Suburban built form and street network development in London 1880-2013: An application of quantitative historical methods

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Abstract

This article describes the methods and findings of a study examining the architectural and spatial development of two of London's suburbs over the past century. Historical analysis of urban growth is constrained by a lack of geographic data that can be used to produce chronologies of analysable geographic data. This study, utilising historical geographic data reconstruction techniques, shows that the single most significant development in architectural form in the study areas is that of the garage, signifying expanded personal mobility potentials coupled to car-oriented road infrastructure developments during the study period. It suggests that an urban history must account for the role of personal mobility technologies in such studies. Furthermore, the implementation of methods for creating usable longitudinal geographic datasets allows for increased insight into the nuances of the urban developmental processes.

Keywords: London, Suburbs, Garages, Historical GIS, Built Environment

1. Introduction

1.1 Background

The focus of this historical research is the suburban fringes of London in two case study area: Surbiton and South Norwood. Geographic data reconstruction is used to quantitatively interrogate the process of urban development, from the perspective of the street network and built form changes, from 1880 to the present day. Three principal questions are explored in this paper: Does the street network and built form co-evolve over time showing similar development trajectories? Do certain time periods exhibit different street network and built form development characteristics that reflect different underlying drivers of growth? Is mobility and transport the key driver and shaper of suburban growth in London? These questions are important since understanding the drivers for urban development in the past, and the way adaptation has taken place, can inform how we plan and envisage the future of urban areas that are under pressure to expand and densify.

The data reconstruction methods that are utilised permit detailed and rapid data generation of historical data that are comparable to contemporary data sets. These are then used to explore the stages and patterns of suburban growth from the perspective of the street network and built form. The key findings of the urban and built form analysis are then linked to a discussion of the broader socio-spatial context, particularly referencing mobility and how development over time fluctuates and is not a steady state of change. This research highlights the potential of historical geographic data reconstruction and analysis methods to generate quantitative insights into the development of particular built forms and the spatial development of the urban environment at a larger scale than is normally possible. Applying these data reconstruction methods and quantifying the historic built environments enables key trends to be identified. This can then be used to link analytically between social processes and urban development. It is suggested that these quantitative data driven methods are important to developing historical accounts of urban development.

The research uses three historical time periods, 1880, 1910 and 1960, and present day (2013) across two suburban case study areas. The suburban setting of this research is of particular interest since it has such a longstanding and contested place in the urban assemblage, as well as developing and expanding greatly during the 20th century. The contemporary differentiation between the urban and suburban is complex, relating to multiple social and economic factors (Harris, 2010) beyond simple spatial arrangements. Even though the populations of peripheral areas often commute to the centre of the city for employment purposes (Van Der Laan 1998), and commuting also occurs in the opposite direction (Glaeser 2001), thus intertwining the social and economic life of the city across urban space, they are often spoken of as separate or different. The spatial notion of the urban and suburban can be seen as a continuum of diverse social and economic relationships occurring across space. Creating definitions that differentiate urban and suburban is not necessarily useful and a better approach is to create local understandings of places and their relationships with their wider urban context (Vaughan et al. 2009).

A particularly crucial aspect to the discussion of the perceived nature of suburbs is their historical development. A great body of literature has been written that has explored the sociology and history of the development of suburbs, primarily focussed on the expansion of the railways (Jackson 1978; Weightman and Humphries 1984; Wolmar 2013) and the social improvement that they aimed to bring about by depopulating the undesirable, at the time, centre of the city. These accounts, whilst providing much needed insight into the dynamics between the railways and urban development, do not fully account for the significance of the settlements or local spatial history and its influence on the development of areas into what are considered suburban settlements. Whilst historical studies of particular epochs in city/suburban development abound (e.g. Hebbert 1998) an historical perspective of a city's change over time is a quite different aspect that this research aims to address by empirically studying the spatial and built form development of areas of peri-urban London over 130 years.

In the context of London's suburban development, mobility infrastructures have played a vital role in the expansion of the urban area. In London the expansion of the railway systems to the urban fringe has been said to dissolve the boundaries of the urban area imposed by historic travel time and cost constraints (Hebbert 1998). Throughout the work of Whitehand at Birmingham University (1975, 2001; Whitehand and Larkham 1991; Whitehand et al. 1999, 1999) the development of specific built forms of residential suburban areas have been shown to reflect social processes and changes. The built form of suburbia is proposed by the Whitehand School of urban morphology to have the capacity to adapt over time through accretive extension and additions, as well as developing new forms. These nuanced and detailed accounts of the changing built form capture at the finest architectural scale the evolution of suburban built form, but do not create generic understanding of urban growth through their limited spatial scope and the research methods that are employed.

