, which could be different), distance and size.

4. Results

The city of Barcelona and specifically the area of study are characterized by having a relatively high density, therefore the convergence points (plazas) are necessary to improve the conditions of the neighborhood and to promote a better environment for children. The case study seeks to find the connectivity relationships of routes between home to school, school to plaza and finally from plaza to home; By doing this, we could identify all the different fluxes throughout the day and mapped which routes are the most critical.

4.1. From Home to the School

In order to find the best routes in this study, we used the data held by the Barcelona City Council to analyze the "betweenness" between homes (Origin points) and schools (Destination points) in a 500-meter radius.

The figure below shows that there's a variety of routes that can be taken in order to transit from homes to

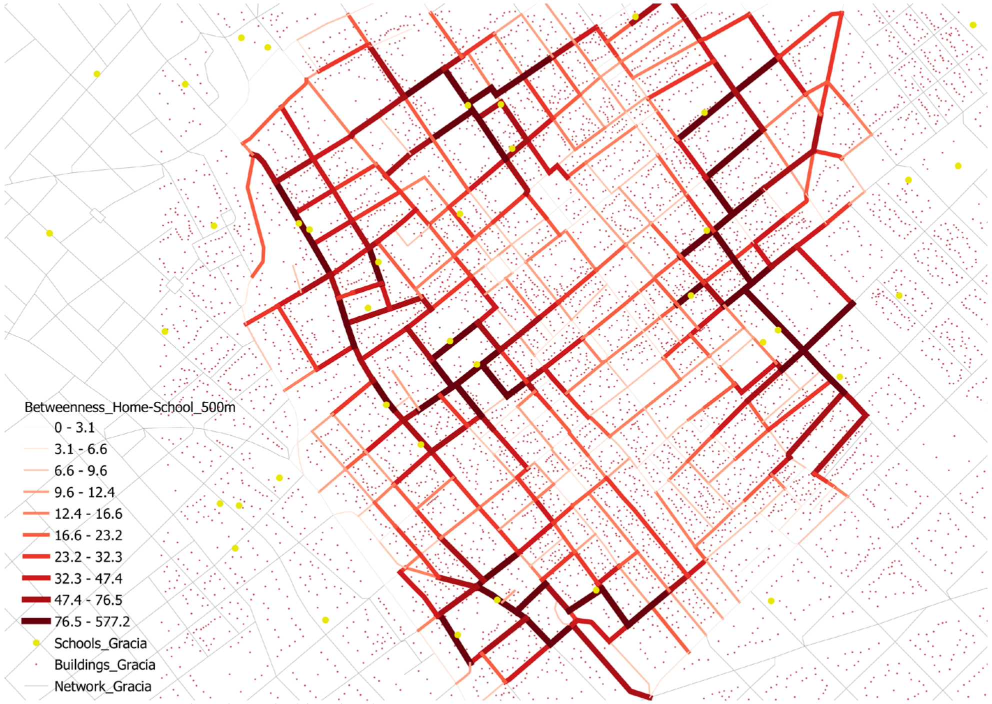

Fig 2. Betweenness analysis households-schools

Fig 3. Betweenness analysis schools-places [squares]

schools so naturally, most of the streets in Gràcia appear to be mapped in the analysis as possible routes because we have a high quantity of Destination points (homes) although the majority of schools are located near the perimeter of the neighborhood, so the critical routes tend to be perimetral as it is expressed in the map.

4.2 From the School to the Plaça

The case study has a particularity within the city of Barcelona since this neighborhood has a high quantity of plazas (18) in comparison to its area, (4.19km2) exceeding the average of plazas/area within the metropolis. This benefits the daily lives and reinforces the development of the children, because as mentioned above, after the kids leave school, the plazas are usually the favorite destinations for walking, playing, or eating something. The lack of spaces like this in bigger cities, is one of the usual reasons why many people who live in highly urbanized zones tend to move to the suburbs to raise their children, but Gràcia opens up its plazas for its smaller citizens whilst giving the benefit of living in the heart of the city.

This particular case omits certain variables that depend on the interests of the families that usually go to these sites, among which we could mention, whether or not the plaza has a green area, friends, the liking of certain restaurants, water fountains, etc. In this way, we can say that the squares that are mapped with the greatest flows in this analysis are the ones that family groups attend due to their proximity.

The results of the analysis show that Plaça del Sol, Plaça del Nord, Plaça de la Revolució, Plaça de la Virreina and Plaça de la Vila de Gràcia, are the ones with the higher fluxes based on their betweenness using distance, proximity, and size as the main parameters. In this case the origins (schools) are much more limited in comparison to the first analysis, so there's less streets that are mapped as possible routes because the closer people are to the destination, the fewer possibilities of alternate routes they have.

4.3 From the Plaça to Home

Finally, the case study finds the most recurrent routes between the plazas and the houses; considering that in this case the same thing happens as in the first one, to go home the shortest route is sought. The study does not consider the different activities that may arise on the journey, such as: grocery shopping, accompaniment between friends or journeys that do not involve a direct relationship between the plaza and home. In this way, the analysis only contemplates the direct routes between these sites.

The results shown in Fig.4 show a concentration of flows in the center of Gràcia, due to the location of different plazas in this area, which is the opposite result from the first analysis where the trajectory from home to school was mostly perimetral, going back home from the plazas has a more central distribution within the neighborhood. The routes with the highest flows are found in the streets of Verdí, Torrent de la Olla, Travessera de Gràcia, Terol, Perla and Or.

