The Impact of Canal Structure on the Spatial Culture of Cities in the Case of London and Amsterdam

by

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DECLARATION

I, Merve Okkali Alsavada confirm that the work present in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

ABSTRACT

Transport infrastructures have a significant impact on cities' spatial configurations. The impact of motorway and railway systems has been widely considered an aspect of urban structure. However, the spatial impact of canals on the configuration of surrounding neighbourhoods has not been clearly investigated as a determining factor in urban morphology studies. This study intends to understand the impact of canals on two different street systems, those of Amsterdam and London. While canal structure was designed alongside the planning of the street configuration in Amsterdam, it was added to the existing urban form in London during the city's growth. On that basis, this study aims to demonstrate the possible impact of this difference on the potential movement and spatial distribution of functions between Amsterdam and London. The main methodology of the study is space syntax techniques that will be used to investigate the generic properties of two cities' layouts and human activity patterns in their canals' space on the city-wide and neighbourhood scales. Diachronic spatial analysis has been performed for three different periods on the city-wide scale for both cities: the 1850s, the 1950s, and contemporary period. It further focuses on the Grachtengordel area in Amsterdam and Regent's Canalside in London for the neighbourhood scale analysis. A series of spatial analysis were undertaken that used demographic and land use data to understand whether the canals were determinant in socio-economic development of the surrounding neighbourhoods. The main result of the study is that Amsterdam has an intermediate spatial structure between its land- and water-based transportation networks, which could be due to its top-down planning process, as centred on the canal network. On the other hand, London has had a dominant land-based spatial structure, but emergent city centres like Camden Town are more generative of canal integration. To conclude, the results suggest that space syntax can be an effective methodology to investigate the relationship between waterways and street configuration for future canalside development plans.

Keywords: Canal System, Spatial Configuration, Diachronic Analysis, Space Syntax, Canalside Urban Development.

To my brother Sefa…

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1. INTRODUCTION

Transport infrastructures can create physical barriers that separate settlements, with subsequent social and economic outcomes, in the urban system. This barrier effect or community severance mainly describes the negative impact of railways or motorways on the mobility of the urban system and social cohesion of the community. Academic studies on the subject of severance have primarily focused on railways or motorways. Still, the urban system contains natural barriers such as canals, rivers, and green belts that separate settlements and cause physical isolation. Restricted access to canals or rivers may decrease the local mobility of inhabitants because they contain a limited number of crossings (Anciaes et al., 2016). Transport infrastructures might create physical barriers even if they include crossing facilities. Poorly designed facilities might also cause "secondary severance", where some social groups are unable to access them or perceive them as being effort-driven, dangerous, or unpleasant (Bradbury, Tomlinson, & Millington, 2007 in Anciaes, Jones and Mindell, 2016). Even when people can cross the barriers physically, they still cause a "psychological severance" which is defined as a "feeling of being cutting off" (Anciaes, 2015) and a "feeling of alienation and dislocation" (Nimegeer et al., 2018). The canal pathways and bridges, which commonly have steps for pedestrian access and are not generally at the same level as the canal space, may lead to restricted movement and the barrier- effect in an urban area. Moreover, canalside industrial wastelands under regeneration in most post-industrial cities had previously created secondary severance. Individuals thought of them as unpleasant and dangerous urban lands, which might have been the cause of the deprived, low-income, or unemployed households that were developed around them. In different circumstances, this barrier-effect of water can also described positively by creating amenity values in the urban system (Anciaes et al., 2016). Canalside neighbourhoods have changed over time and resulted in a certain gentrification of some parts of various cities. Pinkster and Boterman discuss the transformation of the Canal Belt in Amsterdam from a middle-class residential neighbourhood into a place of leisure and consumption. In their research, the residents mentioned how the increasing flows of international visitors and foreign capital have resulted in their inability to deal with the changes in the Canal Belt (Pinkster and Boterman, 2017). Either are subject to the spatial segregation restraining social cohesion and socioeconomic sustainability of a canalside environment. However, there is not enough quantitative analysis focusing on the spatial effect of the canals over time and how the canal systems have an impact on the mobility of the built environment in urban form studies. Therefore, the aim of the proposed dissertation is to explore the unique urban context where water and city meet. While waterways may be described as barriers in terms of accessibility, canal systems might add to the organisational framework of urban form, which does not create segregation, but on the contrary positively affects urban mobility and can be associated with cities' economic performance. Hence, the study aims to test the process of how canal systems are integrated into the street network with an analysis of whether the structure of canal systems contributes to the spatial accessibility and economic activity in two European cities, London and Amsterdam.

London and Amsterdam have been chosen because they have two diverse structures within their urban grids, each representing a different paradigm of city-canal relationship. London can be defined as having a bottom-up emergent urban fabric. In contrast, Amsterdam has seen a more top-down planning process in the form of a grid designed with waterways. Both cities contain designed urban systems but whose canal networks have been integrated to differing extents into their street networks. London has naturally grown from its original city centre, containing many villages. Thus, it is defined as a set of urban villages that are the hubs of locally deformed wheels and that have strong centre to-edge links (Hillier and Vaughan, 2007). On the other hand, Amsterdam is a semi-planned city and has a dispersed polycentric character (Berghauser Pont et al., 2019). Whilst the structure of Amsterdam was designed to include its canals, the canal system was a subsequent addition to London's already existing urban layout. In this context, the study proposes to identify the canal's role in shaping urban form through the city creation process and its socioeconomic outcomes in the urban environment. It questions whether canal systems fragment the city into units that cannot subsequently become self-contained urban spaces. It intends to undertake a comparative analysis of canalside settlements and measure the physical effects of canals on people's potential mobility, which is the physical ability to move around and within an urban environment, and accessibility, which is the physical ability to reach places. Hence, the proposed dissertation will focus on the comparison of canalside settlements in London and Amsterdam. Its aim is to compare the impact of the canal system in each of the cities, as while both are planned systems, they have had different degrees of success with regard to the integration of the canals into the street network. Also, both cities have common social and economic conditions but vary somewhat in their planning systems (Marcus et al., 2017). The study will aspire to re-capture the influence of water in the spatial structure through analyses of street structure and spatial distribution of functions in the cases of

London and Amsterdam, according to which, the study's research questions can be stated as follows:

CITY-WIDE SCALE

Q1: What is the main spatial effect of differences of the canal systems over time on the street configurations of London and Amsterdam– which has different urban growing systems and, thus, different levels of canal integration with the street network?

- The quantitative description of urban street and canal network by space syntax analysis
- Spatio-historical analysis of cities over three periods: the 1850s, 1950s, and contemporary
- Comparison of spatial patterns between three different periods in two cities: comparing areas in terms of proximity to canals

NEIGHBOURHOOD SCALE

Q2: What are the main spatio-functional effect differences of the canal structure on the accessibility and functional diversity of the canalside neighbourhoods between London and Amsterdam?

- Spatial distribution of land use types on the canalside neighbourhoods
- Correlation of choice measure, density of retails and diversity of functions on segment map analysis

By comparing these two cities on two scales, the research will attempt to understand whether different social, economic, and spatial characteristics can be determined with regard to their relationship with each waterfront settlement with canals. The main consensus on both the positive and negative effects of canals will be tested to determine if it is accurate or to what extent it takes place.

2. LITERATURE REVIEW

This literature review is organised according to four headline topics. Four areas of literature are reviewed: first, studies about community severance and barrier- effect; second; earlier studies on canals, urban form and space syntax; third, the explanation of London's and Amsterdam's canal systems in relation to urban structure; and fourth, economic specialisation and morphological descriptions of canals.

COMMUNITY SEVERANCE AND BARRIER-EFFECT

Community severance is generally associated with the study of socio-spatial segregation caused by motorways and railways. Although Liepmann (1944) used the term severance to mean a severance of dwelling and workplaces, the issue was not considered to be a spatial problem by transport authorities until much later (Mindell and Karlsen, 2012). In 1983, the UK Department of Transport formally described "community severance" in relation to trunk roads (major roads built to accommodate travel over long distances and fast-moving traffic) as separating residents from facilities, friends and relatives, place of work and services due to the traffic levels and road patterns (DOT, 1983). Later, "community severance" was defined more broadly as being due to the divisive effects of transport infrastructure on residents in a given local environment (Clark JM, Hutton BJ, Burnett N, Hathaway A, 1991). More recently, transport infrastructure's impact and severance as a spatial problem have been discussed according to the involvement of a larger group of effects such as mental and physical health (Mindell and Karlsen, 2012; Vaughan et al., 2021), the benefit on economic use (Froy and Davis, 2017), the change in the street grid and land use pattern over time (Bolton, 2018).

Mindell and Karlsen (2012) systematically review the literature on the health impacts of transport and health consequences of spatial segregation and independent mobility, caused by traffic volume and speed. A survey was completed by 709 retired Americans, and whose results show that major roads decrease the number of journeys on foot. Participants pointed out that they would never cross a busy street with heavy fast traffic, no matter how much they wanted to go to the other side. Severance particularly affects older people and children, both of whom are less likely to travel independently. This reduces their opportunities to walk within the neighbourhood space and to construct social relations within the community. As a result, it is stated in the study that there were no direct observations of the health effects of severance (Mindell and Karlsen, 2012). However, Vaughan, Anciaes and Mindell (2021) aimed to start to fill that gap, noting that there was little evidence of effects of severance on residents' health. A suite of evidence-based tools was developed to measure the negative effects of busy roads in four case study areas: participatory mapping, video surveys, street audits, a walkability model, a survey on local mobility, health, and wellbeing. The site observation illustrates that pedestrian flows along pavements are much lower than for the surrounding minor roads. Further, the results of the health and wellbeing survey showed that the road deters residents from using local shops and services. A key insight of the study is that the impact of community severance is where residents would ideally like to walk but are most likely to face large volumes of traffic (Vaughan et al., 2021). On the other hand, Froy and Davis (2017) emphasise the potential use of the railway infrastructures as "industrial streets" to connect residents with functional diversity in use. The study analyses the railway arches in three London neighbourhoods using space syntax methodology to research industrial urbanism and the potentials of railway infrastructure for small- and medium-sized enterprises. The result shows that the railway arches contain functional spaces for a variety of businesses by providing inexpensive and flexible spaces. In contrast with the idea of separation, their linear configuration allow access from the surrounding neighbourhoods and bring commercial activities into residential areas (Froy and Davis, 2017). Bolton (2018) also discusses the impacts of railways and their associated structures on street networks using space syntax methodology. A series of spatial, social and economic analyses were undertaken to investigate how the railway terminus has influenced surrounding neighbourhoods over a long period of time. Bolton's space syntax analysis reveals the difference in street patterns of change on either side of such terminals. Land use analysis shows that back areas of termini perform less well than the fronts in terms of non-residential land use density and diversity of functions. Social analysis was achieved via population, household income data, and clearly illustrates a polarisation between the back and front areas of the termini, where front areas are relatively wealthier than back areas. These studies do not contradict the community severance aspects of urban infrastructures but investigates how major infrastructure can affect urban grid continuity and their potentials in use with a functional purpose.

As discussed above, the community severance in urban studies is mainly associated with railways and motorways. However, as stated by Anciaes, Jones and Mindell (2016), the subject can be defined in several different ways regarding different transportation infrastructures or natural barriers such as rivers, canals, greenbelts etc. (Anciaes et al., 2016) (Figure 1). Therefore, the spatial definition of canalside neighbourhoods is addressed through morphological and spatial analysis in this study. The research asks whether canal structures blight their neighbourhoods, or whether any patterns of change can be discovered in canalside areas that might be reasonably identified as blight in today's cities. Hence, the study aims to analyse the canals' impacts on the spatial configuration, potential movement, and socioeconomic activities. After the decline of industry and the development of new transport systems, these waterways have not yet been used for transportation purposes and might generate barriers that have the effect of separating communities. These barriers could be created by the waterway infrastructure in itself (*physical barriers*), by the flow of movement using new transport facilities (*movement flow barriers*), or unpleasantness caused by the canal and surrounding brownfields (*psychological barriers*).

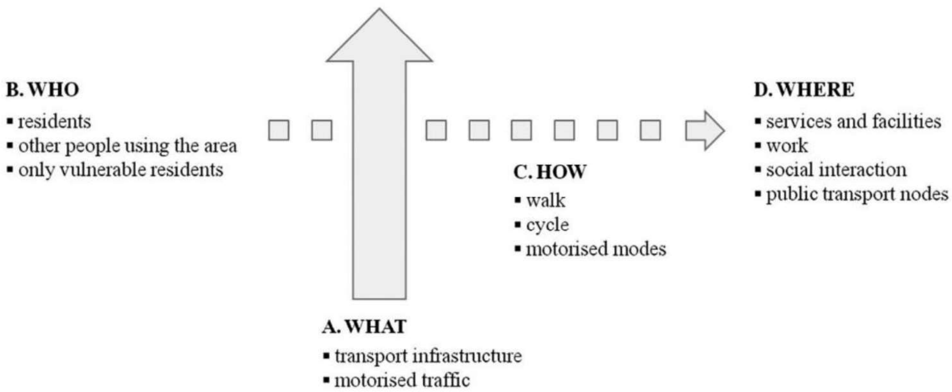


Figure 1. Elements used to define community severance (Anciaes et al., 2016)

URBAN FORM AND CANAL STRUCTURE

Hillier and colleagues discovered that "there is a generic city, that is, a structure that makes a city a city in the first place" (Hillier, 2014). The 'generic city' contains a background network, which structures residential culture, and a foreground network, which organises micro-economic activity within the city. The first proposition of the study is that the generic city dates from the first cities, and water structures were essential spatial elements in the creation and regularisation of a network of movement in some cities. It is mentioned that some cities lay in water bureaucracies, which created and controlled the canal structures that ultimately resulted in concentrations of people and economic activities with regard to food and production (Hillier, 2016). In the discussion of economic activities of old cities, the results of magnetometry of the Uruk site shows that the old city of Uruk originally consisted of a complete canal system, as well as some streets. However, the canal system seems to be more critical than streets in terms of the city's economic mobility (Becker and Fassbinder, 2001). The theoretical conception of the generic city constitutes the dual systems included in foreground and background networks: the foreground network is made up of straight connections with longer lines whilst the background network is made up of more localised connections with less linear continuity (Hillier, 2007). According to Recknagel's main comment on the use of water, the canal structures of old cities were the primary transportation system, not wide streets or other transportation systems. Their major role was not irrigation water but much more a supply of goods, materials, commodities. Hence, canal systems seem to be a part of the foreground structure of such cities, which are clearly in relation to microeconomic activities, in contrast to the streets that form the residential background of the city (Hillier, 2016). From this point of view, Psarra analysed Venice's street and canal system as configurational systems. The syntactic comparison of the network, with and without canals, shows that Venice has a lower mean normalised choice value in analysis of the street network without canals, which means the street segments are less likely to pass through the shortest routes from all spaces to all other spaces across the entire network without canals. Figure 2 illustrates the foreground network of Venice with and without canals. When the canals are added to the system, the canals have the highest values of choice (Psarra, 2014) (Figure 2). According to this analysis, Hillier (2016) finds that the maximum and mean values of the city's system become virtually normalised with the canals added to the system. Table 1 clearly shows results of the space syntax analysis of Venice's networks, which indicates NACH (Normalised Angular Choice Analysis) values for Venice Networks at radii of 500, 1500 and 3000 metres. Accordingly, the normalised choice values of the Venice streets were greater than 1.4, and with the canals added to the system the maximum of the choice measures is increased. Therefore, the foreground network achieves something more than a normal structure (Hillier, 2016) (Table 1).

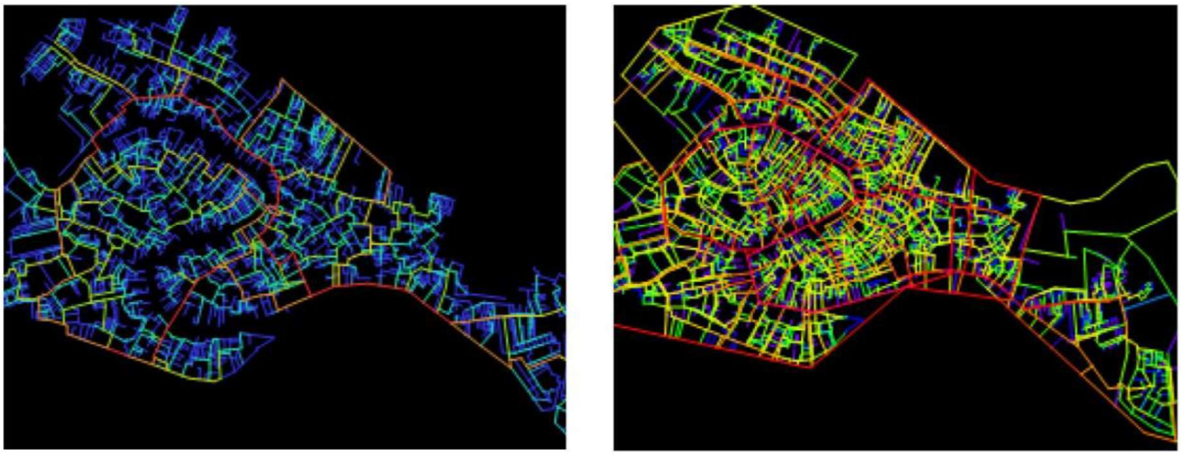


Figure 2. Foreground Network of Venice, without canals (left) and with canals (right) (Hillier, 2016)

Table 1. NACH (Normalised Angular Choice Analysis) values for Venice's Networks at radii of 500, 1500 and 3000 (Psarra, 2014)

NACH	NACH-3000 (radius)				NACH-1500 (radius)				NACH-500 (radius)			
	MAX	MIN	MEAN	% of Campi 0 - 5 0 m	MAX	MIN	MEAN	% of campi 0 - 5 0 m	MAX	MIN	MEAN	% of campi 0 - 5 0 m
Pedestrian network	1.39	0	0.8	38%	1.39	0	0.8	31%	1.51	0	0.84	44%
C a n a l network	1.6	0	1.14	19%	1.45	0	0.91	44%	1.47	0	0.92	11%
Ped.+can. network	1.49	0	0.86	55%	1.54	0	0.82	52%	1.51	0	0.88	53%

Analysing the canal structure on its own illustrates that the Grand Canal is the most central route in Venice. It structures the global movement of the city and the most navigable waterway of the foreground grid, and the canal network is still a dominant mode of transportation infrastructure in Venice for the movement of resources, materials etc. (Psarra, 2018) (Figure 3, 4,5).

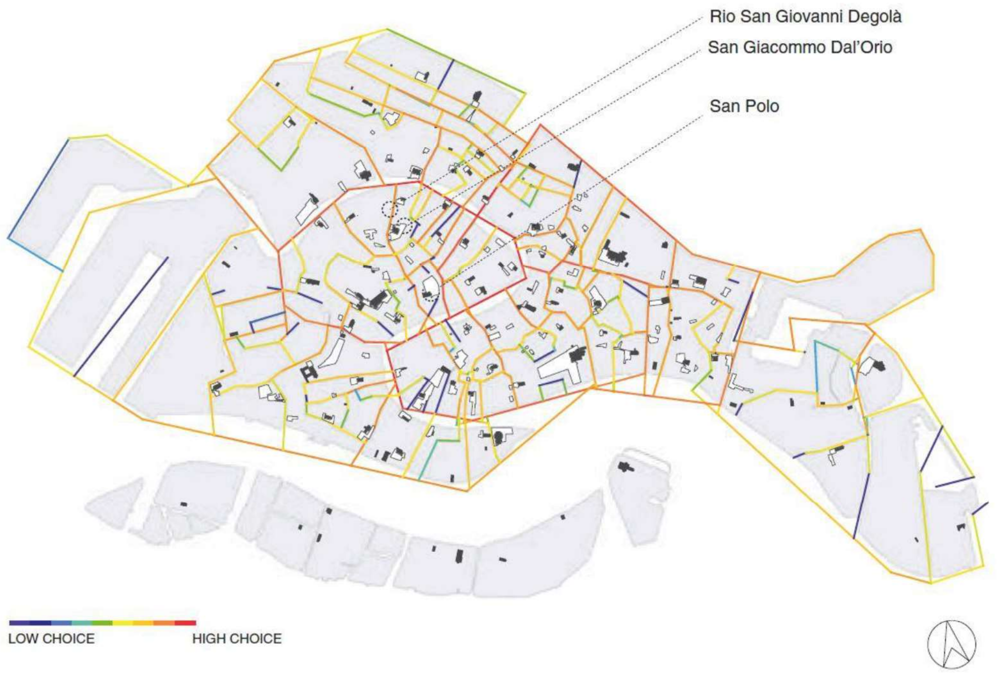


Figure 3. Canal Network of Venice. Measure of NACH at 3000 metres radius (Psarra, 2018)


Figures 4, and 5. Canals as major transportation elements in Venice. Photos taken by Emily Knight (Source: https://www.cntraveler.com/galleries/2014-07-28/living-in-venice-italy)

Psarra (2018) also proposes that even though canals formed a solid connective force in the city, squares and streets were laid out in conjunction with the water infrastructure. This combined type of route illustrates that, in the case of Venice, the squares can be defined as common nodes in two systems with their location at the intersection of the street and canal network. It is clearly shown that many squares contain direct access to canals or are close to them. The majority of squares (94 per cent) are located 50 metres of a canal and squares, and canals are simply linked to each other by straight connections (Psarra, 2018).

Venice is described as a conglomeration of islands through a discussion on the outcomes of spatial, social, and economic networks of the city-creating process. As discussed by Psarra (2018), Le Corbusier's map (1965) shows three critical instances in the history of the urban formation of the city: first, the medieval fabric consisted of embedding an organic collection of islands and buildings; second, Palladian Classicism pointed, through subtle alignments of monuments, to a coordinated scenography of the major spaces of Venice; and third, Le Corbusier's post-war concerns with evolutionary urban growth perceived Venice as a single structure of continues adaptation. In the urban context of adjoining islands of the organic urban fabric, the city's bridges play a significant role in capturing the history of urban formation by enabling the flow of people between island communities or residential areas and economic zones (Psarra, 2018).

Amsterdam has often been compared with Venice in terms of its fame as a mercantile city. Although they are similar to each other in the sense that they both comprise a myriad of islands linked by bridges over watercourses, they differ enormously, and this difference dates back to their origins (Feddes, 2012). The difference can be seen on two crucial maps, which are Jacob van Deventer's map of Amsterdam from 1560 (Figure 6) and Cristoforo Sabbadino's map of Venice from 1557 (Figure 7). Venice began with a collection of natural islands in the water that have been gradually linked to each other. However, Amsterdam cannot be defined as a water city. Its form has been an intermediate between a land and water city from the start of the city-creating process, and the canals and islands were man-made structures (Figure 8, and 9). It is important to emphasise that this original difference influenced the land-based transportation patterns of Amsterdam through the centuries. People can reach everywhere by water in Venice, and as analysed by Psarra (2018), the potential mobility of the street network is much lower in the pedestrian network than the pedestrian network added with canals. In contrast, Feddes (2012) notices that Amsterdam has already been more of a land city and could adopt railways and motorways relatively easily. Places can be accessible both across the water and along streets on the crest of the dikes in Amsterdam (Feddes, 2012).

Figure 6. Jacob van Deventer’s map of Amsterdam from 1560 (Source: noord-hollandsarchief.nl)

Figure 7. Cristoforo Sabbadino’s map of Venice from 1557 (Source: Manuscript 138.c.180, c. XVIIb, Biblioteca Nazionale Marciana)

As explained by Hillier (2016), the canals, as an urban element of the spatial configuration of cities, can be subjected to generic city properties. Following these studies, this research compares London and Amsterdam as two different spatial systems containing canal structure with the purpose of investigating whether their canal structure has the potential for a generic spatial structure in the city network. Canals, as the transport infrastructures of past industrial cities, were provided to connect areas and create economic benefits such as land values or amenities. However, this critical aspect of the canal's role as a function of the economic vitality of cities on people's accessibility to services and socioeconomic interaction has not been tested for London and Amsterdam using quantitative analytical methods. While both resemble each other, they also differ drastically in terms of the histories of their urban formation and the origins of their street-canal integration over time. Therefore, the following sections of the literature review the Amsterdam and London street and canal network structures in terms of urban morphology.

THE COMPARISON OF AMSTERDAM AND LONDON IN TERMS OF URBAN FORM AND CANAL STRUCTURE

Amsterdam has not grown within a structure established simply by land movement routes freely transferring the landscape. The waterway was a prominent transportation system, which served both culture and economy, and thus boating was second nature to the inhabitants of Amsterdam, who are defined as water-bound people (Read, 2000). Hence, canals and water levels have a significant impact on the city-creating process of Amsterdam. Read (2000) emphasises that the spatial configuration of the city network was first established by processes of water containment and management, and the crossings and bridges were the primary patterns that established configurational relations between places in land-based movement. The land-based movement was adjusted to the engineering of canals with precise geometries parallel with canals and the river and perpendicular to the shoreline of the sea. Today, the 16th century city structure of Amsterdam remains in terms of the shape of the urban spatial grid (Read, 2000).

