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Variations of the grid

Multiscale evaluation of new pedestrian streets in the Eixample grid of Barcelona

Álvaro Clua; Universitat Politècnica de Catalunya. Laboratori d'Urbanisme de Barcelona;
alvaro.clua@upc.edu

ABSTRACT

Over the past decade, the necessary responses to the urban climate crisis and the application of new models of proximity have promoted the re-design of public spaces towards a more pedestrian-friendly vision. Cities like Barcelona have gained international prominence after the conceptualization, implementation, and dissemination of the so-called "superblock" model.

Beyond the local political and social discussion that has arisen both in the ideation and in the construction phase, these transformations have strongly impacted the layout of the Eixample Cerdà grid, by changing the section of some streets. Indeed, these re-urbanizations might be regarded as the crystallization of a wider plan aimed at promoting the progressive pacification of some streets of the grid, to provide more space for pedestrians, greenery, and calm activities. This has been built upon the idea of banning through traffic and the extensive implementation of shared surfaces.

In the following paper, we present an evaluation of the spatial configuration of these transformations at different scales. Firstly, we compare the general vision of the plan with the Betweenness Centrality (local and global values) of the street network of the whole Barcelona metropolis, observing correlations with the planned new pedestrian areas.

The second part of the research provides a zoom-in analysis of the sidewalk configuration of Consell de Cent Street, one of the latest re-urbanizations. The research uses visibility graph analysis to compare the spatial attributes before and after the transformation, thus highlighting the impact of the change in the movement patterns and the new distribution of convex spaces within that particular area of the Eixample Grid.

KEYWORDS

sidewalks, public space, visibility graph analysis, isovists, Barcelona

1 INTRODUCTION

The grid designed by engineer Ildefons Cerdà in 1859 for the reform and expansion of the city of Barcelona is now a reality. For more than 150 years of history, the Eixample grid has been developed according to the layout envisioned by him. The result is more than 340 kilometres of linear streets and around 900 blocks allocating a rich combination of uses and activities (Busquets and Corominas, 2009). Cerdà designed the streets with 5m-wide sidewalks on each side, 10m-wide road surface, and trees every 8 meters (Cerdà, 1863), a prototype that is currently an icon of Barcelona's urban identity and also a way of creating urbanity even beyond the limits of the grid.

Throughout its history, the 5-10-5m original street model has been continuously adapted to incorporate new mobility demands, new ways of using public space, new urban services and infrastructures, as well as updated responses to climate change effects. In the last months, several reforms have been implemented under the concept or motto “Barcelona Superilla” (Superblocks). Beyond the theoretical and political discussion about the relevance of the initial concept proposed for a grid like the Eixample (Rueda, 2018; Mueller *et al.*, 2019), the fact is that some of the ideas drafted in that model are now built realities and, therefore, empirically verifiable.

Among them, it is worth highlighting the tactical and complete pacification around the Sant Antoni Market area or, above all, the recent pedestrianization of Consell de Cent Street and some sections of Girona, Comte Borrell, and Rocafort Streets. This transformation has been called the "green axes" and involves the redevelopment of these existing streets into shared platforms, the expansion of the tree pits, the relocation of urban services and, above all, the reconfiguration of the vehicle traffic to avoid thoroughfares across this area. Beyond the specific details raised in this new project -like the allocation of accesses, the new areas for parking and goods distribution, or the strong effects on gentrification and land uses-, this urbanization proposes a different and seemingly antagonistic geometric factor compared to the original model: pedestrians will no longer be walking just on the sidewalks by the facades, but they will be encouraged to use the centre of the street section, as declared in the intentions of the winning project that preceded the transformation of Consell de Cent (Cierto Estudio, 2022).

On the other hand, these urban transformations are not the result of just an acupuncture intervention, but they are part of a more ambitious urban plan for the pacification of existing streets in the following years, and promote the gradual reduction of vehicular traffic within the grid (see Figure 1, www.barcelona.cat/pla-superilla-barcelona/ca). The selection of new pedestrian axes or ‘green axes’ is addressed both as a top-bottom decision influenced by the overlapping of even green infrastructure on the grid and also as an opportunistic transformation to work directly on streets with less traffic pressure. This double decision might lead to some possible contradictions or mismatches, as some new pedestrian streets might be part of the main streets in terms of through-movement patterns.

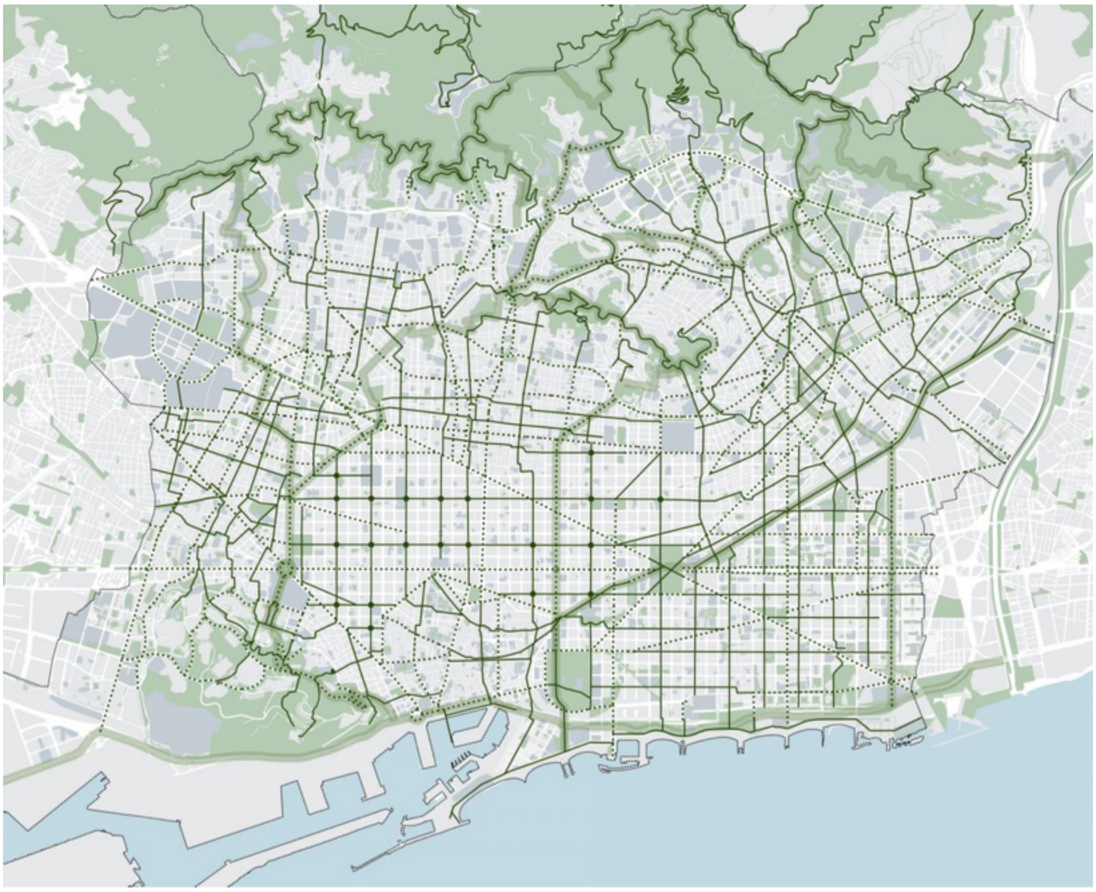

Figure 1: New 'Green axes' of the Superilla Barcelona Plan, Ajuntament de Barcelona. For this study, only the pedestrian priority green axes have been taken into account (dark green continuous line). Source: *https://ajuntament.barcelona.cat/superilles/es/superilla/eixample.*

All in all, if all these recent transformations are observed from a spatial configuration perspective, two questions might arise at different scales. Firstly, at the large scale, the question might be: *Do the Betweenness Centrality values of the grid match with the selection of pedestrianized street segments described in the 'Superilla Plan'?* Secondly, at the micro-scale: *What relevant spatial changes and pedestrian movement patterns do the recent transformation of Consell de Cent 'green axis' promote?* To answer these questions, this research evaluates the 'Superilla Plan' using *space syntax* methods and the Consell de Cent area using *visibility graph analysis* as a measure of accessibility (knee-level).

