Persistence and Change in the Spatio-Temporal Description of Sheffield Parish c.1750-1905

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Sam Griffiths
University College London, Bartlett School of Graduate Studies, London, United Kingdom
sam.griffiths@ucl.ac.uk

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Abstract
This paper brings a range of techniques from space syntax and fractal geometry to the question of the diachronic description of spatial structures that are usually considered in purely synchronic terms. Drawing on historical research into the growth of the English industrial city of Sheffield c.1770-1905 it asks how far the spatial configuration of the city's rural hinterland (its 'parish') was implicated in the processes of social change and continuity that unfolded during this period. Time-series data on the development of Sheffield Parish is provided by the syntactical analysis of detailed historical maps, the routes taken by road-based public transport systems and contemporary newspaper reports. The data is interpreted in the light of Hillier and Iida's notion of angular, topological and metric "distance concepts" which are said to represent distinctive 'modalities of scale' in the emergence of an urban area embedded in the historical spatial configuration of its rural hinterland. In traditional urban geography the growth of cities is conventionally represented as the projection of an expanding built environment onto a blank surface. The discourse that accompanies this teleological notion of urbanization is typically one in which the countryside is 'absorbed' by the rapacious city. This language can be misleading, since urban areas whose growth can be regarded as 'organic' - in the sense of arising piecemeal over time - suggests the inadequacy of conceptualizing the built environment in a single (synchronic) dimension. The evidence from Sheffield Parish indicates how the differentiation of urban form is constituted both synchronically and diachronically in the description of spatial elements structured at different modalities of scale consistent with prevailing patterns of social practice, some of which relate to innovations in public transportation. The analysis of rural road networks represents a relatively new area of space syntax research. An historical study of this kind helps to ground future work by focusing on the emergent properties of space at the urban-rural periphery without also raising complex methodological questions relating to the application of space syntax methodology to large-scale contemporary urban regions. Rather, the emphasis is on drawing together the theoretical and analytical aspects of the Sheffield case study to assert that if the growing city is legitimately said to have 'absorbed' its rural hinterland then it is equally evident that this process of urban transformation can be also described in terms of the persistence of pre-urban road networks, historically embedded in local topography.

1. Introduction

This paper presents a case study of the urbanization of Sheffield Parish, the rural hinterland belonging to the English industrial city of Sheffield, in the eighteenth and nineteenth centuries (Griffiths 2008). It explores the role of Sheffield's pre-urban hinterland in embedding and structuring emergent urban forms during the extended phase of urbanization associated with the industrial revolution. An historical study recommends itself for this kind of enquiry for two reasons: firstly, it facilitates a comparison of the syntactic properties of the spatial configuration of Sheffield Parish both before and after urbanization and secondly, because the geographical scale of the study does not, in itself, represent an innovation in the use of space syntax methodology, such as would have been the case in applying this approach to the extended urban region of a contemporary conurbation (see Chiaradia 2007 and Read, Bruyns *et al* 2007). Rather, the paper's methodological emphasis complements the substantive historical enquiry by deploying a range of space syntax techniques specifically for the purpose of developing a rich spatio-temporal description of Sheffield's urban growth dynamics. Three different time-series analyses are deployed for this purpose. Firstly, axial line length analysis is used to contrast the morphological structure of urban and rural space in Sheffield Parish; secondly, the emergent organization of Sheffield's road network on the urban periphery is explored using axial integration analysis, and thirdly, segment tulip (angular) analysis examines the different modalities of scale at which Sheffield's complex urban form was constituted. Taken as a whole the analyses presented in this paper strongly suggest that an exclusive emphasis on the expansion of Sheffield's built-up area could only provide a partial description of the city's growth dynamics since it would fail to take into account the essentially diachronic process through which the intelligibility of urban space was sustained across scales by its embedding in the persistent configurational structure of its rural hinterland.

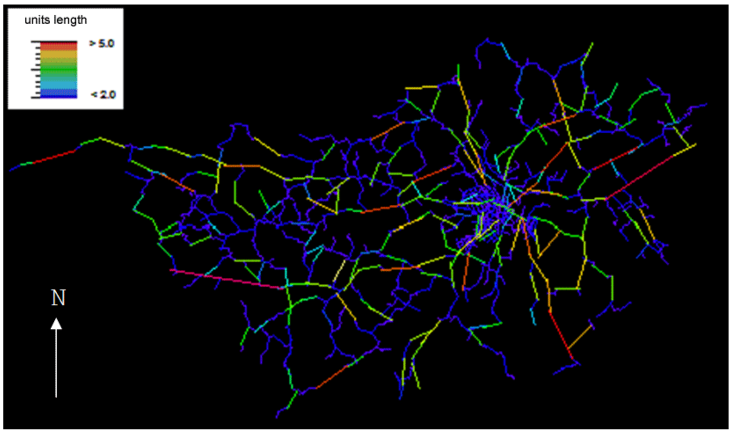
2. The scaling of spatial elements in Sheffield Parish

The analysis of axial line lengths offers a straightforward method to compare and contrast the basic morphological characteristics of urban and rural space. Figure 1(a-c) shows axial maps of Sheffield Parish for three dates: 1795, 1850 and 1905. Axial lines are coloured by line length in each map, with the longest coloured red and the shortest dark blue; the colour scale has been adjusted to facilitate comparison. As with all the analyses presented in this paper the maps have been produced on *Depthmap* software (Turner 2000-2008). It is clear from an examination of all three graphs (a-c) that the longer lines are widely distributed across the parish, occasionally forming sequences of lines that connect the built-up area of Sheffield to the parish boundary. The development of the built-up area across the time series is shown by the increasingly dense background pattern of shorter lines coloured light and dark blue. By 1905 (c) there are significantly more long lines within the built-up area but a comparison of the graphs shows the majority of these predate urbanization.

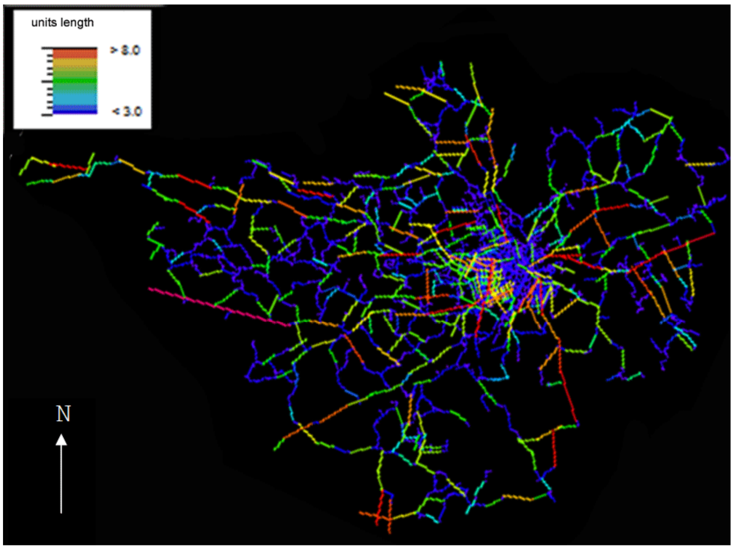
As would be expected, regression analysis shows that axial line length correlates more strongly with connectivity in urban rather than hinterland areas. Analysis of the graphs for Sheffield Parish in Figure 1(a-c) returns r-squared values of 0.11, 0.18 and 0.39 respectively. This compares with values of 0.55 (1850) and 0.54 (1905) for the built-up areas alone, for the two periods where these values are directly comparable (as they are both subsets of the larger parish graphs). In general terms this suggests a characterization of Sheffield's urbanization in terms of short lines being added to a pre-urban structure consisting of longer lines, to the extent that the spatial elements (road sections represented by axial lines) constituting the rural network were differentiated by their graph position in relation to the urban centre of Sheffield.

