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Street morphology analysis citywide: a bi-dimensional approach

Dr Nicolas Palominos[1]
[1] Centre for Advanced Spatial Analysis, The Bartlett Faculty of the Built Environment, University College London, United Kingdom

Abstract

The configurational analysis of urban form is most commonly based on linear representations of streets. The space or right-of-way of streets, however, is subdivided into clearly demarcated and measurable space for pedestrians and vehicles which entails a much more complex spatial organisation than lines can represent. Because of the endurance of street layouts, the reallocation of streetspace becomes a key design operation for street adaptation to new types of movement technologies and for promoting active travel.

The research introduces a new methodology for quantifying streetspace allocation of all streets in a large system using a geocomputational approach that both allows decoding high-resolution topographic data over a large geographic extent and can be replicated across multiple cities. I use GIS to produce a series of maps that describe the visual structure of the pedestrian-vehicular streetspace relation. The programmatic application of the street cross-section technique enables the comprehensive analysis of streetspace citywide at a high-spatial resolution offering new data to expand street morphology studies in informative ways with the potential for interrogating current street designs.

From the analysis of the streetspace allocation of all streets in London, it is possible to argue that studying pedestrian and vehicular space allocation is not only important for understanding the reciprocal relationships between the design and strategic scales of streets but also valuable for supporting urban design and transport policies towards more people-oriented streets.

Keyword: *Streets, Streetspace, Urban design*

Introduction

The study of streets traverses various and diverse fields and disciplines. The intermediate position that streets have in the environment impede an unambiguous delineation between "*public and private, individual and society, movement and place, built and unbuilt, planning and architecture*" (Anderson, 1978: 1). How does the internal organisation of streets affect the relations between people and the urban built environment? Alexander (1965) suggests that the ambiguous roles of the street system and the overlap of the street subsystems generates the conditions for a living city. Two interrelated street subsystems are illustrated in Alexander's taxicab example; the pedestrian and the vehicular subsystems overlap to enable the functioning of the taxi. This conceptualisation shows that streets serve different, sometimes divergent, but often complementary roles for the workings of cities.

Recently, the shift of focus from designing streets for car users to considering the needs of all street users has brought about place-based strategies implemented by cities around the world, reflecting the street's role in shaping the public life of a city beyond pure movement efficiency (Carmona et al., 2018). Moreover, the place function of streets has been incorporated by the 'Link and Place' framework for street classification accounting for a more comprehensive approach to classifying urban streets and providing insights into determining the appropriate balance of pedestrian and vehicular streetspace allocation (Jones et al., 2007).

In this paper, I present a novel method to quantify streetspace allocation measures of all streets in a large urban system. Streetspace allocation metrics are decoded from urban topographic data sets that are typically used in urban planning. Through the programmatic drawing of street cross-sections, it is possible to scrutinise street design by describing the width of footways and carriageways. 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.

Background

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; Porta et al., 2006; Strano et al., 2013; Turner, 2007). Streets are typically represented as links or nodes to examine the relations of all elements in networked system comprehensively (Marshall et al., 2018). The modification of the relations between the elements of the system (e.g.: adding or removing links) results in a new system configuration, which urban designers often pursue to improve the overall connectivity (Mboup et al., 2013). But, even though these operations are key to change the structural relations they are less likely to occur given the difficulty of adding new links particularly in consolidated urban areas. In these cases, given the endurance of streets layouts mainly due to private 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 as a whole.

The 'Link and Place' guide to street planning and design introduces the schematic concept of the trade-off triangle conceptualisation emphasising the physical characteristics of streets (see Figure 1). Link and place are utilised as both to refer to the status of a street as well as its spatial capacity, being the total street width the 'envelope of options' for streetspace allocation. Even though, making a direct connection between link and carriageway space, and place and footway space might seem too simplistic, it is clear that from the design perspective greater spatial capacity assigned to carriageways would aim to address link or movement requirements (the vehicular system), whereas on the contrary greater space allocated to footways would address place-related requirements (the pedestrian system, see (Alexander, 1965) for a discussion on the necessary overlap of these systems). Importantly, the trade-off triangle allows to illustrate the inverse relationship between the link and place spatial capacity when reallocating streetspace.

Emergent transformations in mobility technologies (Kitchin and Dodge, 2011; Sevtsuk and Davis, 2019; Sheller and Urry, 2006), and increasing levels of urban congestion and densification have prompted an important number of transport policies and urban design proposals for a more people-oriented design of streets in big cities, globally (Centre for London, 2017; 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 overlay of functions that streets have besides circulation (Alexander, 1965; Jacobs, 1961). Equally, it highlights the reciprocal relationships between the design and strategic scales of street systems. Consequently, a citywide analysis of streetspace allocation is considered appropriate to get a wider appreciation of the impacts of changing the pedestrian-vehicular streetspace relation, which has been shown to have multi-scalar impacts (Appleyard et al., 1981).

