THE SPATIAL LOGIC OF E-MOBILITY COMMUTES WITHIN URBAN AREAS

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ABSTRACT

Spatial configuration can explain how urban road-networks are connected and navigated, plus why certain locations tend to be more accessible and attract more human activity than others. Movement and accessibility patterns are often associated with the differences found in urban morphology and network configuration. While configurational analysis has validated several measures that estimate likely movement patterns for pedestrian and vehicular-motorised trips, demonstrating significant correlations between real movement and high flow and accessibility in certain radii, there are still uncertainties regarding which radius – or radii – are related to conventional cycling (c-bikes) and, more recently, to e-mobilities such as e-bikes and e-scooters. The latter transportation modes tend to follow spatial logics that are seemingly distinct when compared to pedestrian or vehicular-motorised movements, therefore, not directly relatable to the analyses established radii. This paper investigates the spatial logic of e-mobilities movement within urban areas, through the analysis of a sample dataset of commutes made within the City of Bristol (UK). The paper proposes a method to establish spatial relationships between the e-mobility trips, acquired through GPS monitoring, and configurational analyses. It measures accessibility at different radii covered by e-mobilities to establish which radius tends to have a greater correspondence between high accessibility (to-movement) and real e-mobilities movement. Results show that e-mobility commutes tend to be set in *semi-local* radii of accessibility, in-between those validated for pedestrian and vehicular-motorised movement. Further studies using a larger dataset are required to verify these tendencies. Nevertheless, findings can serve as a guide to policies and actions to both optimise the use of these transport modes, as well as to relate them with the placement of urban services and economic activities.

Keywords: E-mobility; Cycling; Spatial Configuration; Urban Analysis; Space Syntax.

INTRODUCTION

The upcoming restrictions for Internal Combustion Engines (ICE) vehicles sales by 2035 in the EU and the UK (European Parliament, 2023; HM Government, 2021; 2022) and the forecasts of a transition to an electrified fleet have accelerated the adoption of e-mobilities, such as e-bikes and e-scooters, within numerous urban contexts (Wang et. al., 2023; Hardt, Bogenberger, 2019; Fishman, Cherry, 2016). Recent studies have shown that, when combined with other public mobility systems, e-mobilities can indeed displace the use of ICE vehicles in urban areas (Dahl Wikstrøm, Böcker, 2020; Melia, Bartle, 2022). E-mobilities are increasingly being adopted by commuters that used conventional bicycles (*c-bikes*), younger people once reliant on cars to commute (Melia, Bartle, 2022), plus for delivery services and *'last-mile or last kilometre logistics'* in city centres – areas that are increasingly limiting car access. However, barriers to their wider usage remain, including limitations regarding urban infrastructure, pedestrian safety, and anti-social behaviours towards the e-vehicles, such as theft and vandalism (Blazejewski, Sherriff, Davies, 2020). Although often treated as c-bikes for modelling purposes, e-mobilities exhibit different movement behaviours from other human-powered vehicles. As pointed out in Arning, Silva, Kaths (2023), when compared to c-bikes, the 'e-counterparts' can greatly vary with regards to assistance level, maximum speed, power and range, sometimes being considered more akin to motorised vehicles than to bicycles. In this context, understanding the spatial logics – such as accessibility and reach – that underline the use of e-mobilities represents a starting point to devise policies and orient decision-making towards integrating, expanding, and regulating their uptake in urban areas. Still, state-of-the-art methods used by urban planners to analyse the spatial logics of movement, such as configurational analysis, have mainly been applied to pedestrian and vehicular-motorised movement, with few experiments on evaluating cycling movement to date (Ryu, et al., 2021; Schon et al, 2024), and little to none strictly related to e-mobilities.

Configurational analysis such as Space Syntax' Angular Segment Analysis (ASA) (Hillier, Hanson 1989; Van Nes, Yamu, 2021) are network-based approaches used for modelling the distribution patterns of different types of movement within urban areas. ASA interprets road-elements (road segments) as nodes of a graph. Its measures calculate the graph's properties, to identify movement potentials or relative accessibility patterns – also interpreted as *to-movement* or reach to potential destinations – and its preferential routes' choice patterns, based on traverse probabilities, describing *through-movement*. ASA can inform movement patterns at different system scales (*local* or *global*) when associated to certain radii (topologic or metric), which were validated through comparison with real data and fit certain transport modes – such as pedestrian and vehicular-motorised ones. Arguably, these transport modes do not have the same characteristics of e-mobilities, thus, those validated correspondence radii are not directly transferable. In fact, e-mobilities tend to use the same road networks as motorised vehicles, though at slower speeds and covering shorter distances compared to them, while also extending their reach into pedestrian areas. In this case, however, e-mobilities' speed is significantly higher than that of pedestrians, while also covering distances that far exceed the average walking trips. Hence, a different radius must be established to account for these differences.