Amsterdam and London share certain historical and socioeconomic similarities; however, they vary in terms of the growth of their respective urban structures over time. Berghauser Pont et al. (2019) discuss the quantitative description of the three central elements of urban form: streets, plots, and buildings, by comparative analysis across five European cities, including Amsterdam, London, Stockholm Gothenburg and Eskilstuna. In summarising the difference between the five cities, Berghauser Pont et al. (2019) emphasise the remarkable similarities between Amsterdam and London, which show a continuous urban grading, especially in terms of urban density. In the study, the street type analysis results in five street types: first, background streets representing the street segment with low choice values; second, metropolitan streets that represent street segment with choice values increasing at the highest scales- generally defined as the highway networks; third, neighbourhood streets representing streets with high choice values at the local scale; city streets that represent street segments with high choice values at most scales, which is closest to Hillier's foreground network; fifth, dead-end streets, which the street segments with zero choice value at all scales. Amsterdam and London have some similarities with regard to the street network analysis, which are that: first, both cities have fewer dead-end streets and more foreground network compared to the three Swedish cities; second, the spatial layouts of the city street structures of Amsterdam and London illustrate more of a regular grid pattern with cells / local areas. Within these local areas, the neighbourhood streets dominate in both cities. In contrast, the Swedish cities have more tree-like street networks of city streets and large numbers of dead-end streets (Figure 8) (Berghauser Pont et al., 2019).

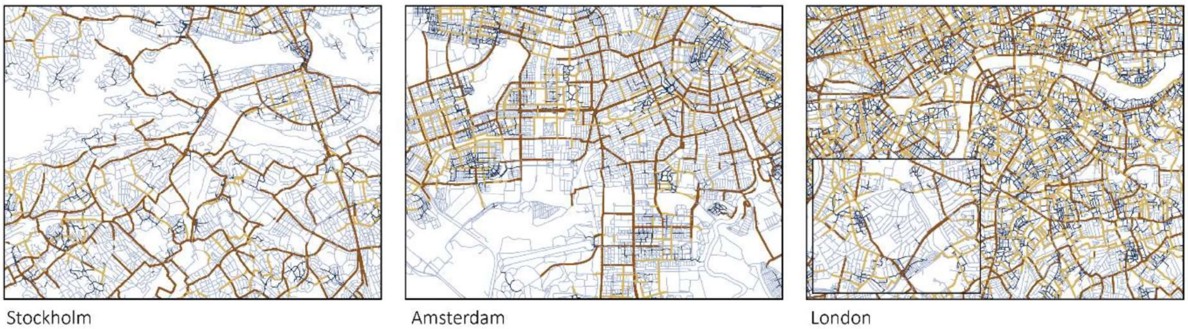


Figure 8. A Comparison of Street Types in Stockholm, Amsterdam, and London (Berghauser Pont et al., 2019)

Building type analysis shows that the densest and most compact building types are found in the historical cores of each city. The main similarity between Amsterdam and London is the dominance of the compact low-rise and mid-rise building types, but the two also demonstrate differences that are worth emphasising. London has a compact high-rise building type- a high concentration of tall buildings that Amsterdam lacks. This type is located only in Canary Wharf in London, which is one of the leading financial centres in Europe. The other difference is that dense mid-rise types dominate the city centre of London, while Amsterdam has mainly low-rise types in its city centre (Berghauser Pont et al., 2019).

London and Amsterdam share common properties with a high percentage of compact and fine-grain plots in terms of plot types. However, in Amsterdam, the smallest and most compact plots dominate at the city's core, while all different types are scattered throughout the entire city structure (Berghauser Pont et al., 2019). Because of this, many villages are observed to be present during the city-growing process. London's villages are defined as hubs of local deformed wheels. The deformed wheels is a way of overcoming the tendency for centres to become segregated as the city grows around them by connecting them to the edges (Hillier and Vaughan, 2007). Therefore, Hillier and Vaughan (2007) find that London's system allows strangers to access the heart of the system, and its inhabitants to access to its edges.

3. METHODOLOGY

This chapter describes the methodology, tools, and datasets, involved in the entirety of this research to explore the spatial impact of the canal network over time in London and Amsterdam. There are two scales of study: the *City-wide* and *Neighbourhood* scales, which answer one of the research questions listed in Chapter 1.

The study uses space syntax techniques as the main methodology to analyse the generic properties of two cities' layouts and human activity patterns in their canal spaces. The analysis is performed using the depthmapX software, initially developed by Alastair Turner and recently redeveloped by Tasos Varoudis at the Space Syntax Lab at the Bartlett School of Architecture, UCL. Afterwards, the results are geographically projected in QGIS, and the statistical analyses are performed in SPSS.

Space syntax theory discusses two fundamental propositions. Firstly, space is not a background to human activity but is intrinsic to it, and second, space is foremost configurational, which is a street or public space, room, corridor, green or blue space etc., that is influenced by the relationship between that space and the network of spaces to which it is connected (Hillier and Hanson, 1984).

The spatial configuration of the street network of the research is derived from the road centre line maps of Amsterdam and London. This segment line model is used as a base for all the street network analyses conducted in the study. The measurements for integration and choice for different metric radii is applied as 800 m for the local scale and 2500 m for the global scale.

The results of the space syntax analysis are colour-banded from red to blue. While warm colours - red, orange and yellow - represent higher values, cold colours - green and blue - indicate lower values.

"Angular Segment Analysis Integration Measure" is a measure of distance, calculates how close the origin space is to all other space and measures the ease of access (Hillier and Iida, 2005). The integration value in angular segment analysis is a predictor of the potential for each segment within a metric radius to be the desired destination. It is the measure forecasting the to-movement potentials when measuring all the shortest angular paths in the street network from origins to destinations (Hillier and Iida, 2005). Hence, the integration measure for each city might reveal the relative depth of the canal paths in terms of accessibility. On the other hand, “Angular Segment Analysis Choice (Betweenness)” measures how the likelihood that a street segment or line passes through all the shortest routes from all spaces to all other spaces throughout the entire urban system (Hillier and Iida, 2005). Choice in angular segment analysis is a predictor of the through-movement potential of a segment in a spatial system. New advancement on angular analysis was introduced as the normalisation of angular integration and choice of measures to compare spatial systems of different sizes (Hillier et al., 2012). Both movement measures are crucial for London and Amsterdam as they home many residents and also attract many visitors from all around the world. Hence, the intention is to calculate both normalised angular segment integration and choice measures to index canal paths’ potential for *to-movement* and *through-movement* in both London and Amsterdam.

DATASETS

Readily available data in the UK and Netherlands are used in the study that enables the application of the chosen methods to different city contexts. Table 1 explains the datasets and spatial variables of the proposed analyses.

The built environment variables of the research are as follow: each variable is constructed from the datasets in Table 2, which is a geographic data surface or raster.

Table 2. Research Datasets

Datasets	**Variables**			
	Street Network	**Land Use Diversity**	**Residential Density**	**Historical Street Network**
Census Amsterdam: CBS Open DataStatLine (https://www.cbs.nl/en-gb) London: UK Census/			X	
Road Centreline Map Amsterdam: OpenStreetMap (Pont Berghauser et al., 2017) London: OpenStreetMap	X			
Land Use Amsterdam: Data.Amsterdam London: Ordnance Survey		X		

Historical Maps Amsterdam: Topotijdreis.nl London: Digimap for London				X

METHODOLOGY: CITY-WIDE

The Regent's Canal in London and Canal District in Amsterdam are the main study areas for comparative research. The main reasons for choosing these two areas are that both areas' designs were based on functionality to access major institutions and zoning through industrial activity and new housing developments for working-class families. Also, they have created new functions in the cities' economic restructuring during the contemporary period.

The city-scale analysis covers a model of 6 km (3 km + 3 km buffer) from the edge of the study area. The city-scale analysis will be performed across three periods: the 1850s, 1950s and the contemporary (Figures 9, 10, 11, and 12). Hence, six different maps over three periods are analysed to understand the spatial impact of canal structure over time during the city-growing process of the two cities.

Figure 9. Amsterdam 1850s (Source: Topotijdreis.nl)

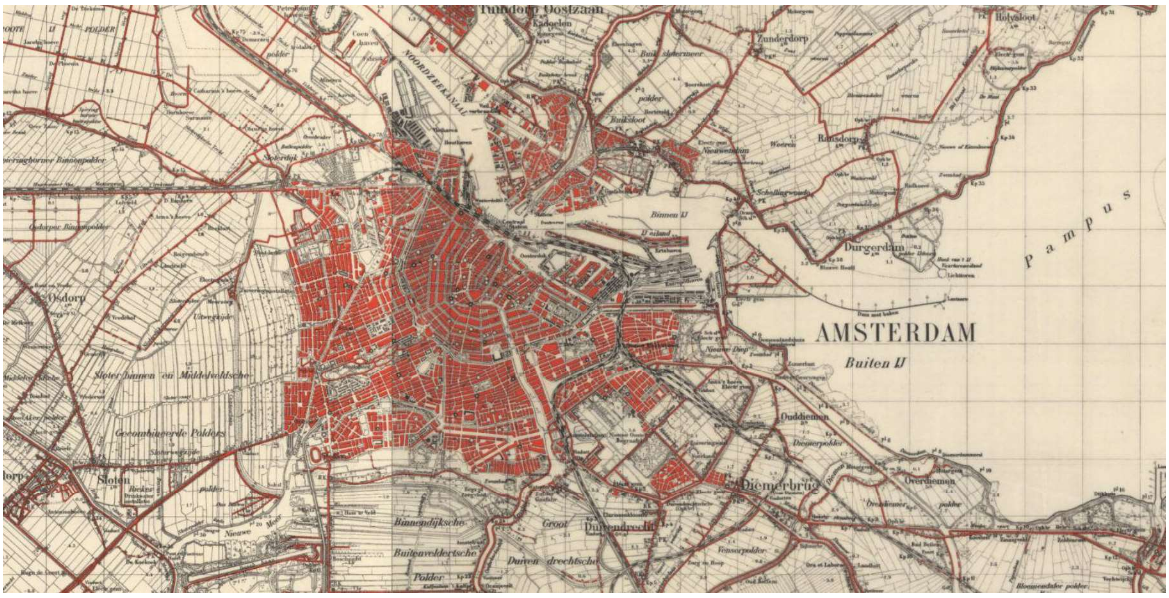


Figure 10. Amsterdam 1950s (Source: Topotijdreis.nl)

Figure 11. London 1850s (Source: Digimap)

Figure 12. London 1950s (Source: Digimap)

Space syntax can take historical maps as starting points for empirical research into the historical relationship between canal and street structure on the basis of the configurational network relationship. Historical maps and cartographies of data are typically illustrative rather than analytical descriptions. Hence, the four historical maps were redrawn as a road centreline maps, which were then segmented at intersections, to make a systematic analytical analysis.

Firstly, a scatter plot is used to show the values of all segments by comparing three periods to investigate where change has occurred. Statistical analysis of change is undertaken to investigate if segment length over time increases or decreases, or is different across the two cases. Also, the comparison of values in terms of proximity to the canal is made to investigate if the canal has an impact on the street network in terms of potential movement.

Secondly, the overall spatial description of the two cities today, with and without the canals, is made: the maximum and mean space syntax measures of the network are illustrated with a star model (following Hillier, 2016). The star model is a technique that allows for the simultaneous comparison of cities in terms of normalised angular integration and normalised angular choice to investigate what the variables mean with regard to urban spatial structure. While the mean and max normalised integration value index the ease of accessibility in the foreground (max) and background (mean) networks in the usual sense of syntax, the mean and max normalised choice show the degree of structure in the system. The mean normalised choice value indexes the degree to which the background network structure is a continuous grid with direct connections, max normalised choice value shows the degree to which the foreground network grid forms the system by deformations of the grid (Hillier, 2016). In addition, the numbers of access points to the street network are compared to understand the relationship between canal and street structure in the two cities.

Thirdly, as discussed in the literature chapter above, while Amsterdam's canal structure is a network, London's canals have a linear structure in relation to street network. Hence, in the London context, the space syntax measures of either side of the canal will be compared to investigate the possible barrier-effect of canal's linear structure on the spatial patterns of the surrounding neighbourhoods.

METHODOLOGY: NEIGHBOURHOOD-SCALE

Regent's canalside arm from Camden Town to York Way in London and *the Canal District* in Amsterdam are proposed as case studies on the neighbourhood scale (Figures 13, 14). Both areas had close proximity to the economic functions of the old core of the city during their construction period.

There is a difference of around 150 years between the construction dates of the two canal areas (the Canal District was constructed between 1613-1663, Regent's Canal was constructed between 1812-1820). However, like the Canal District, the emphasis of the Regent's Canal design was on functionality, access to major institutions, and zoning through industrial activity. The third extension zone of the Canal District was for industrial use and the working class, which is for the same purpose as the construction of Regent's Canal (Essex-Lopresti, 1998; Nijman, 2020). Also, during the industrial age, there was a revolution in transportation systems overland in the two cities, and both canalside districts have been affected in terms of zoning through the exclusion of economic activity. Today, both canalside districts have created new functions in the cities' economic restructuring (Hunter, 2019; Nijman, 2020).

Figure 13. Neighbourhood Scale Study Area in Amsterdam

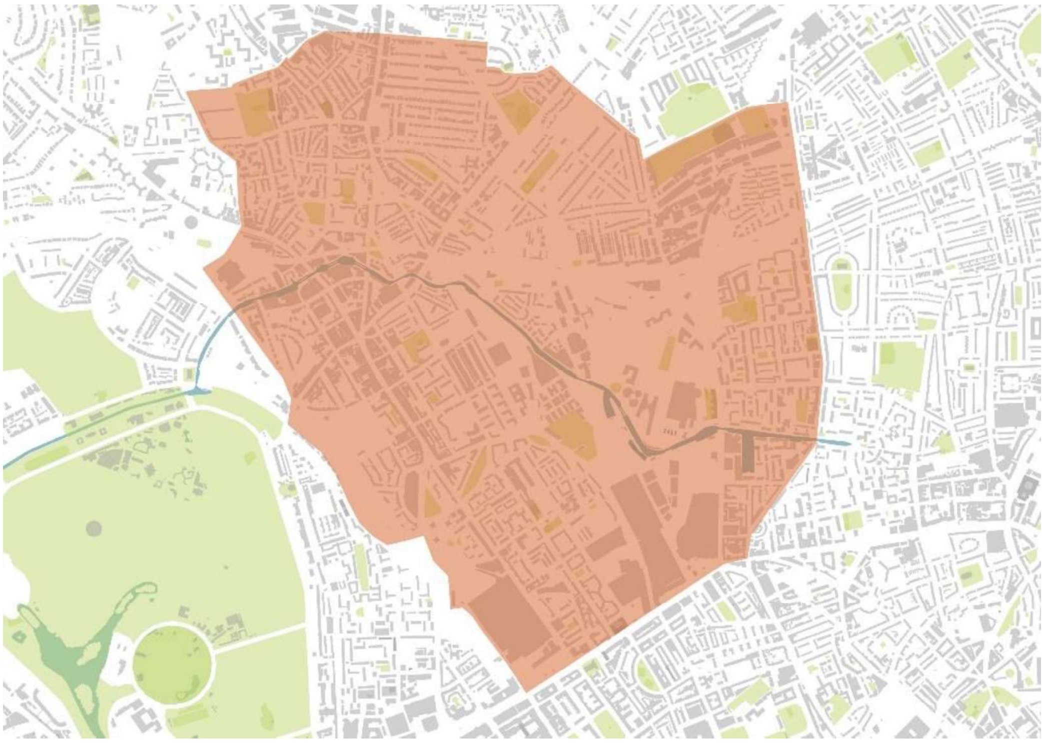


Figure 14. Neighbourhood Scale Study Area in London

Firstly, an analysis of the change in street network and land use over time will assess whether the canals significantly impact the spatio-functional distribution of Amsterdam's and London's canalsides. A series of spatial analyses with the street network, plot size, and land use data might investigate the barrier-effect of the waterbody in terms of the spatial distribution of functions.

Earlier studies address the particular correlations between urban and economic activity that mainly concern the relationship between the street centrality and land use mix (Chiaradia et al., 2009; Hillier, 1999; Narvaez and Penn, 2016) or building density and mixed-use indices (Bobkova et al., 2019; Marcus et al., 2017). The common result of these studies is that the pattern of centres and accessibility within the street network correspond to each other through potential movement analysis.

Marcus, Berghauser Pont, and Bobkova (2017) investigate the impacts of plot systems on the concentration of economic activities in London, Amsterdam and Stockholm. First, the research investigates whether there is a relationship between the structure and shape of plot systems (size, compactness, and frontage index) in the cities and the density of economic activities. Then, it shows that the capacity of plots also carries the number and differentiation of people and functions (Marcus et al., 2017). Following these studies, this research will return to investigating economic activities on the neighbourhood scale as diverse. It aims to compare Amsterdam and London on the plot sizes and the potential impact of the canal structure on the plot sizes, and the opportunity to develop land uses.

Secondly, the correlation between the retail density, diversity of functions, and the accessibility measure will be performed to investigate whether canal systems are a crucial morphological factor in exploring the correlation between the urban form, accessibility, and the spatial distribution of economic activities in cities. To do this, the diversity of land uses will be analysed to explore how the change of street network and canal network affects the spatial configuration and thus to generate land uses of any certain types.

4. CITY-WIDE ANALYSIS

The city-wide analysis contains two different sections: the spatio-historical analysis of Amsterdam and London and the spatial analysis of contemporary Amsterdam and London. The first section examines the city growing process via diachronic analysis from the 1850s to the present. The second section mainly contains a comparative analysis between cities' street networks and street+canal networks. Furthermore, the canalside network and bridges are investigated in detail to explore the canal systems' impacts on the street networks of the two cities.

SPATIO-HISTORICAL ANALYSIS: SYNTACTICAL GROWTH PROCESSES

Spatio-historical analysis research will focus on analysing Amsterdam's and London's syntactical patterning relating to its urban network (street +canal) growth from the 1850s to the present. The spatial analysis of the historical maps will explore the city's growing process and its relationship with the canal structure. This method allows comparative analysis of movement potentials, generating perspectives on urban configurations over time and revealing the possible effects of the canals on city-scale morphologies and spatial dynamics. The diachronic model of the city is intended to investigate the emergence of urban spaces and to detect the generative rules of the growing urban structure (Al Sayed et al., 2009). Hence, this chapter aims to analyse the identifiable logic embedded in Amsterdam's and London's growth and reveal the quantifiable spatial growth knowledge.

Amsterdam: The Spatial Configurations of Growth

By the late nineteenth century, Amsterdam consisted of a collection of islands around a compact city, which was edged by the city fortifications. The map of the 1850s (Figure 9) shows that the city can be defined as a compact landmass that is perforated by the canal structure. The grid of Amsterdam in the 1850s has significant value in terms of grid structure. It contains two different spatial structures. The first can be defined as an organic grid in the first settlements and that are now called De Wallen, Nieuwmarkt en Lastage, and Burgwallen Nieuwe Zijde, which date back to the Middle Ages. The second is a uniform grid of top-down planning decisions.

Grachtengordel and Jordaan are good examples of this planning approach. Grachtengordel is known as the Canal District of Amsterdam and was built in the seventeenth century. Jordaan started to build in the seventeenth century due to the need for a residential area for the working-class (Figures 15, and 16).

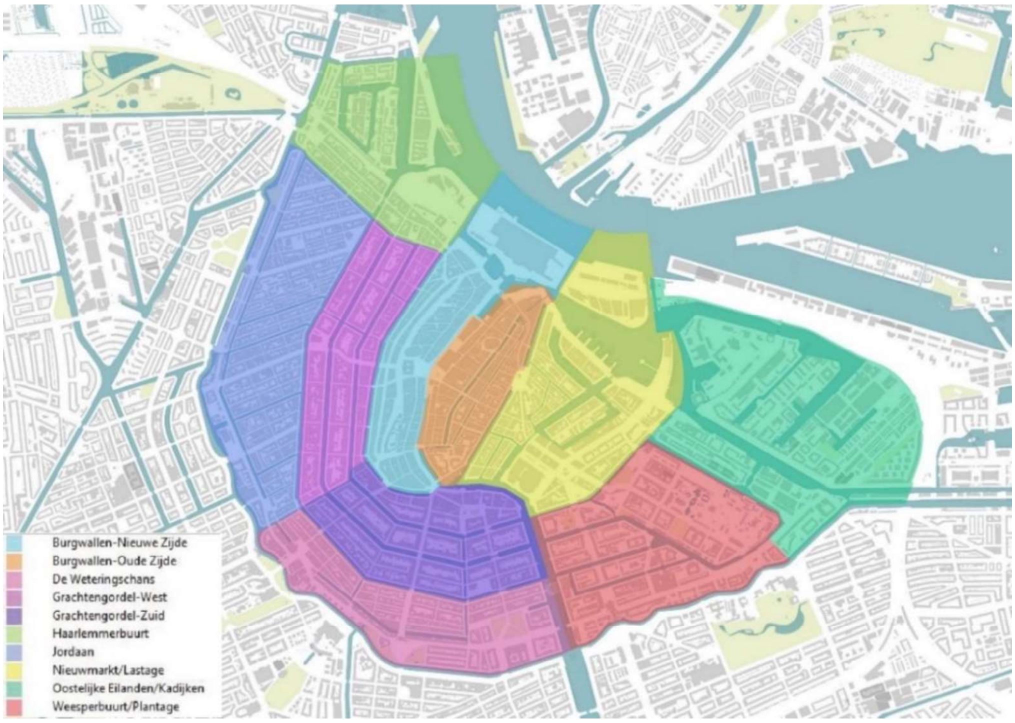


Figure 15. Amsterdam’s Quarters (Source: data.amsterdam.nl/)

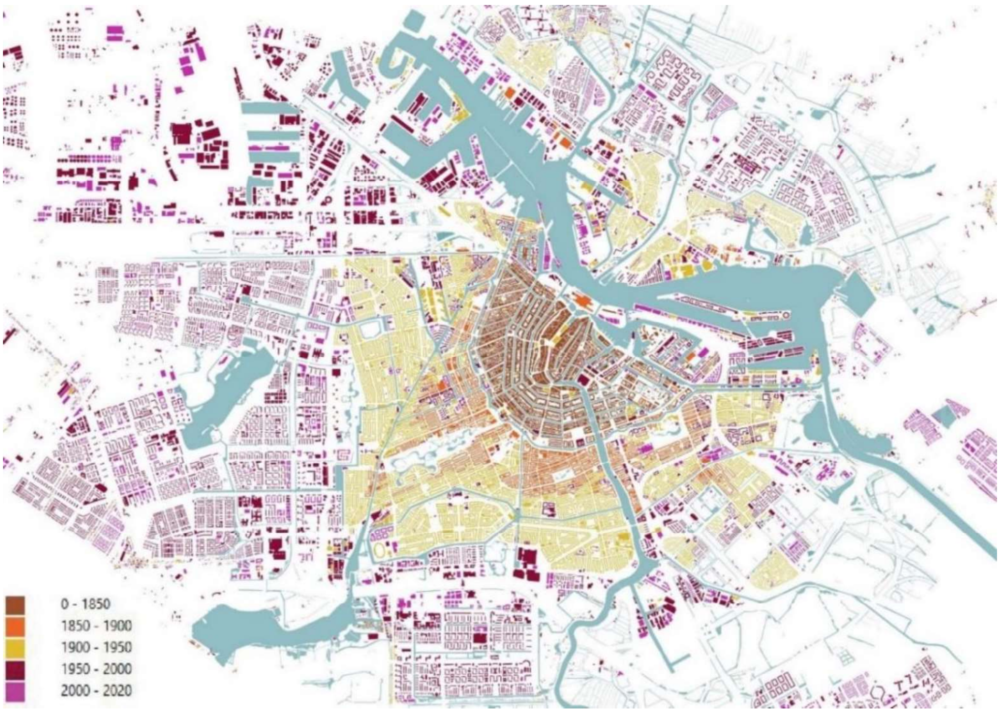


Figure 16. Amsterdam’s Urban Growth (Source: data.amsterdam.nl/)

The approach towards investigating the possible regularities in Amsterdam's growth and the canals' impact on this growth implies the analysis of the three stages of spatial growth: 1850s, 1950s and the contemporary within 800- and 2400-metre radius choice and integration analysis.

Figures 17 and 18 illustrate the results of the analysis of normalised angular integration within 800 and 2400 metres. The mean values of the 1850s segment map are 1.13 for NAINr800m and 0.91 for NAINr2400m. Grachtengordel's west area is locally the most integrated part of the city in the 1850s (Figures 17, and 18).

Figure 17. Amsterdam 1850s NAINr800m

Figure 18. Amsterdam 1850s NAINr2400m

Analysing the three stages of the city as a configurational system reveals that it seems to evolve into the foreground network planned in a grid system. Also, NACHr2400m shows that the canal network follows the city's foreground network by the 1950s (after the fortification has demolished) (Figures 19, and 20).

