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ROAD CENTRE LINE SIMPLIFICATION PRINCIPLES FOR ANGULAR SEGMENT ANALYSIS

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ABSTRACT

Angular segment analysis is one of the most fundamental analyses in space syntax practice that helps understand movement, land-use and other socio-economic patterns. It was initially applied in axial segment maps and later was used in road centre line maps as an attempt to overcome the 'segment problem' (Turner, 2005). Furthermore, the growing need to examine large urban systems has led to the wide use of road centre line maps instead of the previously hand-drawn axial maps. However, this transition to such datasets has lacked systematic studies on what is required to convert a road centre line map into a segment map, in order to produce reliable results of the angular segment analysis. To date, no consensual methodology has been developed within the space syntax community.

This paper attempts to clarify what a road centre line segment represents spatially and suggests principles and rules to simplify a road centre line map to a segment map. Based on previous experience, the simplification mostly relies on the following two principles: reducing the number of nodes in the dual graph representation of a street network; optimising the angular change between adjacent nodes of the dual graph when space allows it.

In addition to the above general principles, we discuss rules for special and complex cases, e.g. roundabouts, underpasses, bridges etc. To evaluate these rules and principles comparisons are carried out between traditional axial and RCL unsimplified and simplified segment maps, to develop a good understanding of how changes in dual graph representation of a street network can affect space syntax measure of 'choice'. Correlations of angular segment choice values are performed in order to evaluate which simplification technique can approximate better the axial representation of actual human activity.

The results show that using a raw road centre line data set raises several inconsistencies in the analysis results, and the progressive application of the different simplification techniques brings these results closer to those of a traditional axial segment map, and thus to a better representation of socio-economic activity. The purpose of simplification is to minimise inconsistencies to ensure maximum accuracy in the results of angular segment analysis.

KEYWORDS

Simplification, road centre line map, angular segment analysis, GIS

1. INTRODUCTION

1.1. MOTIVATION

Given the growing need to grasp the complexity of large scale systems and the availability of big data, such as Road Centre Line (RCL) maps, techniques need to be developed to overcome the gap between different network representations of urban streets and guarantee the rigorous results of the analysis. As Dhanani et. al. (2012) emphasise the big availability of RCL maps can promote the engagement of space syntax to a wider audience and thus expanding space syntax research and applications.

RCL maps cover almost the whole of the globe and are usually free (e.g. OSM; TIGER; OS) and despite their inconsistencies in data representation (Dhanani et al., 2012, p.5) previous research and application have showed that syntactical values can be approximated if derived from a RCL map (Dalton 2001; Turner, 2007).

One of the most popular analyses in space syntax is segment angular analysis (Turner, 2000). Angular segment choice or betweenness centrality as known in graph theory, is a graph measure that can describe the potential of movement of an axial segment map based on its configurational properties. Angular choice is calculated as the total number of least angular paths that pass through a segment, when every segment in the system is an origin and a destination. While studies have proven that angular segment choice can be associated with movement patterns (Turner 2005, p.146; Hillier & Iida, 2005), commercial land uses, land use density, town centres' vitality, high streets' patterns (Chiaradia et al., 2012; Vaughan et al. 2010) and property values (Chiaradia et al., 2013), there is no systematic approach or established methodology of how angular choice analysis should be applied when using a RCL map, leading to possible inconsistencies in representations and thus misleading or poor analysis outcomes.

Therefore, we are interested in exploring the effect of different street network representations on angular segment choice. We hope this paper to contribute to validate the suitability of RCL maps for angular segment analysis and make space syntax analysis more easily approachable by different urban analysts eliminating doubts on the analysis outcome. The first question posed is if simplification is needed. And the second is what simplification process needs a RCL segment map to approximate an axial segment map.

1.2 MAIN OBJECTIVES

Although RCL maps are widely used in space syntax, there is limited research on how RCL maps can be used for angular segment analysis in particular. Questions about the suitability of RCL maps started being posed soon after the introduction of angular segment analysis by Turner in 2000, but to date no consensus has been reached.

The paper's main objective is to test whether RCL maps are suitable for angular segment analysis and experiment on choice measures variations between different street network representations. Based on the assumption that RCL geometric relations can be transformed to simulate axial geometric relations the paper seeks to establish a coherent methodology of applying angular segment analysis to RCL maps. Namely, we hope to shed light on what a RCL segment may represent spatially, how this differs from an axial segment representation and how a RCL segment should be treated prior to angular segment analysis.

The first section begins with setting the background of this research paper by overviewing previous studies using RCL maps with space syntax analysis. The next section presents the method undertaken by the authors, using comparative analysis and statistical methods. The comparisons are made between axial and unsimplified RCL maps and between axial and simplified RCL maps. The intention is to go through a series of simplification processes of a RCL map, and study their impact on the analysis. We believe that this method reveals if geometrical modifications to RCL data are needed prior to analysis and how these can be formulated in a coherent simplification process.

2. BACKGROUND

2.1 ANGULAR SEGMENT ANALYSIS IN SPACE SYNTAX

Axial maps have been used for 30 years to analyse the configuration of urban spaces. The analysis of their network properties has proven to be good proxy for movement, land use, interaction, land value and crime patterns. Their unique representation as the longest and fewest lines of visibility and accessibility in continuous spaces is translated in a dual graph where every segment is a node and every connection between segments is an edge with metric, topological or angular cost (Hillier and Hanson 1984). They are usually hand-drawn which can be a time-consuming process especially in case of metropolitan areas.

The angular segment analysis in particular has been used since the beginning of the millennium and is related to the cognitive behaviour of a person moving in space who is likely to choose the least angular path when getting from A to B. Assuming that every segment is an origin and every other segment is a destination choice is the total number of overlapping trips passing through a segment (Turner, 2000). Calculating choice can be computationally very intensive but the value of angular analysis (Turner, 2000) is that it is a more fine-grain analysis than mean depth analysis, where the focus is moved from the average number of turns to the sum of angular change in one's journey.