This paper aims to investigate these aspects and the spatial logics of e-mobilities by establishing spatial relationships between Space Syntax modelled radii and real e-mobilities (e-bikes and e-scooters) movement patterns. It merges Space Syntax' ASA models with e-mobilities GPS data obtained by the Urban Ride Research project (Thomas, Williams, Gunner 2023). This dataset comprises origin and destinations points, travel distances, timestamps, average speeds, and ping-data that informs the location and routes taken by e-mobilities users, effectively informing the reconstruction of the movement dynamics for these transport modes.

MATERIALS AND METHODS

Datasets, Data Preparation and Models

As e-mobilities tend to have access to and use pedestrian, cycle-oriented and vehicular road-networks, this paper uses the complete urban network of the city of Bristol (UK) to evaluate e-mobilities movement. The dataset comprises a Road Centre Line (RCL) graph obtained from OpenStreetMap (2024) which was further processed in QGIS (2024) to exclude road-elements not regularly used in urban movement (such as mountain or rural tracks); an approach proposed in Altafini, Cutini (2020) to decrease computational time and avoid result distortions. The dataset was then converted into a .dxf format, that underwent a process of angular weighting (angular segmentation), required for running the ASA within the software DepthMapX 0.8 (2020).

This approach considers only one of the ASA measures, the Normalised Angular Integration (NAIN), as the research objective is to establish spatial relationships between urban accessibility/to-movement or reach, and real e-mobilities data. Angular Integration (Ain) estimates the movement potentials – or the relative accessibility – of each road element within the urban network, therefore establishing which areas are more accessible based on the road-network's morphology. It calculates, from the network system's angular-weighted *mean depth* (MD), the road-elements' *real relative asymmetry* (RRA), which represents the normalised average topological distances to reach all other road-elements in the system, through the overall shortest connected paths (Van Nes, Yamu, 2021) (Equations 1-4).

$$MD_C = \frac{1}{k-1} \sum_k d\theta_{Ck} \tag{1}$$

$$RA_C = {}^{2(MD_c - 1)}\Big/_{(k-2)} \tag{2}$$

$$RAA_C = {}^{RA_C}\Big/_{D_k} \tag{3}$$

$$AIn_{Rn} = {}^{1}\Big/_{RAA_c} \tag{4}$$

Where,

k = Node Count (NC)
$\sum_k d\vartheta_{Ck}$ = Angular Total Depth (ATD)
RA_C = Relative Asymmetry
D_k = Diamond Values – a normalisation parameter for RA associated to the network system size.

The normalised version of Angular Integration, at global radius (Rn), $NAIN_{Rn}$, considers the Node Count (NC) and the network system's calculated Angular Total Depth (ATD), to standardize AIn values (Equation 5).

$$NAIN_{Rn} = {}^{\sqrt[1.2]{k}}\Big/_{(\sum_k d\theta_{Ck} + 2)} \tag{5}$$

AIn can also be calculated within limits defined by metric radii, that restrict Angular Total Depth. Metric radii can be associated with a travelled distance, denoting the movement potential of a place within a radius reach – as well as evidencing where the local centralities are located within a road-network (Van Nes, Yamu, 2021). The normalised version of these metric measures ($NAIN_{Rx}$) is defined in Equation 6, where *Rx* represents the set metric distance radius.

$$NAIN_{Rx} = \log(AIn_{Rx} + 2) \tag{6}$$

In this study, ASA values are calculated for the Radius "n" (system) and for 9 metric radii described in the next section. Those are then exported to QGIS (2024) to be georeferenced, categorised, and further geo-processed.

The e-mobilities rides dataset comprises a sample of e-scooters GPS readings, that recorded telematics data at 5 second intervals or "pings". This dataset was obtained, curated and pre-processed by the University of Bristol's Urban Ride Research (URR) project (Thomas, Williams, Gunner, 2023).

