361

Spatio-Historical Impact of Urban Canals on the Street Configuration of Cities

Diachronic Analysis of Amsterdam and London

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ABSTRACT

Constructed waterways have played a major transportation role since the earliest days of cities' recorded history, connecting cities and enhancing commerce. There does seem a possibility that canal networks are associated with the growth of the world's first cities and their spatial structure. Therefore, the aim of the study is to investigate the canal structure in shaping the urban form through the city-growing process and its spatio-cultural outcomes in the city environment. It intends to perform a comparative analysis of Amsterdam and London, two diverse structures within their urban configurations and represent a different paradigm of the canal-street structure relationship. The study analyses the main spatial effect of differences in the canal structure overtime on the street configurations of the two cities. Diachronic spatial analysis has been undertaken for three periods for both cities: the 1850s, the 1950s, and the contemporary period. The study uses space syntax techniques as the main methodology; further, the spatial analysis results are geographically projected in GIS, and the statistical analysis is performed on the analysis results of historical maps to measure the physical effects of canal systems on the potential mobility in both cities. The Amsterdam and London analysis results show different examples in terms of street interconnections with canals in the formation of urban structures. While the urban form has been shaped with a top-down planning process in the form of a regular grid structure designed with canals in Amsterdam, the urban form of London is a dominant land-based spatial structure with regard to its movement potentials. Hence, Amsterdam shows an intermediate spatial structure between water- and land-based networks. On the other hand, places are locally and globally more accessible with land-based transportation systems in London.

KEYWORDS

Urban Waterways, Canal Structure, Spatial Configuration, Urban Form, Diachronic Analysis

1 INTRODUCTION

Cities with waterways have played a significant role in worldwide international trade throughout history, and their open and dynamic nature has given an environment for people from diverse locations and countries to come together. As a result, the ports, industrial zones, and city centres were consistently linked together. However, changing conditions, particularly the growth of highways and railways, have diminished the relationship between the centre and its waterfronts. The alarming consequences of modern urban planning on urban waterways and watersides are becoming increasingly recognised across a wide range of disciplines. The waterway and waterside research in urban studies mainly investigates rivers, seaports, canals, estuaries etc. and their waterfront transformations. In that context, this study focuses on the inner-urban canals and the change of canal-city structure relationships over time.

In the last decade, many intra-city canals and canalside areas in Europe have been mainly studied in terms of hydrology and water management (Disco, 2017), ecology (Biscaya and Elkadi, 2021), landscape, conservation and regeneration (Edwards, 2009; King's Cross, 2020; Cabau, Hernandez-Lamas and Woltjer, 2021), tourism (Pinkster and Boterman, 2017), historical background of canals (Essex-Lopresti, 1998; Nijman, 2020), culture and social life (Vallerani and Visentin, 2017; Wallace and Wright, 2021) and urban form (Čakarić, 2010; Hillier, 2014; Psarra, 2018) to understand canals' role in city life and to create more sustainable water systems and canalside settlements in contemporary cities. Ecosystem approaches examine the city's ecosystem provisioning, regularity, cultural and supporting functions in order to manage the natural environment, promote culturally valued benefits, and keep the water ecosystem in cities healthy and functional (Biscaya and Elkadi, 2021). Furthermore, the decrease in the functionality of waterfront industrial areas along canals has created new chances for regeneration initiatives, and numerous studies have looked at how canal restoration and conservation projects affect the evolving urban landscape (Edwards, 2009; Hunter, 2019; Cabau, Hernandez-Lamas and Woltjer, 2021). On the other hand, the studies of the investigation of canals in urban morphology explore the structural interfaces between canal and city structures and reveal that the existence of water in a city, whether linear or non-linear, influences the form of the relevant city, or more accurately, the recognised geometric look of the physical structure. In this manner, it lends a particular urban identity by combining multiple representations of individual and collective morphological components into a synthesis as an urban landscape with the presence of a kind of water (Čakarić, 2010). Historical studies on urban canals mainly describe the background of canal development, include an extension of the introduction, and include illustrations serving to ground the speculative aspects of case studies by historical materials (Essex-Lopresti, 1998; Nijman, 2020).

First and foremost, the role of canals in the past was travelling, but arguably, they have also been significant infrastructure supporting the ecology and spatial systems of their host cities, helping to sustain their socio-economic lives. Canals have therefore been described as critical for their transformations of urban space, and social life. However, there is a paucity of spatio-historical analysis of canal structure in relation to configurational growth process of cities. This study aims to close that gap by focusing on the spatial impact of canals over time and how canal systems affect the city's street pattern in different periods. It aims to broaden the understanding of the city-waterway relationship by performing a diachronic analysis of the impact of canal networks on the city structures over three centuries: the 1850s, 1950s, the contemporary. Canals may be considered as barriers to spatial accessibility. At the same time, they may contribute to the organisational framework of urban form, which does not create physical segregation but rather improves cities' mobility and socio-economic performance. This study will examine whether canal structure contributes to the spatial accessibility of street configuration and how the integration of canal systems into the street network has changed over time in different spatial systems: Amsterdam and London.

