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An approach to visual interaction analysis of urban spaces. Central Barcelona as a case study

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ABSTRACT

Beyond the binary, traditional, figure-ground reading of urban patterns, this research presents a graduated expression of the geometry of urban spaces from a perceptive point of view. This highlights the spatial relationships and introduces a new set of criteria to evaluate contemporary open spaces according to visual experience. The study produces an innovative reading of central Barcelona by mapping of *Visual Clustering Coefficient*, one of the parameters derived from the *Visual Graph Analysis* of isovists.

KEYWORDS

Barcelona; public space; visual graph analysis; isovist

Introduction

As a result of renewed interest in the potential of the contemporary city's public space and the increasing use of digital tools to represent the city, it is crucial to strengthen and continuously update the body of urban design studies. This is a significant issue, as the analytical method influences the way cities are understood, conceptualized and, there- fore, designed. This paper aims to contribute to the urban analysis by approaching the visual experience of urban spaces applied to the interpretation of central Barcelona as a relevant case study.

This discussion on visual experience of the open space is particularly interesting in cities like Barcelona, whose urban morphology has a high level of compacity, a neat definition of open spaces and a varied number of urban layouts that come together in the central area. The analysis of urban spaces in Barcelona is also relevant after the recognized success of its urban transformation since the 1980s (Busquets 2014a; Rowe 2006; Bohigas 1983; Maxwell and Bohigas 1999; Marti 2004), but also because it is still today at the center of the international discussion on quality of life in cities (McNeill 2003; Gascó and Van Eijk 2018; Turner 2019). The collections on plans and designs for the pubic space published by Barcelona City Council and the Barcelona Metropolitan Area on the occasion of the upcoming Metropolitan Urban Master Plan (PDU), provide a clear example of the strate- gies and the design value that are guiding the construction of the Barcelona metropolis. A range of designs and urban studies stand out, including squares in compact urban fabrics (Busquets 2003), new peripheral spaces that become places of identity for the community (Borja and Muxi 2001), and coastal spaces, avenues and parks integrated as social and ecological "infrastructure" for the metropolis (Ajuntament de Barcelona 2013; Guallart 2015; Barcelona Regional 2019). In summary, the variety and quality of the public space in Barcelona represents the quintessence of what has been called the "Barcelona model" (Acebillo 1999; Maxwell and Bohigas 1999; Esteban 1999; Subirós 1999; Santacana
2000; Capel 2005; Delgado 2005; Montaner et al. 2014).

One of the current, most pressing debates on the urban space and visual experience is related to the search for new formulae to achieve a balance between the much desired shared living spaces (Gehl 2010) and the increasing requirements given by new modes of *soft* mobility (Duncan et al. 2016). In Barcelona, this discussion has guided some experi- ences in the development of the "superblocks" system, with the first pilot test in Poblenou-22@ District (Gyurkovich, Poklewski-Koziell, and Marmolejo 2019; Rueda 2018), following the success of the previous implementation of the narrower street layout of the Gràcia district

(2003–2005). Additionally, traffic calming as a necessary condition for making the street space more people-friendly has inspired more systematic contributions focused on adapting Barcelona's streets to bicycle mobility (Blanchar and León 2018; Rubert de Ventós 2017; Parcerisa 2016).

Ultimately, these contributions reveal a considerable effort by the city to answer to the new requirements for healthy, efficient pedestrian and bicycle mobility through open spaces that, in the case of Barcelona, have relatively limited dimensions and serve a high population density and activities. In particular, the 20-metre streets of the Eixample area or its octagonal squares, the gardens in the center of blocks with dimensions between 500 and 5,500 m^2 Crosas 2011, the large metropolitan avenues (between 30 and 50 m) and the old ring roads around a historical center that is under increasing social pressure are some of the spaces that are constantly the subject of new designs, social vindication and technical discussions, and therefore should be covered by a new and updated analytic description.

In this framework, two major approaches have usually driven the urban analysis of public spaces. First, the analysis of the urban form using classical descriptive categories: street, square, garden, park, avenue, boulevard or passageway. These can be effective for classifying, recognizing and naming the elements, for urban planning and management and for quantifying ratios and levels of proximity. Nevertheless, this analytical approach does not often coincide with the continuous perceptual experience of the space and the way we use and pass through it. Actually, human visual experience unifies the transitions between the above-mentioned categories, which builds up a mentally continuous coher- ent text with blurred boundaries.

On the other hand, a number of digital platforms focus on registering and visualizing flows based on origin-destination diagrams; interactive maps of pedestrian and bicycle routes; and even detailed detection of discontinuities in the urbanization of the public space. Despite the fact that these platforms provide real-time mapping of people's movement, they offer neither a detailed description of spatial attributes nor the visual perception of open space.

In view of the above considerations, the aim of the article is to provide an innovative description of the visual more specifically, to test it in the central area of Barcelona, comprised of the historical center, the Eixample grid and its adjacent neigh- borhoods (including an area of about 1 km around the grid). The definition of this study area of 9 × 7 km enables a fairly complete number of forms of urban spaces which are relevant to discuss both compact and open modern fabrics. In the end, this extensive display of multiple urban forms is designed to provide relevant insights that are applic- able to other similar contexts worldwide, and to offer new analytical criteria for the evaluation of public spaces according to visual perception.

Literature review. Two leading approaches

The research consists of constructing a new perceptual map of the urban spaces in central Barcelona and interpreting the resulting image. The method is based on two leading, complementary approaches: (1) a method drawn from graph theory applied to visual graph analysis to construct the map; (2) interpretation in the light of existing studies on open spaces for the city of Barcelona.

The first group of references includes approaches to space perception based on the analysis of angles of view or isovists. Studies in this area began with C. R. V. Tandy in relation to perception of the natural landscape (Tandy 1967). However, subsequent studies by Michael L. Benedikt should be mentioned, which are summarized in his article "To Take Hold of Space: Isovists and Isovists Fields" (Benedikt 1979). In this paper, he introduced the numerical study

of variables relating to isovists (space visible from a given viewpoint) and their aggregation to form "fields of view". Later studies led by Julienne Hanson focused on the relevance of this approach to the syntactic analysis of space: "People move along axial lines, form groups in two-dimensional convex elements, and see three-dimensional non-convex visual fields or isovists" (Hanson 1994, 676). The same article presented an analysis of domestic architecture based on a graph theory approach to the study of isovists.

As a result of this research, visual graph analysis has been consolidated and imple- mented using *Depthmap X*, multi-platform software to perform a set of visual and spatial network analyses at various scales: from building scale to whole city or country scale. As stated by the software authors, "the aim of the software is to produce a map of open space elements, connect them via some relationship and then perform graph analysis of the resulting network".[1] The development of this tool was discussed in papers such as "Making isovists syntactic: isovist integration analysis" (Turner and Penn 1999) and the related article "From isovists to visibility graphics" (Turner et al. 2001). More recently, Sam McElhinney has produced notable work on *Isovist.org*,[2] space network analysis software based on the stochastic calculation of isovists (McElhinney 2014). More recent advances are being made in this area and will be published in the next book by Michael L. Benedikt, "Architecture beyond experience". All these studies highlight the possibilities of this approach to illustrate the potential accessibility and visibility of a specific space. They confirm the utility of the approach to understand phenomena such as spatial orientation, the value of foci of interest, patterns of flows or the use of the space.

A number of studies have used this (Tahar and Brown 2003). However, the use of this methodology to analyze open urban spaces is receiving more attention (see, for example, De Arruda Campos and Golka 2005; Bada and Farhi 2009; Guerreiro et al. 2015; Psarra 2018). Other advances can be highlighted here, including some professional projects developed at Space Syntax Ltd,[3] the application of visual graph analysis to complex topographic conditions (Culagovski, Greene, and Mora 2014), studies in the academic home of Sam McElhinney (University for the Creative Arts) and recent research drawn up on the correlation between visual perception and urban acoustics in the old city center of Barcelona (Clua, Llorca, and Psarra 2020). Many analogies in the approach and methodol- ogy can be established between the aforementioned paper and the present research.

A second family of references configure the foundations of the research, which are closely related with the tradition of specific urban design knowledge relating to the study of the urban form of Barcelona and the value of urban maps and their interpretation. In particular, an area of research established by Professor Manuel de Solà-Morales in the Barcelona Laboratory of Urbanism (LUB) in 1969 (Barcelona Architecture School [ETSAB]- Universitat Politècnica de Catalunya) can be referred to, as well as his seminal work *Las formas estructurales del crecimiento urbano* (de Sola-morales et al. 1974).[4] In this paper, a new morphological approach to categorization of the urban form was introduced, based on the combination in time of three key layers: the street layout, land parceling and buildings. This line of urban studies influenced a series of doctoral theses on various urban fabrics of metropolitan Barcelona, including informal settlements (Busquets 1974, 1999), modern housing estates (Ferrer 1982, 1996), the Eixample Grid (Corominas 1986, 2002), and the origins and urban formation of the Gràcia District (Serra 1993, 1995).[5]

Other recent studies have a similar methodological background applied to the specific area of Cerdà's Eixample (Busquets and Corominas 2009) or at metropolitan scale (see documents on the exhibition "Barcelona Metròpolis", 2015). More recent studies in the same line of research include overall descriptions of the figure of Barcelona city as a whole: *Ten lessons on Barcelona* (de Sola-morales 2008cb), *Barcelona: The urban evolution of a compact city*

(Busquets 2004, 2014a) and *Barcelona 20th century urbanism: Look to the sea, look to the mountain* (Parcerisa 2014). In the end, all these monographs mainly focus on the description of structural elements that define the morphological identity of the urban patterns and the explanation of their evolution over time. None of them center specifically on the visual perception of urban spaces and their spatial interaction. Thus, this study aims to apply *visual graph analysis* to provide new insights to the aforemen- tioned studies.

Materials and methods. The construction of the plan

The plan that is the subject of this study shows the central area of Barcelona, covering the entire extent of Cerdà's Eixample grid and contact with the adjacent neighborhoods: Poble Sec, Sants, Les Corts, Sarrià, Sant Gervasi, Gràcia, Sant Andreu and Poblenou (Figure 1).

The following operations were carried out in this diverse landscape of urban patterns.