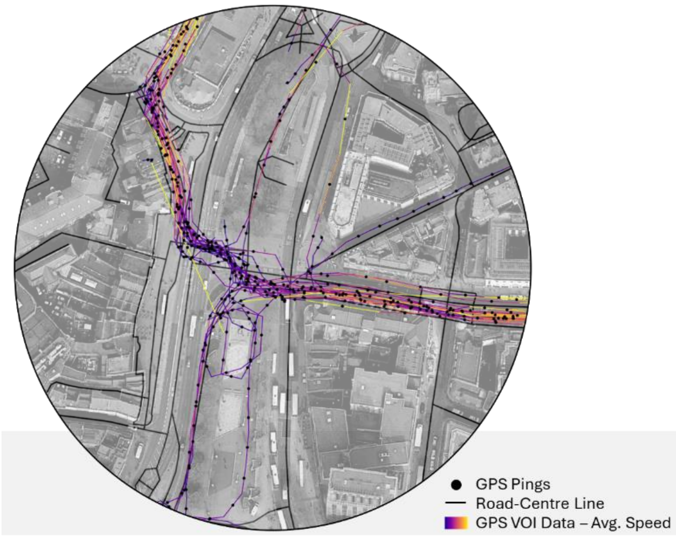

Figure 1: Example of spatialised GPS Ping readings and the RCL positioning for Bristol

The spatialization process converted tabular-based GPS ping readings into network edges that interconnect the nodes. Those edges contain rides' data (Figure 1). The geospatial information 'output' comprises: distance (m), duration (seconds), and average speed (km/h) for each of the 6847 GPS ping readings, henceforth defined as trip segments (TS). Information is used in its disaggregated form (TS) to represent average speeds for each GPS ping reading, allowing for differences in speed within each route to be identified. This information was further aggregated in QGIS (2024) to represent individual rides, amounting to 70 different routings, comprising the sum of the trip segments (total trip distance, m) from where average trip distance (m) and maximum trip distance (m) can be calculated.

Out of these 70 routes, only those made within the City of Bristol limits were considered (66) and associated with the configurational analysis dataset. In addition, origin and destination points (ODPs) were extracted to identify from-to trips trends within the urban territory. No distinction was made between which of the ODPs corresponded to origin or destination as to maintain data anonymization. It is important to note that the GPS data and the generated trip segments does not directly coincide with the RCL road-elements' placement, hence the requirement for additional geoprocessing steps to territorialise the data and establish spatial relationships with configurational analysis models.

Methods for establishing spatial relationships

E-mobilities GPS readings territorialisation needs to be 'reconciled' alongside configurational models within a geometrical grid-based territorial unit (Sahr, White, Kimerling, 2003) to assess their relationships, since GPS data and RCL data do not overlap, thus not allowing a direct intersection. To this end, a hexagon-based grid (Figure 2), similar to those used in other transport-related analysis (Lopes et al., 2023), is used to establish a common frame between GPS data and RCL data.

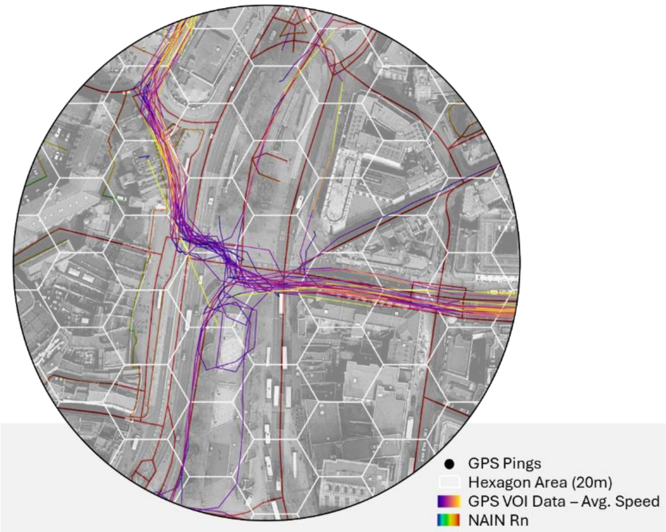

Figure 2: Hexagon grid, NAIN (RCL graph) and GPS Readings data network intersection.

This grid is set to have hexagons with 20m radius, thus able to cover carriageways plus pavement area – as both are used by e-mobilities (Figure 2). The grid is generated based on the RCL morphology.

Once this overlap is 'reconciled', the hexagon grid intersection with the spatialised ASA results can be established by calculating the average (mean) NAIN values of the road elements that intersected each hexagonal feature (Figure 3). This was done to consider the configurational context in which the e-travels are inserted. The operation was repeated for each of the considered NAIN radii, as specified in what follows:

To evaluate correspondences of e-mobilities travels with *local* pedestrian movement patterns, six radii were set starting at 200m, with subsequent increments of 200m until the radius 1200m was reached (Table 1). 1200m is approximately equivalent to the distance covered in a 15-minute walk, considering an average adult walking speed, thus, relatable to the 15-Minute City (15minC) and X-minute City frameworks (Moreno et al., 2021; Logan et al., 2022; Elldér, 2024; Pezzica et al., 2024).