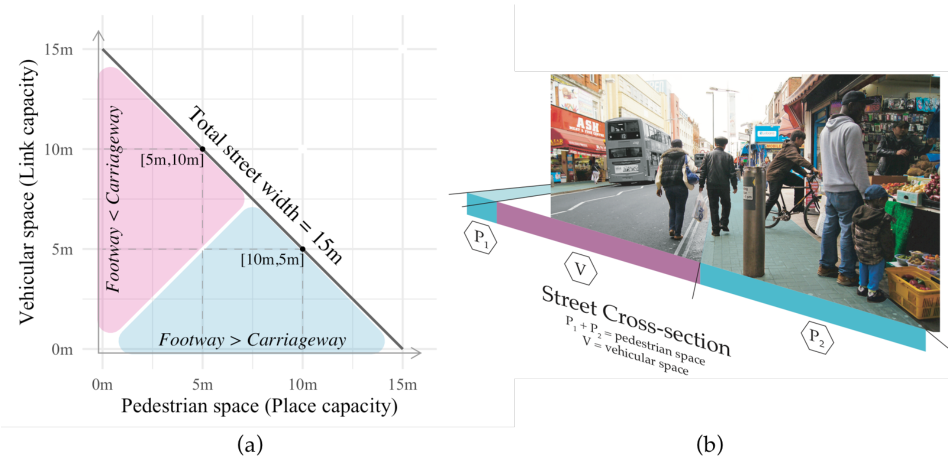


Figure 1. *(a) Share of Streetspace diagram based on the 'trade-off' triangle (Jones et al., 2007), and (b) Diagram of street cross-section*

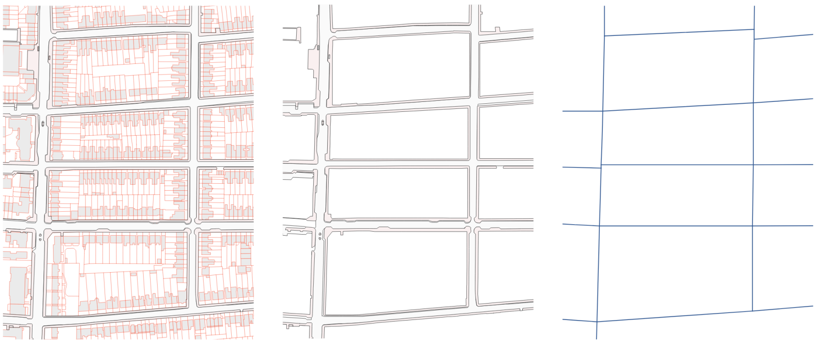
Methodology

Defining streetspace for morphological 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. Streets are a commonly-used element in studies of urban form. They encompass a physical entity described as both an open space related to buildings and an open space that is not a plot also referred to as paths of the boundary matrix (Scheer, 2016). Typically, the linear paths of public rights of way can be derived from landownership urban cadastres. Despite the fact that 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. This distinction alongside the data sources discussed in the following section allows for a precise definition of streetspace. Streetspace is the open space area related to buildings outside the plot boundaries.

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 organisation 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 derived from digital urban survey maps that represent the built environment with high detail as illustrated in Figure 2 . 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. Overall, even though there is a wealth of methods and data alternatives to describe the space of the street, these tend to centre on providing routing solutions, thus with a few open-access exceptions are overwhelmingly linear representations, with a clear emphasis on the vehicular paths of movement, overlooking the geometrical characteristics of the street surfaces that compose the space of the street. Topographic and Road Centre Line (RCL) data sets are needed for the streetspace allocation metrics data-generation-process applying a cross-section technique. Ordnance Survey (OS) 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 Layer, which is the most detailed standardised national data available for the UK. Meanwhile, the linear representation of streets or RCL is offered by OS in different versions varying in scale and detail. But from visual inspection, the OS OpenMap presents an appropriate level of consistency with the polygonal streetspace representation in the OS MasterMap Topography Layer being the one selected for this analysis.



(a) (b) (c)

__Figure 2__. Street environment data sets: (a) Urban area survey representation of the street environment, (b) streetspace: footways and carriageways and (c) the corresponding RCL representation. Base mapping copyright. OS (Digimap Licence)

Study area and data generation

This analysis is conducted over all the near 200.00 streets contained within London's orbital motorway, the M25, which represents a meaningful city boundary both spatially and functionally.

