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FROM THE AXIAL LINE TO THE WALKED LINE: evaluating the utility of commercial and user-generated street network datasets in space syntax analysis

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Abstract

Data availability, reliability and cost are some of the most constraining factors in space syntax analysis and wider commercial acceptance. In recent years user-created Volunteered Geographic Information (VGI) that is free to all via the Internet has gained wider acceptance and proven reliability (Haklay, 2010). Furthermore it has the property of being created by the people who inhabit the spaces being mapped; therefore it captures local knowledge and detail to a far greater degree than commercial mapping agencies. From a space syntax perspective it also relates more closely to the pedestrian network as it is used on foot and captures details of pedestrian routes through the urban fabric that other road-centric data sources ignore.

This paper demonstrates the methodological approaches and analytic outcomes of a space syntax of Open Street Map (OSM) VGI road network data, the UK national mapping agency Ordnance Survey Integrated Transport Network (ITN) road data and a hand-drawn Axial map for an area within the Greater London Region. The space syntax segment analysis was completed within the Depthmap application.

The segment analysis was completed on the ITN model, OSM model and hand-drawn model separately. The comparison of the network models was carried out through standard GIS processing techniques and the evaluation of space syntax measures. The space syntax measures were evaluated on the area of Surbiton in outer London that is the focus of part of the Adaptable Suburbs project at the Bartlett School of Graduate Studies. The analysis was carried out using length-weighted angular segment and choice analysis at radii 800m, 2000m and n (Turner, 2007). Comparative statistics were then generated for the areas to evaluate the analysis outcomes of the different network models.

The OSM, ITN and axial London-wide networks have a total length of 29,700km, 26,000km and 20,000km respectively. The dramatic difference in network length alone demonstrates the divergent realities of the three mapping techniques and the representation of the world that they capture.

It is anticipated that the analysis will find that there was no significant difference in the global syntax values between the ITN and OSM and Axial models but at the local level the additional network segments for pedestrian routes within the OSM data will provide greater network accuracy and syntax values that model the reality on the ground better than the Ordnance Survey ITN model. Furthermore it captures potential pedestrian routes that are not present in the other data sets.

The work carried out seeks to understand whether Volunteered Geographic Information is a viable alternative to official mapping sources when creating models for analysis of small urban areas and what are the impacts of model choice on space syntax analysis outcomes. If VGI data proves to be a reliable representation of urban space it would provide not only a cost effective alternative to commercially produced data but indeed a more reliable network model for the analysis to be carried out on due to the fine grain detail that it captures. Open source geographic data have the capability to improve and enrich space syntax analysis whilst removing high price barriers that commercial data sources impose.

1. INTRODUCTION

In space syntax research the basis for the investigation of the interaction between people and urban form is the street network. The most common method of analysis uses a modified representation of the street network based on network elements called axial lines. Axial lines have been shown to work as the network unit for space syntax analysis through the years across diverse applications. The axial line has been shown to produce a specific representation of the city that is closer to the cognitive representation that people use to navigate the city (Hillier, 2003; Penn, 2003). Due to this it has been extended into many other domains such as crime science (Chih-Feng, 2000; Hillier, 2004) and spatial cognition (Conroy Dalton and Bafna, 2003) as the spatial unit of the city through which investigations into spatial behaviour in urban settings can be carried out.

(Ratti, 2004a, b) has criticised the axial line method of representing road networks, claiming that it can lead to situations where small adjustments to the built-form layout produces radically different axial representations. Whilst this criticism has been addressed in subsequent articles (Hillier and Penn, 2004), (Turner, 2007) shows that this concern can be addressed substantively through the utilisation of road centre line data. It should however be noted that there is no such thing as the perfect – or singular – data source. All maps, and thus all map-derived network models, are subject to inconsistencies. Furthermore as computing capabilities and understanding of cities as integrated complex systems grow, the desire to carry out city scale or regional space syntax analysis is also growing. The construction of an axial map for very large areas is extremely time consuming and can lead to situations where the amount of time spent constructing the data can detract from attention that can be given to the analysis. Indeed, it is increasingly apparent that other sources of data may be relevant – such as street network data. Additionally, for larger areas, the effort required to capture axial lines may be significant.

This paper describes a preliminary comparison to ascertain which of three possible data sources of street network data was the most appropriate model for the purposes of Space Syntax analysis in the context of an extensive study of London's outer suburban town centres for the EPSRC funded Adaptable Suburbs project (Vaughan, 2011). The project will use space syntax analysis as a framework for analysing a wide variety of spatially detailed data on land uses and other social/economic activities. The aim of the work described here was to explore alternatives to the hand-drawn axial maps and to examine both the practical use as well as the theoretical differences between hand-drawn axial maps and alternative methods of mapping. Three mapping sources are compared: the traditional method of tracing axial lines over raster maps at 1:10,000 and conversion to segment maps; segment maps created from road centre-line data; and segment maps created from open source maps drawn by volunteer users.

This paper will illustrate to space syntax practitioners that the model used as the basis for analysis is something that itself should be questioned and considered, as it is the basis of all the findings that stem from it. These findings will be directly affected by the choices that are made in the representation of the street network and urban structures (Miller, 2000). Therefore the question of how to model and represent city structures is of equal importance to the question of how to analyse them as they both have an impact on the outcomes independent of one another (Miller and Wentz, 2003). This reflective discussion has the added outcome of demystifying space syntax analysis for a wider audience.

The discussion that follows hopes to address some of these concerns and present ideas as to how the process can be improved. The section that follows reviews the three data sources considered for analysis of the London street network. Following this, visual and statistical comparisons between the analytic results are made. The paper ends with a summary of the findings and the broader conclusions that can be drawn from the described analysis.

2. REVIEW OF ROAD NETWORK DATA

For the purpose of this discussion three main types of road network data will be discussed and evaluated. These are Volunteered Geographic Information (VGI) road centre-line data, national mapping agency road centre-line data and the hand drawn axial map.

Road centre line data presents the street network as a series of lines that follow the centre-line of the road (Fig 1) in contrast with the axial line, which is the longest straight line that can be constructed in any given urban space with unbroken visibility and accessibility. The hand-drawn axial map has been demonstrated as replicable using road centre lines that are weighted according to segment length thus opening up the possibility of using road centre-line data for space syntax segment analysis (Turner, 2007; Turner, 2009).

Figure 1 Road centre-line representation of a street network

The most common representation of street network data is in road-centre line format. This serves the purpose of government mapping agencies, whose primary purpose of creating the maps is for route solving problems. Such purposes may relate to in-car navigation, transport planning and emergency response planning. The necessity of a representation of the network that is close as possible to the physical reality is borne out of this.

2.1 Volunteered Geographic Information (VGI): Open Street Map

Volunteered Geographic Information (VGI) describes geographic datasets that have been compiled by members of the public who devote a portion of their time to the creation of geo-located information that is free to view and available to download from the Internet via web portals ((Haklay and Weber, 2008)).

A good example of this is the Open Street Map (OSM) (Fig 2) project started in 1994 by Steve Coast at University College London. Open Street Map is now the foremost VGI service in the world and provides coverage across all continents (OSM, 2011). The street network component of the OSM VGI data is created and supplied in road centre-line format. The data can be downloaded through web portals where the public, at no cost, can obtain country and continent specific datasets (see: http://download.geofabrik.de/osm/ and http://downloads.cloudmade.com/).

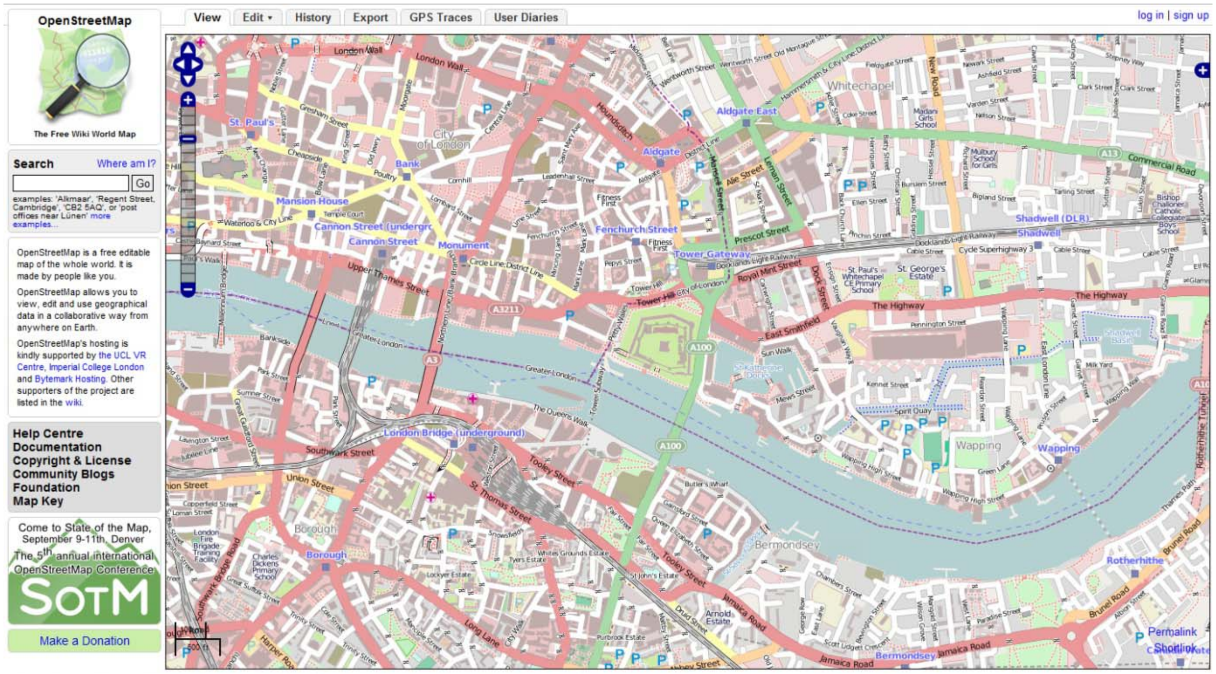


Figure 2 The Open Street Map viewer web page.

The process of the creation and compilation of VGI data is done is several ways including on-foot data collection, aerial imagery digitisation and local knowledge. On-foot recording is where members of the public walk around an area with a hand-held GPS unit and record all the routes that they walk. The route data from the GPS(s) unit are then uploaded onto the OSM website. Here the data are checked and cleaned by the user and then published on the OSM website. The checking and cleaning process involves verifying the collected data is correct and any errors are removed. The user then adds attribute data such as the road name, road type and number of lanes.

The other principal method is through the digitisation of high-resolution aerial imagery. This is carried out by loading aerial imagery within the OSM data editor webpage and then digitizing roads, buildings and all other features that can been seen in the aerial imagery. Once this has been completed the same checking and data attribution that the on-foot methods uses is carried out before uploading in to the OSM global dataset.

The final method does not involve the collection or digitisation of data but relies on local knowledge. People who want to contribute information for their local area can do so simply by entering the OSM data editor web portal and checking and changing the data that is already there for their local area according to what they know to be correct or incorrect about the area that they are knowledgeable about.

The question of primary importance in relation to VGI data is how complete and accurate is this dataset? Studies have been carried out in relation to this (Flanagin and Metzger, 2008; Haklay, 2010). From the studies it can be said that the quality of the data and the completeness is variable. It varies by country and then within each country, with urban areas generally being the most accurately mapped. In order to have a high level of confidence in the data, there need to be fifteen contributors who have edited the same area on average; with this level of participation the accuracy and completeness reaches 95%. There is also variable resolution in the features that are captured. Traffic management features such as road islands, will be captured in some areas whilst they may be absent in others. This reflects the differing views of those who create the data as to what should and should not be captured to create a complete representation of the environment.

