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Bridging configurational and urban fabric analysis: the street as a keystone

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The street is the support of the urbanity par excellence.

1. Introduction

More than 80 years after the Athens Chart (CIAM), in October 2016 a “New Urban Agenda”, also known as *The Quito Papers*, has been proposed at the United Nation Conference on Housing and Sustainable Urban Development (“Habitat III”). This new manifesto for the future of cities is based on three main principles: *the open city*, *the city to the citizens* and *urban design* as a tool for making cities more equitable. As highlighted in this document, urban design regains a central role which should not be limited to the notions of planning, zoning and regulations but also to the small scale of the design of a single street and its physical properties (Sassen et al. 2017).

The street should become the centre of the debate among practitioners and researchers; it represents the mean through which different disciplines in urban studies and design might communicate and interact providing a better understanding of urban spaces and their influence on the overall functioning of cities.

When focusing on urban morphology studies, the importance of streets in urban physical form is anything but overlooked: in the last decades a growing number of quantitative approaches have been focusing and developing street-based and street-related measures in theoretical and empirical studies.

Three main quantitative approaches might be recognised: ***street configuration*** investigating the spatial organisation of streets and its relationship with human flow (Hillier and Hanson 1984, Porta et al. 2006, etc.); ***street design*** focusing on the qualitative and quantitative analysis of the intrinsic characteristics of streetscapes and their effect on human perception (Ewing and Handy 2009, etc.); ***street and urban form patterns*** at wider scales with a typo-morphological approach and more closely related to urban planning (Marshall 2005, Berghauser Pont and Haupt 2010, etc.).

While the first two research directions have been independently developed, cross-analyses between these three aspects have recently been proposed in urban morphology. Several authors have proposed techniques for integrating street-network configurational properties and morphometric descriptors. Four main approaches might be highlighted:

-Juxtaposition of outcomes from specific approaches as in the works of Gil et al. (2012), Berghauser Pont et al. (2017), where classificatory approaches are separately implemented for different urban components (i.e. street configuration and block typologies) and the combined cartography of the outcomes allows analysts to visually compare and discuss the results and their spatial co-occurrences.

-Incorporation of configurational variables into typo-morphological multivariate analysis as in Marshall (2005), Vialard (2013), etc. or, reversely, the introduction of built form measures in configurational analysis such as weighted centrality assessment as in Sevtsuk and Mekonnen (2012) or in Place Syntax in Stahle (2007).

-Mix as in Oliveira (2013), Ye et Van Ness (2014) where configurational and morphometric indicators/procedures are combined in the same spatial unit providing elaborated measures.

-Statistical relationship such as the work of Peponis et al. (2007) investigating the correlation between configurational and morphometric descriptors at the scale of the entire city.

Although these approaches propose interesting insights into the relationship between different aspects of the urban form, the central role of the street is only partially considered. Indeed, these combinatory approaches come from the domain of urban morphology and planning where the traditional street-block/aerial point of view is privileged, whereas configuration and urban design give prominence to streets and pedestrian perception from the streets.

For these reasons, the simple combination of procedures independently developed with different points of view (aerial/street) and goals might not always be the best practice. Moreover, important statistical biases might be introduced when forcing the convergence of analyses using diverse underlying spatial units. As highlighted by Kropf (2017), when the goal is to combine different approaches, urban form analysis should be reconceptualised.

The first goal of this paper is thus to propose a literature review of recent computer-aided procedures in the three aforementioned domains of research, whenever the analysis is focussed on the street. Its second goal is to show that the street segment can be a possible shared unit of analysis, bridging the three domains and avoiding theoretical and statistical inconsistencies found in many cross-analyses.

This paper is organised as follows. Section 2 briefly describes the main notions and approaches developed in street network configurational studies. Section 3 presents urban design GIS procedures for the analysis of the *skeletal* streetscape. Section 4 focuses on recent developments of bottom-up and street-based procedures for the identification of typologies of urban fabrics renewing the traditional approaches of typo-morphology. Finally, Section 5 shows how the implementations of three of the aforementioned procedures using the same spatial unit definition, the street segment, might allow a coherent exploratory data analysis of different facets of the urban physical form. Conclusions are discussed in Section 6.

2. The Configurational Approach: the Street within a Complex Street Network

Inspired by the seminal works of the Centre for Land Use and Built Form Studies at the University of Cambridge, Hillier and Hanson (1984) developed a coherent theoretical framework and methodological procedures for the implementation of graph theory to the physical organisation of spaces, named Space Syntax (SSx). The object of the analysis is the configuration of spaces both at the building level and the urban grid aiming at measuring the capacity of a spatial arrangements to produce encounter patterns. Space is simplified as the juxtaposition of voids separated by visual physical obstructions: at the urban scale, they analyse the spatial structure of the network of public spaces.

SSx theory develops the idea that physical boundaries strongly influence the visibility and perception of enclosed spaces and, consequently, human movement. Focusing on those areas available for pedestrians and delimited by buildings, an innovative reconceptualisation of the complexity of the urban space is proposed. The urban open space is partitioned into convex polygons approximated with visual axial lines; the relationships established between these lines through their intersections allow performing configurational analysis similarly to graph analysis previously elaborated by Freeman (1977) in the domain of complex social networks.