4.4. The Patronage Value of the Plaça

The find patronage tool is used to predict visitation to destination facilities from a network, which in this case are the plazas. The value assigns probabilities for trips from each Origin point to each Destination facility based on how accessible the destinations are. The attractiveness attribute of each Plaza describes any measurable quality that has a positive effect on the space and in this case, we only considered the size of the plazas in the attractiveness index. (Sevstuk, 2022). We wanted to see how the patronage value from the plazas was calculated since our only parameter in the attractiveness index was size and it only became clear that the data was missing more important factors to take into account when measuring the attractiveness from the plazas in Gràcia such as restaurants, fountains, playgrounds and etc. because it only marked the bigger plazas as more accessible which is not entirely true in reality. It would be interesting to compliment the data with the beforementioned parameters in order to get more realistic results but for the exercise's sake we used these values to understand the possibilities and limitations of this tool.

Fig 4. Betweenness analysis squares [places]-households

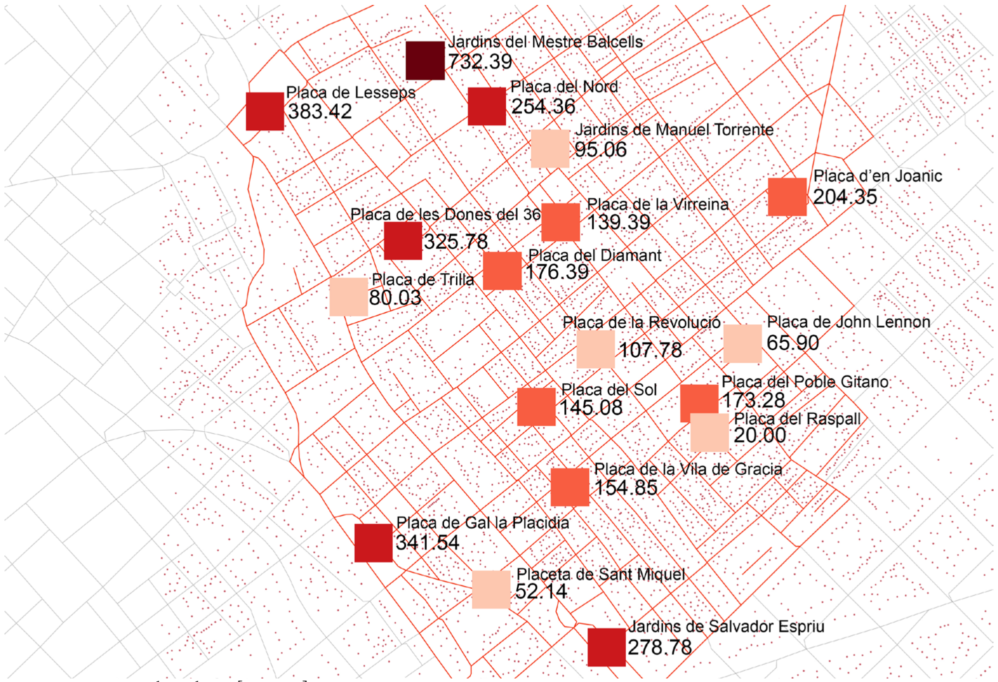

Fig 5. Patronage value places [squares].

5. Conclusions

The UNA toolbox provides a set of instruments that are helpful to analyze the different flows that take place in the city in order to understand the patterns that are involved in the daily urban dynamics. It is important to consider that the more data and different elements are considered, the results will be more precise and in this case study we only focused on the Patronage Betweenness to measure how many trips are likely to pass different network edges based on the set of trips of Origins and Destinations to identify the critical routes found in the triangulation between Home-School-Plaça.

By mapping the housing buildings, squares, and schools, it was possible to find the most travelled routes by children who are accompanied by at least one adult, in such a way that the map represents greater flows with a thicker line and darker color. By understanding the daily mobility patterns of a sensitive group such as the younger citizens, we realized that the morning trips from home to school tend to be in the perimeter of the neighborhood whilst the trips in the afternoon are usually more central. These toolset and analysis provide the necessary information to know which areas require improvement and interventions in order to provide a better environment for the children during their daily mobility routes by taking advantage of the data available, in order to keep improving our cities by understanding how people interact in them.

Acknowledgments

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TEAM 3:

Álvaro Clua
Joan Martí Elias
Francesc Valls

Walking the hills. Analysis of the walkable network around existing and planned L9 metro stations in upper Gràcia, Barcelona

Álvaro Clua, Francesc Valls and Joan Martí Elias

1. Context
The area of Barcelona comprised between *Tres Turons* (the Three Hills) and the north of the Gràcia neighborhood is characterized by a high-density urban fabric that faces a very steep topography. This fact arises serious mobility problems, both on a small scale within the neighborhood and in the metropolitan context.

Historically, this mountain was the natural limit of the population of Gràcia, an independent municipality that was absorbed by Barcelona in 1897. The streams coming from its topography have structured the natural connection between Gràcia and the city, which is woven by the vertical traces of water. This boundary condition granted a peripheral character to this area during the urban growth experienced throughout the 19th century. While the large residential buildings were built in the Eixample, this area was filled with second residences and garden houses. One of the most representative examples of this situation is the Park Güell project designed by Antoni Gaudí and conceived by Eusebi Güell, which was supposed to be a new low-density area for several villas along the top of the hill called *Muntanya Pelada* (bare mountain).