Moreover, two NAIN models representing *semi-local* movement patterns, with radii of 1500m and 2000m (2km), are established. Those are set to evaluate the correspondences in the 'transition distances' between pedestrian movement and vehicular-aided movement. An additional radius of 4000m (4km) is used to evaluate the correspondence between e-mobilities travels and the minimum *local* movement distance assumed for city-wide vehicular movement (Berghauser Pont et al., 2017), which also tends to be assumed as the average distances covered in cycling movement (Schön, Heinen, Manum, 2024).

The NAIN radius 'n', instead, represents the maximum distances that may be travelled by both pedestrians and vehicles in the City of Bristol urban context. Thus, Rn was set as a *global* radius despite it is often assumed to be a distance more compatible with city-wide vehicular motorised movement (Table 1). Overall, NAIN models' intersection with the adopted grid resulted in 151,740 road-elements set within 64,195 hexagons (Figure 3).

Table 1: Considered Distance Radius, Measure Acronym, Measure Type and Significance/Association with Type of Movement

Radius	Acronym	Type	Significance/Movement
200m	R200	Metric	Local (Pedestrian)
400m	R400	Metric	Local (Pedestrian)
600m	R600	Metric	Local (Pedestrian)
800m	R800	Metric	Local (Pedestrian)
1000m	R1000	Metric	Local (Pedestrian)
1200m	R1200	Metric	Local (Pedestrian, *15minC*)
1500m	R1500	Metric	Semi-Local (Transition)
2000m	R2000	Metric	Semi-Local (Transition)
4000m	R4000	Metric	Local (Vehicular-Motorised)
n (System)	Rn	Topological	Global (Vehicular-Motorised)

Once NAIN values are intersected, a second process is made to 'reconcile' the e-mobilities data – trips (TS) and origin-destination points (ODP) – within the same spatial frame. Two different types of data intersections were established: (i) between trip segments for e-mobilities data and NAIN values to better understand differences in speed within a route – usable in further analysis; and