Configuration is defined by the same Hillier “*as, at least the relation between two spaces taking into account a third, and, most, as the relations among spaces in a complex taking into account all other spaces in the complex.*” For this reason, “*Spatial configuration is thus a more complex idea than spatial relation, which needs to invoke no more than a pair of related spaces*” (Hillier et al.1987). This is an essential concept that SSx (as well as other configurational analyses) derives from a systemic approach: the importance of an element is defined by its relative position within the whole system. SSx protocol provides a quantitative description of the spatial properties for each street (more precisely each axial line) within urban space: this method opened the way to a deeper understanding of the relationship between urban form and human movement. The resulting set of indicators have been also proved to be able to capture important aspects of socioeconomic and behavioural phenomena such as land use, retail distribution, crimes etc.

While SSx segment analysis investigate the dual¹ graph representation of the axial network, where axes are represented by nodes and intersections by arcs, a second group of configurational analysis have been more (relatively) recently proposed considering a primal graph representation of the street network. Multiple Centrality Assessment by Porta et al. (2006a) and the metrical/directional centrality indicators by Peponis et al. (2007) independently developed graph theories from structural sociology (Freeman 1977) on the traditional representation of street networks proposed by transportation

¹ Recent works by Marshall (2016) and Marshall et al. (2018) detect some inconsistencies in the scientific literature in the use of the notions of *primal* and *dual* representation of the network graph (for further details see in Marshall et al. 2018 section 3.2); nevertheless, “*a definitive conclusion on this issue awaits a dedicated review of all relevant kinds of graph and their relations*”. For this reason, in this work we still use the conventional primal/dual graph distinction as originally proposed by Porta et al. (2006)

models. Street networks in the primal approach are modelled by graphs where junctions and streets are respectively represented by nodes and arcs.

Further developments and proposals have been considering alternative modelling possibilities: street names, angular analysis, continuity analysis, Intersection Continuity Negotiation, natural roads etc (for an overview, see Fusco and Tirico 2016). Each of these approaches proposes alternative ways to interpret the human movement behaviour in urban space simplifying two elements: the street representation and the modelling of shortest paths.

Graph analysis approaches applied to these different modelling procedures might highlight different street network properties; specific advantages and limitations are associated to each modelling procedure and the choice of the specific method is strictly dependent on the purposes of the research.

A detailed description and comparison of every configurational analysis approach developed in the last twenty years goes beyond the goal of this work. Fusco and Tirico (2016) propose a categorisation through the combination of three fundamental aspects: (i) graph representation (ii) street network modelling, and (iii) network metrics.

After a first broad differentiation between primal and dual model of the street network as previously described, two further aspects should be considered. *“The first one concerns the modelling of the network, i.e. the way we identify the physical elements of the street network. There are at least four different options: topological elements (defined by connections which are consistent through deformation and magnification/ reduction of the urban space), angular elements (defined by directions which are consistent through magnification/reduction but won’t resist deformation), dimensional elements (segments of a given length, which won’t resist neither deformation nor magnification/reduction), socially defined elements (like street names or any other cognitive and social recognition of form elements, which depend on the social representation of urban space). A second additional aspect to be considered is the way distance between form elements is defined within the network: it can be topological (number of connections, whatever the nature of the connections is), angular (modelling the psychological impedance to change of direction in movement) or dimensional (metric or temporal distance on the network, modelling the physical impedance to movement).”* (Fusco and Tirico 2016, p.2).

Based on these large methodological choices, configurational approaches developed specific vocabularies to describe network configurational properties. On one side Peponis, Porta and Sevtzok adopt the traditional parameters and names originally proposed by Freeman (1977) (such as Reach, Betweenness, Closeness and Straightness). On the other, Space Syntax and derivatives use the vocabulary specifically developed by Hillier and Hanson (1984) (such as Node Count, Integration and Choice). Nonetheless, configurational indicators are comparable when differences in vocabulary are overlooked.

Independently of the specific methodological approach, the goal underlying configurational studies consists in finding the best generalisation of human behaviour allowing to describe the overall movement patterns within urban spaces. The only way to prove the superiority of a specific

methodology (*if one exists*) requires its validation through empirical data collected of pedestrian counts. The debate comparing and evaluating the goodness of a specific configurational procedure is far from being closed, and we expect in the next few years a growing number of studies supported by the diffusion of advanced tracking technologies providing new sources of information (i.e. cameras, Wi-Fi, GPS tracking systems).

Despite the awareness among urban morphologists about the importance of the ‘*network effect*’ in the determination of pedestrian flows and socioeconomic phenomena, recent studies highlighted how research still need to better understand how this effect works (Omer and Kaplan 2018). Configurational approaches have been conceived and traditionally assessed in homogenous areas (usually compact monocentric cities). Contrasting results emerge when the same analyses are carried out on case studies presenting main morphological differences.

Berghauser Pont and Marcus (2015) observed different associations between pedestrian volumes and network properties when considering three districts of Stockholm (two in the centre and one in a semi-central area). Lerman and Omer (2016) apply a similar analysis to two sub-areas of Tel Aviv: significant variations are detected between traditional and contemporary neighbourhoods. Analogous conclusions are reached when studying retail distribution in cities with different urban planning developments as in Omer and Goldblatt (2016) or within different sub-regions of the same city as in Remali et al. (2014).

As demonstrated in these recent works, configurational properties on their own they are not enough to explore the multifaceted characteristics of the urban physical form and their impact on behavioural and socioeconomic phenomena. It is therefore evident how the combination with other approaches becomes essential for a better understanding of the urban morphological system.