Turner (2000, p.8) when introducing angular analysis points out that 'angular analysis does not actually fit as succinctly as this into the space syntax paradigm, as the layers which form 'representational' and 'configurational' are not clearly defined in angular analysis.' He continues by highlighting areas where problems of representation can skew the results of this method; 'firstly, the axial map is drawn by hand and therefore the result depends on the skill of the cartographer. Secondly, there may be unnatural weighting to highly spatially complex areas of the space (where large numbers of axial lines are required).' Such questions have opened up the exploration of other representations of the street network.

2.2 ROAD CENTRE LINE MAPS IN SPACE SYNTAX SO FAR…

The discussions on representational issues of axial maps for angular segment analysis started in parallel with the conceptual and computational advances on large scale urban analysis. Space syntax community gradually shifted to RCL maps, in an attempt to look for other datasets that can describe the configuration of street networks in a similar fashion as the axial maps. RCL maps, provided by web mapping services either authoritative (e.g. OS, TIGER etc.) or voluntary (e.g. OSM) are widely used for mapping the street network of cities, analysing its properties and simulating urban activity patterns.

RCL maps represent networks of different modes of movement and not spatial and visual connections as axial maps. In comparison with the axial representation, the RCL representation does not take into account the width of a street as an axial line would do. In a RCL map every street segment between junctions is drawn as the medial axis of the street. Another major difference is that a RCL starts and ends at an intersection where it meets other RCLs. An axial line does not break at an intersection if the space it is traversing is continuously visible and accessible. This means that the axial segments will have no angular differences between them, whereas the RCL segments will still have small angular changes between them. For axial lines space is continuous when is constantly visible and accessible, whereas for RCL space is continuous between decision points i.e. intersections of roads. Despite such fundamental differences, RCL maps continue to gain acceptance within the space syntax community (Dalton et al., 20003; Turner 2005; Dhanani et al 2012).

Systematic research on the effect of applying axial and segment analysis on RCL maps in space syntax analysis started the last 15 years and has illustrated encouraging results. Dalton's (2001) research supported Turner's idea (2000) to explore new graph representation of street networks. He suggests that 'it might be best to begin by reviewing if it is necessary to abandon axial lines when looking at new forms of processing.' His research shows that the integration of GIS data with axial analysis may benefit more from other representations than the axial map.

Another piece of research published by Dalton et al. two year later, showed that when 'traditional syntactic analysis [is] applied directly to TIGER representations of US cities [it] will give results that are quite misleading as compared to the results that would have been obtained by normal syntactic analysis.' Despite that when fractional analysis was used to approximate topological axial analysis in a RCL map, the two representations became syntactically similar. This has provoked other research paradigms where RCL maps become to take over. Turner in 2005 further questioned the necessity of axial segments over RCL segments. He showed that angular segment analysis can be applied in RCL maps and produces good correlation with vehicular movement data although he points that when moving from smaller to radius n, the correlation becomes weaker.

Although big steps were made to validate RCL representations in configurational analysis, representational issues were still acknowledged within space syntax community. Attempts to generalise the values of choice to allow comparisons between different systems have highlighted the importance in the inclusion of depth in the calculation of choice (Hillier et al., 2012). Other methods like weighting choice values by segment length have been attempted (Dhanani et al 2012; Dalton 2003) to "compensate for the numerous segments that RCL data have" (Dhanani et al 2012, p. 9). Dhanani's et al. comparative analysis of axial and two RCL maps - ITN layer from Ordnance Survey (OS) and OpenStreetMap (OSM) - has highlighted that the principal network structure is identified by all three types of maps at radius n, but the smaller the scale the greater the differences become. They showed that "the representation of the network changes the analytical result" (p.17) but different street network representation may have more similarities than expected; "osm, itn and axial models all scale over space in a consistent fashion". Thus, the issue of 'readiness' of a RCL map that Dhanani et al. (2012) raise, is the main focus of this study.

3. THE METHOD

The maps used for this study are an axial segment map of London provided by Space Syntax Ltd to be compared with two types of free RCL maps of London, Open Roads from Ordnance Survey (www.ordnancesurvey.co.uk), the UK government topographic and mapping agency and OpenStreetMap (OSM), a free volunteered geographic information (VGI) online mapping service, using data samples obtained from GEOFABRIK (www.geofabrik.de).

In preparation for the experiment, the maps are cropped to 7 kilometres radius around Central London. This is to ensure that we will still be able to study city-scale radii and analyse the networks in reasonable time using DepthmapX. The RCL-OSM dataset is filtered based on the 'fclass' attribute so that all lines that do not correspond to pedestrian movement are not included, with such categories as: 'cycleway', 'track_grade' and 'unknown'. Categories 'footway', 'pedestrian' and 'path' were also removed as they were often over representing spaces such as sides of pavements or footpaths in parks of minor city-wide importance.

Moreover, all RCL maps are segmented using NetworkSegmenter QGIS plugin (Versluis and Gil, 2016) and cleaned using RoadNetworkCleaner QGIS plugin (Kolovou and Gil, 2016). The cleaning process involves validating the geometries so that they are suitable for GIS analysis, for example invalid geometries, including points, duplicates and overlaps and isolated geometries. The RCL-topology-cleaner also corrects topological errors of RCL maps. These errors might be lines intersecting at common vertices or broken lines between intersection. In these cases, the tool breaks the lines at the shared vertex and merges lines into polylines from intersection to intersection. Another important part of this process is snapping disconnected geometries. As Dalton et al. (2003) point out "one line segment might terminate at coordinates 10222.0222, 3329983.2 and another might begin at coordinates 10222.0221, 3329983.2" which creates invisible disconnections between segment. For this reason, a precision of 6 decimals has been applied as a snapping tolerance to all maps.