Step 1: Outlining the geometric limits of the open space

The basis for the study of isovists is the of redrawing the limits of perceivable open space at a height of 1.5 m for the entire study area (Figure 2). The resulting drawing broadly

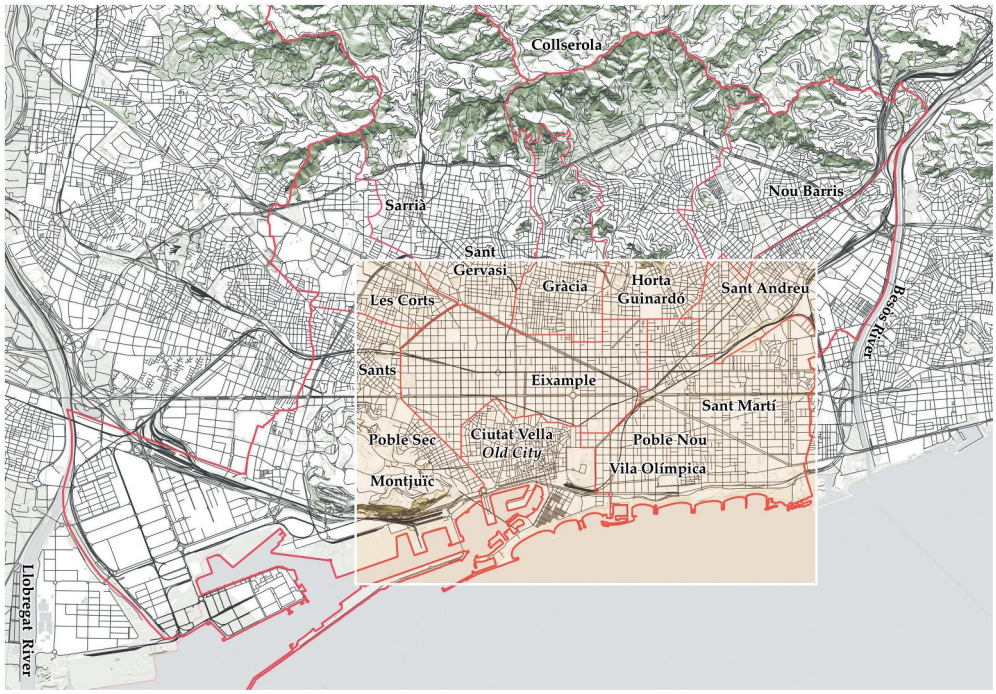

Figure 1. General map of Barcelona. In orange, the area of study (9 x 7 km).

reflects a classical 2D figure-ground map, but also recognizes some opaque elements that close the view although they have little presence in floor plans, such as high walls or fences. In this model, topographical features or prominent inclines are not registered on the map, due to the fact that central Barcelona is evenly distributed as a gentle slope towards the sea. In visual terms, this means that all points are visible as there are very few hills that may block the views. Exceptions to this criterion will be marked throughout the text.

Step 2: Generation of isovists

Visual graph analysis was applied to this georeferenced base, generated by Depthmap X

software (Turner 2001). The resulting space was subdivided into a 4 × 4 m grid of the real scene, so that all open spaces could be recognized and the computing process could be speeded up.[6] The algorithm generates two groups of results: *global* variables based on integrated information from all points of the graph, and *local* variables derived from the information at each specific point and its immediate surroundings. Local variables are the focus of this study.

Step 3: Selection of parameters for analysis

To draw up the plan, the local variable called the *visual clustering coefficient* was used. As detailed in the aforementioned literature (Turner 2001; Turner et al. 2001), the clustering coefficient for a given point v_i, is defined as:

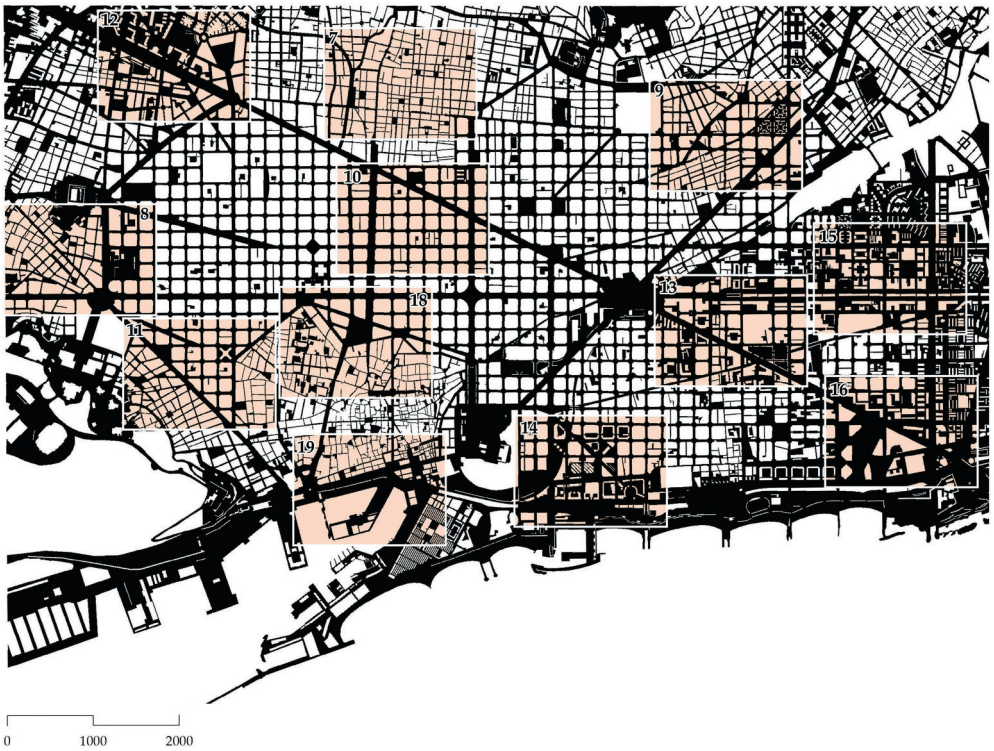

Figure 2. Figure-field map of central Barcelona. In orange, the twelve selected frames. The numbers refer to the figures mentioned in the text.

$$C_i = \frac{\left|\left[e_{jk} : v_j, v_k \in N_i \wedge e_{jk} \in E\right]\right|}{k_i(k_i - 1)}$$

Where E is the set of edges e_{jk} that connects vertices v_j; v_k; and $k_i$is the total number of vertices that forms the isovist (jN_ij).

Expressed in terms of visual analysis, the clustering coefficient C_i (from now on, *VCC*) is defined by the number of visible links between the vertices of the isovist, divided by the maximum possible number of links that could be established in a distribution where all vertices would be visible to each other (Figure 3).

This coefficient indicates that the quotient tends to 1 for spaces where all points are visible from any other point, which are called *convex spaces*.[7] These are isovists where all points can be seen mutually. In contrast, the coefficient tends to 0 at points of the grid whose isovist

adopts the shape of a star with acute angles, which means that it contains points that are not visually connected to each other.

We can associate coefficient 0 with corner situations, that is, places where the degrees of freedom are multiplied as there are many routes that could be seen and selected at that point. Therefore, these could be associated with places to pause (Conroy 2001). Literature on this coefficient has associated points with values tending to 0 with "key decision points within complex configurations" (Turner et al. 2001, 111) and, lastly, as indicators of "the potential for perceivable copresence in a space and therefore the potential to form

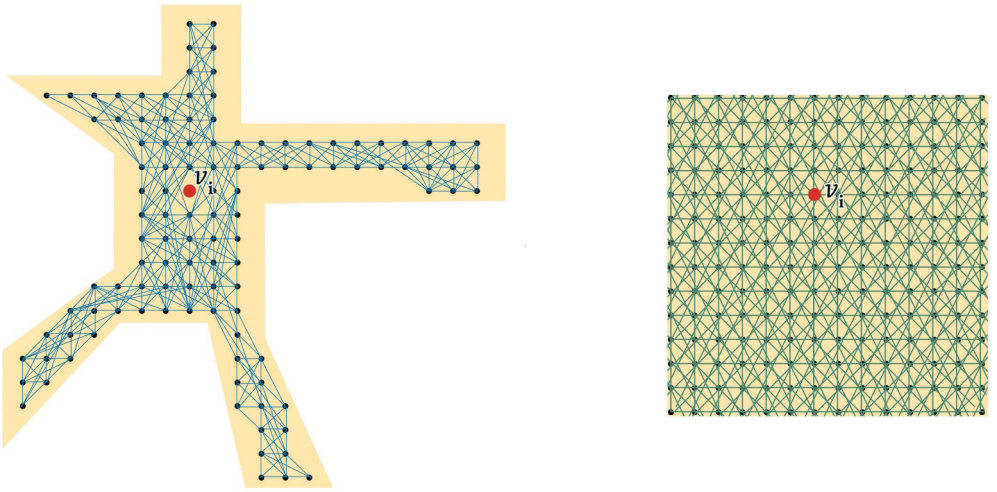

Figure 3. The *Visual Clustering Coefficient* C_i (from now on, *VCC*) for each point v_i is calculated by dividing the number of real visual connections between the vertices of a given isovist, between the maximum possible number of visual connections established in an optimized distribution where all vertices of the isovist from point v_i would be visible to each other.E is the set of edges e_{jk} that connects vertices v_j; v_k; and $k_i$is the total number of vertices that forms the isovist (jN_ij).

groups or to interact" (Turner et al. 2001, 111). We can recognize threshold situations in this parameter as, according to Turner (2001, 111), the coefficient registers the differential value of each point in relation to the rest. In any case, as stated in the previous paragraph, values similar to 0 are places that in themselves do not transmit new information to the system, but act as inflection points as they contain information on other places (Figure 4).

Step 4: Colour gradients

By default, the map that results from the analysis with Depthmap X shows a visual clustering coefficient expressed in colors from red to blue. For this research, this color range has been adjusted to make more evident the points with a VCC tending to 0 (Figure 5). The final map

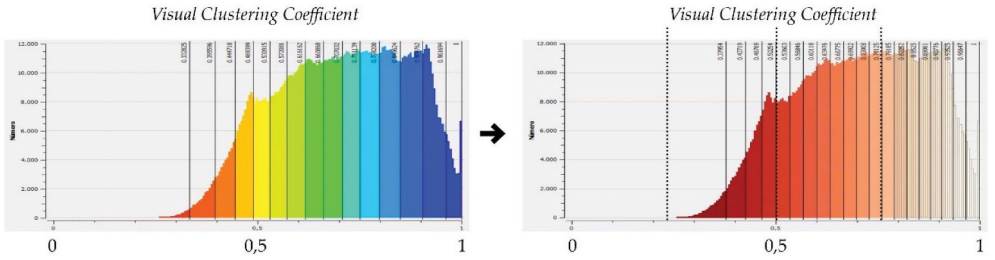

Figure 4. On the left: the area in black has a field of view in which most of the points are not visually related and therefore the *VCC* tends to 0. On the right: almost all points in the visual field are visible to each other. This means that the *VCC* tends to 1.