Amsterdam and London were chosen in this study because their urban grids contain two distinct structures, each representing a different paradigm of the city-canal relationship. A bottom-up emergent urban fabric can be found in London. On the other hand, Amsterdam has a more top-down planning process in the form of a grid with waterways. Both cities have planned urban systems, but their canal networks have been integrated into their street networks to varying degrees. London has grown organically from its original city centre to include many villages. It is defined as a collection of urban villages that serve as hubs for locally deformed wheels and have strong centre-to-edge connections (Hillier and Vaughan, 2007). Amsterdam is a semi-planned city with a dispersed polycentric character (Berghauser Pont *et al.*, 2019). The canal system was a later addition to London’s already existing urban layout (Essex-Lopresti, 1998), whereas the city structure of Amsterdam was designed to include its canals (Feddes, 2012). This research aims to determine the canal structure’s role in shaping urban form during the city growing process and its consequential impact on shaping the configuration of the street network. It raises the question of whether canal networks divide the city into units that can be turned into segregated urban spaces. It intends to conduct a comparative analysis of urban configuration and measure the physical effects of canals on people’s potential mobility and accessibility over three centuries: the 1850s, the 1950s and contemporary. The main research question of the study is *“what is the main spatial effect of canal systems over time on street configurations in Amsterdam and London, which do have different urban growing systems, and thus, various levels of canal integration with the street structure?”*

This research attempts to deconstruct the long-term morphological implications of the growth of canal and street structures in Amsterdam and London. First, the space syntax method was performed on a city-wide scale to examine different spatial configurations of three periods, the 1850s, 1950s and present, and how the canal structure has morphologically transformed those two modern cities. Then, the space syntax analysis results were geographically projected in GIS, and the statistical analysis was performed to measure the physical effects of canal systems on the potential mobility in both cities. As the street network grows over time, the space syntax measures calculated within 800 m (local integration) and 2400 m (global integration) show that the old city still has the highest local and global integration values in both cities. The spatial structures with and without canals added to the system in Amsterdam have roughly comparable space syntax integration values. This highlights the significance of uniform grid structure in revealing the embedded properties of the Amsterdam canal structure into the street network. The street configuration of London, on the contrary, effectively filled the voids between the old towns and emerging suburban centres. According to the space syntax analysis results, the canal structure's integration altered how spatial connections emerged to connect city parts. For example, the impact of the Regent's Canal on the street network varies depending on how the network is connected to the canal's path. While it can hinder the accessibility between banks of the canal, on the contrary, the canal structure can be well integrated into the city network in some sections of the canal. The spatial analysis between King's Cross and Camden Town clearly shows this difference that London's street structure is more adaptable as it adapts to changing conditions. In conclusion, the results also demonstrate that space syntax is an effective analytical methodology to model the configuration itself with syntactic data of cities and explore distinct stages in the evolution of urban forms.

2 THEORETICAL BACKGROUND

The theoretical background of the study is organised according to three headline topics. Three areas of literature are reviewed: first, studies about space syntax in historical research and syntactic growth processes; second, earlier studies on canals, urban form and space syntax; third, the comparison of Amsterdam and London in terms of urban form and canal structure.

2.1 Space Syntax in Historical Research: The Diachronic Model of City Growth

Traditionally, the discipline of space syntax proposes that study of urban systems allows the researcher to obtain a specific architectural knowledge of spatial configuration, which allows comparative analysis of structures across space and time. Given its disciplinary origins in architectural and urban research. Griffiths (2012) explores what kind of history space syntax does and how it could contribute to historical research in architecture and urban studies. Four approaches to spatial history were described in his research: first, history as background primarily provides historical material in order to introduce the locations of a specific case study; second, history as syntactic growth processes contributes more about urban growth processes;

third, syntactic morphological histories bring the social context of architectural and urban form to the foreground, typically with the primary goal of comprehending the contemporary built environment; fourthly, Baker's category of spatial histories (Baker, 2003 in Griffiths, 2012) is explained to characterise historical researches concerned with how social phenomena organise and become organised in time and space. This extends beyond morphological investigation to explain particular socio-economic phenomena (Griffiths, 2012).

Providing some historical background to a case study is generally described as a good research practice, and many space syntax studies do this. Background, in most cases, is a continuation of the introduction with illustrations that assist in grounding the analytical or speculative components of a case study that is particularly useful to the reader in creating a critical perspective on the main research subject (Griffiths, 2012). On the other hand, the studies on the urban growth process of different cities might relate to not the only historical analysis of their urban forms but also the scaling qualities of their urban structures. The studies on scaling qualities of urban form mainly reveal a structural signature of diachronic processes (Carvalho and Penn, 2004; Wagner, 2007). In identifying generic syntactic rules of urban growth, Shpuza (2009) uses syntactic variables of historical city models, such as connectivity, integration, line length, to explore Adriatic cities' morphogenetic growth patterns and evolution of street networks. The analysis mainly reveals continuous patterns in the evolution of street networks in the Adriatic and Ionian regions. All case study areas grow less connected and more differentiated as street layouts evolve from mediaeval organic forms to gridirons, biased grids, and distorted grids, except for two cities established on islands (Shpuza, 2009). As Griffiths (2012) emphasised, Shpuza's work has a potential bridge between quantitative approaches and more traditional urban history studies to explore generic rules of the street network evolution with diachronic models of city growth.

Al Sayed, Turner and Hanna (2009) uses segment angular analysis to discover generic bottom-up syntactic rules of urban growth based on a detailed longitudinal analysis of Barcelona and Manhattan. The study attempts to outline the generative rules that govern the emergence of urban spaces and detect the evolution of growth patterns of different urban structures. The syntactic analysis results show that both cities can be described as emergent products of bottom-up organic growth, especially noticeable in the early settlements. Despite the imposition of a uniform grid on both cities during their growth, it is stated that they managed to distort the regularity in the pre-planned grid in an emergent manner to result in an efficient model reflected in their current spatial layout (AlSayed, Turner and Hanna, 2009). Griffiths (2009) draws on a historical analysis of the growth of the English industrial city of Sheffield (1770-1905) and applies a variety of approaches, including space syntax and fractal geometry, to the problem of diachronic representation of spatial structures, which are often considered in solely synchronic terms. The study questions how far the spatial arrangement of the city's rural hinterland was entangled in the process of social change and continuity that unfolded through this period. The main emphasis of the study is on bringing the theoretical and analytical aspects of the Sheffield case study to argue that whether the growing city can legitimately be shown to have absorbed its rural hinterland, then this process of urban transformation can also be characterised with the continuity of pre-urban road networks embedded in local topography (Griffiths, 2009).