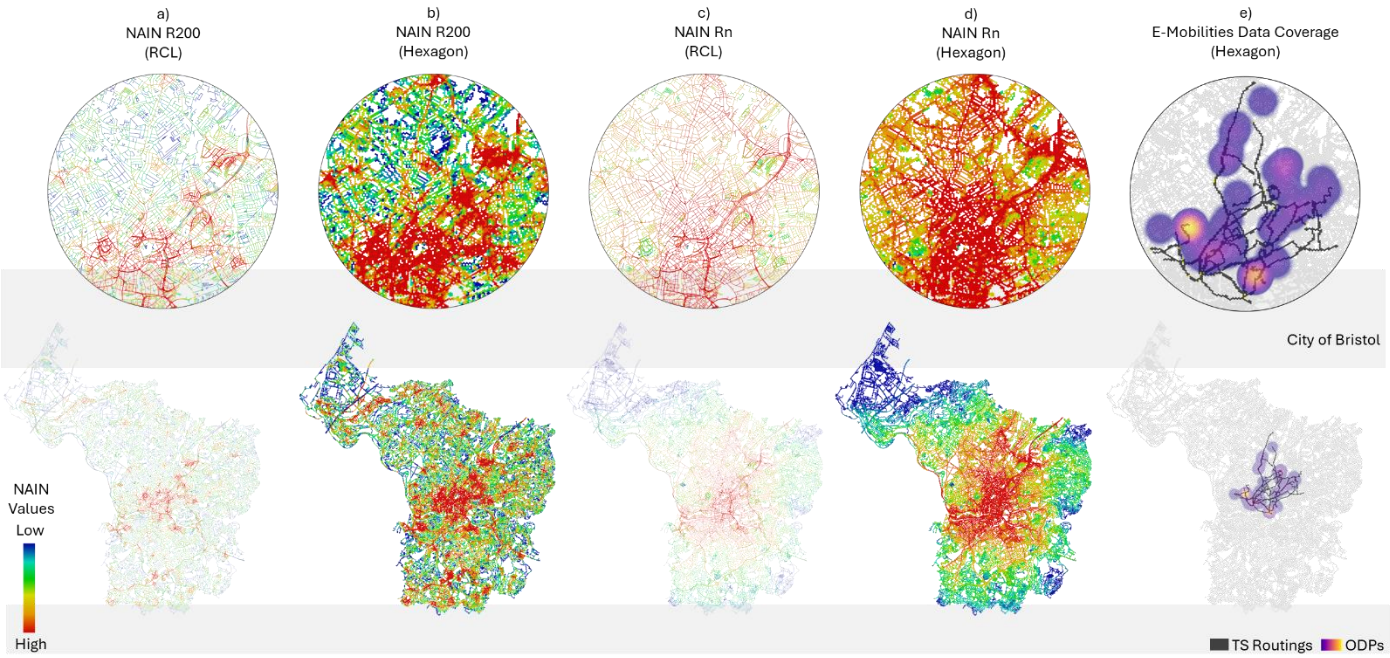

Figure 3: NAIN models for the City of Bristol using a RCL representation and a hexagonal territorialization for R200, Rn; and e-mobilities GPS data coverage area.

(ii), between ODPs for e-mobilities data and NAIN values, to consider the trip total distance covered and the travel time for each trip. Hexagons where no data is present (null intersections) were excluded from the database, as they interfered with QGIS's statistical categorisation and visualization for NAIN data.

Figure 3e represents how the 66 e-mobilities trips and the origin destination points are spatially distributed within the City of Bristol. The 6849 GPS Readings (TS) were distributed in 1536 hexagons (grey), while the ODPs were set in 42 hexagons (heatmap source points).

Spatial relationships are established by comparing the presence of e-mobilities trip segments and origin destination points within the reach of each accessibility core – represented by 20% of the road-elements with the highest values for NAIN in each of the considered radii (Figures 4 and 5). Accessibility cores tend to concentrate most movement within the system, thus being good indicators of movement tendencies within a place. The validity of those spatial relationships is verified based on the Pareto Principle (Pareto, 1919; Newman, 2005). Significance is assumed when 20% of the road-elements that are most accessible (NAIN) spatially relate to at least 80% of any e-mobility travelling presence, either in terms of origin-destination points (ODP), or in terms of total trip segment (TS) covered (Figure 4).

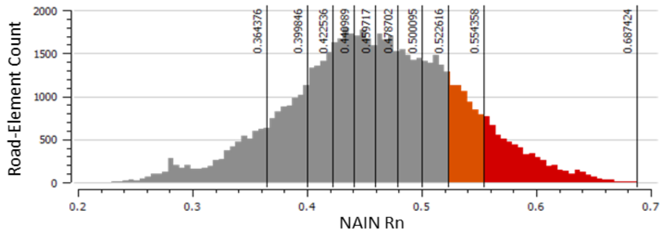

Figure 4: Histogram of NAIN Rn representing 20% of the road-elements considered as the accessibility core (in orange and red).

It is important to mention that, while overall road-elements count remains constant for all the examined radii (12,840), NAIN values and their spatial distribution change for every different radius assigned in Table 1.

RESULTS AND DISCUSSION

An initial numerical assessment evaluated if there was any correspondence between the placement of origin-destination points (ODPs) and the accessibility core radii, listed in Table 1. For all radii, it was observed that more than 80% of the ODPs were set within the established 20% Paretian threshold. This indicates that the places reached by e-mobilities' trips tend to be central *to-movement* places within the system, thus, have high relative accessibility. Moreover, these correspondences peak in-between R1500 and R2000, surpassing the 90% of total ODP set within the accessibility core. Spatial Relationships instead tend to decrease towards R4000 and Rn, an indicative that the e-mobilities trips tend to start and end within distance radii of 1.5km and 2km (Table 2, Figures 5, 6).

Table 2: Overall correspondence between e-mobilities movement (trip segments routings & origin-destination points) related to each NAIN radii.

NAIN Radius	Spatial Relationships					
	Yes (blue)		No (black)		% of Correspondence	
	TS	ODP	TS	ODP	TS	ODP
R200	1125	35	356	7	75.96%	83.33%
R400	1238	35	243	7	83.59%	83.33%
R600	1280	35	201	7	86.43%	83.33%
R800	1311	35	170	7	88.52%	83.33%
R1000	1323	35	158	7	89.33%	83.33%
R1200	1345	36	136	6	90.82%	85.71%
R1500	1357	40	124	2	91.63%	95.24%
R2000	1397	39	84	3	94.33%	92.86%
R4000	1342	36	139	6	90.61%	85.71%
Rn	1242	34	239	8	83.86%	80.95%

A similar trend can be observed in relation to analysing trip segments (TS), where spatial relationships in all radii, with exception of the R200, fall within the significance threshold for the Pareto principle (Table 2, Figures 5, 6).

