WHEELS OF CHANGE
INCLUSIVE MOBILITY

Space syntax of Shkodër, Shirokë, Velipojë and Ulcinj



Connectivity, integration, mean depth and choice in the street networks of the Shkodër–Ulcinj cross-border area.

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Report

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Abstract

This report examines how the structure of street networks can inform more inclusive mobility planning in Shkodër, Shirokë, Velipojë and Ulcinj. Developed within the Wheels of Change project, the analysis complements the project's surveys, consultations and accessibility studies by identifying routes that connect different areas, corridors with a high potential for through-movement, and neighbourhoods that are less directly connected to the wider network.

Using space syntax, the report analyses four models: Shkodër's urban core, an extended Shkodër–Shirokë network, Velipojë and Ulcinj. Four measures—connectivity, integration, mean depth and choice—describe the position of streets within each network. The findings indicate a relatively integrated central network in Shkodër, alongside less directly connected peripheral areas. Shirokë's linear lakeside network offers limited route alternatives within the model. Velipojë's regular grid provides favourable structural conditions for walking and cycling, although the concentration of movement potential along its main access corridor suggests a need to examine competing demands on street space. In Ulcinj, the interpretation is particularly sensitive to gaps in the digital network; analysis after joining nearby line ends suggests a central network along the main boulevards and less directly connected coastal neighbourhoods.

The findings help identify locations for further assessment of pedestrian continuity, cycling connections, crossings, wayfinding and access to public transport. They describe movement potential rather than observed journeys or street quality. Planning priorities should therefore combine these results with local evidence on safety, infrastructure, services and the experiences of women and young people. Technical checks identified model discontinuities, particularly in Shirokë and Ulcinj, which require verification before detailed planning use.

Keywords: space syntax; axial analysis; integration; choice; intelligibility; inclusive mobility; Shkodër; Velipojë; Ulcinj.

1. Introduction

1.1 Purpose and research questions

Reaching a school, a workplace, a bus stop or a public space depends partly on how streets connect. The configuration of a street network influences how different parts of a settlement relate to one another. Some streets provide direct connections across multiple neighbourhoods, while others occupy relatively peripheral positions or depend on a limited sequence of routes. Examining these relationships can help explain differences in movement potential and identify locations where network structure warrants particular attention in mobility planning.

This report presents the space syntax analysis undertaken within Wheels of Change, a cross-border project implemented by CoPlan and GreenHOME with the support of OSF-WB and the Transport Community. The project addresses inclusive mobility in Shkodër and Ulcinj, with particular attention to women and young people. The configurational analysis complements the project's surveys, consultations and accessibility studies by examining the spatial relationships within the street networks.

The analysis covers four models: the urban core of Shkodër, an extended model incorporating Shirokë and the lakeside connection, the coastal settlement of Velipojë, and the town of Ulcinj. The two Shkodër models overlap spatially and represent alternative extents of the same urban system. Their comparison therefore examines the implications of extending the analytical boundary, rather than differences between independent settlements.

The report addresses three research questions:

RQ1. How are connectivity, integration, topological depth and through-movement potential distributed within the four models?

RQ2. How do model continuity, analytical boundaries and cartographic representation affect the interpretation of these distributions?

RQ3. What implications do the findings have for identifying priorities for walking, cycling and access to public transport?

These questions distinguish the description of network structure from the evaluation of actual mobility conditions. Space syntax identifies configurational relationships; the practical significance of those relationships depends on infrastructure, destinations, services and the experiences of users.

1.2 Scope and sources

The source material comprises axial models in MapInfo and DXF formats, a depthmapX graph file for Ulcinj, GeoPackage and shapefile representations, and sixteen EPS map exports produced in depthmapX 0.27.b. Four measures are mapped for each model: connectivity, global integration, global mean depth and global choice.

The report uses the supplied axial representations.. Supplementary analysis examines model connectedness, reproduces the reported measures, evaluates the relationship between local and global centrality, and tests sensitivity to small gaps between line geometries.

A distinction is maintained between the original project exports and subsequent analytical work. Results obtained after joining nearby line ends are presented as sensitivity tests. They indicate how small geometric discontinuities affect network measures but do not, by themselves, establish the physical connectivity of every location concerned.

1.3 Organisation of the report

Chapter 2 introduces the theoretical framework and analytical measures. Chapter 3 describes the source models, computation, cartographic interpretation and validation procedures. Chapters 4–7 examine the four model areas. Chapter 8 compares their configurational characteristics and sensitivity to model discontinuities. Chapter 9 discusses implications for inclusive mobility and planning, while Chapter 10 presents the conclusions. Annex A provides supplementary methodological and validation information.