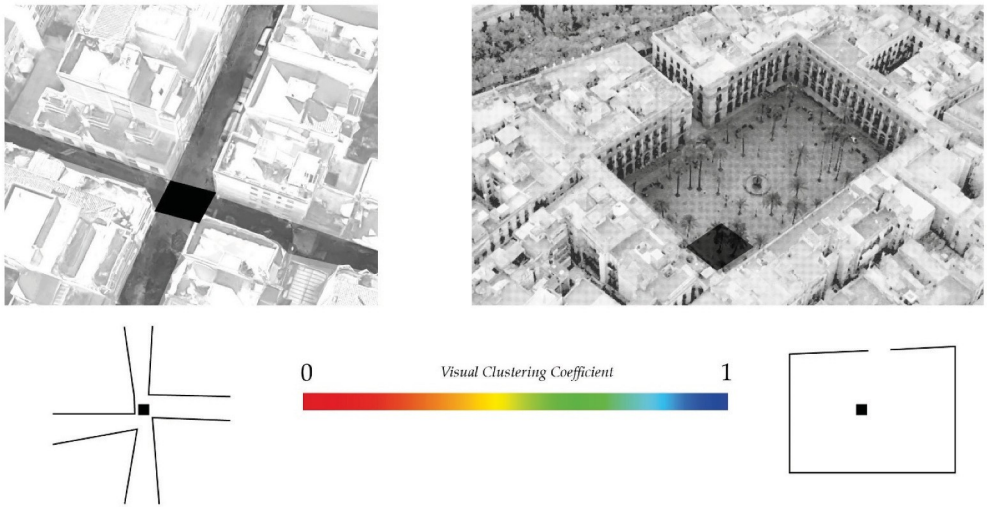

Figure 5. Adjustment of the color gradient of the *Visual Clustering Coefficient.*

shows different values with a color gradient from white to red, distributed according to a Jenks natural breaks classification method (Jenks 1967). It shows graphically the points with a lower VCC and dilutes in the white background the values that are similar to 1 (Figure 6).

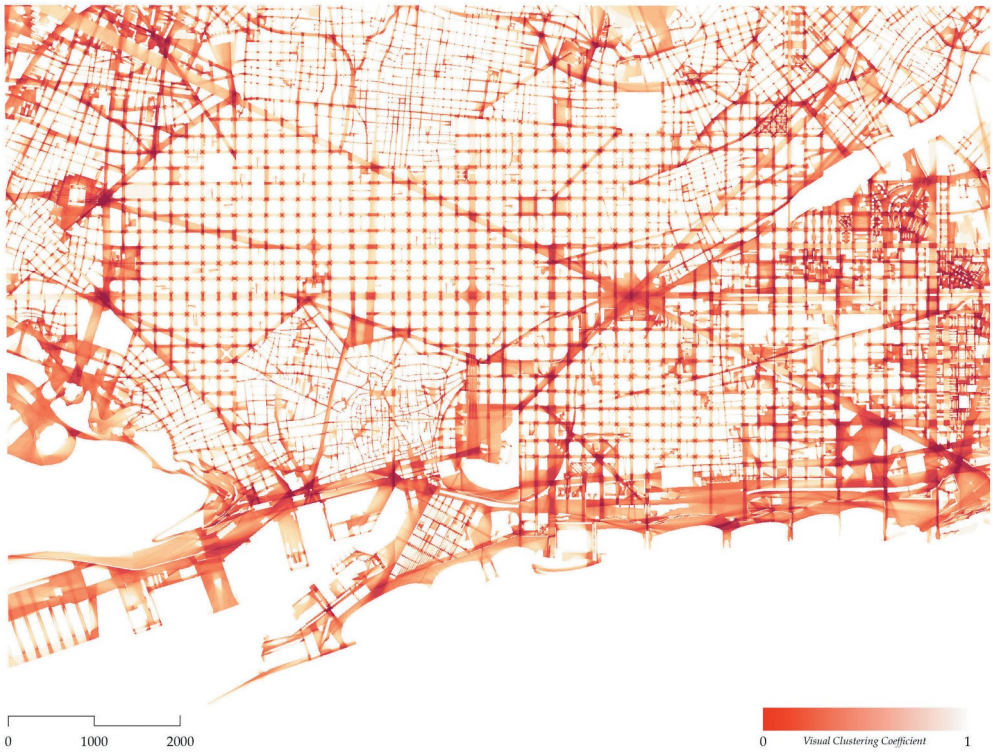

Figure 6. *Visual Clustering Coefficient*, central Barcelona (9 x 7 km).

Results. Interpretation of the VCC map

The resulting map provides an expression in colors and numbers of the *visual clustering coefficient* (VCC) for the central area of Barcelona and adjacent neighborhoods. Note that this magnitude is based on the geometry of the 2D space and therefore the methodology does not consider other attributes of the public space such as the topography, the land- use values, the influence of points of maximum accessibility, or the impact of urbanization and tree planting on the visibility study. Thus, the map provides a view of the open space that is centered only on its geometric attributes in plan. It aims to highlight the impor- tance of the structural layout of the urban form as one of the main variables that define public space. In this line, it is worth remembering that *visual graph analysis* does not directly point to any specific mode of transport, but to an overall description of percep- tion parameters. Intuitively, this method might refer, but not be limited, to 360-degree *slow* mobility or a pedestrian's perception.

The interpretation of the plan has been organized into 12 frames, which do not necessarily follow the administrative definition of the districts. Given that the identities of the neighborhoods have been widely covered in previous urban studies and particu- larly observed from a morphological perspective (see, among others, Busquets 2014b; de Sola-morales 2008a; Serra 1993), the research seeks to capture the frames that explain not only the nature of different patterns but also the continuity of the urban space among them.

Thus, the selection of 12 frames (1200 x 950 m) followed the criteria: (1) they cover a broad spectrum of the central city geography of Barcelona; (2) the frames do not focus only on the Old City and the Eixample Grid (which are the most studied areas in the aforementioned studies), but also on neighboring areas; (3) the selection focuses on the visual breaking points or transition areas that are in between the urban patterns.

Below, we present the interpretation results according to three main approaches: urban patterns, Cerda' streets and main squares.

First approach: urban patterns

The urban layout that comprises the study area clearly shows a distinction between the street space and what are, strictly speaking, the crossroads. However, there are variations within this affirmation for each urban section that is analyzed. Below is the interpretation of various urban patterns with the 12 aforementioned frames equivalent to 700 × 520 m, ordered by the degree of complexity of the *Visual Clustering Coefficient* map.

Gràcia is a district that was structured since 1820s by the continuous assembly of small housing estates built on previous agricultural plots somewhat unrelated to each other (Figure 7). As referred to in previous studies, Gràcia became a rich urban mosaic made of narrow streets and 90° corners, combined with a sequence of public squares [*plaça*] and filled with a compact fabric of row houses and, later, multi-story houses (Serra 1993; de Sola-morales 2008a).

The visual experience expressed in the *visual clustering coefficient* map shows a clear duality between corners and streets. While the streets have values close to 1 (white), the corners have similar values close to 0 (red). The straight and orthogonal grid that config- ured the original housing developments can also be distinguished from the in-between

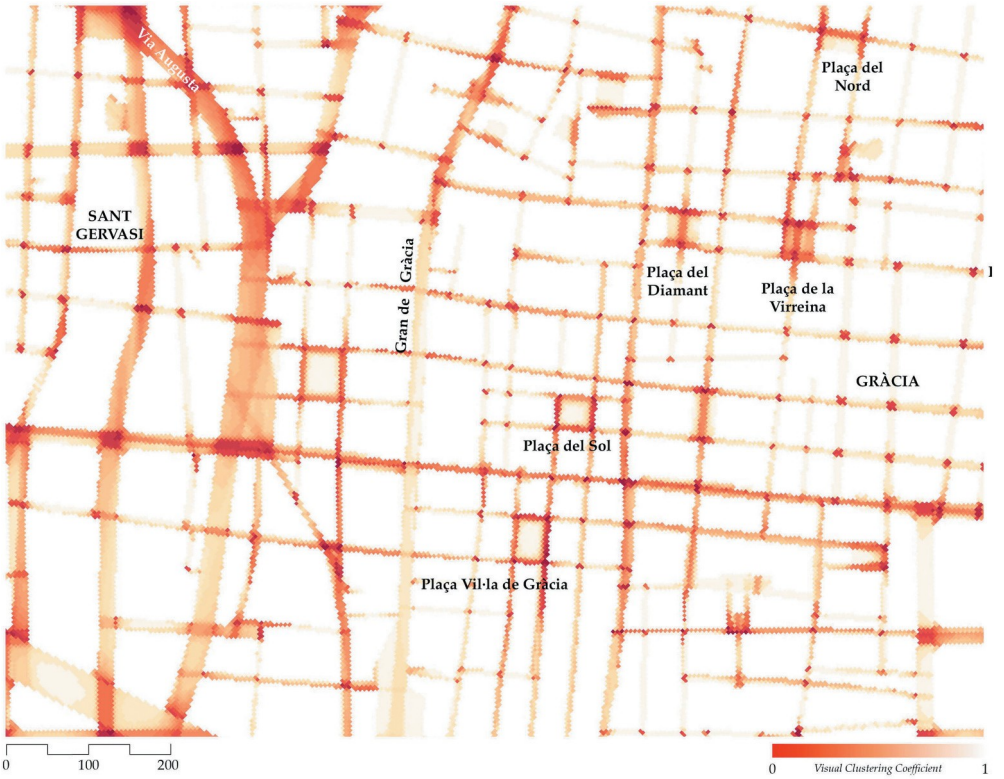

Figure 7. Gràcia and Sant Gervasi, 1200 × 950 m section.

streets that follow the sinuous line of the existing riverbeds. In perceptual terms, the curved streets are registered by the VCC map as a cadence of multiple corners, as each point incorporates in its angle of vision other points that are not visually related.