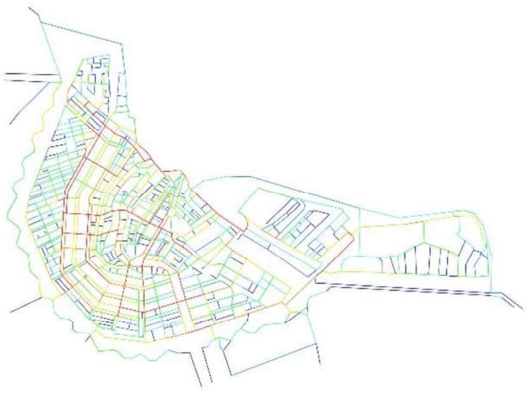


Figure 19. Amsterdam 1850s NACHr2400m

Figure 20. Amsterdam 1950s NACHr2400m

The mean values of NAIN for 800- and 2400-metre radius slightly and gradually decreased during the urban growth. The mean values of the 1950s segment map are 1 for NACHr800m and 1.13 for NAINr800 (Figure 25). The 1950s segment analysis explains that Grachtengordel and Jordaan preserve their high integration values on the local and global scales (Figures 21, and 22). On the other hand, the cores of the 1950s expansion, which can be defined as cores of new centres (west and south part of the expansion) emerged in the 1900s growth, also has high global integration that is visible in the analysis because of the connective attributes of the uniform street grid designed to run parallel and perpendicular to the canals. However, the expansion after the 1950s increased the integration of west Amsterdam (Figures 23, and 24).

Figure 21. Amsterdam 1950s NAINr800m

Figure 22. Amsterdam 1950s NAINr2400m

The mean values of contemporary segment analysis are 0.99 for NACHr800m and 0.97 for NAINr800m. Although the mean values of NACHr800m and NAINr800m were not dramatically changed in the 1950s and contemporary period analysis, the max value of NACHr2400m increased from 1.45 to 2.00, and the max value of NAINr2400m increased from 1.31 to 4.42 between the 1850s and the contemporary period. These results reveal that while the ease of accessibility has not changed in the background network, it has increased in the foreground network on average during the city growing process. Hillier (2016) calls the foreground network "the city-making process" that acquires the form of a pervasive network linked centres at all scale and maximise movement. Hence, this rise at the foreground could seek to concentrate and maximise movement and copresence in Amsterdam.

Figure 23. Amsterdam Contemporary NAINr800m

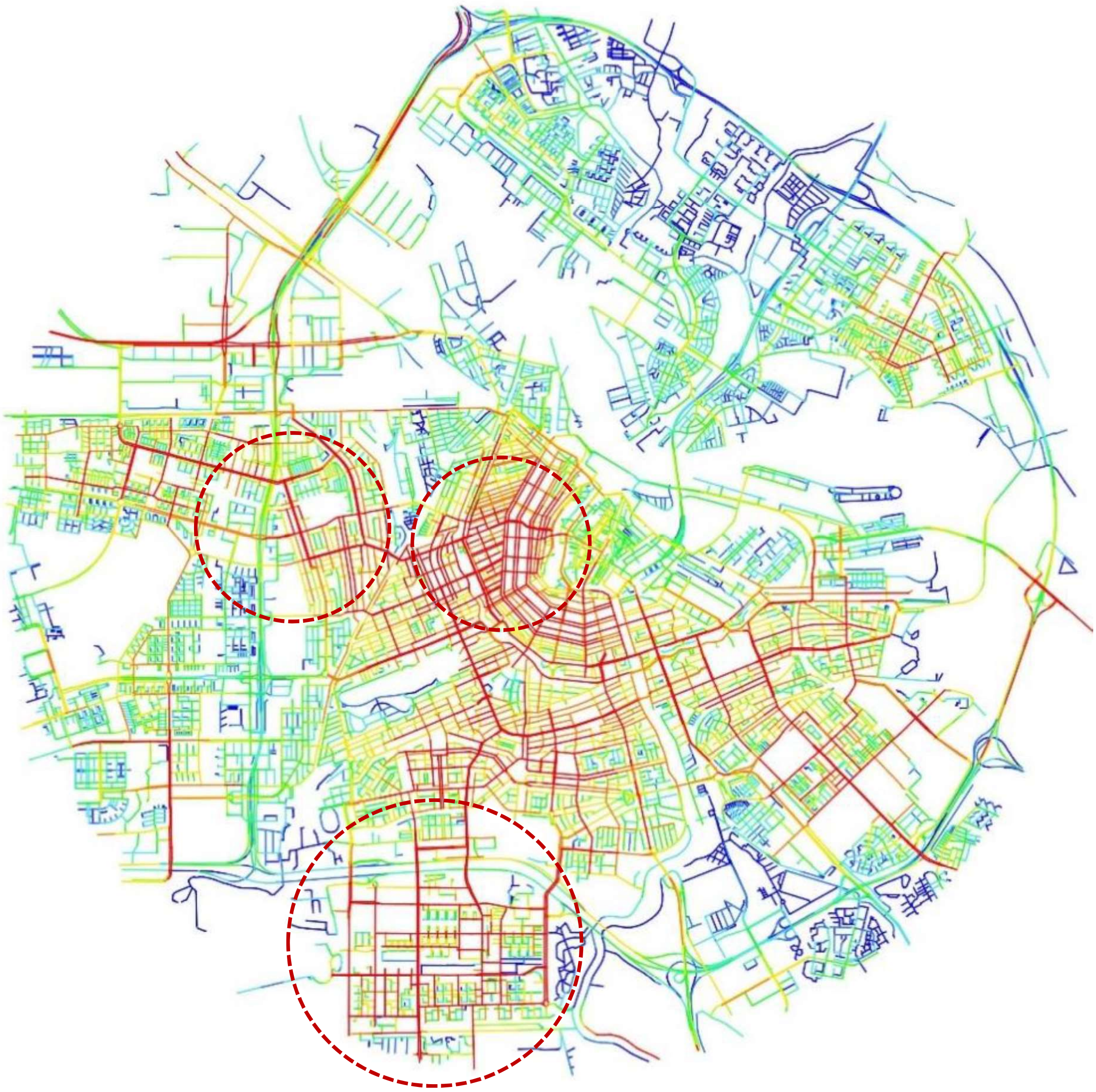


Figure 24. Amsterdam Contemporary NAINr2400m

The diachronic analysis of Amsterdam clearly shows that the integration values of Grachtengordel and Jordaan have increased on the both local and global scales during the city-growing process. These neighbourhoods have become increasingly integrated into the grid (Figures 36-41). As mentioned before, the Jordaan area was a residential background of the city, which was designed for working-class housing needs. However, the area has transformed into a more commercial and popular area over time. The working- class community of the neighbourhood has transformed into an upper-middle- class community during the urban growth process This transformation is evaluated as gentrification that is characterised as a process of class displacement (Suchar, 1993). As illustrated in the analysis, the increase in the integration of the area might have encouraged this process of class transformation during the city-growing process.

Figure 25 shows the comparison of normalised angular integration values between periods in Amsterdam and Figure 26 is the scatter plot of Amsterdam's street networks for different periods. As illustrated in Figures 25 and 26, while the range of integration values (between the min and max NAIN values) in 800 metre radius analysis increases over time, the mean value of the NAINr800m decreases. Thus, the diversity of the integration values of the background network increase over time during the city-growing process. This shows that the system has created both more segregated and integrated spaces within the background grid. However, the Amsterdam street network analysis reveals that bridges play a crucial role in eventually joining the islands up. The integration values of bridges on the local and global scales have gradually increased during the city-growing process. The foreground network of centres embodies the origins of the social structure of Amsterdam that can be defined as semi-autonomous communities. While each has been separated by the canals, they also have the potential to serve as a microcosm of the city as a whole, with interconnections by bridges over time.

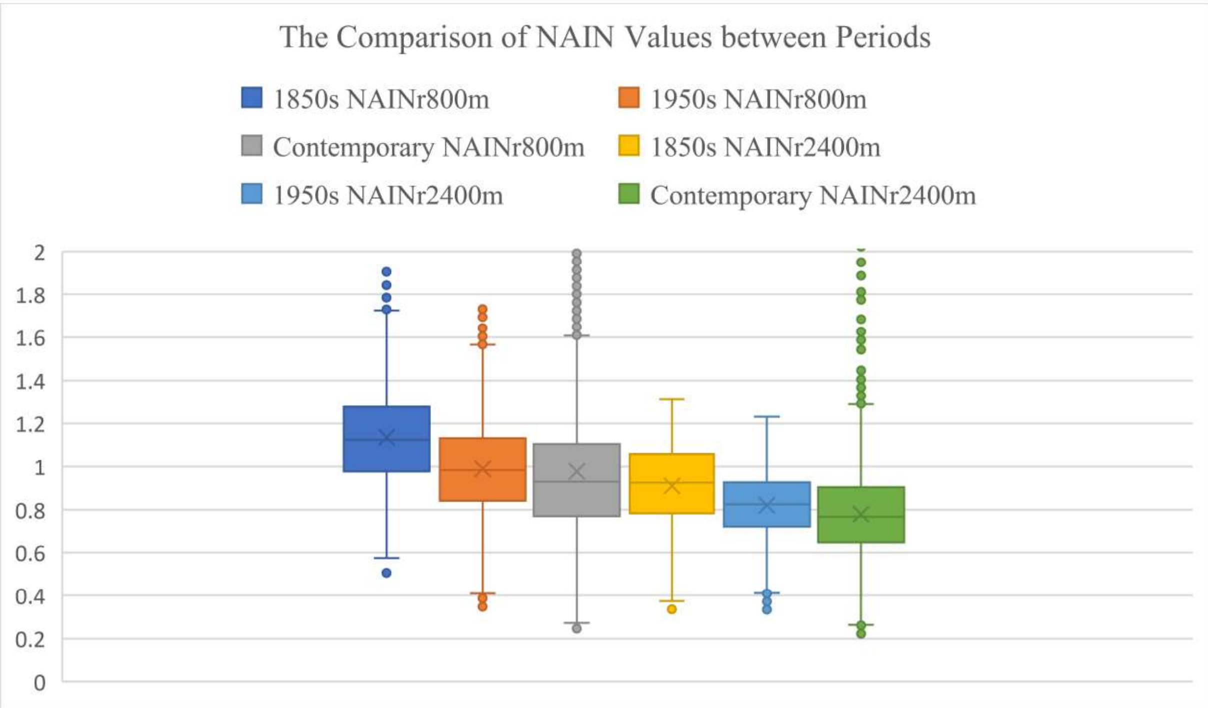


Figure 25. The Comparison of NAIN Values of Amsterdam between Periods

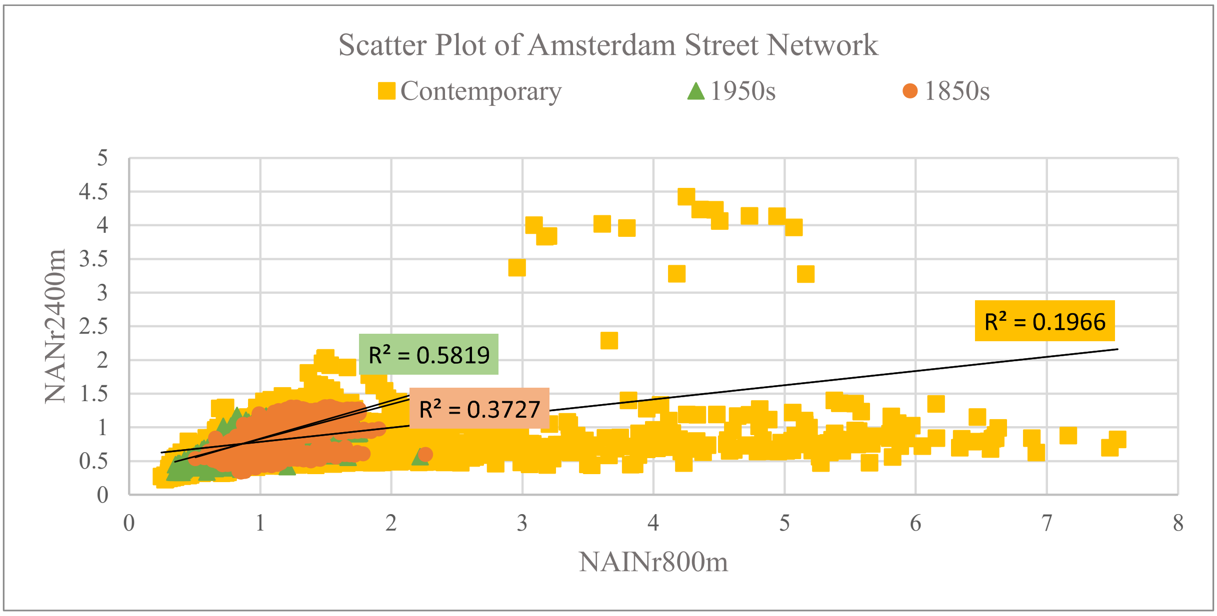


Figure 26. Scatter Plot of Amsterdam Street Network over Three Periods

London: The Spatial Configurations of Growth

The diachronic analysis of the London network of development covers 3000 metre radii around Regent's Canal. London's urban growth context is different to that of Amsterdam. In contrast to having top-down planning decisions from the core to the city's edges, London's city-wide scale study area has been densified over time by block divisions. According to the analysis, while 11 streets were added to the system from the 1850s to 1950s, 1092 new streets were added between the 1950s and the current date. Hence, the change in the number of new streets was much greater between the 1950s and the present date. Table 3 illustrates the comparison of streets in London over three periods. As shown in Table 3, this change results in the lower mean value of frontage length in the grid. However, the max value of the street segment length increases over time.

Table 3. The Comparison of Streets in London over the Three Periods

	Number of Streets	The Max Value of the Frontage Length	The Mean Value of the Frontage Length
1850s	4481	383.77	68.99
1950s	4492	387.27	69.44
Contemporary	5584	402.69	61.04

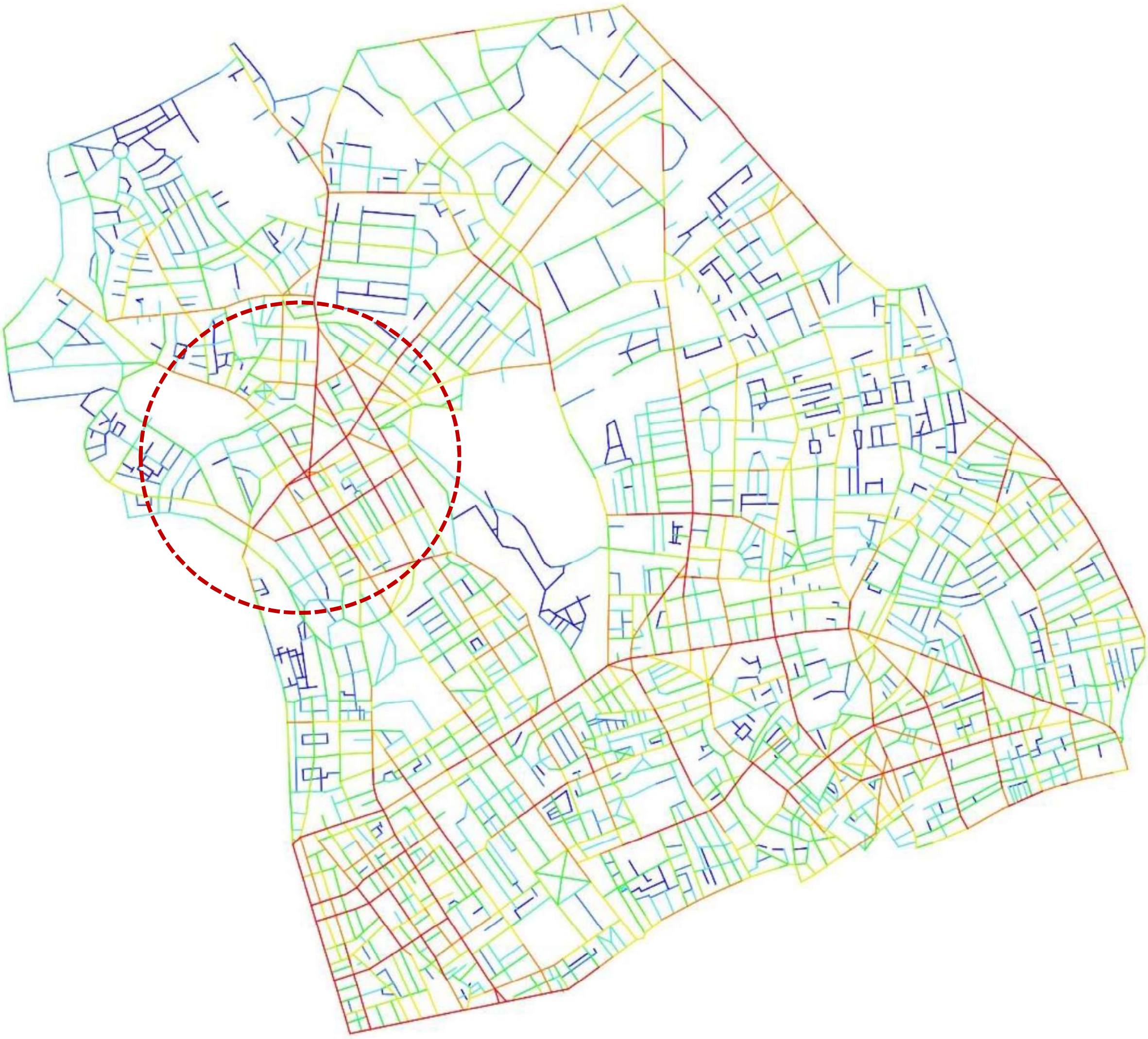


Figure 27. London 1850s NAINr800m

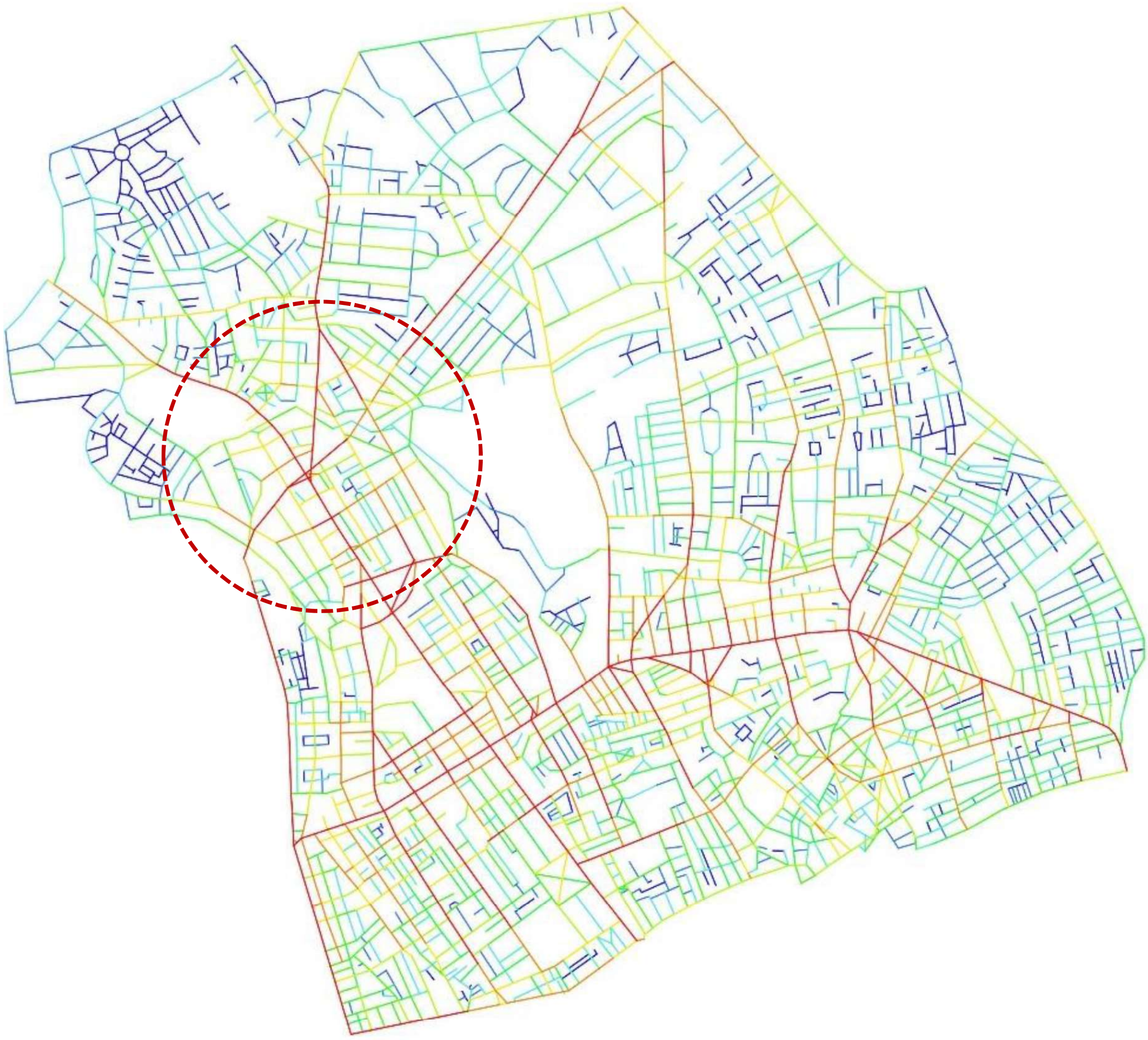


Figure 28. London 1850s NAIN2400m

One of the most integrated parts of the study area is Camden Town on the local and global scales during the 1850s. The diachronic analysis of London illustrated that this has not changed over time in the course of urban densification (Figures 27-32). The comparative analysis of NAINr800m and NAINr2400m between the 1950s and the current date shows that new streets added to urban blocks mostly have low integration in the north side of the Regent's Canal (Figures 31, and 32). In terms of the potential movement of Regent's Canal path, the analysis shows that the mean integration and choice value of the Regent's Canal path has not changed over time. While the mean values were 1.06 for NAINr800m is and 1.03 for NACHr800m in the 1850s angular segment analysis, they are 1.07 for NAINr800m and 1.06 for NACHr800m in the contemporary period angular segment analysis.