2. Theoretical framework

2.1 Configuration and movement

Space syntax examines how relationships between spaces contribute to patterns of movement and social interaction (Hillier and Hanson, 1984). At the urban scale, it treats the street network as a relational system in which the position of an individual street depends on its connections to the wider network.

The concept of natural movement describes the contribution of spatial configuration to movement patterns (Hillier et al., 1993). Configurational measures have been associated with observed pedestrian flows in empirical studies, although the strength and character of these relationships depend on the urban context, analytical representation and other determinants of movement (Hillier et al., 1993; Peponis, Ross and Rashid, 1997).

Configuration also interacts with land use. Streets with favourable network positions may attract activities that benefit from passing movement, while those activities can generate additional journeys. Hillier's (1996) concept of the movement economy describes this reciprocal relationship between spatial structure, movement and urban activity. The framework therefore provides a basis for investigating the relationship between network centrality and the distribution of commercial and service functions. Such relationships require empirical assessment in each study area.

A related dimension concerns spatial cognition. The relationships between directly visible connections and the wider network may influence how readily users understand an unfamiliar environment (Penn, 2003). In this report, this relationship is examined through intelligibility, a statistical property of the axial model.

2.2 The axial representation and its critics

An axial map represents accessible space through straight lines intended to capture continuity of visibility and movement (Hillier and Hanson, 1984; Turner, Penn and Hillier, 2005). In its graph representation, each axial line forms a node, and intersections between lines establish connections.

An axial line does not necessarily correspond to a complete named street. A long, straight street may be represented by one line, while a curved route may require several. Topological distance measures the number of transitions between connected axial lines, rather than distance in metres or cumulative angular change.

The axial representation has been subject to methodological debate. Its sensitivity to map construction, model boundaries and the omission of metric distance has been discussed by Ratti (2004) and Hillier and Penn (2004). Subsequent developments have incorporated segment representations, angular distance and alternative normalisation procedures (Dalton, 2003; Hillier and Iida, 2005; Turner, 2007; Hillier, Yang and Turner, 2012).

The present study retains the axial representation used in the project. Its findings are interpreted as properties of the supplied network models. They are not treated as direct estimates of travel time, movement volume or physical accessibility.

2.3 Measures

The four mapped measures and the additional measures of this study are defined as follows. For each line i, k is the number of lines in the connected part of the graph that contains it, and the depth d(i, j) is the smallest number of steps from line i to line j.

Connectivity is the number of lines that a line intersects. It is a local measure: it shows how many streets can be reached in one step.

Total depth is the sum of the depths from a line to all other lines, and mean depth is the average number of changes of direction needed to reach every other line:

$$TD(i) = \Sigma\, d(i, j), \quad MD(i) = TD(i) / (k - 1)$$

Mean depth is relativised to the range 0–1 as relative asymmetry, and divided by the value of a diamond-shaped reference graph of the same size to allow comparison between systems of different sizes (Hillier and Hanson, 1984). Integration is the reciprocal of this relativised value:

$$RA(i) = 2\,(MD(i) - 1) / (k - 2)$$

$$D(k) = 2\,\{\, k\,[\, \log_2((k + 2) / 3) - 1\,] + 1\,\} / [\,(k - 1)(k - 2)\,]$$

$$\text{Integration [HH]}(i) = D(k) / RA(i)$$

High integration means that a line is shallow with respect to the whole system: it can be reached from everywhere in few changes of direction. Global integration (radius n) uses the whole system; local integration at radius 3 counts only lines within three steps. The normalisation by D(k) reduces, but does not remove, the effect of system size, and other normalisations have been proposed (Teklenburg, Timmermans and van Wagenberg, 1993).

Choice measures how often a line lies on the shortest paths between all other pairs of lines. It is the betweenness centrality of the line in the graph (Freeman, 1977). depthmapX counts ordered pairs and splits ties between equally short paths:

$$\text{Choice}(i) = \Sigma\, \sigma(s, t \mid i) / \sigma(s, t), \text{ over all ordered pairs } s \neq t \neq i$$

Here $\sigma(s, t)$ is the number of shortest paths from s to t and $\sigma(s, t \mid i)$ the number of those that pass through i. Integration describes to-movement, the potential of a line as a destination; choice describes through-movement, its potential as a route (Hillier, 1996). Normalised choice divides choice by the number of pairs in the component, which in depthmapX gives $2 \times \text{Choice}(i) / [(k - 1)(k - 2)]$.

Two second-order measures describe the system as a whole (Hillier, 1996). Intelligibility is the coefficient of determination (R^2) between connectivity and global integration. When it is high, the local information available at each street, how many streets it crosses, is a good guide to its position in the whole. Synergy is the R^2 between local (radius 3) and global integration. When it is high, the local and the global structure coincide. To these this study adds the concentration of choice: the share of all choice carried by the top 10% of lines and the Gini coefficient of choice.

