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River corridors. A study of spatial configuration along two small rivers in London

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ABSTRACT

Increasing urbanisation puts more pressure on urban river banks in terms of their use as recreational areas as well as their potential for development. Usually, interventions on rivers and riversides are focused on improving their ecological and hydrological aspects. However, to better define objectives for interventions and conservation of urban rivers we need a better understanding of how cities have shaped around rivers and the relationship between these elements and the whole city system. This paper argues that the current interaction between small rivers, urban form and socio-economic outcomes can be investigated through the analysis of the spatial network and land use patterns surrounding them. Using a statistical comparison of the spatial network, land use, demographic data and movement along with an assessment of historic maps, this study analysed the areas surrounding two small London rivers as well as four case studies. The study of the river corridors suggests that their urban form and function are strongly shaped by the connections with the city centre and historical land uses. At the same time, river areas are spatially segregated in comparison with their surrounding areas and they are crossed by routes that are important at city scale while local scale connections are more limited. In addition, the study found that spaces that were better utilised on riversides have a relationship with local centralities in their urban context providing more potential benefits for their communities. A better understanding of the characteristics of river areas and their relationship with the urban environment, particularly the level of accessibility of these natural areas, is relevant to improve policymaking and design interventions that can foster a better relationship between natural resources and the city.

KEYWORDS

Urban rivers, London rivers, Space syntax, River corridors.

1. INTRODUCTION

Rivers have benefited in the last decades from infrastructural, industrial and legislation improvements regarding the use of water and waste management (EU Water Framework Directive, 2000) as well as a rise in the environmental awareness in society that is searching for a less detrimental relationship with its natural resources. As a result, riversides are increasingly considered as valuable natural and urban elements that can provide opportunities for successful interventions in cities addressing social and environmental issues (Andersson et al, 2019).
The majority of scientific research dedicated to the topic of urban rivers is focused on the study of the ecological and hydrological aspects including water quality, hydrogeomorphology and restoration, with little exploration in other fields such as ecosystem services or socio-economic aspects (Francis, 2012). Similarly, practical interventions and guidelines for small rivers that aim to restore natural pre-existing conditions, fail to take into account river's social and economic significance. A more comprehensive approach for river interventions needs to consider social objectives which can be effectively measured in addition to ecological parameters (Eden and Tunstall, 2006). Moreover, future river interventions also need to identify societal needs and develop adequate tools to evaluate the social, economic and cultural values of specific cases to define those objectives (Dufour and Piégay, 2009).

A broader approach includes a focus on the potential benefits and services provided by rivers such as being sources of fresh water and food, biochemicals and natural medicines, ornamental resources, regulatory benefits for the climate, flood and erosion protection, recreation and tourism, aesthetic value, encouraging social relationships, spiritual value, inspiration for art, folklore and architecture and a provision of habitat (Everard & Moggridge, 2012). Urban rivers also present a pedagogical significance due to the creation of links between natural ecosystems and people's daily lives. (May, 2006, p. 482). Moreover, there is a valuable creation of affordances around natural systems, including river systems, related to possibilities of interaction (Matsuoka & Kaplan, 2008), restorative experiences (Kaplan, 1995) and identity creation (Benages et al, 2015). A better understanding of the relationship that small rivers have with their urban environment can support the definition of social objectives as there is a clear link between the way we build space and socio-economic outcomes and guide future interventions and conservation on riversides.

This paper aims to investigate how cities have shaped around rivers and the current interaction between small rivers, urban form and socio-economic outcomes. We propose that the analysis of the spatial network surrounding natural settings such as rivers leads to a better understanding of first, how these elements are embedded in the urban context and second, how specific social and economic benefits associated with rivers are affected by the patterns of space formed around them. Furthermore, we explore the possibilities and limitations of the use of this methodology to analyse urban rivers in relation to the city.

In this research, we analyse the spatial network along two London urban rivers at two different scales using space syntax theory and methodology to further understand the relationship of the rivers and riversides with their wider context. In the following sections, we describe the theoretical background for this approach and the methodology applied for analysis highlighting the meaning of the different measures used. We explain the results at two different scales of analysis: at city-scale we analyse two rivers, Brent and Wandle, and at a local scale we analyse four case studies: Brent River Park, Hanwell, Summerstown and Carshalton. Then we discuss the main findings and make some recommendations for future research.

1.1 Rivers and urban space

Rivers have played an essential role in the formation and growth of a large number of cities and they can influence the current morphology and future expansion of urban settlements (Cakaric, 2010). The relationship between both, river and city depends on different factors such as the width of the river, length of the waterfront, number of crossings (Silva et al, 2006) as well as affordances created to have contact with the river including longitudinal, lateral and vertical connectivity (Kondolf and Pinto, 2016). The presence of rivers also affect the morphological configuration as the street network in cities with rivers is more stable, more integrated and better connected internally than in cities without rivers as highlighted by Abshirini and Koch (2016).

Apart from the influence on morphological aspects in cities, rivers also have a role as social elements. Firstly, rivers and their riversides as natural environments are important for leisure and recreation that have an effect on physical and mental health. These current issues drive interest in what riverside places and activities might have to offer (Matsuoka and Kaplan, 2008). Secondly, rivers and riversides are ecological corridors, fundamental in the preservation of flora and fauna species and also for flood management due to climate change (River Restoration Centre, 2009). Thirdly, rivers have the potential of becoming catalysts for regeneration, investment and reuse of land and buildings (Canal and River Trust, 2014). At the same time, riversides face some significant threats, including fragmentation due to urbanisation, excessive pressure on recreational spaces, pollution, and the less discussed threat of excessive development which disrupts the balance between nature and urban space (Greater London Authority, 2018).

While the mentioned studies recognise the connection between rivers and the built environment, there is no further articulation of the relationship of the formal and functional aspects of the urban system in relation to rivers. In this respect, the study of spatial relationships based on space syntax concepts and methodology can provide a better understanding of rivers in their urban context. Space syntax theory describes and analyses space as configurational, meaning relations that take into account other relations and where the relationship between the parts is more important than the parts in isolation (Hillier,1996b,p1). In cities, the relationship between spaces allows us to move in certain ways and encourage certain activities, and it is this system of spaces that has a direct relation to social life 'since it provides the material preconditions for the patterns of movement, encounter and avoidance ’(Hillier and Hanson 1984, ix). In addition, as explained in the theories of natural movement (Hillier et al 1993) and movement economies (Hillier 1996a), the spatial configuration has a systematic effect on movement and subsequently, it affects other aspects of how space functions such as the arrangement of land use. Space is not merely a background for any activity but has an effect on the potential of urban space to generate or replicate social activities.

This methodology also contributes to the understanding of sustainability and environmental aspects of the city through the study of the effect that space has on the use of resources. According to Hillier et al (2009), the form of a city is a consequence of environmental, economic and social sustainability because the generic form of cities is related to optimisation of movement and subsequently the energy needed for that movement. Likewise, the potential benefits that people can get from natural elements like green and blue urban infrastructure which include rivers are linked to other built environment factors such as network structure and topology (Andersson et al, 2019). In terms of mental health benefits such as alleviating fatigue and stress reduction, it is claimed that regular opportunities of contact with nature have a better correlation with health benefits than simply the residential proximity to nature (Ekkel and De Vries, 2017). Furthermore, the frequency of exposure to nature is more relevant than the duration of exposure, highlighting the importance of opportunities for contact during daily activities rather than prolonged but occasional visits (Cox et al, 2017). In terms of supporting community life, the creation of links between people and places, as Benages indicates, is based on a process of ‘appropriation of space of the riverside environment that typically results in a sense of responsibility of the subject towards it’, where interaction over time is an essential factor and a more frequently used space will tend to be better appreciated by the people who use it, creating a bond and feelings of responsibility towards it. This becomes a cyclic process where more responsibility should create better cared for spaces and subsequently more used spaces. The common factor in the aforementioned studies is the relevance of frequency of contact with the natural environment to receive certain benefits which makes the study of configuration of space and how it will have an effect on their potential use even more relevant.