Secondly, the plan differentiates the squares depending on how the streets enter them, that is, their links with the surrounding environment. The plan highlights the sea- mountain direction in squares such as Plaça del Diamant, the horizontality of Plaça del Nord, the perimeter of Plaça del Sol and the greater complexity in terms of spaces of perceptual control in the case of Plaça de la Virreina. According to this observation, we could recognize potential points of conflict between spaces with a greater perceptual value and the real design of a public space that has gradually been pedestrianized since 2003.

Comparable arguments could be made for the center of the districts of Sant Gervasi (see also Figure 7), Sants (Figure 8) and the Camp de L'Arpa neighborhood (Figure 9), which were developed as autonomous towns until they were annexed to Barcelona at the turn of the twentieth century. As these districts share a similar street size and layout, the aforementioned duality between corners and streets can be recognized. The corners are registered in dark red, while the straight streets are shown in whiter colors.

In addition, the isovist analysis of the open space also registers some singular features that are the result of the presence of important sinuous streets like Via Augusta Avenue in Sant Gervasi [Figure 7]; main avenues such as Carrer de Sants street [Figure 8]), or the clear

Figure 8. Sants and Eixample, 1200 × 950 m section.

presence of large open spaces such as Plaça dels Països Catalans by Sants Station (refurbished in 1981 by Piñon and Viaplana architects); or Plaça Espanya, which we will refer to later (Figure 8). The narrow grids of these districts also contrast with the omnipresence of the Eixample's grid, which illustrates the substantial VCC variation considering the width and level of orthogonality. Further explanations on this topic will be presented in the following chapters.

The Old City of Barcelona or Ciutat Vella, in the center of the general map (Figure 6), is the section where the greatest complexity can be seen in the visual clustering coefficient. The following are notable: the differentiation of space in the Rambla del Raval (a new boulevard opened in 2000) or Plaça Nova square (a large space in front of the Cathedral), the identification of corners in Via Laietana (a straight street opened at the beginning of the twentieth century following Haussmann's concept) or, naturally, the influence of the layout of the streets that reach Las Ramblas, which reflect streams that used to exist and the old gateways in the city walls – points of convergence of historical paths (Figures 18 and 19). Nevertheless, the resolution of the 4 m grid used to draw up the plan has a clear methodological limitation: the narrow, sinuous streets of Ciutat Vella would require greater detail in the base grid to be able to extract valid results. Specific studies have already explored this line of research and show the possibilities of a more detailed analysis of this area for future research (Clua, Llorca, and Psarra 2020).

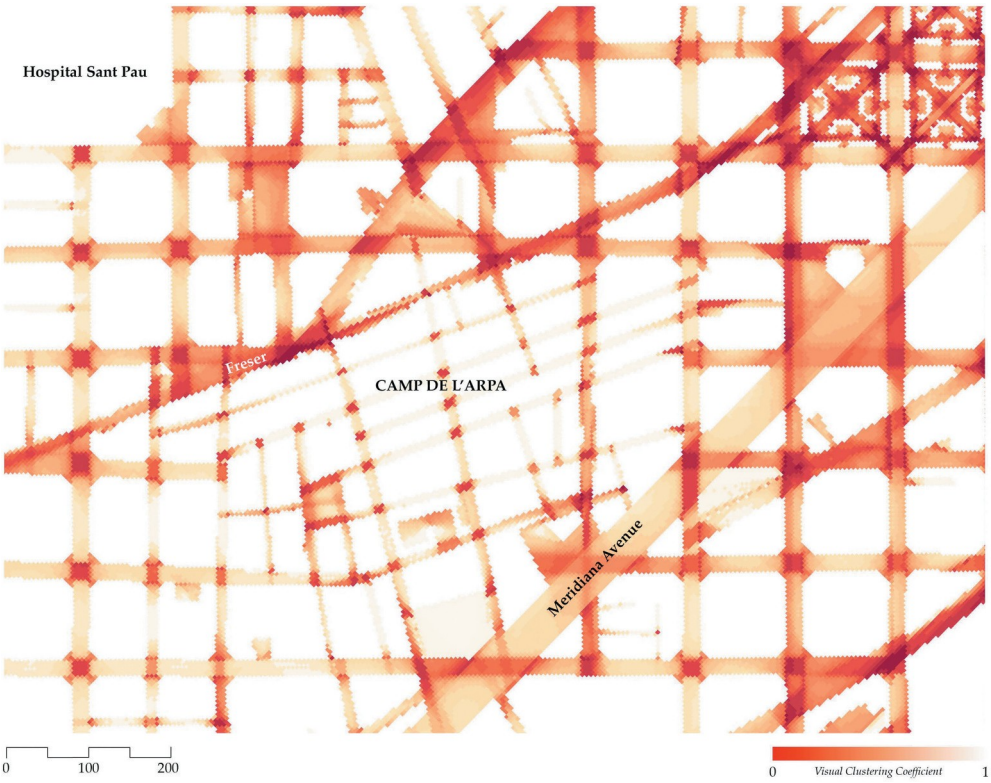

Figure 9. Camp de l'Arpa, 1200 × 950 m section.

In general, the VCC map confirms and enriches the arguments put forward in the previous cases for the interpretation of Cerdà's Eixample (since 1859), despite its regular and canonical streets of twenty meters wide (Figure 10). Again, the intersection points are highlighted as a clear figure in this urban pattern, and corridor sections of the street are diluted in white (VCC similar to 1). However, the intersections of streets in the Eixample are not simple 90° corners as in the case of Gràcia. Instead, they are chamfers that generate a more complex spatial perception. In fact, a closer look at these spaces reveals that the intense tone not only colors the central open space, but also the four pavements of the chamfer. The VCC thus reflects the singularity and richness that this octagonal form gives to the perceptual experience of the Eixample. Here, we can see that the corner has little influence on the interior of the streets, a situation that is replicated with accesses to public gardens within some of the blocks.

Although it is true that this essential pattern can be recognized throughout much of the Eixample, it is also true that the methodology emphasizes the impact of transgres- sions in the canonical grid. This is the singular case of multiple diagonals on the grid: Diagonal Avenue, Pere IV Street (Figure 13), Roma Avenue or Mistral Avenue (Figure 11). As can be seen in Diagonal Avenue (Figure 10), the VCC presents a street constructed from the sequence of corners defined by the overlaying of the Cerdà grid. The plan therefore offers an analytical expression of something that urban design teaching has observed: the diagonal on the grid is a "synthetic element that enables instant comprehension of the two directions of the grid" and "an understanding of our own location as individuals moving through the whole" (de Sola-morales 2008ba).

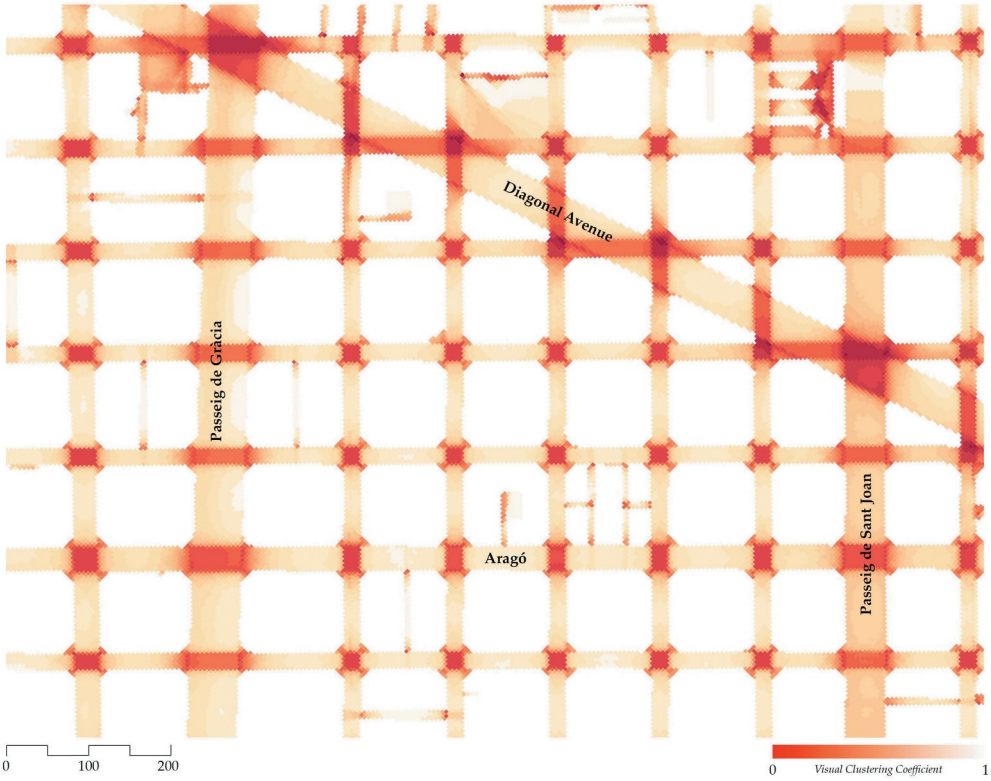

Figure 10. Eixample, 1200 × 950 m section.

In this line of interpretation, places such as the Ronda de Sant Antoni, recently redesigned as a large pedestrian area, are notable as they form a border with the Ciutat Vella (Figure 11). In their expression, we can again recognize the strength of the grid in this place of multiple geometries and the projection of the narrower streets of the historical center. The Ronda is no longer defined as a continuous longitudinal belt, a legacy of the ancient medieval wall, as is usually taken for granted in classical morpho- logical analysis. Instead, the VCC map describes it as a cadence of intersections that marks the strong contrast between the Eixample grid and the smaller urban layout of the Ciutat Vella, between the Sant Antoni Market area and the Raval.

In the end, the application of the VCC reveals again a tacit duality in the free space defined by the strength of the intersection *vs*. the fading of the streets in the compact city. However, in places where the city unfolds the urban layout in open or semi-open blocks, the VCC map can provide evidence-based outputs in situations of greater complexity.