The data generation process follows a similar logic to cross-section drawings (see Figure 1 (b)). Cross-sections are representational technique commonly used in architecture to describe physical and spatial relations that are not evident from the plan. Streetspace allocation metrics are calculated from the intersection of a cross-section line with the streetspace polygons that contain the definition of the kerb and property lines. After drawing cross-section lines programmatically for all street segments in the study area the second operation is to intersect the street cross-section lines with the streetspace data from the OS MasterMap Topographic Layer (features labelled as 'Roadside' and 'Road Or Track' descriptive groups). 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 the corresponding RCL street segment to obtain the footway, carriageway and total street widths.

Results and Discussion

Calculating streetspace allocation metrics citywide essentially implies a jump from the micro to the macro scale that poses challenges for the discovery of meaningful patterns in the data. To address these challenges, I applied visual and statistical analysis to aid interpretation and unveil the latent relationships between the geometry of the streetspace and the structure of the street system.

The histograms in

Figure ***3*** show that streetspace allocation metrics in London have 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 phenomenon 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 the majority of streets with low capacity in a hierarchically-nested organisation as illustrated

Figure 4.

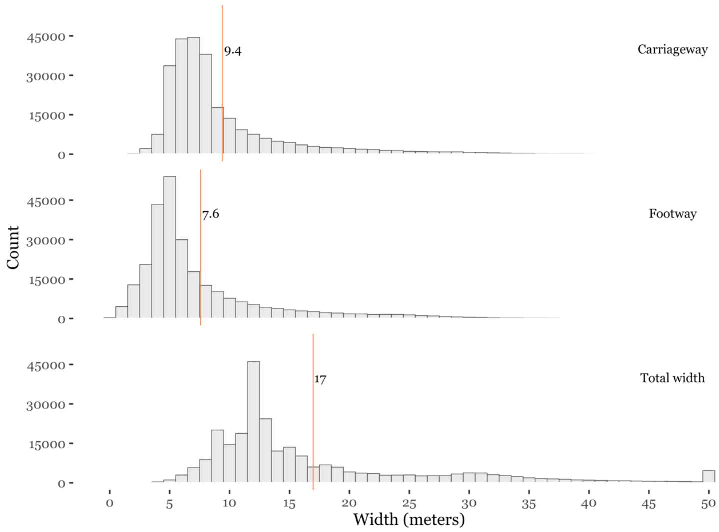


Figure 3. *Distribution of streetspace allocation metrics in London (mean values shown by orange lines)*

The bivariate map in Figure 4 and the heatmaps in Figure 5 allow to analyse street design and streetspace prioritisation at the same time in a quantifiable way. To some extent, the hierarchy of the street system is highlighted, despite the fact that the streetspace allocation in major streets varies from segment to segment portraying the piecemeal street developments and the history and diversity of urban planning paradigms in London.

Following the trade-off triangle concept, the square grid heatmaps relating footway and carriageway metrics in Figure 5 (a) and (b) reveal that the majority of streets have more space allocated for carriageways than for footways, as the area above the 50/50 line has higher colour intensity. Additionally, Figure 5 (b) shows 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). Further analysis indicates that near 1/3 of the streets exhibit both footway and carriageway widths at the same time, in the range of values of 'residential' streets (see Table 1).

From a network perspective, Figure 6 shows the spatial pattern of the carriageway/footway relation with global statistics grouped in two street types according to streetspace preponderance. It is evident from this visualisation that streets with wider carriageway than footway prevail far and wide. Nevertheless, some concentration of streets with wider footway than carriageway is observable at the city centre. Overall, the grid formed by streets with wider carriageways is by far more comprehensive with 77% of the total street length than the one formed by streets with wider footways which represent 22%.