Coverage of a given area is strongly linked to socio-economic profile, with more affluent regions having greater completeness and accuracy; this relates to the accessibility of the technology to record geographic data (GPS) and education relating to Internet technologies and mapping.

2.2 National Mapping Agency Road Network Data: Ordnance Survey (ITN)

The analysis uses the Ordnance Survey (OS) dataset called the Integrated Transport Network (ITN). Similarly to the VGI data it is supplied in the road centre-line format.

Unlike the VGI road network data this dataset is produced to clearly defined standards using traditional methods of surveying and verification within Geographic Information Systems (GIS). This means that the dataset has undergone rigorous testing to ensure that there is complete coverage, consistent connectivity across all network elements and that any errors are removed prior to publishing. Unlike the VGI data this is not free and costs £400-500 (600-750 USD) per square kilometre. This price puts it out of reach of many commercial entities (in the academic realm data are often supplied free of charge) that are not prepared to make the initial investment without clear beneficial financial reasons for doing so.

One key difference between the VGI data and the ITN data is that in the ITN dataset all road features are recorded. This includes all traffic management features which disjoint and fragment the network unnecessarily from the space syntax perspective but provide highly detailed information to those involved in transport planning and analysis, further underscoring the fact that this is a road-centric automotive dataset type (Fig x). This in itself demonstrates the fact that the urban street network is to a large extent viewed as the domain of the automobile and not seen as a space that people inhabit and use or one that should be analysed from the perspective of the pedestrian.

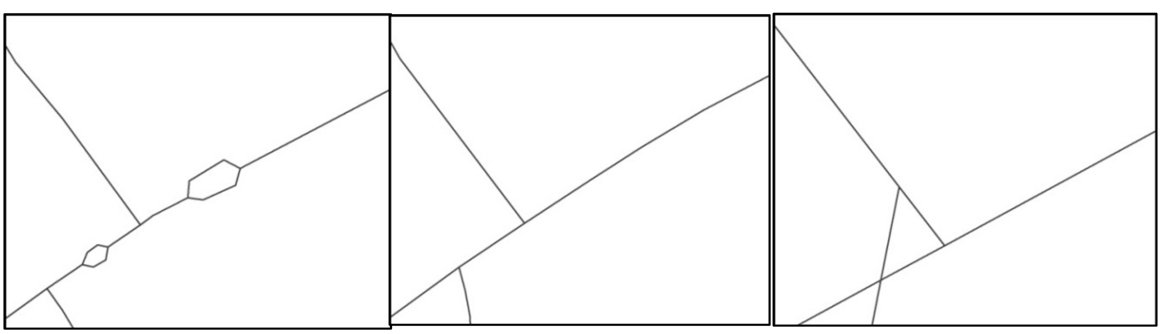


Figure 3 Traffic management features within ITN network (left) not present in OSM (centre) axial representation (right)

2.3 Axial Model Road Network Data: Classic Space Syntax Model

The final model that this paper evaluates is the axial-line map. This representation of the street network is the one that space syntax analysis and research has been built upon over the last 30 years and is the fundamental premise of space syntax theory. It has been shown to function as the spatial unit through which the interaction of society and space can be analysed. This has been borne out in numerous established findings going back 30 years and has created a distinct research field. Through the usage of the axial model the space syntax discipline differentiates itself from other urban network analyses through how it represents space and therefore seeks to understand space.

The axial model of the street network is a representation of the accessibility and visibility that the built environment allows through its structure. The axial representation is constructed through the drawing of lines that show the longest lines of accessibility and visibility within a given built environment.

The process that is used in the creation of the axial map is generally hand-drawing. This process is completed by over-laying raster image maps and then the user draws the lines representing the longest lines of accessibility and visibility (indeed in early years, due to the lack of processing power, this was done using tracing paper overlaid on a paper map, with the axial line model then scanned and redrawn in the computer). This process can be advantageous in comparison to the pre-packaged data that the VGI and ITN provide. The axial map incorporates local knowledge of an area in a 'ground-truthed' model that captures the required information contemporaneous to any social surveys that are carried out. The person who creates the maps can also develop a detailed understanding of the area through the process of creating the axial map.

Although the axial representation is well established and verified as a valid representation it does have several drawbacks. There is inherent error in the process of the creation of the hand-drawn axial map as it is not done in a uniform manner, differing scales of mapping may be used and the level of detail that the user observes may change as they zoom in or out (although this problem can be minimised somewhat by setting the computer to zoom only at fixed scales). These issues are also present in the VGI data but the principal concern is the time that it takes to create the model before any analysis can be carried out. For small urban areas axial maps are relatively quick to construct and accurate but for large urban areas or even complete urban systems this is not the case. To create axial models of large cities it can take considerable time and the quality can vary greatly as consistency in method and accuracy will decrease as the area increases.

Another element that cannot be overlooked is the relationship that the street network has to the surrounding built environment and its characteristics such as land use and socio-economic indicators. The axial representation of the street network is technically very difficult to reconcile with these factors due to the irregular spatial relationship axial lines have to their surrounding environment (fig 4). Through the application of road centre-line data that has a uniform relationship with the surrounding urban form it is easier to create a rich socio-spatial analysis that accounts for the urban system as a whole.

Figure 4 Comparison of axial network's (blue) and road centre-line network's relationship to built environment (ITN, red)

Owing to the specificity of axial maps they are not produced commercially or in the VGI sphere therefore they have to be constructed from scratch. Outside the academic realm this makes the process commercially difficult to justify, preventing space syntax analysis being used more widely as a design tool.

Whilst the axial representation of space is widely understood within the space syntax community this is not the case in the wider realm of urban or social studies. This may not be of great importance to the intellectual aspect of space syntax research but it is of concern in relation to the dissemination and penetration of space syntax research into conventional urban analysis as well as into urban design practice. The field may benefit from utilising more commonly understood and used data models, as this would remove knowledge barriers between disciplines.

3. METHODOLOGY

Three road network models for the Greater London region and one cut out of the Surbiton suburban area in south-west London were analysed using standard GIS statistical processes and Depthmap software (Turner, 2001) to examine the models' suitability for space syntax applications. The analysis is based around the visual interpretation of data and basic statistical tests. Detailed statistical analysis was not utilised due to the limitations of comparisons of such diverse datasets.

The three data sets were prepared so that they could be analysed in Depthmap but they were not simplified (i.e. extraneous lines were left in) and traffic management features were also not removed (see: fig 3) so that the 'readiness' for usage in space syntax analysis could be ascertained and their intrinsic representations of space could be clearly seen. The road centre-line networks for the suburban area were analysed using segment length weighted angular segment analysis at radii 800m, 2000m and *n*. The axial network model was analysed without the segment length weighting at the same radii. The segment length weighting is necessary to compensate for the numerous small segments that road centre-line data have (Turner, 2007). The metric and topological step depth characteristics of the three network models were then evaluated followed by their connectivity.

Prior to the space syntax analysis within Depthmap the ITN and OSM network data were cleaned though a process of removing disjointed elements. (None were apparent in the ITN dataset, probably due to its high production standards). Within the OSM data there were numerous disconnected elements that had to be discarded prior to processing.

The following section describe the analysis undertaken in order to elucidate both the limitations of data not specifically designed for space syntax analysis, and the possibilities that different representations of city networks have for space syntax analysis.

4. ANALYSIS

The first aspect of the London-wide models that the evaluation brought to light was their radically different representations of the street network in relation to length and segment complexity. As shown in table 1, the axial model (which was transformed into a segment model within the proprietary software Depthmap) is both the shortest in total length and the simplest in network composition. The VGI data that OSM provides is the longest network length but only the second most complex in terms of number of segments. This is due to the network being simplified to a greater degree in regards to its capture of small details than the ITN and including paths and alleyways that the ITN data does not. The ITN provides the greatest detail of the structure of the urban network and the greatest resolution of angular change in the orientation of street segments. This is also illustrated in table 2 for the suburban area of Surbiton.

	OSM	ITN	AXIAL
Total Length (km)	29,700	26,027	20,039
Number of Segments	718,118	1,213,646	453,562

Table 1 Comparison summary of London-wide network characteristics

	OSM	ITN	AXIAL
Total Length (km)	1,456	1,197	1,075
Number of Segments	37,585	58,293	20,637

Table 2 Comparison summary of Surbiton network characteristics

A visual comparison of the three datasets was carried out within a GIS to allow the evaluation of their comparative network representations. As illustrated in figure 5 the differences that the models have is clear. The ITN data is the most consistent and detailed whilst the OSM data is a more generalised version without the highly detailed road feature details. The axial model on the other hand is a generalised but also radically different representation. This difference was of less consequence when analysis was made using axial maps – the set of fewest and longest lines that covered the network and minimised depth. When translated into street segments and particularly when used to analyse street network characteristics in relation to land use or other spatially detailed data, the apparent divergence from the street alignments is striking.

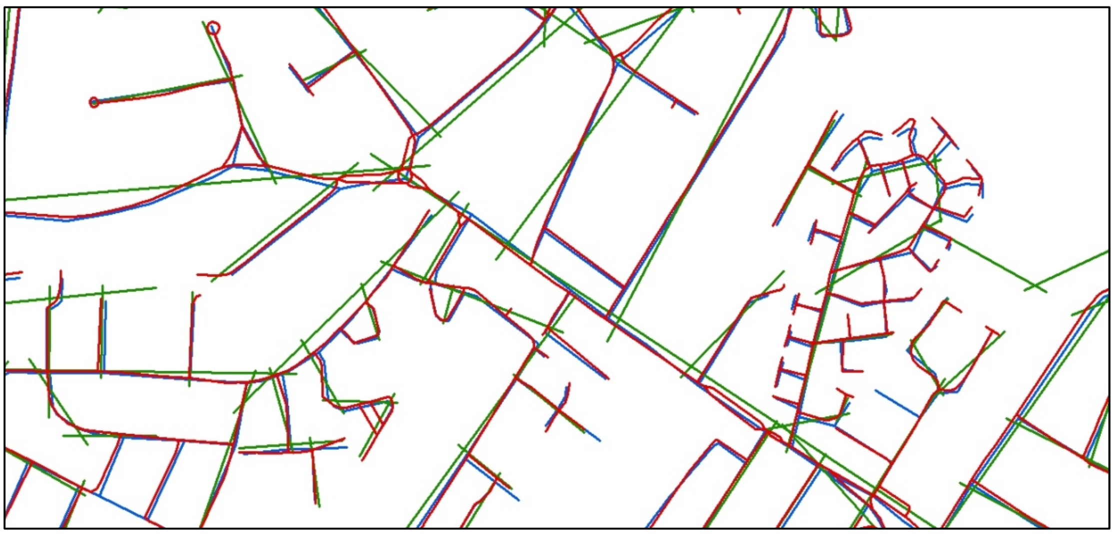


Figure 5 Overlaid image of axial (green), ITN (red) and OSM (blue) network models

This is especially interesting for the current utilisation of angular segment analysis. The axial model was the basis of the analysis prior to the development of the angular analysis techniques but it has been carried forward as the model of urban space used in angular analysis. This is problematic as the angular representation of urban space in the axial model is a significantly deviation from street geometry. This leads to the potential for road centre-line models to be the optimal representation of the geometric structure of urban space for use in angular analysis. In an axial model a curved bend that moves through 90 degrees may be generalised to two segments with a singular angular change of 90 degrees whilst a road centre-line might represent this as 10 small angular changes of 9 degrees each. How this change in representation impacts on the analysis outcomes needs a specific study to understand the precise impact of different street network representations on angular segment analysis. Evidently, road centre-lines present the most accurate representation of angular change in urban space and therefore potentially the most accurate model for movement based on angular change (fig 7).