Most of these studies use historical cartography as a basis for their urban growth models. However, the modelling of the configurational object itself remains the primary focus of the historical analysis. This type of research usually has a significant quantitative component as well as a historical component that usually consists of a diachronically calibrated comparison of different periods in the evolution of city structures. They are valuable resources for urban historians who intend to learn the urban form's emergent aspects embedded in historical maps.

2.2 The Generic City and Canal Structure

Hillier’s generic city concept illustrates how the city network connects buildings in a dual system of two interrelated sub-networks, each with its own set of metric and geometric attributes. These are the foreground network, which is made up of connected centres and is driven by microeconomic activity, and the background network, which is made up of a city’s residential background and structures the movement in the image of cultural activities through mainly residential spaces. The term generic city can be traced back to the earliest settlements (Hillier, 2002, 2007, 2016). Wittfogel’s theory focuses on the origins of the city as a social system rather than a physical and spatial object, the sources of hierarchical social structures in cities that might be found in water bureaucracies. They allowed for greater concentrations of people in terms of food and production (Wittfogel, 1957). Uruk was acknowledged as the first and largest city in history that demonstrates clear evidence of urban structure and the establishment of a network of movement space with a well-developed system of trade and exchange. Canal systems began to appear in the growing settlements in Uruk (Algaze, 2001, 2005 in Hillier, 2016). Recknagel also describes Uruk’s canal system as the city’s primary urban structure. Streets existed at various levels, but the primary and secondary canal systems appear to be more critical for the city’s main movement, the leading transportation network for supplying goods and materials (Recknagel, 2002 in Hillier, 2016). According to Hillier (2016), this resulted in an increase in the scale of settlement that can be described as a “city” in the instance of Uruk. What is being characterised in canal structure appears to be a foreground network linked to microeconomic activity, with streets creating the socio-cultural activities as a residential background network. There does seem a strong possibility that the canal networks formed part of the generic city concept’s dual grid system. In that case, an emergent dual grid system becoming a recognised canal structure would be a clear example of the common processes (Hillier, 2016). Psarra (2014) viewed Venice’s street and canal structures as configurational systems. In the analysis of street networks with and without the canals, the syntactic comparison shows that Venice has a lower mean normalised choice value in street networks without the canal network added to the system. The result illustrates that street segments are less likely to pass through the shortest routes from all spaces to all other spaces across the entire network without canals. The canals have significantly high choice values when they are introduced to the system (Psarra, 2014). Figure 1 illustrates the space syntax analysis of Venice with and without canal added to the entire system. According to this analysis, Hillier (2016) emphasises that with the addition of canals to the system, the maximum and mean values of the city's network become nearly normalised, which demonstrate that the foreground network does more than a regular structure for Venice (Figure 1) (Hillier, 2016).

Figure 1: Space Syntax Angular Segment Analysis of Venice without (left) and with (right) canals (Source: Hillier, B. (2016) 'What are cities for? And how does this relate to their spatial form?', Journal of Space Syntax, 6(2), pp. 199–212.)

Amsterdam is frequently compared to Venice to be a mercantile city in Europe. Even though they are similar in that they both consist of an array of islands connected by bridges over canals, they are remarkably different, and this difference can be traced back to their origins (Feddes, 2012). Venice originated as a series of natural islands in the water that were eventually connected. On the other hand, Amsterdam cannot be classified as a natural water city. The canals and islands were man-made structures, and their forms resulted from the city-building process. Feddes (2012) explained that Amsterdam land-based transportation enabled the adaptation of railways and motorways easily. In that manner, London's canal structure was added o the existing street structure compared to Amsterdam and Venice.

2.3 Street Structure of Amsterdam and London

Amsterdam and London share some historical and social parallels; however, they differ in terms of how their city structures have grown over time. Berghauser Pont *et al.* (2019) employ a comparative analysis of five European cities: Amsterdam, London, Stockholm, Gothenburg, and Eskilstuna, to address the quantitative description of the three critical elements of urban form that is streets, plots, and buildings. In this analysis, Berghauser Pont *et al.* (2019) highlight the similarities between Amsterdam and London in that they exhibit a continuous urban grading, particularly urban density. The densest and most compact building types are found in the centre and the spacious low-rise types are found in the second zone and along the main arteries. The street type analysis in the study yielded five street types: first is *background streets*, namely street segments with low choice values; the second type is called *metropolitan streets*, representing street segments with increasing choice values at higher scales (these can also be defined as highway networks); the third type is described as *neighbourhood streets*, which show high choice values at the local scale; the fourth type is called *city streets*, comprising street segments with high choice values at the global scales, which is closest to foreground network of the generic city concept; finally fifth, *dead-end streets*, represents the street segments with zero choice value at all scales. Amsterdam and London share some similarities in terms of street network analysis as having more foreground networks and fewer dead-end streets (Berghauser Pont *et al.*, 2019).

Comparing building types between Amsterdam and London structure reveals that the most prominent resemblance is the prevalence of compact low-rise and mid-rise building types in both cities, although there is also significant variation between the two within these broad definitions. For example, London contains a compact high-rise building type with a high density of tall buildings, which Amsterdam does not. This type can only be found in Canary Wharf in London, which is a planned financial district in relatively spatially segregated peninsula to the east of the city. Another distinction between Amsterdam and London is the spatial distribution of building types in the city centres. The most dominant building type in London's city centre is the mid-rise building type, but the low-rise type predominates in Amsterdam's city centre (Berghauser Pont *et al.*, 2019). In terms of plot types, Amsterdam and London have a significant percentage of compact and fine-grain plots in common. The smallest and most compact plots predominate in Amsterdam's city core, while all other plot types are dispersed across the city structure in London. This is interpreted as a result of many villages being found during the city-growing process (Berghauser Pont *et al.*, 2019). The villages of London are described as hubs of locally deformed wheels. The deformed wheels are a manner of combating the tendency for urban centres to become isolated as the city grows around them by interconnecting them to the city edges (Hillier and Vaughan, 2007).