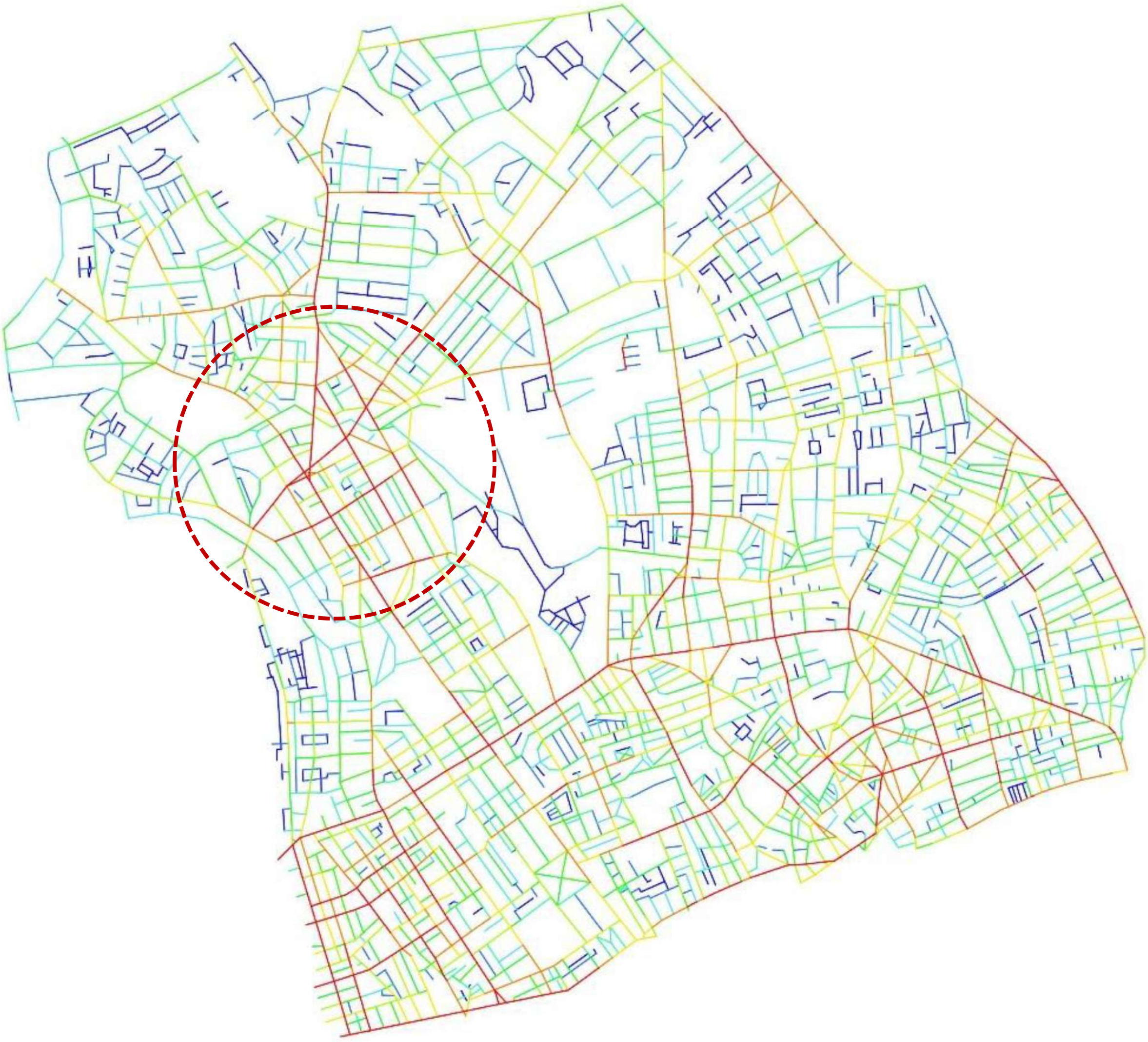


Figure 29. London 1950s NAINr800m

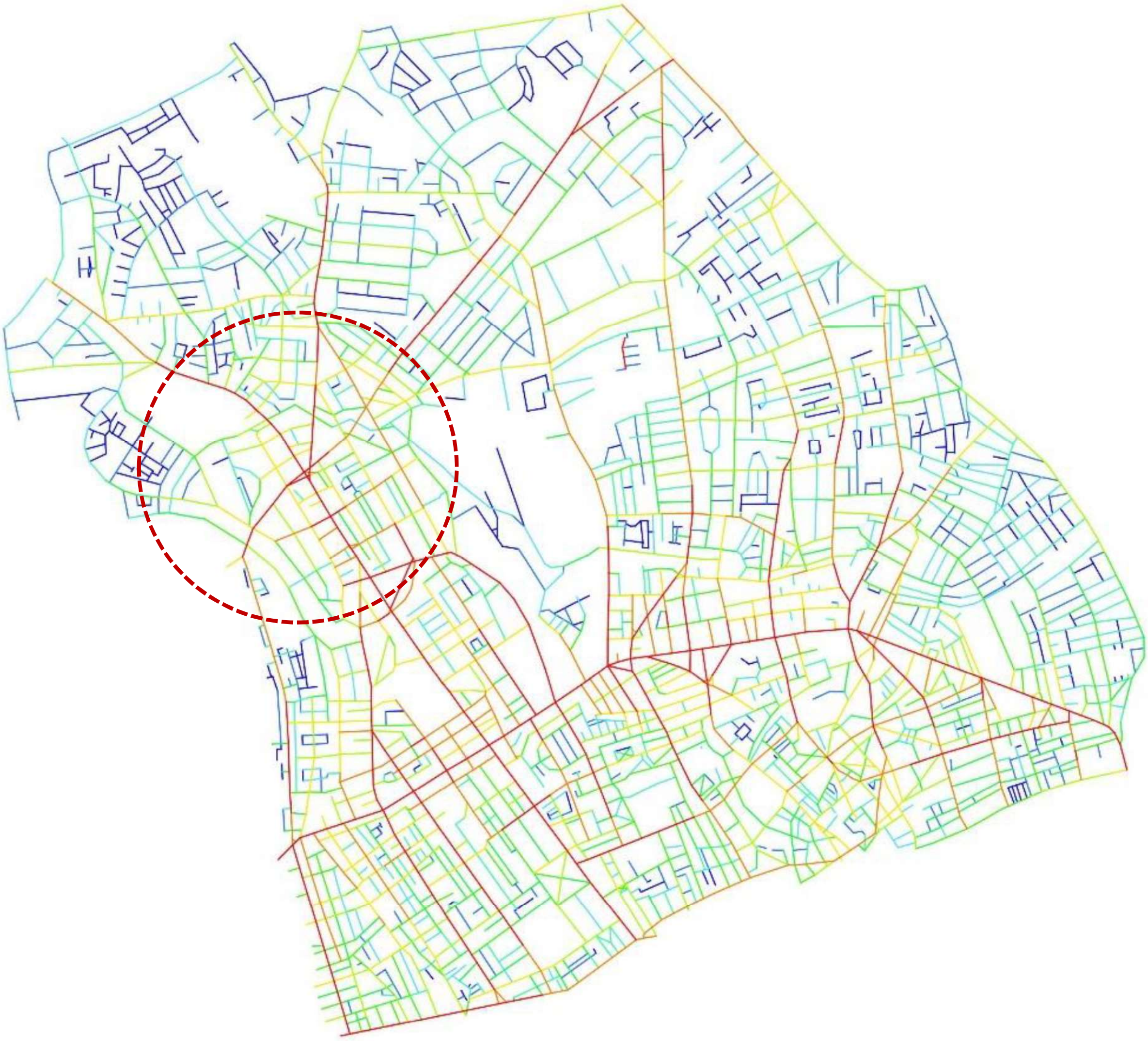


Figure 30. London 1950s NAINr2400m

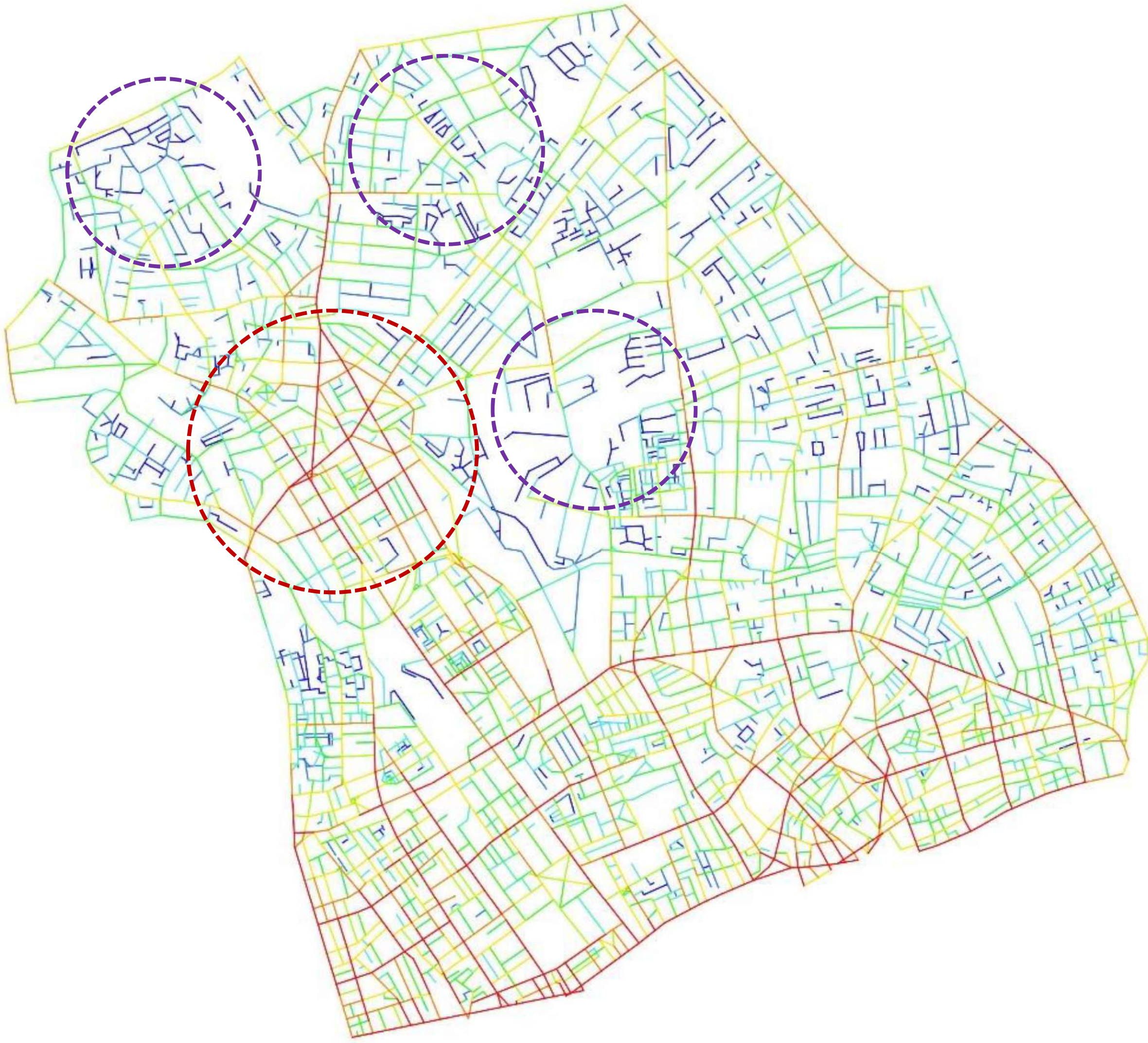


Figure 31. London Contemporary NAINr800m

Figure 32. London Contemporary NAINr2400m

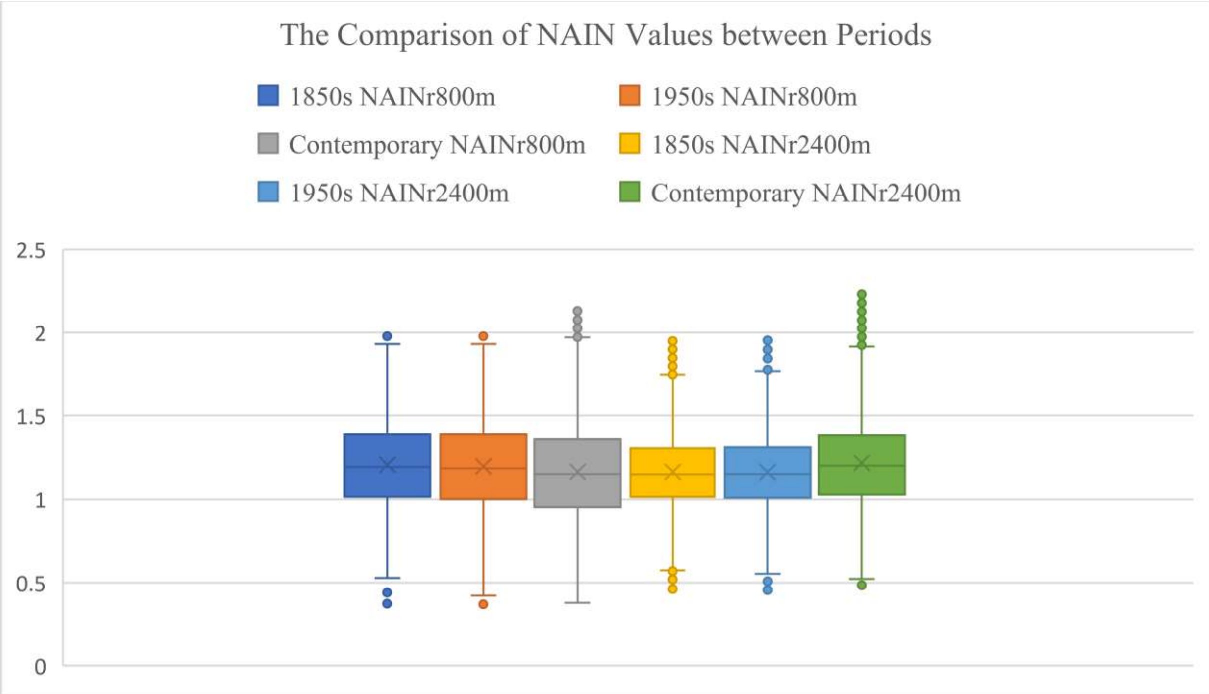


Figure 33. The Comparison of NAIN Values for London between Periods

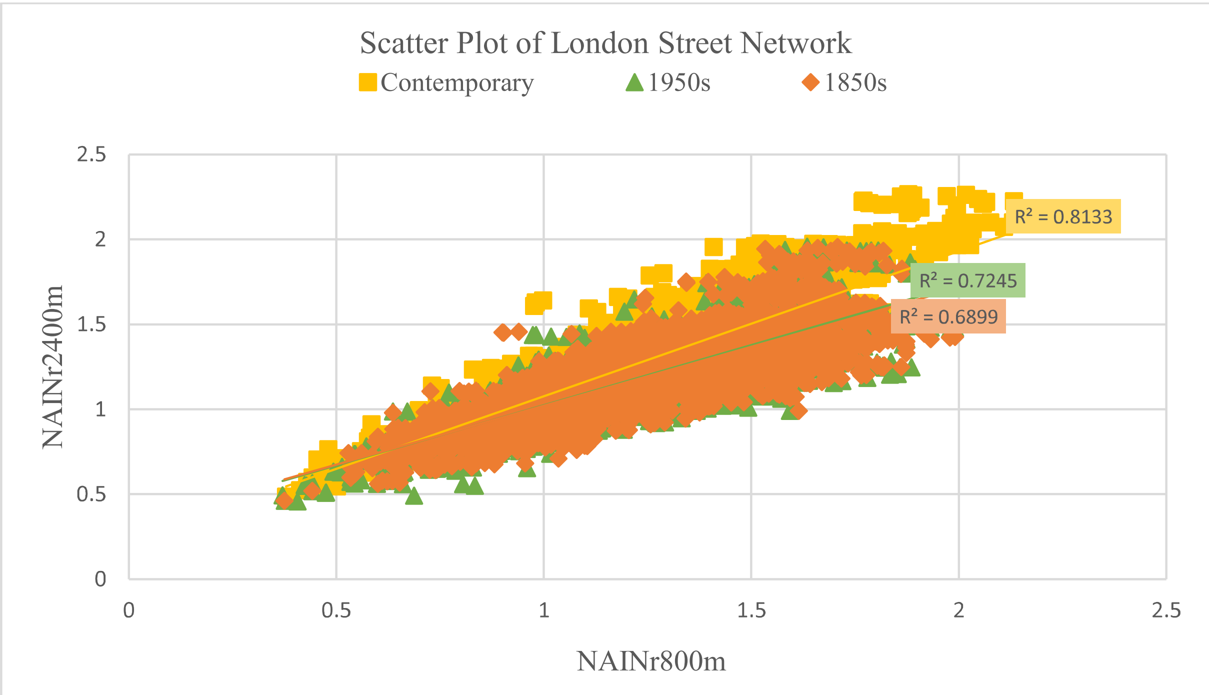


Figure 34. Scatter Plot of London Street Network over Three Periods

Figure 33 illustrates NAIN values for London between three periods. This diachronic analysis of the London network of development shows that there is no dramatic change in the urban grid with regard to the syntactical properties of quantitative analysis results over the three periods (Figure 33). Figure 34 shows the scatter plot of London's street network over three periods. While the r-squared of the street network is 0.68 for the 1850s street network, it increases to 0.83 for the contemporary period in London (Figure 34). In contrast to Amsterdam's change over time, the new streets added to the urban grid in London increased the system's intelligibility.

The study will continue investigating the spatial structure of the contemporary period to scrutinise the impact of canal structure on the street configuration of Amsterdam and London.

SPATIAL ANALYSIS: AMSTERDAM VS LONDON

Angular segment analysis has been applied for London and Amsterdam to provide a large- scale quantitative comparative network analysis across London and Amsterdam on a city-wide scale covering a 6 km radius. In order to understand the morphological influence of the canal structure in the street network, the analysis results of the 400m buffer area from the canals were compared with the street network in both cities. Moreover, the results of the analysis of canal bridges were investigated to understand how likely the bridges are to be passed through on all shortest routes from all spaces to other spaces across the entire street network within an 800 m distance (radius) from each street segment.

Comparison of the Street Network and Street+Canal Network

Figures 35, 36, 37, and 38 illustrate the result of the angular segment choice analysis at 800 m and 2400 m radii which shows the local integration values of Amsterdam's and London's city networks as the spatial system. The majority of the spaces in the cities are in the background network of the urban system, and the mean values of choice and integration represent the through- and to-movement potential of the background of the cities. The maximum values of the integration and choice measures represent the through- and to-movement potentials of the foreground networks of the cities (Hillier et al., 2012). As stated by Hiller, Yang and Turner, NAIN measures co-vary, which means the angle of the line between them is constant. On the other hand, NACH measures do not co-vary and can illustrate radically different patterns from city to city. Hence, the network's mean and max NAIN values demonstrate the ease of accessibility in the background (mean value of NAIN on a local scale) and foreground network (max value of NAIN on a global scale). NACH values indicate the degree of structure in the network. Therefore, the mean value of NACH represents the degree to which the background network structures represent a continuous grid with direct connections between sub-areas; the max value of NACH shows the degree to which the foreground structure forms the systems by deformations of the network structure (Hillier et al., 2012). Hence, the maximum values of NACHr2400m and NAINr2400m represents the foreground network of the system, and the mean values of NACHr800m and NAINr800m represent the background network of the system in the research using a four-pointed star model.

