



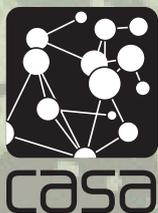
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**Quantifying and
Mapping Streetspace: a
Geocomputational Method
for the Citywide Analysis of
Pedestrian and Vehicular
Streetspace**

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Quantifying and Mapping Streetspace: a Geocomputational Method for the Citywide Analysis of Pedestrian and Vehicular Streetspace

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Abstract

The purpose of this paper is to present a methodology for quantifying streetspace designation across entire cities. The new street level data is generated using a geocomputational approach that both allows for a quantitative citywide description of streetspace at a micro-scale and that can be replicated across multiple cities. The high spatial resolution description of streetspace covering large urban areas can be valuable to city designers and urban planners in the context of current challenges of street congestion, promoting active travel and rapidly evolving mobility technologies. It is observed that London streetspace is assigned mainly to vehicles and wider streets relate to the street network hierarchy and concentrate in the inner city. The new street level data introduced here can yield important insights for street research, planning and design.

1 OVERVIEW

In this paper, we present a novel method to quantify streetspace designation measures of all streets in a large urban system. The data is geometrically derived from urban physical environment digital mapping data, commonly utilised in urban planning, applying a cross-section technique often used in design to describe the physical characteristics of an object. Data processing is conducted using free and open-source software to facilitate replicability. The metrics of pedestrian and vehicular streetspace are mapped citywide to examine the street physical form at the design and strategic scales of the city.

The study of streets traverses various and diverse fields and disciplines. It is perhaps the intermediate position that streets have in the environment as Anderson argues, which constitutes them as a complex phenomenon, at the intersection of ‘public and private, individual and society, movement and place, built and unbuilt, planning and architecture’ (Anderson, 1978, p. 1). What role do streets play in mediating the relations between people and the urban built environment? Mathematically reasoning, Alexander (1965) observes that it is the ambiguous roles of the street system and the overlap of the street subsystems that generates the conditions for a living city. Two interrelated street subsystems are illustrated in Alexander’s taxicab example; the pedestrian and the vehicular. This conceptualization shows

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that streets serve different, sometimes divergent, but often complementary roles for the workings of cities.

Most comprehensive studies of street systems have focused on the analysis of the structural properties of the system or network configuration analysis (Hillier et al., 1993; Strano et al., 2013; Turner, 2007). For such studies, the street is represented as one element; either a link or a node. This process of abstraction allows a comprehensive examination of the relations between the streets that constitute the system (Marshall et al., 2018). Generally, under the lens of street-network configurational analysis the most important streets are those more central (i.e.: better-connected streets have more activity). The modification of the relations between the elements of the system (e.g.: the addition or subtraction of links) results in a new system configuration. This operation has been used in urban design to improve the overall connectivity of street systems (Mboup et al., 2013). However, while these kinds of transformations have been key in some urban design interventions, its application is limited by the difficulty of pursuing such infrastructural renovations, especially the addition of new links in consolidated urban areas. In these cases, given the endurance of streets layout mainly due to property definitions (Carmona et al., 2010; Kropf, 2009; Scheer, 2016), the re-design of streets is more likely to occur redistributing streetspace among the pedestrian and vehicular spaces rather than changing the structural properties of the street system. Because of data availability less attention has been dedicated to the comprehensive study of the relationships between street width and urban structure and dynamics (Barthelemy, 2016).

Recently, as a result of emergent changes in mobility technologies (Kitchin and Dodge, 2011; Sevtsuk and Davis, 2019; Sheller and Urry, 2006) and increasing levels of urban congestion and densification; an important number of transport policies and urban design proposals argue for a more people-oriented design of streets in big cities, globally (Centre for London, 2017; Global Designing Cities Initiative, 2016; Mboup et al., 2013; Sadik-Khan and Solomonow, 2016; Transport for London, 2017). Rethinking the space of the street unveils the competing demands for streetspace and raises questions of how streetspace is allocated to fulfil the multiplicity and overlap of functions that streets play out besides circulation (Alexander, 1965; Jacobs, 2011). Equally, it highlights the reciprocal relationships between the design and strategic scales of street systems. Consequently, a citywide analysis is suggested to get a wider appreciation of the impacts of changing pedestrian-vehicular street space relations (Appleyard et al., 1981).

2 STREETSACE CONCEPTUALIZATION, FORMALIZATION AND DATA PROCESSING

2.1 DEFINING STREETSACE FOR SPATIAL ANALYSIS

Given that a key aspect of this study is to get a precise and accurate measurement of the street physical environment, it is necessary here to clarify exactly what is meant by streetspace. The following definition is intended to fit with both the theoretical framework of the subject of study and the practicality of accessing meaningful data about the subject. The street is a commonly-used notion in studies of urban form. It encompasses a physical element described as both an open space related to buildings and an open space that is not a plot (Scheer, 2016). This definition helps distinguish 'streetspace' in clear terms from the other two key physical elements of urban form; buildings and plots. However, to provide an unambiguous definition of streetspace it is necessary to define what is a plot. To distinguish between plot space and streetspace it is useful to look at the aspects of use and control of space; private and public (Kropf, 2009). This relationship can be often derived from landownership urban cadastres. While urban surveys might not always include the definition of individual plots, the space of the street and the space of the plots are commonly represented as two different elements. As will be seen when discussing the data sources in the following section, this distinction allows for a precise definition of streetspace. Streetspace is the open space area related to buildings outside the plot boundaries.

This streetspace definition highlights the limitations of traditional urban planning approaches. Conventionally, the scope of a road plan encompasses interventions over road space (road width, number of lanes, kerb space), often focusing on traffic efficiency. Similarly, land use plans, while relevant to streetspace social and economic activity, involve decisions over land within private property boundaries. Although these planning instruments can be combined, the planning and design of streetspace often remain outside their scope (Jones et al., 2008). Therefore, the examination of streetspace designation metrics over whole urban areas offers analytical insights for urban street planning and design that can be complementary to traditional planning approaches.

2.2 STREET ENVIRONMENT DATA SELECTION

A close examination of the physical composition of streetspace shows a sub-structure of linear parts that are related to the functional organization of the street. Most commonly these parts are the footways and carriageways which added together constitute the total street width. Generally, the width of streets, footways and carriageways can be consulted from digital urban survey maps that represent the built environment with high detail. The width metrics for each street, however, are not found readily available but need to be measured using tools provided

by Geographic Information Systems software. This makes impractical the comprehensive spatial analysis of streetspace at large scales.