In the field of historical geographic scholarship that this research is situated, when geographic information systems are used as the platform of analysis, data availability and representation become the two key issues. This issue is widely acknowledged within the historical GIS (HGIS) field as being one of the primary barriers to greater levels of geospatial research using historic map data (Southall 2013; Gregory and Healey 2007). This is due to the necessity of deriving and extracting historic geospatial data from map resources to make them comparable with contemporary vector based GIS data representations, which requires extensive time resources (Gregory and Ell 2007). Enabling and defining the processes and resources that should be used in order to accomplish this task is one of the key challenges to the HGIS research field, and historical spatial analysis more generally (Knowles 2008; Gregory 2003; Gregory and Southall 1998). Developing the processes and approaches to this task can benefit all research areas concerned with historic spatial analysis. In historical urban analysis the issue of historical map data capture that has been explored in relation to constructing chronologies of urban street networks (Pinho and Oliveira 2009; Serra and Pinho 2011). This is a highly specific method that only deals with one type of geographic feature and representation. The methods and approaches to the capture of features such as buildings and other areal entities from historical maps for analytical purposes are not fully developed and methods to do so are necessary to advance HGIS scholarship. The methods demonstrated in this paper expand the historical data reconstruction from the street network to building footprints, this is vital since the relationship between the static built forms and the network that connects them together is what the urban built system is. Understanding how they co-evolve over time is central to understanding the urban developmental process, and what this paper attempts to do.

1.2 Case Studies

This research focuses on two suburban areas of London, Surbiton and South Norwood. The dates of 1880, 1910 and 1960 were chosen as the historical periods for study as these dates correspond to the most complete historical mapping available for the whole of London within the shortest total survey time period. Surbiton is located in the southwest of London within the Royal Borough of Kingston-Upon-Thames. The main high street runs along a northeast-southwest axis, similarly the railway line also runs along this axis. In figure 1 the historical time series of the central area of Surbiton is shown. The three historical time periods are the ones that are used for the historical reconstruction of the building footprints and street network.

Surbiton itself is the product of the development of the railways. When the London to Portsmouth railways line was proposed, the town of Kingston-upon-Thames, located north of present day Surbiton, rejected the plan to locate a station there believing that it would damage the coach trade that was important to the area. Instead, the railway station was located close to the centre of present day Surbiton. The station opened in 1838 and was initially called Kingston-Upon-Railway. Surbiton as a named area came into existence in 1855 when it was named as a local government district. The development of the area following the construction of the railway station was driven by businessman Thomas Pooley, who saw the potential for the area to be developed as a location for commuters into the city of London to live. He purchased the land around the station in 1839 and began a project of residential development in the area. This was the first stage in the urbanisation of the area. Since then it has grown and continued to be a major residential area with transport links to the centre of London used by commuters. The significance of the railway and the conflicting interplay with new forms of transport technology, namely the railways and coach services in the development of the area is significant, as will be shown later the emergence of new forms of transport infrastructure play a key role in the spatial development of the area.

Figure 1 Historic mapping of Surbiton town centre ((© Crown Copyright and Database Right 2013 Ordnance Survey (Digimap Licence))

South Norwood is located in the south-southeast of London, almost due east of Surbiton, in the London Borough of Bromley. The town centre is also located adjacent to the northwest of the railway station as shown in figure 2. The time series of maps shows that South Norwood has developed around the train line and station. This railway line and station also play an important role in the history of South Norwood. The station opened in 1839 under the name of Jolly-Sailor Station due to the proximity of a pub by the same name. This station formed part of the London to Brighton railway line. Previous to the opening of the railway station and the urban development of the area it was covered by oak forest. This oak forest covered much of the area around South Norwood, its name deriving from its location within the wooded area, called the Great North Wood. The Croydon Canal also featured prominently in the development of the area with housing and businesses developing along the section of the canal that ran through South Norwood. Brick manufacturing was a significant local trade throughout most of the 18th and 19th Century with brick drying fields visible in historical maps; the location of one of these fields is now a park named Brickfields Meadows. Following the construction the railway the area gradually developed into a residential area with direct links to London for commuters. The area is also close to the site of The Crystal Palace, which was the location of the Great Exhibition in 1851, destroyed in a fire in 1936. This building is present in the two earliest historical building footprint reconstructions shown later.