1.2 The case of London small rivers

London has more than 600 km of rivers and streams, excluding the River Thames, which run through each of London’s neighbourhoods (Greater London Authority, 2016). There are 39 rivers within the Greater London Authority boundary, the majority of them being tributaries of the River Thames. A considerable proportion of London’s rivers are surrounded by suburban areas and they are not navigable in most of their length.

In the last decades of the 20th century, the city’s relationship with rivers shifted from them being mostly used for energy creation, shipping and waste disposal to a more sustainable approach where social and ecological aspects became more relevant. The current London Plan (Greater London Authority, 2016) has a series of policies aimed at protecting these resources based on a vision of a more sustainable city. The London Plan acknowledges waterways as valuable resources in their different respects, and the policies focus on three main aspects. First, development plans and intervention projects seek to increase transportation for people and freight which is based on economic and also sustainability considerations. Therefore, areas dedicated to these activities are protected, limiting land use changes in areas of canals and navigable sections of rivers. Second, policies encourage leisure activities based on people's active involvement with water and also informal recreation, recognising that people often like to gather next to these spaces. The London Plan, therefore, requires new developments to improve the accessibility of rivers. Third, the London Plan implements a series of policies to improve ecological conditions and reduce threats related to climate change; including protection from water pollutants, creation of alternative sewage systems and flood risk protection. Although the policies summarised above deal with fundamental aspects regarding urban rivers they do not provide further guidance about future development and protection of these areas.

1.3 River Brent and River Wandle: past and present

The rivers selected for the study, Brent and Wandle, are located in West London, river Brent at the north side of the Thames and river Wandle at the south. River Brent is about 25 km long and runs from a junction of two small tributary rivers in north London. River Wandle is about 17 km long and starts in two points: Carshalton Ponds (Whyrtle) in Sutton and Wandle Park in Croydon. The rivers Brent and Wandle share a history of agricultural use, industrialisation, pollution, urban development and recent restoration. Today, both rivers have reduced levels of pollution, good ecological diversity and they have been intervened with some restoration projects in areas such as Tokyngton Park, Brent River Park, Carshalton and Morden Hall Park amongst others.

During the 18th century, the River Brent was surrounded by agricultural land, which later changed to pastures of grass and small market gardens (Hounsell, 1991). During the 19th century, an extensive range of manufacturing areas developed around the river dedicated to industries related to gas works, mineral oil, potteries, and breweries. Later in the 20th century, the industries evolved into the motor industry, food processing, chemicals, furniture and others located at the northern stretch of the river. The south part of the river was meanwhile dominated by port-related activities and their related infrastructure (Inwood, 1998). The River Wandle also had an early development for agriculture combined with the extended use of mills due to the speed of the river's current which was later slowed by major modifications. During the 19th century, the river was bounded by industrialised areas dedicated to the production of paper, bleaching, distilleries, chemicals and dying amongst others linked to the textile industry (Inwood, 1998). There had also been exploitation of natural resources in Croydon and a water work facility built in Beddington to process and return clean water to the river (Hobson, 1924).

Certainly, the constant occupation of both riversides indicates how proximity to these rivers has been a significant resource for agriculture and production since before the Industrial Revolution. This condition is reflected in the spatial organisation identifiable in historic maps at the end of the 19th century (Fig. 1), where the majority of old towns and villages on these areas are far from the river, e.g. Mitcham and Hanwell (500m from the river) or Ealing and Sutton (2km from the river)

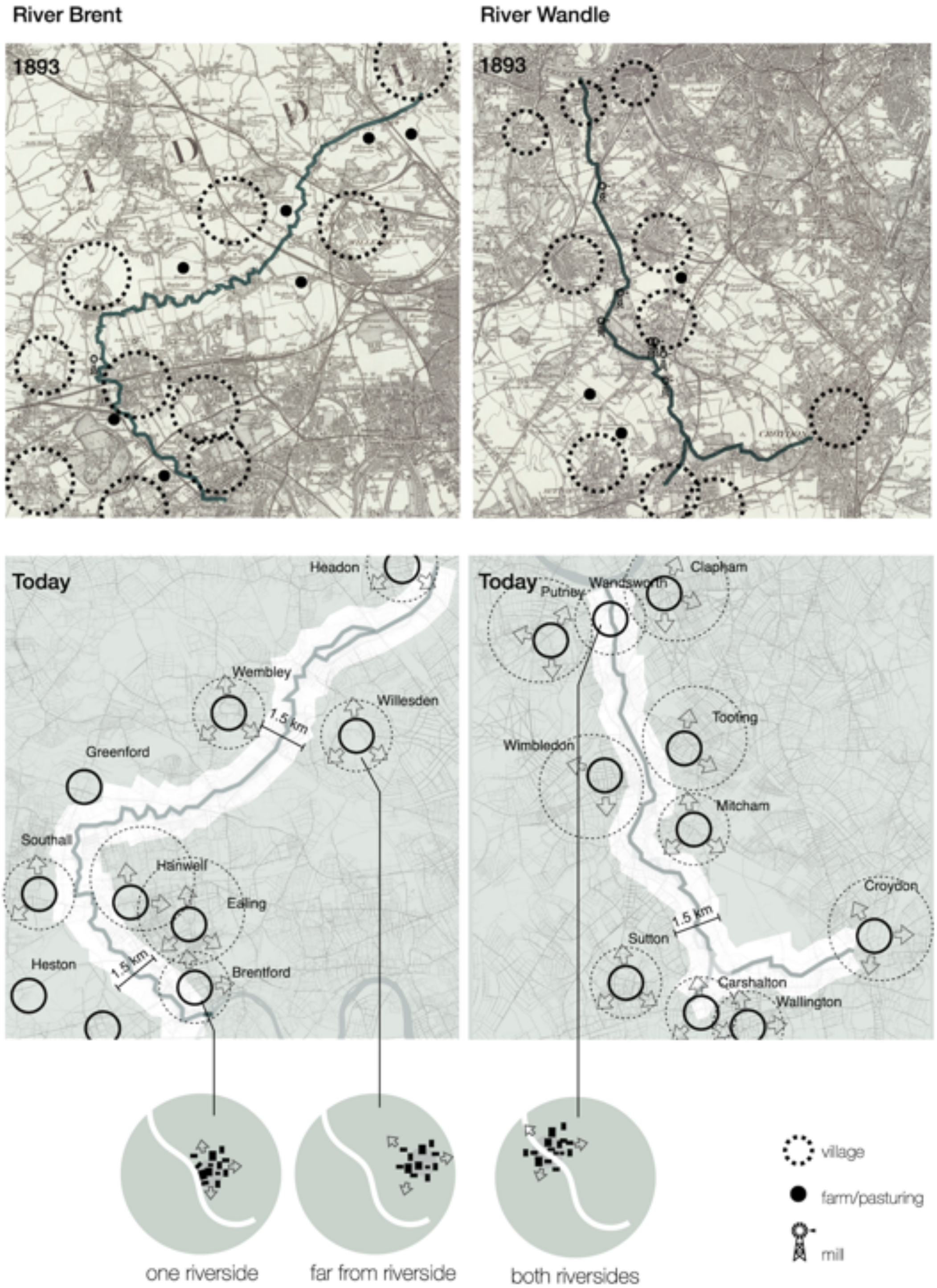

Fig. 1 Historical map of London 1893 (Modified from source: National Library of Scotland). Contemporary spatial network of rivers Brent and Wandle with schematic growth patterns. Author.

and the extensive road and rail network crosses the rivers leaving big pieces of land seemingly dedicated to the uses previously described.

During the 20th century, suburban expansion and new infrastructure changed the areas surrounding the rivers Brent and Wandle; and some green areas were consolidated and opened to the public (Gilbert, 1991). The development of the road network along parts of the riversides suggests that there has been a process of urbanisation in these areas which is surely still undergoing. However, this process is not identical and distinct growth patterns can be identified based on the position of urban centres relative to the river and how the urban grid develops along with it: on both sides of the river as in the case of Wandsworth and Carshalton, on one side of the river in areas such as Brentford and Hanwell and growing at a distance from the river such the case of Willesden, Ealing, Tooting and Sutton (Fig. 1).