In contrast, a widely available street data set are road centre lines (RCL). Essentially, RCL are discrete linear elements representing the two border lines of a road or path that are collapsed into one line drawn in-between at the centre of the road. This type of geometrical abstraction allows the derivation of the street length and the topological structure of the set of streets which is useful for analysing relationships in a street system (connectivity, accessibility, routing, etc.). Nevertheless, the streetspace designation metrics cannot be derived from RCL datasets. Therefore, it is necessary to create a data generation process to efficiently calculate the streetspace metrics by combining RCL with built environment datasets. The typical representation of streetspace derived from urban area survey and RCL data sources is presented in Figure 1.

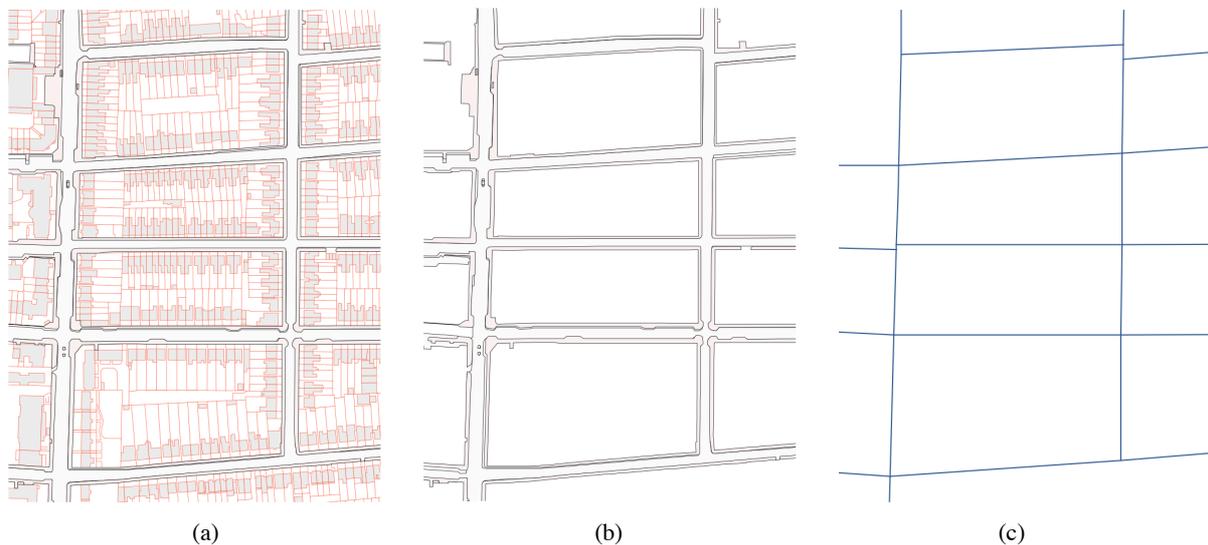


Figure 1: Street environment datasets:(a) Urban area survey representation of the street environment, (b) streetspace: footways and carriageways and (c) the corresponding RCL representation. Base mapping © Crown Copyright and Database Right (2018). Ordnance Survey (Digimap Licence)

The data generation process follows a similar logic of cross-section drawings. Cross-sections are a representational technique commonly used in architecture to describe physical and spatial relations that are not evident from the plan. The drawings are generated from two-dimensional plan data that is cut through transversely by a cross-section line that establishes the position where the metrics will be queried (see Figure 2).

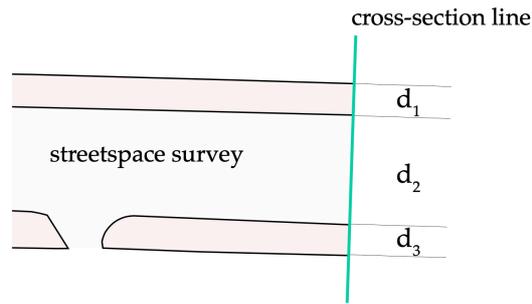


Figure 2: Cross-section line drawn over a detailed street plan to obtain distances between streetspace demarcation lines (kerb and property lines)

Accordingly, the two datasets mentioned above are needed for the street space designation metrics data-generation-process using the cross-section technique. Due the ease of accessing pertinent street data the process is firstly carried out for the urban area of London. Ordnance Survey provides built environment data at different spatial resolutions in urban areas in the UK. The street surface and street's physical demarcations represented by the plot and kerb lines that allow measuring the streetspace widths are represented in the OS MasterMap Topography Layer² which is the most detailed data of the physical environment available for the UK. Meanwhile the linear representation of streets or RCL is offered by Ordnance Survey in different versions varying in scale and detail. Together these data sources provide the appropriate information to obtain the street widths metrics, however, a more comprehensive analysis is necessary to assess their merits and limitations. Following, I discuss the urban survey data and next the RCL data.

OS MasterMap Topography Layer is provided as vectors (polygons, lines, points and text) representing individual topographic features (real world objects) surveyed at a scale of 1:1250 for urban areas. Each feature has a geometrical structure and a set of attributes about the feature (e.g. the kind of real world object it represents). A key attribute is the 'Descriptive Group' which classifies the real-world objects according to their characteristics. The polygonal features in this layer provide the most useful representation of the two-dimensional nature of streetspace. An excerpt from the OS MasterMap Topography Layer guide³ (p.29) showing the description of real-world objects related to the streetspace is shown in Table 1.

² <https://www.ordnancesurvey.co.uk/business-and-government/products/topography-layer.html>

³ <https://www.ordnancesurvey.co.uk/docs/product-guides/os-mastermap-topography-layer-product-guide.pdf>

Descriptive Group	Theme	Real World Examples	Description
Road or Track	Roads, Tracks and Paths	Road sections of varying surfaces, roundabouts and central reservations	Features representing, describing or limiting the extents of roadways and tracks
Roadside	Roads, Tracks and Paths	Verges and Pavements	Features representing, describing or limiting the extents of roadside detail

Table 1: 'Road or Track' and 'Roadside' descriptive group explanation

While this detailed explanation is useful for inquiring and analysing the built environment data, some inconsistencies were found. For example, 'central reservations' are used as examples of the 'Road Or Track' descriptive group, however, the OS MasterMap real world object catalogue⁴ (p.107) classifies them as 'Roadside'. Equally, in a digital file downloaded from the Ordnance Survey website the descriptive group attribute for such features is 'Roadside'. Therefore, this last definition prevails although 'central reservations' might seem anomalously classified under 'Roadside'. The definition of real world objects associated to the street realm is shown in Table 2.

Real world object	Descriptive group	Definition
Central Reservation	Roadside	An area separating the carriageways of a road
Pavement	Roadside	The paved surface by the side of the carriageway for use by pedestrians.
Verge	Roadside	The whole area between the edge of the roadway and the adjoining property boundary.
Road (surface)	Road Or Track	A metalled way for vehicles. A vehicle is one with wheels on both sides of its body. Metalling is any artificial (man-made) surface including areas of asphalt, concrete and gravel.