In the post-war period, this area, which had always maintained a peripheral character, began to be occupied by informal settlements. With the waves of immigration in the 1960s, it was consolidated with the construction of large residential buildings, despite the difficulties presented by the topography to inhabit and occupy this area. The popular novel *Útimas tardes con Teresa*, by Juan Marsé (1966), precisely chooses the mountain neighborhoods to talk about the informal city and the suburb, collecting the testimony of the imagination of a neighborhood built on the top of the hills, but facing back to the city. With the arrival of democracy, Barcelona's municipal government has reversed this imaginary, integrating the mountain neighborhoods into the city. This has been carried out through, among others, multiple public space projects that eased the cohabitation of density with the topography, such as the construction of urban escalators, and the reform of the main squares such as Lesseps or Plaça Sanllehy, gaining back space for pedestrians and ensuring multiple connections within the mountain districts.

It is in this context that, with the attempt to link several points with low metropolitan connectivity and reversing the original radial approach of the Metro network, at the beginning of the 21st century the construction of Line 9 of the Metro was discussed, understood an urban railway deep underground that would connect Santa Coloma de Gramanet with the Airport, providing service to the entire northern area of the city. The ambition of the project, as well as the technical difficulty derived from drilling rocky substrates and political discrepancies, have stretched this debate until today. For now, the extremes of this line have been executed, and the construction of the central section, which precisely occupies the scope of the study, remains pending. However, over the years the number and location of the new metro stations have changed, and an area that was originally supposed to be served by three stations (Lesseps (connecting with L3), Muntanya and Plaça Sanllehy) will finally have only two, coinciding with the recently renovated squares (Lesseps and Sanllehy). This is a particularly sensitive debate, as it is an area where the topography plays a key role in pedestrian mobility, in a densely populated area with quite an ageing population and, also, a very attractive point for tourists visiting Park Güell.

This work aims to present evidence on the impact of topography on the catchment area of the metro stations

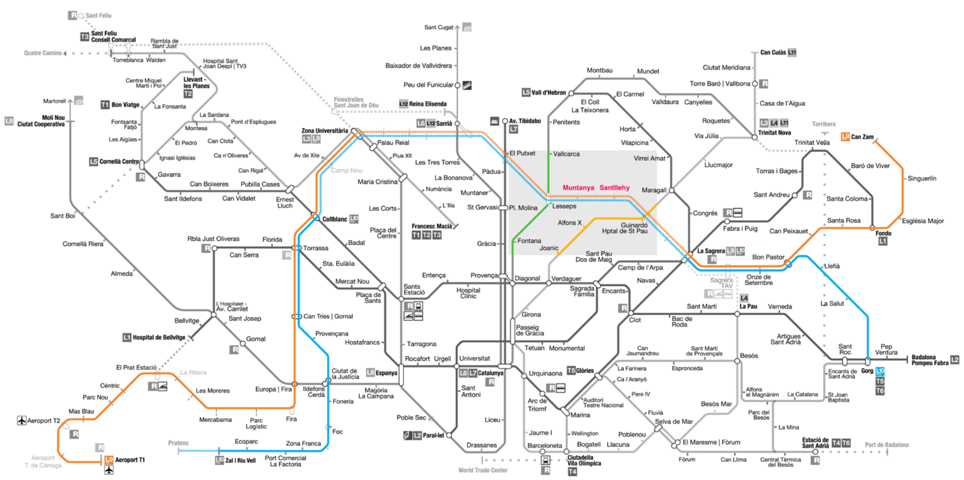

Fig 1. L9 metro line (orange) within the metro system of Barcelona. The original project included Muntanya and Santllehy stations between Lesseps and Guinardó/ Hospital de Sant Pau. The updated version discusses the need for Muntanya station. Source: elaborated by the authors from the original metro map (TMB, Barcelona)

in hilly contexts such as upper Gràcia and to evaluate the consequences for pedestrians of deleting the Muntanya L9 metro station. To do so, the project uses Urban Network Analysis toolbox for Rhino to model and evaluate people's movement within the existing sidewalks according to three key scenarios:

> *Current Scenario*: Present situation of the metro stations within the studied area. This comprises the Lesseps and Fontana stations (L3, green line), and Joanic, Alfons X and Hospital Sant Pau stations (L4, yellow line).
>
> *Scenario 1*: Original project of new L9 line with four new stations in the studied area. Two of them (Lesseps and Hospital Sant Pau) are exchange stations with L3 and L4. The other two -Muntanya and Santllehy- are new stations located in the vicinity of Ronda del Mig avenue.
>
> *Scenario 2*: Amended project of new L9 line with three new stations. Two of them (Lesseps and Hospital Sant Pau) are connecting stations with L3 (green) and L4 (yellow). The station of Santllehy is a new one. Muntanya, in turn, has been avoided in this scheme.[1]

2. Source data

The station locations were introduced manually using OpenStreetMap (OSM) and Google Maps as a reference. Since stations were modelled as single points, the most representative entrance in terms of pedestrian traffic for each station was chosen for the existing stations, while for planned stations the expected location of the entrance was deduced from available information. The coordinates of these points were recorded in a table using the EPSG:4326 geodetic coordinate reference system (CRS), along with their name. The points were then projected into the EPSG:25831 projected CRS that corresponds to the Barcelona area.

The combined buffer geometry of the points was computed to define the area of study. Because the indented maximum walking time to the stations to analyze was 15 minutes, an empirical walking distance of 0.9 m/s was assumed. This average speed considered the time required to cross streets, reducing the speed from the standard 1.42 m/s. This speed translated to about 800 meters in the equivalent distance in flat terrain, but a radius of 1200 meters was chosen to ensure a sufficient margin to avoid edge effects and also to accommodate the possibility of travelling further than 800 meters when walking downhill.