Figure 35. Angular Segment Analysis of Amsterdam NACHr800m

Figure 36. Angular Segment Analysis of London NACHr800m

Figure 37. Angular Segment Analysis NACHr2400m

Figure 38. Angular Segment Analysis of London NACHr2400m

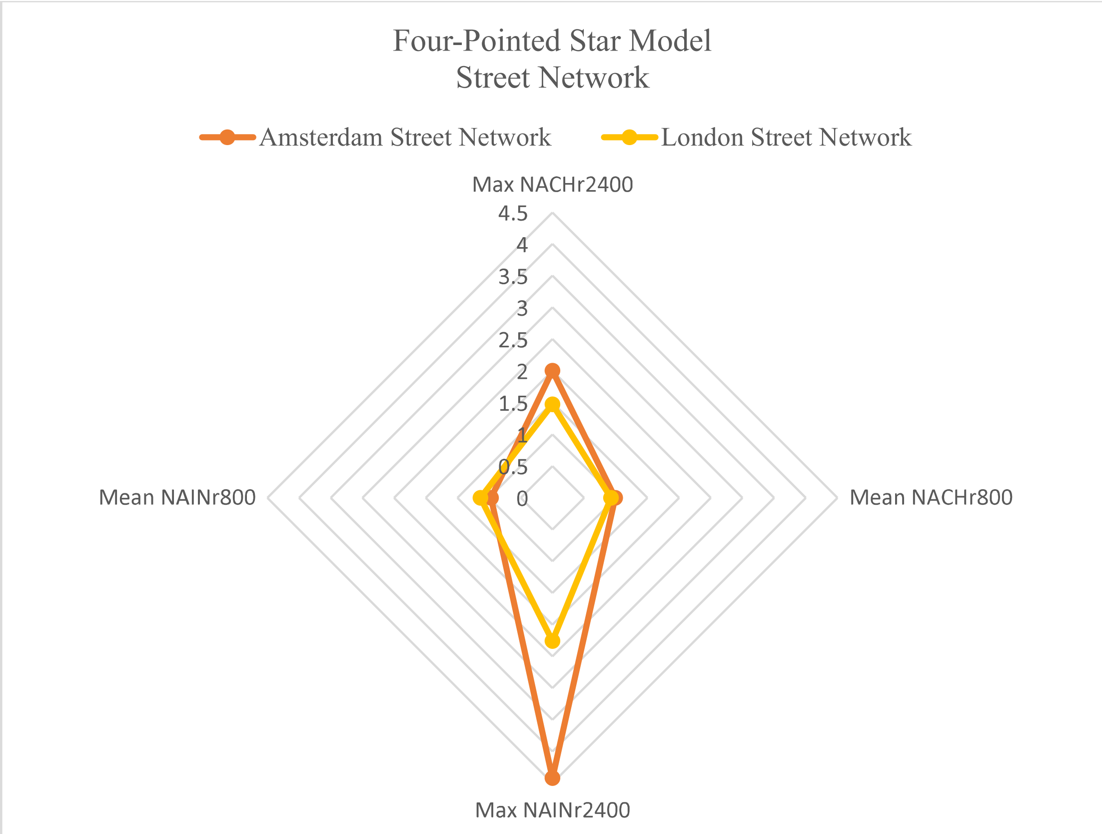


Figure 39. Four-Pointed Star Model of Street Networks

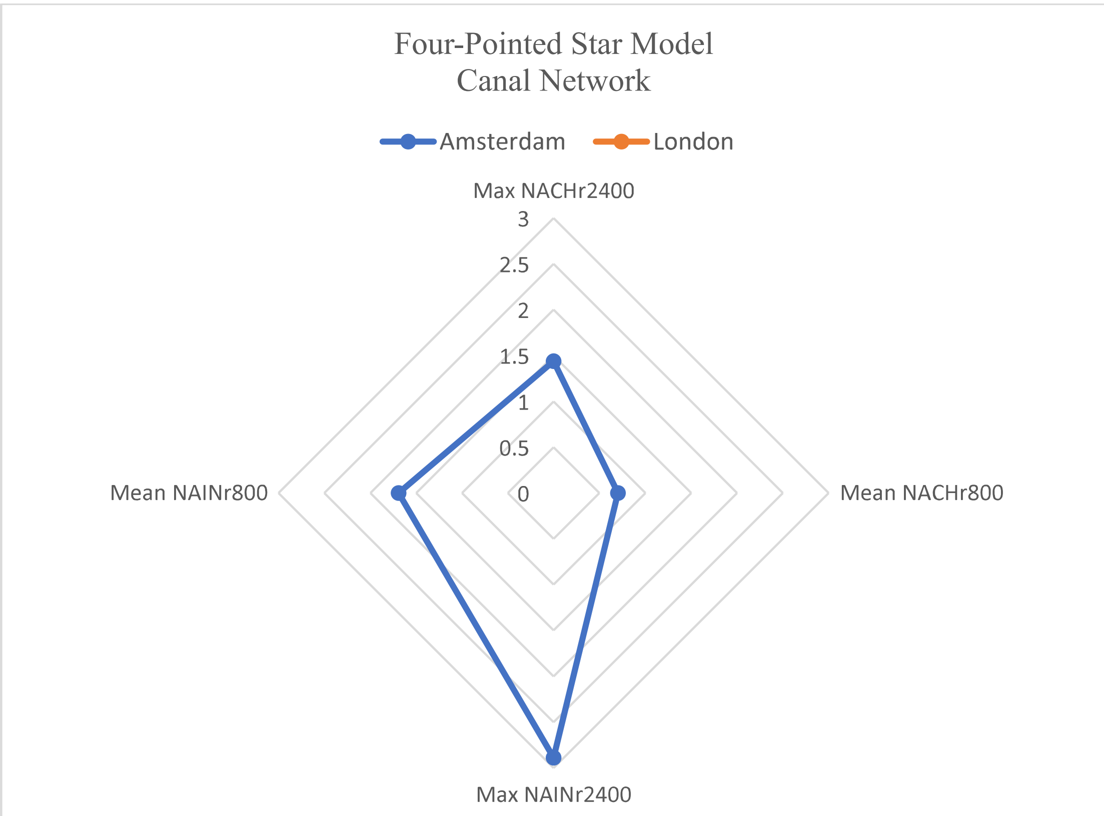


Figure 40. Four-Pointed Star Model of Canal Networks

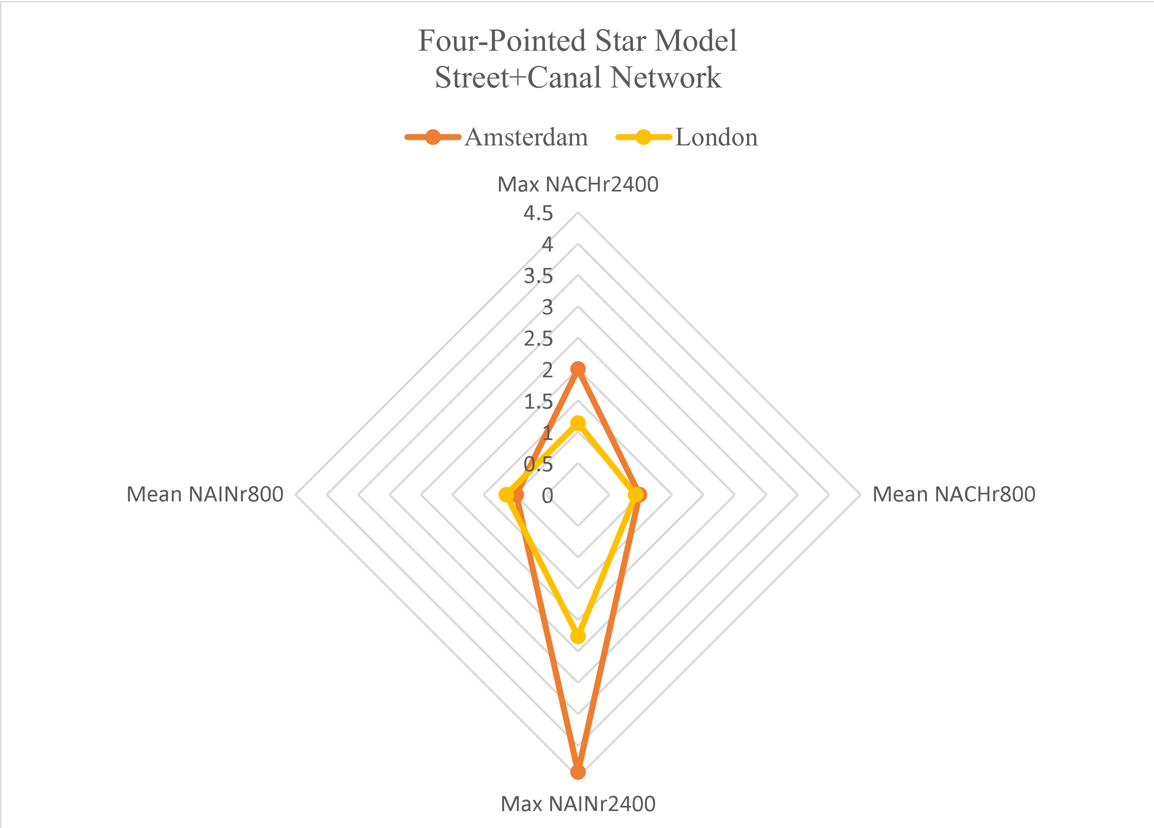


Figure 41. Four-Pointed Star Model of Street+Canal Networks

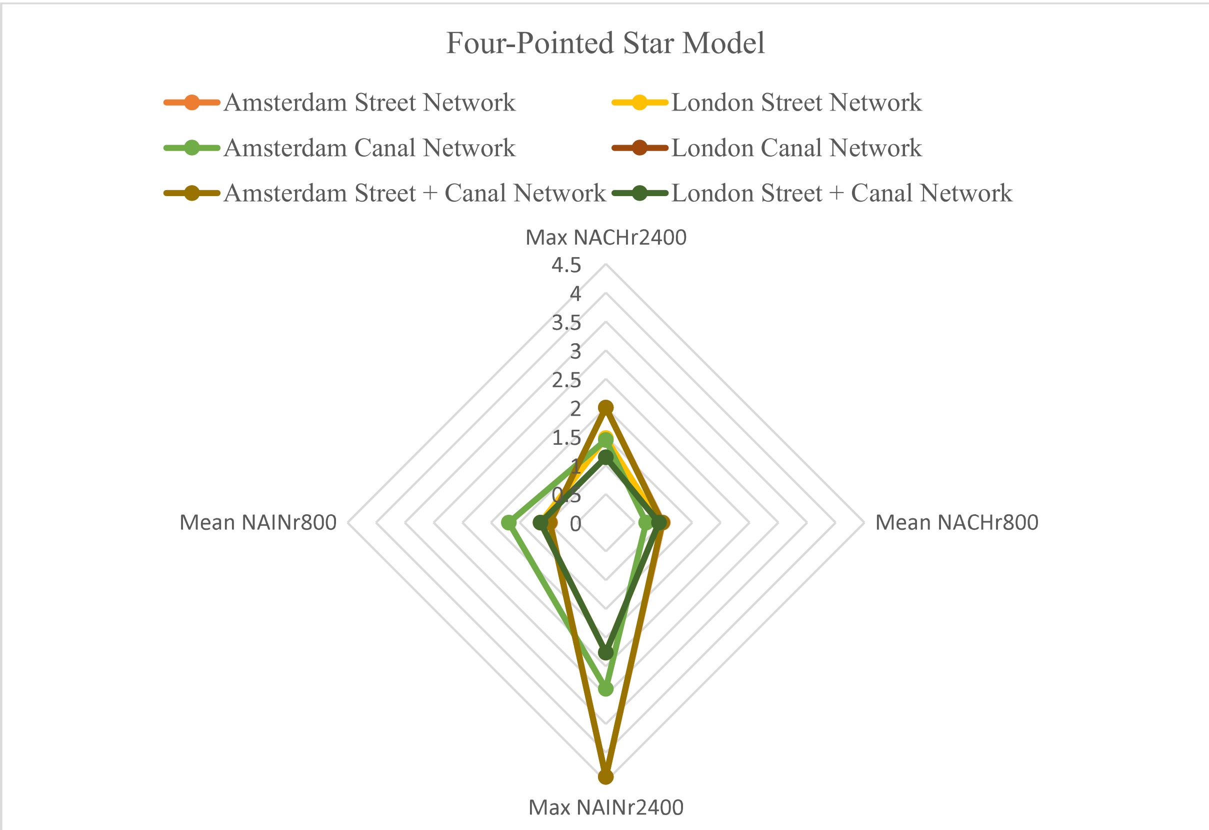


Figure 42. Four-Pointed Star Model of Networks

The four-pointed star models of cities (Figure 39, and 41) show that canals do not impose significant change on the cities' networks in terms of potential movement in the background and foreground networks. In more detail, Table 3 shows the normalised angular choice and integration analysis results for both cities' street, canal, and street+canal networks. Accordingly, in comparing Amsterdam's and London's street networks, Amsterdam has a higher mean choice and integration values than London, except that London has higher integration with the 800 metre radius (Table 4). While the mean value of NACHr800 is 0.99 for Amsterdam, it is 0.92 for London. In the comparison of the maximum value of NAINr2400, Amsterdam (4.43) has a significantly higher NAINr2400m than London (2.26). This illustrates that Amsterdam's street network shows significantly more ease of accessibility in the potential for to-movement for both the background and foreground networks of the system (see Figures 39-42).

Table 4. Space Syntax Analysis Results of Amsterdam and London

		Max NACHr2400	Mean NACHr800	Max NAINr2400	Mean NAINr800
(a) Street Network	Amsterdam	2.00	0.99	4.42	0.97
	London	1.47	0.92	2.26	1.14
(b) Canal Network	Amsterdam	1.44	0.70	1.69	2.89
	London	-	-	-	-
(c) Street + Canal Network	Amsterdam	2.00	0.99	4.42	0.98
	London	1.14	0.92	2.26	1.14

As discussed in the literature review, the canal systems are associated with microeconomic activities and seem to be a foreground network (Hillier, 2016). From this point of view, the statistical analysis was performed in order to investigate the role of canal systems on the transportation of commodities, materials, and necessary resources. Paired T-test were applied to both cities for the comparison of cities, with and without canals. Tables 5 and 6 illustrate the statistical results of Amsterdam and London, which show paired T-test analysis results between the street networks and street+canal networks to identify whether canals have an impact on the cities' spatial configurations.

Table 5. Paired T-test Values for the Amsterdam Network

Paired Samples Test

		Paired Differences					t	df	Significance	
					95% Confidence Interval of the Difference					
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			One-Sided p	Two-Sided p
Pair 1	Street Network NAINr800m - Street+Canal Network NAINr800m	-,005042350	,5186415957	,0030325770	-,010986335	,0009016360	-1,663	29248	,048	,096
Pair 2	Street Network NACHr800m - Street+Canal Network NACHr800m	,0002153808	,4710896500	,0027545335	-,005183627	,0056143889	,078	29248	,469	,938
Pair 3	Street Network NAINr2400m - Street+Canal Network NAINr2400m	-,048254200	,2829518537	,0016544629	-,051497021	-,045011379	-29,166	29248	<,001	<,001
Pair 4	Street Network NACHr2400m - Street+Canal Network NACHr2400m	-,000777914	,4483963096	,0026218420	-,005916841	,0043610125	-,297	29248	,383	,767

Table 6. Paired T-test Values for the London Network

Paired Samples Test

		Paired Differences					t	df	Significance	
					95% Confidence Interval of the Difference					
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			One-Sided p	Two-Sided p
Pair 1	Street Network NAINr800m - Street+Canal Network NAINr800m	-,001521616	,3826891481	,0021065068	-,005650443	,0026072117	-,722	33003	,235	,470
Pair 2	Street Network NACHr800m - Street+Canal Network NACHr800m	-,000488898	,5542894274	,0030510780	-,006469118	,0054913222	-,160	33003	,436	,873
Pair 3	Street Network NAINr2400m - Street+Canal Network NAINr2400m	-,002264495	,3301513716	,0018173133	-,005826493	,0012975033	-1,246	33003	,106	,213
Pair 4	Street Network NACHr2400m - Street+Canal Network NACHr2400m	-,000323801	,5488288682	,0030210204	-,006245108	,0055975050	-,107	33003	,457	,915

The T-test results allow us to compare the mean values of the London's and Amsterdam's street networks with the canals added to the system. There is no significant change in London's system with regard to the mean values of NAIN and NACH on the local and global scale (Table 6). However, London's max NACHr2400 decreased from 1.47 to 1.14 when the canals were added to the system (Table 4). Therefore, the analysis of the street network with the canals added to the system shows that the maximum choice value of the foreground network has decreased in London. London has no value above 1.49 in global choice measures with the canals (Table 4). Therefore, the potential mobility of the canal+street network on the global scale is lower than just the street network in London. However, the space syntax values of Amsterdam did not change with the canals added to the system (Table 4).

The mean values of NAIN and NACH in the 800 metre radii do not significantly differ between the street network and the canals added to the system in Amsterdam (Table 5). Hence, the potential movement in the background network did not change with the canals added to the system (Table 5). Table 5 shows paired T-test values for the Amsterdam Network with and without canals and in terms of the foreground network, the analysis finds that the addition of the canals significantly increases only the mean values of NAINr2400 for the system (Table 5). The NAIN and NACH max values with the 2400 metre radii are the same for the street and street+canal networks. This confirms the statement by Feddes that "Amsterdam has been more of a land city, and places can be accessible both across the water and along streets" (Feddes, 2012). The results for Amsterdam, London, and Psarra's Venice analysis show three different examples in terms of the land-based interconnections of waterways in the urban formation of city structures. While places are more accessible with waterways in Venice (Psarra, 2018) (Table 2), Amsterdam can be defined as an intermediate between a land and a water city. The canal network formed part of the emergence of the city's dual grid. The embedding of London's canal network is the lowest in these three cities. Hence, London can be defined as having a dominant land-based spatial structure in terms of its movement potentials.

Canal Structure and Bridges

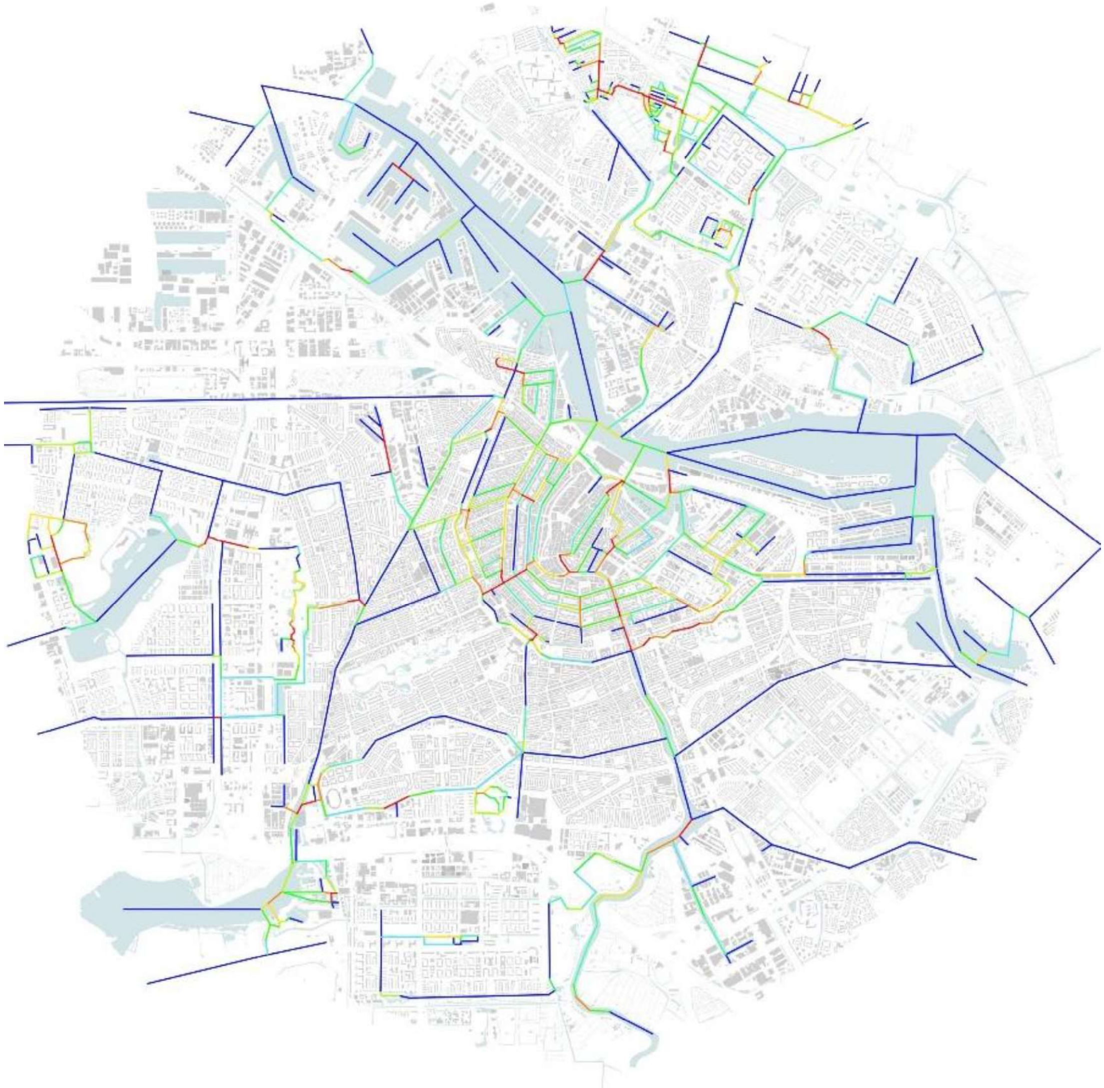


Figure 43. The Canal Structure of Amsterdam NACHr800m

Figure 44. The Canal Structure of Amsterdam NACHr2400m

Analysing the canal structure of Amsterdam on its own illustrates Leidsegracht and Prinsengracht Canals are the most integrated canals of the city centre (Figure 45). It structures the global movement of the city and the most navigable waterway of the foreground grid, which has the potential on structuring the general form of the city's global movement. The analysis shows that the canal network can still be a dominant mode of transportation infrastructure in central Amsterdam for the movement of resources, goods etc. (Figures 43, and 44).

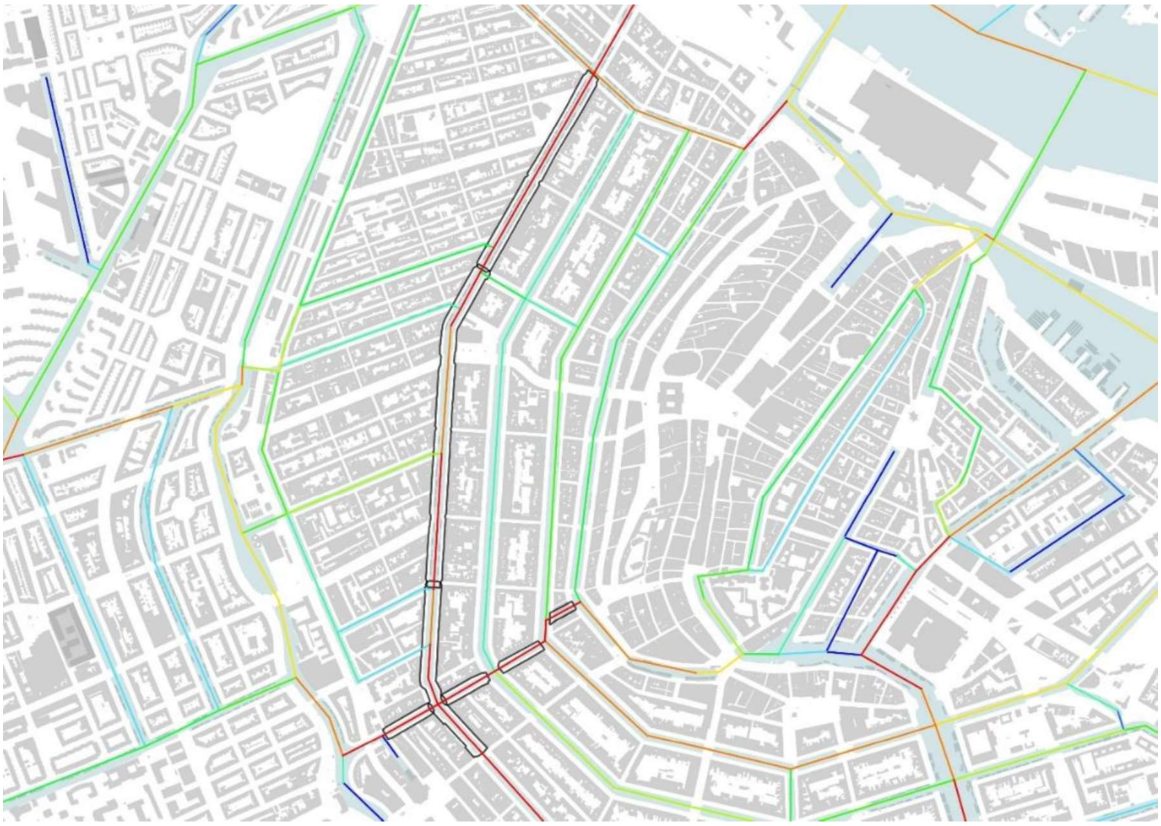


Figure 45. Prinsengracht and Leidsegracht Canals NACHr2400m

While London has 43 bridges over Regent's Canal, Amsterdam contains 731 bridges over its canals in the city-wide scale site area (Figures 46, and 47) Both London's and Amsterdam's canal bridges have higher NACH and NAIN mean values than the cities' street networks. However, Amsterdam's maximum NACH and NAIN values for the bridges are significantly higher than those for London (Table 7). Hence, the analysis shows that the islands of Amsterdam are well joined to each other with bridges, and the canals do not create severance between the island communities in the city structure.

Figure 46. Amsterdam Waterways and Bridges NAINr800m

Figure 47. London Waterways and Bridges NAINr800m

Table 7. A Comparison of NACH Values

	NACHr800m				NACHr2400			
	Amsterdam		London		Amsterdam		London	
	Max	Mean	Max	Mean	Max	Mean	Max	Mean
Street Network	2.5	0.99	1.6	0.92	2	0.94	1.47	0.90
400m-Buffered Area from Canals	2.33	0.99	1.6	0.92	1.38	0.95	1.44	0.91
Bridges	2.39	1.06	1.37	1.19	1.38	1.05	1.42	1.18

Comparison of Canalside and the Entire Street Network

The statistical analysis is here applied to London's entire street network in comparison with a 400m- buffered area from the canals (an approximation to a five-minute walking distance and which can be defined as the canalside area). Table 8 and 9 illustrate the statistical analysis results of the comparison of the 400 m- Buffered (Canalside) Area and Entire Street Network of London. The analysis shows that the mean values of NAIN with 800 and 2400 metre radii are significantly different. The canalside area's mean integration on the local and global scales is lower than for the city as a whole (Tables 8, and 9). Hence, while the potential through-movement of the canalside district is similar in terms of the space syntax accessibility measure, the potential to-movement for the canalside is lower than the city network on the local scale according to the segment angular integration with 800 metre radii. Hence, the results find that the Regent's Canal has a negative impact on its closer area (400 m buffer area) in terms of the potential movement to a space as a destination from all other spaces.

Table 8. Group Statistics for the 400 m- Buffered (Canalside) Area and Entire Street Network of London

Group Statistics

	Buffer	N	Mean	Std. Deviation	Std. Error Mean
NAINr800m	400m	4154	1,095444429	,2715578280	,0042133650
	non-400m	28905	1,156162356	,3047245265	,0017923422
NACHr800m	400m	4154	,9282538175	,3900320857	,0060515565
	non-400m	28905	,9258503210	,4043868984	,0023785407
NAINr2400m	400m	4154	1,136340205	,2306798542	,0035791213
	non-400m	28905	1,173119043	,2963361420	,0017430030
NACHr2400m	400m	4154	,9108896931	,3888816017	,0060337061
	non-400m	28905	,9017861766	,4011729482	,0023596368

Table 9. Independent T-test Values for the 400 m- Buffered (Canalside) Area and the Entire Street Network of London

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means							
						Significance		Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
		F	Sig.	t	df	One-Sided p	Two-Sided p			Lower	Upper
NAINr800m	Equal variances assumed	85,066	<,001	-12,167	33057	<,001	<,001	-,060717926	,0049904915	-,070499465	-,050936388
	Equal variances not assumed			-13,261	5764,930	<,001	<,001	-,060717926	,0045787482	-,069693992	-,051741860
NACHr800m	Equal variances assumed	12,876	<,001	,360	33057	,360	,719	,0024034965	,0066805374	-,010690592	,0154975845
	Equal variances not assumed			,370	5516,353	,356	,712	,0024034965	,0065022144	-,010343406	,0151503993
NAINr2400m	Equal variances assumed	401,948	<,001	-7,672	33057	<,001	<,001	-,036778838	,0047938581	-,046174969	-,027382708
	Equal variances not assumed			-9,239	6305,489	<,001	<,001	-,036778838	,0039809759	-,044582906	-,028974771
NACHr2400m	Equal variances assumed	9,719	,002	1,373	33057	,085	,170	,0091035164	,0066313879	-,003894237	,0221012696
	Equal variances not assumed			1,405	5501,973	,080	,160	,0091035164	,0064786954	-,003597287	,0218043202

In the comparison of the mean values of street segment length, there is no significant difference between the canalside and the city in either city. However, a detailed examination of London shows that the maximum street segment length value of the canalside area is significantly lower than that of the city street network, which are 551.16 metres for the canalside and 1070.4 metres for the city's street network, respectively. On the other hand, there is no significant difference between canalside and the city networks in terms of the maximum street segment length in Amsterdam.

Comparison of North and South Side of Regent's Canal

The statistical analysis was undertaken in order to investigate whether Regent's Canal has different impacts on the north and south parts of the canalside.

Table 10. Group Statistics for the North and South Sides of the Regent's Canal

Group Statistics

	Side	N	Mean	Std. Deviation	Std. Error Mean
NAINr800m	North	12352	1,044033928	,2616426387	,0023541812
	South	20707	1,210867918	,3063079986	,0021286279
NACHr800m	North	12352	,8794878112	,4444182749	,0039987409
	South	20707	,9539883345	,3726935307	,0025899612
NAINr2400m	North	12352	1,001281983	,2114420836	,0019024918
	South	20707	1,268243980	,2831885915	,0019679641
NACHr2400m	North	12352	,8574082171	,4381722442	,0039425410
	South	20707	,9300844605	,3721676691	,0025863069

Table 11. Independent T-test Values for the North and South Sides of the Regent's Canal

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means							
						Significance				95% Confidence Interval of the Difference	
		F	Sig.	t	df	One-Sided p	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper
NAINr800m	Equal variances assumed	373,134	<,001	-50,528	33057	,000	,000	-,166833990	,0033018033	-,173305640	-,160362339
	Equal variances not assumed			-52,565	29171,274	,000	,000	-,166833990	,0031738345	-,173054847	-,160613132
NACHr800m	Equal variances assumed	659,347	<,001	-16,342	33057	<,001	<,001	-,074500523	,0045588734	-,083436075	-,065564971
	Equal variances not assumed			-15,637	22522,947	<,001	<,001	-,074500523	,0047642238	-,083838732	-,065162314
NAINr2400m	Equal variances assumed	1065,981	<,001	-90,761	33057	,000	,000	-,266961997	,0029413660	-,272727178	-,261196816
	Equal variances not assumed			-97,530	31446,982	,000	,000	-,266961997	,0027372171	-,272327049	-,261596945
NACHr2400m	Equal variances assumed	566,867	<,001	-16,057	33057	<,001	<,001	-,072676243	,0045260797	-,081547519	-,063804968
	Equal variances not assumed			-15,413	22754,836	<,001	<,001	-,072676243	,0047151472	-,081918254	-,063434233

The T-test analysis between the north and south sides of the Regent's Canal clearly shows that the mean values of the space syntax analysis at both scales (800 m and 2400 m radii) significantly differ from each other (Table 11). The south part has a higher normalised choice and integration value for an 800 and 2400 m radius (Table 10).

Figure 48 shows the comparison of the south and north side of Regent's Canal in four-pointed star model. In terms of the comparison of maximum values of choice and integration analysis of the foreground network, the maximum value of the integration analysis is significantly higher for the south side (2.26) than the north side (1.67) (Figure 48). As illustrated in Figure 49 in the form of a scatter plot, the percentage of highly integrated streets in the background network is higher in the south than the north side of Regent's Canal in London.