Table 2: Definition of real world objects associated to pedestrian and vehicular use represented on the OS MasterMap Topographic Layer from the real-world objects catalogue

Other inconsistencies observed in the data have to do with the capacity of the datasets to synchronously reflect the ongoing changing nature of the built environment. In recent years the design of streets has begun to adapt to new urban mobility requirements adding street elements

⁴ <https://www.ordnancesurvey.co.uk/docs/legends/os-mastermap-real-world-object-catalogue.pdf>

or surfaces of hybrid nature which are difficult to fit within the two dominant groups of 'Roadside' and 'Road Or Track'. Few of these physical transformations are reflected in the data set, however there are some exceptions that generate ambiguity in the classification of features. In a small number of cases street elements appear classified under other descriptive groups. This is problematic because these groups include real world objects that do not fit exclusively with the street definition. For example, it was found that a parking bay was classified as 'General Surface' and a lane as 'Path'. Even so, the vast majority of the streetspace surface represented in the OS MasterMap Topography Layer is classified as either 'Roadside' or 'Road Or Track'. From the definitions presented in Table 1 and Table 2 it is possible to imply that the 'Roadside' and 'Road Or Track' are the surfaces or areas of a street most commonly used by pedestrians and vehicles respectively. Therefore, for the purpose of this research I selected the features classified under these descriptive groups.

As can be observed in Figure 1 RCL are a simpler representation of streets. Ordnance Survey provides RCL data with different levels of generalization that can be associated with different analytical purposes. Two types of cartographic generalization can be identified in the preparation of RCL datasets. Semantic generalization aimed at selecting information according to the objects classes, and geometric generalization which purpose is to simplify the object's geometry by reducing detail.

At this point it worth restating that a key objective of this research is to examine the relationships between streetspace designation metrics and urban structure. Such goals affect the selection of the RCL data in at least two ways. The selected data set should allow the possibility of expanding the analysis of street designation metrics using robust analytical techniques from network science to gain understanding of the structure of the street system, and the possibility of identifying relations with other street-based urban form data. From the network science perspective, it would be tempting to choose the RCL data set with the highest level of detail of the street environment expecting to get the most insights about how the system functions (Newman, 2010). However, to allow for the integration of the streetspace designation metrics with the RCL data the selection criteria that prevails is consistency between the representation of streetspace and the representation of the RCL. Moreover, because the comprehensive study of streetspace designation metrics remains unexplored the data set from which this data is derived (OS MasterMap Topography Layer) predominates for the selection of related street data sources. Therefore, the selected RCL data selected is the one that most closely represents the open space area outside plot boundaries. In other words, wherever there is a street represented in the OS MasterMap Topographic Layer ('Roadside' and 'Road Or Track' descriptive groups) there should be one corresponding RCL.

Because a common purpose of RCL data is supporting routing for driving and transport planning, most datasets focus on providing an accurate representation of routes of movement

mainly through vehicular infrastructure. For this reason, for example, the OS MasterMap Integrated Transport Network Layer displays two lines in the case of street with two separated carriageways. Although this greater amount of detail could be considered useful for transport planning analysis it is not appropriate to be integrated with street space designation metrics for the reason signalled before.

In order to select one of the RCL data available from Ordnance Survey I compared three datasets with different levels of geometric and semantic generalization. This comparative analysis seeks to identify differences between the number of centre line features represented in each data set. With this intention, the RCL datasets are turned into graph representations following an intuitive conversion where street segments are the edges and their endpoints (junctions or intersections) are the vertices. Then, I determined a 1 square-mile study area of inner and outer London to observe the degree of variation dependent on location. As can be seen in Figure 3 the graph representation facilitates the comparison by allowing the quantification of vertices and edges for each RCL dataset. Being that the RCL datasets can be ranked from higher to lower detail according to the number of vertices and edges I selected the OS OpenMap Local data set because it has a medium number of streets segments that closely mirrors the representation of streetspace (OS MasterMap Topographic Layer 'Roadside' and 'Road Or Track' descriptive groups). This street representation not only has an adequate level of generalization of the skeleton of the street network but also is suitable for the network modelling and analysis of the street system at a citywide scale.