3. The Urban Design Approach: the Streetscape

Urban design focuses on the description of the urban form at a small scale ranging from the design of individual façades, to the street environment and up to a small urban fragment. It is an interdisciplinary domain at the middle ground between architecture, urban morphology and planning. Urban design “*is concerned with the extension of architecture beyond the design and construction of individual buildings and with the attainment of environmental quality, broadly defined*” (Rowley 1994). While urban typo-morphology was mainly initiated by the European schools, urban design finds its origins in the North American context of the late 50s².

The notion of urban design is a multifaceted concept at the crossway of several domains (Rowley 1994). While configurational studies are associated to the human movement in public spaces, urban design studies are related to environmental psychology, human perception, cognition, behaviour and

² in 1957, the American Institute of Architecture established a Committee on Urban Design and the creation of the first course of urban design at Harvard University in 1960. The seminal works of Lynch (1960) and J. Jacobs (1961), Alexander (1977), are joined by north European authors as Cullen (1961), Ghel (1971), etc.

more recently, health. Studies in urban design traditionally investigate the relationship of morpho-functional descriptors with walkability, liveability, physical activity, appeal, perceived safety etc.

Within urban design literature, numerous perceptual qualities have been described and their importance have been widely debated in the last decades; nonetheless, it is only in more recent years that urban design literature has attempted to objectively measure perceptual qualities, rather than simply assert their importance (Ewing et Handy 2009). Ewing et Handy (2009) propose a systematic approach to operationalise design notions through quantitative measures. Not all urban design qualities might be reinterpreted in quantitative terms; some are more amenable to measurement than others.

Based on the importance assigned in the literature, Ewing et Handy (2009) select and successfully operationalise five main notions (*Imageability, Enclosure, Human scale, Transparency, Complexity*). They propose 28 indicators such as counts and proportions of specific micro-grained features which might be observed in urban spaces. The correlation of these indicator with walkability measure is then investigated. Similarly, Purciel et al. (2009) operationalise streetscape measures using a variety of GIS data sources; in this study a set of “*objective and theoretically-grounded indicators*” quantify physical and functional variables of 588 block-faces in New York and correlated to pedestrian counts.

GIS algorithms are also developed in the works of Harvey et Aultman-Hall (2015) and Harvey et al. (2017). These authors differentiate between *skeletal* and *skin* components of a streetscape. “*The former supplies the spatial structure for a scene, defining the size and shape of space; the latter embellishes with visual texture.*” Despite the fuzzy boundary between the two aspect, skeletons of streetscapes are defined as the spatial distribution of massing of surrounding buildings, providing spatial proportions that may be elemental to perceptions as comfortable urban spaces (Harvey et Aultman-Hall 2005). This intrinsic geometrical/compositional description of the physical form as perceived from the street might be closer to the notion of perceived volumes of Alexander (1933). Based on this definition of skeletal streetscape, several variables are proposed and implemented: measures such as facades set-back, height, cross-sectional ratio between height and width, façade frequency etc. are measured on vector representation of buildings and street centrelines. These variables are finally individually correlated to different phenomena such as crash severity and perceived safety (Harvey and Aultman-Hall 2005).

In a more recent work Harvey et al. (2017) measure 12 streetscape skeleton variables on more than 120 thousand block-length streetscapes in three north-eastern U.S. cities: Boston, New York, and Baltimore. Cluster analysis is then used to identify four streetscape skeleton classes that are also consistent between cities: upright, compact, porous, and open which is proposed as alternative to the functional classification traditionally proposed by transport planners (arterial, collector, and local).

These last works focus on GIS procedures applied to vector data describing the physical layout of the built form along the street edges; we should also mention that, in the last few years, data science is contributing to urban design with innovative algorithms for the operationalisation of more qualitative

measures from street view images³. These highly sophisticated approaches based on imagery analysis will provide in the next years interesting insights assessing and developing the traditional notions proposed by the seminal works of urban designers.

Algorithms for street view image processing propose a pedestrian perspective in the analysis of urban spaces as alternative to traditional satellite/aerial images. Similarly, GIS skeletal streetscape represents the street-based alternative for traditional urban morphology analysis. Nonetheless, while the former requires sophisticated algorithms and large volumes of data, the latter is based on simpler geo-processing algorithms on vector representations of the urban form elements. Further research should investigate the relationship between *skeletal* and *skin* attributes of the streets and their relative importance on human behaviours.

The skeletal streetscape is not only the interface between private and public or street and block spaces. It might be also considered as the interface between urban design and urban morphology (traditionally focusing on different aspects and scales of the urban form) and, as we discuss in the next section, the starting point for the identification of the urban fabric from the pedestrian point of view.

The streetscape as defined in the aforementioned works has received less attention in urban morphology studies which have traditionally privileged aerial approaches based on street-block measures. Vialard's work (Vialard 2013) is an exception: from the original definition of block-face in Purciel et al. (2009), Vialard specifically focuses on the interface between streets and blocks. "*The block-face emerges as the morphological element that naturally associates the properties of the street network and the properties of the buildings*" (Vialard p.36). Nonetheless, the notion of block-face is conceived and operationalised following the classical block-centred approach typical of urban typomorphology (i.e. absence of the third dimension, implementation of built form indicators using street-block barycentre as reference, etc). Moreover, classification of block-face is obtained mixing geometrical descriptors with street network configurational properties going beyond the definition of the streetscape in urban design.