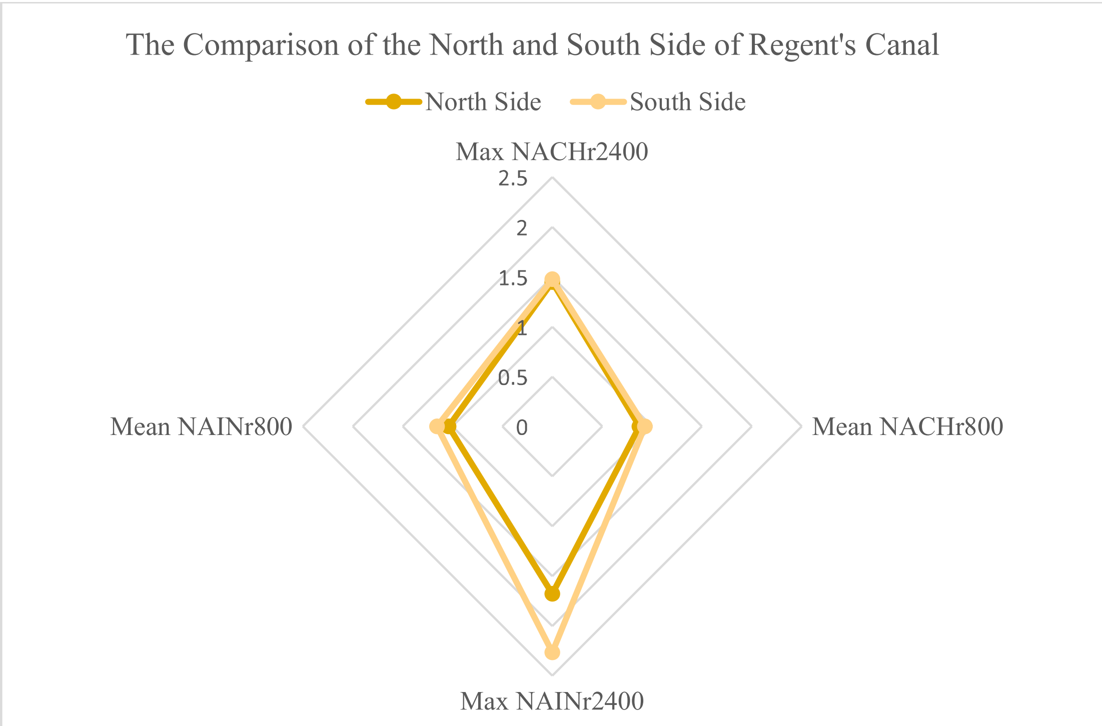


Figure 48. The Comparison of the Street Networks of the North and South Sides of Regent's Canal

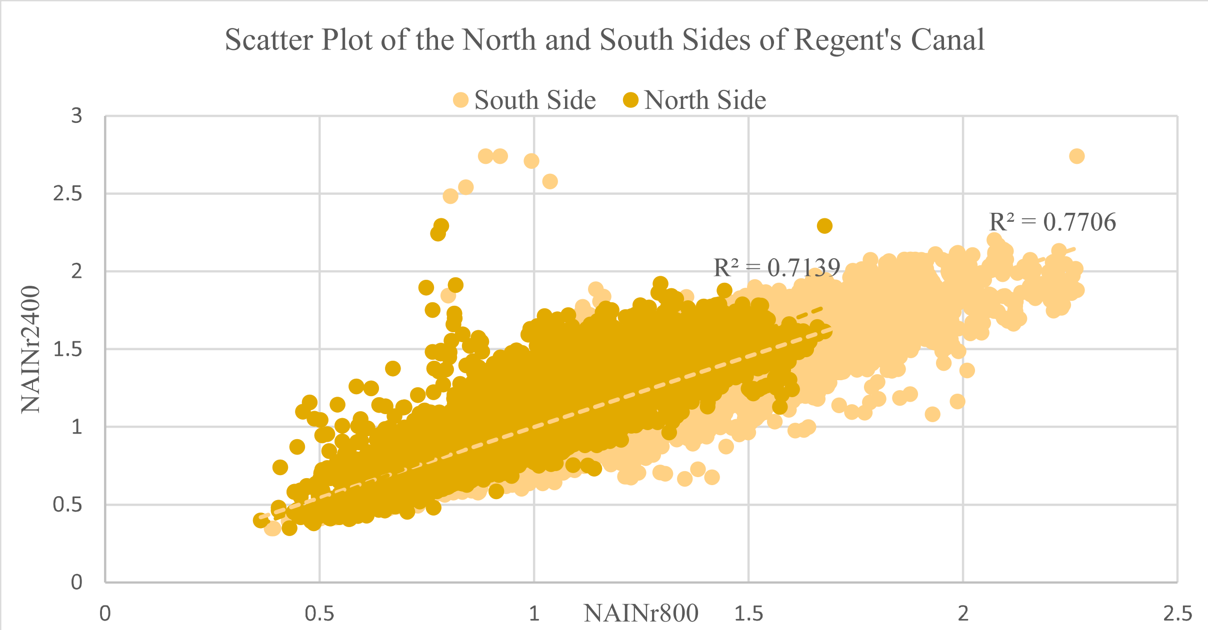


Figure 49. Scatter Plot of the Street Networks of the North and South Sides of Regent's Canal

Comparison of the North and South Sides of Regent's Canal via Catchment Analysis

The next step of the analysis is to measure where the difference in NAIN values between the north and south sides of Regent's Canal occurs in London, and thus the detailed analysis was performed according to proximity to the canals. The street network is grouped into three catchment areas which are 0-400 m, 400-800 m, and 800-1200 m on both sides of the Regent's Canal. The paired T-test is applied to these groups to compare the mean values of NAINr800, which is essential in order to understand where the marked difference occurs in terms of the potential movement between the south and north canalside networks. Table 12 clearly illustrates the results of the analysis of the paired T-test between north and south sides of the Regent's Canal with catchment, which show that the significant change in terms of the mean values of NAINr800 between the north and south canalsides occurs within the 0-400 m canalside area (Table 12).

Table 12. Paired T-test Values for the North and South Sides of the Regent's Canal with Catchment

Paired Samples Test

		Paired Differences							Significance	
					95% Confidence Interval of the Difference					
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	One-Sided p	Two-Sided p
Pair 1	0-400 North Side NAINr800m - 0-400 South Side NAINr800m	,0343434490	,3667540039	,0100077594	,0147108943	,0539760036	3,432	1342	<,001	<,001
Pair 2	400-800 North Side NAINr800m - 400-800 South Side NAINr800m	,0158261090	,3467792821	,0095195777	-,002848967	,0345011846	1,662	1326	,048	,097
Pair 3	800-1200 North Side NAINr800m - 800-1200 South Side NAINr800m	,0170159572	,3778789176	,0108230785	-,004217987	,0382499018	1,572	1218	,058	,116

These statistical analysis results suggest that the Regent's Canal has a barrier- effect in terms of betweenness centrality and integration of the street network on the 400 m buffered area from the canal, given that the north side of the canalside within the 400 m catchment area is locally segregated from the city centre and old city.

5. NEIGHBOURHOOD SCALE ANALYSIS

Measuring the impact of canals on the urban mobility and spatial segregation of communities on the neighbourhood scale include spatial and economic dimensions in the study, and therefore the analysis of the neighbourhood scale is presented in three different sections, which are 5.1. Introduction to Case Study Areas, 5.2. Urban Context and Spatial Analysis, 5.3. Impact of the Canals in Land Use Distribution and Retail Density.

The first section (*Introduction to Case Study Areas*) will introduce the method to examine the status of canals within the spatial network in both cities.

The second section *(Urban Context and Spatial Analysis*) will present the space syntax methodology to investigate spatial network connectivity and integration at the neighbourhood scale by comparing the two different sides' contexts from Amsterdam and London.

The third section (*The Impact of the Canals in Land Use Distribution and Retail Density*) will be formulated to transform land use and retail density into comparable spatial values. The aim of this section is to analyse the influence of spatial conditions around the canals on local economic activities.

INTRODUCTION TO CASE STUDY AREAS: THE HISTORY OF GRACHTENGORDEL AND REGENT'S CANAL

Amsterdam Canal District: Grachtengordel

Amsterdam's neighbourhood scale case study area is Grachtengordel, which is known as the Amsterdam Canal District and is located in the Centrum district of the city (Figures 50, and 51). It was built during the 17th century and the area was added to the UNESCO World Heritage List in 2010. It is the most recent Dutch heritage property to be inscribed on the World Heritage List.

Figure 50. Grachtengordel (Canal District of Amsterdam)

Figure 51. Aerial Photo of Grachtengordel (Source: parool.nl)

At the beginning of the seventh century, Amsterdam had new urban development plans to facilitate economic growth and control increasing densification. The plans mainly covered the Grachtengordel and Jordaan regions, which can be evaluated as different plans in comparison to previous expansions (Berghauser Pont and Haupt, 2021). The plan of Grachtengordel is a regular and symmetrical layout with rectangular urban blocks that are diagonal and parallel to the canals. The plan of the area consisted of a strict set of rules, which determined which functions could be located on which canals and urban blocks. The first two canals in the area (Herengracht and Keizersgracht) (Figure 52) were part of the housing development of Amsterdam, especially for the ruling class. On the other hand, businesses were placed on the Prinsengracht canal (Bruin et al., 2013).

Figure 52. Herengracht Canal in Grachtengordel (Source: https://www.amsterdamsdagblad.nl/)

According to the 1859 census data, Grachtengordel's density was only 270 inhabitants per hectare. However, the Jordaan area housed 830 inhabitants per hectare. The housing units in Grachtengordel were larger than those in Jordaan, which were designed for immigrants and the working class. It is stated that after the economic situation changed in Amsterdam, the housing units in Grachtengordel were subdivided and transformed into office buildings. As a result of the increase in the number of offices, more people started to work in the area. This resulted in a decrease in population density. However, the spatio-histocial analysis of Amsterdam shows that the changes in land use and population density did not result in a change in the urban fabric's layout (Berghauser Pont and Haupt, 2021).

Bruin *et al.* (2013) uncovered the functional developments of Grachtengordel with a case study area to analyse the evaluation of functions in the area. The case area of the study is a building block called F20 surrounded by the main canals, Herengracht and Keizersgracht, and the streets Leidsestraat and Nieuwe Spiegelstraat (Figure 53).

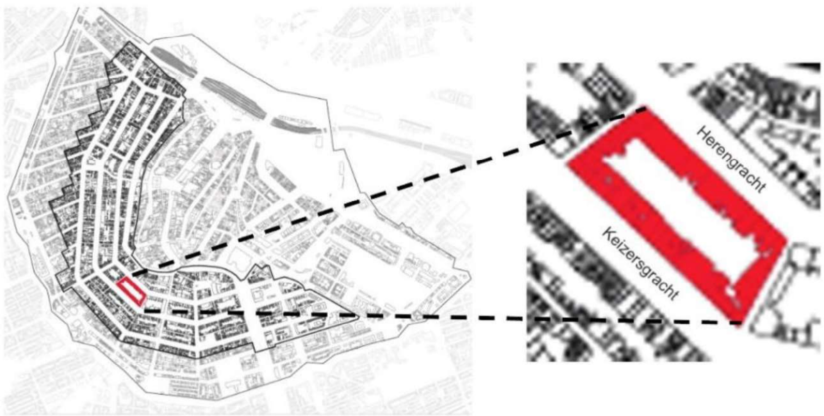


Figure 53. The Sample Building Block in Grachtengordel Neighbourhood called F20 (Bruin et al., 2013)

The study analyses the functional mix quantitatively, in an area and unit size, by geographical distribution at six moments in time (1959, 1969, 1979, 1994, 2002, and 2010). The research dataset is the hard-copy Building Block Documentation (BBD), which is available for Amsterdam's inner city conservation area (Bruin et al., 2013).

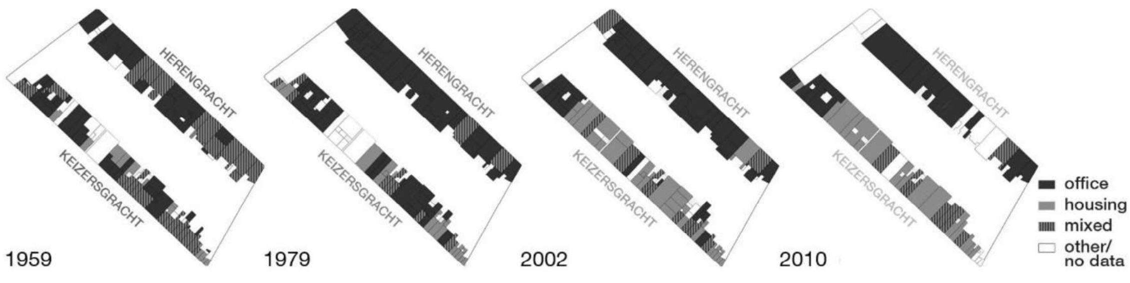


Figure 54. The Geographical Distributions of Function in the F20 Block in Grachtengordel (Bruin et al., 2013)

As illustrated in Figure 55, the main finding of the research is that the F20 block is dynamic in terms of functional mix. Although the Herengracht originally consisted of houses in the 17th-century plan, the canal has now become dominated by offices, which make up approximately 75% of the buildings (Figure 54, and 55). The Keizersgracht Canal was more mixed but has, since 2002, begun to contain more residential functions, which make up approximately 70% of the buildings (Figure 54, and 55).

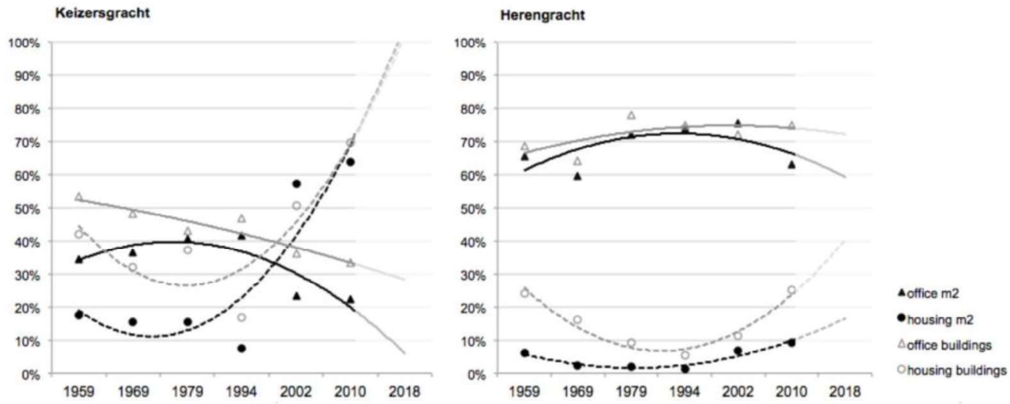


Figure 55. The Functional Mix of the Canals in the F20 Block (Bruin et al., 2013)

The quantitative analysis indicates that the F20 block shows two types of mono-functional trends: housing and office functions. This indicates that the new functional developments have a negative impact on the diversity of functions on the building block scale (Figure 55) (Bruin et al., 2013).

Regent's Canal in London: Between Camden Town and King's Cross

London's neighbourhood scale case study area is Regent's Canal between Camden Town and King's Cross (Figure 56). Figures 57, and 58 illustrates the current situation of King's Cross and Camden Town canalside area. Regent's Canal was built during the early 19th century as a link between the northwest of Paddington Basin and the Limehouse Basin and Canal to the River Thames in east London. The first section of the canal runs from Paddington to Camden Town, and which opened in 1816. The Camden to Limehouse section opened four years later in 1820. The industrial revolution and the development of railways made Regent's Canal indispensable, and the canal played a fundamental role in supporting different industries. There were many projects to convert the canal into a railway, but the government objected to the idea of a railway that passed through Regent's Park; in any case, the funds could not be raised to effect this transformation (Essex-Lopresti, 1998).

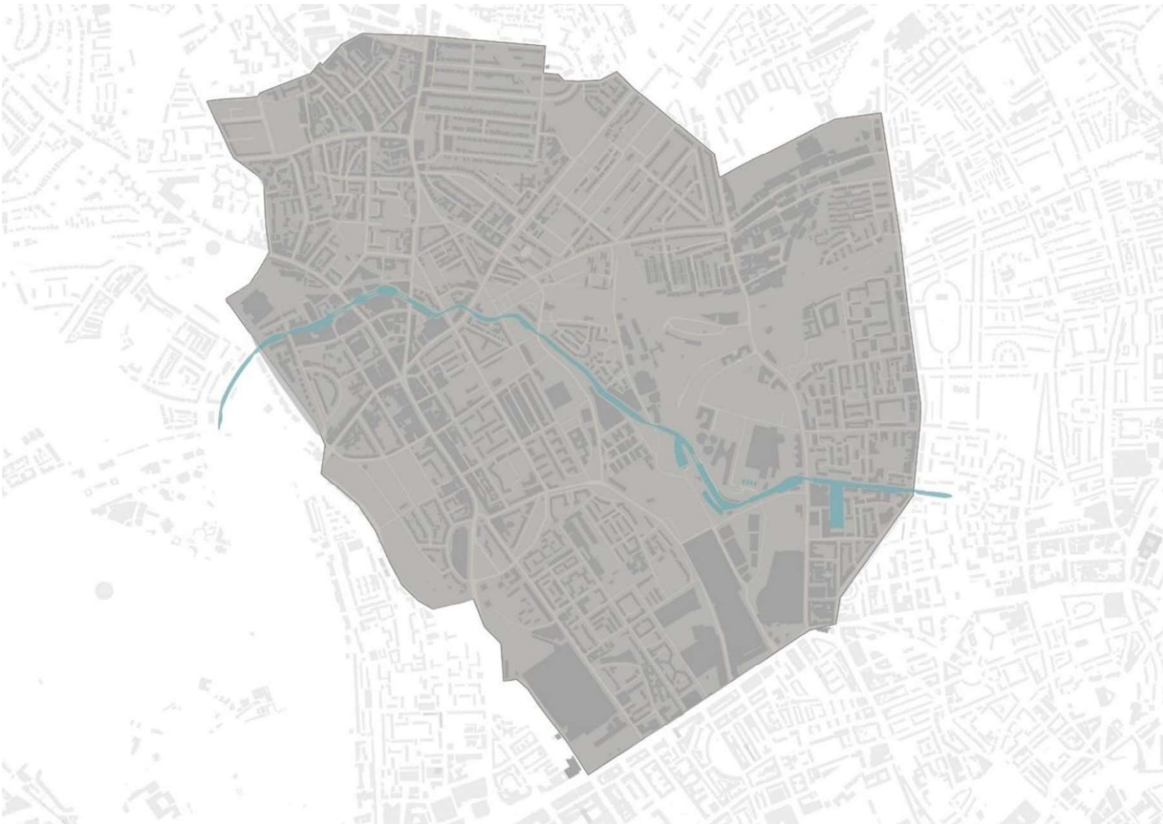


Figure 56. Regent's Canalside Between Camden Town and King's Cross

The railways came to King's Cross in the mid-1800s and transformed it into an industrial heartland. The world's first underground metro system was constructed in the area a few decades later. The area became directly connected to numerous cities across the country and was a key focus of industry. However, after the Second World War, the road replaced rail freight, and the area went into decline and is now known as an industrial wasteland with its disused buildings, warehouses, and railway sidings. Numerous attempts have been made to revive King's Cross over the decades, but high unemployment and crime, and the poor pedestrian environment ultimately prevented developers from investing in the area. This all began to change towards the end of the 20th century, however, when the King's Cross Partnership was established to invest in a regeneration project in the area. The King's Cross redevelopment plan is an example of the huge transformation of a previous industrial hub into a mixed-use area. The regeneration project increased the building density and diversity of functions in the area (King's Cross, 2020) (Figure 59). However, there are critics of the regeneration who argue that it cannot be not seen as a process that serves low- and middle-income localities; rather, it is seen as a business activity, aimed at growth and competitiveness (Edwards, 2009). Michael Edwards (2009) explains that new housing developments are subjected to gentrification with private rents, which represent a 5- to 10- fold increase in the level of council rents.

Figure 57. Regent's Canal in King's Cross, London (Source: Author's photographs)

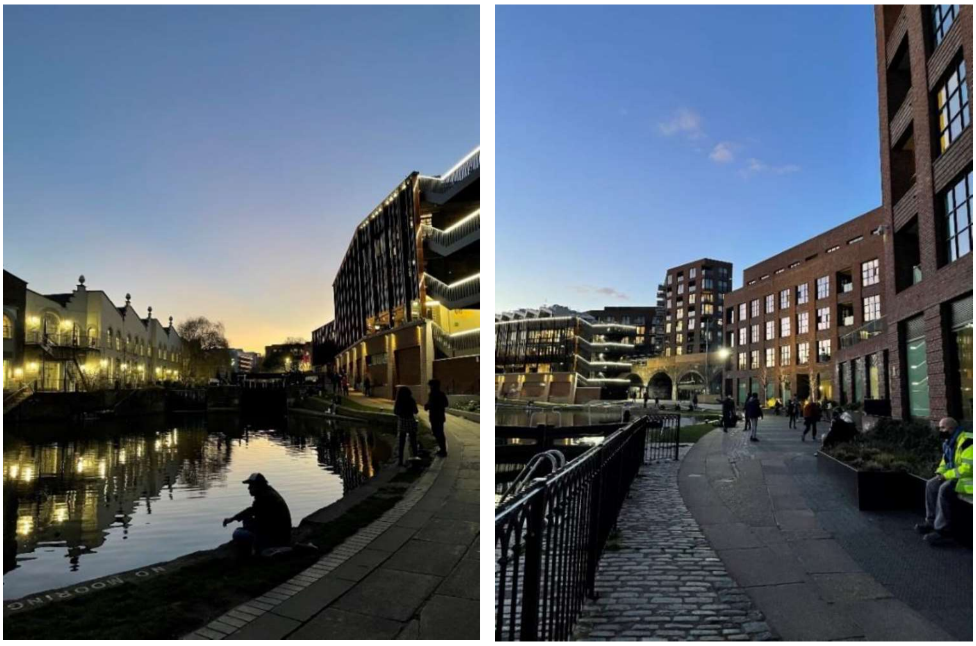


Figure 58. Regent's Canal in Camden Town, London (Source: Author's photographs)

Figure 59. The Redevelopment Process of King’s Cross

Concurrently, the restoration of several historic buildings and creation of several new public spaces began with the University College of Arts London relocating their campus to the restored Granary Square warehouse in 2011. Also, the two Victorian buildings that made up the Coal Drops Yard were restored, and the area was designed with public facilities creating a contemporary setting. The other important part of the redevelopment plan is the former gasholders. These three structures were restored and underwent an unusual transformation to adopt a residential function (King’s Cross, 2020).

While King’s Cross was built for industrial canalside use, Camden Town Canalside development mainly consisted of residential functions in the early 19th century. Camden Town was described as a Georgian suburb of the early 19th century by the architectural historian John Summerson (McCarthy, 2018). The Regent’s Canal was first built across the centre of Camden Town. The initial construction consisted of dwellings along the main roads and then the bridges over the Regent’s Canal. The second phase consisted of a new road called Camden Road, which also contained squares and crescents, back gardens for the terraces and the development of wharves for the canal. The development of Camden Town was a part of London’s urban expansion. The process of development began in 1789 and was completed in the 1870s (McCarthy, 2018). Similar to the Grachtengordel neighbourhood in Amsterdam, most of the housing units in Camden Town were designed for middle-class families. The social reformer Charles Booth walked the London streets and gathered evidence for a revision of his colour-coded “poverty map” in 1898. His notebooks showed Camden Town as “middling” with no examples of either extreme poverty or wealth (Figure 60).

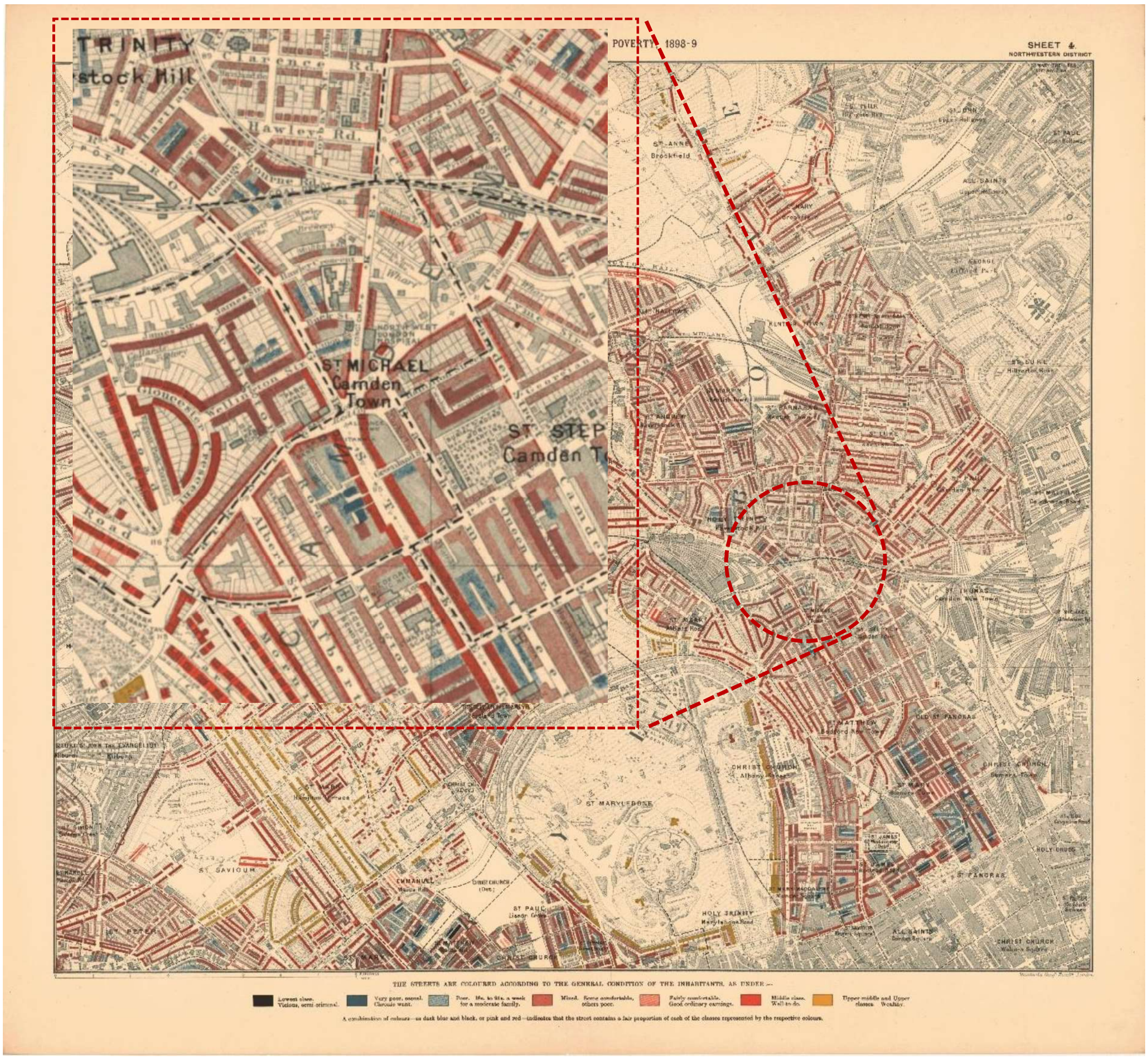


Figure 60. Charles Booth's Descriptive Map of London Poverty, 1889, sheet 4 (Source: https://booth.lse.ac.uk/map/14/-0.1174/51.5064/100/0)

In the London Atlas, it is stated that the Camden Town area was predominantly residential and Marylebone Road/Euston Road was essentially a part of a business district with offices, hotels and hostels (Jones, 1965). A dot distribution map of the population of London, which was completed in 1961, shows the percentage of one-person households (Figure 61). The data for all the enumeration districts within the London County Council was used. It is clear that a high percentage of one-person households was located in the central business district area, which contained hotels and hostels. Kentish Town and parts of Camden Town showed a low percentage of one-person households (Jones, 1965) (Figure 61).