2 LITERATURE REVIEW

This study is based on four major groups of previous research. The first explores the use of space syntax methods to evaluate regular *urban grids*. Among them, the works of Haq and Berhie (Haq and Berhie, 2015, 2018) stand out, particularly in the study of regular North American cities such as Lubbock or Pittsburgh. While confirming the validity of angular choice for grid-like cities, the authors also confirm the mismatch between centrality and the location of activities, a key feature that, in turn, has been widely confirmed for organic grids (Hillier, 1999). The contributions of Al-Sayed *et al.* comparing the urban evolution of Manhattan and Barcelona's grid are also notable, as they parametrize the impact on *Angular Integration* values of some geometry variations such as Broadway Avenue in New York or Parc de la Ciutadella and the diagonals in Barcelona's grid. Although a uniform grid might lead to the foreseeable allocation of most central and accessible areas within the geometric centre, their work also explains how adjacent old organic structures influence the attributes of the accessibility values of the regular grid (Al Sayed *et al.*, 2009).

The second group of research encompasses studies on *public spaces* using *Visibility Graph Analysis*. This approach is based on the analysis of geometry parameters retrieved from isovists or viewsheds and allows the creation of high-resolution accessibility maps, providing insights into the most visible points, potential routes, or less integrated areas. This calculation can be performed using software such as *Depthmap* (Turner, 2001) or, more recently, *Isovists.org* (McElhinney, 2014). While these methods have been particularly relevant in indoor studies, such as museums and galleries (Tzortzi, 2003; Peponis *et al.*, 2004), working environments or hospitals (Penn *et al.*, 1999; Sailer and McCulloh, 2012; Sailer, 2021), and the study of dwelling typologies (Tahar and Brown, 2003), its application to the analysis of open urban spaces is gaining more attention (Campos, 1997; Batty, 2001; Guerreiro *et al.*, 2015; Psarra, 2018; Clua *et al.*, 2020).

The third group of references focuses on the study of *urban spaces in Barcelona* as its urban morphology exhibits a high level of compactness, a well-defined arrangement of open spaces, and a diverse range of urban layouts converging in the central area. Analysing urban spaces in Barcelona holds significance not only in light of the recognized success of its urban transformation since the 1980s (Bohigas, 1983; Miquel Martí, 2004; Capel, 2005; Rowe, 2006), but also because it remains at the forefront of the international discussion on the quality of life in cities today (McNeill, 2003; Turner, 2019). Local publications from the Barcelona City Council and the Barcelona Metropolitan Area (AMB), particularly those related to the upcoming Metropolitan Urban Master Plan (PDUM), exemplify the strategies and design principles guiding the construction of contemporary urban spaces. A range of designs and urban studies stand out, including squares in compact urban fabrics, new peripheral spaces that become places of identity for the community, coastal spaces, avenues and parks integrated as social and ecological "infrastructure" for the metropolis (Ajuntament de Barcelona, 2013; Guallart, 2015; Barcelona Regional, 2019), and of course, the recent 'Superilla Barcelona' transformations (AA.VV., 2021), which has been object of study from multiple perspectives (Gyurkovich *et al.*, 2019; Speranza, 2018). All these references might help to illustrate what, already in the last century, became the quintessence of what has been eventually called the "Barcelona model" (Acebillo, 1999; Capel, 2005; Delgado, 2005; Montaner *et al.*, 2014).

Finally, the study of those public spaces in Barcelona has been also approached through *network analysis* and *space syntax*. In addition to those already mentioned, it is worth highlighting works such as Millán's on the diachronic evolution of Barcelona's historic super grid comparing the centrality and intelligibility of its organic and non-organic parts (Millán *et al.*, 2012), the exploration of a *Visual Clustering Coefficient* map of central Barcelona to offer a graduated image of the spatial and visual qualities of the open spaces (Clua *et al.*, 2021) or, lately, the modelling and evaluation of the accessibility measures of the sidewalk network system (Clua *et al.*, 2022). None of these studies provides a focused analysis of the 'Superilla' model and the recent transformation of the streets of the Eixample Grid using space syntax tools and methods.

3 VARIATIONS OF THE GRID. PLAN VERSUS THROUGH-MOVEMENT

To address the study of the coincidences or mismatches between the *Betweenness Centrality* values of the grid and the selection of the new pedestrianized streets included in the 'Superilla Plan', a segment model of the whole Metropolitan Area of Barcelona has been generated. The model has been drawn based on OpenStreetMap's original centreline, merging road centre lines in one single segment and manually checking large open spaces. The model does not consider the real use of the street (pedestrians or cars), but only the essential geometry of the urban layout. It also takes into account the urban main discontinuities to establish its boundaries -such as the seaside or the largest mountain ranges (Collserola, Garraf and Marina)- following a more precise picture of the 'urban metropolis in continuity' (Parcerisa and Clua, 2014). The model also takes into account enough area around the Eixample grid to avoid significant edge effects (van der Laag Yamu *et al.*, 2021) (see Figure 2).

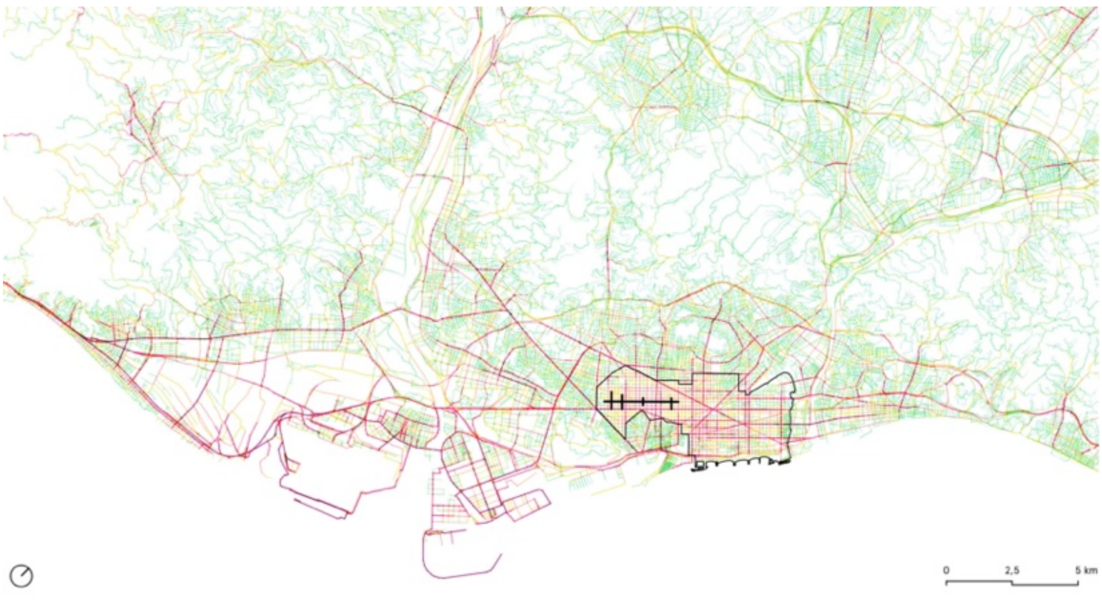

Figure 2: Segment model of the Barcelona Metropolis. *Normalized Angular Betweenness Centrality* or *Choice* (NACH) at a 5,000m metric radius. Elaborated by the author.