Consistent with this interpretation, when the relationship of axial line lengths to the integration of the parish system is tested statistically using regression analysis, only the local measure of radius-3 integration provides a significant trend, returning increasing r-squared values of 0.08 (1795), 0.11 (1850) and 0.27 (1905). Tests against radius-radius (r-27) and global integration are consistently low (r-squared $0< 0.03$). The increasing correlation over time, particularly after 1850, between local measures of integration and axial line length, can be understood by the fact that, between 1795-1850 Sheffield's urbanization frequently took the form of planned 'greenfield' griddy developments in the area around the historical nucleus. Only in the second half of the nineteenth century did a distinctive phase of suburban growth begin to concentrate connectivity along the access roads of the rural parish. This implies a dynamic in which the global structure of Sheffield was constituted 'bottom-up' by a piecemeal process of grid intensification.

a) 1795



b) 1850



c) 1905

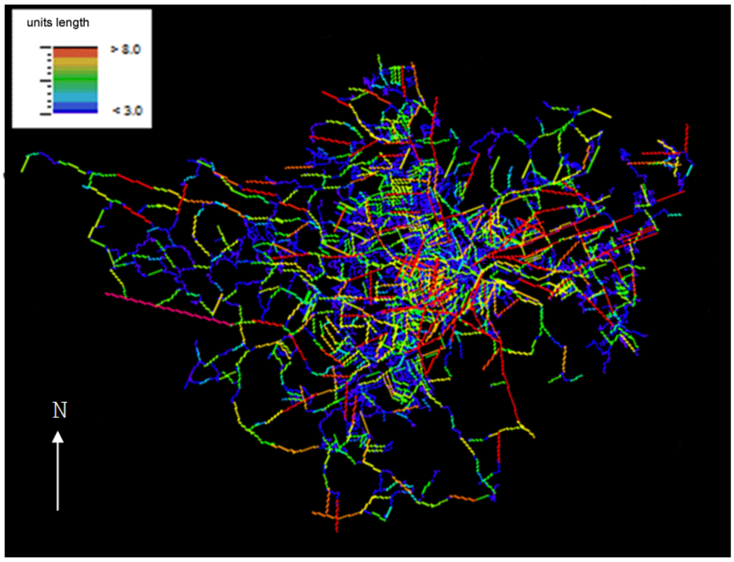
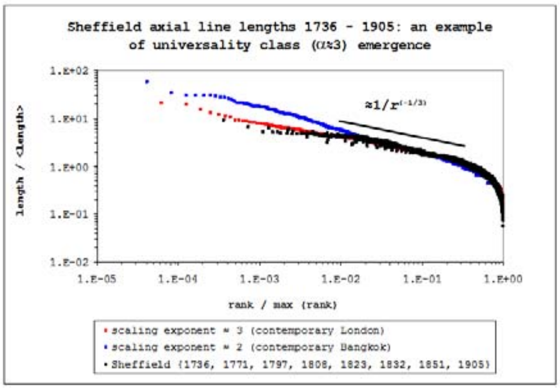


Figure 1 (a-c)
Lengths of axial lines, Sheffield Parish 1795-1905

Frequency distributions of the axial line lengths in Figure 1(a-c) record notable statistical consistency over time characterized by a relatively large number of short lines and small number of longer lines. The skewness of this distribution (calculated as a function of the standard deviations from mean line length) is consistently in the range of 3<4, implying a degree of stability over time. Where frequency is distributed on the basis of ten equal-range intervals, the percentage of short lines in the first decile rises from 65% in 1795 to 85% in 1850 and 82 % in 1905. If the built-up area is considered in isolation from the parish then the percentage of short lines in the first decile rises from 24% in 1797 to 47% 1850 and then to 63% in 1905. The difference in the two trends can be explained by the fact that, while Sheffield's urbanization before 1850 dramatically increased the number of shorter lines in a relatively dense urban system, the process of suburbanization post 1850 did not add proportionately more short lines (or very long lines) than were already present in the rural road network. Consistent with ongoing urbanization, parish and urban line length distributions increasingly converge after 1850 but without increasing the proportion of very short lines in the system overall. By 1905 the suburbanized city and its hinterland are not categorically distinctive in terms of the metric properties of axial line length

a)



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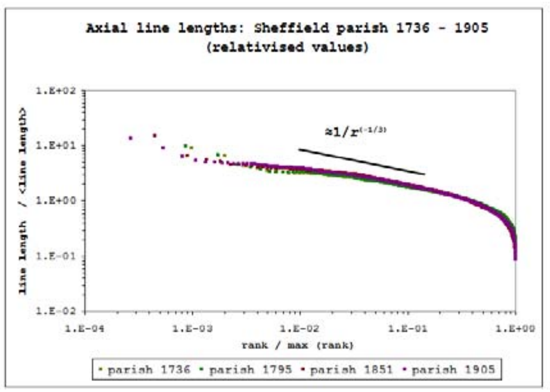

Figure 2 (a-b)

Distributions of axial line length in built-up Sheffield and Sheffield Parish 1736-1905

The emergent homology of urban and rural morphologies in terms of axial line lengths is emphasized by a comparison of the graphs in Figure 2 (a-b), which represent the logarithmic distribution of rank-ordered line lengths for a time-series of axial maps of Sheffield 1736-1905 derived from town plans (a) and parish maps (b). In both plots, axial line lengths have been relativized for comparison according to the formula: relativized $rank_i$ = $rank_i$ / maximum rank and relativized line $length_l$ = $length_l$ / <line lengths> (Carvalho and Penn 2003). Figure 2(a) shows how, by 1905, axial line length distributions for the built-up area of Sheffield collapse onto a curve convergent with that for contemporary London rather than contemporary Bangkok. Figure 2(b) illustrates how the equivalent distribution for Sheffield Parish collapses onto the same curve. The typology established by Carvalho and Penn (*ibid.*) classifies Sheffield's line length distribution as an example of a universality class α≈3 city (such as London), characterized by an organic pattern of urbanization incorporating historical road networks, rather than one featuring more global-scale planning interventions (such as Bangkok).