Urban designers like Purciel et al. (2009) or Harvey and Aultman-Hall (2005) correlate detailed local urban morphometric variables with pedestrian counts or human behaviour/perception similarly to what proposed in street network configurational studies. In both cases, these works overlook the importance of the urban morphological context. As configurational analysis needs to investigate the 'network effect' in different urban contexts, similarly, urban design should investigate the role of a specific street design indicator within different urban contexts: variables as height, length or continuity of facades along streets might play different roles in historic centres, planned or peripheral neighbourhoods etc. The identification of the urban morphological context becomes necessary in urban design especially when streetscape measures are implemented on large geographical extents

³ Such as street frontage in Law et al. (2018); Liu et al. (2017); greenery in Naik et al. (2017), scenicness in Seresinhe et al. (2017), etc.

(as in the works of Harvey) encompassing a wide heterogeneity of urban fabric typologies and morphological regions.

Remali et al. (2014) go in this direction. They investigate both street design and configurational properties in relationship to socioeconomic descriptors of three emblematic neighbourhoods of Tripoli (Libya) with three different planning historical developments. Here again, the expert-based identification of archetypical neighbourhoods is a fundamental step in the analysis of street characteristics in different urban physical subspaces.

As we discussed in the previous section, both configurational properties and urban design morphometric descriptors, when applied to large urban areas encompassing a wide variety of urban forms, might show different correlation values with pedestrian counts and socioeconomic variables. The identification of the morphological context becomes an essential phase of the analysis which might contribute to the understanding of the effects of the street network and/or of the streetscape within a wider urban area.

4. Typo-morphological Approach: the Urban Fabric seen from the Street

The implementation of GIS-based analyses in urban morphology studies finds its theoretical background in the British, Italian and French schools where the notion of typo-morphology has been developed. Typology refers to the systematic study of architectural forms, and the direct relationship that the building has with the plot and its serving street, while the notion of Morphology denotes the study of larger urban structures and patterns (the urban fabric, the morphological region). The final goal of typo-morphological studies is to recognize the spatial structure of an urban fragment, village, town, city or metropolitan area by examining the patterns of its component parts (Mudon 1994).

Classical typo-morphological schools privileged qualitative approaches, with emphasis on the historical process of production of observed urban forms. Quantitative analyses were limited by both the computational power and data availability to small urban fragments. Only in the last few decades, quantitative computer-aided procedures have known a fast development providing more robust and scientific support to this discipline, allowing the identification of urban fabrics and morphological regions within vast study areas.

When observing the quantitative procedures recently developed in urban typo-morphological studies, a three-step *modus operandi* might be recognised (i.e. Gil 2012, Song 2013 etc.). **Step A)** A specific spatial unit, a subset of urban elements and a scale of the analysis are chosen. **Step B)** A set of size and shape descriptors quantify the characteristics of the urban form (morphometric descriptors) within each spatial unit. **Step C)** The implementation of multivariate analysis procedures supported by graphical representations or more sophisticated classificatory approaches.

The development of these quantitative multivariate protocols offer two main advantages: “*firstly, they allow for the definition of types based on multiple variables in a precise and repeatable manner, enabling the study of large samples and the comparison between both cities and regions; secondly,*

they frame design choices in terms of types without being fixed and so open up for design explorations where the relation between the variables can be challenged to propose new types." (Berghauser Pont et al. 2017)

Two main limitations might be highlighted when implementing the traditional three-step classificatory approach at the neighbourhood level. Firstly, the definition of the spatial partitions: a large number of urban typo-morphological studies focus on specific emblematic morphological regions traditionally delimited by the expert knowledge of the analyst or they adopt exogenous spatial partitions (i.e. administrative units). The second is that these works traditionally focus on the spatial distribution of urban form elements overlooking the importance of the street both as a point of view from which urban form is perceived and as a spatial constrain along which humans move and explore the urban fabric of a city.

To overcome these limitations (individually or conjointly considered), researchers have recently proposed new approaches for the bottom-up pedestrian-based delimitation and description of different types of the urban fabric. These automatic procedures allow the spatial aggregation of fine-grained spatial units in coherent spatial patterns (urban fabrics) without a predefined delimitation of their spatial extents (which could result in whole morphological regions).

Song et Knaap (2007) and Song et al. (2013) propose a *location-based* definition of spatial units: Euclidean buffers are traced around each location, morpho-functional indicators are calculated, factor analysis and classification finally allow the identification of typologies of neighbourhoods. Location-based approaches use a more consistent definition of neighbourhoods focusing the analysis and classification to the relative *immediate* urban context.

While in these works the context surrounding specific locations is evaluated with Euclidean buffers, Berghauser Pont and Marcus (2014, 2017), propose a similar location-based approach to measure and classify built form context introducing network-constrained distances. From each location, a set of built-up density descriptors is implemented on a network-based floating catchment area.

Combining measures of network-constrained accessible built form (as in Stahle et al. 2007, Sevtzuk 2012, etc.) with the Spacematrix graphic classification (Berghauser Pont and Haupt 2010), a new approach for the bottom-up identification of density typologies is described and implemented in the recent works of Berghauser Pont et al. (2017). Through this innovative approach, each location is associated to a typology of built-up density context.

All these approaches share a similar methodological innovation modifying the first of the three steps of the aforementioned procedure: instead of defining fixed spatial units for the subsequent morphometric measures, they consider a larger moving area centred on each location (point, street, parcel etc.). These procedures implement a smoothing operation of the individual fine-grained morphometric characteristics considering the local surrounding area to each location under study (Euclidean or network-constrained).