Later, the *Betweenness Centrality* was calculated at different metric radii using the *PST Plugin* developed by the Spatial Morphology Group (Chalmers University). All the analyses have been normalized using NACH (Normalized Angular Choice), to provide a more accurate picture of the through-movement and avoid some dysfunctions when measuring *Betweenness Centrality* in less integrated segments (Hillier *et al.*, 2012). The radii have been selected to approach different results according to different modes of transport and urban scales: (1) 50,000m metric radius (weighted by *Road Capacity* data provided by the City Council of Barcelona in 2018, and using angular distance). This measure collects all the routes within the whole model and, therefore, highlights natural movements at a global scale and gives significant correlations with real long-distance vehicular traffic according to similar research on this issue (Bazzoni *et al.*, 2018); (2) 5,000m metric radius (weighted by segment length to grasp better the absence of crossing points as decision-making feature, and using angular distance). This illustrates mid-distance movements, such as those made by bicycle at 20km/h in 15 minutes, which of course, points to the well-known deployment of the 15-minute city (Carlos Moreno *et al.*, 2021) and, in our case, also accounts a value close to the average trip done with the Bicing shared bike system of Barcelona (13,5 minutes); (3) 1250 m metric radius (weighted by segment length). This analysis aims to reflect local walking movements within the grid at a time distance of 15 minutes at 5km/h speed, a value which addresses proximity walks. In this case, the *Betweenness Centrality* has been calculated using *metric distance*, as it provides a better picture of the daily movements of locals within the grid than the angular distance metrics. As the experience shows, locals tend to follow diagonal movements following the chamfered corners, rather than vertical and horizontal movements (less angular cost). The study of movement patterns of other kinds of users such as tourists or non-locals might lead to other metrics.

Finally, the new pedestrian streets that will be part of the ‘Superilla Plan’ and, more specifically, the Consell de Cent ‘green axis’, have been overlapped on the three different maps, thus providing a synthetic image of coincidences or mismatches between *Betweenness Centrality* measures and the selection of new pedestrian streets of the ‘Superilla Plan’. Additionally, the data has been also published as a histogram, representing the number of segments with each *Betweenness Centrality* value and highlighting the aforementioned case studies in black line (‘Superilla Plan’) and black filling (Consell de Cent ‘green axis’). This histogram only collects 3565 segments within the Eixample Grid, corresponding to 336,3 km street length. 600 segments (59,7km) are streets to be pedestrianized according to the Superilla Plan pedestrian priority scheme, and 38 are the ones linked with the Consell de Cent recent transformation (around 4,6km). The histogram is subdivided into 15 equal intervals grouped in 5 sections.

The resulting image (Figure 3) shows different coincidences and mismatches between high *Betweenness Centrality* (through-movement) and the selected streets to be pedestrianized. At the global scale, a total of 92,7% of the planned ‘green axes’ are within the three first sections of the *Betweenness Centrality* histogram, which represents potential low values of through vehicular traffic.

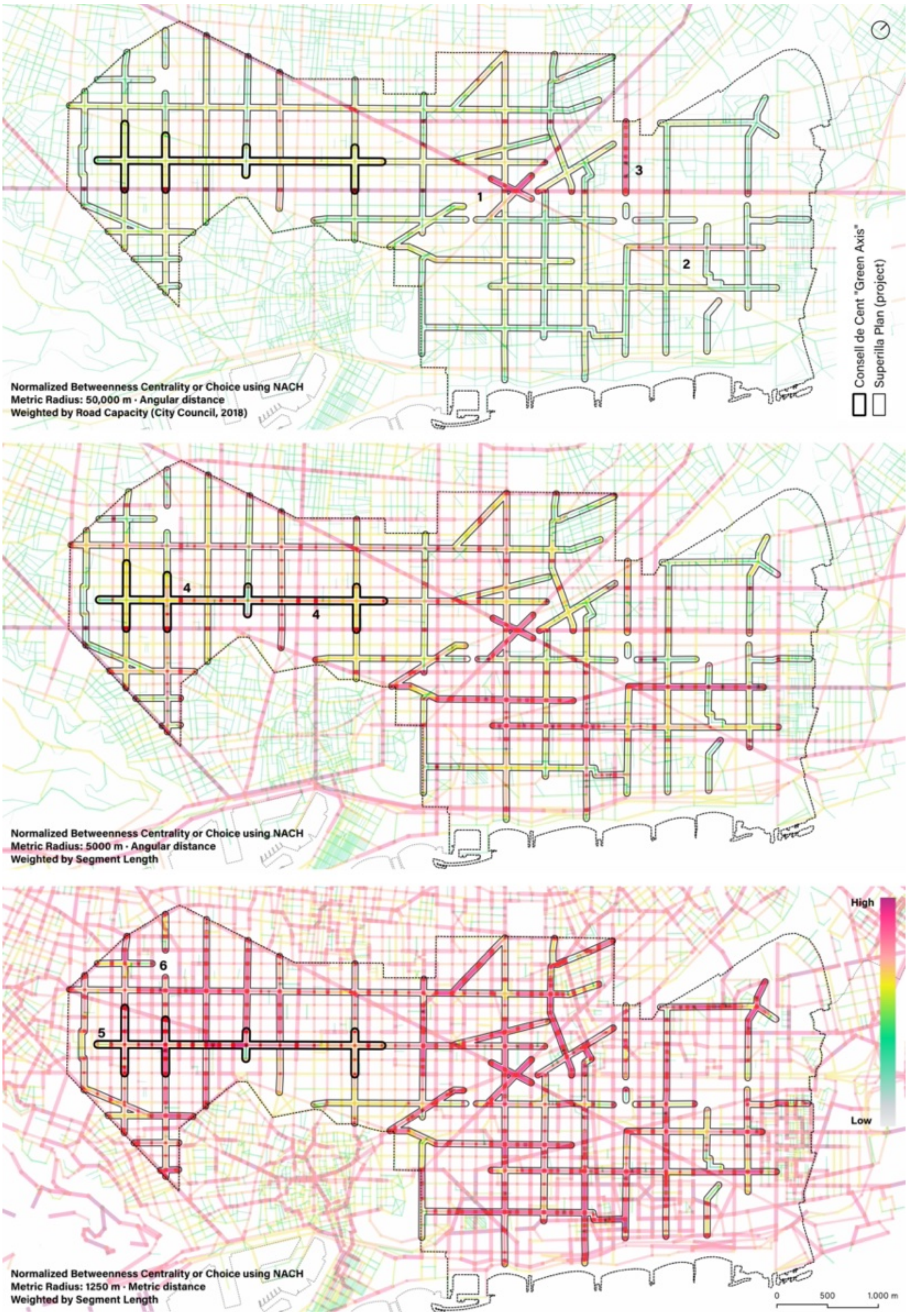

Figure 3: Comparison of *Normalized Betweenness Centrality* (NACH) at different metric radii: 50,000m Radius (weighted by Road Capacity, angular distance), 5,000m Radius (weighted by segment length, angular distance) and 1,600 m Radius (weighted by segment length, metric distance). Eixample Grid of Barcelona. Elaborated by the author.

Only 1,8% of the total segments of the planned pedestrian streets are segments with high values of through-movement. As shown in number 1 on the map, some correspond to the Plaça de les Glòries square, a transformation which is now under redevelopment. Number 2 is, in fact, the new opening of Cristóbal de Moura Street, planned as a 'green axis' even though the potential of this line might be seen as a vehicular artery for the whole metropolis. Number 3 is Carrer Bilbao Street, a key link for vehicles arriving from the north of Barcelona. This leads to the conclusion that those three interventions are not opportunistic but part of a proactive intention to reduce the global movement of vehicles within the core of the city. On the other hand, it is true that the rest of the planned 'green axes' are not neutral interventions, as only 4,8% of the segments are on the first section of the histogram (low *Betweenness Centrality*). Finally, 94,7% of the Consell de Cent intervention (bold line) is within the central section of the histogram, which might explain some controversies raised in the media after the banning of through-vehicle traffic.