3 DATASETS AND METHODS

Space syntax is the primary method of the study to analyse the spatial impact of canal structure on the street network over time. The case study area comprises a circular spatial model of 5 km around a focal point within the canal networks of each of the two cities (taking a 2.5 km contextual area + a 2.5km buffer to eliminate edge effects). The research entailed drawing three spatial models for each city, each of which depicts the evolution of the city-canal structure during the 1850s, 1950s and contemporary periods (2021). The contemporary period street network model of Amsterdam (Berghauser Pont *et al.*, 2017) and London is drawn from the road centre line maps based on NWB (Nationaal Wegenbestand) for Amsterdam and the OS MasterMap ITN

(Ordnance Survey Integrated Transport Network) for London. Historical maps were created using the contemporary period spatial models by cartographic drawing, which is a method for manually drawing a vector layer of street network based on a historical raster map. This method enables creating and comparing the street network of multiple periods (Pinho and Oliveira, 2009; Dhanani, 2016). The datasets and resources are explained in Table 1.

Table 1: Research Datasets

Datasets	Sources	
	Amsterdam	London
Road Centre Line Map	Nationaal Wegenbestand Data Credit: (Berghauser Pont *et al.*, 2017)	OS MasterMap
Historical Map	Topotijdreis.nl	Digimap

The historical street network of the two cities was cartographically built by eliminating streets that did not exist in the road centre line map of the relevant period. The Space Syntax Toolkit in QGIS was used for configuration analysis of the street networks. *Angular Segment Analyses* were performed, and the measurements for integration and choice for different metric radii were applied as 2400 m for the global scale and 800 m for the local scale. *The Angular Segment Analysis Integration Measure* is a distance measurement that estimates how close the origin space to all other spaces based on the total number of angle changes made on each route and predicts how easy it is to get around (Hillier and Iida, 2005). It predicts the likelihood that each segment within a metric radius would reach the intended destination. When measuring all the shortest angle pathways in the street network from origins to destinations, it is used to forecast to-movement potentials. Therefore, the integration measure of each period in the diachronic model may disclose the accessibility depth of the street network and canal paths of the three periods. *The Angular Segment Analysis Choice (Betweenness) Measure* calculates the potential that a street segment passes through all the shortest paths to all other spaces through the complete urban network. The shortest path through the system is the pathway with the least angular deviation (i.e., the straightest route). It is a predictor of a segment's through-movement potential. The normalisation of the angular segment analysis integration and choice was introduced as new advancements on angular analysis to compare spatial systems of different sizes (Hillier and Iida, 2005). The reason for the normalisation of choice and integration is not the same as emphasised by Hillier and Iida (2005). The properties of the network calculated by variable radius integration can potentially be predicted to draw more movement to some destinations than others simply due to the network's topology, which is precisely what is seen in urban reality. However, the network's influence does not end there since there will be network effects on through-movement that are more visible than those on to-movement (Hillier and Iida, 2005). The main goal of the research is to calculate both normalised angular segment integration and choice measures to investigate the configurational growth of each city quantitatively and thereby to compare periods and cities that are spatial systems of different sizes.

The values of all segments were reflected on the scatter plot to explore where and when change has occurred in cities. Also, statistical analysis of change is performed to analyse the analysis results of periods in cities. The overall spatial description of two cities at present, with and without canals, is illustrated by a *star model*. The star model is a technique for comparing cities with regard to normalised angular integration and normalised angular choice at the same time to see what variables represent in urban spatial organisation. While the mean and maximum normalised integration values demonstrate the ease of accessibility in the foreground (max) and background (mean) networks, the mean and maximum normalised choice values reveal the systems degree of structure. The mean normalised choice value indicates the degree to which the background network is a continuous grid with direct connections, whereas the maximum normalised choice value indexes the degree to which the foreground network forms the system by interruptions and distortions of the grid (Hillier *et al.*, 2012).

4 THE DIACHRONIC ANALYSIS OF CITY GROWTH: AMSTERDAM AND LONDON

The diachronic model of the two case's growth is intended to examine the evolution of urban spaces and identify the generative laws of the evolving street structure in this study. This section aims to explore embedded logic underlying Amsterdam and London city growing process and provide measurable spatial growth knowledge.

4.1 Amsterdam

By the late 1800s, Amsterdam had become a collection of islands encircling a compact city surrounded by fortifications. The city can be classified as a compact urban fabric perforated by the canals. Figure 2 shows the quarters of Amsterdam. The grid structure of Amsterdam in the 1850s has two different urban structures: the first, which dates back to the Middle Ages and is today known as De Wallen, Burgwallen Nieuwe and Nieuwmarkt, can be classified as an organic grid; the second is a regular grid structure of planning decisions, which are Grachtengordel and Jordaan.