The persistence of Sheffield's pre-urban longer-line structure indicates how a concatenative growth dynamic constituted an essential aspect of the urbanizing city's ability to sustain local to global intelligibility. Wagner (2007) has suggested that universality class α≈3 cities would typically comprise a distributed network of suburban centres. In Sheffield the dynamic process of localized grid intensification along concatenated radial and lateral access roads, discussed in relation to Figure 1(a-c), was accompanied by the emergence of an equally dynamic global structure but one which functioned to sustain localized centres consistent with Hillier's temporal characterisation of "centrality as a process" (Hillier 1999). While the angles of incidence between such centre-edge structures are often obtuse, it is significant for the purposes of historical research that they are not, in fact, straight lines. To represent them as such would risk erasing the diachronic information which, it is argued, was embedded in the emergent structure of Sheffield's historical space.

3. Structural continuities in the urbanization of Sheffield Parish

Measuring shifts in the relation of local and global integration over time can help reveal the emergent relationship between morphological transformation and social organization at different scales. Figure 3 (a-c) show axial maps of Sheffield Parish at three stages of development between 1795 and 1905. Each figure represents axial integration analysis at both radius-*n* and radius-3 with values coloured on a spectrum of red (high values) to blue (low values) according to equal colour ranges. The accompanying scattergrams show 'synergy', which is the extent to which local grid conditions provide a good indicator of the global structure of space. It is immediately clear from an examination of the three axial maps (radius-*n*) how global integration becomes increasingly drawn into the central urban area over time. The first map for 1795 (a) suggests how the medieval settlement location occupied the shallowest nodes on the underlying graph, meaning Sheffield's urban space was relatively the closest to all other space in the parish. This can be explained by the town's topographically privileged and accessible location at the confluence of two river valleys. The grid intensification associated with rapid urbanization, evident in Figure 3 (b-c), served to concentrate more and more global integration at this location over time. Consequently, as mean radius-*n* values increased 0.43<0.63 across the series, the spoke-like access road structures clearly visible in 3(a) become less easily distinguished.

The emergent pattern of local integration is somewhat different. An examination of the radius-3 maps and accompanying scattergrams in Figure 3(a-c) shows that mean values for radius-3 integration also increases over time but that the spatial distribution of high radius-3 lines (shown in warm colours) follows a more dispersed pattern than is the case for radius-*n*. If the 50% of lines with the highest radius-3 integration are selected in the axial map for 1795 they are widely distributed around the parish as well as in the urban centre, often along the centre-to-edge concatenations of longer lines that constituted Sheffield's access roads. In the axial map for 1850 the selection of the same proportion of lines shows that most radius-3 integration is overwhelmingly concentrated in the central area and in the radials that extend directly out from this location. By 1905 radius-3 integration is again more widely distributed around the system but now the centre-to-edge structures are characterized by local grid intensification; a web of secondary lateral routes is similarly defined. This three-stage transformation is consistent with the characterization of Sheffield's urbanization as involving intensive local grid development along the longer lines on the urban periphery as these were spatially differentiated by their historic shallowness (accessibility) within the pre-urban rural road structure.

This emergence of local-global structuring is also evident from an examination of the synergy scattergrams in Figure 3(a-c), which confirm how configurational, rather than metric, scaling effects differentiated predominantly rural and urban areas of the parish. The scattergrams in Figure (a) for 1795 shows a clear banding effect of radius-3 integration on the *y*-axis. The pattern breaks up a little towards the end of the *x*-axis where radius-*n* integration is highest, although lines with high radius-*n* integration (and therefore high synergy) are altogether relatively few in an urban centre of this scale. In the scattergram for 1850 (Figure 3b) the banding of radius-3 integration is less evident and by 1905 (Figure 3c) it has almost entirely disappeared. This trend shows how, as Sheffield expanded, the urban system sustained centre-to-edge structure by the increasing organization of locally embedded spatial elements according to differentials in their global integration. Such a process is correctly characterized as 'bottom-up', not to imply the absence of large scale global structure but rather to assert that such a structure arose unplanned by exploiting the potential of the persistent, relatively long, spatial elements in the historical road network to constitute synergy at a range of different graph scales. By 1905 the built-up area of Sheffield that had developed after 1850 is not meaningfully distinguishable from its pre-urban hinterland in terms of the configuration of local-global centrality.

This emergent local-global structure suggests an interpretation consistent with Salingaros and West's (1999) notion of 'scale coherence', which refers to a sufficiency of localized scales being necessary to express the intelligibility of the system overall. Where radius-3 banding is strong as in Figure 3(a) for 1795 there is not enough information in the spatial configuration for the parts to relate to the whole — meaning the 'whole' as such does not exist; the distribution reflects a discrete rural pattern. Where, as in Figure 3(b) for 1850, radius-3 banding is present but strongly distinguished from a well-defined high synergy pattern, it suggests two relatively distinguishable urban and rural domains in close proximity. Finally, where as in Figure 3(c) for 1905, radius-3 banding is not present but synergy is not well-defined globally, it highlights a distributed structure of centrality that is more than a sum of its historical parts because it constitutes a distinctive local-global settlement formation.

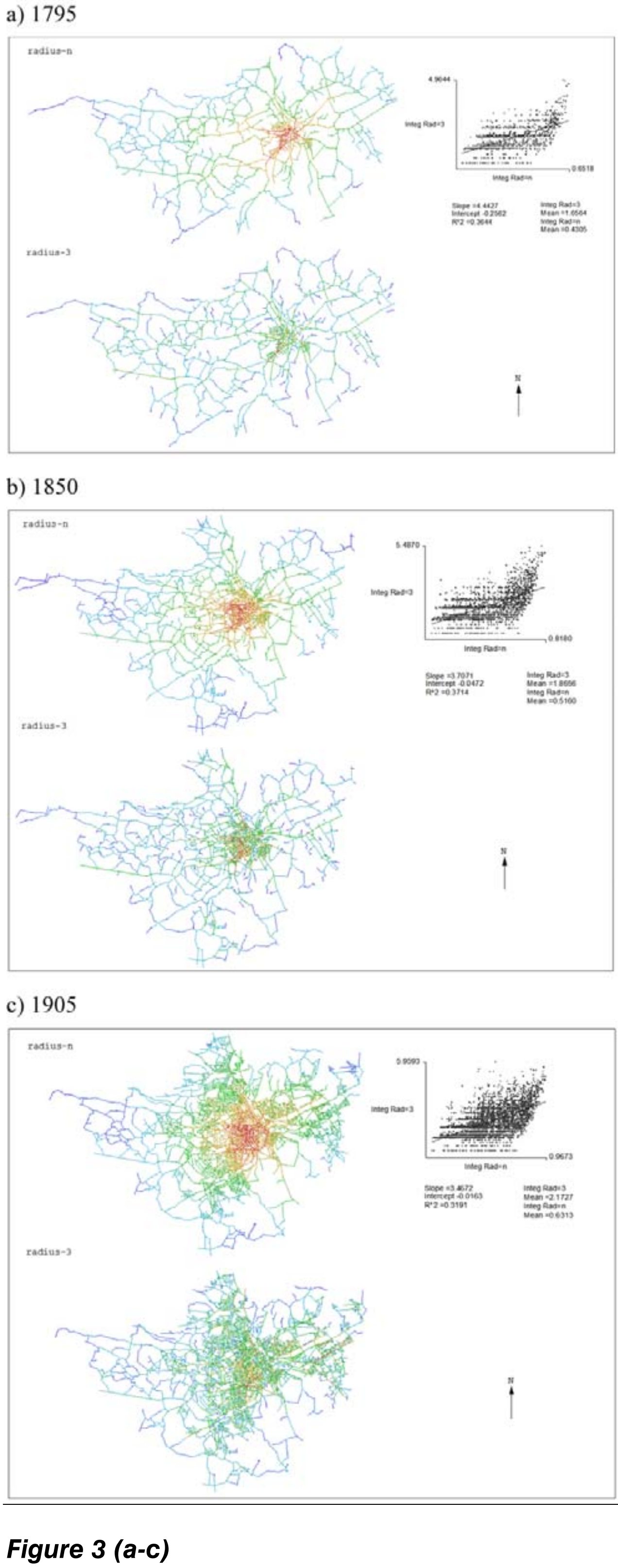

Figure 3 (a-c)