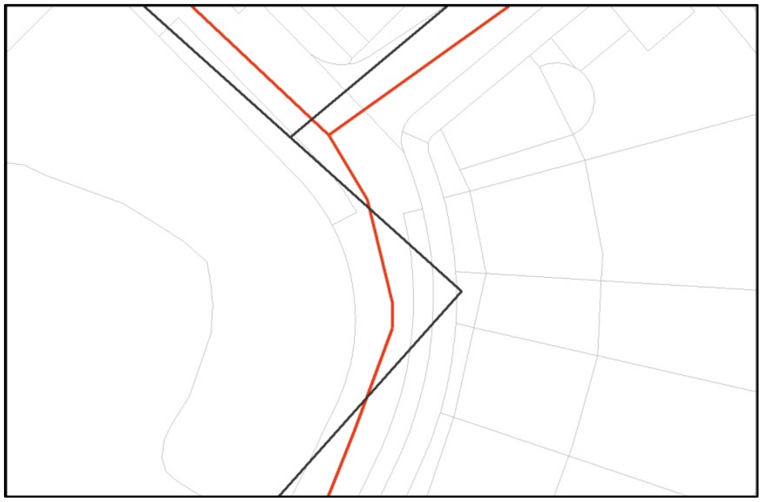


Figure 6 Angular representation of street geometry (ITN-red, axial-black)

4.1 Analysis of Choice Measures

Figures 6, 7, and 8 show the results of the Depthmap analysis of the three network models for choice at radius *n* for the area of Surbiton (town centre is indicated by arrow in fig. 6). These images clearly illustrate the same principal network structures are being identified as having the highest choice value, with the exception of the footpath route along the river in the OSM network model (Fig 8). This element is not present in the other network models so it cannot be included in their respective analyses. The inclusion of pedestrian only routes also creates a visually significant deformed wheel structure that is more intricate and apparent than in the other two network models. The may lead one to hypothesise that the urban-village structure of London can be seen most clearly when all possible network elements are considered. The similarity of the results visually indicates that although they are radically different representations, as is their purpose of representation, the space syntax analytical tools can interrogate the data effectively. In figure 7 showing the ITN network it also emphasises the main trunk (vehicular) road, confirming the ITN representational characteristics as being road-centric.

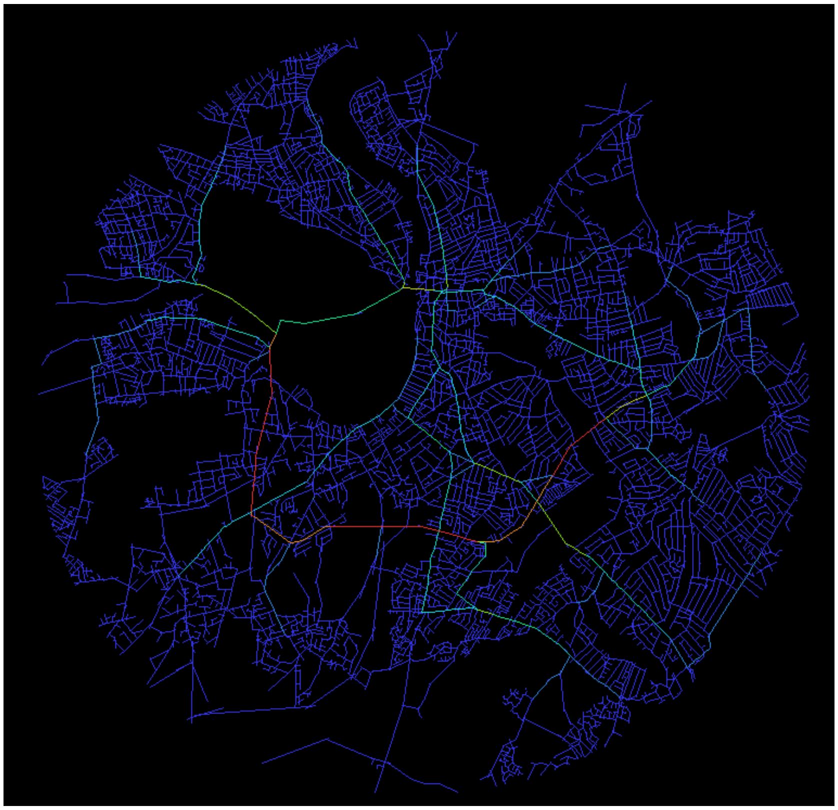


Figure 7 Surbiton axial network model analysed at radius n

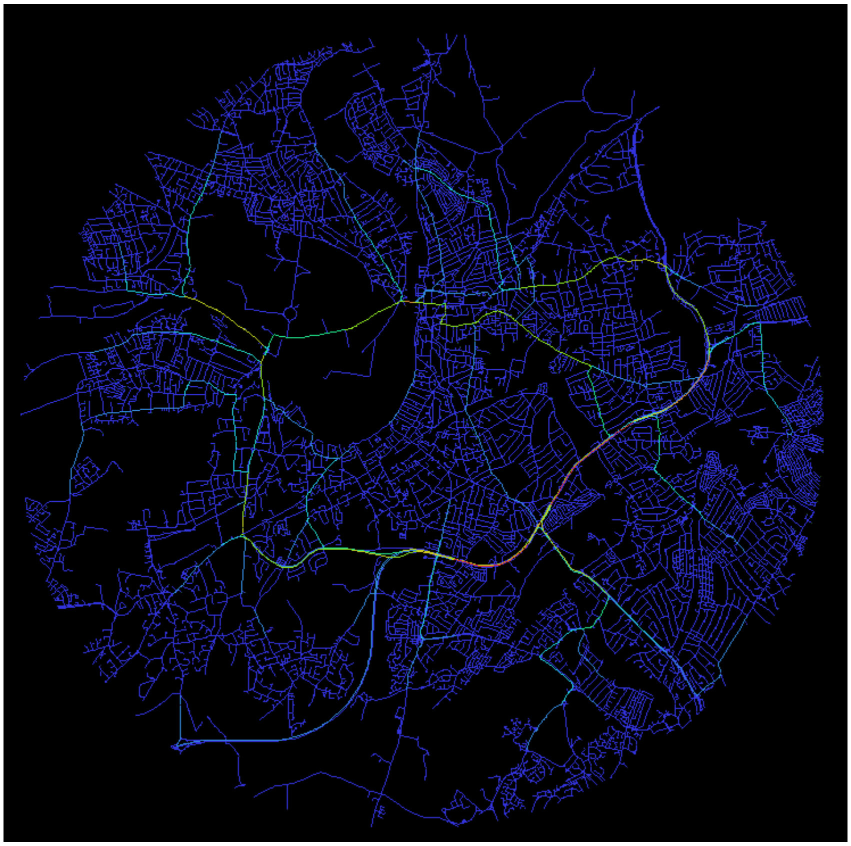


Figure 8 Surbiton ITN network model analysed at radius n

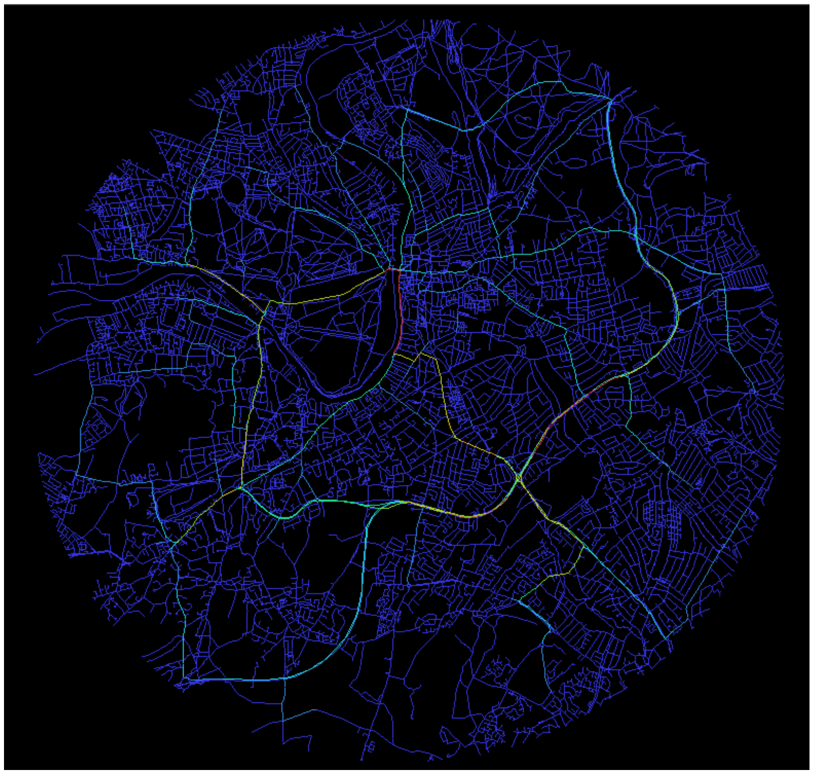


Figure 9 Surbiton OSM network model analysed at radius n

Figures 9 to 14 show the results of the analysis for choice at radii 2000m and 800m.The results from the 2000m analysis show that at the smaller scale the axial model shows markedly different results to the ITN and OSM models. The axial model more clearly defines peaks of choice values whilst the road centre-line models show a more diffuse gradient of choice values across the network. The reason for this could be the disjointed network structure that the road centre-line data has due to traffic management features (fig 3) or it could be the result of the nuanced representation of angular change in the network that the axial model does not capture. The axial model also does not highlight the choice importance of the arterial road that encircles the south-east of the area. This is a major network feature that is of significant structural importance in the area and for through-movement of traffic.

The 800m choice measure in figures 12 to 14 further illustrates the differences between the axial model and the road centre-line models. The axial model identifies the small centres clearly whilst the ITN and OSM models pick out the centres in a more diffuse way whilst still highlighting elements of the arterial road network and junctions that the axial model does not.