The network sidewalk data was downloaded from OSM, within the bounding box of this area of study. Using the QGIS QuickOSM plugin, polylines representing the sidewalk network have been downloaded, namely those with a "highway" attribute equal to "footway", "living-street", "pedestrian", "residential", or "steps". The result is a coherent sidewalk network within the studied area, although -since it is a collaborative map- this method contains relevant mistakes in less central areas or complex open spaces. In recent research by the authors, a workflow has been developed to model a high-resolution network of the sidewalks of Barcelona integrating spatial data such as width or slope.[2]

The dwelling locations were downloaded from the open data available from the Spanish Cadaster, which has freely accessible data adhering to the INSPIRE[3] directive to accessing European spatial data. This data consists of the parcel and building footprint geometries, and includes an attribute that corresponds to the estimated number of dwellings per parcel. These counts are derived from ownership data, and exhibit some inconsistencies because may count a building with multiple rental apartments as a single dwelling because it has a single owner. Despite this limitation, the property structure in Spain rarely includes the case described,

[1] https://beteve.cat/mobilitat/estacions-pendents-tram-central-l9-metro-mapa/
[2] Valls and Clua, 'Modeling Barcelona Sidewalks: A High-Resolution Urban Scale Assessment of the Geometric Attributes of the Walkable Network'.
[3] https://inspire-geoportal.ec.europa.eu/

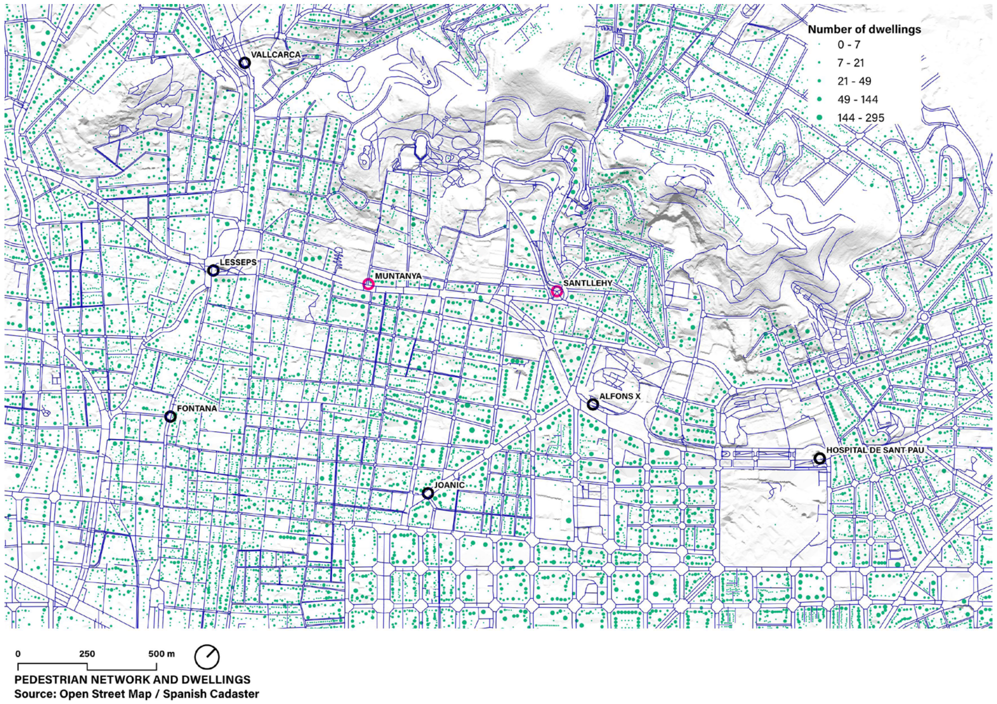

Fig 2. Topography (DEM map), sidewalk network (dark lines) and dwellings (circles) in Gràcia and neighboring urban tissues. Source: elaborated by the authors. Data retrieved from ICGC, OpenStreetMap and Spanish Cadaster

and therefore the data is accurate enough, in particular at the intended scale of analysis. The cadastral data was downloaded using the QGIS plugin[4] "Spanish Inspire Catastral Downloader", and included data on around 70,000 buildings that included almost 700,000 dwellings in Barcelona. Of these buildings, around 22,000 were within the area of study, including almost 200,000 dwellings.

The Digital Elevation Model (DEM) data were downloaded from the Cartographic and Geological Institute of Catalonia (Catalan mapping agency) using the "Open ICGC" QGIS plugin.[5] The DEM was downloaded as a GeoTIFF at 5-meter pixel resolution for the complete area of Barcelona, because the maximum resolution available of 2 meters was not required, and oftentimes has more interpolation artefacts. Since the interest was on height instead of the slope, the lower resolution was considered sufficient and more adequate for the analysis. In addition, the lower resolution data was more recent (2020), compared to the 2008-2011 period of the higher resolution data. The raster was then cropped to the extent of the area of study to reduce the processing time.

3. Pre-processing steps

Because UNA requires point features for origins and destinations, the cadastral building footprints were reduced to their centroid, imposing that the centroid was located inside the geometry of the corresponding polygon. The DEM data were used to assign the height to the z coordinate of each centroid using the v.drape tool from GRASS GIS, using bicubic filtering for the interpolation. Likewise, station point features were also assigned the corresponding height from the DEM.