Axial maps of Sheffield Parish 1795 – 1905 showing integration radius-n and radius-3 with scattergrams showing synergy

However, this urbanization sequence is misunderstood if it were to be characterized as a simple succession of states with the emergence of one state erasing the conditions of the previous state. On the contrary, each 'phase' of urbanization was premised upon structural continuities bequeathed by previous phases. The complexity of this structure suggests how 'scale coherence' in the built environment refers not simply to synchronous spatial descriptions that generate movement 'interfaces' within, between and across conventional scales of movement (for example 'local' and 'global') but also to historically rich patterns of diachronic intelligibility that are constitutive of the scales of movement themselves in the sense of establishing them over time as effective domains of social practice. To characterize Sheffield's urbanization simply in terms of the 'absorption' of its hinterland would be incorrect since it fails to take account of the way in which the city itself became deeply embedded into the historical road network of its rural parish. Increased global centrality was sustained through emergent concatenations of local grid intensification, giving rise to a distinctive suburban field of social practice which would characterize Sheffield's urban culture well into the twentieth century.

The argument that the relationship of spatial elements in inhabited space contains important diachronic descriptions pertaining to how a settlement persists in time begs the question of the relationship of statistical scaling patterns to these descriptions. Is it possible for example, that something like the three-phase transformation of the spatial configuration of Sheffield Parish described previously could have occurred in the absence of such scaled phenomena? To evaluate such a possibility Figure 4(a-c) presents an elementary space syntax model of this transformation in which all linear elements are the same length (with one exception in graph (c)). Other surfaces could have been used to execute the model but the hexagon has two advantages. Firstly, in its sequences of lines at obtuse angles of incidence, it most nearly expresses, in a highly abstract form, the intuitive impression given by Sheffield Parish's rural road network. Secondly, it is consistent with the widespread use of hexagons in geography as the most efficient form to tessellate a surface, minimizing both the distance from centre to edge of each unit and the length of its perimeter (Haggett 1965, 48-50).

Figure 4(a-c) show graphs representing radius-*n* and radius-3 integration alongside scattergrams giving synergy values for three different configurations based upon the hexagon model. They have been deliberately arranged asymmetrically into a shape similar to that of Sheffield Parish. In Figure 4 (a) limited syntactic differentiation is a consequence of the relative depth of each axial line within the system, since line length and connectivity are otherwise uniform. In Figure 4(b) the hex pattern has been deformed by the omission of a number of axial lines, generating greater configurational differentiation. In Figure 4(c) griddy lines of the same length have been added to the hex pattern on a heuristic basis, working out from the most globally integrated line element in Figure 4(a). One line has been extended to evaluate the impact of a more globalizing intervention in the rural road network, such as might be associated with a road widening scheme.

The configurational model of urban growth represented in the hexagon model does not claim to be generally applicable but it is notable that in the sequence of scattergrams accompanying Figure 4(a-c) the trend of radius-3, radius-*n* synergy closely imitates that for Sheffield Parish in Figure 3(a-c), despite the absence of any metric scaling properties in the system. In both cases mean integration values increase across the sequence and radius-3 banding gradually gives way to a clear linear correlation of local and global integration as more lines are added.

What then, is the significance of the scaling pattern of metric spatial elements, consisting of many short and relatively few long (and even fewer very long) lines, in Sheffield Parish, if the emergence of a local-global system of integration can be simulated in a simple model where almost all lines are of the same length? The reason, it is argued, is that the metric scaling of spatial elements in the configuration of the *actual* lived environment is indicative of how each element's persistence as a distinctive spatio-temporal entity is constituted at different spatial resolutions and modalities of scale over time. The hex model is indicative of abstract geometrical, rather than inhabited, space because, despite displaying a strong pattern of local-global integration, its uniform spatial elements lack coherence at any scale except the global one deployed for a specific analytical purpose. In Sheffield Parish, by contrast, the scaling pattern of the historical road network is indicative of an evolved, information-rich local-global structure that could be constituted at a number of different scales other than the ones identified by the analyses presented here.

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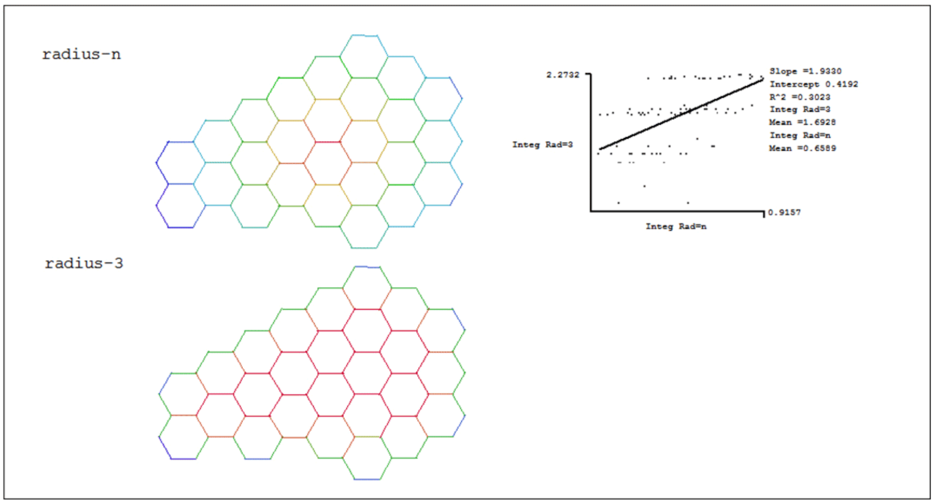