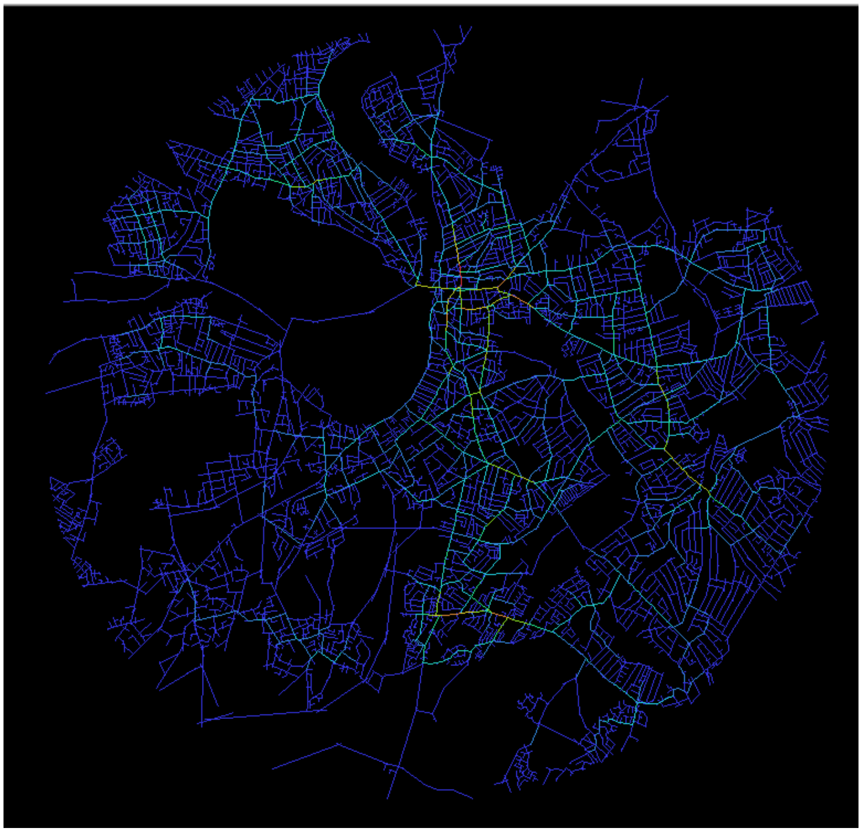


Figure 10 Surbiton axial model choice radius 2000m

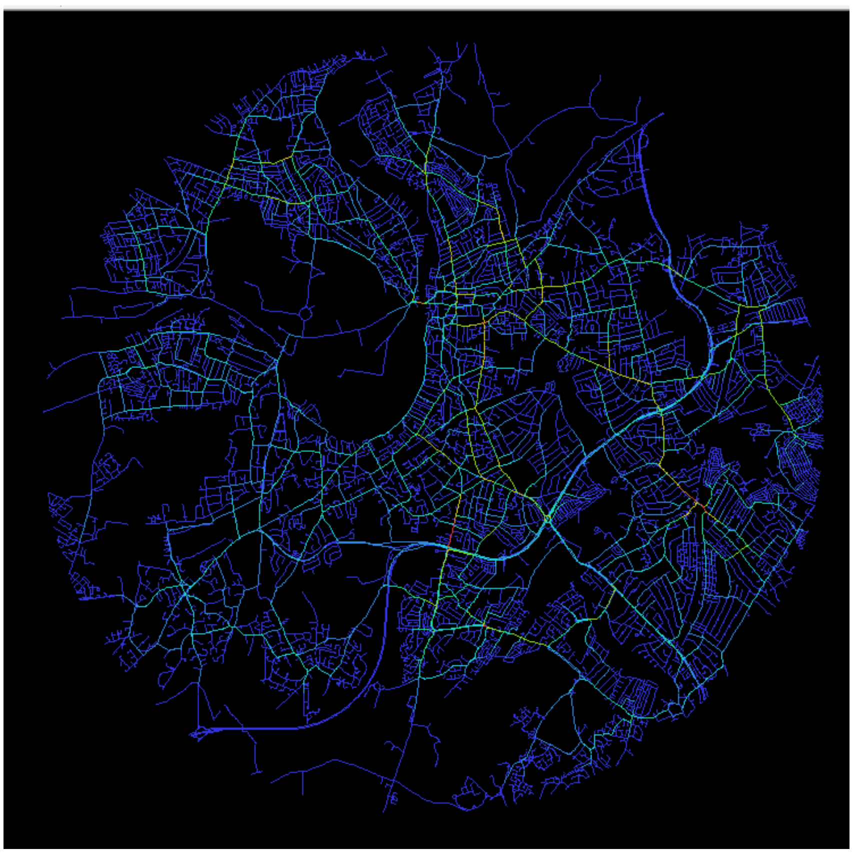


Figure 11 Surbiton ITN model choice radius 2000m

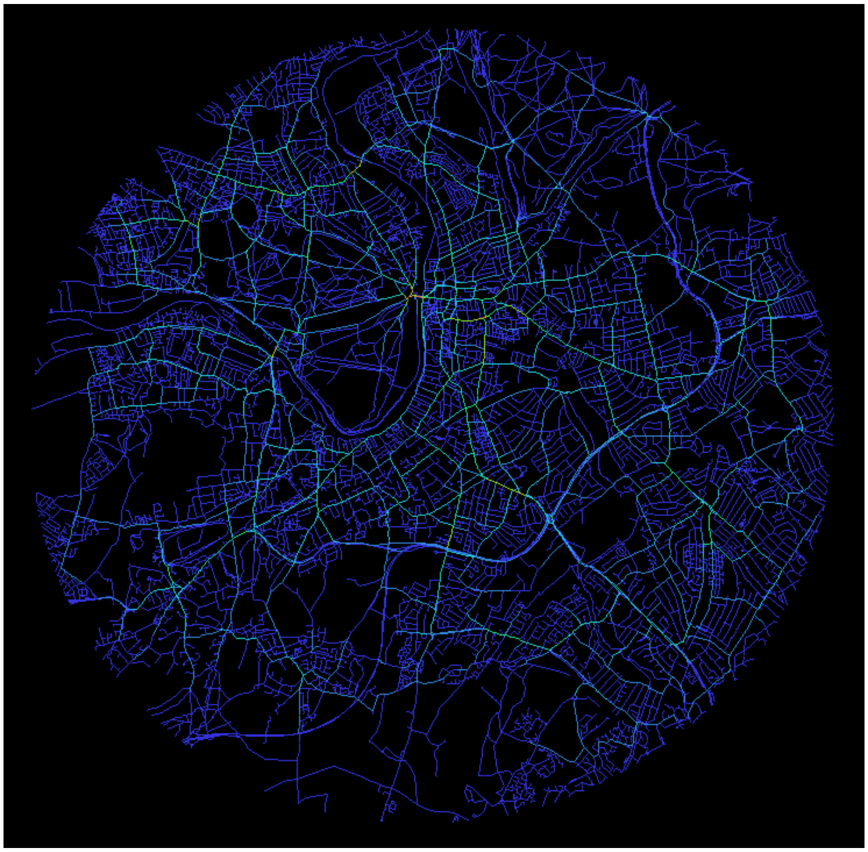


Figure 12 Surbiton OSM model choice radius 2000m

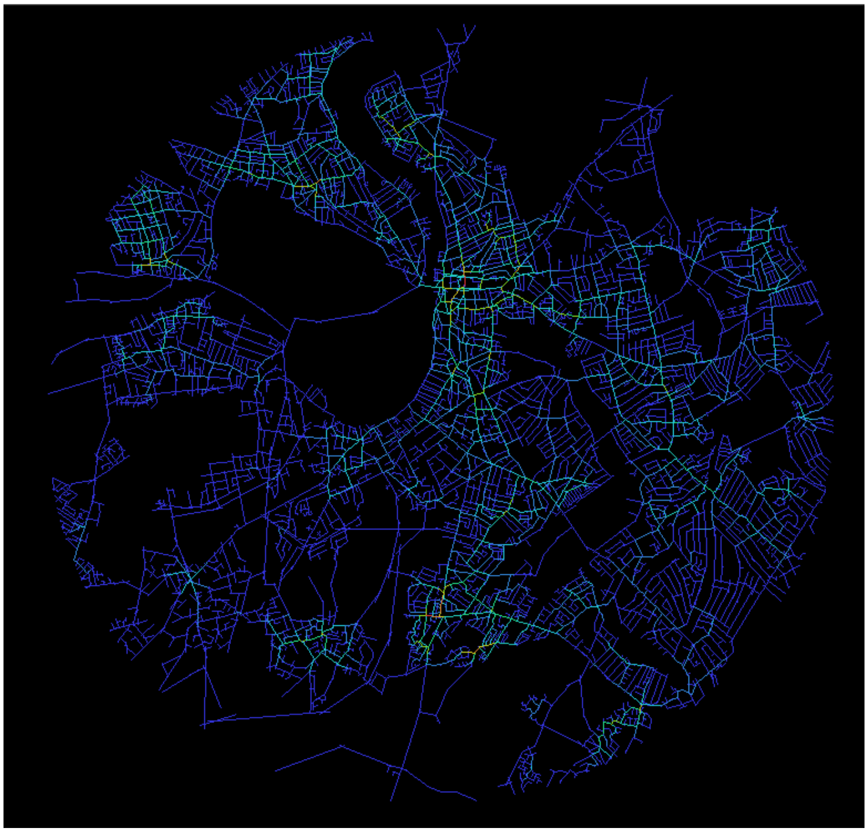


Figure 13 Surbiton axial model choice radius 800m

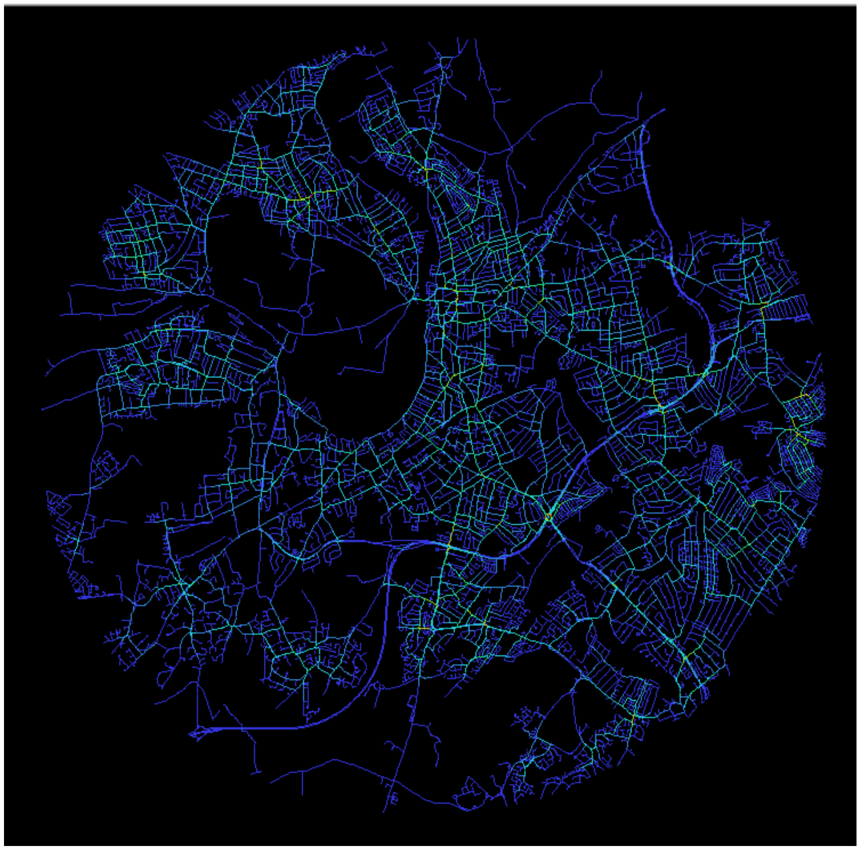


Figure 14 Surbiton ITN model choice radius 800m

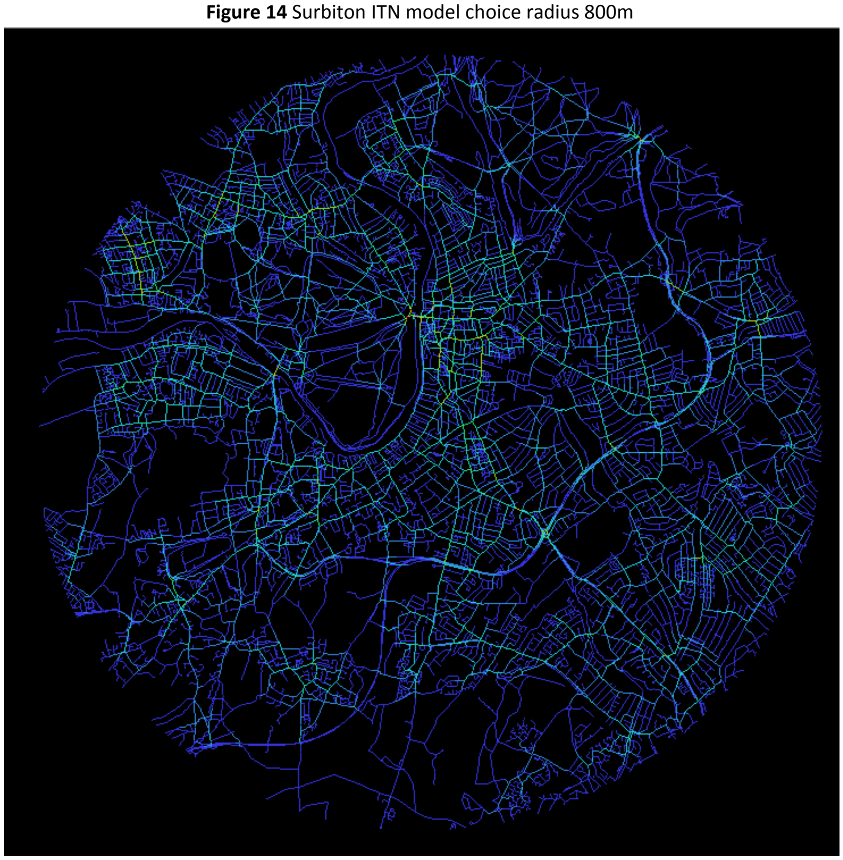


Figure 15 Surbiton OSM model choice radius 800m

4.2 Analysis of Integration Measures

Figures 15 to 18 show the results of the analysis of integration at radius *n* in Surbiton using the three network models. The results again clearly show that the choice of network model has significant impacts on the results. Similarly to the choice analysis the ITN network emphasises the arterial road as the most integrated element in the network. The axial model also demonstrates this to a lesser degree with a more circular pattern to the integration across the area. The ITN network is demonstrating a highly car centric view of the network.