The second map shows potential correlations at an intermediate scale (radius 5,000 m), highlighting in red those that are more used for mid-distance movements. The result shows how most of the planned 'green axes' are on the third (34,5%) and fourth sections of the histogram (51,6%), which helps understand the debate about how the idea that those 'green axes' shouldn't be thought of as bike platforms, but as shared surfaces prioritizing pedestrians. Indeed, the model shows that the new 'green axes' will have to cope with a large number of mid-distance "natural-movements" (Hillier *et al.*, 1993), potentially made with bikes or scooters. As the design for those axes does not include proper bike lanes in the street design and both bikes and scooters are requested to drive at low speeds, future designs will have to promote appealing alternatives and faster bike lanes in the vicinity, thus promoting the transformation of the whole Eixample grid.

However, this possible conflict is not still a key problem, as the Consell de Cent axis (bold line) is not specifically showing a high correlation with large values of *Betweenness Centrality* (through-movement). In this case, though, it is worth noting potential conflicts that might occur with those red links crossing the existing Consell de Cent intervention (no. 4). As it will be argued in the following chapter, real experience shows how these points are the weakest points of the transformation in terms of pedestrian security.

Finally, at a local level, a clear homogeneous distribution of high centrality values is observed. Urban regular grids offer multiple and equally competitive itineraries to go from A to B, which accounts for the value of a regular grid as the most versatile urban layout (Busquets, 2019). Although this homogeneity is not visible at the global scale due to the aforementioned impact of adjacent tissues, at the local scale, the centrality is well distributed, thus promoting the almost homogeneous scattering of activities, services and values across the grid (Crosas and Gómez-Escoda, 2020). Nonetheless, the resulting map and histogram show that most of the planned 'green axes' correspond with high values of centrality: 87,5% of the segments are on the fourth section (77,2%), thus highlighting the preponderance of the ‘Superilla Plan’ for improving short-distance through-movement. However, only 12% are on the fifth section of the histogram, which may point to the fact that high values of through-movement are not the aim of this Plan, as these values tend to concentrate on main avenues of the city with lanes for vehicular traffic. Finally, the map also shows how segments with the lowest values are those usually located in *cul-de-sac* configurations, thus promoting calm and ‘neighbourhood-scale’ public spaces also within one of the densest areas of Barcelona (see numbers 5 and 6).

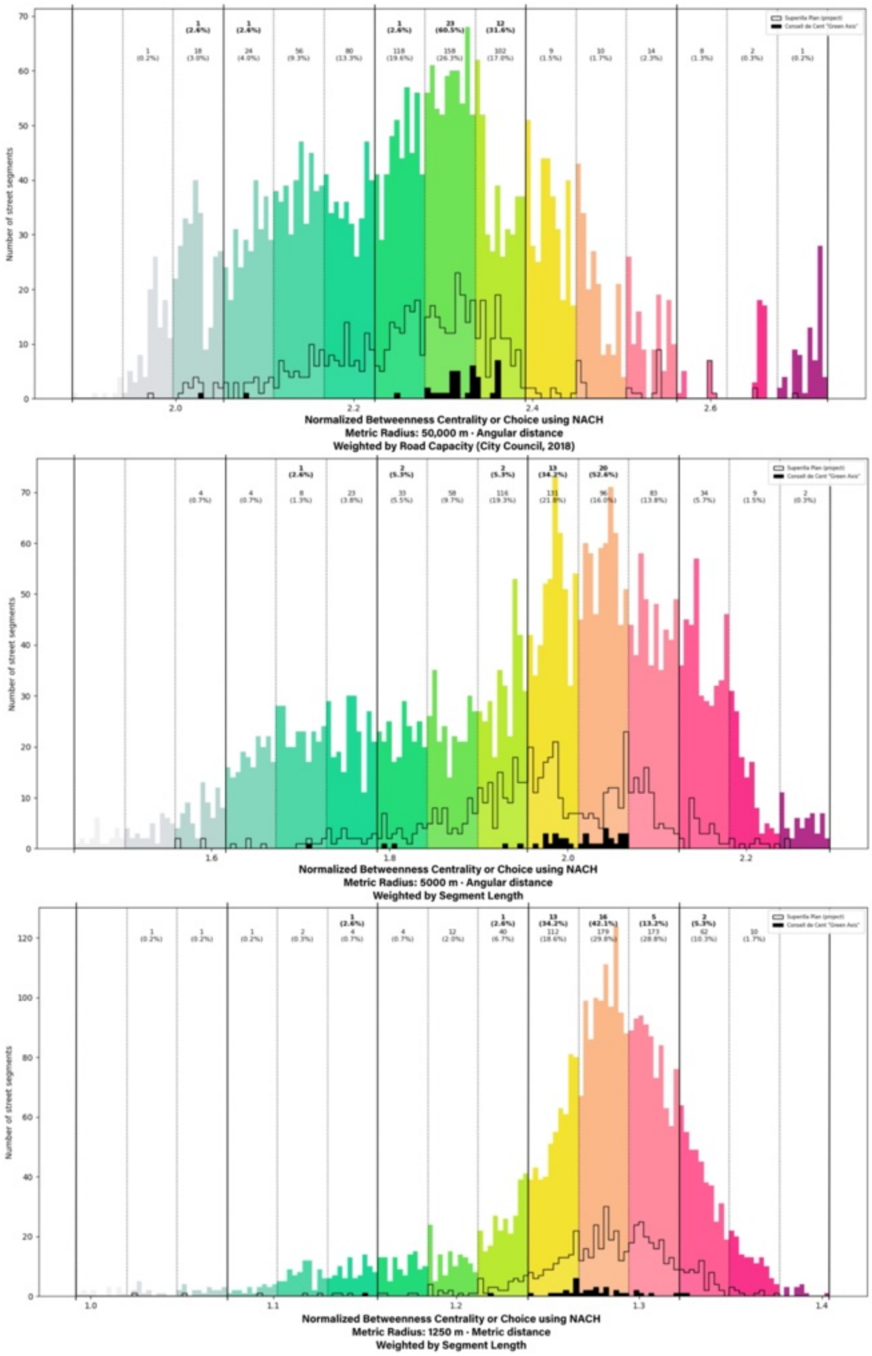

Figure 4: Histogram counting the number of segments per *Betweenness Centrality* values, divided into 15 equal intervals grouped in 5 sections (bold vertical lines). In borderline, the street segments planned in the ‘Superilla Plan’; in black, the street segments of Consell de Cent's recent renovation. Elaborated by the author.

4 VARIATIONS OF THE GRID. THE NEW FORM OF THE CERDÀ'S STREET SECTION

The second reading on the Eixample grid configuration focuses on the recent transformation of Consell de Cent Street at the micro-scale. For the analysis, two new cartographies have been developed including the previous situation (2018) and the new recent layout (2023). The base model used for the following isovist calculation takes into account the facades, the limits of sidewalks and pedestrian spaces, and those more prominent elements in the street organization, such as tree pits and sheds. Ephemeral or mobile elements such as garbage containers or parked vehicles, have not been taken into account, as well as those items with low presence such as street lamps or urban furniture like benches or chairs. All the lines drawn in the model might be considered opaque boundaries, since the study is not focused on the visibility patterns but on the accessibility -or visibility at knee-level. The result is a comparative cartography which might lead to four different findings:

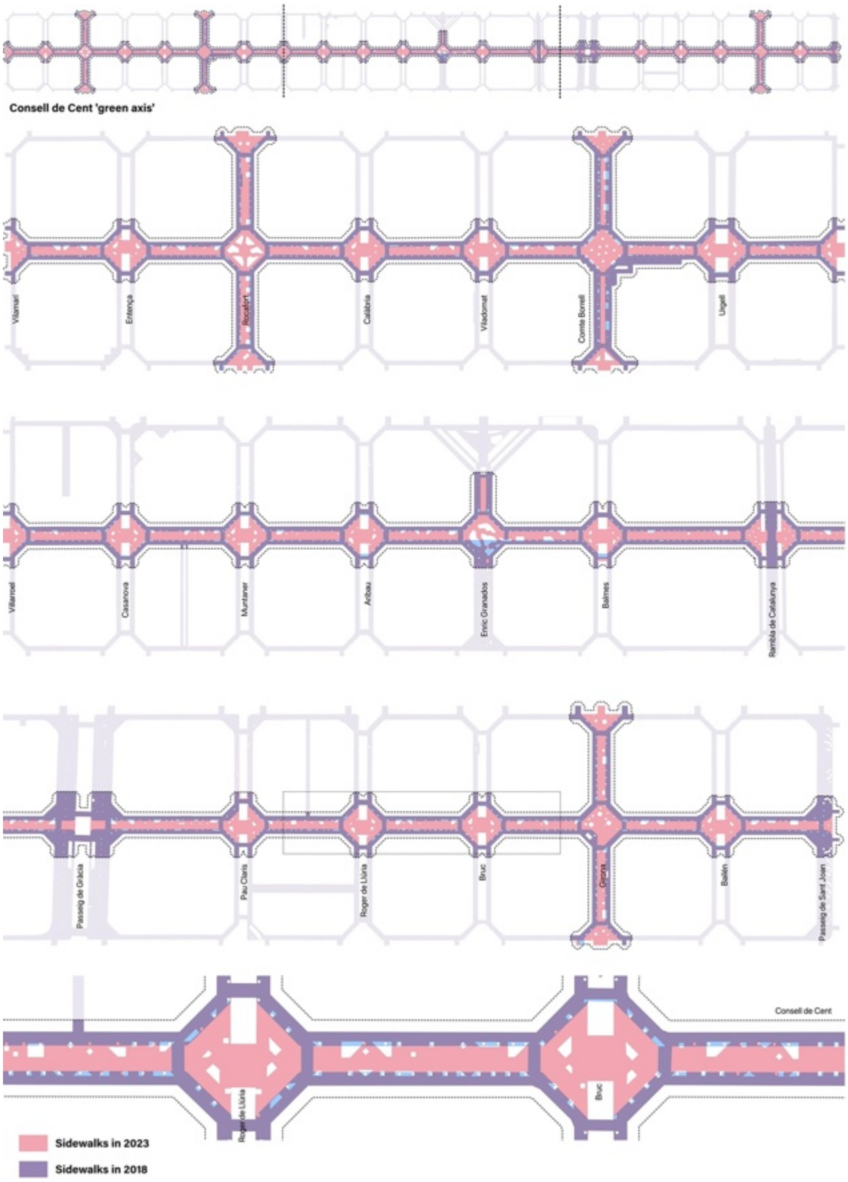

Figure 5: Comparison between the sidewalks in 2018 and in 2023. Elaborated by the author.

4.1 Multiplication of the pedestrian surface

The first difference between the two scenarios is the change in the distribution of space between facades. If we look at the comparison between the previous situation in 2018 and the recent transformation in 2023 (Figure 3), some findings might be highlighted:

(1) The project achieves an increase of 180% of the pedestrian spaces by using shared surfaces. This solution is deployed by deleting the classical distinction between sidewalks and asphalt lanes and providing the same pavement for the whole section. This street design solution has been widely used in many streets in Barcelona and worldwide and, although it is undeniable the benefits provided, it is also true that it is not a real pedestrian street, as pedestrians might conflict with the sporadic passage of low-speed vehicles (Ruiz-Apilánez *et al.*, 2017). It is important to note that this solution in Consell de Cent has been also in debate, as most of the urban services such as garbage bins are moved from the corners to the linear streets and, also, most of the loading activities are constantly occupying this area along the day.

(2) Consequently, the project promotes the reduction of 45,227m^2 of asphalt surfaces, leaving only those linked to through vertical streets. This is equal to a reduction of 89% of the total asphalt area within the studied area (see dotted line).

(3) Finally, the project achieves an increase of 3,44 times the size of the tree pits and green areas, creating new Sustainable Urban Drainage Systems (SUDS) and changing the pavement for more porous solutions. While in 2018 the mean size of the tree pits was 1,4 m^2, in 2023 is 4 m^2. This is aimed at producing a more resilient response to the strong rain periods typical of the Mediterranean basin climate.

Overall, the result is a multiplication of the pedestrian space, but also the incorporation of a new geometry of tree pits and alignments made by lines at 45º, which tries to generate multiple spaces and subspaces, corners and areas to stay and rest and, in the end, to create a variety of atmospheres within a homogeneous street pattern rhythmed by the tree alignment designed by Cerdà.

4.2 From walking on the side to walking in the centre

The Consell de Cent in 2018 was a street as most of the grid designed by Cerdà: two sidewalks of 5 meters on each side, with trees every 8 meters and tree pits of approximately 1.2m x 1.2m, and pedestrian crossings at the end of each block. This configures a dual and lineal perception of a street, allowing not only access to dwellings and ground floor activities but also the location of services, motorcycle parking, or terraces in the space left between the trees or, of course, occupying the sidewalks to a point where the free space for pedestrians is reduced to 2 meters or less (O'Connell *et al.*, 2022). In the new spatial configuration, a new shared surface is proposed, trying to promote low-speed movements and where pedestrian itineraries are prioritized.

To evaluate the new spatial configuration, an *Agent-Based Model* has been developed, proportionally releasing agents in the 89 accesses to the studied area, balancing the number of agents according to the *Betweenness Centrality* calculation using a sidewalk model of Barcelona at a distance of 15 minutes walking (Valls and Clua, 2023). The result is a grid (1x1m) counting the simulated number of agents registered on each plot and, therefore, providing a simulation of the routes without considering other external inputs such as environmental conditions, ground-floor attraction, lighting, ephemeral furniture or precise data on people counting, which might be addressed in the future.

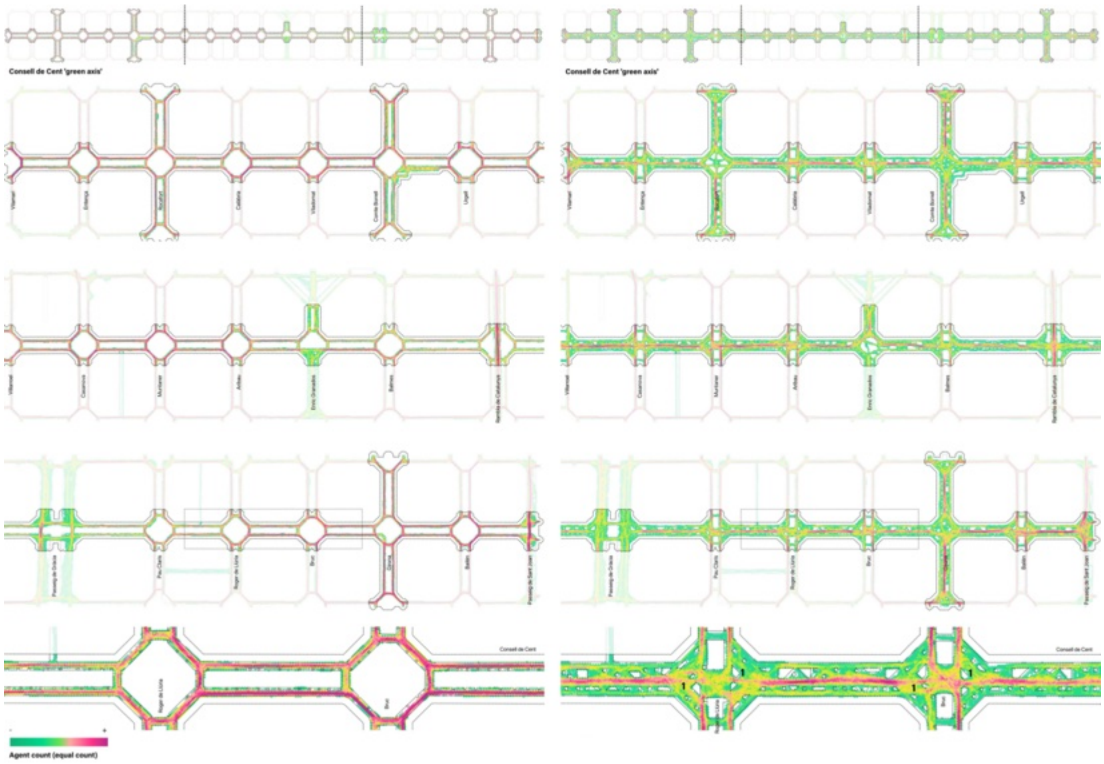

Figure 6: Comparison of agents count in Consell de Cent Street in 2018 and 2023. Elaborated by the author.