With the draped point collections, a new field was created with the height information extracted from the z coordinate. This information was processed in an R script to compute a cross-join between the dwellings and the stations, resulting in 174,040 combinations of origins and destinations (8 stations, and 21,755 buildings). In each of the combinations, the height difference was computed, and the travel direction in the direction towards the station was encoded as an integer. The matrix was then converted into a wide format, with one building per row, and all height differences and directions in columns with the corresponding connecting station name. Finally, the data was exported as GeoJSON for further processing in UNA within Rhinoceros.

The network data was first processed with a CAD workflow, consisting in using the join tool on the line geometries, followed by the intersect tool to find the overlapping points of intersecting geometries, and finally using the split tool using the points to split the joined line geometries.[6] However, this operation did not produce a clean topology useful for network analysis. Therefore, the raw geometry from OSM was first processed using a dissolve operation in QGIS (equivalent to the join tool in CAD), followed by the GRASS v.clean[7] command, which includes a comprehensive toolset for cleaning the topology of the vector map.

To compute the network weights, the segments were first draped onto the DEM to assign the corresponding height to each of the vertices. With the draped heights, a height difference was computed as the absolute value of the highest and lowest z coordinates in each segment. The network weights were derived from this height difference, adjusting the actual geometric length depending on the travel direction. This approach is not entirely accurate, as the slope of each network edge is almost always not constant, and therefore the cost should be integrated along the length of the edge, to summarize a single weight for the total span of the segment, but was considered representative enough for the case of study.
In the case of the downwards direction, the height difference was subtracted from the length (in the same metric units) reducing the weight, while in the case of the upwards direction, a penalty of four times the

[4] https://plugins.qgis.org/plugins/Spanish_Inspire_Catastral_Downloader/
[5] https://plugins.qgis.org/plugins/OpenICGC/
[6] Sevtsuk, Urban Network Analysis for Rhinoceros 3D. Tools for Modeling Pedestrian and Bicycle Trips in Cities.
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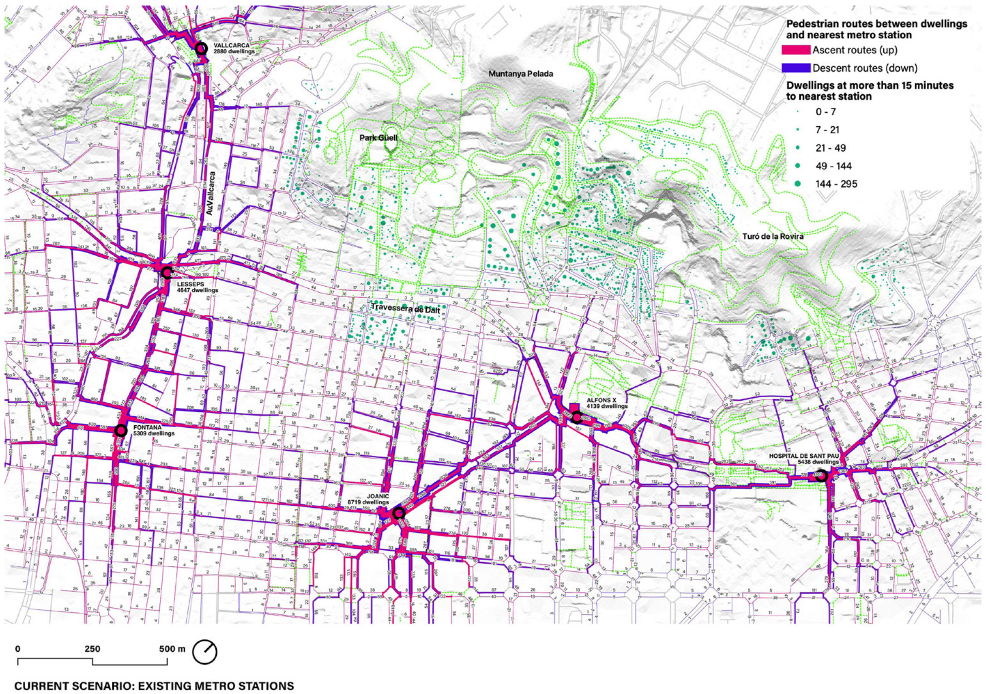

Fig 3. Current scenario. Existing metro stations. Representation of walking routes between metro stations and dwellings at a 15-minute walking distance. Source: elaborated by the authors using the UNA tool for Rhino

height difference was added to the length. The results were exported as a GeoJSON file including both weights, with the objective that in UNA each of the network segments could use the corresponding weight depending on whether the destination was higher or lower than the origin.

4. Methodology

Considering the influence of the slope in network calculations has the limitation that the time to walk a sloped route depends on the direction of travel, and therefore requires two weights depending on whether a segment is traversed in the forward or backward direction. It was therefore required to model the network within the constraints of the model used in the software as an undirected graph with a single weight for both directions of travel.

This limitation was approached by constructing two variants of the network, with the weights corresponding to the upwards and downward directions respectively, and conducting the analysis separately for each of the eight stations. This approach was only feasible because of the reduced number of stations, for which the calculations were run twice in each of the network definitions, and because it was possible to select and aggregate the results of the computation for each of the building-station combinations. A height differential (Δh) was derived from the absolute value of the height difference between the highest and lowest vertices in each segment. The weight in both directions consisted in the planar length of the linestring, but adding four times the Δh in the upward direction, while subtracting the Δh in the downward direction.