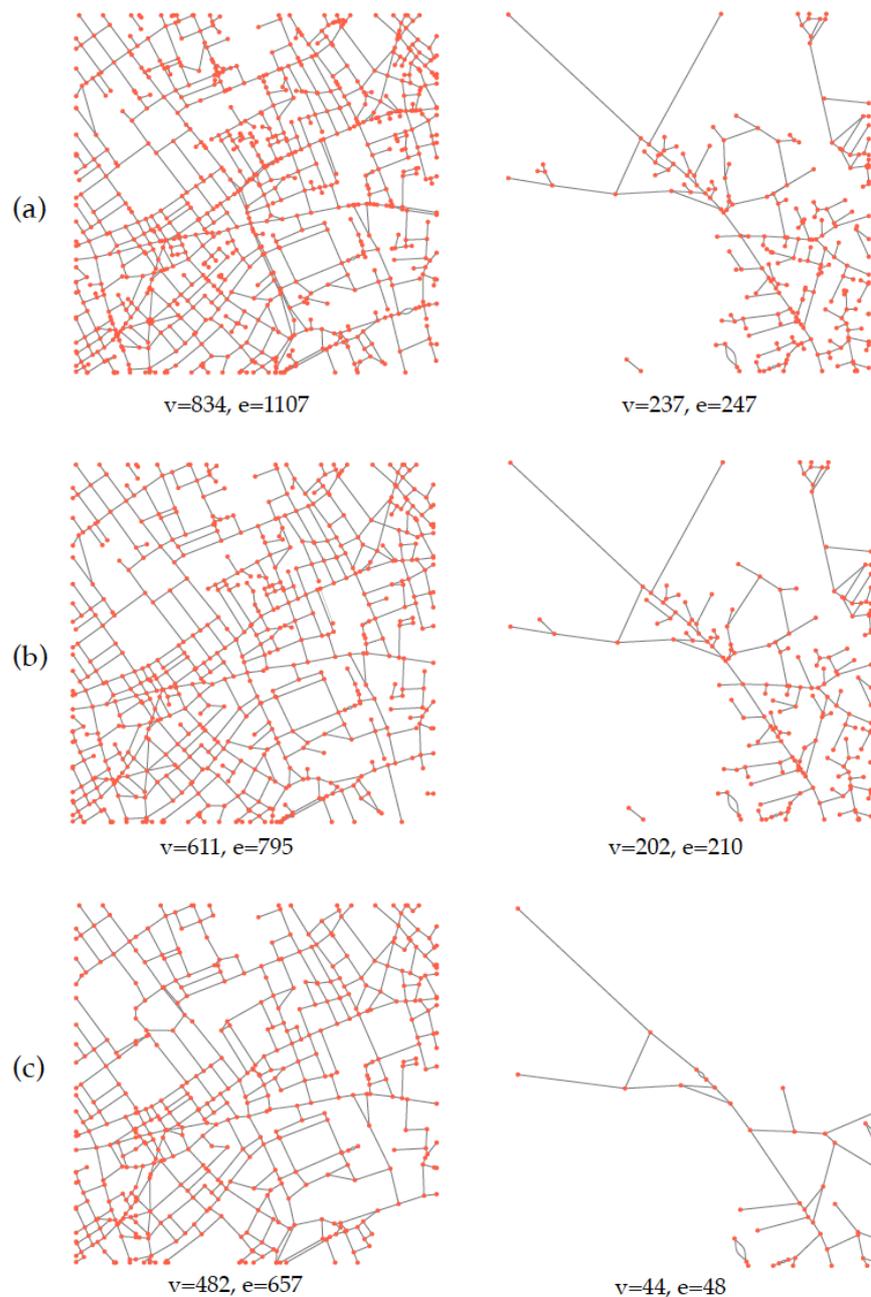


Figure 3: Comparison of three graph representations of RCL datasets with different levels of generalization in inner (left) and outer (right) London. (a) OS MasterMap® Integrated Transport Network™ (ITN) Layer, (b) OS Open Map Local, (c) OS Meridian™ 2. Base mapping © Crown Copyright and Database Right (2018). Ordnance Survey (Digimap Licence)

2.3 STREET DATA GENERALIZATION AND CLEANING

This section describes the process of semantic and geometric generalization and cleaning of the OS OpenMap Local RCL data set. The data can be downloaded from the Ordnance Survey website⁵ as an ESRI shapefile format. The geographic coverage is defined by 100 x 100 km tiles so the first step for data processing is to establish a meaningful spatial boundary of the London urban area. Of course, there will be degrees of arbitrariness in any criteria adopted for determining city boundaries, but for the purpose of this research we chose to adopt an approach

⁵ <https://www.ordnancesurvey.co.uk/business-and-government/products/os-open-map-local.html>

that is both coherent with the ways streets are managed/designed (functional) and that is manifested physically in the built environment (spatial). For those two reasons the subject matter are all the streets contained within London's orbital motorway, the M25.

The processing of the vector data is conducted using a Geographic Information System (GIS) software package. Quantum GIS (QGIS⁶) is a free and open-source software which extends the possibilities of replicating streetspace studies extensively across urban areas. The cleaning and generalization process follows a sequence of operations that remove or add line features as described in detail in Table 3. As it was mentioned in the previous section there are two general selection principles to follow: consistency between streetspace and RCL representation and topological integrity that allows for connectivity analysis of the street network. Additionally, due to the large number of features and for practical reasons we opted for cleaning and generalization operations that can be automated and replicable.

The roads included in the data set have a public and private definition that can be derived from their 'classification' attribute. Only public access streets are included in the study. Through an exploratory inspection of the street classes it was found that 'Restricted Local Access Roads' and 'Local Access Roads' correspond to urban precincts such as cemeteries, gated developments (residential and industrial), hospitals, universities, etc., which have restricted access, therefore are excluded from the analysis. Also, 'Guided Busway Carriageway', of which there are only 2 features, were eliminated because of inconsistency with the urban area survey data. These semantic generalizations account for the largest set of features eliminated from the RCL data set.

In similar manner, geometric generalization of street segments is applied to reduce the amount of detail in junctions' representations that are at less than 1 meter of distance which occurs when two tributary RCL are unaligned by 1m. The segments of length < 1 are removed and then geometries are snapped at a tolerance of 1 to preserve connectivity. Similarly, the topological correction is necessary to conduct street network analysis with the RCL data set.

The data is processed using two tools from the Geographic Resources Analysis Support System (GRASS) vector module in QGIS; 'v.clean' that checks for topological errors and create new features to correct them, for example, split continuous lines in crossings, and 'v.net.component' that identifies self-connected components allowing to retain the main connected component to adequately perform network analysis. As a result, the original set of RCL features is reduced in around 12% to 183,389 street segments.

⁶ <https://qgis.org/>

Operation Type	Geoprocess(QGIS)	N after process	diff.
Cleaning	Delete duplicate geometries	209,770	122
Semantic gen.	Delete 'Classifica = Restricted Local Access Road'	183,130	26,640
Semantic gen.	Delete 'Classifica = Local Access Road'	181,163	1,967
Semantic gen.	Delete 'Classifica = Guided Busway Carriageway'	181,161	2
Cleaning	Fix geometries	181,161	0
Geometric gen.	Delete 'length < 1'	180,918	243
Geometric gen.	v.clean (cleaning topology)	183,806	3,118
Geometric gen.	Snap geometries to layer (tolerance=1)	183,806	0
Geometric gen.	Delete <v.net.component (strong, threshold=0)	183,475	331
Cleaning	Fix geometries	183,475	0
Cleaning	Delete duplicate geometries	183,416	59
Cleaning	Delete 'length < 1'	183,411	5
Cleaning	Delete 'length is missing (null)'	183,389	22

*gen. = generalization

Table 3: RCL generalization summary (initial N=209,892)

3 STREETS SPACE METRICS CALCULATION

3.1 DRAWING STREET CROSS-SECTION LINES

After the street data is selected, generalized and cleaned the first operation of the streetspace-designation-metrics generation process is to draw a cross-section line for all the street segments. Recent advancements in Geographic GIS allow the automation this process which will otherwise be excessively time consuming to compute for large urban areas that typically have a high number of streets. While in the preliminary stages of this research this drawing process was programmed using ArcMap and Python, eventually a more efficient processing model was created using a combination of algorithms from the processing modeller in QGIS 3.6.

The OS OpenMap Local data set provides the base spatial units necessary for the analysis represented as lines. In some cases, a line corresponds to one segment between the crossing with other lines and in other cases multiple lines constitute one segment. Given that there is no

clear logic for either kinds of representation, each individual line with a start and end point regardless if they cross with other lines is treated as a street segment.