Bottom-up identification of morphological context might be also obtained through the modification of the third step of the traditional classificatory approach, like in the procedure proposed by Hamaina et al. (2012). The first two steps remain mainly the same as previously described: definition of a fine-grained spatial unit (generalised Thiessen tessellation based on built-up footprints) and implementation of morphometric measures including both traditional density measures (such as GSI and FSI) and innovative visual measures generated by empty spaces (such as isovists and sky view factors). The third step represents the innovative component: instead of traditional classificatory analysis, the authors implement spatial clustering approaches (geographical self-organised maps Geo-SOM) allowing the identification of twelve categories of urban fabrics coherently distributed in the urban space.⁴

Nonetheless, the street perspective is only partially integrated in Hamaina et al. (2012): several innovating indicators of visibility of the built form are integrated, overlooking the street network connections among spatial units. On the contrary, the works of Berghauser Pont and colleagues consider street network constrained measures (accessible densities) with the traditional aerial point of view and thus overlook the street perspective of the built volumes.

To overcome these limitations, a third bottom-up procedure approach have been recently proposed by Araldi and Fusco (2017; 2019): Multiple Fabric Assessment (MFA). MFA allows the identification of urban fabric typologies and the analysis of their spatial organization integrating both the analysis of the urban streetscape (similarly to the works of Harvey) and the location-based network-constrained approaches. The procedure might be summarised as follow: i) definition of a street-based partition of the urban space and implementation of skeletal streetscape morphometric descriptors. ii) identification of location-based network-constrained autocorrelation patterns of streetscape morphometric by means of specific spatial statistics approaches. iii) Clustering of morphometric spatial patterns through Bayesian methods in order to identify and characterize typologies of urban fabrics.

This third protocol modifies the traditional three-step procedure intervening on the second phase: instead of classifying raw indicators, MFA highlights spatial patterns of morphometric indicators on a fine-grained partition of the space. The street point of view is considered twice: the first time for the identification of the spatial unit in relation to which morphometric indicators are computed; a second time in the network-based calculation of patterns.

In Fig.1 we summarised the traditional three-step procedural approach of quantitative typomorphological analysis and the three alternatives for a bottom-up identification of urban fabrics. Differently from traditional approaches, these procedures do not need an *a priori* and expert based knowledge and definition of the space study and of its sub regions (similarly to configurational analysis). We claim that, without introducing bottom-up approaches, traditional classificatory

⁴ The only limitation of this approach is associated to the application of measures such as isovists and sky view factors, which might limit the spatial extent of the analysis. The example of Hamaina is indeed implemented on a small urban fragment of 5 square kilometre area.

schemes either produce classes of urban form components (missing the spatial dimension of the urban fabric) or characterize exogenously defined spatial units.

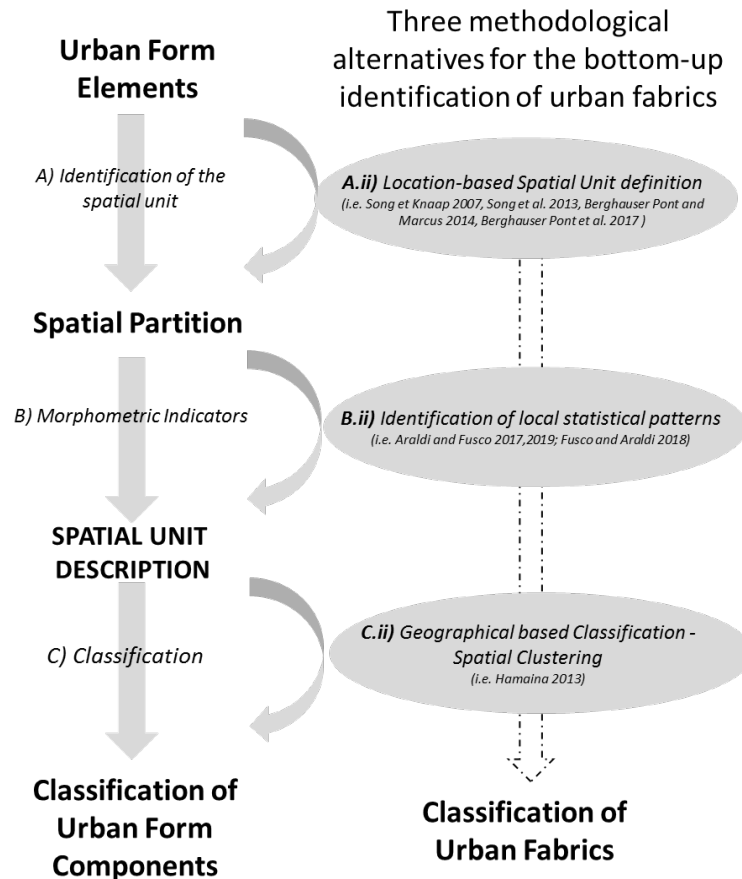


Figure 1 Traditional three-step identification of urban morphological patterns (left) and three methodological alternatives for bottom-up approaches, which become necessary to identify urban fabrics.

5. The Street as a Bridging Element

In the previous sections, three main quantitative approaches for the study of the urban physical form from the street point of view have been outlined: i) **configurational/relational**, ii) **compositional/geometrical**, and iii) **contextual/typo-morphological**. The three Cs represent three approaches able to describe different facets of the urban public physical space. While the first two have been naturally conceived and implemented for the description of street properties within urban space, the third has been only more recently developing new bottom-up street-based protocols.