In the analyses, the buildings were snapped to the nearest network edge when they were within a 100-meter distance. In the case of stations, it was necessary to use the function "unaBindEdge" to manually attach some stations to a specific edge to avoid a bug in the calculation.

4.1 Service area

After building the network, for each network variant, the destination points (buildings) were added to the network, because they were the same for each of the stations, while the origins (stations) were selected for each run. The service area calculation was run for each of the stations, and after the calculation finished, a numeric attribute was assigned to the selected destinations and network edges, with the name of the attribute denoting both the direction and the destination station. Therefore, reachable buildings had a value of 1 if they were reachable from a particular station in a specific direction, and none if they were unreachable. The calculations required around 4 minutes per station, for a total computation time of around one hour.

After all runs, the geometries were exported to GeoJSON for further processing in R, separately for points and lines. The results were joined with the table with the precomputed height differences, to be able to differentiate whether the results in the upwards or downward direction should be used, discarding the one not applicable, as both directions were mutually exclusive.

With the results, a redundancy index was computed which consisted of the number of stations that served each building within the specified network distance, in each of the three defined scenarios. Having the data separated per station allowed more flexibility in defining different scenarios as the research progressed, without requiring running the calculations every time there was a change in their definition.

4.2 Betweenness

With the same approach as with the service area calculation, the patronage betweenness tool was also run for the two network definitions with weights in the up and down directions, and individually for each of the stations as a destination. Since the betweenness is an aggregate sum of the number of shortest paths flowing through a specific edge, it was possible to add the results of the different calculations.

The origin weights were set to the number of dwellings in each building, while the same weight (count) was assigned to the destination weights. The detour ratio was set to 1, to avoid increasing the calculation time

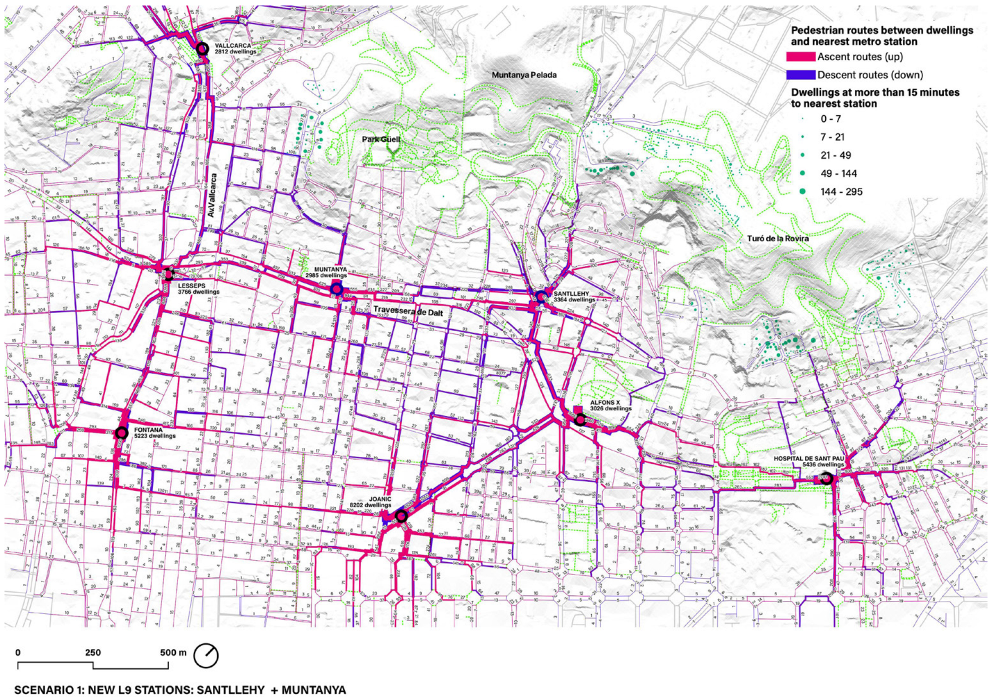

Fig 4. Scenario 1: construction of the new L9 metro including two new stations: Muntanya and Santllehy. Representation of walking routes between metro stations and dwellings at a 15-minute walking distance. Source: elaborated by the authors using the UNA tool for Rhino

excessively. The model used exponential decay but without considering gravity accessibility because there were no competing destinations as each calculation was independent of the other, and for the same reason the nearest option was also disabled. Each iteration finished in 5 minutes, and the complete set was completed in around 1.5 hours.

The results were also saved as a numeric attribute in the edges, with the same convention of the name including the direction and the destination station name. The results were exported to GeoJSON for further analysis and representation of the results in QGIS. The results had to be represented as the width (or color) of the network segment, and therefore the flows were aggregated in both directions, for the cases involving the stations considered in each of the three scenarios.

4.3 Patronage

The "find patronage" tool was used using the buildings as origins (with their number of dwellings as weights) and the stations as destinations. The analysis was conducted twice, once in the upwards direction and the other in the downward direction, for the three scenarios, sequentially removing first the "Muntanya" station and then also the "Santllehy" station. The calculations finished in around three minutes, with a combined calculation time of 20 minutes, and the results were copied to the clipboard and then transferred to a TSV file.

The "find patronage" tool was used using the buildings as origins (with their number of dwellings as weights) and the stations as destinations. The analysis was conducted twice, once in the upwards direction and the other in the downward direction, for the three scenarios, sequentially removing first the "Muntanya" station and then also the "Santllehy" station. The calculations finished in around three minutes, with a combined calculation time of 20 minutes, and the results were copied to the clipboard and then transferred to a TSV file.