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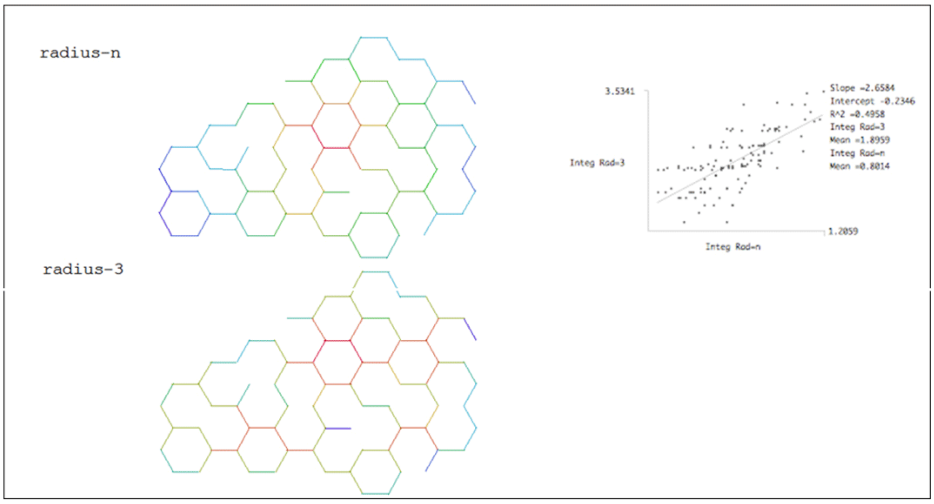

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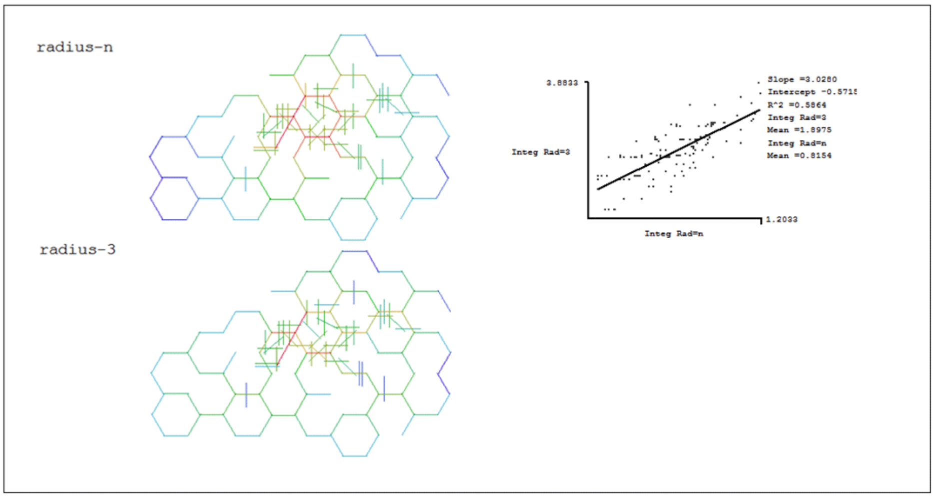

Figure 4(a-c)

A simple model of urbanization with scattergrams showing synergy

4. Emergent scale differentiation in the urbanization of Sheffield Parish

In order to better gauge how the underlying structure of Sheffield's historical road network may have functioned as an agent of change, this section compares the routes taken by Sheffield Parish's system of turnpike roads 1756-1867 with the city's intensively used system of electric tram routes, implemented from 1898 (Smith 1997; Derry 1915). Figure 5(a) highlights in red on an axial map the routes of the turnpike road system in Sheffield Parish by 1850, including sections that had been disturnpiked by this date. Figure 5(b) highlights the routes of the electric tramways evident in the 1905 Ordnance Survey. The two transport systems are not equivalent: the turnpike road system extended beyond the parish boundaries while the tram served the built up area of the town and took several lateral routes into suburban areas that were never turnpiked; even so, it is notable how the basic radial structure is virtually identical in both. This suggests how routes hosting turnpikes and trams both exploited systemic synergies of local and global integration to traverse Sheffield Parish. The scattergrams accompanying Figure 5(a-b) clearly show how in both cases the synergy values for the selected lines are higher than those for the system overall. The selected lines do not represent all the highest synergy lines in the systems (which are concentrated at the centre) but those lines which constitute an approximately optimum route from centre to edge.

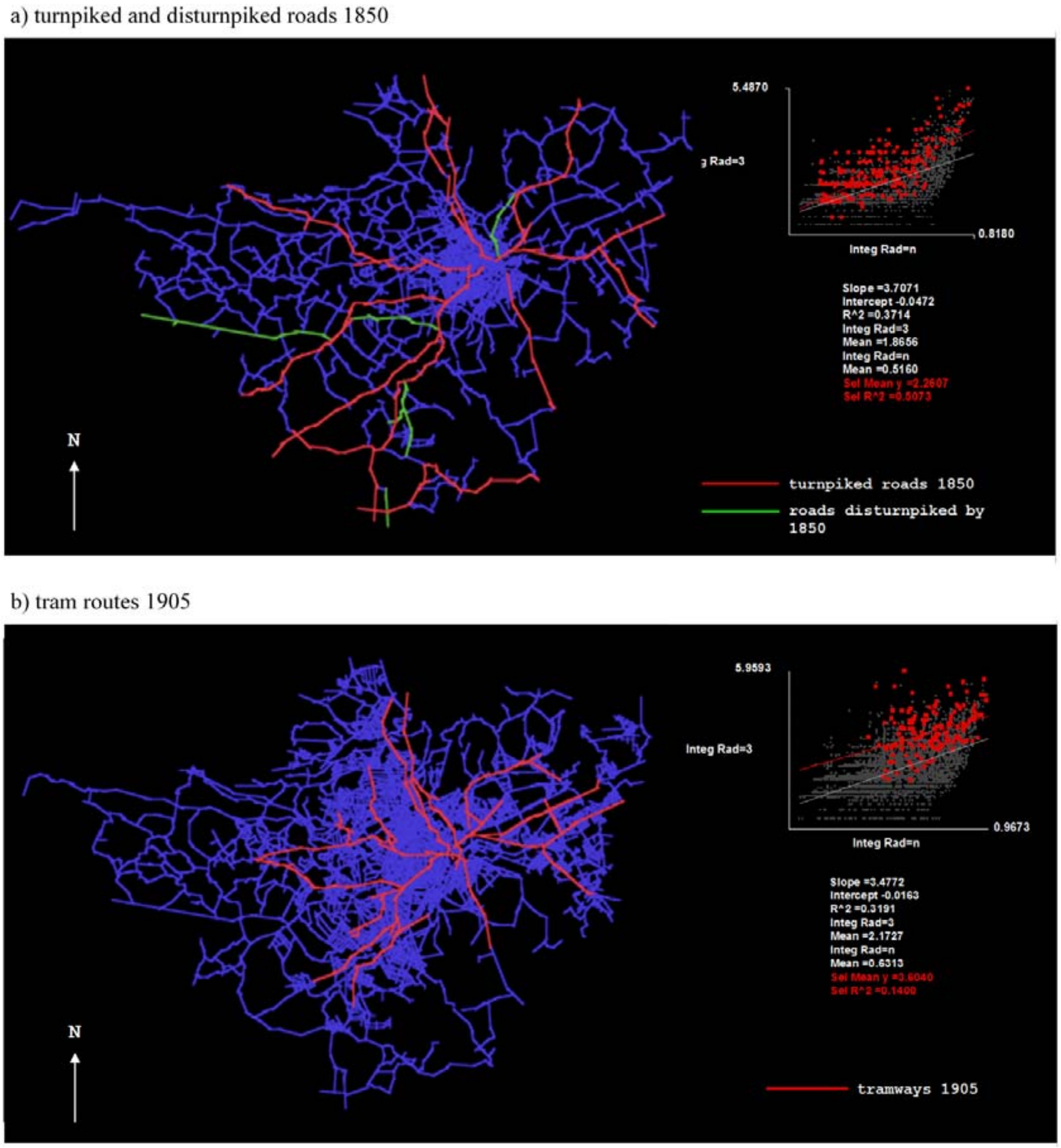

Figure 5 (a-b)