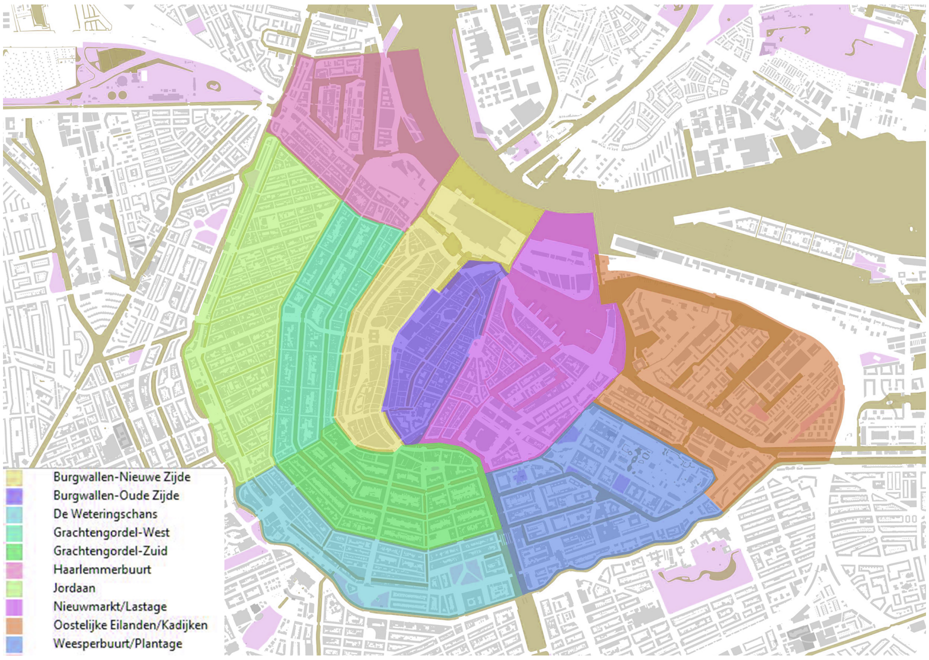

Figure 2: Quarters of Amsterdam

Analysing the city's three periods as a configurational system indicates that it appears to emerge into a grid-based foreground network. By the 1950s, after the fortification was removed, NACHr2400 analysis illustrates that the canal network follows the city's foreground network (Figure 3).

Figure 3: Angular Segment Integration Analysis of Amsterdam

The angular segment integration analysis shows that the mean NAIN values for 800- and 2400-meter radius declined steadily during the city growing process (Figure 4). The mean values of NACHr800m and NAINr800m did not change significantly between the 1850s and the contemporary period. However, the maximum value of NACHr2400 increased from 1.45 to 2.00, and the maximum value of NAINr2400m increased from 1.31 to 4.42. As illustrated in Figure 3, these findings show that, whereas accessibility in the background network has remained constant, it has on average increased in the foreground network during the city-growing process. Hillier (2016) refers to the foreground network as "the city-making process" in which a pervasive network connects centres at all scales and maximise movement. As a result, the rise in the dominance of the foreground network in the city growing process can be seen as the outcome of decisions undertaken to maximise potential movement and – through this – copresence in Amsterdam.

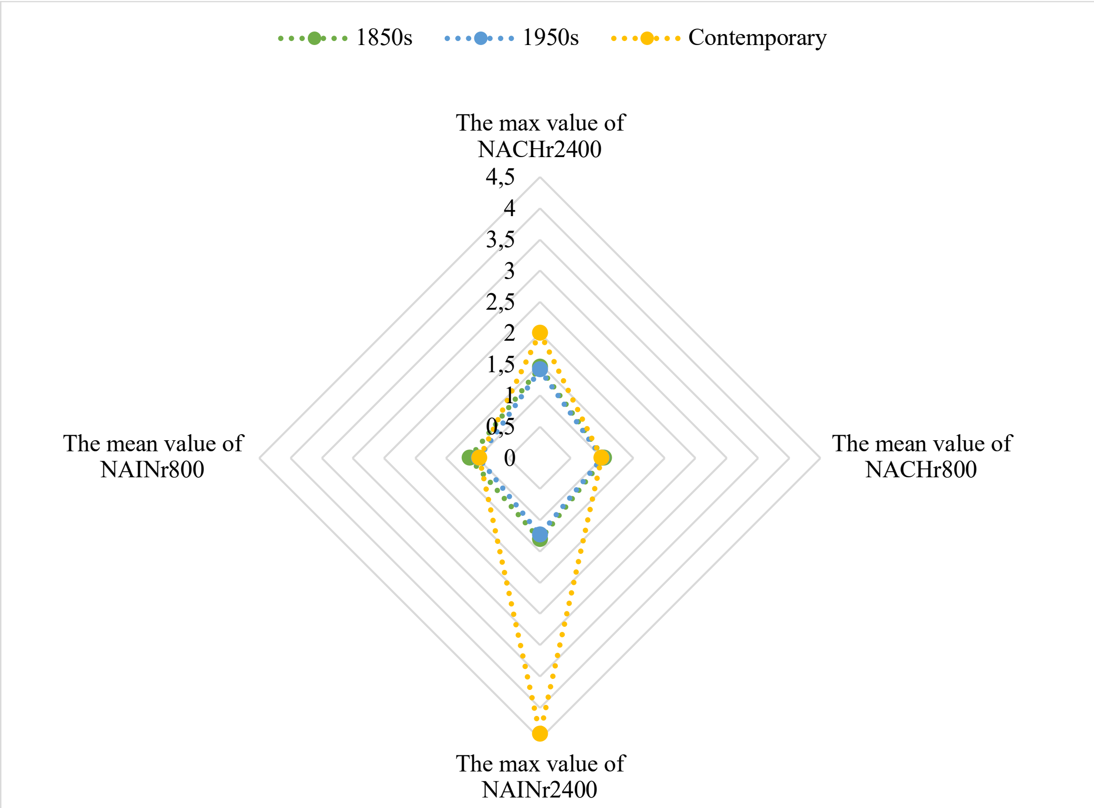

Figure 4: The Four-Star Model of Amsterdam Street Network

The diachronic model of Amsterdam reveals that the integration values of Grachtengordel and Jordaan have risen on both local and global scales over the study period. These neighbourhoods have become increasingly integrated with the city structure over time. The Jordaan was first planned for working-class families housing needs. However, the area has evolved into a more commercial and popular destination throughout time, and the neighbourhood's community evolved into an upper-middle-class community. This transition is referred to as gentrification, which is defined as a process of social class displacement (Ruth, 1964; Suchar, 1993).