Figure 2 Historic mapping of South Norwood town centre ((© Crown Copyright and Database Right 2013 Ordnance Survey (Digimap Licence))

1.3 Methodological Approaches

In order to accomplish the research a range of practical methods were used in the management, creation and analysis of data. To manage the geographic data a geographic information system (GIS) was used where all the contemporary and historic data can be stored, manipulated and analysed.

In order to create a time series of network representations of the case studies' street network at the three historic periods between 1862 and 2014 a method called 'cartographic redrawing' (Pinho and Oliveira 2009; Pinho and Serra 2011) was employed. This is necessary due to the analysis techniques requiring a vector line based representation of the street network in order for the analysis to be carried out and the historic map data only being available in raster image format. Cartographic redrawing is a method that allows for the non-destructive creation of chronologies of urban morphological change. The process is carried out from the present day backwards with the most accurate contemporary vector street network data forming the basis of all the historic street network representations. The contemporary vector line data is overlaid on the historic mapping for the first preceding period under investigation (in this case 1960) and all sections of road network are deleted that are not present in that period. This is repeated for each preceding historic period being studied (1910 and 1880). This method satisfies the necessity of having data of historical periods being interoperable with contemporary data in order to carry out comparative analysis (Gregory 2003), and also minimises the time-cost by minimising the need to digitise geographic features from scratch.

This process creates an individual layer for each period but preserves a common identity for the line parts across all periods so that each period can be compared and analysed against one another easily, quickly and accurately. It also minimises the time that is required for the process as deleting line segments is considerably faster than drawing street lines from scratch. The contemporary street network dataset used is the Ordnance Survey Integrated Transport Network (ITN). This is a road centre-line dataset that captures the central lines along a street. The map data that was used as the reference mapping in the cartographic redrawing process is the 1:2500 Ordnance Survey Country Series historic mapping. The three historic time periods used were: c.1880, c.1910 and c.1960. These periods were selected as they provided almost complete coverage for the London region within the M25 in the shortest range of years around these dates of any historic mapping datasets. This ensures that when the areas are compared they represent the same time period in each case. It also provided for any future comparative research to be carried out on other parts of London using this base mapping, due to the coverage of the whole of London within a similar time frame.

Similarly to the street network, the historic building map data is only available as a raster image and needs to be extracted in vector line format from the historic maps so that it can be analysed in the GIS software. Doing so can be an especially time consuming process, so methods of semi- automated building footprint vector data extraction were employed. This was achieved using the RXSpotlight Pro software produced by Rasterex Software a.s. This software is capable of extracting detailed vector line representations from raster imagery (Figure 7). The extracted vector line representations were then fed back into the GIS where they were cleaned so that only built structures were present in the final datasets. The same source maps used for the street network redrawing (OS Country Series 1:2500) were used here, ensuring that the reconstructed built record matches the time period of the reconstructed street network, although inevitably there are time lags in the surveying and updating of the maps, especially when a large area is being studied. For both South Norwood and Surbiton an area of 3km around the present day town centre is use for the historical reconstruction of the street network and building footprint records.

The two methods for historical data capture that are described form the basis for the analysis of the change in the road network structure and built environment over the time period of the study. Applying these methods creates datasets that are comparable to contemporary data sets and therefore allows chronological and comparative analysis between all the time periods in question. Simply by the creation of these interoperable datasets avenues for analysis are opened up that would otherwise be impossible. In the context of contemporary data driven analysis of urban systems, these types of historical data capture are crucial to allow for an analytically based historical perspective on urban development. Only through such methods is it possible to fully chart the development of cities and their environs.

2.1 Results

2.2 Street Network Development

The outcome of the cartographic redrawing methods can be seen in figure 3. Here the street networks for both Surbiton and South Norwood clearly shows the significant development over the time period, creating the dense and highly connected street network that exists today.

Figure 3 Reconstructed street networks: Surbiton left and South Norwood right. (© Crown Copyright and Database Right 2013 Ordnance Survey (Digimap Licence).