This is the case in areas such as Les Corts-Diagonal Alta. Here, we see how large avenues such as Diagonal Avenue, even outside the context of the Eixample, persist as corridor streets in an urban layout that is progressively broken down (Figure 12). In this regard, it is significant to see how the VCC draws episodes as singular as the L'Illa Diagonal building (designed by architects 1993, Moneo and Solà-Morales). The VCC map shows the building's effort to extend the virtues of the compact city, with the duality between corner and street, and to establish a link with the greater dispersion in the arrangement of isolated tower blocks that continue the avenue. On the other side of the street, the buildings form a continuous façade with the mountain behind, although the visual field is opened up in a very different way to that found on the sea-side of the street.

Figure 11. Eixample, Poble Sec and Ciutat Vella, 1200 × 950 m section.

Beyond the corner-corridor street pattern that was observed in the above cases, Figure 12 shows noticeably lower levels of VCC, reflected in a greater concentration of red tones. This expresses two phenomena: (1) the increase in red open spaces (VCC → 0) that are not strictly intersections between streets, (2) the irregularities in the layout of the streets. Given that both these phenomena coexist with urban layouts made of corners, a more varied, richer order is created in the open space.

The process of the progressive breakdown in urban compactness can be seen with greater clarity in the extension of the Cerdà grid towards the River Besòs, in Sant Marti district. As shown in Figure 13, the emergence of VCC values determines a wide range of situations in the Poblenou- 22@ district, a new technological and innovation district built on a former industrial area. First, the rhythm of crossroads in the Cerdà grid continues and is clearly stamped on Badajoz Street but can even be discovered at the other end of the frame, towards Bac de Roda Street. On the underlying grid, we can note a sort of deformation in the pattern: (1) Diagonal Avenue considered as a corridor of practically continuous façades despite the singular arrangements in the Media TIC cluster; (2) the subtle curvature of streets like Pere IV or Sant Joan de Malta; (3) the hermetic nature of the Parc del Poblenou and its isolated accesses; (4) the diversity of spaces inside the blocks; and, naturally, (5) the star-shaped shadow of Plaça de les Glòries marked by the outlines of the vertical streets.

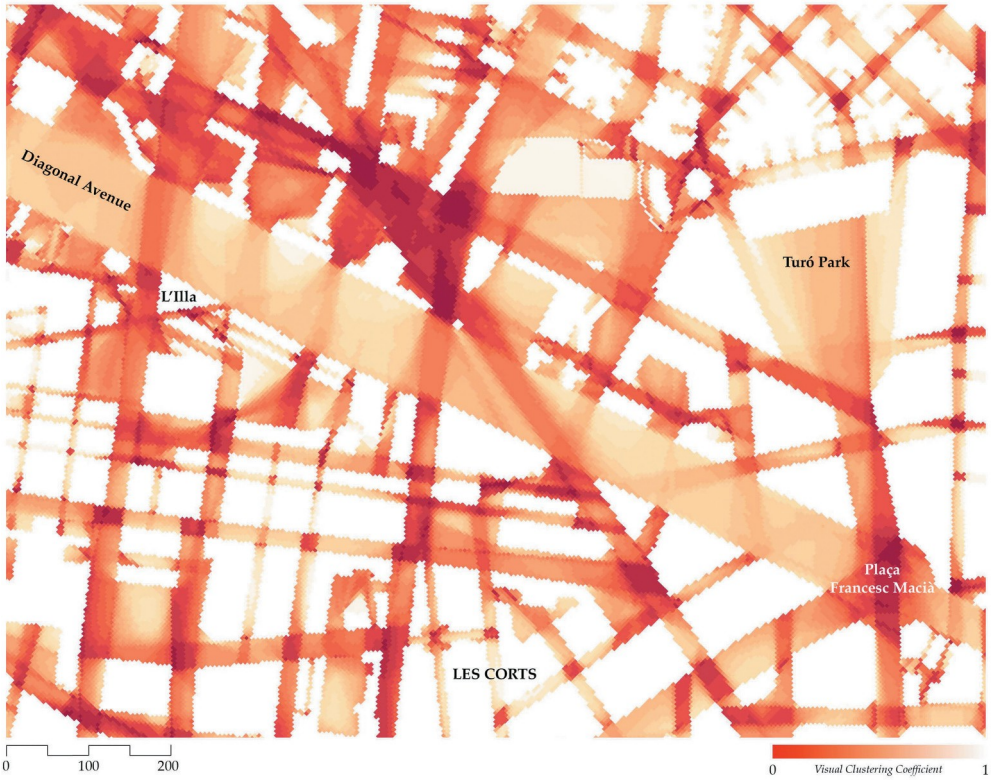

Figure 12. Diagonal Avenue, 1200 × 950 m section.

Figure 14 shows the expression of the visual clustering coefficient in Vila Olimpica, a neighborhood built for the Barcelona '92 Olympic Games. The urban masterplan, designed by Martorell, Bohigas and Mackay (MBM architects), transformed a section of the industrial Cerdà grid into a new housing district that explored the possibilities of "semi-closed blocks" and "almost a corridor" streets (Parcerisa 1997). Thus, some aggrega- tions and deformation of Cerdà's blocks were proposed, to establish a range of new housing units with a rich variety of housing typologies that defined semi-open inner courtyards (Ajuntament de Barcelona 1987).

The VCC map shows a layout that echoes the original Cerdà pattern but, at the same time, enriches the visual experience with new diagonal views, the opening of chamfered corners and new entries to some passageways leading to the inner courtyards. These diagonal accesses might be the main reason why the inner courtyards here have a clearer effect on the visual perception from the streets, in contrast to the central Eixample (Figure 10).

The frame of Figure 15 towards the Sant Marti district presents another variation of the above arguments, although with some special characteristics. First, it is surprising how much Cerdà's grid persists, even in areas like the Sud-Oest del Besòs housing estate, the La Pau housing estate or certain arrangements in Sant Marti beyond the Gran Via Avenue. The Sud-Oest del Besòs modern housing estate (built in 1959) is shown as an urban pattern with distinct intensities and is therefore structured. In contrast, the two other cases form arrangements without hierarchies in relation to the VCC, so any point in the open space generates very similar information to adjacent points. It could be stated that these are places where the multiplication of similar corners that are close to each other and undifferentiated ($VCC \rightarrow 0$) ends up negating the potential spatial richness. Therefore, more corners do not always confer greater urban richness.

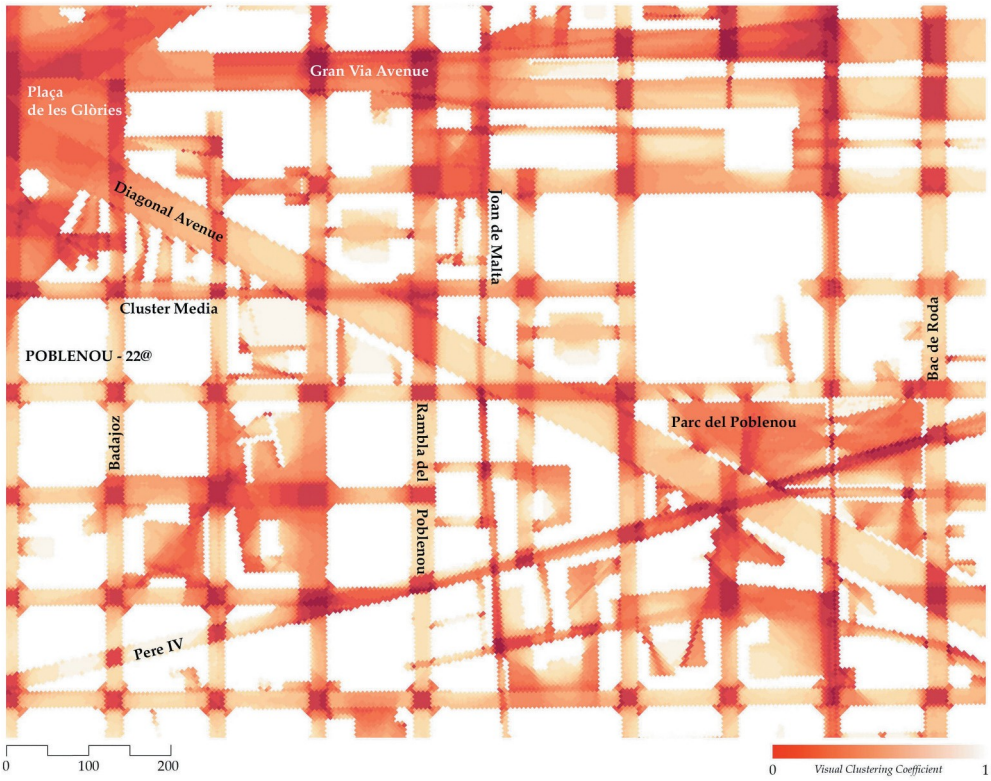

Figure 13. Eixample in Sant Marti. Poblenou – 22@, 1200 × 950 m section.

The frame of Diagonal-Mar in Figure 16 reveals a final differentiation in the interpretation of the plan: spaces where the area of low VCC (red) has much larger dimensions than the intersections or squares of the compact city. These are not, as we could initially assume, corners associated with the modern city of open blocks. Instead, they are spaces associated with situations of transformation in recent decades. Examples of these areas include the end of Diagonal Avenue and its culmination in the platform of the Forum, with the Museu Blau (2004, Herzog & de Meuron, ground floor mapped) and marked by the Telefónica building (2001, Estudi Massip-Bosch). These are spaces that perceptual experience reveals as areas with a privileged urban orientation, as confirmed by the visual clustering coefficient.