2. DATASET AND METHODOLOGY

The research was developed through a comparative study of two London rivers at two scales of analysis and it used a detailed spatial network model including roads and paths, a waterways network model, buildings footprint, demographic and land use data. The study area along each river was determined using a Metric Catchment Analysis (MCA) from the network segments close to the river, which were defined using a 30m buffer from the centre line of the river. Subsequently, a second Metric Catchment Analysis was run from the segments selected by the first MCA using a 2,000m distance. The area captured by the analysis was used to compare segments close to the river or 400m catchment -between 0m and 400m on each side of the river- with a wider area or 2,000m catchment -between 400m and 2,000m on each side of the river-, which correspond to 5min and 25min walking distances respectively.

To understand river spaces in relation to the built environment and social parameters we investigated the following aspects. First, we charted four elements: road network, buildings, bridges and land use which give a general approximation of the morphological and functional characteristics of the urban fabric surrounding these two rivers. Second, we compared and contrasted two syntactic measures obtained from the analysis of the spatial network. Third, we explore the relationship between distance from the river and syntactic measures with demographic data. These three steps allowed us to understand how embedded rivers are in the physical environment and possible links to social parameters.

The analysis of network extension and river crossings included the comparison of the length of spatial network per each kilometre of the river at two catchments (400m and 2,000m) as well as the number of river crossings including vehicular and pedestrian per each kilometre of river length. The number of crossings is an indicator of how they contribute to the use of the river (Silva et al, 2006). The constitution of the riverside understood as the relationship with buildings ' interface was analysed including all buildings within a buffer of 50m from the river centreline, and it considers the number of units per every 100m of river length. Land use patterns were analysed to establish the functional orientation of each catchment and evaluate any significant differences between them. Land use data was transferred into network segments and then compared considering the proportion of the number of segments per land use type on each catchment area.

Syntactic Analysis used the measures of normalised integration (NAIn) and normalised choice (NACh) at a city and local scale. The measure of integration shows how shallow (integrated) or deep (segregated) a space is in the whole system being analysed (Hillier and Hanson,1984,p108) and it predicts to-movement. The measure of choice highlights elements in the network that have the potential to be chosen as routes between all parts of the network and it predicts through-movement. Areas with high integration values have the potential to become destinations in the urban grid and elements with high choice value are likely to become routes between spaces (Hillier and Iida, 2005). These measures were obtained through angular segment analysis, which refers to the angular change between segments, using 400m, 800m, 1200m, 2000m, 5000m, 10000m radii chosen for this study. The mean values of both catchment areas were compared to assess the tendency of each area to attract different types of movement. Additionally, multi-scale analysis which only considers the values in the 10th decile of NACh measure was performed to visualise the routes which have high choice values at a local scale, global scale and a combination of both (multi-scale).

Socio-economic conditions were evaluated using the Index of Multiple Deprivation (IMD). IMD is a score resulting from the combination of various socio-economic components including income, employment, education, health deprivation, crime, barriers to housing and living environment deprivation. The values of IMD of defined census areas were compared according to the proportion of output areas falling into each decile of these parameters. IMD values were also transferred into network segments to perform Pearson's correlation which was used to assess the relationship of IMD, metric distance from the river and syntactic measures.

Finally, we carried out a more succinct examination of four case studies along both rivers that included spatial analysis, movement and socio-economic data. Movement was recorded using gate counting – the number of people crossing an imaginary line- on various points for each case study. River paths, streets and parks around the selected areas were observed at similar hours on weekdays during the first week of August 2019 with similar warm weather conditions in all cases. Thereafter, movement was compared to spatial and socio-economic variables to determine if there was a pattern of variation and using Pearson's correlation. Observed movement as the dependent variable was studied as total movement (adding together all four cases) as well as movement separated per case study. The Index of Multiple Deprivation (IMD) values were transferred into the network segments to conduct a bivariate correlation.

3. ANALYSING SPATIAL AND FUNCTIONAL CHARACTERISTICS ON RIVERSIDES

The extension of the network highlighted by the metric step depth analysis is compared between both rivers. The first comparison is between the spatial network captured by metric step depth of 400m on each side of the river and the second comparison is between the network captured by metric step depth of 2,000m on each side of the river. River Wandle has a more extensive network reachable at these two catchments per meter of river length, 29% more network in the 400m catchment and 18% more network in the 2,000m catchment. Similarly, the number of river crossings on river Wandle is 30% greater than the number on River Brent. Both measures provide a first hint on how differently the urban fabric has developed along both rivers (Fig. 2).

Regarding the constitution of riversides, the analysis shows a clear difference between how much built space (in units) exists on each riverside. River Brent has extended areas with none or a very low number of buildings, particularly on the southwest part of the river and river Wandle has the majority of its length surrounded by a considerable number of buildings. While this comparison does not take into account the area of coverage nor the intensity of land use, it provides a quantitative assessment of how the riverside is conformed in terms of built elements (Fig. 3).

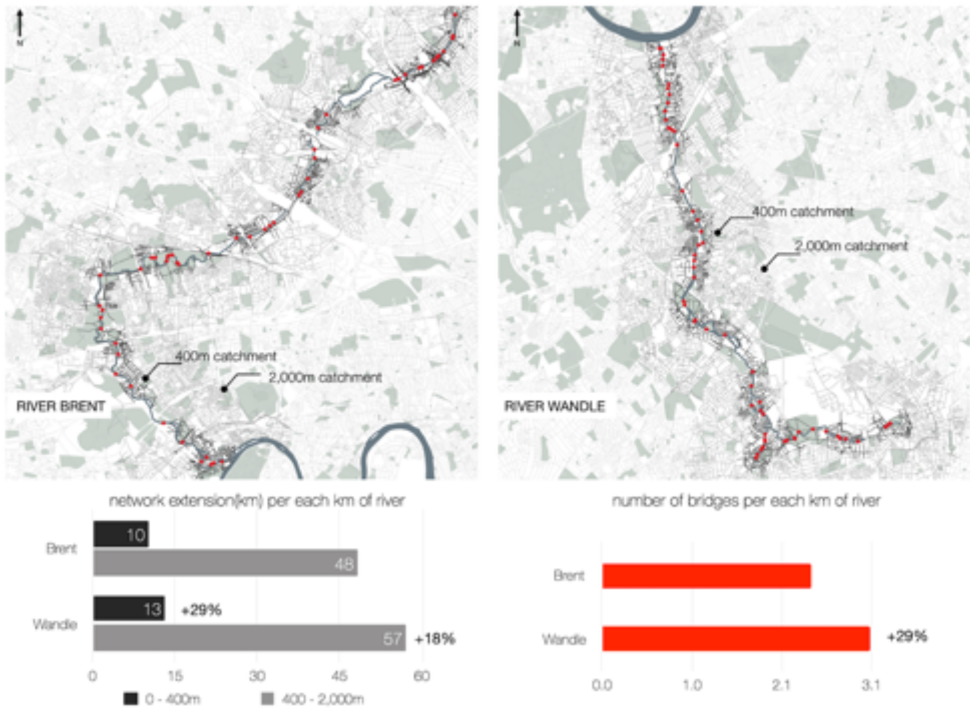

Fig. 2 Network extension and river crossings. Author.

The analysis of land use indicates the functional orientation in the areas surrounding the river (Fig. 4). About 50% of the network on the 400m catchment along both rivers corresponds to residential use, 45% in river Brent and 55% in river Wandle, while a mix of uses including commercial, education, health, government and services present a higher percentage on river Brent 13% than along river Wandle 9%. The residential land use increases to almost 70% in the 2,000m catchments in both cases. The analysis also shows that in the 400m catchment around 25% of the network corresponds to different types of green space including open space, natural reserves and forests and an approximate 10% of the network is dedicated to industrial use decreasing in further areas. Commercial uses remain steady in all catchments around 8%.