It should be noted that the necessity of the RCL-topology-cleaner tool mostly applies to OSM, as the dataset is not as rigorously validated as the Open Roads layer. This is expected due to the VGI nature of OSM; different volunteers usually have different perceptions of space, different views on when a space should be included or not and different ways of drawing.

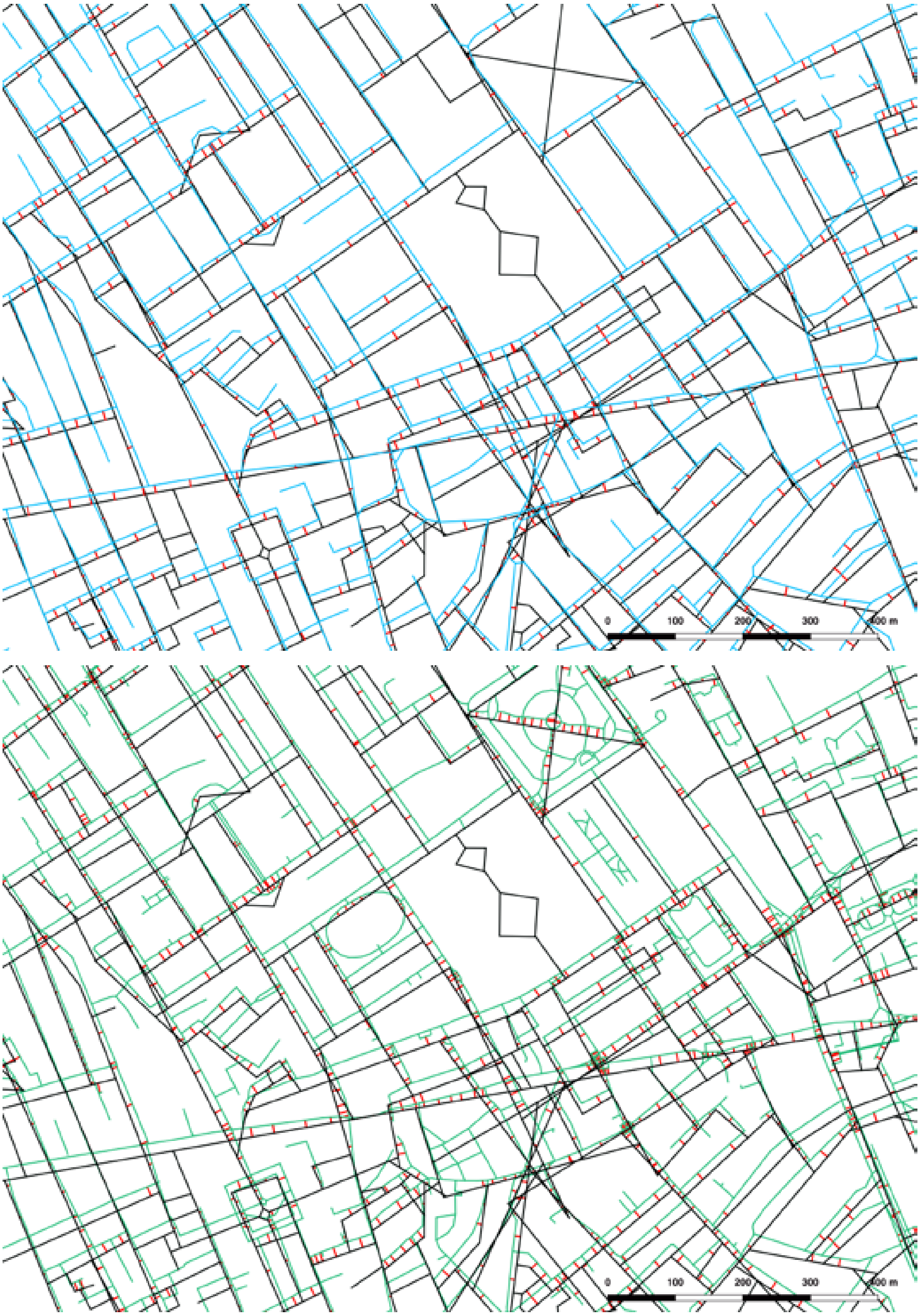
The study is made up of three experiments comparing between axial and RCL where the RCL maps are: unsimplified (Open Roads and OSM); simplified with Douglas-Peucker algorithm (Open Roads and OSM); simplified with Douglas-Peucker algorithm and proposed modelling rules (only Open Roads).

The first experiment uses the Open Roads and OSM unsimplified. The second experiment simplifies the RCL maps using the Douglas-Peucker algorithm. This algorithm is used in cartographic generalisation to reduce the number of vertices that represent a digitised line. Here we use this algorithm to reduce the number of vertices of polylines between intersections. For the final experiment, we take the Open Roads map simplified with Douglas-Peucker algorithm and further simplify it by hand. A set of five modelling rules are applied which have come up as cases with special particularities on how angular change may affect choice at local and global conditions. The rules follow the principles of the axial map, where the fewest and longest axial lines are drawn. Below follows a short description of each rule and examples in figure 5.

1. **Roundabouts:** Roundabouts are simplified with straight links between consecutive entries or exits to the roundabout. Roundabouts with buildings in the middle can be treated similar to urban blocks.
2. **Staggered junctions:** When two almost parallel lines can be approached by a slight change in direction of movement a diagonal line can be drawn.
3. **Squares:** Connections are drawn between all "entry" and "exit" points to a square. If two points are directly visible and accessible a straight link is drawn between them. The cartographer should attempt to draw the least number of lines with all possible connections.
4. **Underpasses, overpasses and bridges:** This rule is the easiest to implement as lines of RCL maps cross but not intersect where there is a level difference. Thus, the only requirement is when using DepthmapX that no unlinks layer is loaded and that the RCL map is directly converted to segment map.
5. **Parallel lanes:** In a RCL map different lanes typically found in motorways and highways are represented by two parallel lines. An axial map is not directional. In these cases, parallel lanes are drawn as a single medial line.