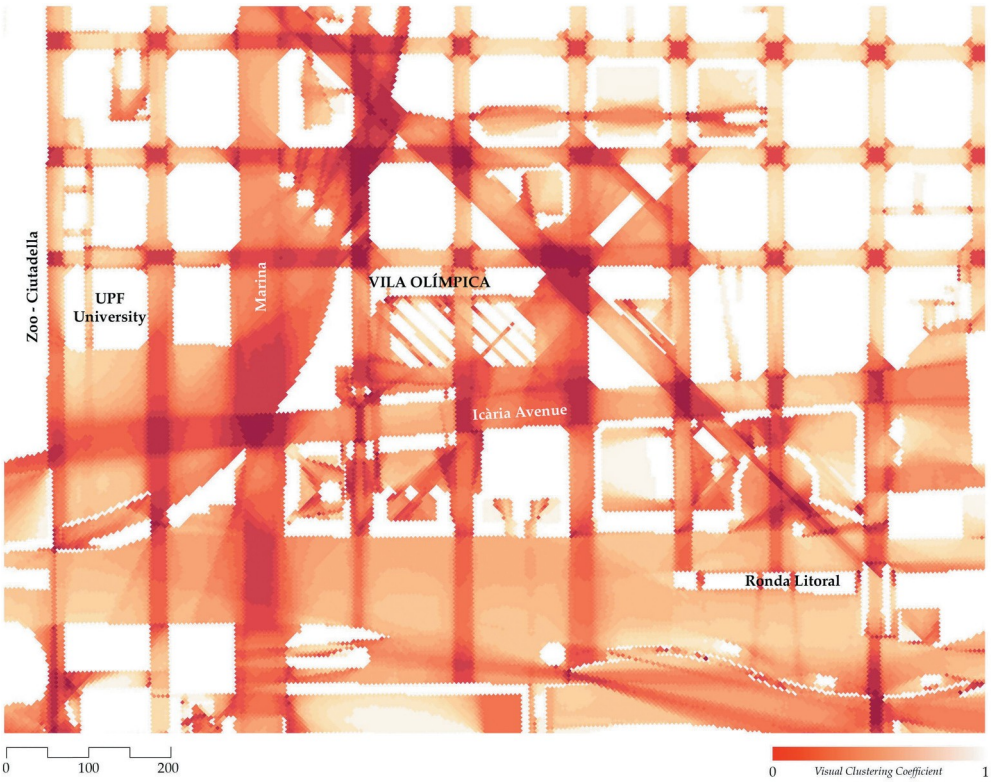

Figure 14. Eixample in Vila Olimpica, 1200 × 950 m section.

Next to this and separated by the large artefact of Diagonal Mar Shopping Centre, the arrangement of tower blocks developed around the Diagonal Mar Park (2002, EMBT) confirms the predominance of the corner at the park entrance (Diagonal Avenue with Josep Pla Street). It also indicates the perceptual importance of Passeig del Taulat and enables recognition, as in Plaça Catalunya, of a central open space with a higher VCC (→ 1) and, therefore, without attributions in the orientation systems.

In any case, this section underlines arguments that were already stated in the case of Sant Marti: an accumulation of corners is not necessarily synonymous with urban and perceptual richness, but rather an expression of indifference in the space and, conse- quently, excessive confidence in the value of architectural objects. In this case, unlike Sant Marti, these are corners where the low values of VCC (red) introduce a greater surface area of public space.
Nonetheless, some general remarks should be made on the interpretation of the map. As registered for Diagonal Mar Park and at the end of Diagonal Avenue toward the Forum area, the topography and the presence of vegetation and urbanization is relevant to the visual perception of the urban space. A dense group of trees, a subtle topographic feature or a public space design solution substantially influence and distort the perception described by the VCC method. This aspect is particularly relevant to an understanding of the open city, where the open space is defined by the buildings, as indicated in the VCC map, and by other transitory, ephemeral elements such as greenery and street design. Further research on these elements might help to provide new insights into the reading of the plan geometry displayed by the VCC.

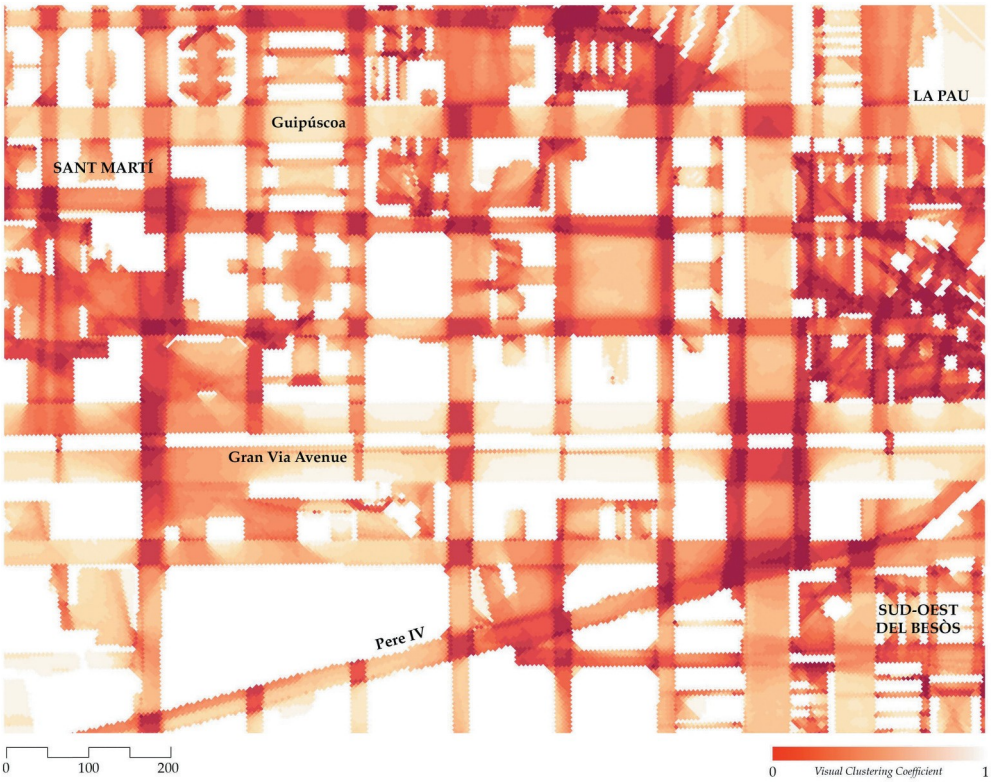

Figure 15. Eixample in Sant Marti. Sud-Oest del Besòs, 1200 × 950 m section.

Second approach: horizontal streets in Cerda's grid

Mapping of the visual clustering coefficient also reveals the sequential nature of the intersection spaces forming avenues and urban streets. As an illustration, we can compare three long equidistant avenues in Cerdà's grid with no relevant topographical irregula- rities: Gran Via Avenue, Aragó Street/Rambla de Guipúscoa and Provença Street.[8] If we consider their longitudinal section, we see a contrast between the rhythmic cadence of the extension area and its points of disruption (Figure 17).

Cerdà's grid introduces a strongly marked, constant rhythm with values oscillating between 0.3 and 0.6. Likewise, while Provença Street is notable for its evident uniformity, except where it crosses Diagonal Avenue, both Aragó Street and Gran Via Avenue display progressive unevenness towards the extreme right, caused by the aforementioned open- ing in the urban fabric beyond the Plaça de les Glòries. However, Cerdà's grid continues to be present in all these streets.

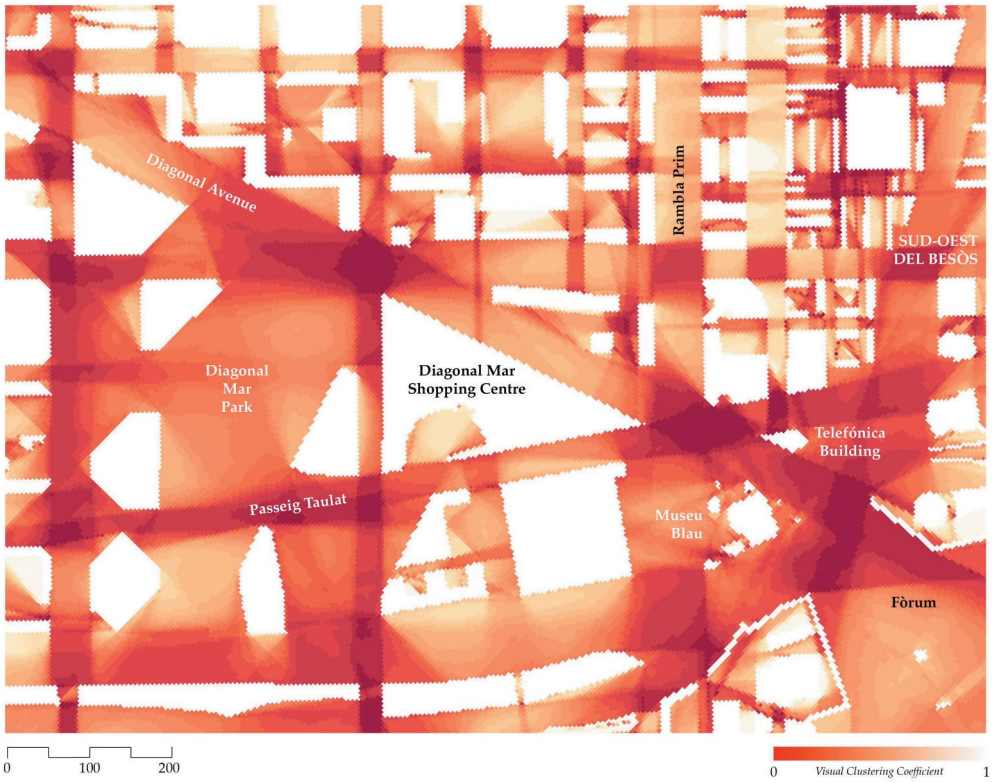

Figure 16. Eixample and Diagonal Mar/Fòrum, 1200 × 950 m section.

The comparative image of the three streets therefore illustrates the weight of differ- ences in the repetition of Cerdà's extension area, a discussion that has been present since the original design. Despite the prototypical image of the isotropic grid, and even without considering the variation in the architecture and activities that differentiate each street, the VCC frame of streets shows some substantial differences in the interaction between open spaces and the blocks, and the three longitudinal streets that were examined are clearly characterized.

In summary, up to four types of irregularities have an impact on Cerdà's repetition, in order of relevance: (1) intersections with wider avenues, (2) crossing points with diagonal streets; (3) the presence of open block areas; (4) the intersection with large metropolitan squares. While the first only subtly modifies the rhythm of the crossroads, the latter provide the greatest complexity of visual perception.

Third approach: main squares

The clustering coefficient plan provides a new interpretative image of the large open spaces of Barcelona, configured as key intersection points and usually considered in the nomenclature as large urban squares. Below some arguments are presented on a selection of these squares.