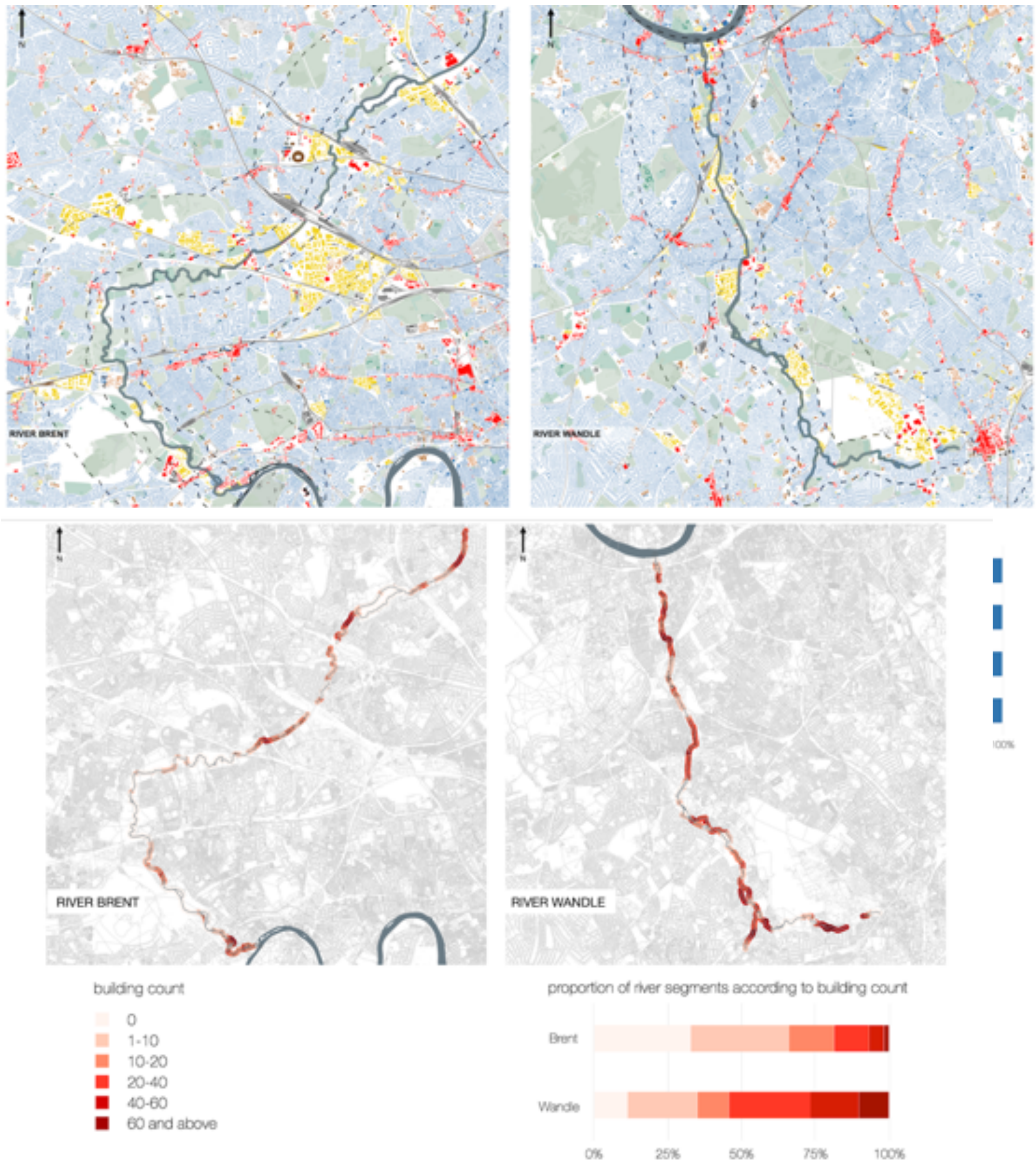

Fig. 3 Constitution of riversides. Author.

3.1 Syntactic analysis

The syntactic analysis of river areas uses space syntax measures of Normalised Integration (NAIn) and Normalised Choice NACh to understand which elements of the spatial network, closer or further from the rivers, have the potential to become destinations or routes at local and city scale.

In the first step, the analysis focuses on the mean values of the 400m catchment compared with the mean values of the 2,000m catchment for each river at multiple metre radii. The line graph shows on one hand that in terms of Normalised Integration there are 8 of 12 comparisons where 400m catchment presents lower values than 2,000m catchment meaning that in most of the radii compared the areas closer to the river are less integrated than further zones (Fig. 5). In more detail, the analysis shows that in the case of river Brent, the segments on the 400m catchment present lower integration values at smaller radii (400m – 1,200m) while at larger radii (2,000m – 10,000m) they present higher values than its 2,000m catchment. In contrast, the segments on the 400m catchment of river Wandle have higher values at very small radii (400m) and lower values than its 2,000m catchment in all other radii of analysis. Overall, the comparison between both rivers shows 400m and 2,000m catchments of river Wandle have higher integration values than those of river Brent in most of the radii analysed (400m – 5000m). On the other hand, in terms of Normalised Choice, there are 12 out of 12 occurrences where 400m catchment presents higher values than 2,000m catchments indicating that areas closer to the river are consistently crossed by a higher rate of through-routes. Additionally, 400m and 2,000m catchments for both rivers present very similar mean values with a slight variation in this pattern on a city-wide scale (5,000m and 10,000m radii).