In graph 1 the development of the street network density is shown for each of the two case studies' three-kilometre analysis areas. The values presented in the chart show the density of network in kilometres of network per square kilometre of land area, these figures are normalised for the slightly differing areas that the 3km area encompasses, so that the figures are directly comparable. Surbiton has a lower road network density than South Norwood across all time periods, with densities of 10.9km/km^2 and 13.6km/km^2. There is also a linear progression through time as the network grows in both cases. The chart also illustrates how constant the proportional relationship is between the case studies. This suggests that even the development that we see in the present day city has its roots in the initial structure and topology of development that began centuries ago.

Graph 1 Street network density (km/km2) from 1880 to 2013 in Surbiton and South Norwood

In order to capture the structure of the connectivity of the network, and its change over time the density of junction points in the network (Masucci et al. 2013) and also the relationship between junctions and dead ends can be used. By examining the ratio between junctions and dead-ends in the network, the connectivity in relation to exploratory network growth can be evaluated. The connective nodes are that which form the junctions between different sections of the network, integrating them together. Dead-ends are the terminus points of the network from which no further space can be accessed through the network. These can be considered as exploratory network elements since they are the furthest point that the network has reached.

The case studies' junction density change over time mirros the trend observed in graph 1, with a linear progression of the development of junction density over time in, with Surbiton having a grater density than South Norwood.

When the junction to dead end ratio is examined, as shown in graph 2, rather than a steady increase, an overall decline can be seen. In understanding the presence of dead-ends as being indicative of exploratory growth in the network, the trend of first an increasing junction to dead-end ratio between 1880 and 1910 and then this declining for subsequent periods, shows an early stage of connective development consolidating the area and developing a more connected local grid. From 1910 onwards there is a decline in South Norwood whilst not in Surbiton, as the development pattern of the network changes. This is likely to be attributable to the case study areas becoming focuses for a second stage of development as commuter areas of the city, and exploratory growth in the network occurs to provide more space for residential developments. This is primarily achieved through the splitting of land parcels as network elements branch off pre-existing network structures.

Graph 2 Comparison of junction to dead-end ratio change in Surbiton and South Norwood

It is also interesting to note that although South Norwood has a higher network density and junction density, once dead ends are taken into consideration

Surbiton has the more connective network. This indicates that whilst connectivity as measured by junction density is important, a consideration of disconnection must also be present to understand the overall character of the network and its development trajectory.

2.3 Built form development

The understanding generated from the analysis of the changing building forms and the previously presented street network evaluation aims to capture the interdependencies between the spatial forms of new infrastructural developments and the buildings of the everyday. Using the methods for extracting vectorised building footprints from historical map data that has been described earlier, an area of 12.5km^2 around each of the town centres of Surbiton and South Norwood was reconstructed. For the present day the data that is used for building footprints is a subset of the Ordnance Survey Master Map Topography dataset that includes all buildings and built structures.

Figure 1 Reconstructed historic building footprints for Surbiton (top) and South Norwood (bottom) (© Crown Copyright and Database Right 2013 Ordnance Survey (Digimap Licence).

Graphs 3 and 4 show the changing network length in comparison to built area across all time periods in Surbiton and South Norwood. In these graphs the network length is doubled in order to represent the fact that buildings can be built on both sides of a length of road. The land area covered by buildings increased from 200,000m^2 to 1,628,000m^2 in Surbiton, and from 250,000m^2 to 2,342,000m^2 in South Norwood over the time period of study. This represents an increase of 814% and 936% in the built area of Surbiton and South Norwood respectively. In comparison to the network development over the same period in the two cases in terms of length and area built structures develop at a far greater pace than the network. Over the same time period the network grows by approximately 275% in both cases. This indicates that the relationship between built area and network length over time is not linear and that as the process of urbanisation takes place and built structures grow at a greater rate than the network. The ratio of built area to network length in Surbiton rises from 1.5m^2 of built area per metre of road network to 4.5m^2 of built area per metre of road network between 1880 and 2013. In South Norwood over the same time period the ratio increase from 1.6m2 of built area per metre of road network to 5.4m^2 of built area per metre of road network.

This mismatch between built structures and network growth indicates that the network development, in a sense foreshadows building development, in that capacity is present in the street network that is only later exploited by buildings that populate it. The ability of the network to absorb future urban growth is vital in an ever changing and expanding urban region so that the skeletal structure of the city is capable of providing routes to greater urbanisation.