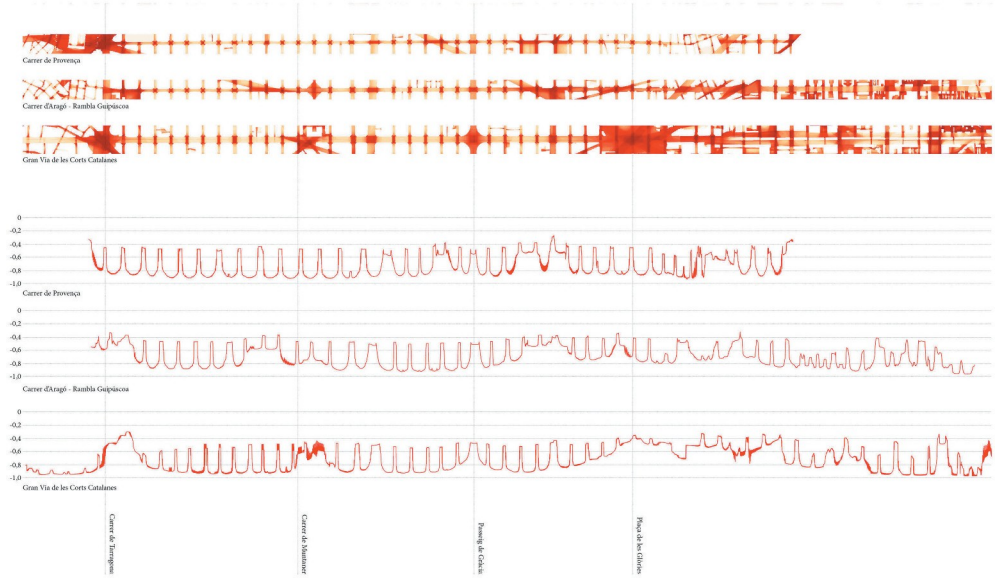

Figure 17. Comparison of the *VCC* (inverse value) in Provença Street/Aragó Street-Rambla Guipúscoa/ Gran Via de les Corts Catalanes Avenue.

Firstly, the most notable are the spaces that were designed according to the canons of *beaux-arts* squares and have consolidated the position of the old walls or key points in the orography of Barcelona (Figure 18). This is the case of Plaça Universitat, where the visual clustering coefficient enables differentiation of zones of varying intensity as a result of the extension of nearby streets. The plan provides an image of the square that extends beyond the rectangular geometry in front of the main building of Barcelona University (UB) designed by Elias Rogent (1862–1882). The intensity of the VCC values (red, tending to 0), highlights the strategic role of this space in the urban orientation of this tangential point with the Ciutat Vella: Gran Via Avenue, Ronda de Sant Antoni and Pelai Street. Likewise, it indicates the attribute of a central point with greater visibility that was occupied from 1904 to 1940 by a monument to Doctor Robert (currently in Plaça Tetuan). These data show how the plan can identify places with exceptional visual fields that therefore act as urban landmarks (Lynch 1960).

Similar points could be made about Plaça Urquinaona, where the image of *carrefour* places is reinforced: an image that is so popular in urban design literature but so difficult to express figuratively (or through artistic or intuitive procedures). Nine streets come together in traces of the old bastion of the wall around Barcelona to form a singular place in perceptual terms between the sea (Via Laietana), Collserola mountain (Roger de Llúria and Pau Claris streets), and towards Arc de Triomf (Ronda de Sant Pere) or the entry to Ciutat Vella.

Unlike the above squares and perhaps rejecting a certain deductive image, Plaça Catalunya does not reveal its condition as an orientation point but as a central open space surrounded by places of greater relevance in terms of perceptual orientation (Figure 18). Here, the continuation of the shadow of La Rambla de Catalunya is notable, as well as the more tenuous trace of Passeig de Gràcia, due to the effect of spatial occlusion towards Portal del Ángel, and the strong corner where Les Rambles begin. The central space that these streets enclose has values of VCC tending to 1; similar to the values of shared living spaces. This condition is still confirmed today by the perimetral solution of vegetation, stairways and

ornamental fountains, echoing the original idea by
J. Puig i Cadafalch between 1923 and 1927 (Parcerisa 2014, 53).

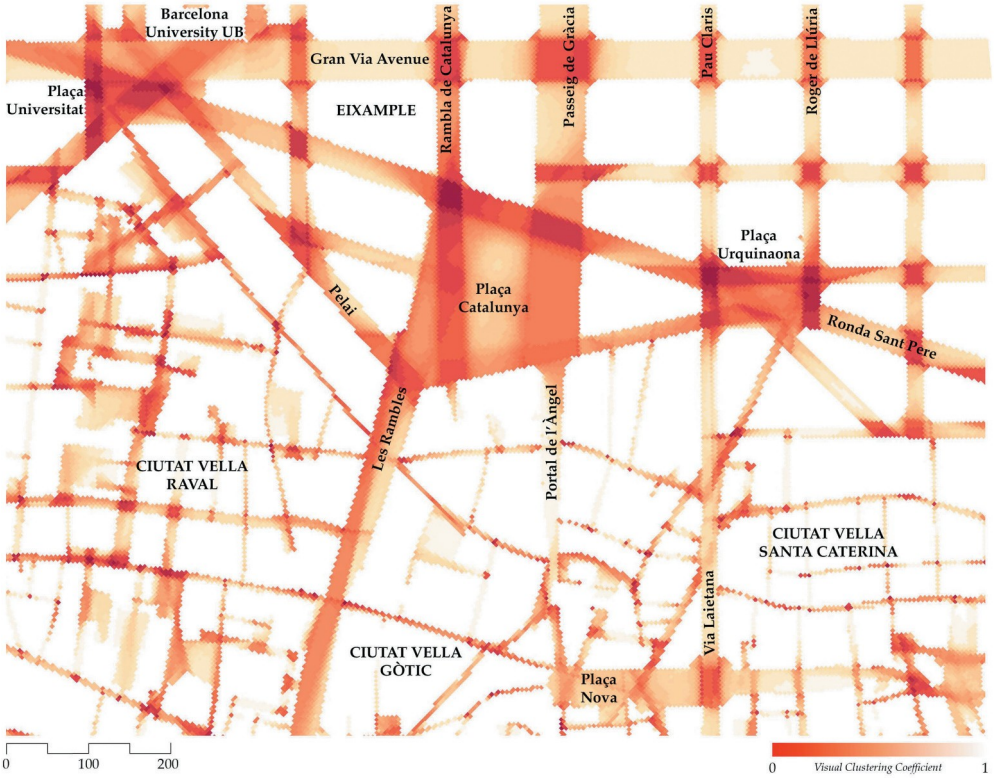

Figure 18. Ciutat Vella and Eixample. Plaça Universitat, Catalunya and Urquinaona squares, 1200 × 950 m section.

In line with the previous considerations, we can include Plaça Espanya here (Figure 8). In this square, the circular form marked by two Venetian towers for the International Exhibition of 1929 appears totally distorted. The VCC shows a fan that starts in Paral·lel Avenue (a diagonal street planned by Cerdà) and opens up towards Sants neighborhood. The nature of Maria Cristina Avenue as the main large hall-corridor for exhibitions is highlighted by the decrease in clustering value.

Finally, the description of the squares that surround the historical center of Barcelona culminates with a last setting of greater interpretive complexity: the façade towards the sea.[9] Here, what is notable is the contrast between the Plaça del Mirador de Colón's condition as a node and the expression of Moll de la Fusta promenade (designed by Manuel de Solà-Morales at the beginning of the 1980s) as two parallel urban halls with the same directionality and few points for decision-making defined by the pedestrian bridges (Figure 19).

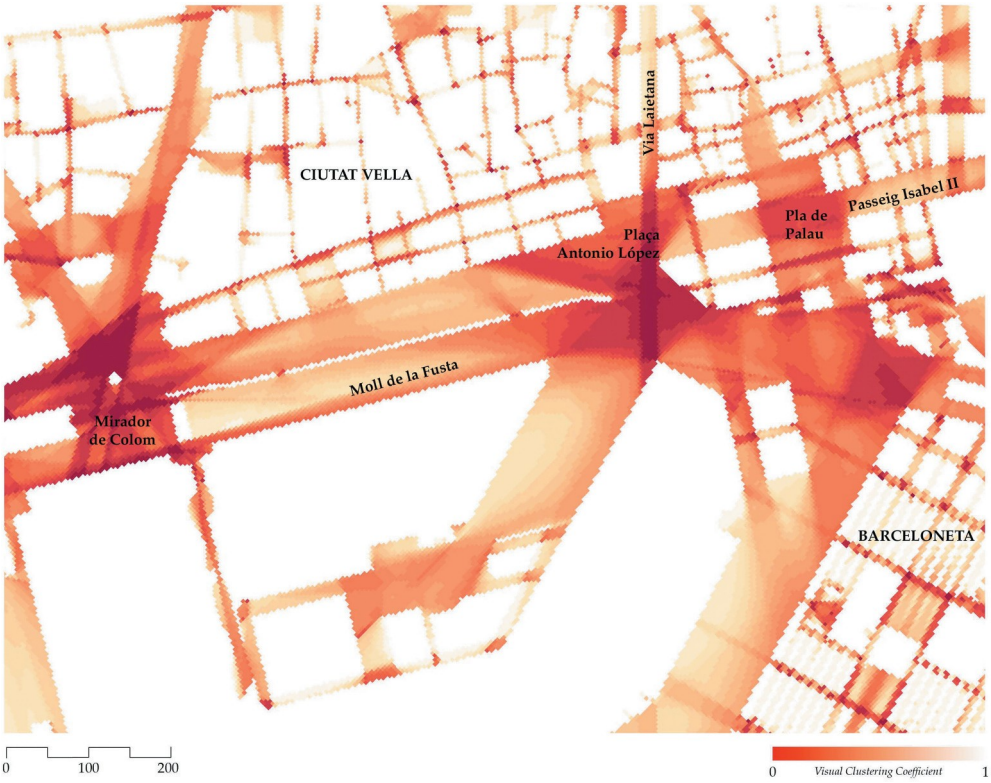

Figure 19. Seafront of Barcelona. Ciutat Vella and Barceloneta, 1200 × 950 m section.

Towards the east, the configuration of Pla de Palau square, the closest commercial spot to the sea gate during Medieval times, should be highlighted. Here, the subtle differentia- tion of zones with less intensity is confirmed as well as the strong conflict where the point of greatest perceptual relevance comes together with the space under greatest road traffic pressure in Passeig Isabel II. Is this a crossroads or a square? In reality, this is a dilemma that was introduced in the discussion of the Eixample's corner but also appears strongly in Plaça Antonio López (where the guiding line of Via Laietana street predomi- nates) or in the disconnected nature of the interstitial space between this and Barceloneta.