The comparison between both scenarios (Figure 6) shows, on the one hand, how crowded are the sidewalks in the previous situation, showing that there are very few spots of the layout without agent tracks recorded, mainly between tree pits. In 2023, the situation changes and the new geometry tends to concentrate more tracks on the centre of the street canyon, thus leaving the itineraries along the façades as the second most used option. At the same time, many spaces in green and yellow stand out as areas with few agents, which might indicate key areas for rest and sitting.

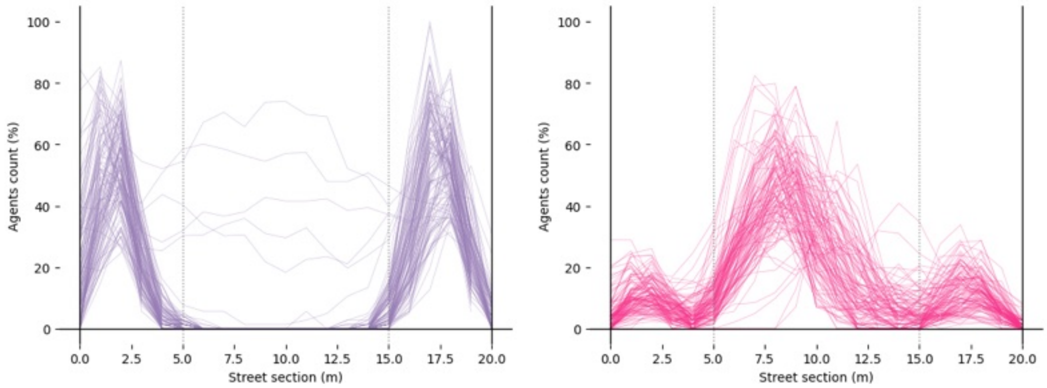

Figure 7: Comparison of agent counts in Consell de Cent section, 2018-2023. Elaborated by the author.

Figure 7 has been produced by providing 123 sections across the street canyon every 10 meters and calculating the % of the Agents registered in that street. The result is a density plot overlapping all the registered sections. Two lines in grey represent the 5-meter sidewalks of the standard Cerdà street. The result confirms the previous map but also gives some new insights into the distribution of people within the area. Firstly, the distribution of agents in 2018 is far more concentrated than in 2023. Secondly, in 2023, as the new layout tends to promote large tree pits and rest areas in the northern section of the street (on the right of the plot) by taking advantage of the sunniest areas of the street, that results in a displacement of the tracks towards the left of the section.

4.3 From a linear space to a sequence of square-like spaces

One of the most appealing goals of the transformation of those streets is the promotion of areas to stay and sit, or, to put it in other words, to turn the bi-linear original layout into a sequence of square-like spaces. This idea has been already tested in streets such as Passeig de Sant Joan, where flow and rest activities are combined thanks to the width of that specific avenue (50m). However, the standard streets of 20m are not able to easily include large spaces to stay and be protected from vehicular and pedestrian flows. The renovation of Consell de Cent has been a key opportunity in this matter.

To evaluate the real impact of this intention, the *Average Radial* has been calculated using *Isovists.org*. This value is a normalized measure of isovists that expresses the mean view length of all space visible from a location. Higher values tend to highlight those concave places with greater dimensions in a square-like configuration, while small values usually appear on corners or elongated unidirectional spaces. From the use of the measure, it seems that the parameter is especially useful for detecting square-type spaces, while the lower values tend to highlight linear geometries such as streets or alleys (Clua, 2024).

Figure 4 shows a comparison of the values of *Average Radial* for 2018 and 2023, considering the result not a *visibility* interpretation of the space -as tree pits are not visual obstacles- but using this parameter to evaluate *spatial attributes* which might help to understand *accessibility* patterns (visibility at knee-level). In 2018 the highest values (green) are only present in large avenues such as Passeig de Gràcia and Rambla de Catalunya, as well as in Enric Granados pedestrian street (done in 2000). Due to computation limits, the result is not fine enough to bring out the micro-spaces located between the trees within the street. All in all, most of the sidewalks are mostly in red, representing lower values of *Average Radial* and, according to our interpretation, highlighting linear geometries.

The scenario in 2023 is radically different as the *Average Radial* highest values are spread all over the new street layout. If the areas of wide crosswalks are not taken into consideration, the resulting map shows that new square-like spaces appear in the centre of the street canyon, yet not as continuous spaces but as a *sequence of interconnected convex spaces*. This is due to a deliberate design decision to allocate tree pits to create wider squares to stay and rest.

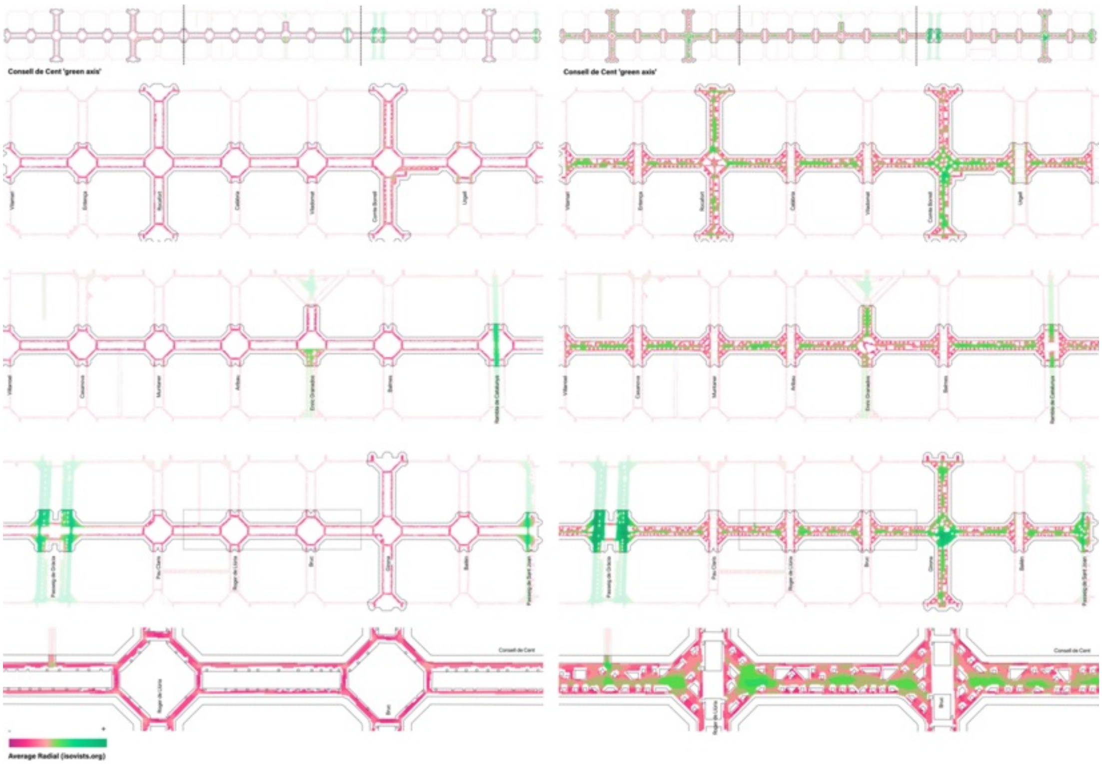

Figure 8: *Average Radial* (isovists.org) of Consell de Cent Street in 2018 and 2023. Elaborated by the author.