Axial maps of Sheffield Parish showing routes of turnpiked roads and tramways to 1905 with scattergrams showing synergy of axial lines on the routes

The historical structure of Sheffield's road network, in pushing local-global integration along concatenations of lines at obtuse angles of incidence, proposed paths of natural movement that anticipated not only the turnpike and the tram (and later the car) but also the trajectory of urban development itself, as part of a linearizing multiplier effect that privileged the global scale of movement. Even where the concatenative structure of narrow roads was preserved (as it generally was in this period) the kinematic effect of travel in an electrified tram would clearly have emphasized linearity when compared to foot or even horse-powered transport. This linearizing movement trajectory associated with an expanded area of the built environment increasingly articulated the extended, suburbanized, scale at which urban life in Sheffield was taking place. This meant that domains of social practice occurring at smaller scales risked becoming marginalized — possibly even physically erased, a process reported in contemporary newspaper articles. However, it has also been demonstrated that Sheffield's urban transformation in the second half of the nineteenth century was highly constrained by the configuration of the historical road network of its Parish. The implication of this was the persistence of meaningful domains of social practice at relatively localized scales, despite the increasingly large geographical area at which the global scale of urban movement occurred.

5. A spatio-temporal description of Sheffield's urban transformation at three modalities of scale

The analysis in this section investigates Hillier and Iida's notion of 'distance concepts' as distinctive kinds of spatio-temporal descriptions embedded in the configuration of inhabited space (Hillier and Iida 2005). In their empirically grounded study Hillier and Iida make the interesting argument that distance possesses three distinctive modalities: angular (relative straightness), topological (number of turns) and metric (units distance). By proposing that network effects differentiate these distance concepts by the graph scale at which they become effective in terms of movement patterns, the authors also imply how a spatial configuration might be constituted temporally. The notion of a distance concept allows that a graph may be variably constituted according to how being-in-space becomes intelligible to situated agents through their experience of distance informing relative notions of scale (*ibid*., 480). Elsewhere Hillier characterizes this theoretical development as a "phenomenology" of distance (Hillier 2005, 19-20).

The syntactic properties of distance concepts can be investigated using segment-tulip analysis to calculate the angles of incidence between individual road segments (generated where axial lines intersect) using an algorithm that assigns similarly sized angles to a number of 'bins' selected by the user (Turner 2000-2008). The analysis can then be weighted according to three radius modes: angular, topological and metric — equivalent to Hillier and Iida's three 'distance concepts' — at a given radius range (scale). 'Choice' (or 'betweeness') analysis measures the number of times a segment appears on the shortest path between all pairs of segments in the urban system at a given radius range from each segment, where the mode of distance is either topological (changes of direction), angular (straightest path) or metric (units distance).

Sheffield's urban transformation involved the complex organization of an urban space, historically constituted at multiple scales of social practice; a process that can be understood in configurational terms. Figures 6(a-c) and 8(a-c) present three segment maps for the periods 1795 and 1905 at three contrasting modalities of scale. In each case graph (a) is weighted for angular choice graph (b) is weighted for topological (or 'step') choice and graph (c) is weighted for metric choice in units distance assigned by *Depthmap*. Radius range was selected at the point where it best expresses the structural characteristics of Sheffield Parish for that scale mode: globalizing linearity in the case of angular choice, circulatory web-like 'ringyness' in the case of topological choice and locally intense-fied areas of convex 'griddiness' in the case of metric choice. This explains why the range for angular weighted choice is consistently radius-*n*, whereas for topological and metric choice the values vary in systems of different sizes. Segment-tulip analysis is represented on maps similar in appearance to axial maps, with the highest value lines in red and the lowest in blue. The visualizations in Figures 6-8 have been adjusted to emphasize the structural differentiation of segments.

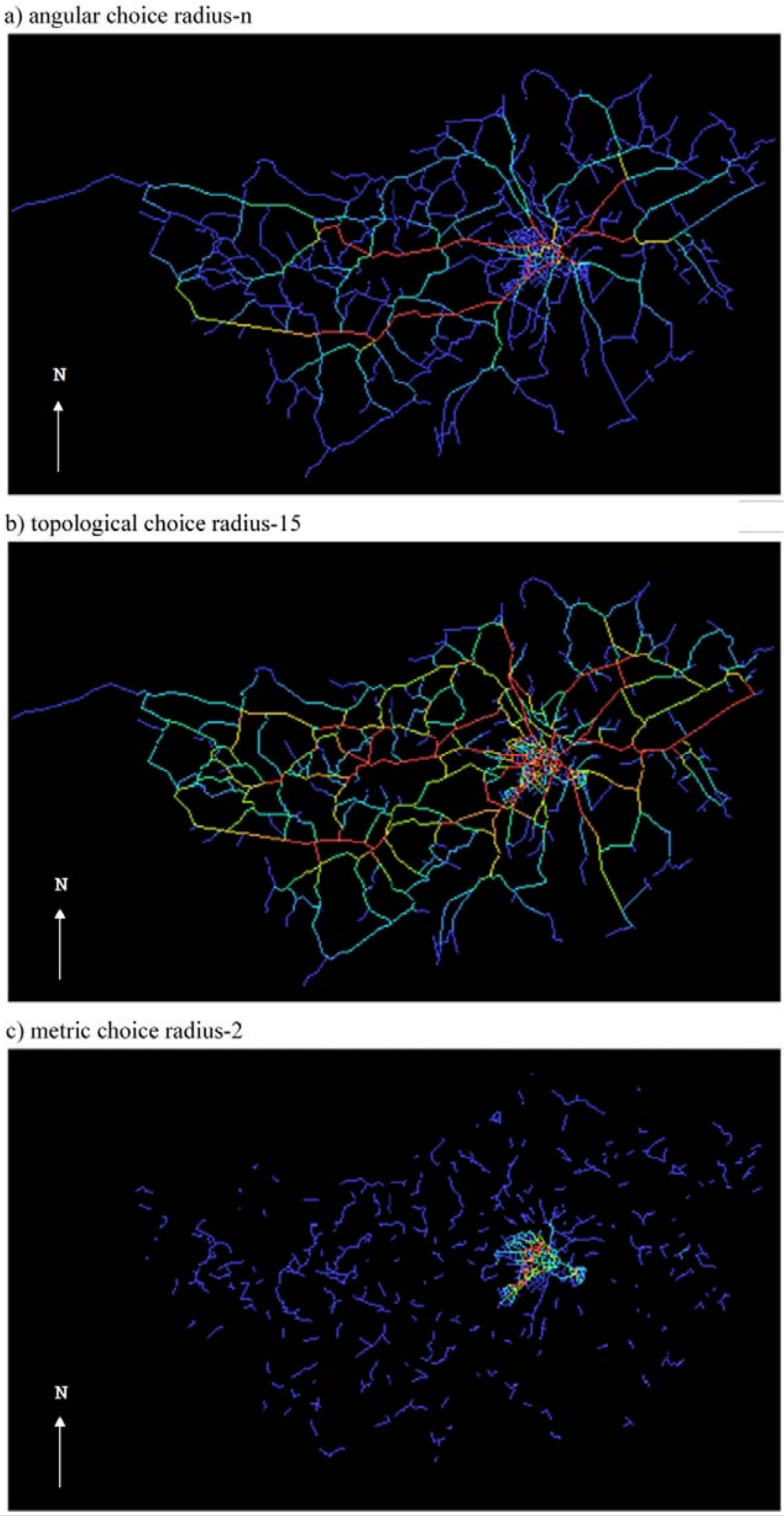

Figure 6(a-c)