Graph 3 Comparison of Surbiton street network length (m) change in relation to built area (m^2) change

Graph 4 Comparison of South Norwood street network length (m) change in relation to built area (m^2) change

In graphs 5a to c the basic properties in the development of built structures over time are shown. In graph 5a the ratio of built area to land area within the analysis boundary is shown for both Surbiton and South Norwood. South Norwood consistently has a higher ratio of buildings to land area, South Norwood experiences a nearly ten-fold increase in the ratio over the period of the study. In graph 5b the count of individual built structures per square kilometre of the analysis area is shown, here the dramatic increase is also illustrated with Surbiton increasing from 266 to 2,284 and South Norwood increasing from 235 to 3,691. These huge increases in the built-up area and building counts further indicate that the non-linear relationship between network length and buildings has another component that is not captured in these numbers.

When the size of the buildings is taken into account the reasons for this become clear. In graph 5c the average building sizes for both case studies over the period of analysis is shown. Over time the average size of the building footprints decreases steadily with the exception of the Surbiton in the period from 1880 to 1910 when there is an increase. In Surbiton the average building size increases from 61m^2 to 76m^2 between 1880 and 1910, and then decreases to 57m^2 by 2013. In south Norwood the average building size decreases across the whole time period from a peak of 84m^2 in 1880 to 50m^2 in 2013.

The changing size in the buildings partially accounts from the non-linear relationship that is observed between network length and built area. As the area is urbanised and the street network grows, the built landscape also changes in character, the buildings' spatial distribution becomes more dense as shown in graph 3 but also the buildings become smaller, or at least partially constituted of more smaller buildings, allowing for more built area to be accommodated on a network that does not grow at the same rate. From this it can be seen that over time built landscape changes to accommodate greater density with the development of smaller and more densely packed buildings that are more efficient at creating areas of greater density on a limited network space. This illustrates succinctly the city forming process, as an area transitions from semi- rural to urban the buildings condense into smaller more densely packed areas that allow the city to grow, whilst minimising expansion over a larger area that would create inefficiencies in distance and therefore accessibility to different parts of the urban area.

Graph 5 (a) Changing built land coverage over time, km^2 buildings per km^2 land area; (b) Changing building density. Count of buildings per km^2 (c) Changing average building size over time (m^2)

To further investigate the changing buildings graphs 6 and 7 show the frequency distribution of building footprint size in Surbiton and South

Norwood areas respectively, across all time periods of analysis. On these graphs the building footprint size is logged to reveal the underlying pattern in the distribution that is obscured by the exponential distribution of building sizes in both cases across all time periods.

Graph 6 Change in distribution of building footprint area (log) in Surbiton

Graph 7 Change in distribution of building footprint area (log) in South Norwood

Within these frequency distributions the same pattern of change over time occurs, in the earliest period of 1880 there is a normal distribution in both cases with the peak of values representing the domestic dwellings that account for the majority of the buildings with sizes mainly in the range of 40 to $70m^2$ footprint area. This distributional structure persists in 1910 when there has simply been a growth in the number of building, which are present in each case and still show a normal distribution. It is in the 1960 period that this distribution changes significantly.

In the 1960 period as can be seen in the graphs of both case studies a secondary distribution appears in the footprint size distributions. This indicates that a new typology of building appears between 1910 and 1960, these structures are mainly 10 to $18m^2$ in footprint area. In the period from 1960 to 2013 in both Surbiton and South Norwood this secondary distribution grows, in the case of Surbiton even more so than in South Norwood. Whilst there is the emergence of a new size typology of building from 1910 onwards the principal peak in building sizes remains roughly constant, indicating that the earlier analysis that showed a reduction in the average building size is the result of these new building being constructed in conjunction with increased density, rather than a reduction in the average size of the main components of the overall building composition.