The automated process of drawing street cross-section lines follows the series of algorithms illustrated in Figure 4. First, two points are created for each segment at $L/2 + 1$ and $L/2 - 1$ positions and merged into a single layer. Second, a line is drawn connecting this two points. Third, this new line is rotated 90 degrees. Finally, each side of this line is extended 24m to obtain a cross-section line of 50m for each street segment. In total 183,389 cross-section lines are created for the study area (see Figure 5)

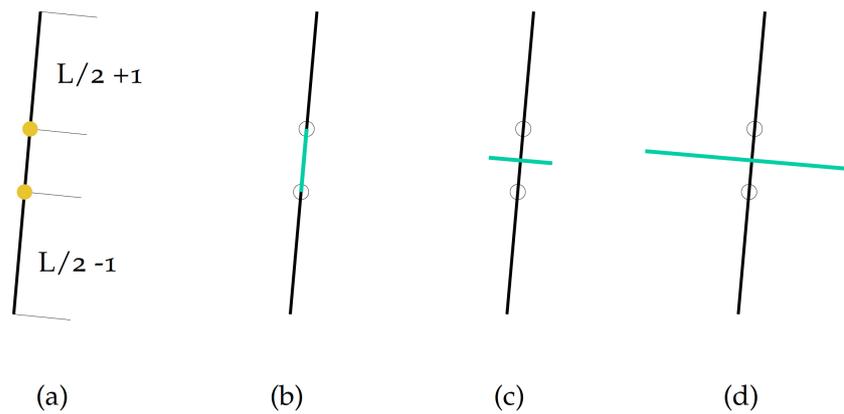


Figure 4: Algorithmic sequence of street cross-section line drawing

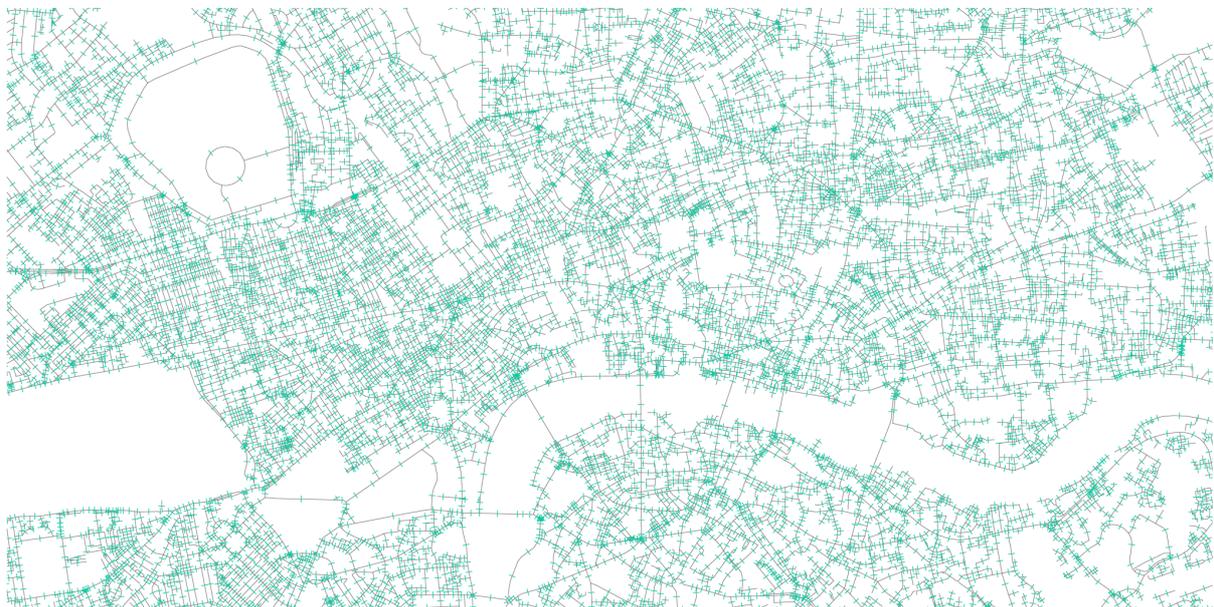


Figure 5: 50 square km detail of Central London cross-section lines

Following, the second operation is to intersect the street cross-section lines with the streetspace data from the OS MasterMap Topographic Layer ('Roadside' and 'Road Or Track' descriptive groups) (see Figure 6). This is a basic mathematical operation in GIS that allows to get the individual portions of the street cross-section line that overlay with the 'Roadside' and 'Road Or Track' polygon features. As a result, the street cross-section line is broken down into

the 'Roadside' and 'Road Or Track' lines. Finally, the length of these resulting lines is summarized to get the footway, carriageway and total street widths. At this point the streetspace designation metrics are assigned back to the corresponding RCL street segment for further analysis.

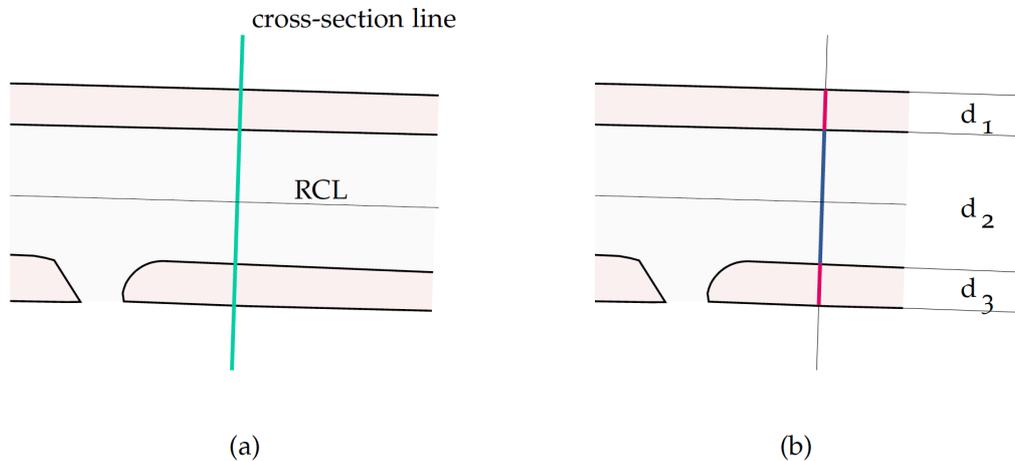


Figure 6: Street data integration: (a) cross-section line overlaid over streetspace data, then (b) carriageway width $\{d_2\}$, footway width $\{d_1 + d_2\}$ and total street width $\{d_1 + d_2 + d_3\}$ is derived from the intersected segments.

3.2 DESCRIPTIVE STREETS SPACE DATA ANALYSIS FOR LONDON

The street segments analysed describe the street network within the M25 area. After the streetspace designation calculations a small number of street segments (less than 0.5%) had a total street width value below 2 m and were excluded from the analysed data points. It was observed that generally this occur in segments that are too short and cluttered close to street junctions, hence the cross-section line fails to intersect properly with the adjacent kerb and property lines. Following this, the streetspace designation metrics dataset is composed of 182,555 street segments.