Segment-tulip analysis of Sheffield Parish 1795 showing choice at three modalities of scale

In Figure 6(a) angular choice radius-*n* indicates the strongly articulated network centrality of Sheffield's eighteenth-century nucleus which is accessible via a clearly articulated linearized structure of centre-edge movement through the system. This utilizes segment-routes constituted by many of the longer axial lines represented in Figure 1 (a-c). Figure 6(b) showing topological choice at radius-15 picks out lateral 'hex-like' structures with a rather more convex definition of local-to-global movement potentials. However, in 1795 this sparse network remains relatively unconstituted by further grid intensification meaning the structure of topological choice at this radius range closely resembles that for angular choice. In Figure 6(c) metric choice analysis at a low range of radius-2 shows how areas of highly dense urban space characterized by segments of short length (longer segments are not visualized) are generally restricted to the historical urban core. Although this metric analysis is clearly meaningless in configurational terms, as a representation of a modality of scale it effectively differentiates between structure and concentrated areas of grid development where the most imbricated, radically localized forms of movement are possible.

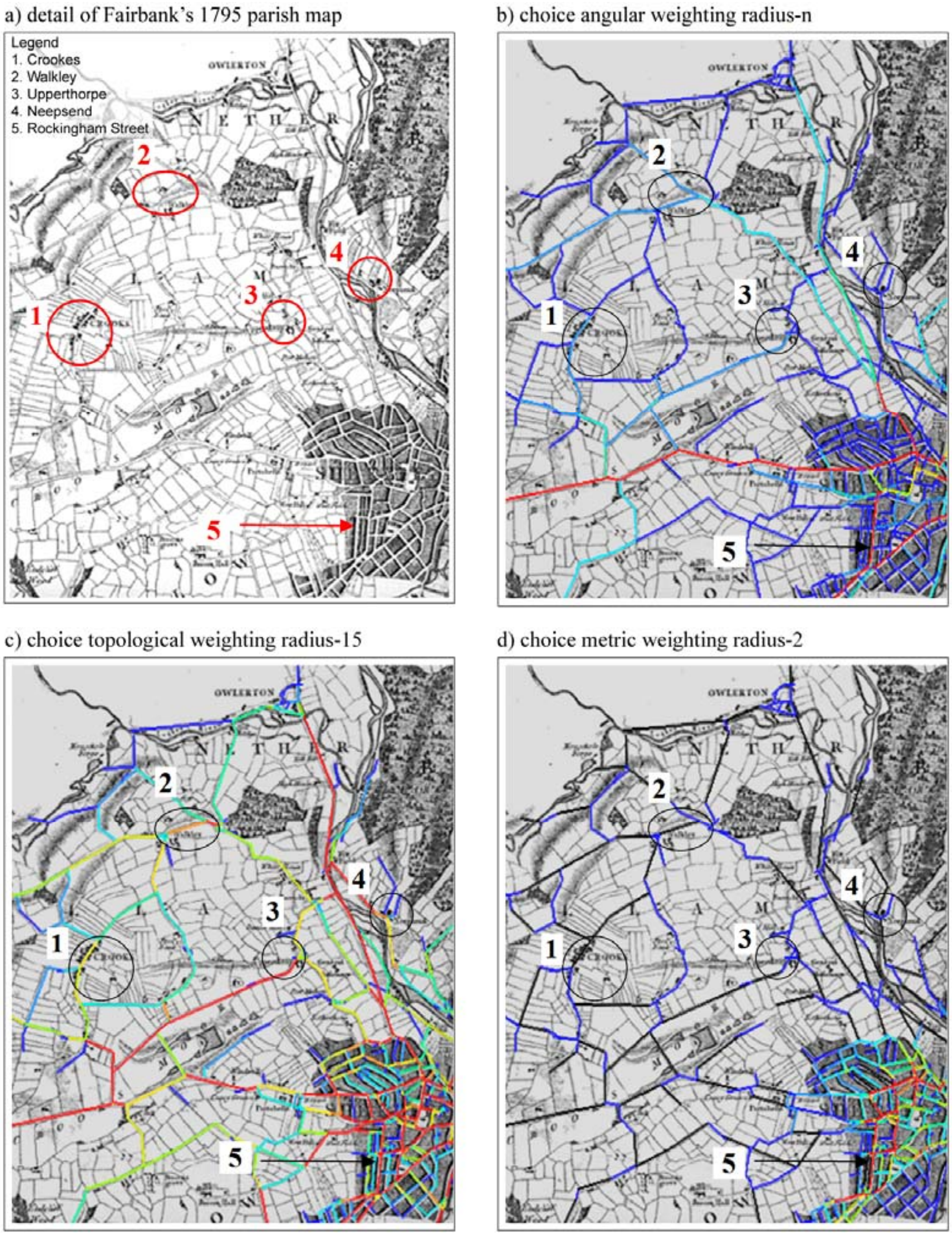

Figure 7 (a-d)

Detail of Sheffield Parish in 1795 with segment tulip analysis showing choice at three modalities of scale

In order to illustrate the relationship between spatial configuration and the spatial description of settlements embedded at different modalities of scale, Figure 7(a-d) shows enlarged sections of the 1795 segment map overlaid on the corresponding section of Fairbank's 1795 map of Sheffield Parish (7a). In Figure 7(b) angular choice at radius-*n* clearly distinguishes the strongly linear westerly access route into Sheffield and also a 'ring road' effect in the urban area which links the westerly and southerly access routes. In Figure 7(c) topologically weighted choice at radius-15 shows how the four circled settlements (1-4) are positioned on, or proximate to, high choice routes at this modality of scale, with settlements (2-4) nucleated in the interstices of concatenated centre-to-edge routes. Figure 7(d) by contrast, shows how metric choice analysis (radius-2) serves to distinguish the most urbanized areas from the relatively longer segments that characterize the historical hinterland (in black). It is noticeable in this context that Rockingham Street (5) is identified as a high choice route at each modality of scale, suggesting the importance of this axis to structuring movement in the built-up area of Sheffield.