The comparisons across the three experiments are made for basic descriptive statistics and statistical analyses: **primal graph statistics** - number of segments, numbers of intersections, total segment length; **dual graph statistics** - number of nodes (segments), number of edges (segment to segment connection), connectivity distribution, angular connectivity distribution; **analysis correlations** - spearman rank correlations between angular segment choice at 800m, 1200m, 2000m, 3200m, 5000m, N.

To make comparisons between analysis values of an axial and a RCL map, link layers are created in PostgreSQL and PostGIS software using SQL scripts to spatially link the values of a RCL segment with the corresponding values of axial segments, when they are no more than 15 meters apart and do not have difference in angle greater than 14 degrees. Below is an example of such linkages for Open Roads and OSM.



— axial map

— Open Roads RCL map

— OSM RCL map

— Links

Figure 1 - Each RCL segment is linked to one or many axial lines

4. THE RESULTS

4.1 EXPERIMENT 1: AXIAL AND UNSIMPLIFIED RCL MAPS

Beginning with comparing the axial and the unsimplified Open Roads and OSM maps of London, their primal and dual graphs look very different (table 1). An OSM map has many more segments than an axial or an Open Roads map and a lower average angular connectivity in its dual graph representation. Moreover, most of the connections between segments of the three maps are at 0 or 90 degrees, but the percentage of connections to the total changes. Axial maps have many more segments connecting at angles close to 0 degrees, whereas the RCL maps have fewer connections at 0 degrees and more connections at 90 degrees (figure 2). Urban space in RCL maps is represented more fragmented and not as continuous as in the axial map.

Map	Primal Graph			Dual Graph			
	number of nodes	number of edges	total segment length (m)	number of nodes	number of edges	connectivity (average)	angular connectivity (average)
Axial	43,422	66,090	3,185,002	66,090	147,979	4.48	60.29
Open Roads	51,837	60,854	2,880,571	60,854	96,046	3.16	52.88
Osm	173,469	194,445	4,330,880	194,445	280,616	2.89	45.83

Table 1 - Comparing the structure of the primal and dual graphs of an axial, an Open Roads RCL map and an OSM RCL map.

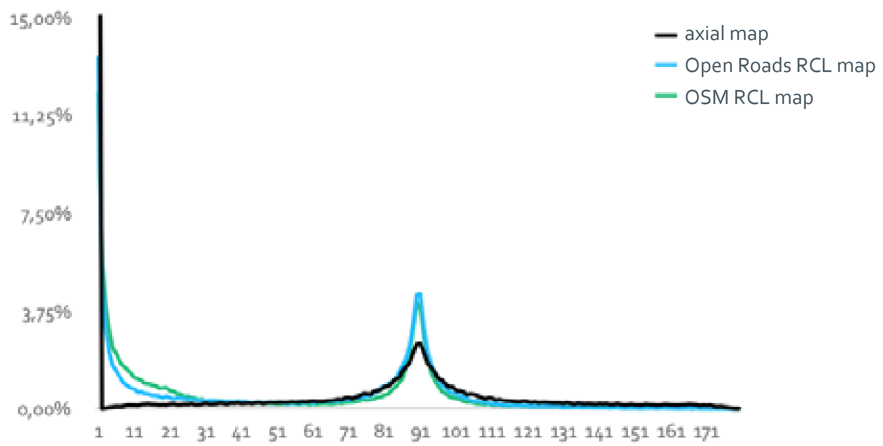


Figure 2 - Angular connectivity distribution of dual graph edges for axial segment map, Open Roads segment map and OSM segment map.

In addition to the chronological differences of the maps in comparison, another important factor to consider is the resolution of the maps. A traditional axial map has less number of segments than an OSM map and more than an Open Roads map. This certainly draws a very clear conclusion about the nature of the RCL maps. Since Open Roads is a dataset that originally comes from a detailed and complete dataset of the network in UK (OS ITN layer), it is a more generalised representation of the street network that has already undergone some process of validation and filtering. On the other hand, the voluntary nature of OSM is evident by the varied resolution in the geometrical representation of spaces. For example, the bridge in figure 3 is just a single straight segment in an axial map whereas in the Open Roads map it consists of three segments and in an OSM map of ten segments. In addition, the southwest river walk is absent in the Open Roads map, but drawn in much detail in the OSM and partly drawn in the axial map.