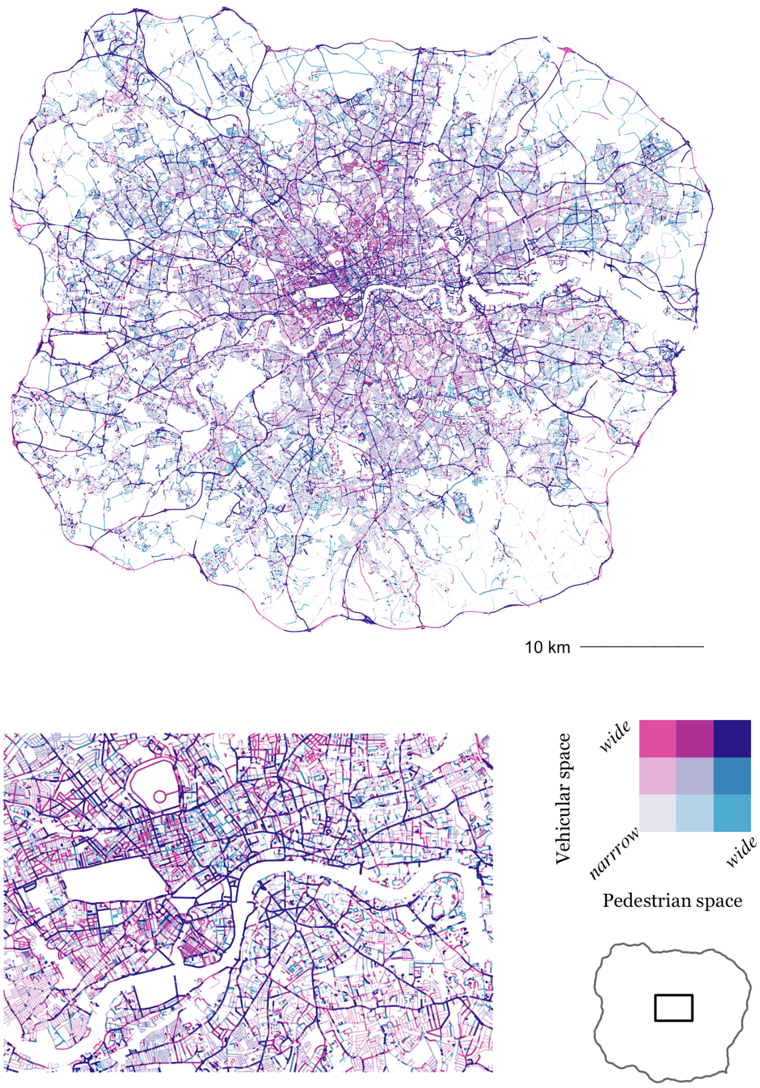


Figure 4. *Bivariate representation of streetspace allocation in London. Basemapping Crown Copyright. OS (Digimap Licence)*

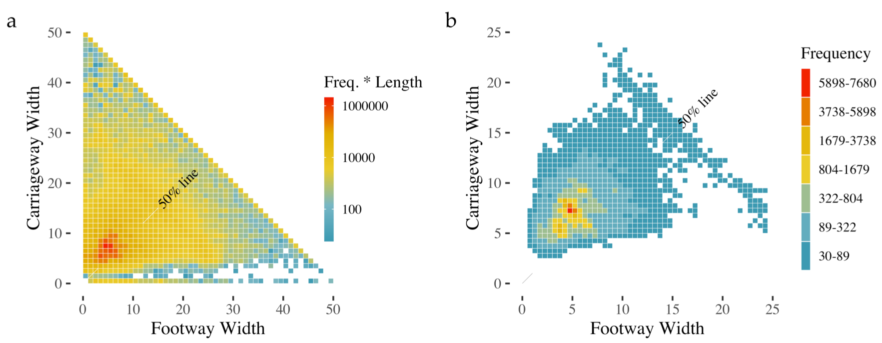


***Figure 5**. Heatmaps of street frequency according to Footway and Carriageway widths, (a) weighted by length and (b) absolute count below 25m*

Table 1. Contingency table of carriageway and footway widths in percentages

	Carriageway (m)			
Footway (m)	0 - 6	6 - 10	10 - 15	15 - 50
0 - 4	9.3	7.6	1.9	1.9
4 - 8	8.7	**33.8**	5.3	2.8
8 - 10	1.0	3.4	1.7	1.7
10 - 50	1.9	5.9	5.7	7.4

***Figure 6**. Comparison of street network patterns according to streetspace primacy*

The streetspace allocation analysis is a close representation of the functional organisation of streets, however 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 or the footways spatial characterisation could be improved by adding street greenery and public life studies data.

Conclusions

This paper has introduced a new methodology to generate streetspace allocation metrics: footway, carriageway and total street width for whole urban areas. The street morphology analysis accounting for the ‘Link and Place’ dimensions can expand street morphology studies in informative ways. These results have important implications for developing mechanisms for determining streetspace allocation that accounts for the many competing streetspace demands of various street user groups and contemporary perspectives of streets for transport, streets for sustainability and streets as place (Creutzig et al., 2020; Jones et al., 2007). Prior studies that have noted the importance of reallocating streetspace to protect neighbourhoods from traffic have revealed the mutual connections between metropolitan and neighbourhood scale policies (Appleyard et al., 1981). It can thus be suggested that a citywide streetspace allocation analysis might help better understand the multi-scale implications of reallocating streetspace.

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, particularly because the designation of streetspace inherited from motorized-transport prioritization is contentious with emergent mobility behaviours and the public space dimension of streets. The geocomputational technique to generate new street level data presented here can open up alternative methods for street planning and design that are consistent with current patterns of urbanization and transformative urban transportation solutions.

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