The buildings that are identified as making up the centre of the new, first peak in the footprint size distributions are garages designed for the storage of motor vehicles. This finding is conversant with smaller studies such as the work of Whitehand (1991, 1999, 2001) and Clapson (2003), yet this analysis indicates that besides densification it is the most important shift in the make-up of the built landscape over the last 130 years in suburban London. In 2013 within the two case study areas buildings of this size, that are principally composed of garages, account for 4.7% of the total built area in South Norwood and 5.4% in Surbiton. When seen in conjunction with the building analysis it is clear that there are two processes at work in the urban environment between street networks and buildings at the individual, domestic level. Whilst the road infrastructure is reacting to planning ideas about movement efficiencies in the city and access in an ever growing and densifying metropolis, and the car is becoming attainable and available as a personal possession the buildings also develop so as to be able to accommodate the personal mobility technology into the daily lives of the population of the city by the construction of buildings to accommodate the motor vehicle.

3. Discussion

. In relation to the questions that this paper sought to address it is clear that the street network and buildings, whilst developing coherently alongside one another do not do so in a linear relationship, with the built area growing at a faster rate than the street network. In regards to fluctuations in developmental trajectory over time, whilst most metrics showed a continual steady increase over time, the junction to dead-end ratio analysis showed that the street network growth character changed at certain points, likely reflecting the type growth (expansionary or connective) that was needed in a given period. Finally the role of transport and mobility broadly in the development of suburban London was clearly demonstrated to be of high importance since the garage was the singular new typology of building to appear throughout the 130 years that this study covers.

Expanding on these points, as residential expansion took place the network developed through exploratory growth, primarily through the subdivision of pre existing land parcels. This created a network with many dead-ends in relation to junction points. When consolidation of the area took place the ratio fell as the network become more connective in its character. The built form analysis showed that the garage emerged between 1910 and 2013. The emergence of a whole new category of buildings across such a large dataset of approximately 35,000 individual built features in each case and in each time period indicates, that apart from the overall growth in residential buildings, garages were the most important change to the built form over the study period. From this alone it can be said that the garage is a fundamental feature within the history of the built environment of suburban areas of London. There has been extensive discussion of the re-modelling of the suburban landscapes, and specifically the development of garages in suburban areas (Clapson 2003; Whitehand 1991, 1999, 2001). The affirmation in this research of the importance of the garage through empirical reconstruction of the built environment on a large scale demonstrates that they were central to the construction of the suburban architectural landscape.

Transport played a vital role in the expansion of London into new territories by reducing travel time. This was achieved through the expansion of the rail and Underground network, and the development of road infrastructures. Whilst there is significant credit given the rail and Underground network in enabling this expansion (Jackson 1978), less is given to the similar role played by the private motorcar in the social and spatial development of London except Law (2012), although this is widely appreciated in studies of the US, Australia and elsewhere (Bullard at al. 2000; Cohen 2004; Kane et al. 2014). This analysis demonstrates the role of the motorcar in shaping the architectural forms of UK suburbia.

The relationship between the development of garages and ownership of motor vehicles reveals a strong correspondence. In 1960 there were approximately

9.5 million privately licensed vehicles, by 2008 there were 53.5 million (Olympic Britain, 2012). This represents an increase of 5.6 times. When the figures for the garage in the overall composition of built forms are examined, normalised for the number of domestic sized buildings in each area, in Surbiton there is an increase of 4 times and in South Norwood an increase of 5.4 times, for the same period.

The intertwined story of the development of mobility technologies and peri-urban development has a multiplicity of components, not least the railway systems. Whilst the railways have been linked to the general urban expansion of the periphery (Levinson 2008), at the 'micro-scale' (Whitehand 2001) of the individual building, the relationship between the mobility technologies and the development of urban form has not before been empirically measured at this scale. This analysis has shown that they share a common history. Whilst discussions largely focus on railways and road based infrastructural developments, other mobility enhancing technologies that predate these also will have had fundamental effects on the development of urban areas. In figure 5 a section of the same area within the Surbiton study area is highlighted in the periods 1880 and 1910. In the 1880 period the buildings are being used as stables, by 1910 they are no longer stables and a tramway has been built along the adjacent road. Stables and muse buildings have been adapted over time to be used for a range of uses including residential, commercial and light industrial. Garages have been adapted over time as well, and been used as storage space, and also incorporated into houses as extra living space. Where rows of garages currently exist it is possible they will mirror the change in use of muses and stables and be adapted or redeveloped for residential and other uses as demand for these spaces continue to increase in London. The continual evolution of transport systems is paramount to understanding the spatial and architectural development of suburban areas (and the urban system generally) that are reliant on advances in transport systems to sustain their development. How the built forms of particular transport epochs can then adapted over time goes on to inform future development.