4.4 From crossroads to pedestrian squares

The chamfered corners are one of the most notable elements of the Cerdà grid. There are around 1,200 of them and they are octagonal spaces of around 1,930m^2, which is a comparable size to the squares in the nearby Gràcia neighbourhood. Usually, those crossroads are organized with perimeter sidewalks 5 metres wide and an inner central area used for circulation, temporary parking and the location of urban services. Although the distribution of sidewalks and asphalt areas allows for efficient traffic management, it is not a friendly layout for pedestrians, as it forces them to follow the chamfered geometry to navigate from one block to the other. This was already a problem envisaged by Cerdà who tried to solve it by allocating kiosks in the free-traffic areas of the corner and linear crosswalks (Magrinyà and Marzá, 2009:114). In isovist terms, it is worth noting how the area with the highest visual control -or the lowest *visual clustering coefficient* (Watts, 1999; Turner, 2001; Koutsolampros *et al.*, 2019; Clua *et al.*, 2021)- is in the geometric centre, although it is usually inaccessible to pedestrians. The widening of some sidewalks in front of schools is one of the recent transformations that allows approaching that central point (see project *Protegim escoles*, Ajuntament de Barcelona).

However, the project built in Consell de Cent offers at least two different patterns within the corners. On the one hand, some corners need to allow through traffic in vertical streets, as in Urgell or Muntaner streets. Although wide crosswalks are provided, the octagon is finally subdivided into two large separated units. The preponderance of the vertical streets as well as the will to avoid thoroughfares, has led to a design of tree pits that promotes a discontinuity or funnel effect between one section of the promenade and the other. This can be seen in number 1 of Figure 6.

However, the most celebrated alternatives to Cerdà's standard chamfered crossroads are the new public spaces designed in the crossing points with Rocafort, Comte Borrell, Enric Granados and Girona streets. Each of these designs gives answers to similar overall geometry but with subtle differences. Girona's design (Under Project Lab, BOPBA) takes into account the metro station and premises underground. Enric Granados' (LandLab, GPO) might be seen as the spatial extension of the gardens of the Seminar, which is allocated in one of the four corners. Comte Borrell (Clara Solà-Morales, Albert Casas, Frederic Vilagrasa) is not a regular octagon as one of them is an open corner with a two-slab building designed by modern architect Antoni Bonet Castellana (Edifici Mediterrani, 1966), and the other is a new public facility with a stepped façade. Finally, Rocafort's design (Estudi 08014, Arquitectura, Ciutat, Territori) is the most canonical solution as it is a perfect octagon shape (Figure 9).

Figure 9: Squares in Consell de Cent: Rocafort (Estudi 08014, Arquitectura, Ciutat, Territori), Comte Borrell (Clara Solà-Morales, Albert Casas, Frederic Vilagrasa), Enric Granados (LandLab, GPO) and Girona (Under Project Lab, BOPBA). Photographies/ 3D: P. Viladoms, C. Solà-Morales, R. Cugat, Ll. Teixido, 2023.

To evaluate the impact of the new design on the movement patterns, an isovist study has been applied on the at-knee level, which accounts for an expression of where movement is allowed (Turner *et al.*, 2001). The result of this analysis has been synthesized in Figure 10. It provides a comparison of the four squares according to three selected parameters: *Average Radial*, *Overt Control* and *Agent Counts*. The former and the latter have been already explained in previous sections. *Overt Control*, in turn, "expresses the visual 'linking' dominance of any location; the options each space offers for its immediate neighbours as a junction, or where movement may provide access to multiple restricted visual fields" (*Isovists.org*). In Depthmap, this value is equivalent to *Visual Control*.

Regarding the first parameter -*Average Radial*-, the four squares provide a significant improvement of that value. However, the value (and colour) is different for each one: Rocafort's mean *Average Radial* is 0.55, Borrell's is 0.65, Enric Granados's is also 0.55 and Girona's is 0.71. Girona provides the largest square-like space of the whole transformation, without trees or any furniture. This solution led, for instance, to the use of this space as an ephemeral volleyball pitch some months ago. The interpretation of the result of Borrell is not automatic, since the *Average Radial* values are also significantly high all over the square but there are not large square-like spaces. Indeed, it reflects how the small size of the tree pits in the centre does not block the possibility of getting large isovist lengths and, consequently, a high level of *Average Radial*.

Finally, the Enric Granados square and Rocafort are pretty similar as the larger green areas in the centre do not allow the generation of big square-like spaces, with a minor exception at the centre of the Rocafort square. Both designs might be regarded as new interpretations of the old crossing condition of that space, now rethought at the human scale and searching for a garden-like and more intimate atmosphere. As a consequence of this, the squares do not offer large open platforms, yet they are located within the adjacent streets.

The *Agent counts* analysis gives a more precise interpretation of how the different squares are crossed by people’s movement. In addition to the arguments stated in the previous chapter, here it is worth noting the impact of the geometry of each square on the way agent tracks are channelled. The way agents approach all four squares is similar, i.e., with a high agglomeration in the central section of the streets. Once inside the square, agents behave differently.

Girona square's lower side allows almost total free movement, while the upper part is more subdivided by tree pits and large furniture pieces. The result is almost a neat cross-shape of agents within the central area of the space. Comte Borrell, in turn, provides a very regular distribution of the space, thus allowing a dispersal of the agents once they enter into the central area. Rocafort might be regarded as a variation of Borrell’s square, although the green areas are larger and, therefore, the agents are forced to walk through the narrow paths inside the new design, most of them through path number 1. In the case of Enric Granados’s layout, beyond the organic geometry that defines the overall space and might be linked to the way Rocafort square is designed, the space promotes a clear shift of the agent tracks towards the upper part (number 2). Both the vertical and horizontal directions are not easy to follow. As a result, the green areas become real obstacles in the movement of people and, therefore, a system of small paths with less potential for through-movement of pedestrians.

The *Overt Control* is also relevant in this regard, as the interpretation of this parameter is useful to grasp the more visible and hidden spaces of each square. In spatial configuration terms, this might be helpful to find decision-making areas (high values of *Overt Control*) and, inversely, the more central areas in the control terms. For the analysis of squares or public spaces, the latter might help to find areas away from main movement lines and, therefore, spots where sitting activities might take place. However, this interpretation should be compared with the *Agents Count*, by pointing out those areas with low *Overt Control* and a smaller number of *Agents*. Those spaces might be seen as perfect spots for sitting activities or urban services. The last row of Figure 10 shows the different distributions of this combined factor and might explain the capacity of each square to generate calm and sitting spaces.