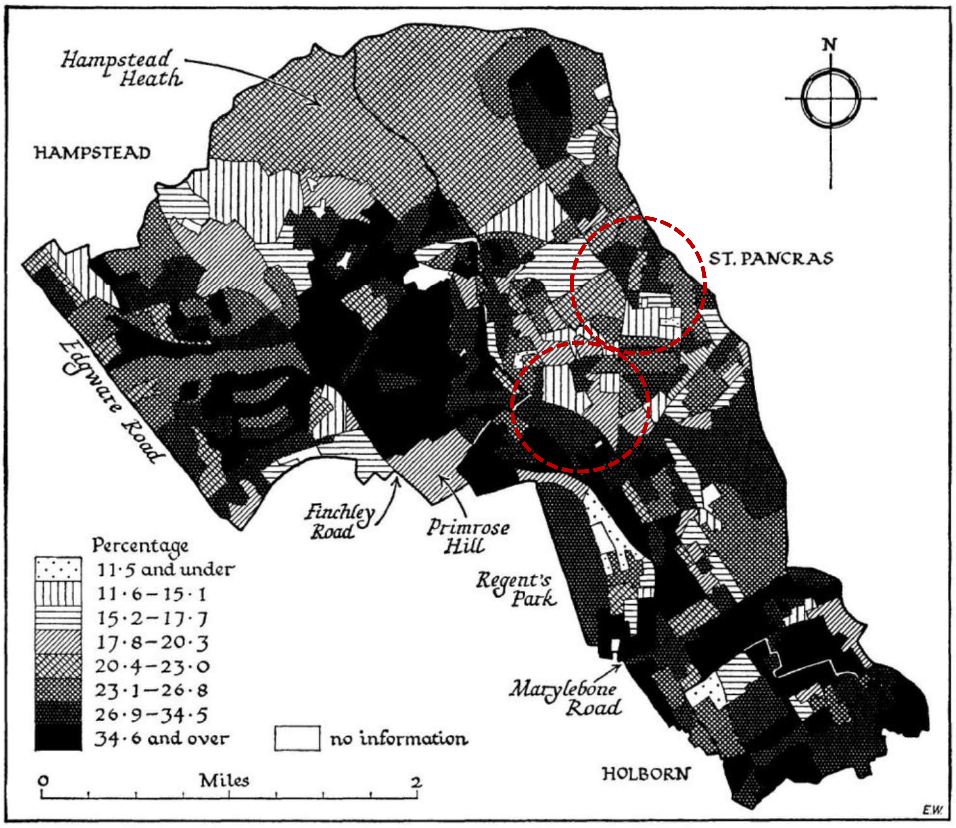


Figure 61. Percentage of one-person households by enumeration districts in London, 1961 (Jones, 1965)

URBAN CONTEXT AND SPATIAL ANALYSIS

The concept of natural movement describes that the distribution of movement flows is significantly determined by the configuration of urban street networks (Hillier et al., 1993). Hence, the neighbourhood scale research attempts to examine the urban context for an overview of canalside neighbourhoods. Recent contributions to space syntax approaches in urban studies address the issue of urban density in order to examine on the relationship between the capacity and quality of space and the performance of the urban form (Berghauser Pont et al., 2019; Berghauser Pont and Haupt, 2021; Marcus, 2007; Marcus et al., 2017). In this section, the spatial conditions of canalside environments, including urban block size, population density (number of people per hectare), building density (number of building units per hectare), network density (number of street segments per hectare), and block and canal coverage have been analysed in QGIS, and a statistical comparison has been made to describe and compare the use of space and their limitations in the case of Amsterdam and London canalside neighbourhoods.

Table 13. A Comparison of Amsterdam's and London's Urban Block Areas

Descriptive Statistics

	N	Minimum	Maximum	Sum	Mean	Std. Deviation	Variance
Amsterdam Block Area	63	,084	5,838	79,122	1,25590	,985778	,972
London Block Area	265	,005	31,439	378,774	1,42934	2,898543	8,402
Valid N (listwise)	63						

Table 14. A Comparison of Amsterdam's and London's Urban Block Coverages

Descriptive Statistics

	N	Minimum	Maximum	Sum	Mean	Std. Deviation	Variance
Amsterdam Block Coverage	63	,009	,922	42,271	,67097	,148156	,022
London Block Coverage	218	,004	,991	80,372	,36868	,177636	,032
Valid N (listwise)	63						

Table 13 shows that Regent's Canalside case study area in London has larger sized blocks than Grachtengordel in Amsterdam. However, the statistical analysis results show that there is no significant difference between Amsterdam and London in terms of the mean values of urban block areas. However, Grachtengordel in Amsterdam has significantly higher block coverage than Regent's Canalside (Tables 14, and 15). This means that Grachtengordel has a lower percentage of open space in comparison to Regent's Canalside context.

Table 15. T. Paired T-test Values for Urban Block Area and Coverage

Paired Samples Test

		Paired Differences							Significance	
					95% Confidence Interval of the Difference					
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	One-Sided p	Two-Sided p
Pair 1	Amsterdam Block Coverage - London Block Coverage	,088492	,225632	,028427	,031667	,145317	3,113	62	,001	,003
Pair 2	Amsterdam Block Area - London Block Area	-,141016	2,496862	,314575	-,769842	,487811	-,448	62	,328	,656

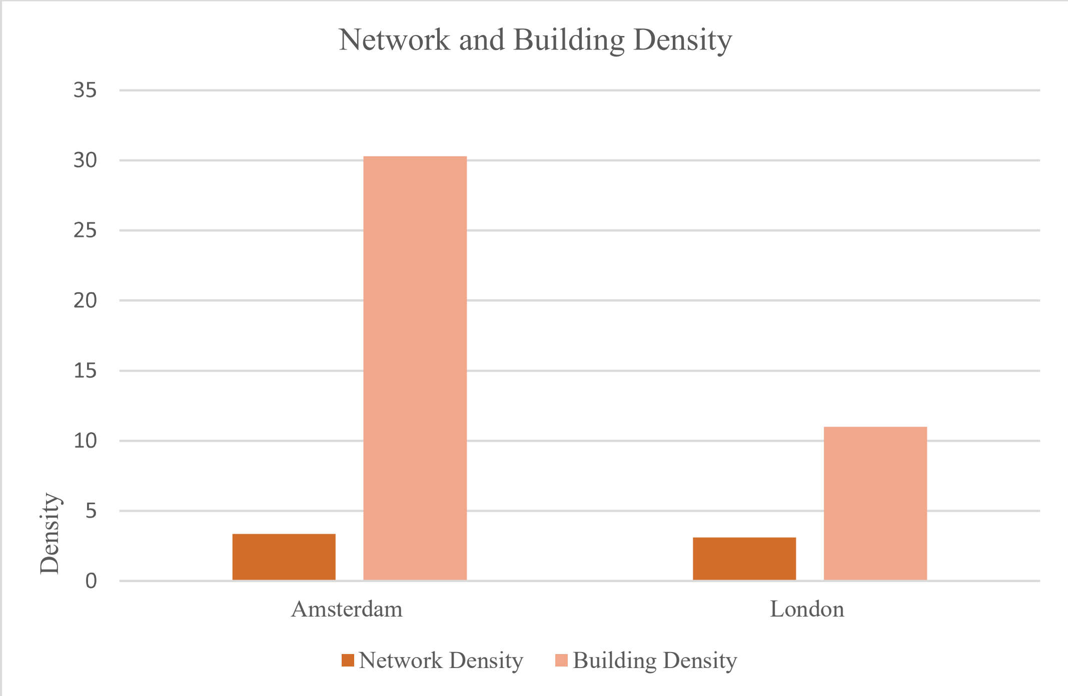


Figure 62. The Comparison of Building and Population Densities for Amsterdam and London

In terms of canal space coverage (canal area/case study area), Grachtengordel's canal space coverage (0.222) is significantly higher than Regent's Canalside (0.015). However, the population density is similar in Amsterdam (140 people per hectare) and London (147 people per hectare). This could be evaluated in the sense that Grachtengordel offers more water space to its residents than Regent's Canalside.

The network is also one of the basic elements that indicates the grain of the urban fabric. The network measurements and the grain of the urban fabric are decisive in terms of investigating the relationship between urban form, blocks and façade length. In this context, network density is defined by the amount of network per area unit (Berghauser Pont and Haupt, 2021). It is calculated as the number of street segments per hectare in the study. In terms of the network density, both case study areas show similar values. However, Amsterdam (30.28) has a greater building density than London (11.00) (Figure 62). The main reason behind this difference is due to the old industrial areas in Regent's Canalside - King's Cross. Both Grachtengordel and Regent's Canalside are geographically located close to the associated city centres, where there would be a high volume of global and local movement within the city (Figures 66, and 67). While Grachtengordel in Amsterdam and Camden Town in London both inherited well-structured street networks that had been developed over centuries with higher building densities, King's Cross in London is a regenerated area with fewer streets, building units, and much larger urban blocks (Figures 63, 64, and 65) (Table 16). Also, the continuity of the street network in King's Cross is affected by the huge infrastructure penetrating the south of the Regent's Canal. Huge blocks in King's Cross might possibly decrease the connectivity of the street networks. Hence, the block size and coverage, network density, and building density analysis show that Regent's Canalside includes different spatial conditions. While the urban grid is locally intensified with a higher network density in Camden canalside in a similar manner to Grachtengordel, King's Cross still shows segregated industrial land characteristics with its huge urban blocks (Figures 63 and 65) (Table 16).

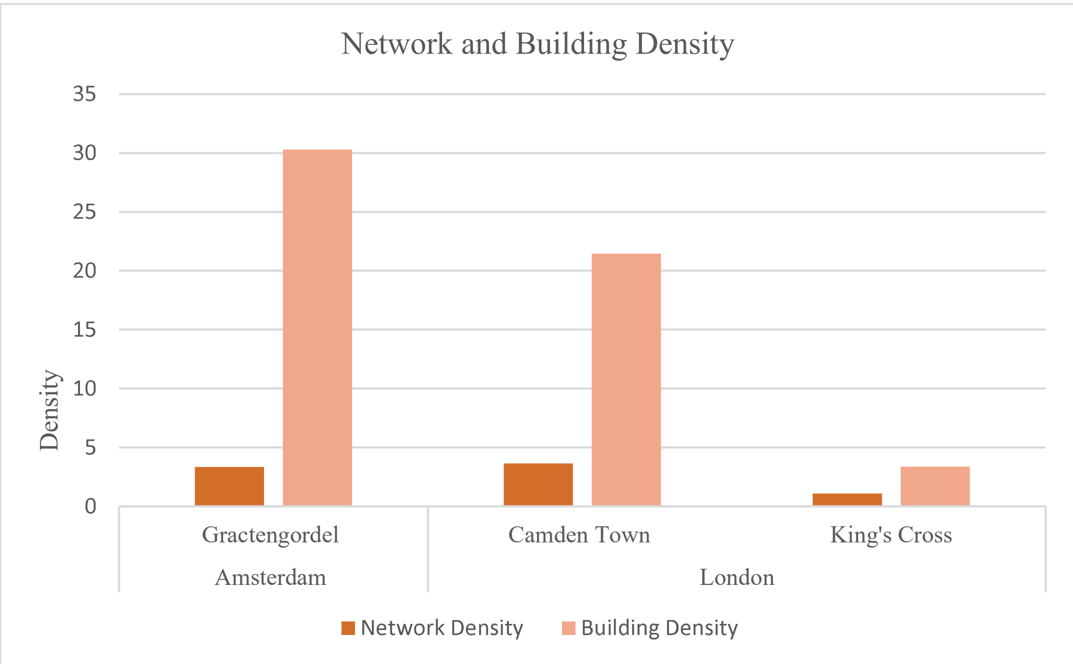


Figure 63. A Comparison of the Building and Population Densities of Grachtengordel, Camden Town, and King's Cross

Table 16. The Comparison of Camden Town and King's Cross Urban Block Area

Descriptive Statistics

	N	Minimum	Maximum	Sum	Mean	Std. Deviation
Camden Town Block Area	28	,048	2,445	18,616	,66486	,520895
King's Cross Block Area	9	,255	31,439	57,290	6,36556	9,727597
Valid N (listwise)	9					

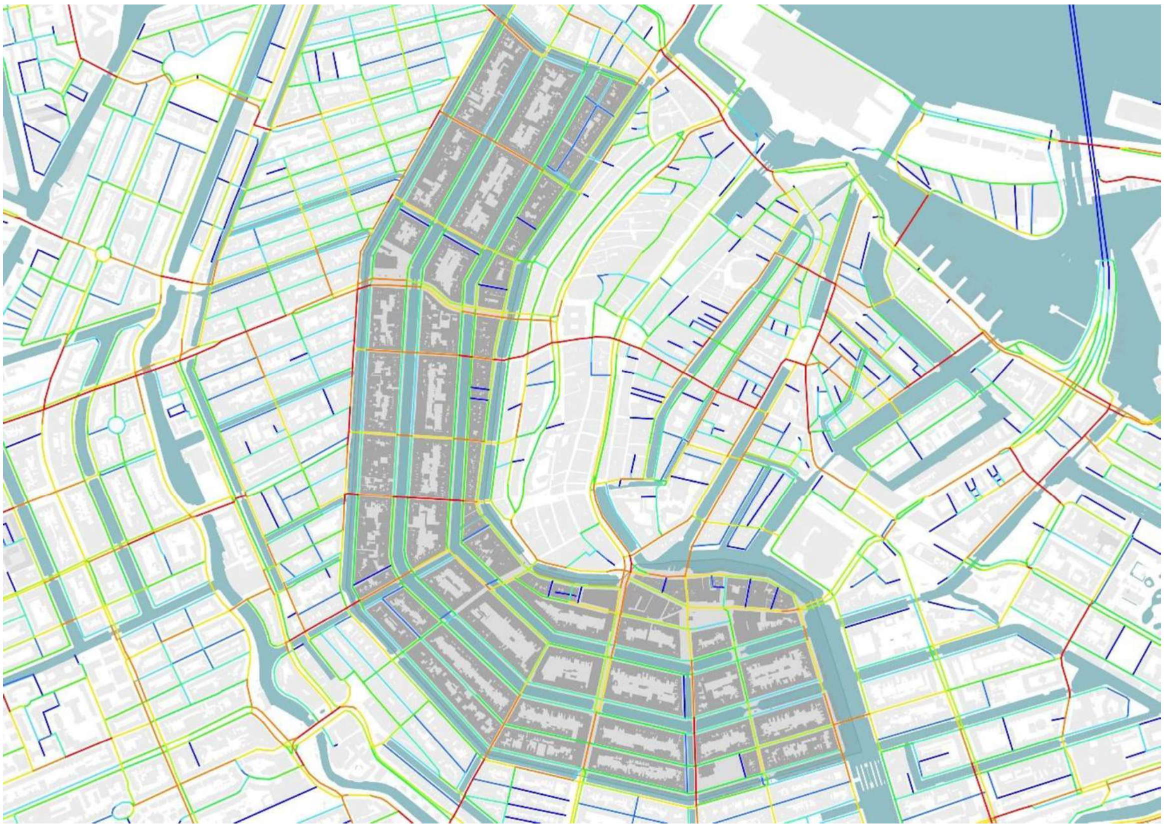


Figure 64. Grachtengordel NACHr800m

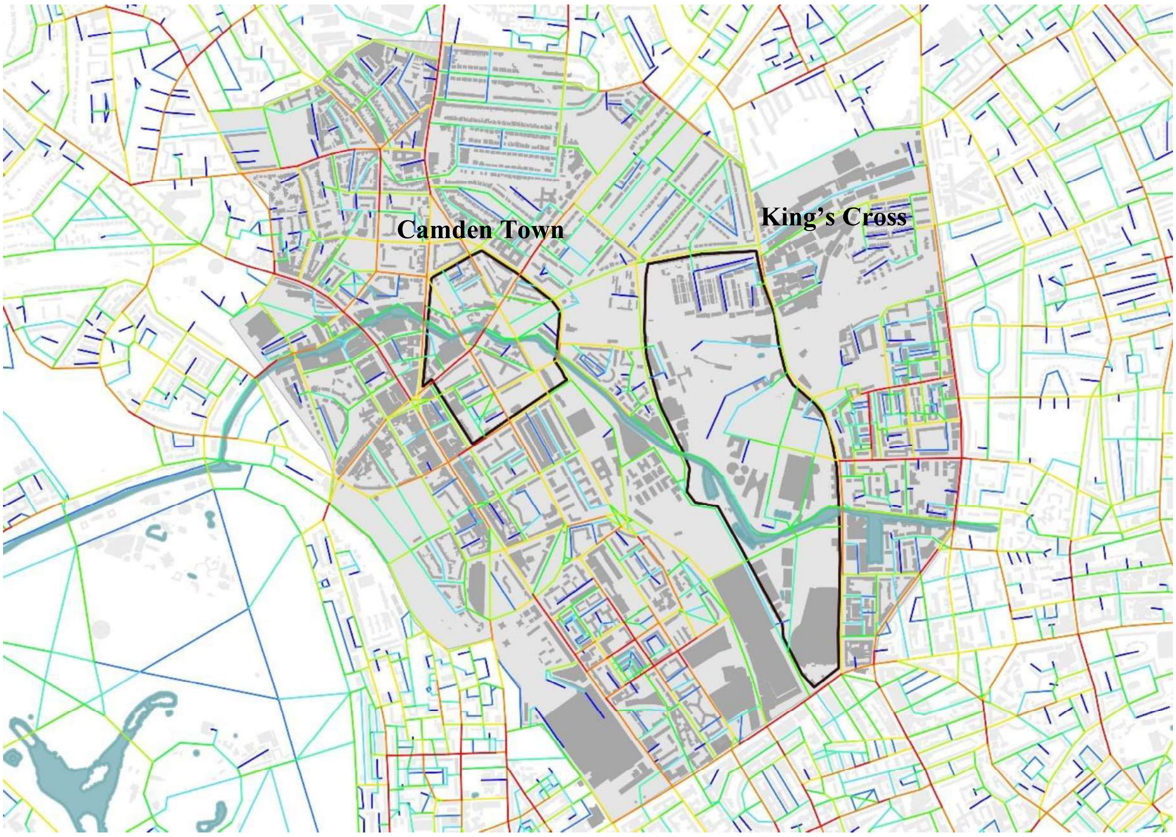


Figure 65. Regent's Canalside NACHr800m

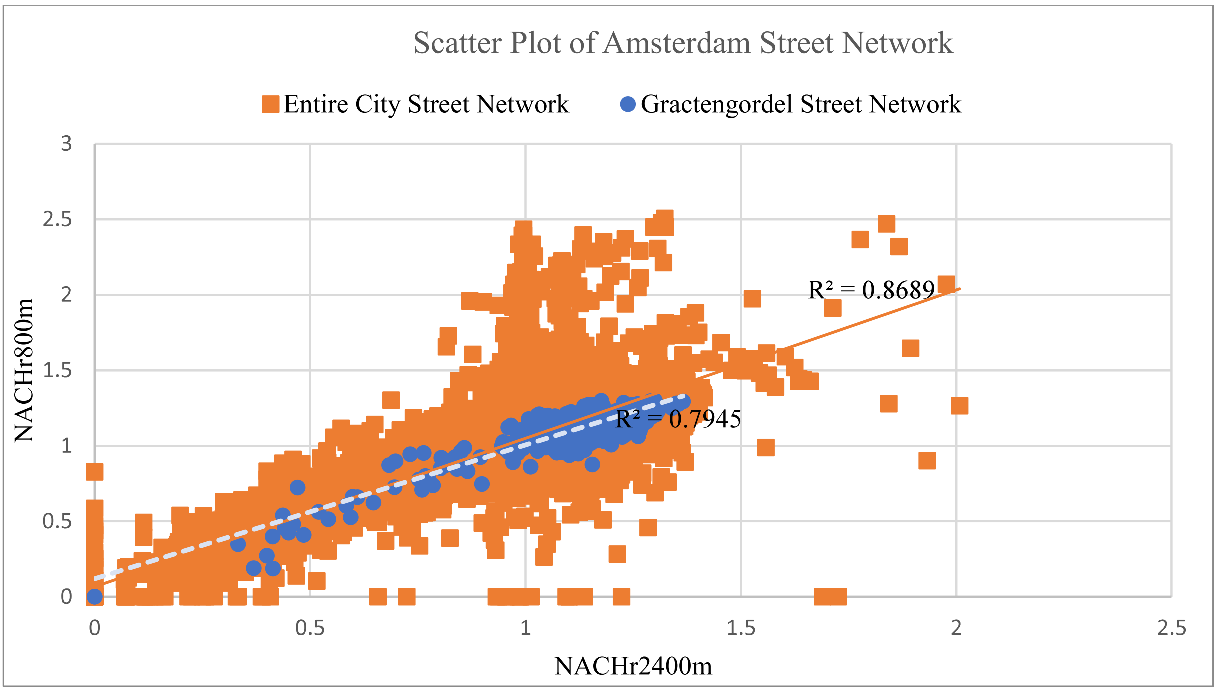


Figure 66. A Comparison of NACH Values of Grachtengordel and Amsterdam's Entire Street Network

Figure 67. A Comparison of NACH Values of Regent's Canalside and London's Entire Street Network

ECONOMIC IMPACT OF CANALS IN LAND USE DISTRIBUTION

The aim of this section is to analyse the influence of the spatial conditions of canalside environments on land use distribution and economic activities. Three main aspects will be examined in this section: land use distribution, retail density and land use diversity. First, the land use distribution can be used to examine the economic activities around canals. Second, the syntactic analysis results of the relationship between street configuration and density of retails can provide for a comparison between Amsterdam's and London's canalside contexts in terms of whether the associated network accessibility is correlated with the economic activities. Finally, the impact of canals on the diversity of land use will be investigated to identify whether the canals have an impact on the mixed-use environments in these cities. Vaughan and Geddes state that a diversity of functions supports an area's long-term economic development and enhances pedestrian movement (Geddes and Vaughan, 2014).

Land Use Distribution

Figure 68. Land-Use Distribution of Non-Residential Functions in Grachtengordel

Figure 69. Land Use Distribution in Regent's Canalside

The land use pattern reveals the interaction between economic and social activity within the built environment. Eleven types of land use have been plotted into GIS according to data from Data.Amsterdam for Amsterdam and Ordnance Survey AdressBase Plus for London, including community services, education, health facilities, industry and businesses, mixed use, recreation and leisure, religion, residential, retail, transport, utilities and infrastructure.

In both case study areas, the residential function dominates the land use distribution. At the same time, the urban forms are supported by non-residential functions in both cities. Figure 70 clearly shows that retail and business functions dominate the non-residential land use distribution in Grachtengordel; by contrast, mixed-use and retails are the most dominant non-residential functions in Regent's Canalside (Figure 70). Most of the retail and transport land uses located on the south side of the canal in London. The retail functions are significantly intensified in Camden Town with smaller urban blocks and high intensity of streets. Hence, Camden Town appears to be more likely to attract movement as well as additional economic activities. The land distribution of King's Cross contains no residential function with large urban blocks and transport infrastructure. The land use distribution pattern shows evidence that the Camden Town area has a better spatial structure to support increased retail density than King's Cross (Figure 74).