Figure 2 Changing mobility technologies in Surbiton. Adjacent locations, 1880 (left) highlighting stables and 1910 (right) highlighting tramway (© Crown Copyright and Database Right 2013 Ordnance Survey (Digimap Licence).

The combinations of the historical GIS data capture methods, and street network reconstruction techniques overcome the primary barriers that exist in historical geospatial research, of data interoperability and availability (Southall 2013; Gregory and Healey 2007). This facilitated the construction of a representation of the street network and built form across all the time periods of analysis. The next step would be to extend this into the third dimension and account for height, although obtaining reliable data for this would be a significant challenge. In this research the integration of approaches from GIS, historical geography and spatial analysis have been brought together to enable research to be carried out that has been able to digitally reconstruct the physical urban past in detail, allowing for quantitative analysis of the changing urban landscape. The analysis of change over the last century can be used to inform development strategies for future development that conserves what makes these area unique and identifiable as places, but maximises their potential to grow and adapt to changing demands.

4. Conclusion

Cities are in a constant state of flux, constantly changing in both their physical and social capacities. Whilst no account can be complete in all aspects, this research has demonstrated as comprehensively as possible through a range of approaches, the spatial and architectural stages through which suburban London has developed, at both urban and building scale. The finding that the growth of the built mass greatly exceeded the network growth in all periods demonstrates the crucial aspect of urban development, namely redundancy within the network to absorb increasing density of buildings and therefore population. It also highlights the inherent potential in the street network, that if properly understood can be used to effectively densify peripheral areas by working with the grain of the spatial ordering that is already in place.

The common developmental trajectories, such as greater built form density and network growth, contained nuanced and fluctuating variations over time and space in the composition of the built form and network character. Whilst in London the railway system has been shown to have a significant impact on historical urban development patterns (Levinson 2008), this research reaffirms that the car, and the infrastructures of both the street network and built forms associated with it, have played a significant role in the forms of urbanisation seen in suburban London. The impacts on socio-spatial dynamics that these changes in mobility bring about is an important area that needs further research to enable an understanding of the particular socialities that different mobilities engender. When looking forward at future urban and suburban development appreciating the crucial role of transport in shaping the built environment will be necessary. Furthermore understanding the potential adaptabtion of the current built environment to absorb a growing and densifying population will be necessary, and garages and associated buildings may be central to this.

Through the longitudinal analysis of the change in the urban form of London, one important aspect that was analysed was the structures that are altered, appear or disappear between periods. Rather than simply analysing a particular historical state, this research enabled an understanding of the specific spatial and architectural changes that took place that enables reflection on the continual process of change. Understanding the components of change is in some respects more important that understanding the static historical states, as they reflect the fluctuating nature of society.

The methods that were used in the reconstruction of chronologies of the street network and built urban form aimed to augment the traditional practice of historical geographic research. This was achieved by using the approach developed specifically for this piece of research for the reconstruction of historic building footprints from historic mapping. These methods could usefully be applied to historical urban research generally, but specifically for historical analysis going back several hundred years, where appropriate mapping exists to be used in the process. Long duration chronologies would be particularly powerful in understanding the processes of urban development and change. The importance of new methods that enhance methodological approaches to historical research, such as in this case, enables a scale of research that, without bringing together methods from multiple disciplines would not have been possible.

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References

Bullard, R., Johnson, G. S., and Torres, A. O. (Eds.). (2000). Sprawl city: Race, politics, and planning in Atlanta. Island Press.

Clapson, M. (2003). Suburban century: Social change and urban growth in England and the USA. New York: Berg.

Cohen, B. (2004). Urban growth in developing countries: a review of current trends and a caution regarding existing forecasts. World Development, 32(1), 23-51.

Glaeser, E. L., & Shapiro, J. (2001). Is there a new urbanism? The growth of US cities in the 1990s. National bureau of economic research.

Gregory, I. N., & Healey, R. G. (2007). Historical GIS: structuring, mapping and analysing geographies of the past. Progress in Human Geography, 31(5), 638- 653.

Gregory, I., & Ell, P. S. (2007). Historical GIS: Technologies, methodologies and scholarship. Cambridge University Press.

Gregory, I., & Southall, H. (1998). Putting the past in its place: the Great Britain Historical GIS (pp. 210-221). Taylor & Francis.