By using the street segment as a common spatial unit, we can implement and combine these three procedures. In this section, we implement the *three Cs* on the primary approach where the street segment is defined as the centreline segment between two intersections. Several reasons motivate this choice: firstly, “*the dominant network model is the one that represents the street junctions as vertices in the graph and the linear street segments as its edges*” Marshall et al. (2018). Secondly, using street network centrelines and the primal approach would allow the identification of configurational properties independently of the physical shapes or sizes of the built forms surrounding the street segments (isolating configurational properties and morphometric measures). Thirdly, the use of centreline plays the important role of geometrical reference when studying the streetscape from the street point of view (measures of setback, parallelism of facades, etc. use as reference street edges and/or street centrelines). The use of visual axes as in SSx or alternative street-like representations of the street network would provide a distorted reference system for streetscape descriptors.

Our case study is the street network of the French Riviera, on which we implement Multiple Centrality Assessment (Porta 2006), skeletal streetscape indicators (similarly to Harvey 2017 and Araldi and Fusco 2017) and Multiple Fabric Assessment (Araldi and Fusco 2017, 2019). Figure 2 shows some of the results describing the cities of Cannes and Antibes and their inner municipalities: configurational properties (Reach, Closeness and Betweenness Fig.2-left), streetscape morphometric indicators (Street acclivity, Building Setback and Facades Misalignment Fig.2-centre) and urban fabric typologies (the nine families of urban fabrics described in Fusco and Araldi 2017, Fig.2-right).

Beyond the mapping of each descriptor, we can provide several statistical exploratory analyses of the relationship between several urban features like Peponis (2007). The coherence of these analyses is assured by the shared level of the individual street segment and the integration of a morphological contextual variable. For instance, in Figure 3 the conditional boxplots show the distribution of some streetscape indicators and configurational properties (local Reach [300m], Betweenness [1200m], building frequency and building setback) within different urban fabrics. Similarly, Figure 4 provides the conditional density distribution (left) and prevalence (right) of configurational properties within different urban fabrics.

Similarly, other measures such as qualitative pedestrian counts or socioeconomic occurrences might be straightforwardly correlated to individual morphometric measures on the overall space study considering different urban morphological regions. This approach might propose new insights in the analysis of the network and urban design effects conditional to urban morphological regions as introduced in the first section. Other innovative statistical modelling approaches might also be implemented (such as Network Constrained Geographically Weighted Regression, Multilevel Linear Modelling, etc.).

The street becomes a bridging element between different urban quantitative approaches (the three Cs) but also between close and still different disciplines such as urban design and urban morphology. Transport studies, social sciences, environmental psychology and many other fields in urban studies might also benefit from this coherent, multivariate and multiscale description of the urban form.