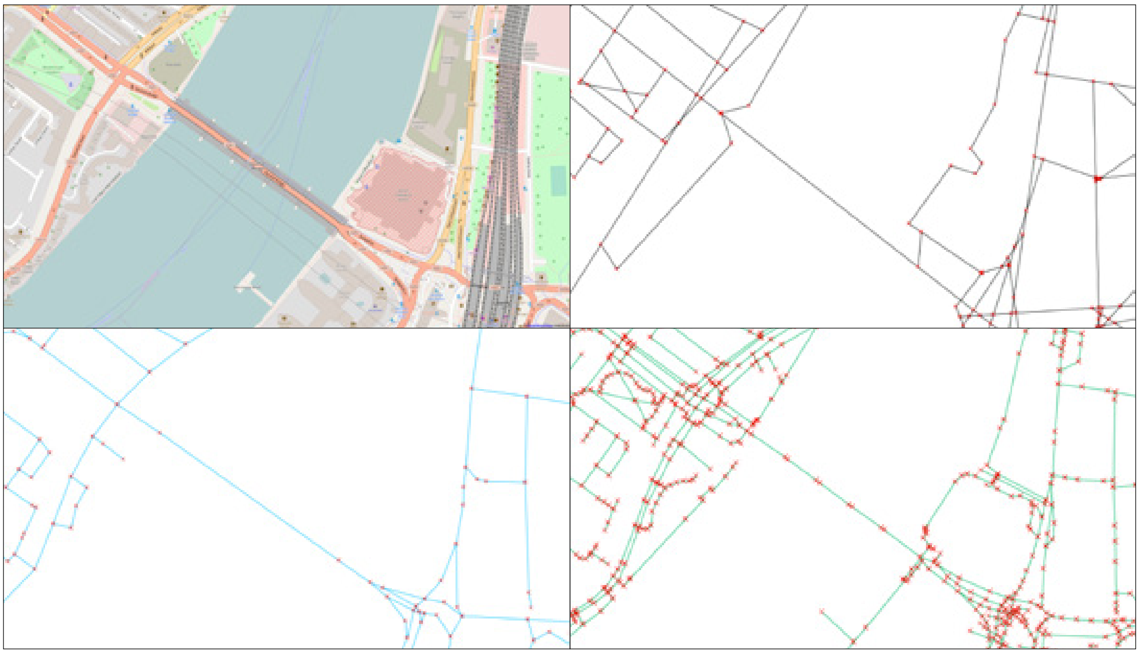


Figure 3 - Differences between the representation of spaces in axial and RCL maps. (1) OSM web map (2) axial map (3) Open Roads map (4) OSM map

Acknowledging such inconsistencies, the first question to answer is if the angular segment analysis of a RCL map using DepthmapX can produce similar results to an axial segment map analysis. Comparing choice values of the axial segment map and the RCL maps (table 3), the analyses look very dissimilar with more eminent differences at smaller metric radii. The weak correlation of the results of angular segment choice analysis between RCL maps, especially for a RCL- OSM, implies that it is probably inaccurate to analyse a RCL map as a raw dataset.

4.2 EXPERIMENT 2: AXIAL AND SIMPLIFIED RCL MAPS WITH DOUGLAS-PEUCKER ALGORITHM

Our second question is if RCL maps can be transformed to approximate an axial map. For this experiment, we use the Douglas-Peucker algorithm to transform the RCL maps. This transformation can minimise the excessive fragmentation of a continuous space as represented in a RCL map, especially one coming from OSM. As shown in figure 4, a rather uninterrupted continuous route from A to B is shown as four line strings with small angular changes between them. With Douglas-Peucker algorithm the angle when moving from A to B can reduce to even 0 degrees when a tolerance of 15 is used. Similar for journey from A to C.

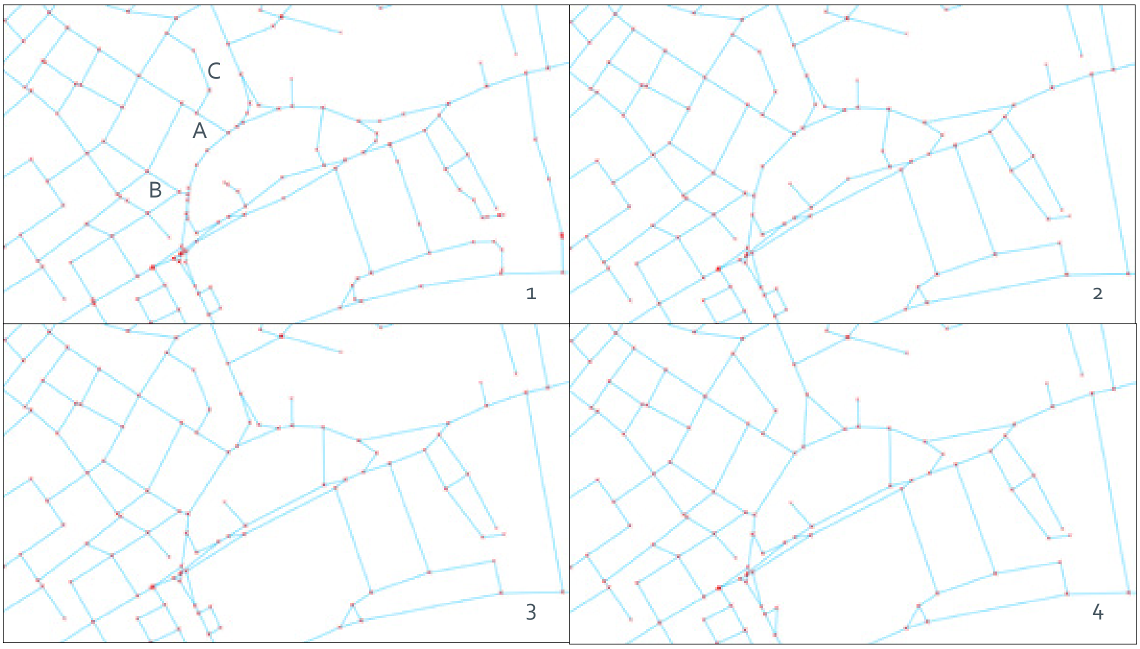


Figure 4 - Open Roads map unsimplified (1) and simplified with Douglas Peucker algorithm with tolerance 10 (2), 15 (3), 20 (4)

The result suggests that angular change calculations are optimised between continuous segments. When looking at the impact of the simplification on the structure of the RCL maps, it is obvious that their primal and dual graph shrink. The graphs become shallower, meaning that a space between two points of decision - intersections - is represented by fewer lines. This results in the increase of average angular connectivity; the nodes of the dual graph decrease but the connections between the nodes become sharper in angle.