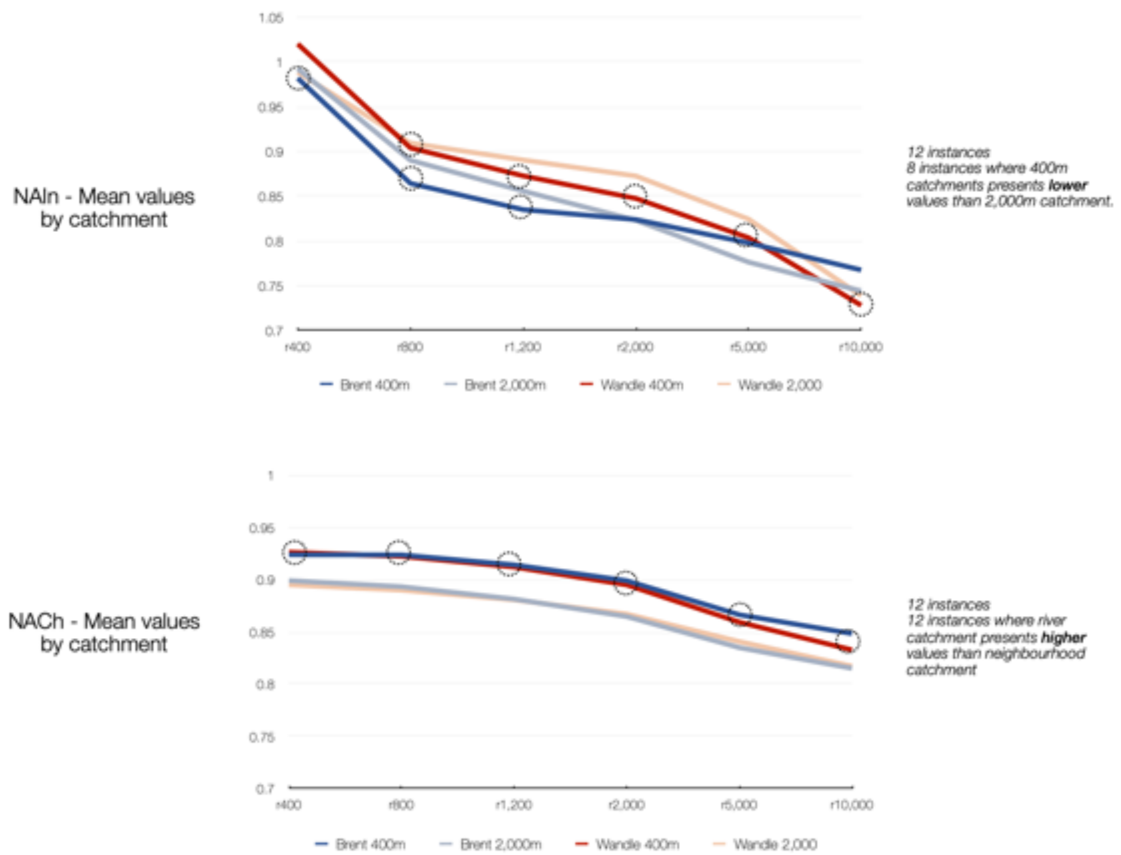

Fig. 5 Variation of NAIn and NACh mean values across all radii. Author

A closer look into NAIn values, at a local scale (1,200m radii) and city-wide scale (10,000m radii) illustrate differences in the network configuration of both rivers (Fig. 6). On the local scale, river Wandle has few points where the river is embedded into highly integrated areas such as Wandsworth, Colliers Wood and Carshalton and river Brent has only a few highly integrate segments crossing it but they do not form integration cores. This suggests that these two rivers are not spatially related to nearby local centres in most of their length. On the city-wide scale, a large area on the eastern side of the river Brent has high NAIn values, being part of the most integrated structure at city scale that continues from Central London to Hammersmith and Shepherd's Bush. It is worth noting that almost all the eastern riverside of the Brent is surrounded by segments with high integration values. River Wandle's surrounding area is highly integrated at its northern part and gets connected with the south London areas of Battersea, Clapham and Lambeth. The proportion of the most integrated segments varies according to the radii of analysis. On a local scale, river Wandle has a larger proportion of segments with high integration values being the opposite for city-wide scale.

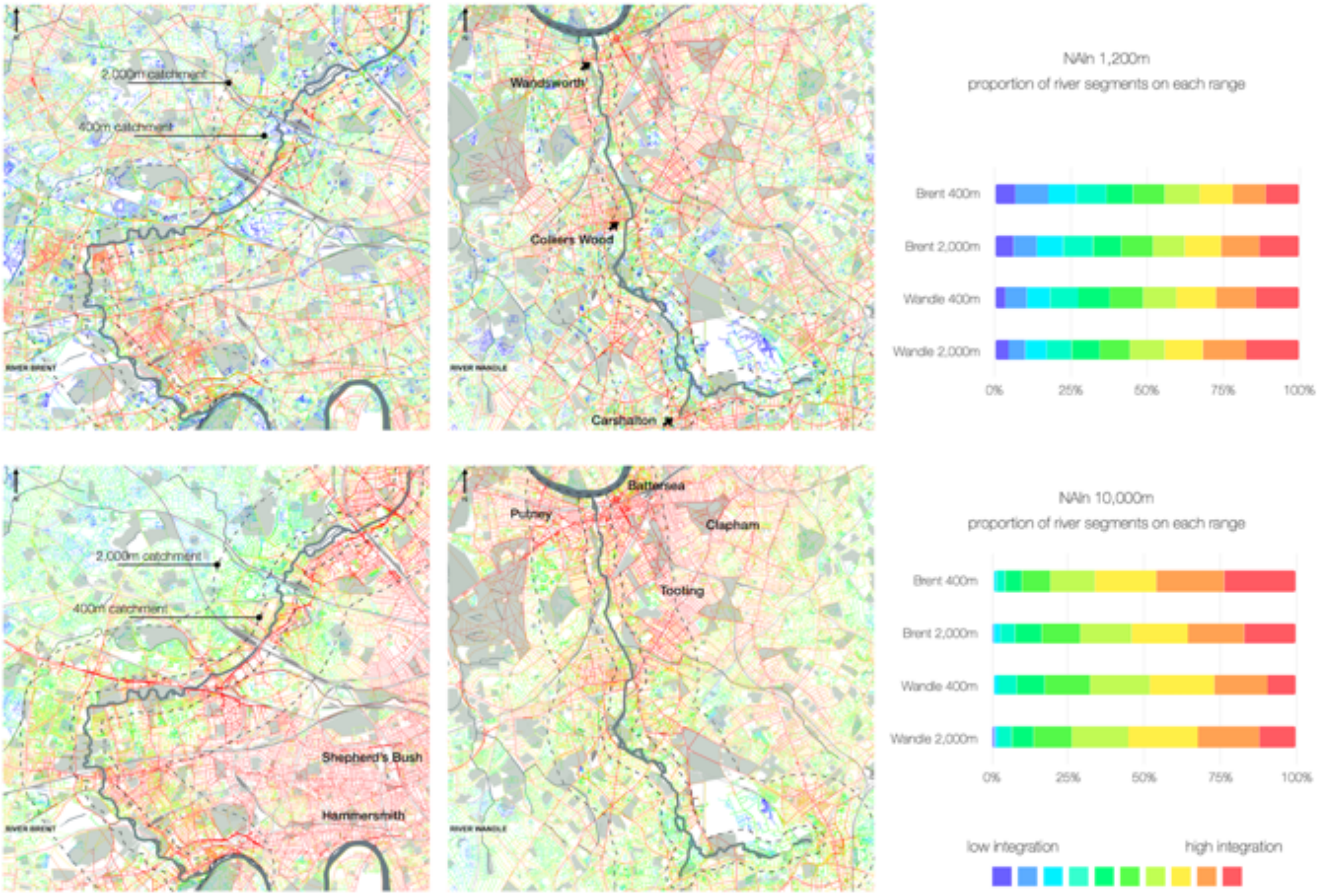

Fig. 6 NAIn analysis at 1,200m and 10,000m radii

The multi-scale analysis brings into view the foreground network at local (1,200m), city-scale (10,000m) and a combination of both through selecting the highest values of normalised choice at each scale (Fig. 7). The visual assessment of the mapped results highlighted that both rivers, Brent and Wandle, are crossed by segments with multi-scale values, predominantly directed towards the city centre and only a few sections along river Brent have segments with multi-scale values adjacent to the river. In both rivers, segments with the highest local choice are sparse and the local network structure coincides with the river only in a few locations, eg. Brent River Park, Brent Valley Park, Wandsworth, Earlsfield, Colliers Wood, Mitcham and Carshalton. The comparison of the proportion of segments with the highest values at local, city and multi-scale for each catchment highlights how different Wandle's riverside is in terms of their foreground network, having more segments with high choice value at local scale.