The OSM network shows the most significant difference in regards to the structure of integration in the network. Whilst the arterial road is important the centre of the area is strongly linked to it and exhibits high levels of integration to the network as a whole. The extra network elements of paths and alley ways are likely to have caused this as it will increase the density of routes in the town centres and create a more integrated network. The OSM network in comparison to the ITN network clearly illustrates how the representation of the network changes the analytical outcomes. The holistic representation of the network of all routes that OSM represents highlights the space that people will move through as much as the spaces cars will. The combination of fine grain detail of small local routes and global routes creates a richer picture of the structures of integration, but also potentially reduces the distinction between localised and wider-scale of potential movement patterns.

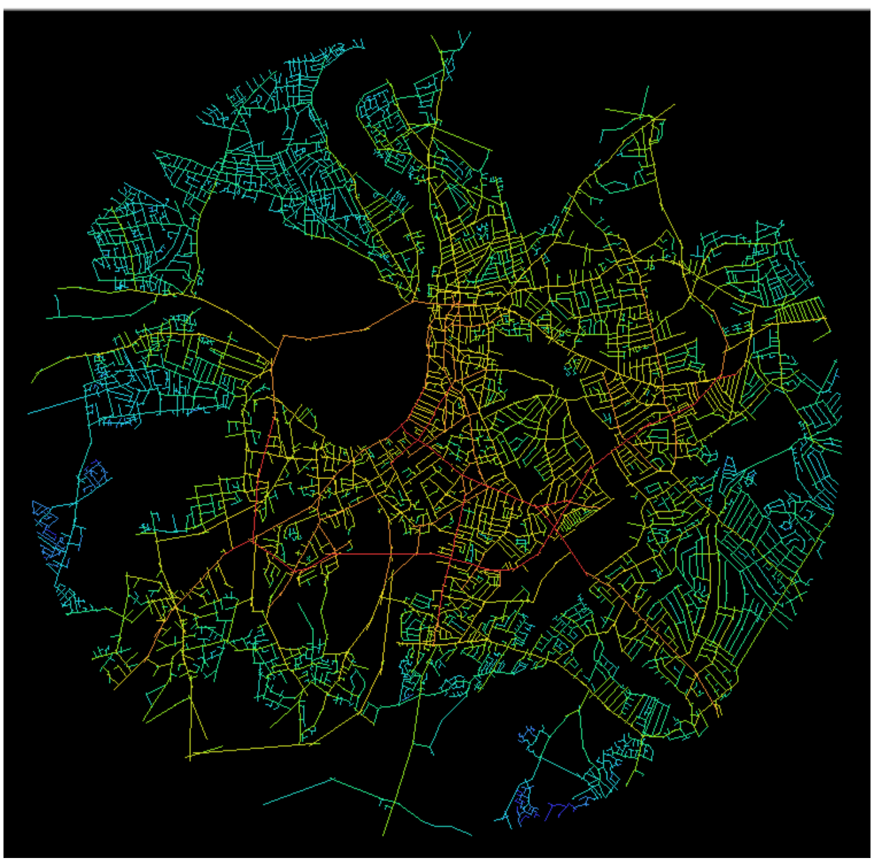


Figure 16 Surbiton axial model integration radius n.

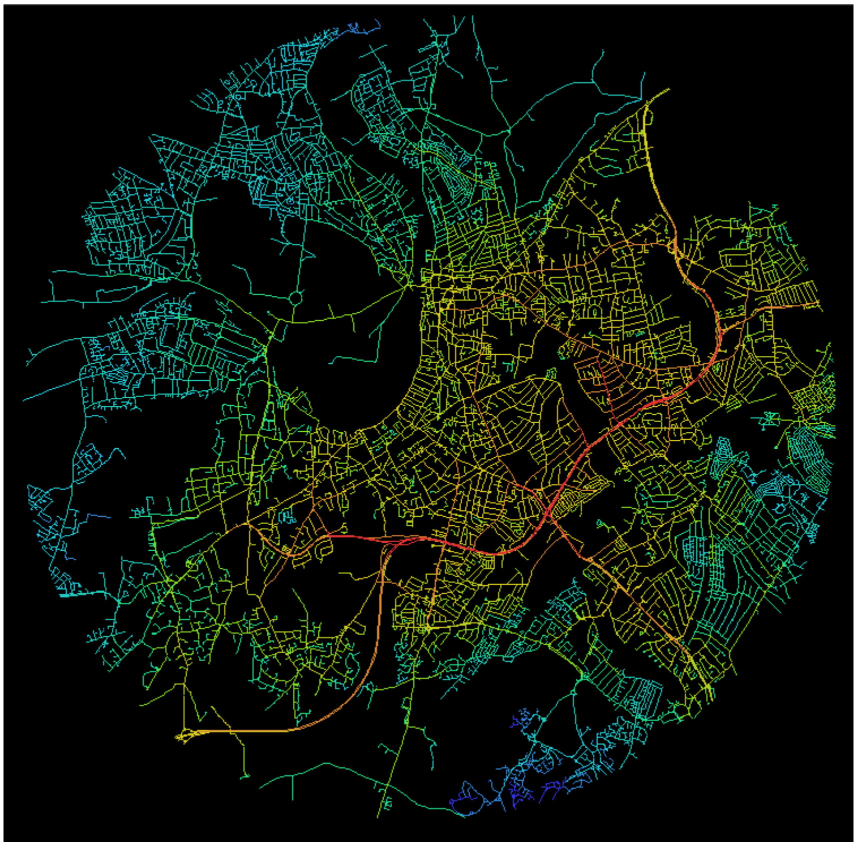


Figure 17 Surbiton ITN model integration radius n.

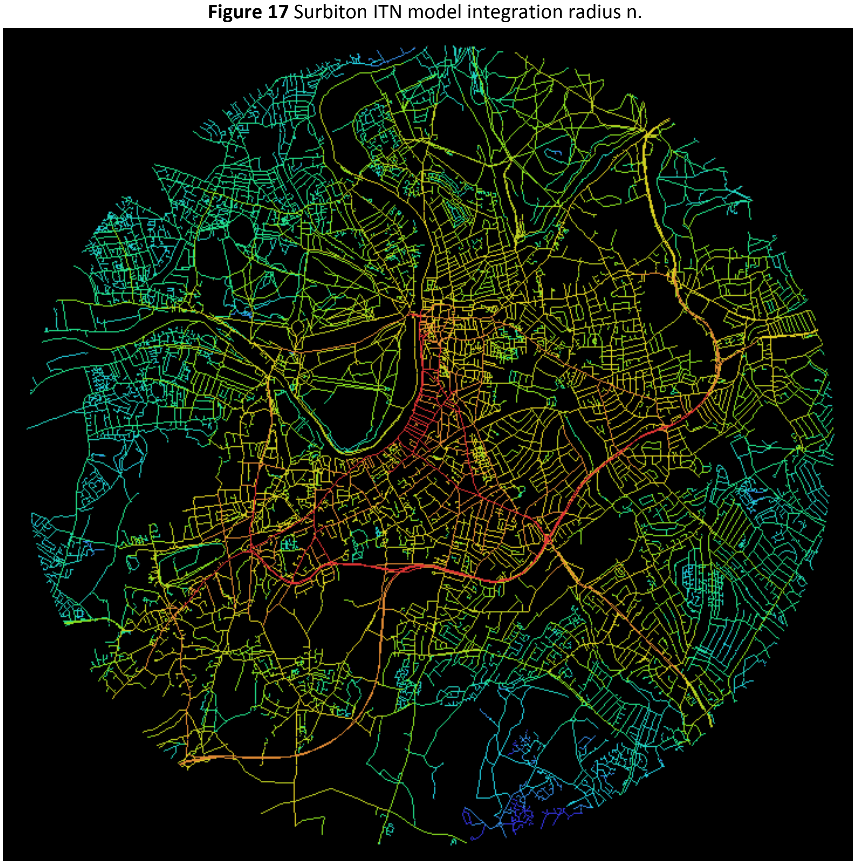


Figure 18 Surbiton OSM model integration radius n.

Integration at the local radius of 800m as shown in figure 19 is similar to choice at 800m radius for the ITN network. The junctions of the major arterial roads maintain their importance to the local area whilst the roads connecting them do not. This makes sense spatially as they are the access points for the local areas to the wider network. The ITN model also shows distinct local areas similarly to the axial model in figure 18. The axial model clearly identifies and separates the local areas from one another and identifies them as local units without detecting the larger structural elements such as arterial road junctions as of significance to the 800m radius of analysis.

The OSM network in figure 20 shows a far more incoherent picture than the axial or ITN models. The centre in the north west of the network is more integrated than any other part of the network. This is likely to have arisen from the inconsistent mapping of the different areas or the quality of the mapping leading to multiple lines intersecting where in reality they do not.