Discussion. Graduated intensities of the urban spaces

This study highlights the potential of visual graph analysis applied to the urban space. The following conclusions mainly refer to central Barcelona, which is a compact urban context where the gentle topography towards the sea hardly interferes with visual perception, the street greenery has a low, seasonable impact on vision, and the buildings configure a neat definition of the open spaces. However, the same methodology could provide outstand- ing results in other central areas with similar morphological features. This would be the case of central Milan, Paris, New York or London. In fact, the VCC also has the potential to be applied to any urban context, in areas with low compacity that have strong topogra- phical features or evident predominance of greenery. In those cases, the method for constructing the map and the ensuing interpretation would have to be adapted.

The following concluding remarks are mainly focused on the scale of the urban fragments discussed in this paper. However, further research may provide for new insights and a structural understanding of the overall city. In fact, the VCC map could be understood as an innovative expression of the general shape or "forma urbis" of the city, illustrating unpre-

cedented relations among their elements. This could inspire further research in the future.

Following these preliminary remarks, some specific findings could be listed here.

(1) Beyond the classical descriptive readings based on categories of urban entities, the study of isovists shows a continuous, graduated reading on the geometrical attributes of the open space. The mapping of VCC highlights a preliminary differ- entiation of the compact city based on the form of its corners (in red), in contrast with the system of linear elements or streets (in white). However, as shown in the different frames, corners have multiple expressions in the map due to their shape and the interconnection with streets, passageways and inner courtyards. This is especially remarkable in the analysis of the Cerdà Grid, where the VCC clearly registers the impact of the chamfered corner and, at the same time, the notable influence of irregularities in the street layout (Figure 20).

(2) Secondly, this study provides new insights for a graduated expression of the urban space beyond the binary figure-ground analysis. Colin Rowe and Fred Koetter referred to this analytical technique when they compared the design for Saint- Dié (1944, Le Corbusier) and the city of Parma (Rowe and Koetter 1978). Their study placed at one end the "utopia" of the modern city, where the object is built as a predominant element and consequently the empty space becomes less ten- sioned. In contrast, in the compact historical city, open space is minimized and intensified due to the tense juxtaposition of the buildings, the built-up space. However, the authors presented this duality to illustrate a necessary "strategy of accommodation and coexistence" both from the perspective of *bricolage* and its conceptualization in the *Collage City* (Rowe and Koetter 1978).

(3) In comparison with the fundamental distinction between figure and field (black and white respectively in Rowe and Koetter's studies), the VCC method highlights the form and interaction of the open spaces. In our case, the *figure* is defined instead by the *open space* (in graduated colors), while the objects remain as background in white. A comparison with an inverted image of the original Rowe and Koetter's analysis (Figure 21) helps to illustrate the value of VCC, which can grade the attributes of open space between the two opposing models. This is especially relevant for an understanding of urban situations in the open city model. As stated in the following paragraphs, VCC analysis may be useful to inspire new urban transformation criteria in areas where buildings are laid out as singular objects within a continuous open space that is commonly perceived as homogeneous and without any hierarchy.

(4) VCC is also relevant for the analytical understanding of the public spaces in semi-open blocks (Lucan 2012; Rowe and Kan 2014). Beyond the discussion of the material design of these spaces, it reveals values that are often hidden in a reading of the urban space, based on simple aggregation of spatial units. This is a crucial issue, as

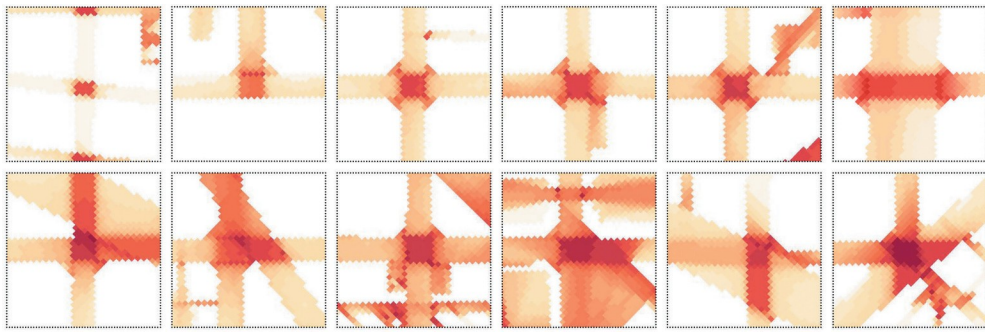

Figure 20. Selection of corners in Cerda's Eixample. 125 × 125 m sections.

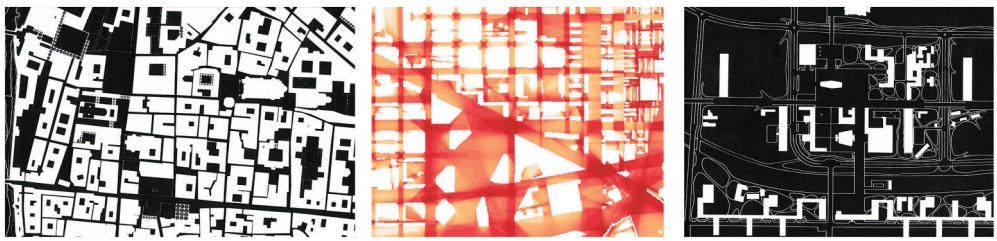

Figure 21. Grading of the *Visual Clustering Coefficient* compared with an inverted version of the figure- field map of Parma and Saint-Dié (Le Corbusier, 1944), published by Rowe and Koetter in *Collage City* (1978).

the analytical method objectifies the importance of the relational value that each public space should have in the city. Frequently, the design and redesign of elements is produced by independent pieces in a self-referential way, not just because of the intentions of the designers, but also due to the way these spaces are referred to and managed. In contrast, the VCC map differentiates each element according to how it is interrelated, and highlights nuances between similar elements whose geometry and position invite analogical, non-independent design solutions. Ultimately, VCC analysis indicates what is essentially good urban design: an understanding of the local singularity of each element in its capacity to simultaneously interrelate with the rest of the elements that are more or less nearby, which configures the urban structure to which they belong.

(5) The fact that VCC can identify the relative value of each point in relation to its perceptual capacity may provide some criteria for understanding the hierarchy of open spaces. Although a linear, automatic application of VCC to urban design criteria is not evident, some arguments could be highlighted. Firstly, the VCC method is a valid tool for understanding certain attributes of urban intensity, as it registers the places that are most visible with respect to the environment and, at the same time, gives greater visibility to the environment. Using these tools, it is easier to consider the suitability of some sculptural landmarks, the preponderance of successful stores placed on corners or the role of some urban elements in the visual experience of the city.

Secondly, if low levels of VCC (red) refer to decision-making points, these areas might be associated with spaces of high movement friction, spaces where multiple itineraries converge. In turn, high levels of VCC (white) might mainly refer to bidirectional spaces, where friction is not so prominent. Flows and visual interaction might therefore be linked, following previous studies on the understanding of the spatial layout as the "primary generator" of patterns of movement (Hillier et al. 1993). In this line and following specific insights on squares in Gràcia district or large intersection squares in central Barcelona, the VCC might help to drive the eventual refurbishment and reorganization of these spaces according to their potential use patterns and their specific role in a given urban layout. Some recent studies have tested the capacity of a higher resolution and precision analysis to elucidate specific arguments in this line (Clua, Llorca, and Psarra 2020), which makes the current research a sound base for further research in selected areas.

6. As a corollary to the previous argument, the value and limitations of the VCC method should be explained. The VCC method is not designed to provide a holistic description of the use of a given space. It does not consider prominent attributes that also describe the intensity of an urban space, such as the land use of ground floors, topographical features, environmental parameters, the urban density of activities and dwellings, or the level of connectivity and centrality in terms of public transport, among others. Nevertheless, the VCC method is particularly relevant as it puts the emphasis on more unvarying urban elements: the front lines, land parceling and enclosures, as reliable structural components in the definition of open space.

To sum up, the quantified exploration of perception through isovists that has been tested here for one of their magnitudes, the *Visual Clustering Coefficient*, emphasizes a field of study that could strengthen evidence-based approaches to the analysis and transformation of open space, through the integration of other more circumstantial variables to achieve greater wealth, optimization and integration of the spaces and routes of inhabitants of the metropolis.

Notes

1. An open source version of the software and documentation is available at: https://varoudis.github.io/depthmapX/Date accessed: 21/04/2019
2. A free version and full documentation of the software *Isovist.org* is accessible at: https://isovists.org/Date accessed: 21/04/2019
3. Some of the application of this methodology by Space Syntax Ltd can be found at: https://spacesyntax.com/urban-places/streets-parks-and-public-spaces/Date accessed: 21/04/2019
4. Despite the fact there is no English translation of this text, many years later the author published an adapted synthesis in *Lotus International* with the title "Space, time and the city/ Spazio, tempo e città" (de Sola-morales 1986).
5. Other relevant lines of research that LUB opened at that time could be mentioned, such as urban topology and accessibility (Gómez Ordóñez 1971), an issue that received renewed attention in studies on the metro system (Parcerisa and Rubert de Ventos 2002).
6. To speed up computing for the 1,156,816 points that form the case-study grid, 10 + 10 subsamples of 1600 × 2400 metres were superimposed. Using this method, the deformation of the values generated at the edges was minimised. The aforementioned software *Isovists.org* can be used to compute the entire frame simultaneously, with greater resolution and speed. Further research will explore this software, which is now under continuous development.

7. Here the term “convex space” is used according to the definition used by Hillier and Janson in *The Social Logic* of *Space*, i.e., a “convex space is one in which no straight line drawn between any two points goes outside the space”(Hillier and Hanson 1984, 97). In intuitive terms, this geometrical concept is often related with concavity.
8. Inverse values of the clustering coefficient have been used to make an intuitive interpretation more evident.
9. In this case, a limitation in the generative process of the model should be highlighted, as the sea is represented as an opaque solid. This results in an image that cannot be discussed in the same perceptual terms as in the above cases: in reality, the other side can be seen. However, the VCC can also be interpreted as places for decision-making in pedestrian routes (Cfr. Turner et al. 2001, 111) and, therefore, the representation of the sea as an impassable solid is also accurate.

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