The comparison of histograms in Figure 7 for the carriageways, footways and total widths show a unimodal skewed long-tail distribution. This can be explained by the fact that urban street networks are a complex transportation system with efficient spatial organisation, and that the London street system grew following a space-filling phenomena within a service region constrained by the idea and materialisation of the green belt (Masucci et al., 2013). Often the construction of major roads precedes minor roads and thus major roads operate as primary distributors. This translates into a street system with few streets with high capacity or width and plenty of streets with low capacity with a hierarchically-nested organisation. Before a closer inspection of the basic statistics it is important to notice that as

Table 4 shows near 2/3 of streets are classified as Local and the same if looking at the relative street length. This is informative to understand that the median values for footway and carriageway portray the measures of a typical 'residential' street with a footway (5.5 m total) some decimetres above the 2 m minimum recommended and a carriageway (7.7 m) that can accommodate 2 lanes plus one space for on-street parking or 1 lane and on-street parking on both sides (Großbritannien, 2007). Taken together, these metrics suggest that there is an association between the hierarchical classification of streets and their footway and carriageway widths.

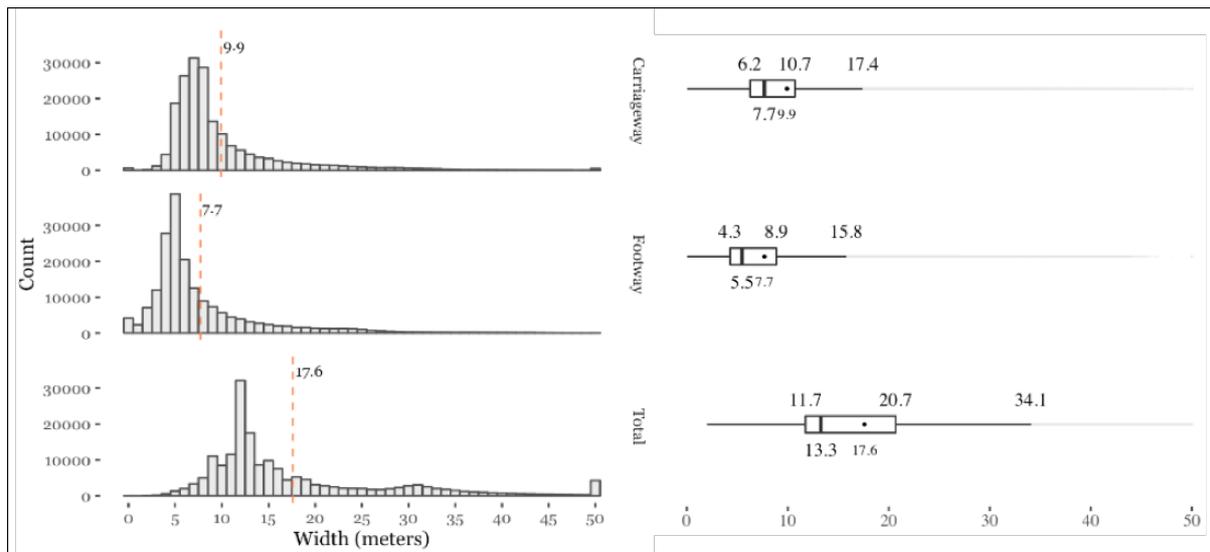


Figure 7 Distribution and variance of streetspace designation measures in London

Hierarchy	Designation	Freq.	Relative freq.	Total length (km)	Relative total length	Total street width median (m)
Local	Local Road	120919	66.24	12322	67.80	12.4
Local	Shared Use Carriageway	190	0.10	13	0.07	14.1
Minor	B Road	7741	4.24	696	3.83	16.8
Minor	B Road, Dual Carriageway	302	0.17	16	0.09	28.4
Minor	Minor Road	22897	12.54	2448	13.47	15.4
Minor	Minor Road, Dual Carriageway	574	0.31	39	0.22	29.9
Major	A Road	18228	9.98	1379	7.59	21.1
Major	A Road, Dual Carriageway	2594	1.42	175	0.97	31.1
Major	Motorway	575	0.31	119	0.66	30.6
Major	Motorway, Dual Carriageway	685	0.38	250	1.38	44.7
Major	Primary Road	4948	2.71	364	2.01	25.2
Major	Primary Road, Dual Carriageway	2902	1.59	346	1.90	35.1

Table 4 Three-tier hierarchy street segments frequency and total length

An interesting aspect of the boxplots in Figure 7 is the similarity of the footway and carriageway width interquartile ranges which demonstrates a common design pattern in the allocation of space to the pedestrian and vehicular systems, which can be explained by the application of street standards. However, footway and carriageway widths differ in their relation with total street width. The scatterplots in Figure 8 show a greater relationship between footway width and total street width than carriageway width. A possible explanation is that carriageways are designed with a minimum standard width to carry motorised-vehicles which effectively is a module (the street lane), therefore the increments in carriageway widths necessarily are modular, whereas footway widths can vary and increase without this restriction.

The pattern displayed on the carriageway to footway scatterplot show that carriageway and footway widths have an inverse relationship. This may be associated with the fact that the total street width is frequently fixed, therefore as any of these variables increments the other one is reduced in the same rate. This relationship has been conceptualized as the trade-off triangle (Jones et al., 2008) that illustrates the competing demands of multiple street users within a fixed street width and that as either carriageway or footway width increase the respective carriageway or footway width decreases.

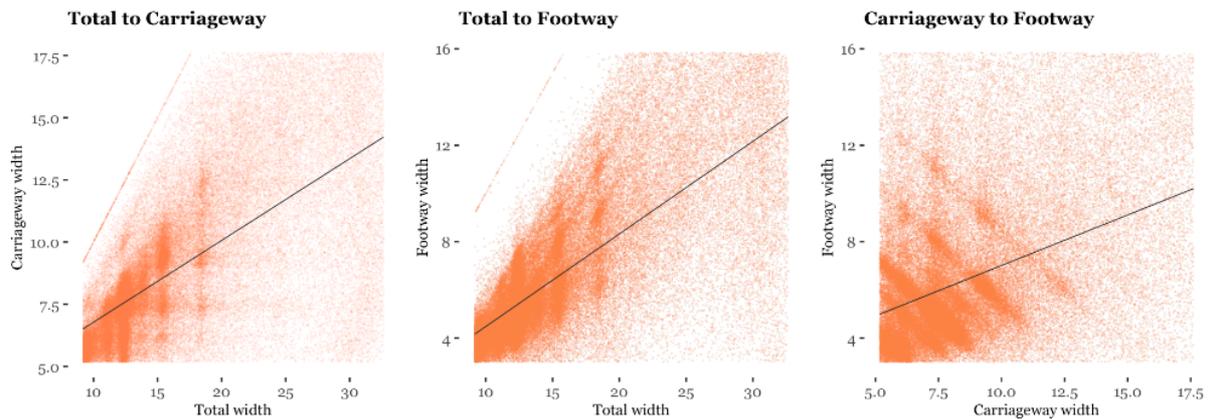


Figure 8 Relationships between streetspace designation measures in London

Following the trade-off triangle concept, the square grid heatmap relating footway and carriageway metrics in Figure 9 reveals that the majority of streets have more space allocated for carriageways than for footways. Also, from this visualisation it is possible to derive that the typical street in London has a carriageway width of 7.25 m and a total footway width of 4.75 m (n = 7680).