The scatter plot of Amsterdam's street networks over three periods is shown in Figure 5. The range of integration values (between the minimum and maximum NAIN values) in 800-metre radius analysis rises between the 1850s and the contemporary period. The background network's integration values become more diverse over time. This demonstrates that the system has developed both more isolated and integrated areas within the background grid as the city grows. In that sense, bridges serve a critical role in eventually connecting the islands during the city-growing process, and the detailed examination of the integration values of bridges shows that they have gradually increased on a local and global scale in the diachronic model of city growth.

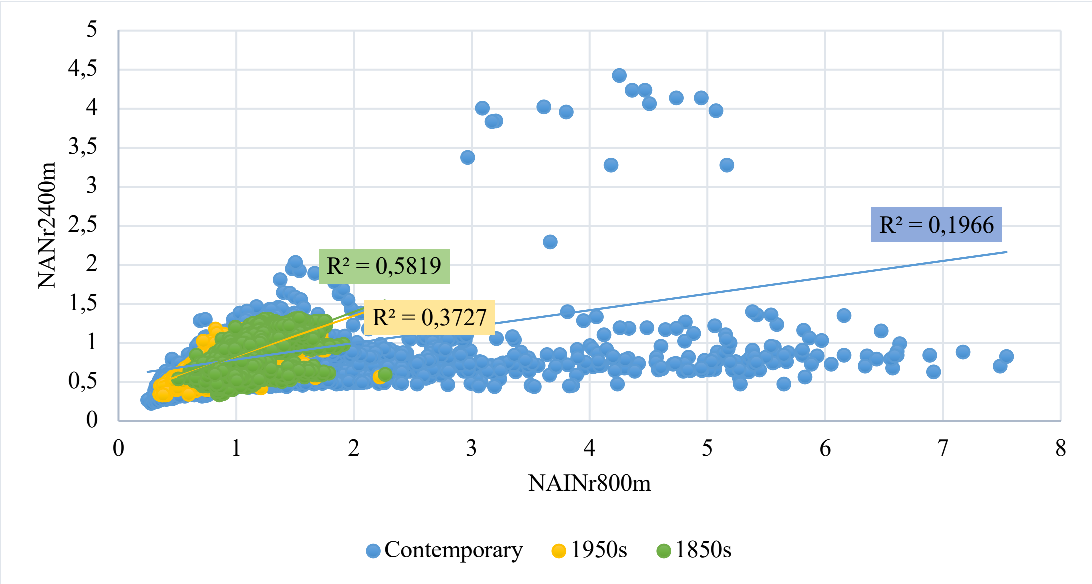

Figure 5: The Scatter Plot of Amsterdam Street Network (over Three Periods)

4.2 London

The diachronic model of London covers a 2500 metre radius around Regent's Canal (with an additional 2500 metre buffer area). The urban growth context in London is different from that in Amsterdam. The case study area in London has been densified through time by block divisions instead of top-down planning decisions from the city centre to the city edges. According to spatial analysis, the number of new streets added to the existing system has increased dramatically between the 1950s and the present. While 11 new streets were added to the system between the 1850s and the 1950s, 1092 new streets were added between the 1950s and the present. Table 2 shows the comparison of streets in London over periods. The mean value of the frontage length decreased as the number of streets increased. However, the maximum value of the frontage length increases over time.

Table 2: Comparison of Streets in London

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

Angular segment analysis illustrates that Camden Town was one of the most integrated areas of the study area on the local and global scales in the 1850s. The diachronic analysis shows that this has not changed through time. Between the 1950s and the present, a comparison of NAINr800m and NAINr2400m demonstrates that new streets added to the urban blocks usually have low integration values on the north side of the Regent's Canal (Figure 6). Moreover, the analysis indicates that the mean integration and choice value of the Regent's Canal path have not altered through time, demonstrating that the path's potential movement has not changed since the 1850s. In the 1850s angular segment analysis, the mean values were 1.06 for NAINr800m and 1.03 for NACHr800m, whereas, in the contemporary period angular segment analysis, they are 1.07 for NAINr800m and 1.06 for NACHr800m.

Figure 6: Angular Segment Integration Analysis of London

Figure 7 is the scatter plot that reflects the angular segment analysis values of streets in three periods. While the 1850s street network has an r-squared of 0.68, the contemporary period has an r-squared of 0.83. In contrast to Amsterdam evolution through time, the new streets added to the urban blocks boosted the system's local-global correspondence in a manner akin to the space syntax concept of axial intelligibility (Hillier *et al.*, 1987), thus suggesting an improvement on spatial connections from the local system to the wider urban setting.