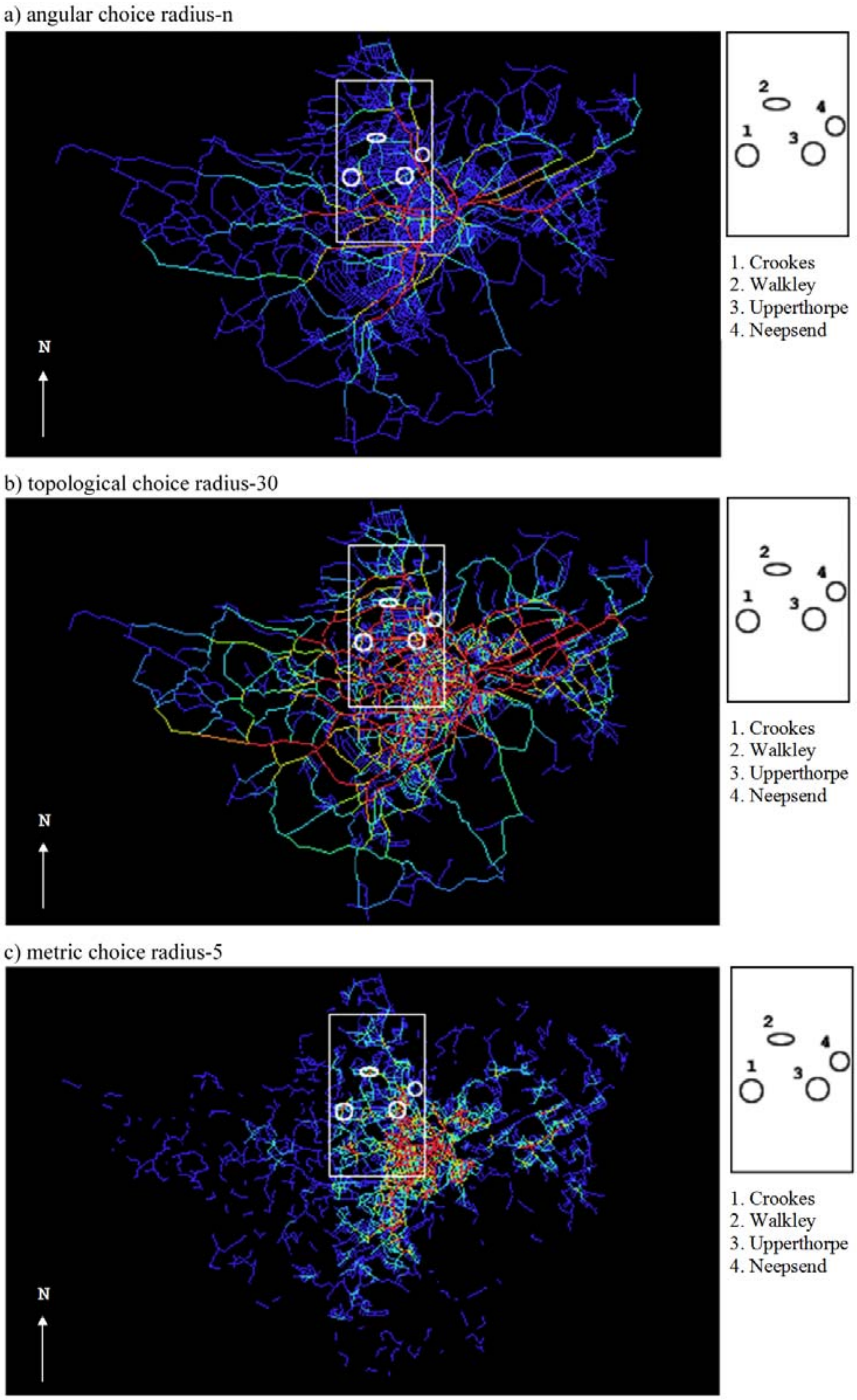

Figure 8 (a-c)

Segment-tulip analysis of Sheffield Parish 1905 showing choice at three modalities of scale

To facilitate time-series comparison the section highlighted in a white rectangle in Figure 8(a-c), showing Sheffield Parish 1905, is equivalent to the area extracted from the 1795 Fairbank map provided in Figure 7(a-d). By the later period settlements (1-4) (circled) clearly lie within the built-up area of the city. In Figure 8(a), showing angular choice radius-*n*, the extent of urban development means that the highly linearized global structure is less clearly defined here than in Figure 6(a) because the number of origin and destination segments has concentrated betweeness in the continuously built-up area. The distinctive orbital structure encompassing much of the central Sheffield is largely a product of this more recent development. However, the underlying centre-to-edge structure of historical radial roads is still evident even within the urbanized area. Figure 8(b) showing topological choice radius-30, suggests how multiple local grid intensifications constituted a web of lateral connecting roads that gave structure to the emerging suburban neighbourhoods on the periphery of the mid nineteenth-century town. The metric choice (radius-5) analysis presented in Figure 8(c) shows how the increased quantity of urban space no longer resembles an island in a rural 'sea' as in Figure 6(c) but rather constitutes an extended area of 'background noise' for highly localized movement in areas which are structured at more globalizing modalities of scale.

In Figure 8(a), showing angular choice radius-*n*, it is evident how Neepsend's (4) development was influenced by its location on a strongly defined northern radial route. The suburb's strong global accessibility — also via the River Don and the central railway — helps to explain the presence of large industrial plants in this area. In Figure 8(b) topological choice radius-30 shows how the historical centres of Walkley (2), Crookes (1) and especially the increasingly urbanized Upperthorpe (3) are all proximate to dense grid developments defined by the lattice of segments coloured red. Neepsend, by contrast, has a less clear definition at this intra-urban scale. The metric choice analysis in Figure 8(c) complements the angular and topological analysis. It suggests that Walkley and Crookes maintained 'urban-village' qualities (still evident today) because they constitute dense griddy developments clearly peripheral to, but not quite separate from, the extended built-up area of central Sheffield. Upperthorpe, by contrast, is relatively 'absorbed' into Sheffield Township *at this modality of scale*, in the sense that its local grid deformation cannot easily be differentiated from that of central Sheffield. By this measure Neepsend appears barely to exist at all; its separation by water from the town centre emphasizes its relative isolation despite geographical proximity.

The pre-urban rural road network of Sheffield Parish gave rise to distinctive spatio-temporal descriptions that strongly influenced the emergent pattern of urbanization. In different ways the four hinterland villages discussed above were all intelligible at various modalities of scale — both analytically and experientially — in the sense that they remained (and remain) identifiable places. Their persistence pertains to an historical process of embedding complex spatio-temporal descriptions in the material world of inhabited space.

6. Conclusion

The range of historical evidence and syntactical analyses presented in this paper has suggested a characterization of Sheffield's eighteenth and nineteenth-century urban transformation in terms of a bottom-up dynamic in which widespread localized grid intensification became embedded into the historical road network of Sheffield's rural Parish. It was argued that this urbanization process embodied continuity as well as change and that both these diachronic processes can be identified syntactically through intelligible descriptions of the city's spatial configuration at different modalities of scale.

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