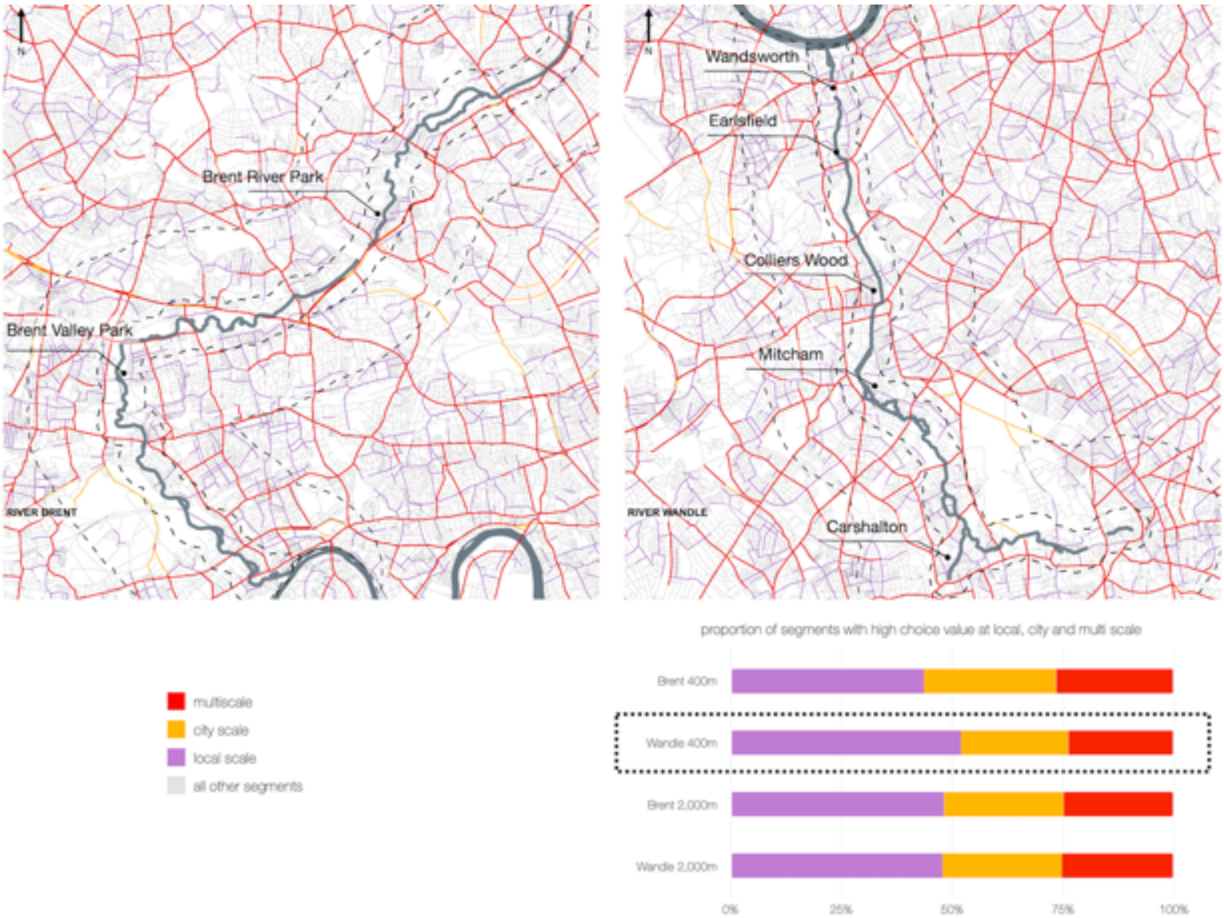

Fig. 7 Multi-scale analysis r10,000m and r1,200m. Author

3.2 Social and economic conditions

The Index of Multiple Deprivation (IMD) shows that river Brent is surrounded by areas with high deprivation spread across most of the length of the river, while in the case of the river Wandle there is a concentration towards the south of the river (Fig. 8). The comparison of social and economic indicators of output areas located closer to the river reveals that 35% of these areas along river Brent have a high Index of Multiple Deprivation (index 1-3) compared with 15% along river Wandle.

The evaluation of the relationship of social and economic data (IMD domains) with metric distance from the river shows weak correlations for all parameters compared. The evaluation of the same data with syntactic measures presents rather weak correlations with NAIn measures and no correlations with NACh measures.

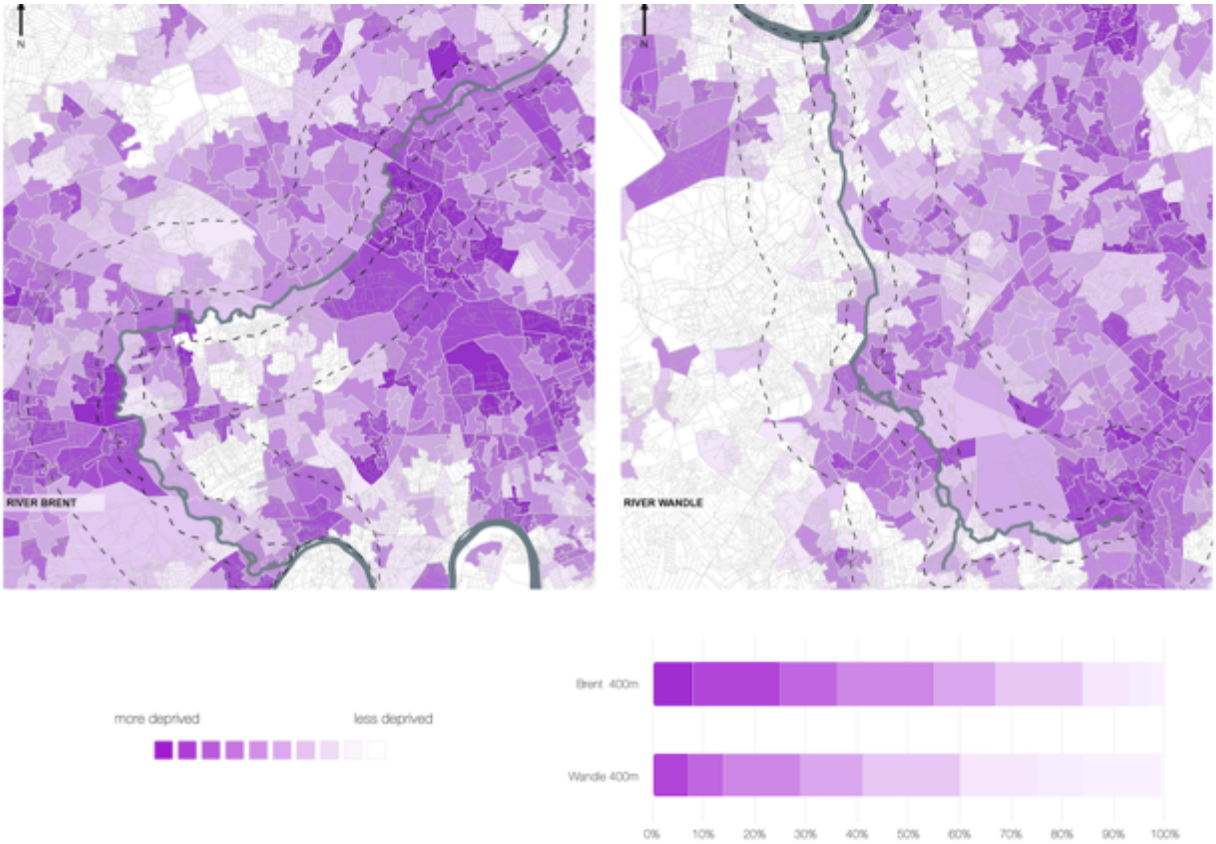

Fig. 8 IMD along rivers Brent and Wandle and proportion of IMD per catchment. Author

3.3 Case Studies

We studied four areas along rivers Brent and Wandle. Brent River Park is a section of the river Brent limited by the railways from Wembley Station to the north and Stonebridge Park to the south, located in the central area of the Borough of Brent. It has a public linear park on the west side and some open areas and paths to the east. Hanwell's case study consists of a section of the river Brent next to Hanwell and Boston Business Park in the borough of Ealing. The river has a sole path on the east side and it is next to Elthorne Park and Waterside woodland. Summerstown comprises a section of the river Wandle located between the boroughs of Wandsworth and Merton. There are some paths on the west side of the river and a park on the east side separated from the river by allotments. Carshalton's case study consists of a part of the river Wandle next to Carshalton Ponds in Sutton. This section of the river runs adjacent to The Grove Park.

The four case studies have major differences in recorded movement. Carshalton's riverside has the highest average movement amongst the four areas (88 people per hour), 1.5 times more than Summerstown (54 pph), 3 times more than Brent River Park (29 pph), and almost 15 times more than Hanwell (6 pph). The analysis of integration at radii 2,000 picks up an extended and highly integrated network surrounding the river in Carshalton´s case study and a lesser integrated area towards the south of the river in Brent River Park. Hanwell's case has a series of parallel and well integrated segments on the east side of the river, and Summerstown's area is framed by segments with high integration values though distant from the river (Fig. 9).