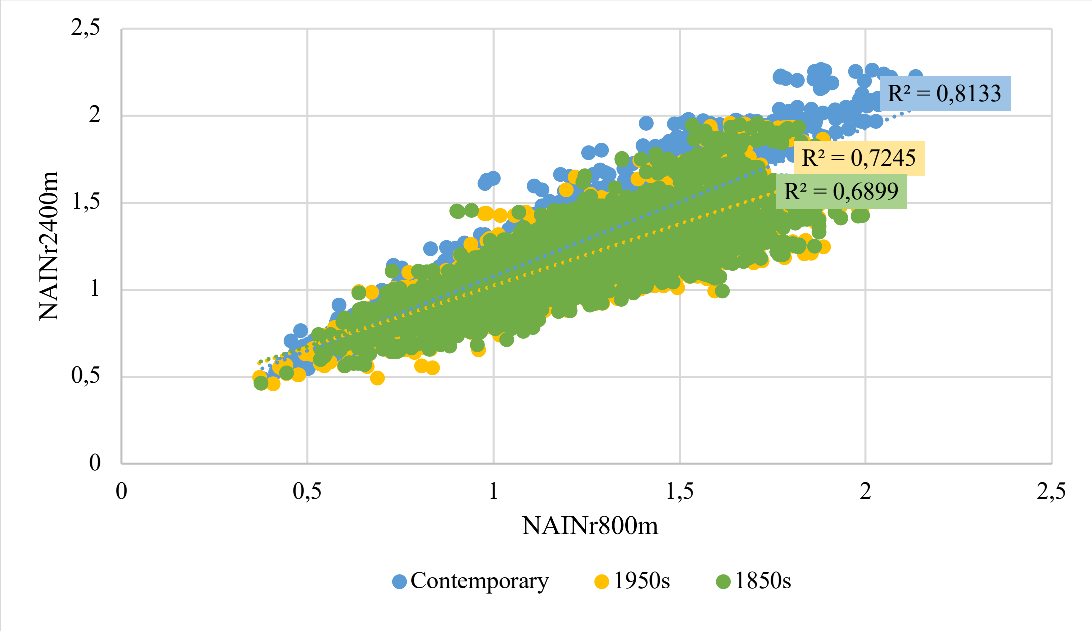

Figure 7: The Scatter Plot of London Street Network (over Three Periods)

4.3 Spatial Analysis of Contemporary Period: Comparing the Network with/without the Canal System

In order to understand the morphological influence of the canal structure, the analysis results of the street network, and a model that includes the canal system and the 400m buffer area from the canal ("street+canal network") were compared in both cities. In addition, analysis of the canal bridges themselves aimed to determine how likely the bridges are to be passed through on all shortest paths from all spaces to other spaces across the entire spatial system within an 800m radius of each segment.

The angular segment analyses of the street network and street+canal network can be seen in figure 8 which illustrates the four-point star model of cities structure. Firstly, when comparing the street networks of Amsterdam and London, Amsterdam has greater mean choice and integration values than London, except for the 800-metre radius where London has higher integration (Figure 8). Comparing the highest value of NAINr2400m, Amsterdam (4.43) has a much higher value than London (2.26). This reveals that the street network in Amsterdam is much more accessible in terms of to-movement potential for the background and foreground networks of the urban grid.

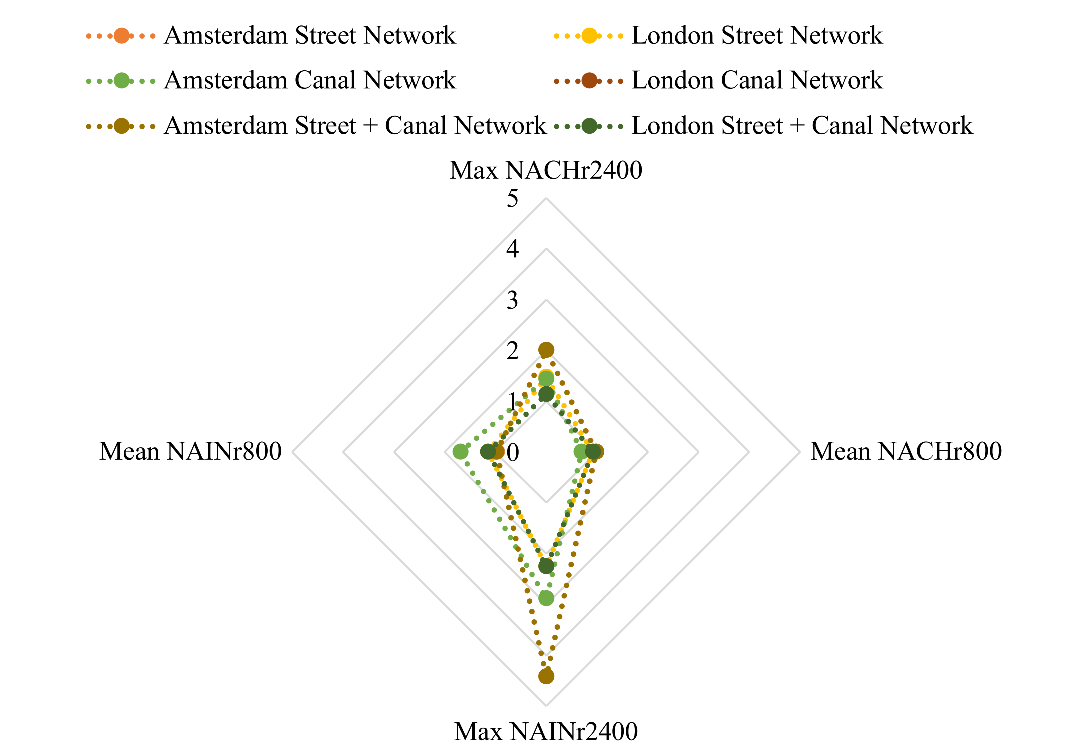

Figure 8: The Four-Star Model of Amsterdam and London Street Network without and with Canal Structure

A paired T-test was performed on both cities, and the statistical results of Amsterdam and London are shown in Tables 3 and 4 that illustrate T-test analysis results comparing street networks and the street+canal networks to determine whether canals have a significant impact on the cities spatial configurations. On a local and global scale, the statistical analysis shows that there has been no significant change in London's system in terms of the mean values of NAIN and NACH. However, London's maximum NACHr2400 dropped from 1.47 to 1.14. Therefore, the potential mobility of the street+canal network on the global scale is smaller than that of London's street network.