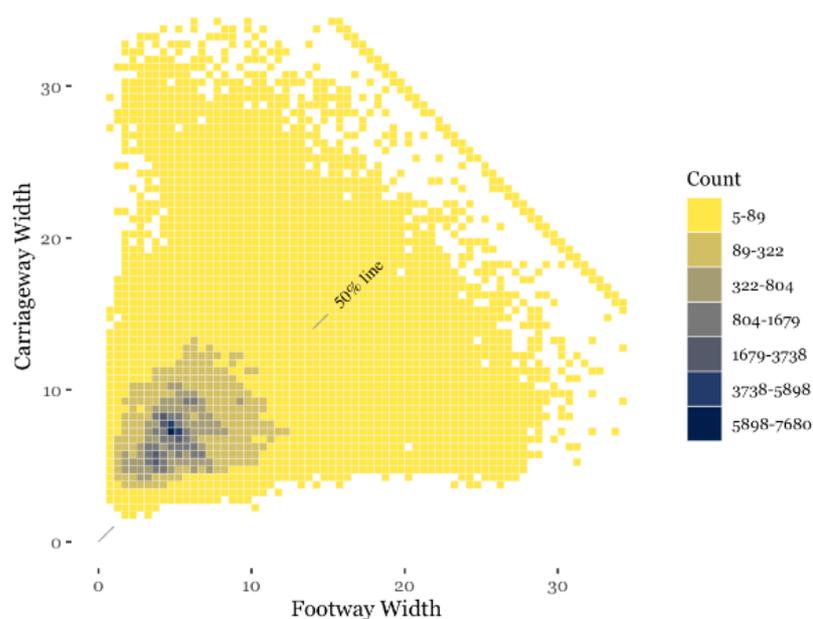


Figure 9 Frequency according to Footway and Carriageway widths

The next section discusses a spatial visualization method of streetspace designation metrics that displays simultaneously the main variables presented here to begin to understand their spatial arrangement across the London urban area.

4 STREETSPLACE CARTOGRAPHY

The visualisation of the physical metrics of street widths at high spatial resolution across a large geographic extent is cartographically challenging. As discussed previously, commonly street data sources simplify the RCL as a line. The RCL can be analysed according to the street length (Strano et al., 2013), however, here we have introduced additional streetspace metrics that offer a more detailed quantification of the street's physical environment. For example, by analysing total street width it is possible to observe that the pattern displayed in Figure 10, representing the upper wider half of London streets, resembles the pattern of road traffic volumes (see Figure 8.4 in Batty, 2013). A similar spatial organisation can be observed from the most economically and socially active areas of the city.

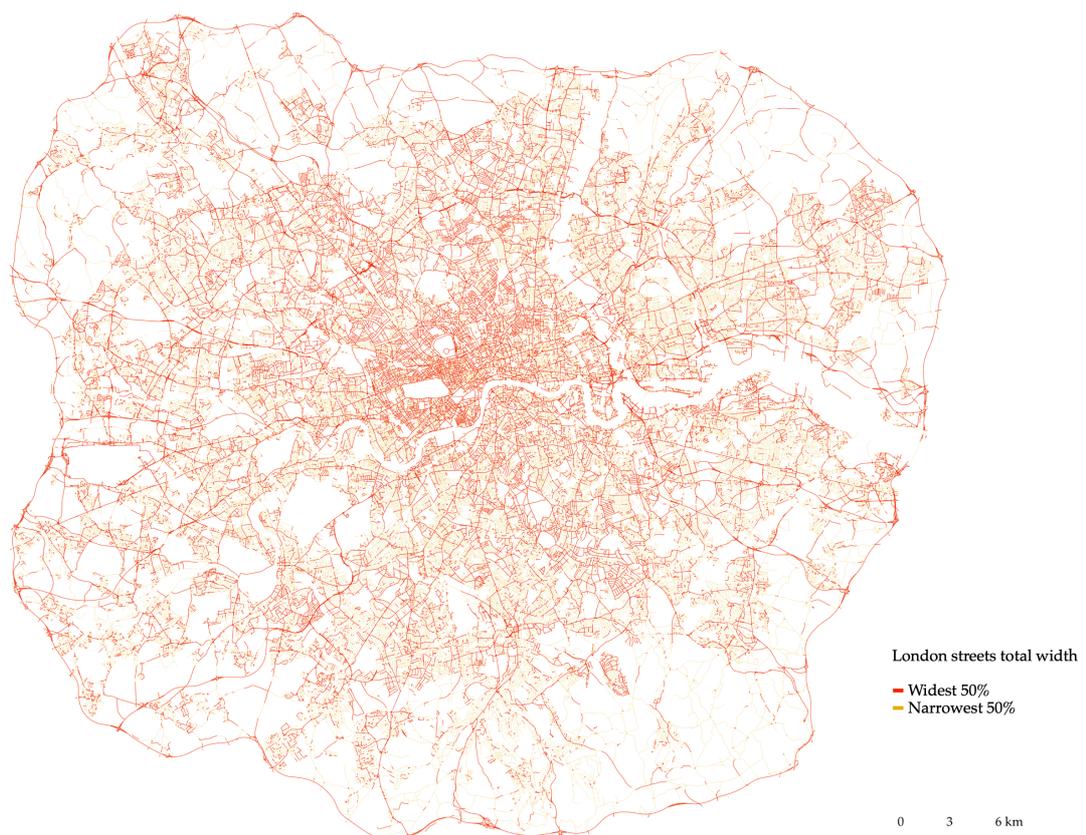


Figure 10 London widest streets show a centre-periphery pattern with a central area full of wide streets and radial distributors towards the periphery. Basemapping © Crown Copyright and Database Right (2018). Ordnance Survey (Digimap Licence)

The designation of streetspace is a multi-scalar problem (Appleyard et al., 1981). Strategic scale considerations affect and are affected by design scale factors in a complex way. Certainly, because of urban land ownership structures, street plans have a low rate of change, therefore street redevelopment schemes will most likely operate modifying the pedestrian and vehicular space ratio. To understand how much space is designated to pedestrians and vehicles we visualize this two variables simultaneously using a bivariate thematic map. The map in Figure 11 shows footway-carriageway relationship in central London. This visualisation helps analyse street design and streetspace prioritisation at the same time in a quantifiable way. The hierarchy of the street system is highlighted, despite the fact that the streetspace designation of major streets varies from segment to segment portraying the history and diversity of urban planning paradigms in London.