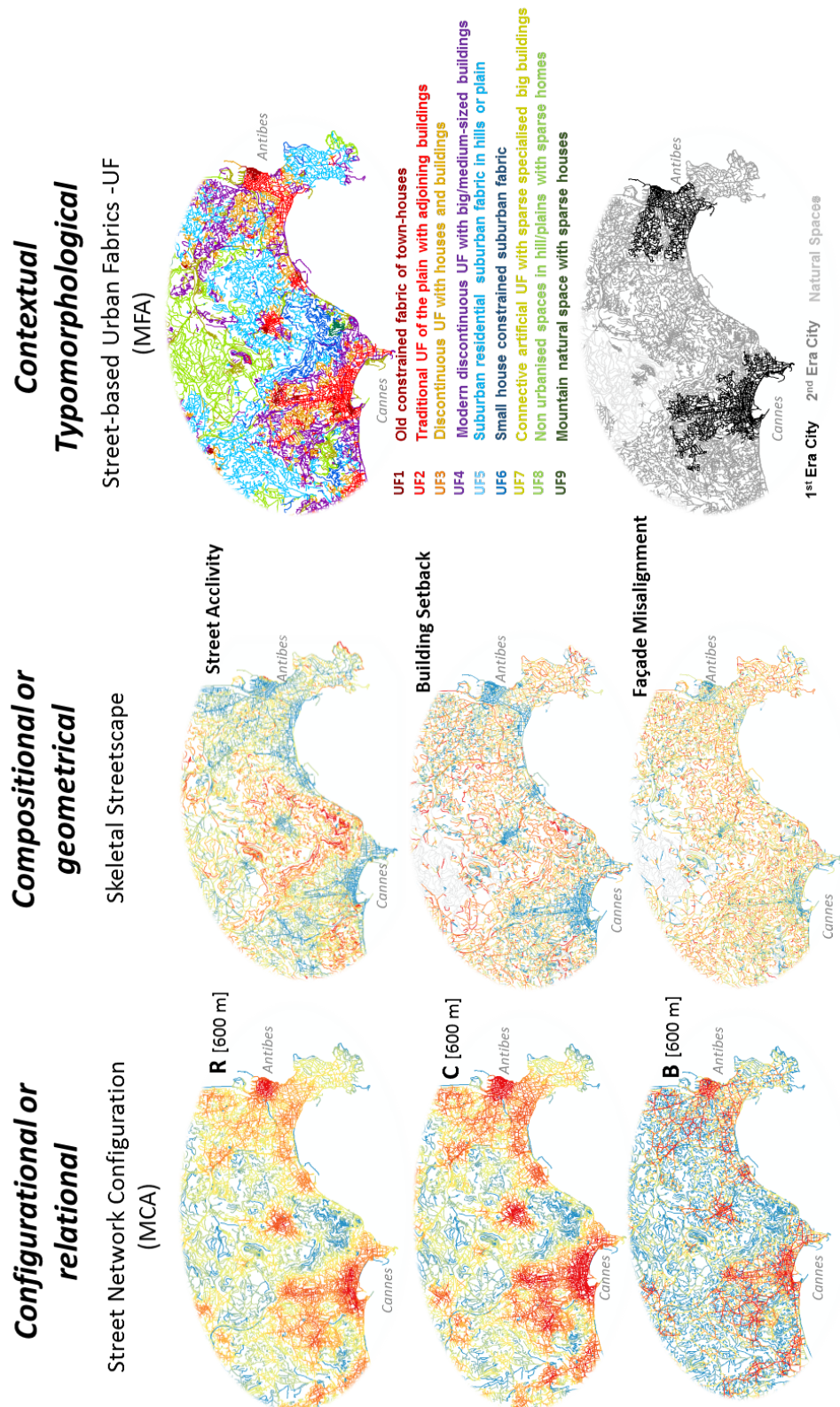


Figure 2 From the left to the right: implementation of street network indicators (MCA-Porta et al. 2006), skeletal streetscape indicators (Harvey et al. 2017.), typologies of street-based morphological regions (MFA-Araldi and Fusco 2017,2019)

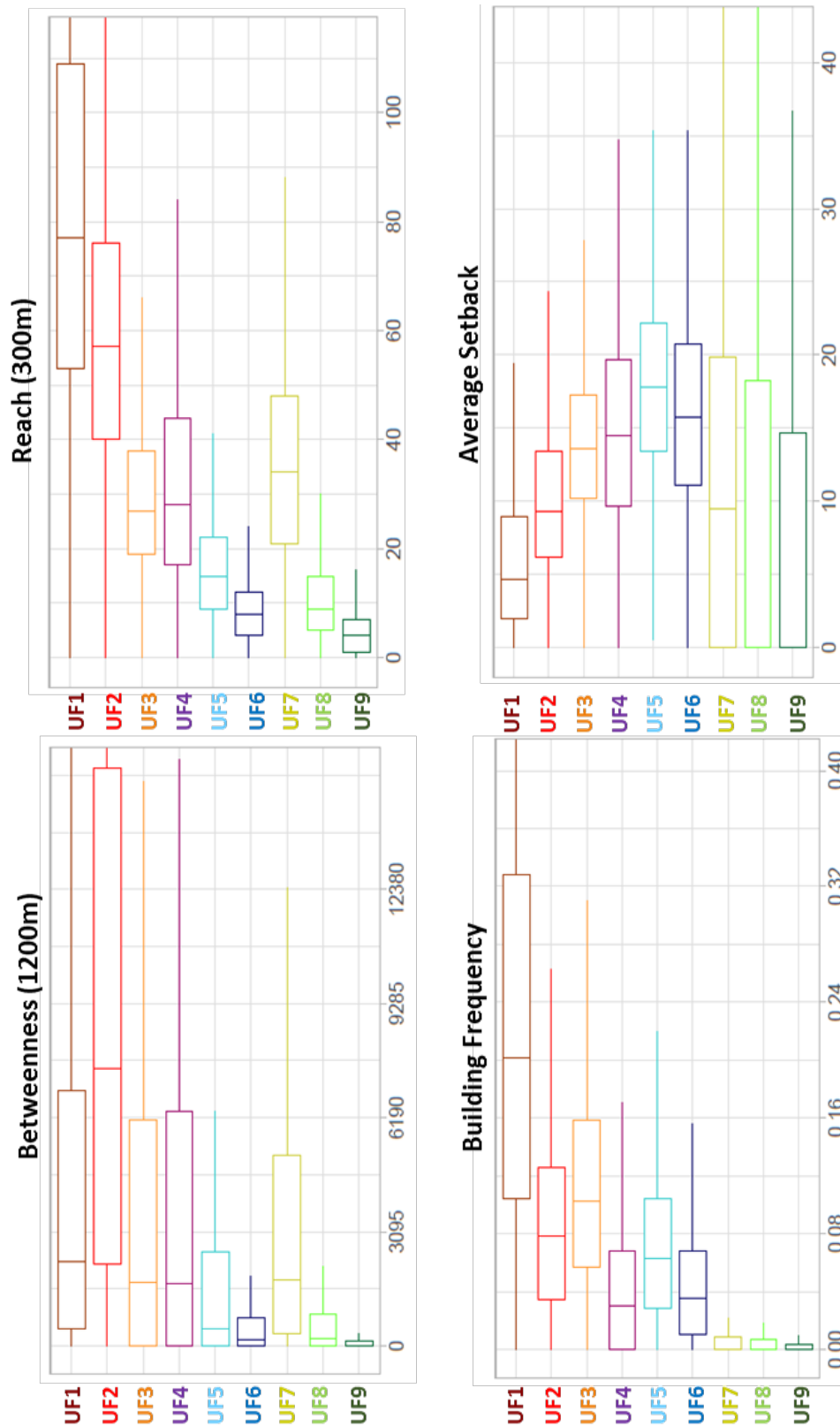


Figure 3 Example of EDA: conditional box-plot of two configurational indicators (*Betweenness[1200m]* and *Reach[300]*) and two skeletal streetscape indicators (*Building Frequency* and *Average Setback*) considering nine typologies of urban fabrics.