The 200m exception means that distances lower than 200m do not usually warrant the use of e-mobilities (or other kinds of vehicles) on single or roundtrips as this distance tends to easily be covered by foot.

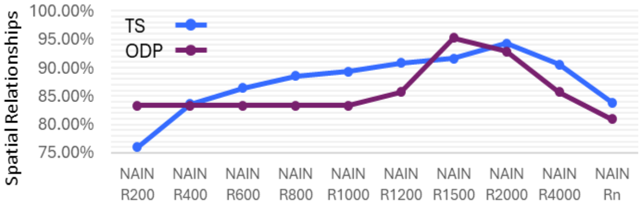

Figure 5 – Correspondence (%) patterns of TS and ODPs.

Further explorations considering where and how the e-mobilities trips are geographically distributed within the accessibility cores are made to investigate the numerical results (Figure 6). In Figure 3 it can be observed that the ODPs tend to concentrate in areas where accessibility cores are constant across all radii – around the Bristol City Centre albeit often starting/ending within *'local'* centralities, such as R200 (Figures 3, 6). Nevertheless, it is verified that e-mobilities tend to go beyond these *'local'* neighbourhood centres extending across *'semi-local'* radii – R1500 and R2000, which exhibit higher % Spatial Relationship with the TS routings. Therefore, e-mobilities usage tends to be set in-between the "maximum" *'local'* radius of 1.2km, (R1200), equivalent

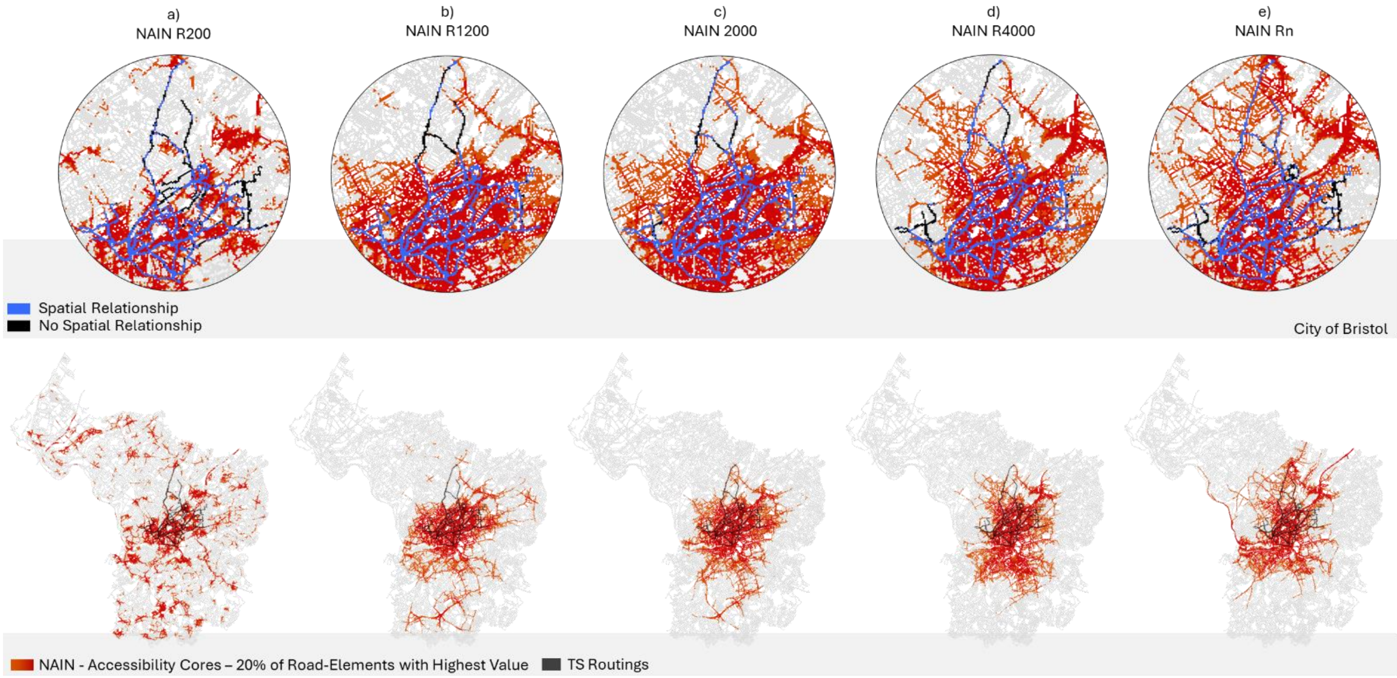

Figure 6: Spatial Relationships between E-mobilities GPS Readings data spatial distribution (TS) and the areas covered by the NAIN accessibility cores for R200 (200m), R1200 (1.2km), R2000 (2km), R4000 (4km) and Rn (System).