RCL-OS	Primal Graph			Dual Graph			
	number of nodes	number of edges	total segment length (m)	number of nodes	number of edges	connectivity (average)	angular connectivity (average)
unsimplified	51,837	60,854	2,880,570.54	60,854	96,046	3.16	52.88
Douglas-Peucker 10	34,571	43,493	2,868,190.09	43,493	78,363	3.60	61.87
Douglas-Peucker 15	32,639	41,495	2,855,497.07	41,495	76,154	3.67	62.33
Douglas-Peucker 20	31,352	40,122	2,838,266.29	40,122	74,507	3.71	62.43

Table 2 - Changes in size and properties of the primal and dual graphs of unsimplified and simplified RCL maps (Open Roads)

RCL-OS	Primal Graph			Dual Graph			
	number of nodes	number of edges	total segment length (m)	number of nodes	number of edges	connectivity (average)	angular connectivity (average)
unsimplified	173,469	194,445	4,330,880.0	194,445	280,616	2.89	45.83
Douglas-Peucker 10	75,533	95,728	4,283,746.1	95,728	180,904	3.78	62.94
Douglas-Peucker 15	73,133	95,752	4,251,204.1	95,752	190,565	3.93	63.22
Douglas-Peucker 20	69,336	89,785	4,228,202.3	89,785	174,143	3.88	63.31

Table 3 - Changes in size and properties of the primal and dual graphs of unsimplified and simplified RCL maps (OSM)

The Douglas-Peucker generalisation seems to make a better proxy of the human cognitive wayfinding behaviour regarding the perception in change of direction of a person moving from one segment to another and how a person perceives a space to be continuous. The correlation coefficients between angular choice values of linked axial and Open Roads map and OSM map support this idea. The values of the simplified maps are closer than the ones of the unsimplified maps.

When looking at the percentage change of the correlation (table 3) the simplified maps improve greater at local scales where the gap between values of the axial and the unsimplified RCL maps was bigger anyway as shown in the previous experiment. However, at local radii the maps are still quite different. At city-scale scales of 3,200 meter or more axial and RCL choice values are closer. Regarding the simplification tolerance, the improvements are minor when increasing the threshold from 10 to 15 or to 20. Moreover, it seems that the simplification algorithm can address the sensitivity of the analysis to the over-representation of space in OSM by improving the correlation up to 40% in comparison with the unsimplified OSM.

4.3 EXPERIMENT 3: AXIAL AND SIMPLIFIED RCL MAP WITH MODELLING RULES

This section focuses on the Open Roads RCL map, which in the previous experiment had a better correlation with axial segment analysis. The Open Roads map from the previous experiment, already simplified with the Douglas-Peucker algorithm, is being further simplified in this experiment with modelling rules of special spatial cases typically found in a city's grid. These rules have been set in section 3 and have been applied manually to the model as they yet lack efficient simplification algorithms.

The modelling rules applied at roundabouts, staggered junctions, squares, underpasses, overpasses, bridges and parallel lanes all aim at reducing the number of nodes in a dual graph representation of the RCL map (figure 5). Geometrically speaking, when moving from intersection A to intersection B if no other point of decision of direction is involved in one's movement, a segment is drawn as a straight link between A and B. For example, if you entering a roundabout, where multiple directions of movement cross there is no choice in changing the direction of your movement until you meet the next entry/exit to the roundabout. Similarly, direct connections are drawn in open convex spaces where there can be uninterrupted movement and clear visibility between the surrounding junctions of a square. The angular deviation of trips between all possible entry and exit points of the square is optimised with a direct straight link. Although the rule of staggered junctions might conflict with the attempt to decrease depth in a RCL map it seems to account for slight changes of angle between almost continuous segments.

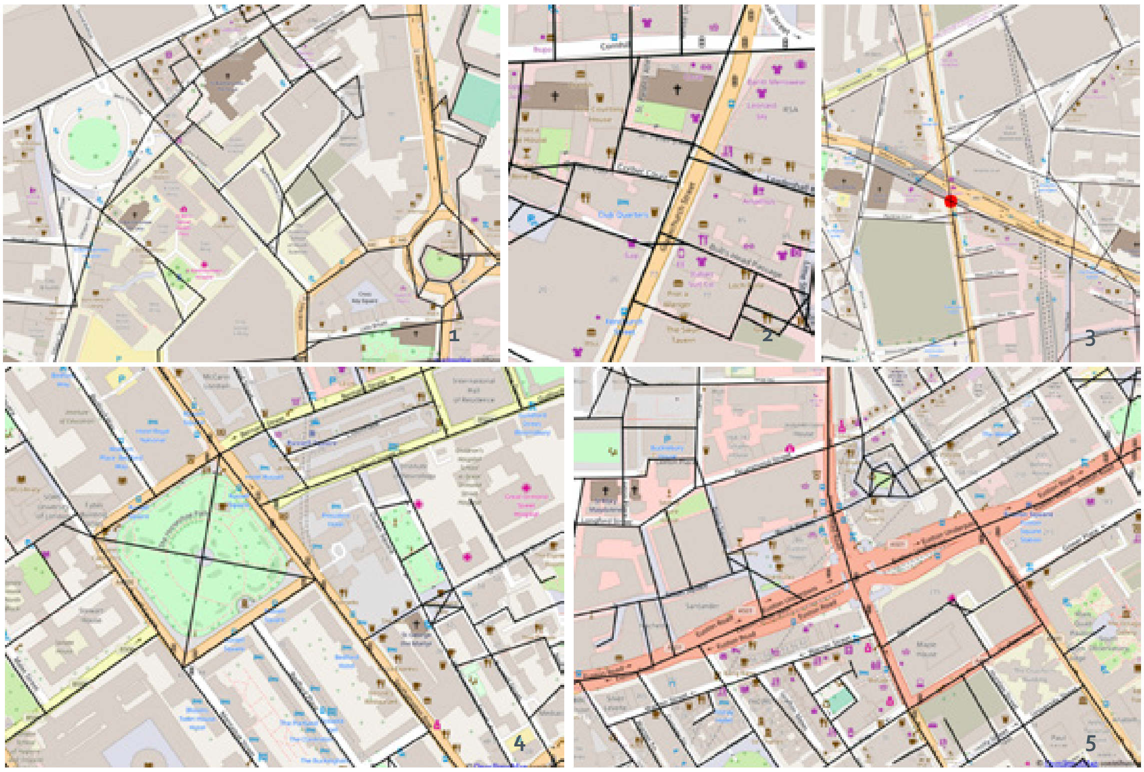


Figure 5 - Example of suggested modelling rules in London map (1) roundabouts, (2) staggered junction, (3) overpass, (4) squares and (5) multiple lanes.