Gregory, I. N. (2003). A place in history: A guide to using GIS in historical research. Oxford: Oxbow.

Harris, R. (2010). Meaningful types in a world of suburbs. Research in urban sociology, 10, 15-47.

Harris, R., & Larkham, P. (Eds.). (2003). Changing suburbs: foundation, form and function. Routledge.

Hebbert, M. (1998). London, More by Fortune Than Design. John Wiley &

Sons.

Hillier, B. (1997). Cities as movement economies. In P. Droege (Ed.), Spatial Aspect of the Information Revolution. North Holland: Intelligent Environments.

Hillier, B. (1996) Space is the Machine: A Configurational Theory of Architecture. Cambridge University Press.

House of Parliament Report (2012) 'Olympic Britain: Social and economic change since the 1908 and 1948 London Games'. House of Commons Library. UK

Jackson, A. A. (1978). London's local railways. David and Charles.

Kane, K., Tuccillo, J., York, A. M., Gentile, L., & Ouyang, Y. (2014). A spatio-temporal view of historical growth in Phoenix, Arizona, USA. Landscape and Urban Planning, 121, 70-80.

Knowles, A. K. (2008). GIS and history. Placing history: How maps, spatial data, and GIS are changing historical scholarship, 1-13.

Kwan, M. P., Murray, A. T., O'Kelly, M. E., & Tiefelsdorf, M. (2003). Recent advances in accessibility research: Representation, methodology and applications. Journal of Geographical Systems, 5(1), 129-138.

Law, M. J. (2012). 'The car indispensable': the hidden influence of the car in inter-war suburban London. Journal of Historical Geography, 38(4), 424-433.

Levinson, D. (2008). Density and dispersion: the co-development of land use and rail in London. Journal of Economic Geography, 8(1), 55-77.

Pinho, P. Oliviera, V. (2009). Cartographic analysis in urban morphology. Environment and Planning B: Planning and Design 36 (1). 107-127.

Serra, M., & Pinho, P. (2012). Emergent Configurational Effects of Differentiated Growth Patterns at Oporto's Urban Fringe. In Proceedings: Eighth International Space Syntax Symposium. Santiago, Chile

Simon, D. (2008). Urban environments: issues on the peri-urban fringe. Annual Review of Environment and Resources, 33, 167-185.

Southall, H. (2013). Guest Editorial: Working Digitally with Historical Maps. Journal of Map & Geography Libraries, 9(1-2), 1-7.

Van der Laan, L. (1998). Changing urban systems: an empirical analysis at two spatial levels. Regional studies, 32(3), 235-247.

Vaughan, L. Griffiths, S. Haklay, M. Jones, CE. (2009) Do the suburbs exist? Discovering Complexity and specificity in the suburban built form. Transactions of the Institute of British Geographers 34 (4), 475-488.

Vaughan L, Haklay M, Griffiths S, Jones CE. (2010) The Shape of Belonging in the Outer London Suburbs: Beyond the Discourse of Alienation. PLiC: Public Life in the In-Between City Conference Proceedings.

Weightman, G., & Humphries, S. (1984). The making of modern London, 1914-1939 (Vol. 2). Sidgwick & Jackson.

Whitehand, J. W. R. (2001). British urban morphology: the Conzenion tradition. Urban Morphology, 5(2), 103-109.

Whitehand, J. W. R. (1975). Building activity and intensity of development at the urban fringe: the case of a London suburb in the nineteenth century. Journal of Historical Geography, 1(2), 211-224.

Whitehand, J. W. R., & Larkham, P. J. (1991). Housebuilding in the back garden: reshaping suburban townscapes in the Midlands and South East England. Area, 57-65.

Whitehand, J. W. R. (2001). Changing suburban landscapes at the microscale. Tijdschrift voor economische en sociale geografie, 92(2), 164-184.

Whitehand, J. W. R., & Carr, C. M. (1999). England's interwar suburban landscapes: myth and reality. Journal of historical geography, 25(4), 483-501.

Whitehand, J. W. R., & Carr, C. M. (1999). England's garden suburbs: development and change. Changing Suburbs: Foundation, Form and Function, London: E&F Spon.

Wolmar, C. (2013). To the Edge of the World: The Story of the Trans-Siberian Railway. Atlantic Books Ltd.