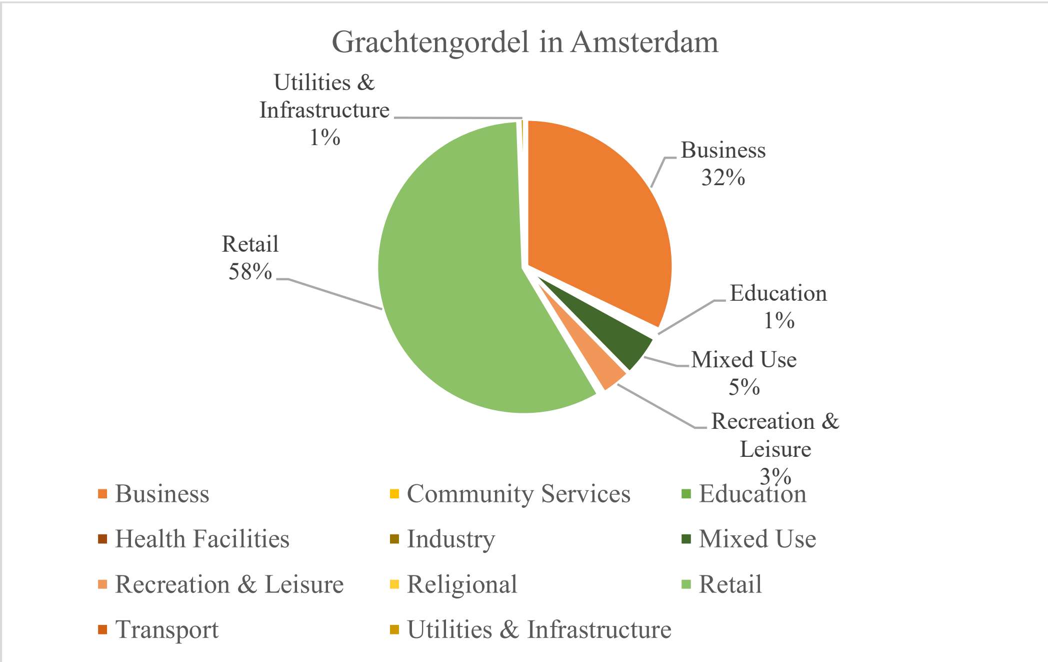


Figure 70. Non-Residential Land Use Pie Chart for Grachtengordel

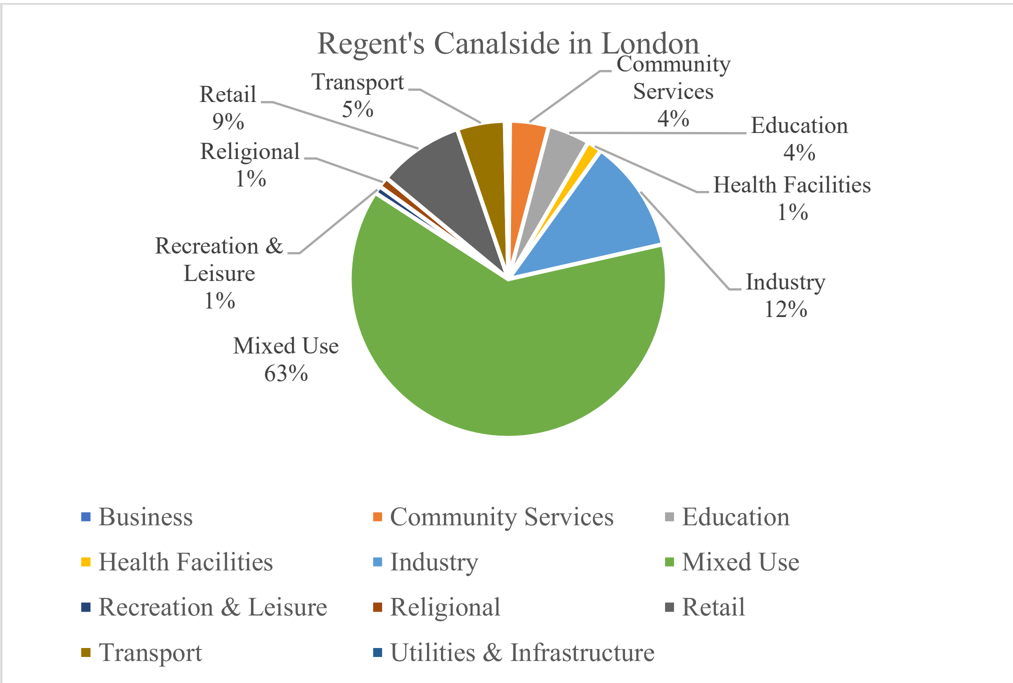
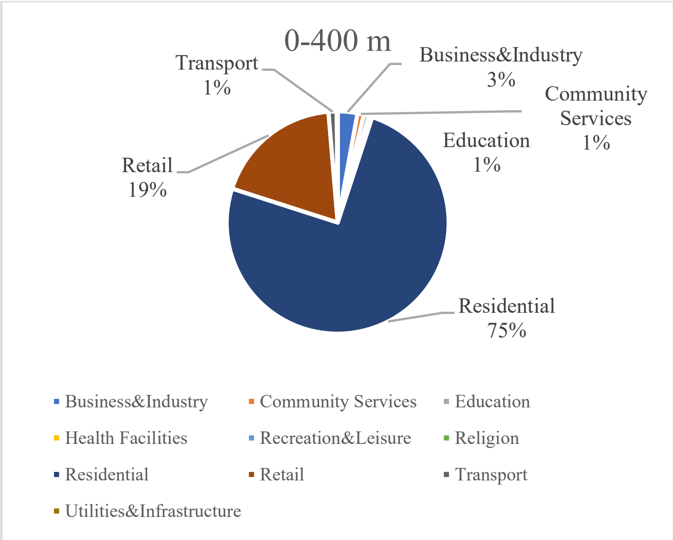
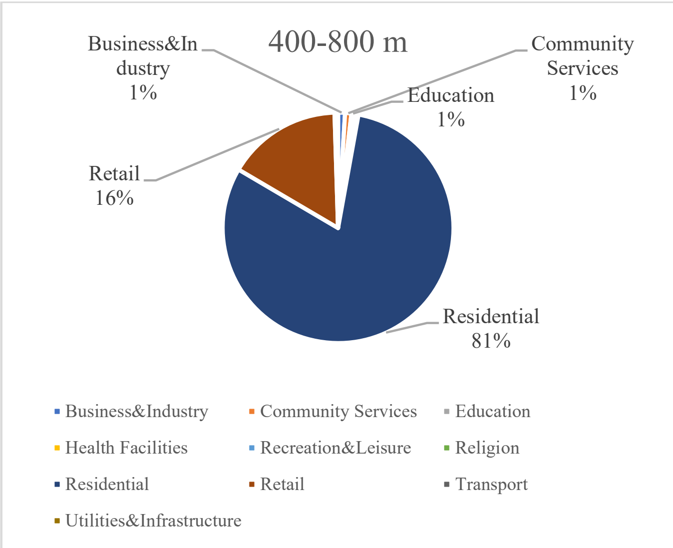


Figure 71. Non-Residential Land Use Pie Chart for Regent's Canalside

The land use distribution analysis with different catchments from the Regent's Canal reveals that the percentage of retail units increases according to proximity to the canals. However, the percentage of residential buildings is lower within the 400 m catchment compared to the 400-1200 m catchment area (Figure 72).

From the results of the land use analysis, the next chapter investigates the retail density of the case study areas to analyse the relationship between street network accessibility and economic activities.





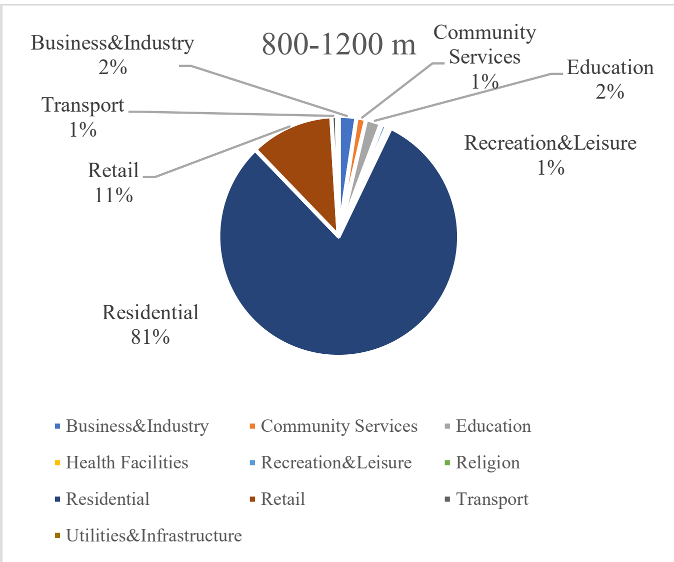


Figure 72. Land Use Pie Chart for Regent's Canalside in Different Catchments

Retail Density

To understand the relationship between street network accessibility and economic activity, the space syntax measures have been applied for the retail distribution variables: total number of retails and retail density based on the Point data of the retails (Figures 73, and 74). The retail distribution is measured according to the number of retails per street segment weighted by length. Statistical analysis has been applied to the space syntax measures to investigate whether the retail variables are statistically significant. Pearson correlation has been used for the analysis of both cities.

There is no significance found in Grachtengordel analysis between spatial configuration and retail distribution (Table 17). The analysis of Regent's Canalside implies a low significance for the influence of potential local movement on retail number and density (Table 18). From the correlation analyses between retail density and space syntax measures across multiple scales, this study does not support the hypothesis that the potential global movement dominates the retail activities. The reason for this could be that the canals and regeneration projects have an impact on the retail distribution; for example, the King's Cross regeneration project has increased the retail count and density.

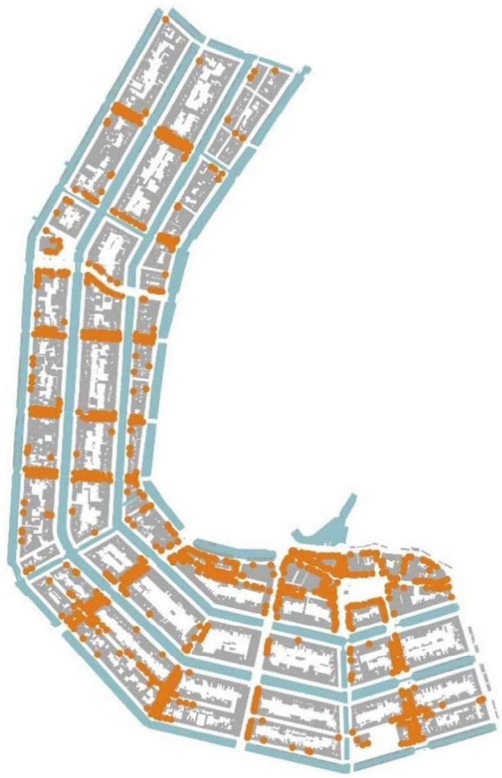


Figure 73. Retail Distribution in Grachtengordel

Figure 74. Retail Distribution in Regent's Canalside

Table 17. Correlations Between Retail Distribution and Space Syntax Measure in Grachtengordel

Correlations

		RetaiDensi	RetaiCoun	NACHr800m	NAINr800m	NACHr2400m	NAINr2400m
RetaiDensi	Pearson Correlation	1	,493**	,074	-,065	-,015	-,134*
	Sig. (2-tailed)		<,001	,160	,215	,774	,011
	N	364	364	364	364	364	364
RetaiCoun	Pearson Correlation	,493**	1	,121*	,078	,033	-,050
	Sig. (2-tailed)	<,001		,021	,140	,534	,338
	N	364	364	364	364	364	364

Table 18. Correlations Between Retail Distribution and Space Syntax Measure in Regent's Canalside

Correlations

		Retail Den	Retail Cou	NACHr800m	NAINr800m	NACHrr2400	NAINr2400m
Retail Den	Pearson Correlation	1	,823**	,032	,198**	,059	,093
	Sig. (2-tailed)		<,001	,588	<,001	,317	,112
	N	292	292	292	292	292	292
Retail Cou	Pearson Correlation	,823**	1	,073	,212**	,117*	,141*
	Sig. (2-tailed)	<,001		,210	<,001	,045	,016
	N	292	292	292	292	292	292

As illustrated in Figure 73, streets running at diagonal to canals have higher retail densities than parallel streets. Lesger and Delaney (2011) examined the pattern of retail locations and urban form in Amsterdam in the mid-eighteenth century, finding that the greatest number of commercial activities took place on or around the old town of Amsterdam - the Dam, in the Amstel. During the city's growth, the retail distribution patterns were shaped by a series of streets oriented with their axes towards the old town (Figure 75) (Lesger and Delaney, 2011). In the case of the contemporary period, the correspondences of empirical data and the results of the statistical analysis of this study clearly show that the highest number of retails was still located on the streets with axes orientated towards the old town of Amsterdam. Hence, the structure of the urban grid affects the actual distribution of retails.

Figure 75. Shopping Streets of Amsterdam in 1742 (Lesger and Delaney, 2011)

Land Use Diversity

An entropy-based measure of diversity is a common comparative approach used in urban studies. The study has adopted Shannon's Diversity Index that can be applied to measure the number of a categorised land use within the defined neighbourhood area. The functional diversity (1) is calculated as follows:

$$H = -\sum_{i=1}^{s} p_i \times ln p_i \quad (1)$$

The comparison of mean values of retail density and functional diversity shows a significant difference between Grachtengordel and Regent's Canalside in terms of functional diversity. The street configuration of Grachtengordel (mean value of HIndex: 0.4790) shows greater diversity than Regent's Canalside (mean value of HIndex: 0.1473).

Table 19. A Comparison of Retail Density and Functional Diversity between Grachtengordel and Regent's Canalside

Paired Samples Test

		Paired Differences							Significance	
					95% Confidence Interval of the Difference					
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	One-Sided p	Two-Sided p
Pair 1	Amsterdam Retail Density - London Retail Density	,018283	,218969	,011477	-,004287	,040853	1,593	363	,056	,112
Pair 2	Amsterdam HIndex - London HIndex	,331610	,632718	,033163	,266393	,396827	9,999	363	<,001	<,001

The statistical analysis of the Grachtengordel street network illustrates a significant difference between streets running at a diagonal and parallel to canals in terms of retail density and functional diversity (Tables 20, and 21). While diagonal streets have higher retail densities than parallel streets, the statistical analysis results show that the functional diversity is considerably higher in parallel streets. Accordingly, the analysis shows no fundamental advantages to canals in terms of retail density, but the canals strongly influence functional efficiency with high diversity as measured by Shannon's diversity index. Furthermore, the canals appear to be more attractive for pedestrians with a high density of mixed land uses along the canal towpaths.

Table 20. A Comparison of Streets Running Diagonal and Parallel to Canals in Grachtengordel

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Diagonal St Retail Density	,10728	144	,117020	,009752
	Parallel St Retail Density	,06998	144	,111039	,009253
Pair 2	Diagonal St HIndex	,41413	144	,363307	,030276
	Parallel St HIndex	,52541	144	,369087	,030757

Table 21. Paired T-Test Values for Streets Running Diagonal and Parallel to Canals in Grachtengordel

Paired Samples Test

		Paired Differences							Significance	
					95% Confidence Interval of the Difference					
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	One-Sided p	Two-Sided p
Pair 1	Diagonal St Retail Density - Parallel St Retail Density	,037299	,157739	,013145	,011315	,063282	2,838	143	,003	,005
Pair 2	Diagonal St HIndex - Parallel St HIndex	-,111285	,520762	,043397	-,197067	-,025503	-2,564	143	,006	,011

6. DISCUSSION

The canals are not located randomly in the entire city structure, nor are they interconnected without any spatial logic. Over this entire research, the spatial network analysis of street and canal structures from the city-wide and neighbourhood scales have been quantified by space syntax measures to compare and contrast two different spatial contexts of canalside settlements in Amsterdam and London.

CITY-WIDE SCALE

The city-wide scale research question of the study was: **What is the main spatial effect of differences in the canal systems over time on the street configurations of London and Amsterdam?** First, the street networks of Amsterdam and London were explored in depth with and without the canals added to the system to trace the impact of canals on the potential movement of the cities. A statistical analysis was performed to investigate the land-based interconnections of waterways in the urban formation of city structures. Secondly, the diachronic analysis of the London network of development are analysed over three periods: the 1850s, the 1950s and the contemporary periods. Hence, the discussion part of the city-wide scale analysis mainly contains the comparison of two cities in terms of their canal networks' impacts on urban mobility and spatial segregation. The degree to which their canal systems are integrated into the street networks over time is discussed.

The analysis calculated within 800 m and 2400 m shows that the old city still maintains the highest local and global integration values in both cities as the street network grows over time. In the case of Amsterdam, the spatial systems with and without canals added to the system show similar integration values. This demonstrates the significant effect of spatial growth of the uniform grid to reveal the embedded properties of the Amsterdam canal structure into the street structure.

On the other hand, the analysis found that the grid in London effectively filled the void between the old towns and the emerging suburban centres. By doing so, the integration of the canal structure changed how the spatial connections start to rise to link city parts. Regent's Canal's impact on the urban grid changes in terms of how the grid is connected with the canal's path. While it creates an obstacle in some parts of the city, the spatial analysis between Camden Town and King's Cross demonstrates that the grid of London is more flexible as it adapts to specific conditions in the city. The difference in the spatial configurations of growth between King's Cross and Camden Town clearly illustrates this difference in London. Distinct local centres like Camden Town become stronger at linking the city parts. Its current spatial structure can be defined as a result of the intertwining between the old city and the emergent suburban growth. While it is an emergent product of a bottom-up spatial growth that can be distinguished as the organic grid of an old Georgian suburb, King's Cross is a part of top-town planning decisions as a need for industrial land in the 1850s and was regenerated after the 2000s. The area appears to be segregated in both local and global space syntax measures; further, the north and south parts of the Regent's Canal in the King's Cross are segregated from each other. Overall, it is evident that Regent's Canal shows different spatial impacts in the different parts of the city in relation to how the street structure is connected to all the city parts and the canal. The subsequent analysis then aimed to analyse the different sections of Regent's Canal in relation to the connective attributes of the spatial structure such as bridges or streets adjacent to canals.

The diachronic analyses of Amsterdam and London illustrate different logic behind the city growth process of these two cities. The space syntax analysis considers the quantitative properties of the cities' structures by taking into account their historical development to understand the spatial evaluation of the existing urban grid and regularities concerning canal structure. There is a final observation worth noting, namely that the integration of Amsterdam spreads from the city core, further suggesting that the city core can be defined as the city's emergent morphology with its regular grid structure designed with the canals. This process allows for the overall successful integration of motorways and waterways into the urban fabric. It can be clearly stated that Amsterdam's grid structure shows that relatively modern parts of the city have the same impact as the old town centre. The success of its regular grid success can be closely associated with the poly-central conurbation and its regularity of its waterways. Turning to the literature review, it was discussed that Amsterdam is already more of a land city compared to Venice and its motorways could be adopted easily (Feddes, 2012; Psarra, 2018). This study adds the analytical analysis of the relationship between waterways and motorways over time via the diachronic spatial analysis, which finds that the city's places have remained accessible both across water and along streets during the city growth process in Amsterdam.

Having discussed how the city-wide scale analysis demonstrated the main spatial difference between Amsterdam's and London's canal structures and canals' spatial impact during the city-growing process, the following section addresses neighbourhood scale analysis results with regard to the spatial distribution of functions in the two case study areas, which are Grachtengordel in Amsterdam and Regent's Canalside in London.

NEIGHBOURHOOD SCALE

This section was dedicated to discussing intrinsic spatial patterns of canal networks in two different urban systems. The impact of canals on the concentration of economic activities and land use distribution are explored in order to consider the particularities of Grachtengordel in Amsterdam and Regent's Canalside in London as neighbourhood scale case studies.

In response to the research question, **"What are the main differences in the spatio-functional effect of the canal structure on the accessibility and functional diversity of the canalside neighbourhoods between London and Amsterdam?"**, the neighbourhood scale research has not only considered the relationship of the canals to the functional diversity, building and network density of the cities but also highlighted the differences in land use distribution between different spatial configurations of Amsterdam and London. No significant correlation was found between retail distribution and integration and choice measures in both cities. To answer the other broad question, **"Does the retail density follow the high potential movement pattern?"** the answer would appear to be "no" for the canalside context because from the analysis, which shows functional distribution has differing and distinctive spatial patterns at waterfront settlements. By careful considerations of both cities' spatial configurations, some comparable features were detected, not in their integration and choice measures, but in the geometric relationship between canal and street structure.

While Regent's Canal has a linear structure within the spatial configuration, the canals of Amsterdam appear in a regular grid spatial system with cells, defining the local areas with streets that are oriented diagonal and parallel to the canals. Hence, through the case study of Grachtengordel in Amsterdam, the spatial properties of the urban structure were investigated with the geometric relationship with regard to distribution of functions. The distinctive diagonal streets to the uniform grid of canals were found to play an important role in the concentration of retails in Grachtengordel. They receive high commercial activities passing through them compared to streets running parallel to canals. On the other hand, lines running parallel to the canal network play an important role in terms of diversity of land use. When the results of the analysis are compared to Lesger and Delaney's (2011) spatio-historical analysis on the retail distribution of mid-18th century Amsterdam, which is explained in the Neighbourhood Scale Analysis section, the spatial distribution of retail units has still been oriented to the old town. On the other hand, the spatial patterns of land uses were investigated in near proximity to canals in the London context. Studying land use types within the close proximity to the canal (0-400 m) was allowed the identification of larger number of retails in comparison to other parts of the case study area. The percentage of retail units increases the nearer one comes to the canal.

As another spatial parameter, the sizes of the blocks do not vary within Grachtengordel. In the case of Regent's Canalside, there is a significant difference between the mean and max values of the block areas between Camden Town and King's Cross. On the one hand, the network density of Camden Town is significantly higher than King's Cross, with low street segment lengths and small blocks. On the other hand, both the foreground and background analysis illustrate a distinctive network of continuous lines representing a high potential for movement with an organic arrangement characteristic of Camden Town.

To summarise, the spatial distribution of functions in each city differs from the other in the case of Amsterdam and London. This logical difference in the spatio-functional urban context in relation to canals was attributed to the distinctive difference between Amsterdam's planned regular grid structure and the less-planned London, the latter growing from the centre while absorbing various villages and suburbs. Following the literature review, which discussed the comparison of London and Amsterdam, the two cities are configurationally different and come up with similar pattern with certain commonalities (Berghauser Pont et al., 2019). Hillier and Vaughan (2007) suggest that cities are created by a dual process. On the one hand, streets order space to optimise the reach of space and maximise movement and co-presence. This is referred to as a public space process whose intention is one of bringing people together; on the other, the residential space process structures movement in the residential culture and seeks to form relations between inhabitants and strangers (Hillier and Vaughan, 2007). This study suggests that Amsterdam and London exploit the relation between space and movement in a different way by analysing the impact of the canal structure on the potential movement of cities. The canal structure can be evaluated according to the public space process, which is driven by the micro-economic factors inherent to each of the cities. The canal process gives rise to the global structure of the city.

7. CONCLUSION

This study has addressed a series of research questions centred on the relationship between urban morphology and canal systems. The conclusion will summarise the study by emphasising the importance of analytical methods based on space syntax in terms of indicate several indicators for improving the embeddedness of canal systems in cities. The use of objective methods can enable us to provide design guidelines to minimise severance and generate options for redesigning existing infrastructure. It is crucial to determine the barrier effect of waterways on mobility and accessibility is the initial manifestation of a complex chain of community severance in cities.

Canals are planned as a transportation network that can enhance mobility for wide-scale movement, and old canalside industrial lands can bring the opportunity to enhance functional diversity and local development within the city environment. The aim of this research is to raise awareness of the relationship between the canal network and its surrounding environment.

The first research question was concerned with the spatio-configurational growth of different urban systems and their canal integration over time. The city-wide scale research has given a broad overview of the main spatial effect of the canal systems over time on the street configuration of both London and Amsterdam, which have different urban growing systems and, thus, different levels of canal integration with the street network. According to the above, the spatial growths of Amsterdam and London have had different impacts on the relationship between canal and street structure. Amsterdam has been shown to constitute an intermediate spatial structure between land- and water-based transportation networks. Places are both accessible by canals and streets in Amsterdam, the reason for which could be Amsterdam's long history of top-down urban policy that has remained centred on the canal network, in which mobility systems have emerged to create opportunities for the integration between streets and canals.

On the other hand, London has had a dominant land-based spatial structure in terms of movement. In the case of London, the planned processes such as King's Cross were historically used for industrial land and were spatially segregated. In contrast, the organic city and the emergent city centres like Camden Town are more generative of canal integration with smaller urban blocks and high street network densities.

The neighbourhood-scale research has investigated the main spatio-functional effect of the canal structure on the accessibility and functional diversity of the canalside neighbourhoods in both London and Amsterdam. The main findings of the research are that the geometric relationship between street and canal networks seemed to be a factor in the spatial distribution of functions in Amsterdam. On the other hand, the distribution of functions changes according to proximity to Regent's Canal in London. The residential functions are proportionately higher within the small catchment area.

From the comparative spatial analysis, this research suggests several criteria that might allow for better embeddedness of canals within the neighbourhoods and canalside area of the city, including:

- High connectivity and accessibility to both local and global network
- A high density of the street network
- Small urban blocks
- A proper geometric relationship between canals and streets in canalside neighbourhoods

These research processes and results affect how the canal systems in contemporary cities could work on a variety of scales. The canalside neighbourhoods that sit in the area that have high network accessibility could possibly ensure the successful optimisation of both local and global urban developments.

For future study, there are a few potentially interesting directions that could evolve from this study. First, new cities could be added to spatial patterns and urban grids across more global urban cities. Venice and Brugge could act as good examples. Secondly, the comparative analysis between different canalside neighbourhoods within a given city would represent a different approach. Hence, the case study area in London and Amsterdam could be extended to compare different sections of Regent's Canal or different canalside neighbourhoods in Amsterdam. This direction would allow us to investigate the different spatial conditions and spatial factors of the impacts of canals within a given city.

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