The values of Spearman's rank correlation between the hybrid map and the axial map show great improvement at local scales from 800 m. to 2000 m. (table 3). However, at bigger scales of analysis there is a slight negative impact on the correlation. Naturally local analysis of street network configuration improves when local conditions are taken into account, but this is not necessary beneficial for larger scales of analysis.

The above findings imply that when analysing the angular configuration of urban systems at local scales, where trips are no further than 2000 metres, a necessary process of validation must be conducted by the analyst. This may involve drawing additional segments, deleting connections that may no longer exist and optimising angular changes between routes in the maps. This process of validation can be achieved by overlaying maps from web mapping services such as Google maps, OpenStreetMap etc. However a site visit is recommended.

	OS Open Roads				
	unsimplified	**simplified** (Douglas-Peucker 10)	**simplified** (Douglas-Peucker 15)	**simplified** (Douglas-Peucker 20)	**simplified** (Douglas-Peucker & modelling rules)
choice800	0.5673	0.598	0.6063	0.6113	0.638
choice1200	0.62	0.6454	0.6545	0.6586	0.6718
choice2000	0.6698	0.6872	0.697	0.7014	0.7055
choice3200	0.6997	0.7094	0.7194	0.7242	0.7173
choice5000	0.7075	0.7165	0.7267	0.7313	0.7149
choicen	0.6704	0.6867	0.6964	0.701	0.6839

	OpenStreetMap			
	unsimplified	simplified (Douglas-Peucker 10)	simplified (Douglas-Peucker 15)	simplified (Douglas-Peucker 20)
choice800	0.4129	0.4506	0.4618	0.4634
choice1200	0.4622	0.5	0.5083	0.5129
choice2000	0.509	0.5448	0.5493	0.5584
choice3200	0.5282	0.5641	0.5676	0.5784
choice5000	0.5322	0.5685	0.5714	0.5829
choicen	0.4952	0.5415	0.5402	0.555

	OS Open Roads			
	simplified (Douglas-Peucker 10)	simplified (Douglas-Peucker 15)	simplified (Douglas-Peucker 20)	simplified (Douglas-Peucker & modelling rules)
choice800	5.41%	6.87%	7.76%	12.46%
choice1200	4.10%	5.56%	6.23%	8.35%
choice2000	2.60%	4.06%	4.72%	5.33%
choice3200	1.39%	2.82%	3.50%	2.52%
choice5000	1.27%	2.71%	3.36%	1.05%
choicen	2.43%	3.88%	4.56%	2.01%

	OpenStreetMap		
	simplified (Douglas-Peucker 10)	simplified (Douglas-Peucker 15)	simplified (Douglas-Peucker 20)
choice800	9.13%	11.84%	12.23%
choice1200	21.09%	23.10%	24.22%
choice2000	31.94%	33.03%	35.24%
choice3200	36.62%	37.47%	40.08%
choice5000	37.68%	38.39%	41.17%
choicen	31.15%	30.83%	34.42%

Table 4 - Spearman's rank correlation coefficient between angular choice values of unsimplified and simplified RCL maps and axial map (left). % difference in Spearman's rank correlation between unsimplified RCL maps and simplified RCL maps (right).

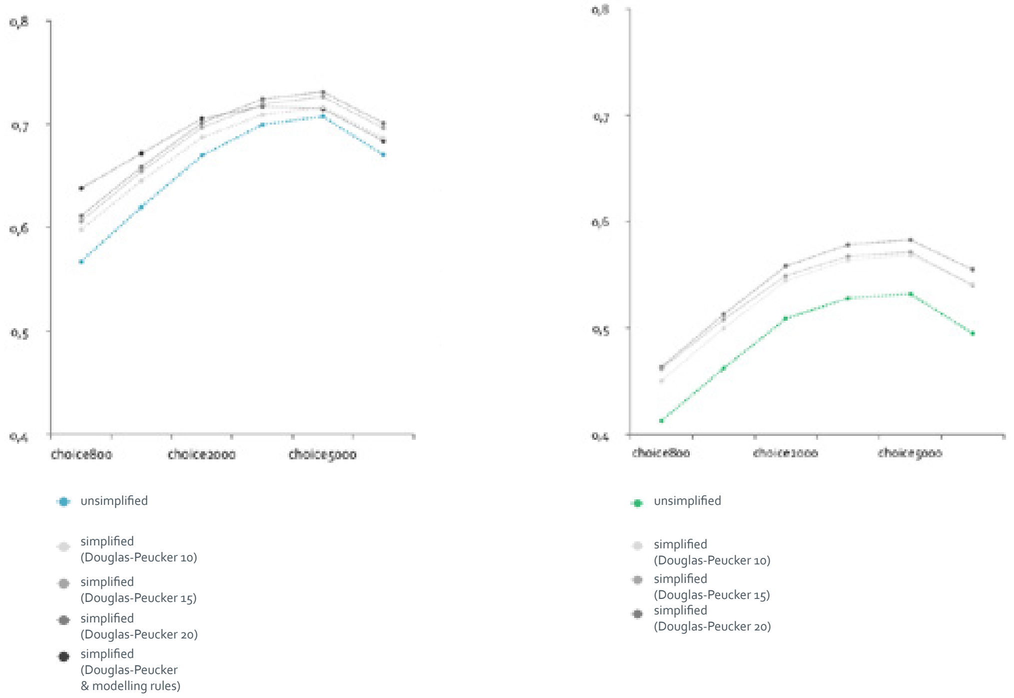


Figure 6 - Changes in the Spearman's correlation across different scales of angular segment analysis for axial and Open Roads maps (left) and axial and OSM map(right)

5. DISCUSSION

Gathering the results of our analysis, we will make an attempt to formulate the simplification processes for RCL maps prior to angular segment analysis. The suggestions made here should be further tested and validated. The principles on which the rules are based are the optimisation of angular change between continuous intersections and the reduction of nodes, provided that connections are not distorted.