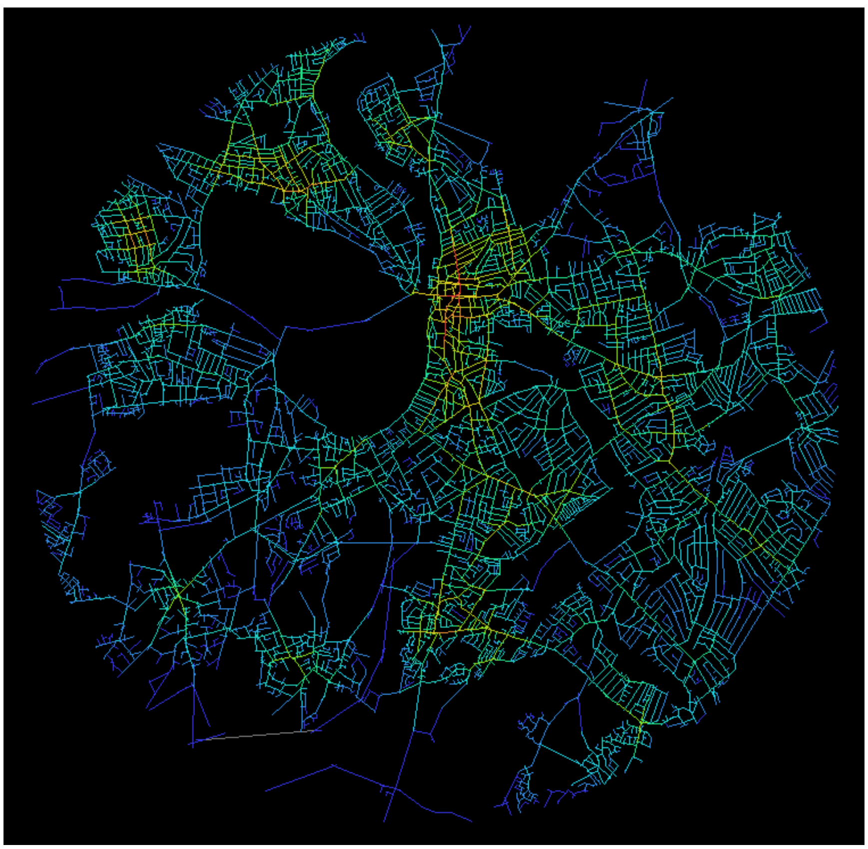


Figure 19 Surbiton axial model integration radius 800m

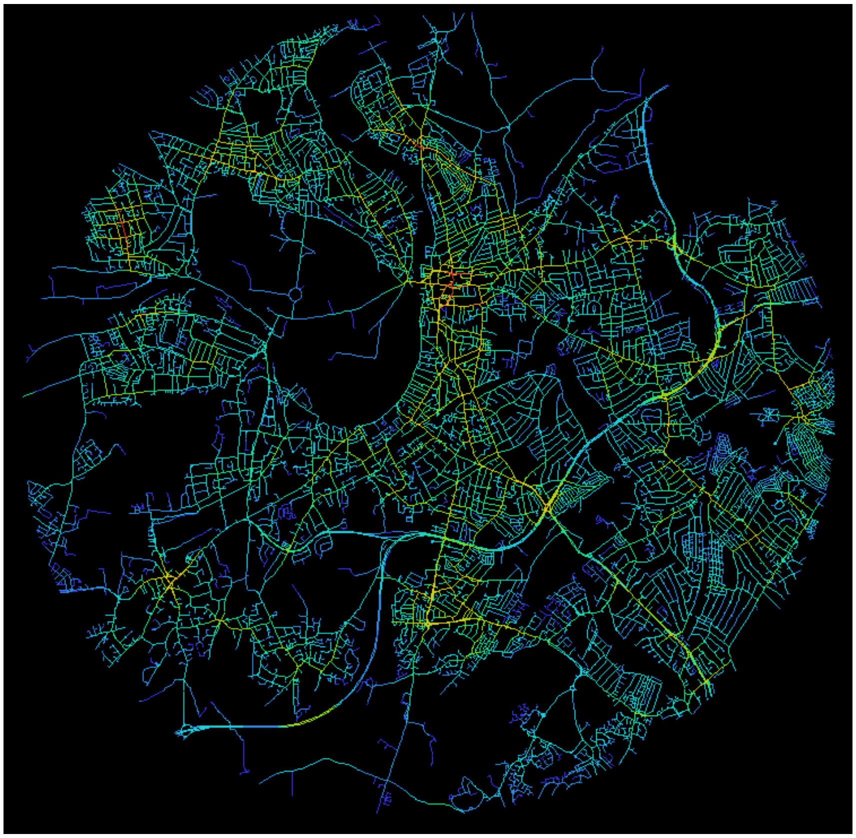


Figure 20 Surbiton ITN model integration radius 800m

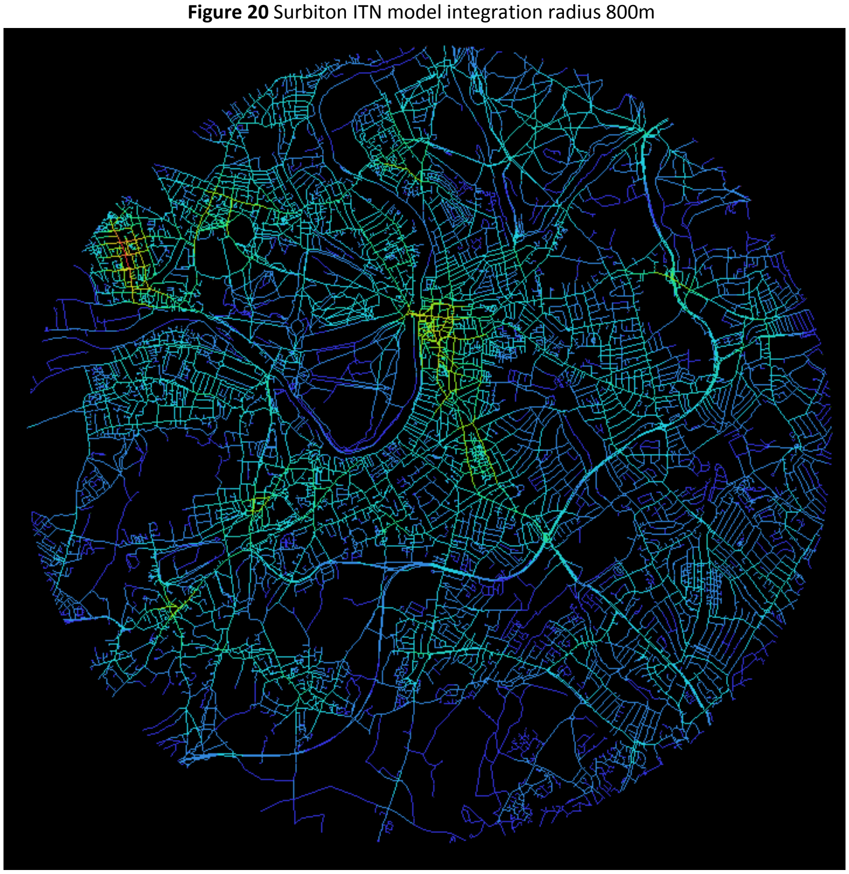


Figure 21 Surbiton OSM model integration radius 800m

4.3 Topological Step Depth Analysis

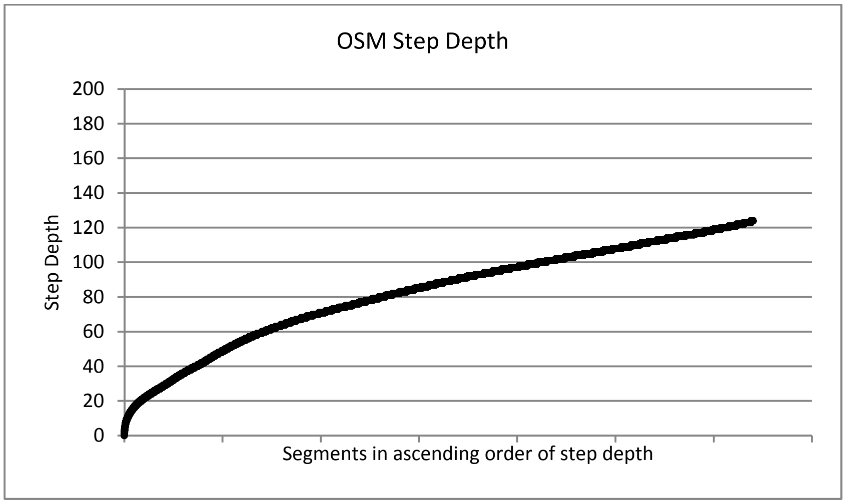
Table 3 presents the topological step depth characteristics of the OSM, ITN and axial network models. The measurements in all three networks were taken from the segment in the centre of the network directly outside Surbiton railway station. Here the greatly differing complexity of their segmental representations is shown.

Topological Step Depth	OSM	ITN	AXIAL
Mean	90	197	49
Median	94	204	50
Maximum	197	422	90
Mode	106	224	44

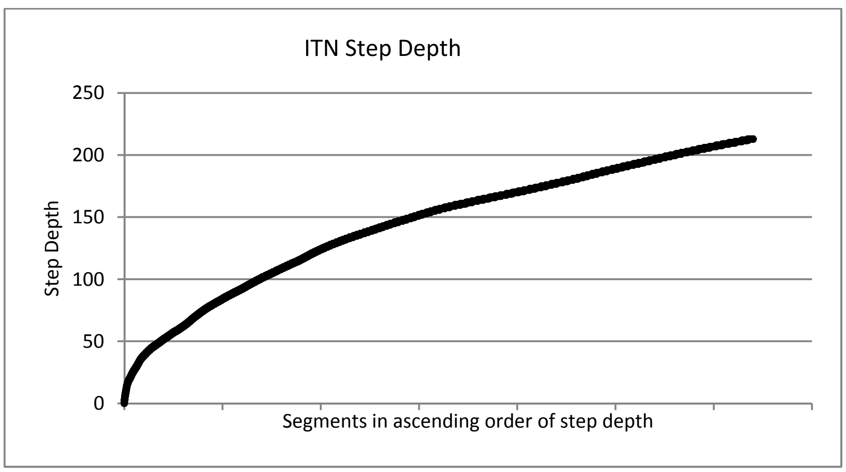
Table 3 Topological step depth characteristics of network models

The ITN network model of the road network is made up of a far greater number of segments. The average step depth for the ITN model is more than twice the OSM model and four times greater than the axial model. This highlights the intricacy of the ITN model that attempts to represent the smallest changes in orientation of the street structure through the usage of many more segments to describe the network structure. The similarity of the relationship between values in table 3 is also relevant. All three models share similar relational properties between their respective mean, mode, median and maximum.

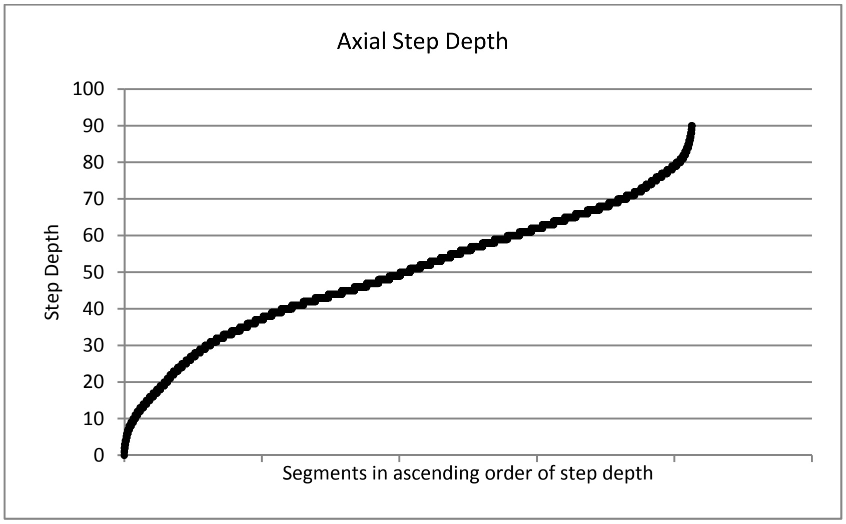
Although the step depth values are very different between the models they all have a common structure to the distribution of the step depth values. Graphs one to three show the step depth value of every segment in each model sorted according to their step depth value. These graphs all show the same shape of distribution for the values. This highlights the similar structural properties that the network representations have. The three models represent the street structure in different ways yet the structure of that representation is similar across all three models regardless of the detail or purpose of their representation.