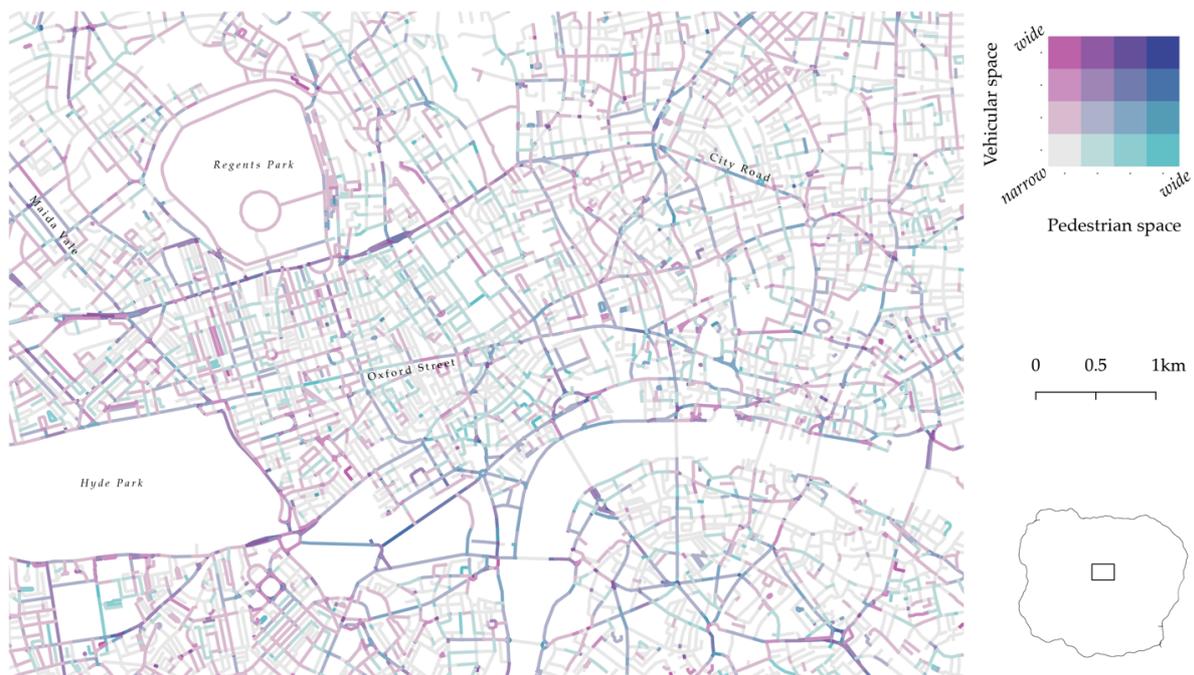


Figure 11 Streetspace designation metrics for central London. Basemapping © Crown Copyright and Database Right (2018). Ordnance Survey (Digimap Licence)

Together these visualisations provide important insights into the way the street system functions. From a policy perspective, urban street planning has been conceptualized as a three stages transition from a car-oriented city to a sustainable mobility city and to a city of places (Jones, 2016). Under those circumstances, central streets and streets, in general, are expected to meet the requirements of both their local and metropolitan functions. As a result, the multiplicity of streets functions not only nurture each other but also collide. As an illustration, London streets carry 21.1 million trips daily (car, walk, bus, cycle, taxi and motorcycle). By 2041, 80% of all trips in London are expected be made on foot, by cycle or using public transport (Greater London Authority, 2018). Because the space of the street is often fixed and limited, the designation of space for vehicles and pedestrians arises as a crucial design problem,

which can be better understood analysing the spatial pattern of streetspace designation citywide presented here.

The study of the physical form of streets offers important insights about the spatial organization and dynamics of cities. From the land-use perspective, street studies are relevant because the space occupied by streets accounts for near a fourth of a city's developed land and constitute their main transport infrastructure. The designation of streetspace inherited from motorized-transport prioritization is contentious with emergent mobility behaviours and the public space dimension of streets. City officials and active travel advocates have begun to promote the re-design of streets in a way that acknowledges the relevance of non-motorized transport and socio-economic street activity for more sustainable urban development.

The geometric generalisation of streets into linear features has been most often used to study urban structure and dynamics with important results. However, the omission of metrics such as width, because of lack of available data, diminishes the contribution of such analysis into re-thinking the design of streets as urban places. The geocomputational technique to generate new street level data can open up alternative methods for street planning and design that are consistent with current patterns of urbanization and transformative urban transportation solutions.

While the physical description of the streetspace analysed here is a close representation of the functional organisation of streets, it is still general and could be conveniently expanded with complementary street data attributes. For example, a more detailed description of the carriageways could be obtained by including bus and cycle lanes, speed limits, on-street parking and kerb space use data. Equally, the footways spatial characterisation could be improved by adding street greenery and public life studies data. Street flows data can give a good proxy to study streetspace use dynamics, however, the availability of such data is still scarce in both spatio-temporal resolution and geographic coverage.

5 CONCLUSIONS

This paper has described a methodology to generate streetspace designation metrics; footway, carriageway and total street width for whole urban areas. This novel data set was computed from existing urban physical environment surveys using geocomputational techniques in GIS software. The method presented is replicable and can be extended over other cities spatially organised around motorized traffic and facing urban mobility challenges. The analysis of the streetspace of whole street systems at a high-spatial resolution can expand street morphology studies in informative ways. Overall, the application of combined spatial research methods including geocomputation and information visualisation provides a method to obtain relevant information that can support street design and planning in a new way and suggests an opportunity to advance in the understanding of streets as places as well as links.

Streetspace designation statistics for London confirm the predominance of space allocated for vehicular over pedestrian uses. Most streets are designed following ‘residential’ streets standards which is coincident with street hierarchical classification. This also explains the spatially efficient organisation of the London street system with few wider distributors and many narrower local streets. Nevertheless, the spread of streets segments types is not homogeneous and follows a centre-periphery pattern. The hierarchy of the street system is highlighted in the London-wide streetspace visualisation, despite the fact that the streetspace designation of major streets varies from segment to segment portraying the history and diversity of planning paradigms in London. The central area of London has wider streets and shows a relative larger streetspace designated to pedestrians corresponding with higher levels of social and economic activity and traffic flows.

The approach presented here is timely with urban mobility challenges and policies. Alongside the insights for intra urban comparison it can allow the comparison of urban planning paradigms across cities. Additionally, the fine grain streetspace physical metrics introduced not only can enrich street research methods that focus on urban structure and dynamics but also can offer alternative analytical methods for street classification, planning and design.

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