Sequence	Operation
1	selecting only lines of the network that correspond to the pedestrian/ vehicular or any other mode of movement the analyst is interested in
2	removing invalid geometries (including points)
3	removing duplicate geometries
4	removing overlapping geometries
5	breaking geometries where they share vertices; geometries should not be broken where they cross but not intersect as these crossing points in a RCL map are the equivalent of unlinks in an axial map
6	segmenting
7	snapping geometries
8	simplifying with Douglas-Peucker algorithm

Table 5 - General simplification operations and algorithms to apply prior to the analysis of a RCL map.

The operations and algorithms in table 4 are suggested to be used when the analyst's focus is primarily at large scales over 2,000 m. When the analyst is looking at a local radius then it is suggested that the RCL map should be further simplified using the modelling rules covered in section 3.4. These modelling rules are based on two principles: the minimisation of nodes representing a space and the optimisation of angular change. For example, it is still valid to create additional nodes if a route cannot be optimised otherwise (figure 7). But it is not necessary to add an additional segment that already represent a connection with a similar angle. This process of simplification might be a very time consuming task however it is necessary if one wants to look at how angular changes may affect local patterns of activity.

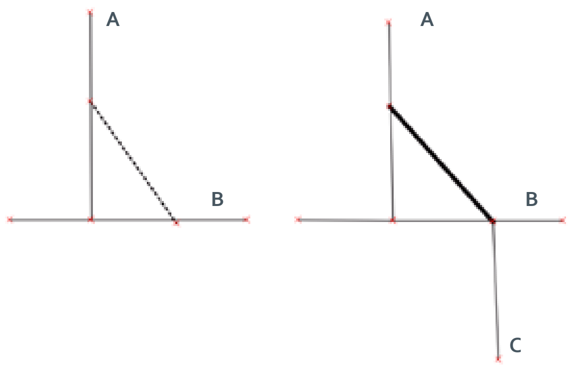


Figure 7 - The dashed line does not minimise the angle between segment A and B and thus it is not necessary (left). The highlighted line is not necessary to minimise the angle from A to B but is necessary to minimise the angle of A and C (right)

To generalise these rules further, experiments should be conducted with different map sizes, maps from different cities with different complexities in their geometry and maps from different data sources. Moreover, to create a better specification of the modelling rules, separate tests on each rule would help us understand the effect of individual changes on the analysis outcome. Stronger arguments need yet to be developed explaining why these modelling rules are improving the results of the analysis.

It is also important to note that all four maps used in this study are maps with different levels of resolution, of different years and from different sources. Therefore, there are cases where one street may appear in one map and not the other. This may explain partly the low correlation coefficient in local radii. The aim of this study was not to achieve a high correlation between analyses of axial and RCL maps but to explore how their correlation changes when maps are simplified.

Methodological limitations of this research also include the linking of axial and RCL maps, where in complex cases the links may fail to link segments correctly. Processing time limitations have discouraged us from using larger models of London and cast doubts on the correlations at radius N, which therefore has not been commented on so far. Opportunities for future development of this methodology lie also in the integration of other datasets or properties of the networks. Open Roads for example includes information on type of a line such as 'roundabout' or 'sliproad', which could be useful if simplification processes were to be automated. This is an approach taken by the sDNA software when using RCL maps from OS ITN (the most detailed commercial RCL data sets of the UK). Additional datasets could also help cases such as open spaces and parks. Cases that involve level differences (stairs, lifts etc.) would require much more extended research.

These results are preliminary and there is a lot more to be explored. However it is important to highlight that if you think of the number of lines of a city-scale map, it is inevitable to simplify all geometric cases. There will always be unique and complex cases. Even attempts to automate the creation of the axial map itself "have highlighted the fundamental inconsistencies of any representation" (Turner, 2005). The simplification algorithms and rules are explored with the purpose to approach an axial map analysis. The axial representation is "an approximation to the underlying nature of space [as understood by the occupant]" (Hillier 2003 in Turner 2005) itself and the simplification of RCL maps is used as another proxy for that.

6. CONCLUSION

The main objective of this study was to show how the simplification of RCL street network representation can enhance the accuracy of the analysis. Our three experiments have indicated that if RCL segments are simplified their analyses can come closer to an axial segment analysis. However, different rules apply to different depths of analysis. Analysts should always be very cautious of what simplification they apply according to the question they are looking to answer. When the focus is on city-wide radii, general simplification rules seem to be enough to push the results closer to an axial map, but when the emphasis is placed on local radii a process of validation and optimisation is required to improve the results of the analysis.

The theoretical underpinnings of how a RCL segment represents space have only slightly been discussed in this paper. The principles suggested are derived from the definition of axial maps as the longest and fewest lines and are specific to the choice segment analysis that uses the shortest angular path algorithm. Minimisation of node count is achieved by removing redundant segments that involve minor angular changes in a nevertheless continuously visible and accessible space, while at the same time nodes are introduced where there is a potential of optimisation of angular change.

The authors' intention is to continue research on optimal algorithms for simplifying RCL maps by attempting to introduce generalised rules and case-specific simplification algorithms. We hope techniques to evolve that will help analysts apply space syntax analysis in a consistent and rigorous way.

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