Graph 1 OSM step depth distribution



Graph 2 ITN step depth distribution



Graph 3 Axial step depth distribution

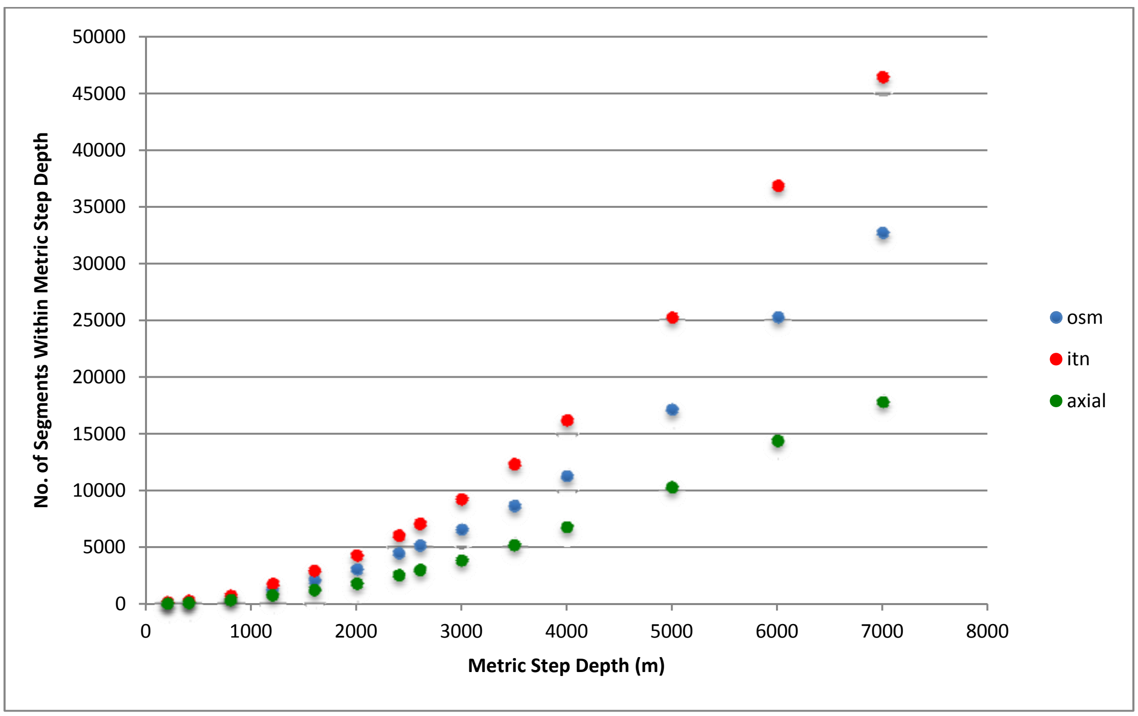
4.4 Metric Step Depth Analysis

Metric step depth analysis further illustrates the similarities and differences in the network representations. In table 4 the number of segments that are within a specified metric step depth are shown. Again we see the difference between the three networks in terms of number of segments is very large. At 7000m the ITN model is comprised of 46,442 segments whilst the axial model has 17,812 segments. .

Metric Step Depth (m)	**OSM**	**ITN**	**AXIAL**
200	54	135	18
400	159	255	77
800	518	706	325
1200	1265	1747	755
1600	2074	2905	1210
2000	3036	4265	1774
2400	4459	6025	2523
2600	5139	7066	2984
3000	6559	9232	3824
3500	8647	12337	5178
4000	11274	16220	6776
5000	17167	25196	10292
6000	25248	36813	14403
7000	32669	46442	17812

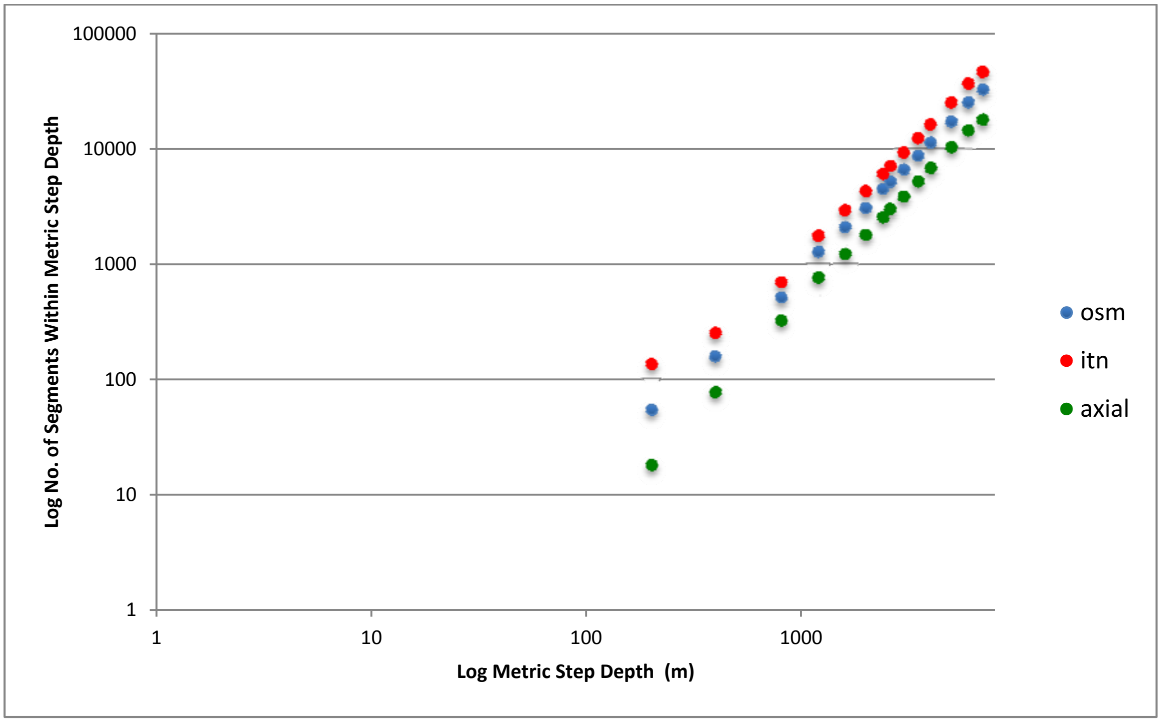
Table 4 Total number of segments within specified metric step depth for each network model

Whilst the raw numbers show a very different image of the three networks they are in fact very similar. Graph 4 shows the values of table 4 plotted as a graph.



Graph 4 Number of segments within specified metric step depth for OSM, ITN and axial models

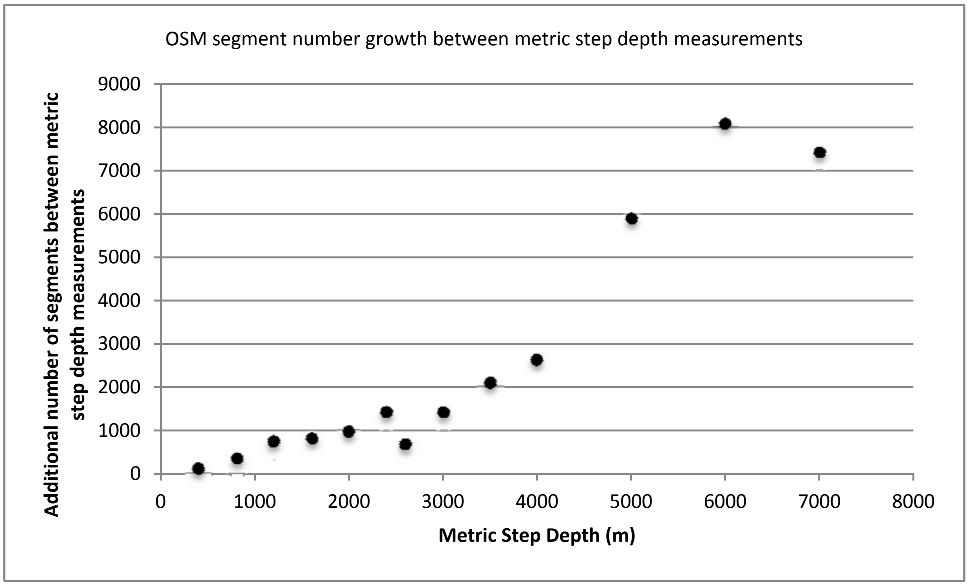
Graph 4 shows all three models display the same structure to the growth of the complexity of the network over the space that they cover. It shows that the level of detail in which they render the street network is consistent across scales. This is better shown on a log-log plot of the values where the similarities between the models' growth pattern is clearer, as shown in the graph5.



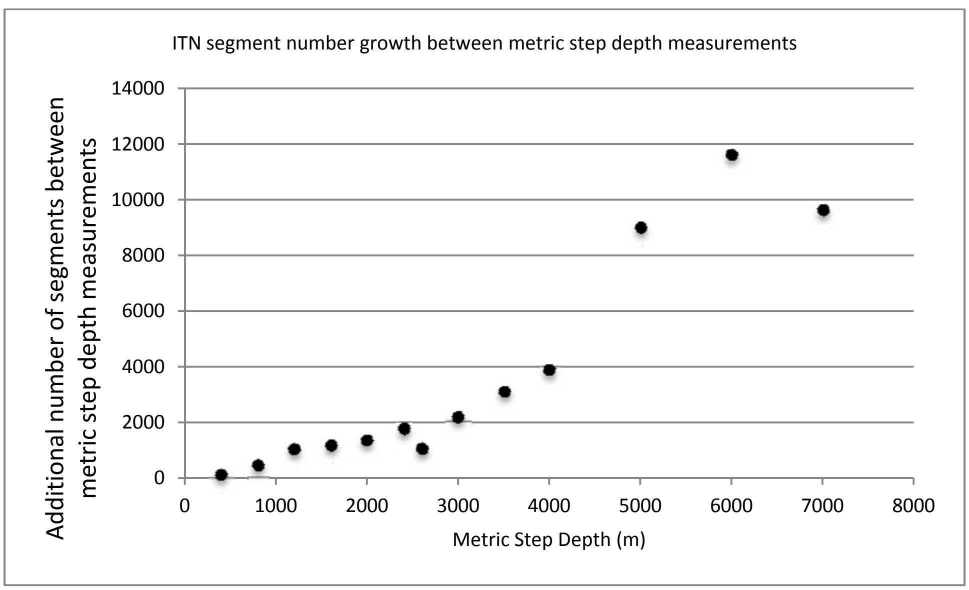
Graph 5 Log-Log plot of number of segments within specified metric step depth radius for OSM, ITN and axial models

This indicates that the OSM, ITN and axial models all scale over space in a consistent fashion. This might indicate that as representations of the street network they are in fact the same and do not represent a fundamentally different structure of city space when using a segment model. If they were a representation of a fundamentally different spatial structure one would not expect them to be so similar. The road centre-line representations of the OSM and ITN models would be expected to be different to the axial model, but this is not the case. The differences that remain are the resolution of detail of the street structures (as shown in the step depth analysis) and the detail in the geometric representation of the relationship between street segments. In both these cases the ITN is the most detailed account of the structure of the street segments and the geometric relationships between segments, OSM is the second most detailed and the axial model is the least detailed.

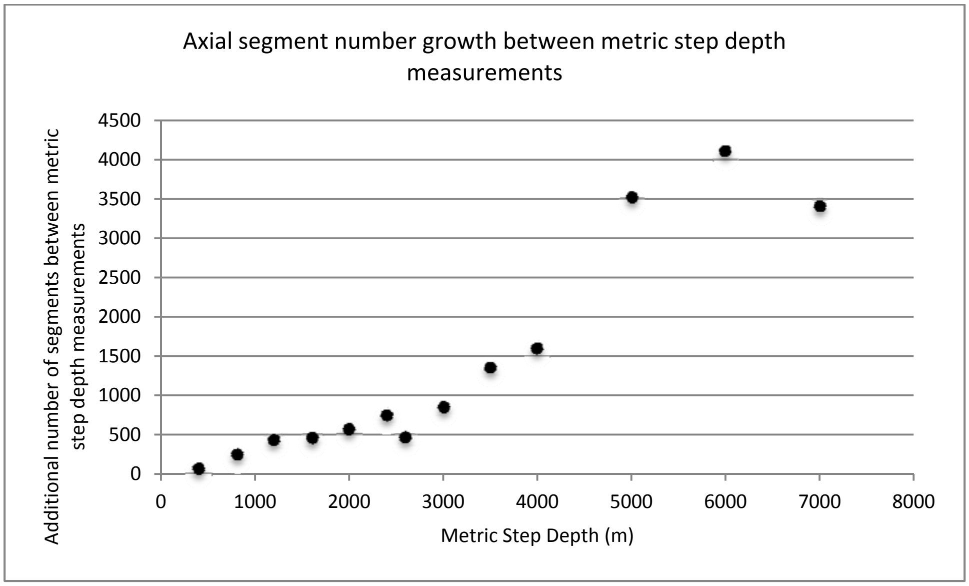
The similarity of how the network representations scale over space is further highlighted by graphs 6 to 8, that show the number of segments that are added in each model between each distance in metric step depth that was measured, as can be seen the segment structure of the street network grows in respect to metric step depth in a nearly identical fashion in each model.