to a 15-minute walk, and the reference for pedestrian movement, and the "minimum" *'local'* radius distance for which vehicular-motorised travels start to become more common within urban areas (Berghauser Pont et al., 2017), which demonstrate the hybrid behaviour of e-mobilities. These results agree with calculated median distances covered by the e-mobilities trips (1998.9m) with the distances ranges between 1500m and 4000m being predominant (68% of total trips), even though outliers that cover more than 4000m – 6% of total trips – and less than 1200m – 9% of total trips exist.

CONCLUSIONS AND FUTURE WORK

This paper provides a first insight on how e-mobilities relate with urban movement and accessibility patterns. Through establishing spatial relationships between the e-mobilities real data and several radii, commonly used in configurational analysis to represent different types of urban movement potentials, it individuates that these transport modes tend to follow 'semi-local' movement patterns, set in-between the "maximum" pedestrian radius and the "minimum" vehicular-motorised radius for movement. Furthermore, the verified concentration of e-mobilities movement towards high accessibility areas, such as the Bristol City Centre, reflects the logics associated to 'last-mile (or last kilometre) logistics' – that are predominant tendencies in areas with vehicular-motorised movement restrictions. The analysis also locates where and how e-mobilities movement happen in relation to the road-network configuration, providing valuable information for policy makers on the possible interfaces between e-vehicles and forms of transport within the city (pedestrian, motorised vehicles and other public transport modes). In this aspect, the adopted methodology and its derivative geographical overview provides insightful information as it allows to assess the logics of accessibility, that are related to – and important to guide – the localisation of different types of services, infrastructure – including charging and parking areas – and commercial activities.

Future work aims to extend the analysis using a database comprising a larger number of e-mobilities trips, that will also be provided by the West of England Combined Authority (WECA). The enlarged dataset will be used to confirm the findings from this paper and will have further information on variables related to e-mobilities time, distance and speed, which can be related to other kinds of configurational analyses – such as those related to flow probabilities. Investigations in this regard can relate speed and time to flows, in order to determine what are the road-elements most prone to road-sharing with motorised vehicles/congestion, therefore providing information to guide infrastructural interventions and policies oriented for potentializing e-mobilities usage within the City of Bristol and cities with similar contexts.

DATA ACCESS

For access to the raw e-mobility GPS data used in the paper please contact the Urban Ride Research project: https://www.urbanride.uk/team/

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REFERENCES

Altafini, D., Cutini, V. (2020). Tuscany configurational atlas: a GIS-based multiscale assessment of road-circulation networks centralities hierarchies. In: Gervasi O et al. (Eds) Computational Science and its Applications, Lecture notes in Computer Science. Cham: Springer Nature, p. 291-306.

Arning, L., Silva, C., & Kaths, H. (2023). Review of Current Practice and Research on E-Bikes in Transport Models. *Trans. Research Record*, *2677*(12), 436-448. https://doi.org/10.1177/03611981231168848

Berghauser Pont, M., Stavroulaki, I., Gil, J., & Marcus, L., Serra, M., Hausleitner, B., Olsson, J., Dhanani, A. (2017). Quantitative Comparison of Cities: Distribution of street and building types based on density and centrality measures. In: proceedings of the 11th International Space Syntax Symposium 2017 - University of Lisbon, Lisbon, Portugal.

Blazejewski, L, Sherriff, G and Davies, N (2020) Delivering The Last Mile: Scoping the Potential for E-cargo Bikes Available at: https://usir.salford.ac.uk/id/eprint/59007

Dahl Wikstrøm, R; Böcker, L. (2020). Changing Suburban Daily Mobilities in Response to a Mobility Intervention: A Qualitative Investigation of an E-bike Trial. Sustainability 12, no. 6: 2413. https://doi.org/10.3390/su12062413

depthmapX development team. (2020). depthmapX (Version 0.8.0) [Computer software]. Retrieved from https://github.com/SpaceGroupUCL/depthmapX/

Elldér, E. (2024). Built environment and the evolution of the “15-minute city”: A 25-year longitudinal study of 200 Swedish cities, Cities, V. 49, 104942, https://doi.org/10.1016/j.cities.2024.104942.