Table 3: Paired T-test Values for the London Network

	Paired Difference							Significance	
				95 % Confidence Interval of the Difference					
	Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	One-Sided p	Two-Sided p
NAIN800m without/wi	-.001521616	.3826891481	.0021065068	-.005650443	.0026072117	-.722	33003	.235	.470

th canal network									
NACH800m without/with canal network	-.000488898	.5542894274	.0030510780	-.006469118	.0054913222	-.160	33003	.436	.873
NAIN2400m without/with canal network	-.002264495	.3301513716	.0018173133	-.005826493	.0012975033	-1.246	33003	.106	.213
NACH2400m without/with canal network	-.000323801	.5488288682	.0030210204	-.006245108	.0055975050	-.107	33003	.457	.915

The values of NAIN and NACH in the 800 metre do not differ considerably between the street network and the canals added to the system in Amsterdam (Table 4). As a result, the background network's potential movement did not change when the canals were introduced to the system. However, the mean values of NAINr2400 significantly rise as the canals are added to the system. The NAIN and NACH max values with a 2400 metre radius are the same. The statistical analysis results of Amsterdam claims Feddes (2012) statement that "Amsterdam has been more of a land city, with places accessible both across the water and along streets" (Feddes, 2012).

Table 4: Paired T-test Values for the Amsterdam Network

	Paired Difference							Significance	
				95 % Confidence Interval of the Difference					
	Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	One-Sided p	Two-Sided p
NAIN800m without/with canal network	-.005042350	.5186415957	.0030325770	.010986335	.0009016360	-1.663	29248	.048	.096

NACH800m without/with canal network	-.0002153808	.4710896500	.0027545335	.005183627	.0056143889	.078	29248	.469	.938
NAIN2400m without/with canal network	-.048254200	.2829518537	.0016544629	.051497021	-.045011379	-29.166	29248	<.001	<.001
NACH2400m without/with canal network	-.000777914	.4483963096	.0026218420	.0026218420	-.005916841	-.297	29248	.383	.767

The angular segment analysis results of canal bridges illustrate that the bridges in Amsterdam and London have higher NACH and NAIN mean values than the cities' street networks. Furthermore, the maximum NACH and NAIN values for the bridges in Amsterdam are much greater than those in London. This result demonstrates that bridges well connect the islands, and the canals do not generate severance between island communities.

Another statistical analysis is used to compare London's entire street network to a 400-meter buffered area away from the canal (appr. five-minute walking distance and which can be defined as the canalside area). The mean values of NAIN 800 and 2400 metre radii are considerably different, and the canalside's integration is significantly lower in local and global scales. Therefore, the analysis results show that the Regent's Canal negatively influences its closer area in terms of potential movement to space as a destination from all other spaces (Table 5).

Table 5: Independent T-test Values for the Entire Street Network and Regent's Canalsidendon

		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	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

5 DISCUSSION

The diachronic models of Amsterdam and London show that the city growth processes in these two cities follow different logics. The space syntax analysis addresses the quantitative aspects of urban structures while also considering their historical evolution to comprehend the spatial evaluation of the present urban grid and canal structure regularities. The point worth mentioning is that Amsterdam's integration spreads from the city core, implying that the city core can be characterised as the city's emergent morphology with its regular grid pattern designed with the canal network. This process ensures that street configuration and canals are successfully integrated into the urban fabric. Analysis of the grid structure of Amsterdam demonstrates that a relatively recent part of the city has the same impact as the historical town centre. The poly-central conurbation is strongly linked to the regular grid. In terms of land-based interconnections of canals in the urban configuration, Amsterdam, London, and Psarra's earlier analysis of Venice (2018) indicate three different ways in which canals can operate as spatial systems within cities. While canals make Venice more accessible (Psarra, 2018), Amsterdam can be described as an intermediate stage between a water-based and a land-based city. In the latter case, the canal network was shaped as a part of the emergence of the city's dual grid. In contrast, the canal network in London is the least embedded of the three cities. In terms of movement potentials of street and canal networks, London can be classified as having a dominant land-based spatial structure. Several historic canals in Amsterdam predated urban development and consequently played a city-forming function. However, in the old centre, as well as various other parts of the city region, the canal system was constructed in tandem with the street system with the primary goal of water management. As the city expanded in the Middle Ages, the canals have acquired an important new function: the transportation of merchandise. This made the city grow and gave it the most efficient system of navigable waterways. Thus, there is a distinction between canals that operated primarily as water drainage and, as a result, were utilised for transportation, and canals that were merely designed for transportation as Regent's Canal case.

6 CONCLUSIONS

This study has addressed the research question of "*what is the major spatial influence of canal system changes over time on street configurations in Amsterdam and London?*" which centres on the relationship between urban form and urban canal structure. The study's primary purpose was to increase knowledge on the canal network embeddedness with its surroundings and whether the canals create severance in their surroundings. The study's results have implications for urban design in their ability to shape decisions regarding how to minimise severance in canalside settlements. Indeed, such an evidence-based approach can be used to generate design options for redesigning existing infrastructure.

The link between canal and street structure has been affected differently by Amsterdam and London's growth pattern. In Amsterdam, places are accessible by both canals and streets, probably due to the city's long history of top-down urban policy and water management that stayed focused on the canal network, in which mobility systems have emerged to allow for the integration of streets and canals. However, London has had a dominant land-based spatial structure in terms of potential movement. The result of a planned urban process of Regent's canalside, in projects such as the King's Cross redevelopment in the 1990s were historically utilised for industrial land and subsequently led to relative spatial isolation despite the best efforts to integrate the canal and street systems and by creating activities along the canalside. On the other hand, the organic city network and the emergent city centres in the Regent's canalside, such as Camden Town, have become more conducive to the integration of the canal with the surrounding commercial activities along its streets. As a result, not all canals are conceptually the same. While the London case study analyses the function of city-forming canals, the Amsterdam case interprets water-management canals primarily. Future research would be required to compare the linear structure of the canal network in London to extend the case study areas and compare different sections of Regent's Canal in London with different canalside neighbourhoods in Amsterdam. In addition, consideration of how land uses evolve in canal-street integrated systems is a subject that demands further attention, and indeed the author is developing such a line of enquiry.

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