Graph 6 OSM change in segment number between metric step depth measurements



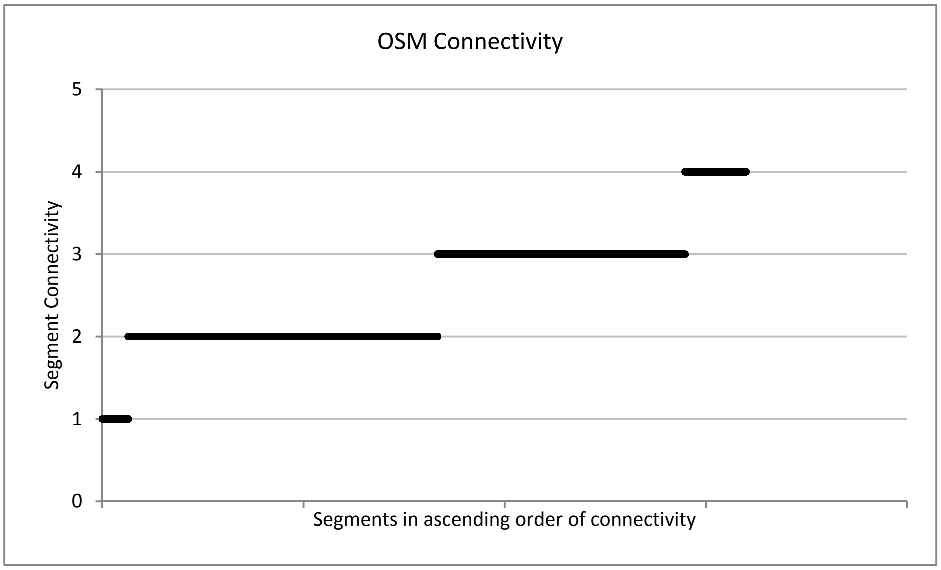
Graph 7 ITN change in segment number between metric step depth measurements



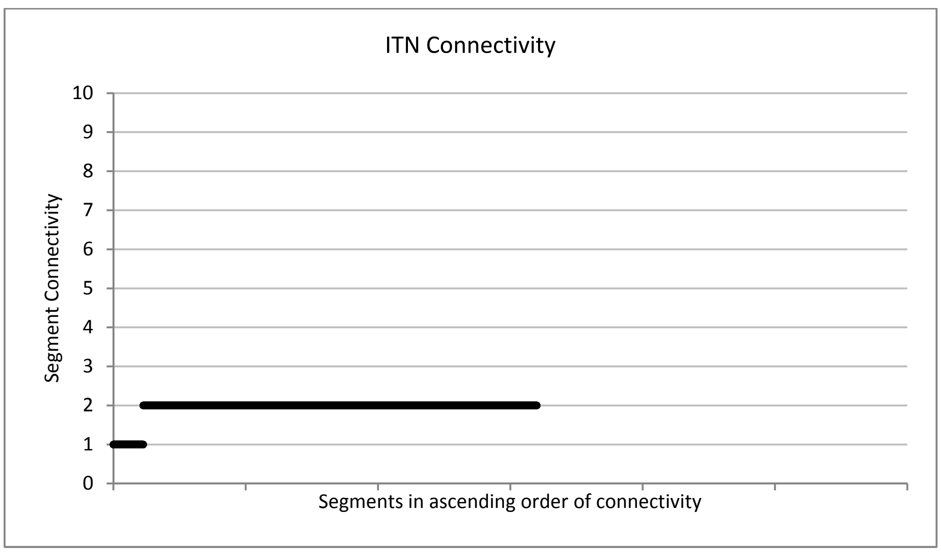
Graph 8 Axial change in segment number between metric step depth measurements

4.5 Connectivity Analysis

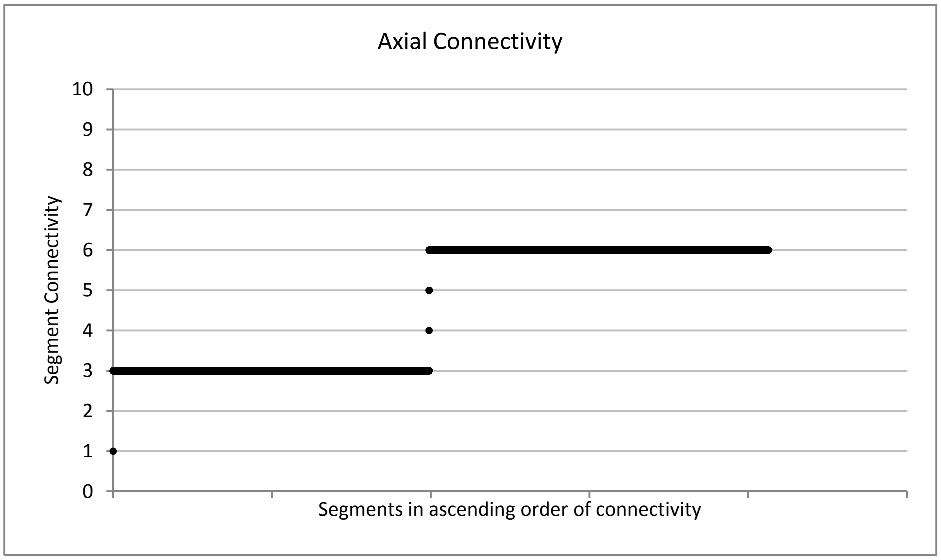
Graphs 9 to 11 show the connectivity of all segments in each network model. From these graphs it can be seen that the OSM and ITN have a very similar distribution of connectivity, in both cases connectivity values of two are the most common and overall show a normal distribution of values. They also demonstrate a coherent structure to the connectivity across the whole network. In contrast the axial network model does not show a similar distribution of connectivity values. With a few exceptions all the segments have connectivity of three or six. Whilst the step depth and metric step depth show that all three models are very similar the connectivity values show that in this regard the axial model has a very different structure. The axial network does not have coherently structured connectivity across the network. The segmented axial model is structurally similar to the OSM and ITN road centre-line models but it does not have the same relational structure between segments as the road centre-line models. Again this points to the possibility that the axial models' account of relationships between segments is very different from road centre-line models and possibly problematic for angular segment analysis.



Graph 9 OSM connectivity structure



Graph 10 ITN connectivity structure



Graph 11 Axial connectivity structure

4. DISCUSSION

The results of the analysis reflect the fact that the ITN network is primarily a representation of the *road* network; whilst the axial and OSM models explicitly set out to include pedestrian networks, thus constitute a representation of the *street* network. This was borne out in the analysis where the main road structures within the ITN data maintained their importance across the scales of analysis (figures 10-11 and 13-14). This in itself is not unproblematic as it raises the question as to whether these features should be indicated to be relevant to small scales (a topic of further investigation). It could be hypothesised that they remain relevant as they are access points to a non-local network and in effect they represent an end point to a journey within a local network that then continues on within a different network structure.

The main problem with the ITN road centre-line data is the need to remove features such as traffic islands (fig 3) that create breaks in otherwise continuous lines. For space syntax applications such traffic management features are incongruent with the required description of the street and the result of including such features is that choice and integration values are distorted unduly. Apart from this issue the ITN network is the most consistent and for the purposes of our study, forms an ideal basis for the analysis of the road network. It is also the most nuanced account of the geometric properties of the urban network - which may be of benefit to angular segment analysis.

The UK national mapping agency has also now recently released an Urban Paths network dataset to supplement the ITN road network data. This extra dataset includes all pedestrian and cycle routes through the urban fabric. This shows the growing appreciation that the network representation of London that has been the norm for many years is not a complete image, but a partial one and a representation of the normative view of the street system as serving the car. With the creation and release of this new dataset the urban system will be able to be seen and analysed as a complex interplay of car and pedestrian movement through all the possible routes that the network affords rather than primarily an automotive road network that national mapping agency data has afforded thus far.

The OSM dataset is more problematic for usage in space syntax analysis as there is a lack of consistency in the accuracy and coverage of the data. Whilst it can theoretically be used for analysis in urban areas that have been well mapped, it cannot replace official mapping data nor can the results be relied upon unless the dataset is comprehensively checked to be a complete representation of the area being studied. The main use that OSM data provides is the supplementation of official data for small local areas. It would be particularly important as a supplement to official network maps that exclude pedestrian pathways (as has been the case in the UK until recent times). It may provide new information that is not officially recorded and give insight into the local area from the perspective of citizens rather than government agencies. The fact that this includes non-road structures and it is created by people on the ground or viewing the city planimetrically from aerial images and they choose to include non-road network elements, demonstrates that peoples understanding of the city is not that one that focuses on the road as the primary and sole space of movement potential in the city. This creates a lived representation of the city network form. This can be used as an indication as to what should be included in a network representation from the perspective of those who inhabit the space under analysis.

The axial model of urban space is a separate entity to the other models. It does not seek to replicate reality but represent a unique aspect of urban space. This has been proven to be effective in numerous studies but with the wide spread usage of angular analysis and dual analysis of the network and its surrounding environs the axial model needs to be tested to verify its contemporary utility. If it is found that we can improve upon the axial model then we should seek to do so. The analysis of the topological and metric step depth clearly shows that as a representation of space in segmented form the axial model is not different to the OSM and ITN models. They all scale across space in a similar fashion and do not represent fundamentally different spatial structures; they do however represent the geometric and segmental relationships very differently. The connectivity analysis highlights the differences between the models' segmental relational structure. The axial model is not as clear in this regard and may not be a reliable representation of connectivity. The road centre-line representation may well be a more accurate representation of the segmental structure of urban space.

5. CONCLUSION

Through the discussion and analysis of the different models of urban environments that we have at our disposal it is clear that work has to be done to reconcile the underlying network representation with the analytical toolkit of space syntax. Whilst we can create and analyse models that are accepted and easy to justify on theoretical grounds it is necessary to revisit the fundamental building block for the practical analysis of urban environments. Two key factors that should drive this are; the wide spread adoption in space syntax research of angular segment analysis techniques, that might be better served by detailed road centre-line accounts of the geometric relationships between line segments and the need to analyse the city network and the surrounding urban environment as one system. This would also be more readily facilitated by road centre-line representations that are spatially congruent with the urban built form.

This paper has sought to explore the issues of network representation but it is simply a starting point for further research. The future research directions that could be of great use to the field as a whole are to seek to understand what the optimal model of the street network is in regards to land use, pedestrian movement and vehicular flows. Whilst a model can be created that correlates with these variables it is necessary to find what the optimal model is: not simply one that correlates but the one that correlates better than any other.

This also highlights questions of what should be modelled. The OSM data highlight the impact of including pedestrian routes, but should they be included? What is the impact of their inclusion? Do urban routes through un-constituted spaces such as parks warrant inclusion? How does the detail of geometric and segmental representation effect analysis outcomes? These questions are the broad questions that need to be answered in order to ensure space syntax continues to be seen as a strong analysis tool within the entire urban studies realm.

The comparative analysis also highlights the fact that a comprehensive model that includes footpaths in open space puts these on an equal footing with other pedestrian routes. The potential for such a model for allowing planners and designers to understand how an area functions for spaces of movement and economic activity could be quite significant. Such a model may give planners insights into how and where to develop the urban fabric. By doing, so the utility of network structures that currently exist is maximised and potential is released in the urban structure without large-scale urban reconfiguration.

How we choose to represent the real world through data is a vital task that cannot be overlooked. The axial line laid the foundations for the discipline of space syntax and serves a very powerful purpose in how it represents the linkages between space in the city, but if the axial line as a representation can be substituted for a more widely understood representation that brings with it a greater detail to the analysis and that can be analysed with space syntax tools– arguably this model might be the preferred method in the future. This paper has demonstrated that a model based on road centrelines – so long as its traffic management detail is simplified and so long as it includes pedestrian pathways - has the potential to provide a robust and replicable model that both: captures spatial configuration for individuals as they use and understand their local environment; as well as reflects the configuration of the local environment within the context of an entire city.

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