The combined patronage results for the six analyses consisted in around 85,000 rows that were processed using an R script. Using the relative height of each origin and destination pair, the appropriate patronage value in the direction of travel was selected, and the results were aggregated for each of the stations in each of the three scenarios considered.

5. Results

By using the previous workflow, three new interpretative maps have been produced representing the three scenarios. Each map shows, firstly, the location of the stations and the catchment network at a 15-minute walking distance (at 0,9m/s mean speed) from the dwellings to the nearest station, and routes from the stations to nearby dwellings. This distinction makes it possible to highlight the differences between ascending and descending itineraries, which is a key aspect of the context. A description of the results is given here below.

Current scenario: existing metro stations.

The pedestrian flow model shows the distribution of itineraries between homes and metro stations through the sidewalk network. Numbers in each segment represent the total number of dwellings linked to each itinerary. The map also provides a dual representation of the routes: in red, are the ascending itineraries to the stations and the dwellings; in blue, descending routes are represented. This is useful to provide high-resolution calculations of walking catchment considering topography. For this model, no consideration of escalators has been included.

On the other hand, green lines are sidewalks which are not used for the previous itineraries, either because they are off the main routes or because they are further than a 15-minute distance on foot. These yellow sidewalks are mainly located around the Park Güell, within the central section between the Lesseps (L3) and

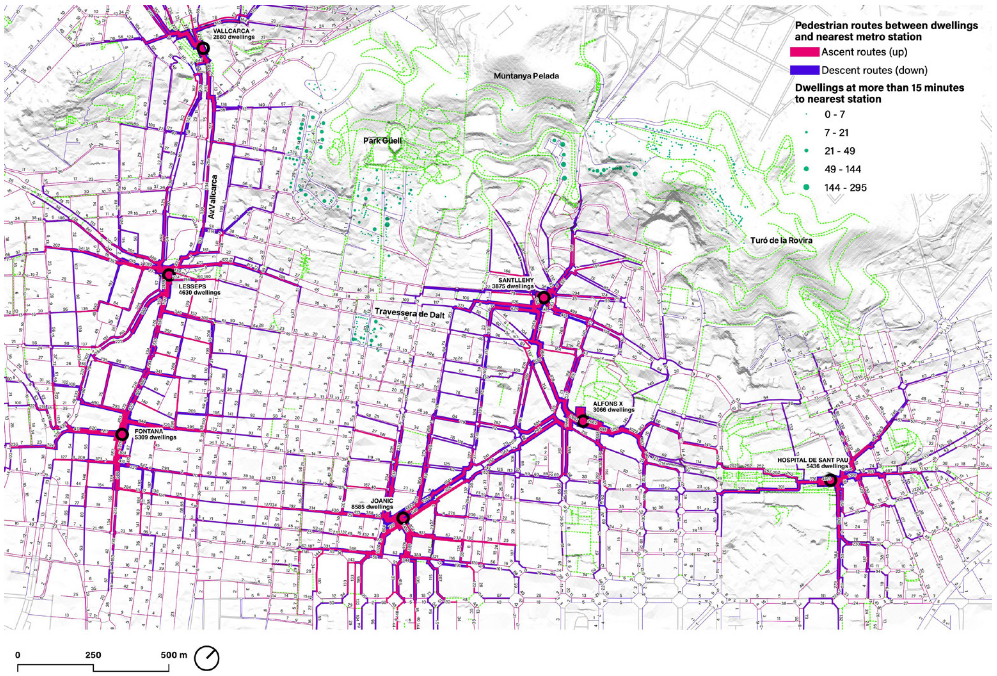

Fig 5. Scenario 2: New version of the project of the L9 metro including only Santllehy station (Muntanya excluded). Representation of walking routes between metro stations and dwellings at a 15-minute walking distance. Source: elaborated by the authors using the UNA tool for Rhino.

Alfons X (L4) stations, as well as in the vicinity of the Turó de les Bateries. This accounts for 9,293 dwellings without proximity to stations (considering ascending routes), a fact that promoted in 1999 the creation of 'neighborhood' buses to take people to the metro, markets and care centers.

Finally, the simulation also makes it possible to observe asymmetric distributions of pedestrians on the sidewalks of the same street. For example, the degree of continuity of the network geometry leads to situations such as the initial section of Av. Vallcarca where there is a 1:20 ratio between the sidewalks on each side or 1:2. in Ronda del Mig in some of its sections.

Scenario 1: Original project with two new metro stations: Muntanya and Santllehy
Scenario 1 was designed to provide high coverage of metro stations within this area. As figure 3 shows, 2047 dwellings within the studied area are still at a distance higher than a 15-minute walk (considering ascent routes). The allocation of Muntanya and Santllehy stations almost covers the dwellings on the slopes of Muntanya Pelada, Turó de la Rovira and Park Güell mountains.

More specifically, the Santllehy station provides renewed accessibility to 3364 dwellings, reducing the affluence to Alfons X around 27% of the people accessing the station according to the model. Muntanya station, in turn, might not be only a key access point for the Park Güell tourist attraction but also a relevant station providing quick access to the metro station for central Gràcia. Providing less than 15-minute access to public transport should be considered a substantial improvement for the efficiency of the city, even more in upper Gràcia, where existing metro stations are today located at around 500m and within the neighborhood's boundaries. Providing two new stations in the hilly area of Gràcia would therefore provide better accessibility with stations in a higher position.