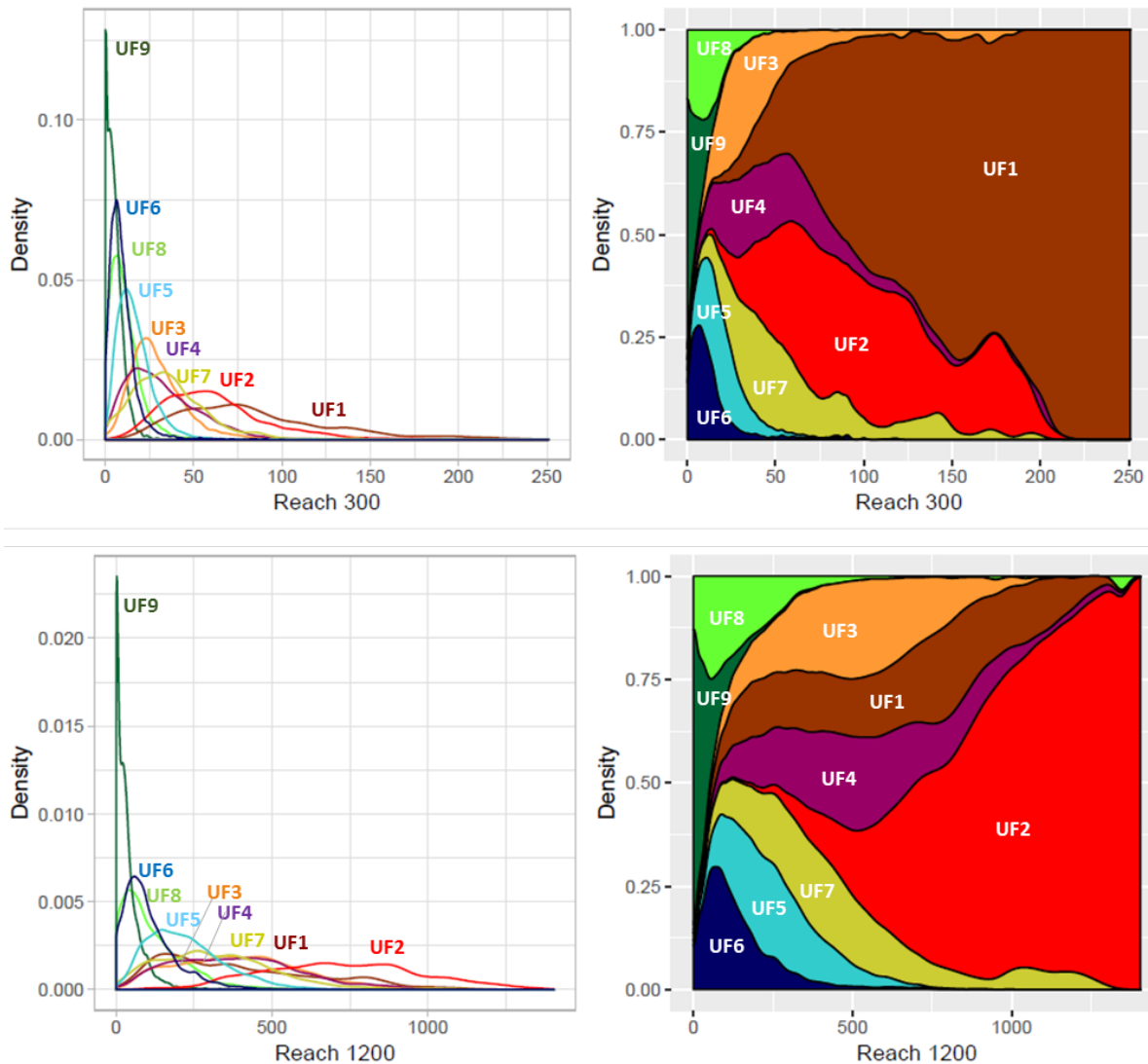


Figure 4 Example of EDA: conditional density distribution of two configurational indicators (*Reach[1200m]* and *Reach[300]*) considering nine typologies of urban fabrics. (left: densities- right: prevalence)

6. Discussion/Conclusion

In this work we described how different approaches for the analysis of the urban form might be implemented and bridged within the common framework of the street point of view. Configurational analyses and urban design studies of streetscapes have been using street-based approaches very early. Typo-morphological research has also integrated the street in its theoretical approaches (and above all by the authors of the Italian school) but quantitative analyses have traditionally relied on aerial block-based approaches. We showed how

typo-morphological analyses have recently been renewed by street-based and bottom-up approaches for the identification of urban fabrics as perceived from the street.

Configurational, urban typo-morphology and urban design can now converge on a common definition of the basic spatial unit, the street segment, allowing a coherent analysis of the multifaceted reality of the urban physical form. As the application to the French Riviera shows, cross-analyses of the different aspects of urban form become much easier and avoid the methodological inconsistencies associated with different conceptual frameworks of the urban space.

Of course, this does not mean that the street-based approach should become the only reference in urban morphology. The block-based approach is still essential in the analysis of the urban morphogenesis, and urban planning is still concerned with blocks and plots more than with streets (even if this could be a shortcoming of contemporary planning practice). The final goals of urban form analyses justify the approach to be privileged. What the paper suggests is that when the goal is the explanation of human phenomena taking place on public space (like pedestrian flows, pedestrian perceptions, car accidents, retail activity, crime, etc.), a common framework becomes necessary and the street segment is the most natural one. By calculating configuration properties, streetscape features and urban fabric characteristics, the analyst is finally able to determine the relative importance of the position within the street network, the quality of the local design and the wider urban form context on observed human phenomena. A precise assessment of the role of urban form in the aforementioned research domains is left as future research endeavour in urban studies.

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Captions:

(insert max 4 B&W images JPEG 300 dpi as separate files)