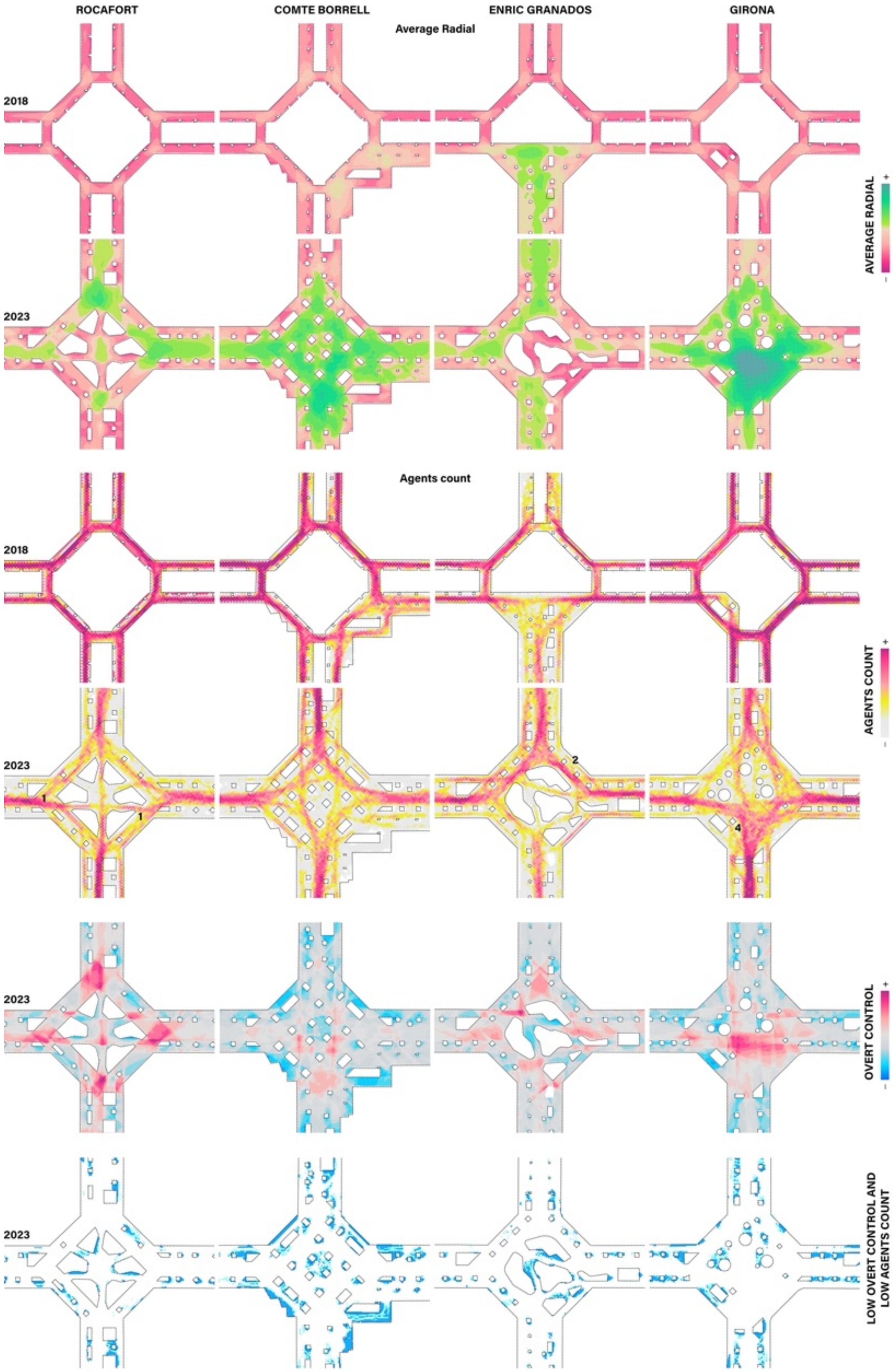

Figure 10: Comparison of *Average Radial*, *Agents count* and *Overt Control* in four squares of Consell de Cent 'green axis'. Elaborated by the author.

5 CONCLUSIVE REMARKS

Regarding the large scale of the analysis, the research confirms how most of the planned 'green axes' are segments with low through-movement on the global scale (metric radius 50,000 m). However, some punctual exceptions show, as described before, that those are areas under current urban transformation. Although these might be considered key links for through-movements at the global scale, the new pedestrianization might be regarded as a strong political and technical will to avoid traffic in those areas.

At the intermediate scale (radius 5,000 m), in turn, the analysis highlights how the 'Superilla plan' is impacting and modulating the way mid-distance movements will be produced after the pedestrianization. If this result is understood as an expression of short-distance routes made by car within the city centre, the green axes will offer clear obstacles to this itinerary, as selected segments to be pedestrianized are meant to intervene on high values of through-movement. In turn, if these results are regarded as bike-movement patterns, the in-detail design of the new green axes should be it into account, by providing bike lanes within the axis -which might lead to a change in the aim of the urban design of these streets- or, as referred previously, to providing efficient bike lines in the vicinity.

Finally, the highest correlations are found also at the local scale (radius 1,600 m) between the planned 'green axes' and the highest values of *Betweenness Centrality*. Indeed, this was foreseeable as the whole grid has homogeneous values of high *Betweenness Centrality* (mainly in the fourth and fifth sections). However, the fact that most of the Consell de Cent segments are not within the fifth section, leads us to observe that there will be other future 'green axes' with a major impact on short-distance movements: around 70,9% of the total planned segments are on red and pink segments and most of them are still under debate.

Nonetheless, among all the common limitations that might be observed in the segment analysis and results, each new future transformation should indeed be analysed accordingly at the global (50,000 m radius) and intermediate scale (5,000 m radius). The segment model in 2023, for instance, might be barely different from the one in 2018, as some streets around the Consell de Cent area are no longer continuous traffic lanes, some streets have been reconfigured and, of course, the *road capacity* used for the weighted model is constantly changing month after month with progressive reduction of lanes. That might point to the fact that this segment analysis should be dynamic and iterative: each new transformation changes the way *Betweenness Centrality* is deployed. Further research might explore how these future 'green axes' might change the role of isotropy of centrality measures within the grid.

On the other hand, the in-detail study of the Consell de Cent 'green axis' and adjacent streets provided in this paper confirms how the spatial configuration has been drastically changed in the recent renovation. It is not only a matter of increasing the pedestrian space using shared surfaces, but more importantly, it has become a purposeful process to generate a new way of using the public space of streets and crossroads of the grid. From linear sidewalks to a sequence of square-like spaces, from homogeneous patterns to varied experiences of atmospheres, and from corners to squares.

More specifically, one of the key confirmations is that only by managing a redistribution of the tree pits layout, does pedestrians eventually tend to concentrate within the centre of the street. This is a difference in the perception of the grid and the street canopy. However, everyday experience of those spaces underlines some controversies: those central spaces are not necessarily the friendliest area to walk through, as many vans and cars use it as a loading space and temporary parking, and also some furniture and urban services are changing the neat perception described by the isovist analysis. Further research might be developed here by including an evidence-based discussion on how ephemeral elements can change the use of space. All in all, it must be acknowledged also that any of the previous spatial simulations are necessarily a simplification of reality as no real measurement of people has been conducted for this research. Although there is a sound knowledge of the correlation between space syntax analysis and movement patterns, the complexity of urban spaces needs to be weighted by other external factors. In this research, only the segment model at a large scale has been weighted by road capacity and the others by segment length. At the micro-scale analysis of Consell de Cent, a comparison with real recordings of people's movements might be valuable. Here, ongoing works by Noumena will provide real measurements of people in this area (Sollazzo, 2023).

Finally, the analysis of the corners has shown that, despite their similar approach to increasing grid porosity and biodiversity, their response to movement patterns is very different. Visually, all of them seek similar unique perceptions of the space between facades, but from an accessibility standpoint, each one generates distinct corners and atmospheres. The analyses conducted demonstrate how the arrangement of tree pits can favour them as smooth thoroughfares (as in the case of Borrell) or rather as intricate gardens for staying (as in Rocafort or Enric Granados). It is true, however, that despite efforts to turn them into 'squares' in a classical sense of the word, the previous junction condition is still very present, being the tranquil places not the most relevant areas within those spaces. However, this crossing-place condition is manifested in a different way to the original Cerdà's design, where he approached the traffic intersection with tangent contacts and wide turning radii. In great or low measure, the new designs are intended to promote complex and diverse encounters for pedestrians, providing more richness in the way people, built environment and nature interact, which might be understood, in the end, as the most essential definition of "material urbanity" (De Solà-Morales, 2008:146–153).

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