Scenario 2: New version of the project without Muntanya station.
The current project for the L9 metro line proposes the elimination of Muntanya station. Beyond the technical details that might justify the complexity of the location of this station, the fact is that it will have a clear effect on accessibility. Following the results published in figure 4, the new layout will still provide close accessibility to dwellings on the slope of Turó de la Rovira (Santllehy station) but around 2,471 dwellings will still be further than 15 minutes from the nearest station. The difference between the previous scenario is indeed 424 dwellings and this number might not be enough to promote the construction of a new station, hence the final decision of the authorities. However, as mentioned, Muntanya station was meant to cover also the accessibility to Park Güell and, to Larrard CUAP Gràcia Care center and Hospital de l'Esperança. As it might be imagined, the role of this station should be understood not only as a reference for dwellers within the central area of Gràcia and upper Gràcia but also as a mass-transit mode of transport for visitors and people accessing the aforementioned facilities.

Finally, the high-resolution model also shows the role of some sidewalks like the one at C/ Mare de Déu de la Salut, fairly horizontal streets which would be highly activated by pedestrians' routes accessing Santllehy station. In turn, Travessera de Dalt does not point out in the model, as that station is located at a different location, thus leaving the avenue in a secondary position. These insights might help to inform new urban actions to enlarge or maintain the existing sidewalks using evidence-based data based on pedestrian movements.

6. Discussion

The *Urban Network Analysis* tool has provided relevant evidence-based data for evaluating the impact of the location of the metro stations in the city. The capacity of discriminating by ascending and descending routes is a valuable tool for computing real catchment areas, especially in hilly contexts such as the one in Gràcia. The tool seems a powerful and consistent way to understand the pedestrian flows without the costly effort of manually counting people, thus allowing a quicker way to assess the urban transformation of sidewalks and, also, to evaluate the impact of alternative scenarios.

However, some limitations of the model and research should be acknowledged. In our research, a framework of a 15-minute walk has been used, a consideration that is inspired by the urban discussion on the 15-minute city model widely spread by recent studies and experiences.[8] However, it must be admitted that this might be considered a too-long walking distance when analyzing accessibility to and from metro stations in compact cities. Nonetheless, although new calculations at lower time distances might help to better illustrate the pros and cons of each scenario, general insights should prevail.

For the analysis, the role of activities, greenery, shadows or crosswalks has not been taken into account. As we know, these are relevant elements that deeply influence route choice preferences.[9] For example, the analysis does not take into consideration the role of crosswalks in the itineraries, although they usually provide an extra-time for walking itineraries. However, as it has been mentioned, the tool includes the "detour" functionality, which is very unique among spatial network analysis tools, and allows modelling more faithfully the actual behavior of users in urban networks, despite its computational cost. By this function, not only more direct itineraries are considered, but also others that may be followed by pedestrians within a given detour ratio.[10] This function, which was not selected in this study for computational speed limitations, is suitable for tracking routes that do not necessarily match the shortest path and might be influenced by the conditions of the sidewalks or user preferences.

From a pedagogical and professional point of view, it should be noted that the UNA tool is a relevant tool for analyzing urban networks. Its integration with a state-of-the-art and widely used CAD tool allows using its powerful editing commands and avoids the complexity of GIS tools that constitute an initial barrier to the adoption of quantitative methods in urban research. This is particularly beneficial in educational contexts, where the students are already comfortable with Rhinoceros3D, and in most cases are familiar with its Grasshopper parametric programming environment. In addition, the toolbox models very accurately the requirements of network analysis from the urban planning perspective, with a selection of tools focusing on specific aspects of analysis which provide sensible defaults for its options, resulting in a powerful but flexible toolbox.

Nonetheless, although the UNA tool offers also multiple options for advanced users, in our case, it was not possible to easily automate the development of multiple variations in the analyses, for example running the same analysis with different parameters. This limitation -which might have been addressed by accessing the source code of the tool- was solved in this research using the extensive export functionality, and the analyses were completed using a combination of R scripting and GIS.
Finally, it must be mentioned that the UNA tool is mainly based on an origin-destination matrix. This is very useful to analyze specific sorts of movement such as the mobility from dwellings and metro stations, or vice-versa. However, the result should not be considered a complete expression of pedestrian movements in upper Gràcia, as other important origins and destinations might be taken into account, such as the tourist attractions, movements from dwellings to services and public facilities, walking itineraries to other means of transport or also strolling as a sport activity without a clear destination provided. This raises the open question if a more comprehensive or realistic pedestrian model is or should be possible. From our perspective, this is not fully achievable, given the complexity -and many times hazardous- conditions of movement

[8] Carlos Moreno et al., 'Introducing the "15-Minute City": Sustainability, Resilience and Place Identity in Future Post-Pandemic Cities'.
[9] Sevtsuk et al., 'A Big Data Approach to Understanding Pedestrian Route Choice Preferences'; Basu and Sevtsuk, 'How Do Street Attributes Affect Willingness-to-Walk?'
[10] Sevtsuk, 'Estimating Pedestrian Flows on Street Networks. Revisiting the Betweenness Index'.

patterns. However, the UNA tool, and pedestrian network research in general, could help to understand why we choose particular routes and which is the quality of the sidewalk network system as critical urban movement infrastructure.[11]

In conclusion, the Urban Network Analysis tool is a very powerful toolbox that provides urban planning practitioners access to powerful network algorithms to model the movement through the urban fabric, either to understand its current state and identify its most critical points or to predict the changes of a future planned modification of its infrastructure.

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