European Parliament (2023) EU ban on the sale of new petrol and diesel cars from 2035 explained, 3 November, 2022

Fishman, E; Cherry, C. (2016). E-bikes in the Mainstream: Reviewing a Decade of Research, Transport Reviews, 36:1, 72-91, https://doi.org/10.1080/01441647.2015.1069907

Hardt, C., & Bogenberger, K. (2019). Usage of e-scooters in urban environments. *Trans. Res. Proc.,* 37, 155-162. https://doi.org/10.1016/j.trpro.2018.12.178

Hillier, B., & Hanson, J. (1989). The social logic of space. Cambridge University Press.

HM Government (2022) Net Zero Strategy: Build Back Greener. Department for Energy Security and Net Zero and Department for Business, Energy & Industrial Strategy, 19 October, 2021, updated on 5 April, 2022. ISBN 978-1-5286-2938-6, Available at: https://www.gov.uk/government/publications/net-zero-strategy

HM Government. (2021). Transitioning to zero emission cars and vans: 2035 delivery plan. Department for Transport and Office for Zero Emission Vehicles, 14 July 2021. Available at: https://www.gov.uk/government/publications/transitioning-to-zero-emission-cars-and-vans-2035-delivery-plan

Logan, T.M., Hobbs, M.H., Conrow, L.C., Reid, N.L., Young, R.A., Anderson, M.J. (2022). The x-minute city: Measuring the 10, 15, 20-minute city and an evaluation of its use for sustainable urban design, Cities, V. 131, 103924, https://doi.org/10.1016/j.cities.2022.103924.

Melia, S; Bartle, C (2022) Who uses e-bikes in the UK and why?, Int. Journal of Sust. Trans., 16:11, 965-977, https://doi.org/10.1080/15568318.2021.1956027

Moreno, C., Allam, Z., Chabaud, D., Gall, C., & Pratlong, F. (2021) Introducing the “15-Minute City”: Sustainability, Resilience and Place Identity in Future Post-Pandemic Cities. Smart Cities 2021, 4(1), 93–111.

Newman, M. (2005). Power laws, Pareto Distributions, and Zipf's law. Contemporary Physics. 46 (5): 323–351. https://doi.org/10.1080/00107510500052444.

OpenStreetMap contributors. (2024). *Planet dump – Bristol, UK. Retrieved from https://planet.osm.org* . https://www.openstreetmap.org

Pareto, V, (1919) Manuale di economia politica con una introduzione alla scienza sociale. Vol. 13. Milan, Società editrice libraria.

Pezzica, C., Altafini, D., Mara, F., Chioni, C. (2024). Travel-Time in a Grid: Modelling Movement Dynamics in the “Minute City”. In: Marucci, et. al. (eds) Innovation in Urban and Regional Planning. INPUT 2023. Lec. Notes in Civil Eng., vol 467. Springer, Cham. https://doi.org/10.1007/978-3-031-54118-6_58

QGIS, Prizren, version 3.34 “Long-Term Release” (2024) Available at: http://www.qgis.org/en/site/index.html

Ryu, S.; Chen, A.; Su, J.; Liu, X.; Yu, J. (2021) Considering Space Syntax in Bicycle Traffic Assignment with One or More User Classes. Sustainability, 13, 11078. https://doi.org/10.3390/su131911078

Sahr, K., White, D., and Kimerling, J. (2003). Geodesic Discrete Global Grid Systems. Cartography and Geo. Inf. Sci., Vol. 30, No. 2, 2003, pp. 121-134

Schön, P., Heinen, E., Rangul, V., Sund, E. R., & Manum, B. (2024). The impact of street network connectivity on active school travel: Norway’s HUNT study. *Env. and Plan. B: Urban Analytics and City Science*, *0*(0). https://doi.org/10.1177/23998083241235978

Schön, P; Heinen, E; Manum, B (2024) A scoping review on cycling network connectivity and its effects on cycling, Transport Reviews, 44:4, 912-936, DOI: https://doi.org/10.1080/01441647.2024.2337880

Thomas, J., Williams, M., Gunner, S. (2023). Urban Ride Research Project: https://www.urbanride.uk/

Van Nes, A; Yamu, C. (2021) Introduction to space syntax in urban studies. Springer Nature. ISBN: 9783030591403, 9783030591403, https://doi.org/10.1007/978-3-030-59140-3

Wang, K; Qian, X; Taylor-Fitch, D; Lee, Y; Malik, J; Circella, G. (2023) What travel modes do shared e-scooters displace? A review of recent research findings, Transport Reviews, 43:1, 5-31, https://doi.org/10.1080/01441647.2021.2015639