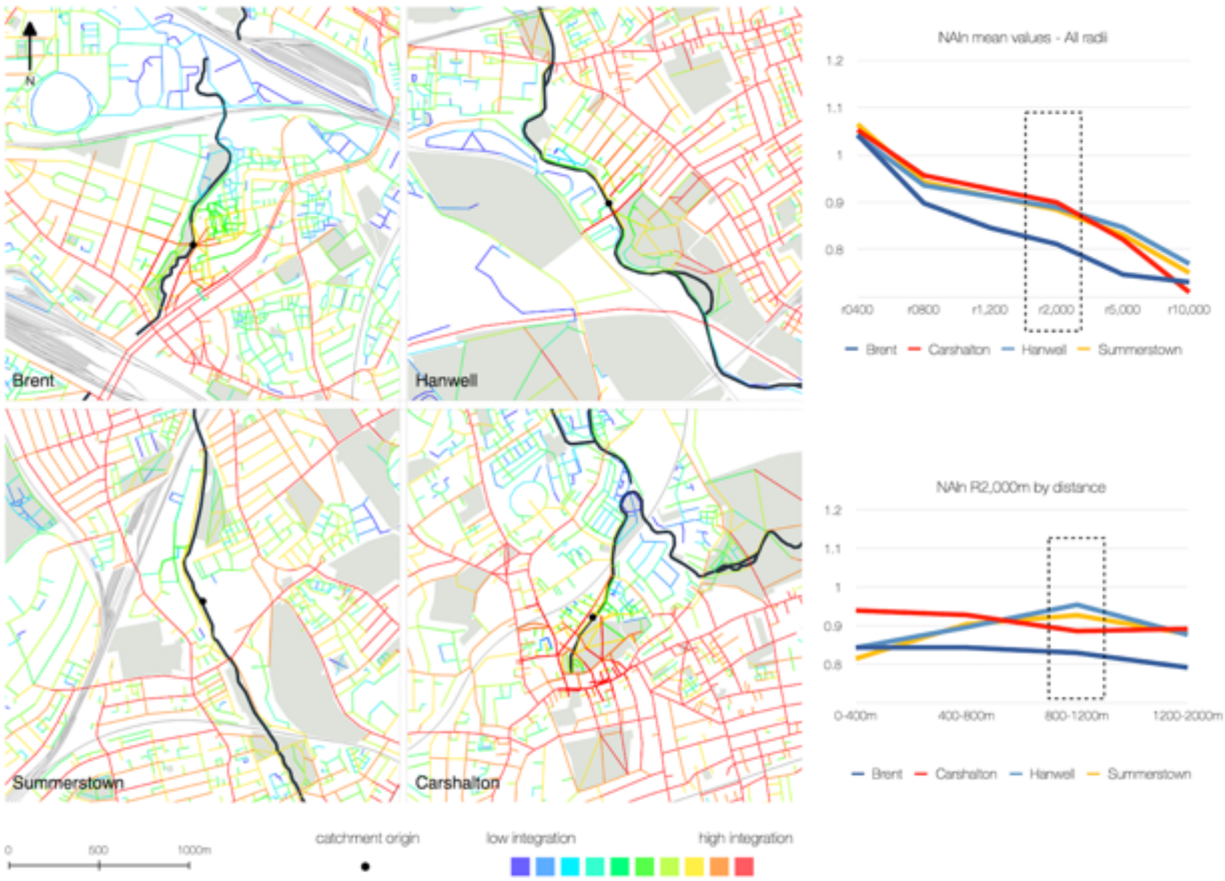

Fig. 9 NAIn R2,000 in four case studies. Mean NAIn values at all radii (top) and Mean NAIn values at R2,000 divided by distance from river (bottom).

The comparison of syntactic measures reveals that across different radii of analysis (400m - 10,000m), 3 out of 4 cases have similar values on both measures and Brent River Park stands out as it has the lowest mean values of NAIn and the highest mean values of NACh. The comparison by distance at 2,000 radii shows that Carshalton and Brent River Park have higher integration values closer to the river (0-400m), both decreasing with distance from the river up to 1,200m where Carshalton's integration value increases slightly. Hanwell and Summerstown present lower integration values when closer to the river, they reach a peak between 800m and 1200m and decline slightly further from the river (1,200m-2,000m). Regarding normalised choice, in Brent River Park and Carshalton, the average choice values fall with distance from the river with the lowest value at 800-1,200m and rise again further. Hanwell and Summerstown present an opposite pattern going slightly up in values at 800-1,200m.

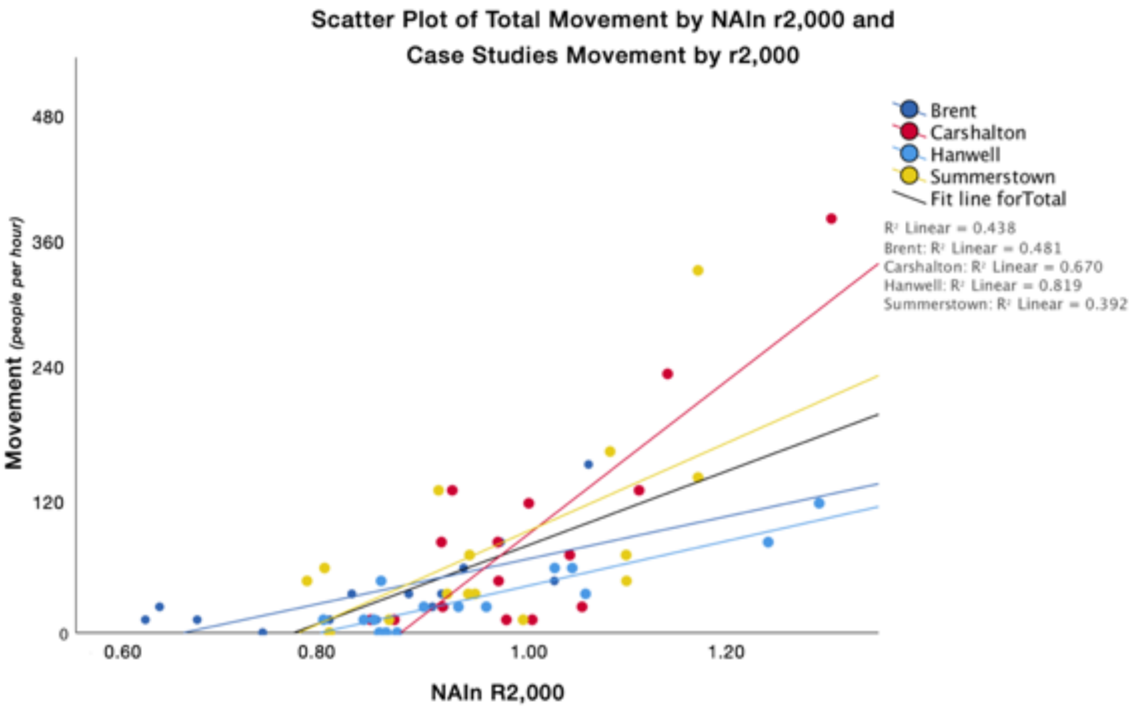

Fig. 10 Scatterplot of Total Movement, Movement per Case Study and NAIn r2,000. Author

Pearson's correlation coefficient using observed movement, syntactic measures and Multiple Deprivation Index indicates how the current movement relates to spatial configuration and socio-economic parameters on each area. The relationship between total observed movement and syntactic measures at all radii shows that 10 out of 12 correlations are statistically significant and are greater or equal to r(58) = .45 and the highest correlation, with NAIn r2,000, is r(58)= .66 and r2 = .44 (Table 1). Normalised integration analysed at 2,000 radii also presented the most significant correlations across all case studies when plotted separately. Looking at each case study, Hanwell has the highest correlation r(13)=0.91 and r2=.82 and Carshalton has r(13)=.82 and r2=.68 (Fig. 10). The relationship between total observed movement and Multiple Deprivation Index and its domains reveals a rather low correlation between observed movement and Multiple Deprivation Index r(58) = .26. Additionally, there are two significant correlations with two MDI domains: Employment Deprivation r(58) = .35 and Barriers to Housing and Services r(58) = .31 (Table 2).

Table1: Correlation between Total Movement and NAIn - NACh

Correlations

Variables	Statistics	MV_total_m	NAIN_r0400	NAIN_r0800	NAIN_r1200	NAIN_r2000	NAIN_r5000	NAINr10000
MV_total_m	Pearson Correlation	1.00	.58**	.62**	.55**	.66**	.55**	.30*
	Sig. (2-tailed)		0	0	0	0	0	0.02
	N	60	60	60	60	60	60	60

Variables	Statistics	MV_total_m	NAIN_r0400	NAIN_r0800	NAIN_r1200	NAIN_r2000	NAIN_r5000	NAINr10000
MV_total_m	Pearson Correlation	1.00	.21	.45**	.45**	.53**	.53**	.53**
	Sig. (2-tailed)		0	0	0	0	0	0.02
	N	60	60	60	60	60	60	60

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 2: Correlation between Total Movement and IMD domains

Correlations

		MV_total_m	ID_IMDSco	ID_Income	ID_Employm	ID_Educati	ID_Health	ID_CrimeS	ID_Barrier
MV_total_m	Pearson Correlation	1	-.260*	-.182	-.347**	-.207	-.150	-.124	-.309
	Sig. (2-tailed)		.045	.165	.007	.113	.254	.345	.01
	N	60	60	60	60	60	60	60	6

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

4. REACHING TOWARDS THE RIVER

Since the 19th century, the urban fabric surrounding the two rivers subject of this study tended to grow around villages located at distance from the river leaving large areas dedicated for production activities. Despite more than 100 years of city's growth, this analysis shows that this signature has been maintained, where centralities are located away from the river and current riverside's land uses, manufacture and logistics, show a parallel with the previous function of these areas. Although urban development in both areas is concentrated closer to the Thames and directed towards central London as highlighted by the integration measure, the elements analysed - network extension, bridges, land uses and buildings- shed some light on how both riversides areas are distinctly shaped. The process of approaching the river is more consolidated in the area of the river Wandle, as seen by the extension of the network and the constitution of the riverside while keeping extended industrial land. In contrast, river Brent has a more limited network, a lesser proportion of buildings facing the riverside and it has preserved more areas of urban forest.

Certainly, rivers are embedded in the urban fabric differently as illustrated by the spatial configuration analysis. Both riversides are more spatially segregated than their immediate context at a local scale as integration values of river areas are lower than those of surrounding neighbourhoods. At a city-wide scale, this relationship is different in each case, as Brent's riverside (400m catchment) is more integrated at a city scale than its 2,000m catchment, while Wandle's riverside is more segregated than its 2,000m catchment. These results suggest that areas closer to the rivers tend to be less accessible at shorter distances and have less potential to become local centres as the growth of the spatial network has concentrated around the centralities developed at distance from the river, in contrast, the relationship with the wider network varies giving each case a different degree of embeddedness at city scale. Riverside areas (400m catchment) also tend to be orientated for through-movement at a city-scale suggested by the consistent higher choice values when compared with a larger catchment (2,000m), due to the routes connecting towards the city centre and the wider region.

The reduced overlap between the foreground network and riverside segments exposed by the multi-scale analysis indicates that the network that maximises movement across scales is only partially associated with the riverside, as it runs parallel but far from the rivers. The points where the foreground network coincides with the river are mostly part of the linear structures connected towards the city centre. Thus, riverside areas are shaped by these radials with local and city-scale connectivity and have limited links to local areas. This characteristic agrees with Abshirini and Koch's study of river and non-river cities (2016) where they suggest that the foreground network, essential for transportation and movement, in the case of river cities, is focused on preserving the efficiency of the network more than just crossing the rivers. An efficient network is inherent to the type of movement necessary for manufacturing and logistics leading to the location of industrial activities in these areas which was confirmed by the analysis of the riverside's land-use patterns and a visual assessment of mapped land uses. However, while the attention to city-scale movement results in a more stable and integrated foreground network, it also tends to generate a system of motorways and high-traffic roads which hinder even more the limited local accessibility of inner areas.

Whereas the analysis highlighted some general attributes of the rivers at a large scale, the four case studies showed that rivers are not homogeneous entities. Spatial configuration differs between areas so there is not an overarching spatial pattern shared between these river areas and likewise the strength of the relationship between spatial configuration and use of space varies for each case. The analysis of interdependence between syntactic measures of integration and choice and observed movement has results that vary from weak to strong correlations depending on the case study, where Hanwell and Carshalton, which present the lowest and highest observed movement respectively, also have the strongest correlations with syntactic measures. It follows that the geometrical and syntactical structure of the riverside's spatial network has a variable effect on their potential use and that the integration measure is more effective in explaining this relationship. We can point out that the condition of centrality generated around rivers is the predominant factor that affects movement on riversides and that in the cases analysed it is more significant than routes through the river. Live centrality as it is described by Hillier means the element of centrality which is led by retail, markets, catering and entertainment and other activities which benefit unusually from movement (Hillier, 1999). When the spatial structure around rivers is part of that centrality, the river has more people interacting with it due to movement at different scales coming together. Additionally, a more segregated condition with less through-movement at a city scale has advantageous results for river areas as they do not become severed by large elements of road infrastructure. Therefore, it is centrality at a local scale while being less connected at a wider scale that seems key to creating an environment where small urban rivers are part of the daily activities of the population.

In terms of socio-economic conditions, IMD shows some clear variations along the rivers in combination with the contrast between both sides of the river, hence the river appears as a connected feature in the urban structure or as a boundary. In the first case, when the river is immersed in areas of similar integration values and has more links at a smaller scale, it corresponds with similar socio-economic indicators. In the second case, where there are more inequalities in the spatial network across the river and fewer connecting routes at a smaller scale, there are also notable socio-economic differences. It could be said that an asymmetrical situation would make the physical division caused by the river more profound. However, this kind of association proves difficult to establish as it was confirmed by the absence of any significant correlation between socio-economic parameters and the spatial network. The analysis considering the whole length of the river and the case studies suggests that proximity to the rivers and the syntactic measures used are not primary factors in the current socio-economic conditions of the observed areas and it denotes that the relationship between the analysed elements is more complex and has not been clarified by this approach.

These results point towards a dual aspect of river accessibility and the subsequent need to look at local and city spatial relations regarding urban rivers. Accordingly, urban interventions alongside rivers should consider that overcoming the geographical separation produced by the river relates not only to the construction of bridges associated with city-scale but also to the creation of an enhanced network reaching the river at a local scale. Thereby, small rivers can function as integrators instead of hard barriers in the urban environment.

Finally, spatial configuration affects rates of movement differently, and so the potential of some areas to provide specific benefits associated with river accessibility. Exploring how the configuration of space makes the interaction with these natural elements possible brings another layer of information to better approach the creation of spaces that are frequently used by the population, who then benefit from regular interaction with those spaces, as well as the generation of more secluded areas. Although the mechanics of specific benefits such as those related to mental health and space appropriation need to be well established, the consideration of frequent access is pertinent, particularly for people with certain limitations who cannot do purpose trips to enhance their contact with nature. We can conjecture that the future relationship with urban rivers will be more and more associated with this kind of benefits underlining the role of the urban structure to create opportunities for interaction.

5. CONCLUSION

The spatial analysis of river Brent and river Wandle highlighted their relationship with the city structure which has been sustained in time and has influenced the current role of rivers. These riverside areas are characterised by limited local accessibility, industrial use and predominant connectivity towards the city centre. The study has also shown that small urban rivers have a dynamic relationship with the urban environment and although they present specific characteristics defining their role at a city-wide scale, this does not necessarily reflect spatial relationships at more local scales. The varying relationship with the spatial network at different scales indicates a dissimilar approach towards rivers, as they are sometimes bypassed or limited by major roads and at other times crossed by more local routes with the potential of being reached at a pedestrian scale.

While the analysis of the spatial network allowed us to have a better understanding of their general configuration which explains why these areas function the way they do, it also showed that the study of social and economic conditions present limitations in this approach. Further research in this area should consider additional spatial properties as well as more granular data, especially when analysing rivers at a smaller scale as they might respond to more localised and complex conditions.

To conclude, this research was conducted before the surge of the Covid-19 pandemic, therefore a natural continuation to this work would be to assess the use of riversides in the context of the pandemic where local areas have become fundamental in daily life. A different line of investigation can focus on an evaluation of how riverside areas are changing under redevelopment and their possible implications.

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