2.4 Configuration and inclusive mobility

Configurational analysis contributes to inclusive mobility research by identifying spatial conditions that may interact with differences in resources, responsibilities and travel needs.

One relevant relationship concerns movement and co-presence. Integrated streets may provide opportunities for passing movement and interaction, depending on their land uses and physical conditions. Research has examined relationships between configuration, street use and safety (Hillier, 2004). These relationships should not be interpreted as evidence that higher integration automatically produces safer streets. Perceived and experienced safety also depend on traffic, lighting, visibility, maintenance and social conditions.

A second relationship concerns the organisation of everyday journeys. Travel associated with care responsibilities may involve several destinations and linked trips (Law, 1999; Sánchez de Madariaga, 2013). Limited route alternatives and indirect network connections can be relevant to these journeys. However, topological depth alone does not establish their duration, physical effort or exposure to risk.

A third relationship concerns orientation. Weak correspondence between local connectivity and global integration may indicate that immediate network connections provide limited information about wider centrality. This can support further investigation of wayfinding needs, particularly along routes used by people unfamiliar with the area.

The relevance of these relationships to women and young people must be established through the project's survey, consultation and accessibility evidence. The axial model itself does not distinguish users by gender, age, income or mobility capability.

3. Data and methods

3.1 The axial models

Table 1 summarises the four axial models, including their size, total represented line length and connected components.

The Shkodër core model includes attributes stored in the supplied MapInfo file, enabling direct comparison between existing and recomputed values. DXF drawings provide the principal line geometries for the remaining models. The extended Shkodër dataset required cleaning to address duplicate and zero-length geometries; the analysed model is reported as containing 3,967 lines.

Lengths are expressed in UTM zone 34N, EPSG:32634. The Shkodër core was supplied in Web Mercator, EPSG:3857, and was transformed before metric measurements were interpreted. Total axial line length should not be read as an independently verified inventory of physical road length, because it depends on the analytical representation.

Table 1. Axial models analysed

System	Lines analysed	Length, km	Components	Largest component, lines (share)
Shkodër urban core	3,608	252.1	61	3,471 (96.2%)
Shkodër and Shirokë	3,967	271.5	65	3,468 (87.4%)
Velipojë	720	83.5	5	715 (99.3%)
Ulcinj	3,837	176.1	478	2,354 (61.4%)

3.2 Computation

The supplementary computations use Python with the shapely and networkx libraries. Each axial line is represented as a graph node. Connections are established where line geometries intersect or touch, with no additional joining tolerance in the original-model analysis.

Global measures are computed within each line's connected component. Consequently, a global value in a fragmented model describes the component containing that line rather than the full settlement. Local integration uses a topological radius of three steps. Choice is computed over shortest graph paths, with contributions divided between equally short alternatives.

Measures that are undefined for very small components are treated as missing values. Their cartographic representation is distinguished from valid low values, including zero choice.

3.3 Reading the exported maps

The exports use ten colour bands extending from dark blue to red. The bands represent equal intervals between the minimum and maximum values displayed in each export. Grey identifies lines without a defined value.

Colours must be interpreted in relation to the measure and legend. Higher integration and connectivity indicate greater centrality or direct connection, whereas higher mean depth indicates greater topological separation. The same colour therefore does not have a uniform planning interpretation across the four measures.

Small disconnected components can influence the displayed range substantially. Extreme integration values in such components extend the scale and compress variation within the main connected network into the lower bands. This effect is particularly pronounced in Ulcinj and also affects the Shkodër integration maps.

The EPS colour sequences were interpreted according to the PostScript drawing order. The technical procedure is described in Annex. The maps retain the exported colours and black backgrounds, with reconstructed legends, north arrows and scale bars derived from the projected geometries.

The original embedded scale bar was not used where its model units did not correspond to ground distances. This distinction is particularly relevant to the Shkodër core export supplied in Web Mercator.

3.4 Additional analysis by this study

Connectedness is assessed through the number and size of graph components and the distance between each smaller component and the nearest line belonging to another component.

Intelligibility, synergy and choice concentration are calculated for the largest connected component of each original model. Their statistical populations are therefore not identical in spatial coverage across the study areas.

A sensitivity test joins line ends located within 0.5 m of another line and recomputes the measures. This tests the effect of small geometric discontinuities. The resulting connections require spatial verification because proximity alone does not establish a traversable junction.

Street names are assigned by matching axial geometries with OpenStreetMap streets in Shkodër and Ulcinj and the General Local Plan road layer in Velipojë. Neighbourhood summaries use approximate associations with named places. These associations support interpretation but do not constitute an administrative delineation of neighbourhood boundaries.

3.5 Limitations

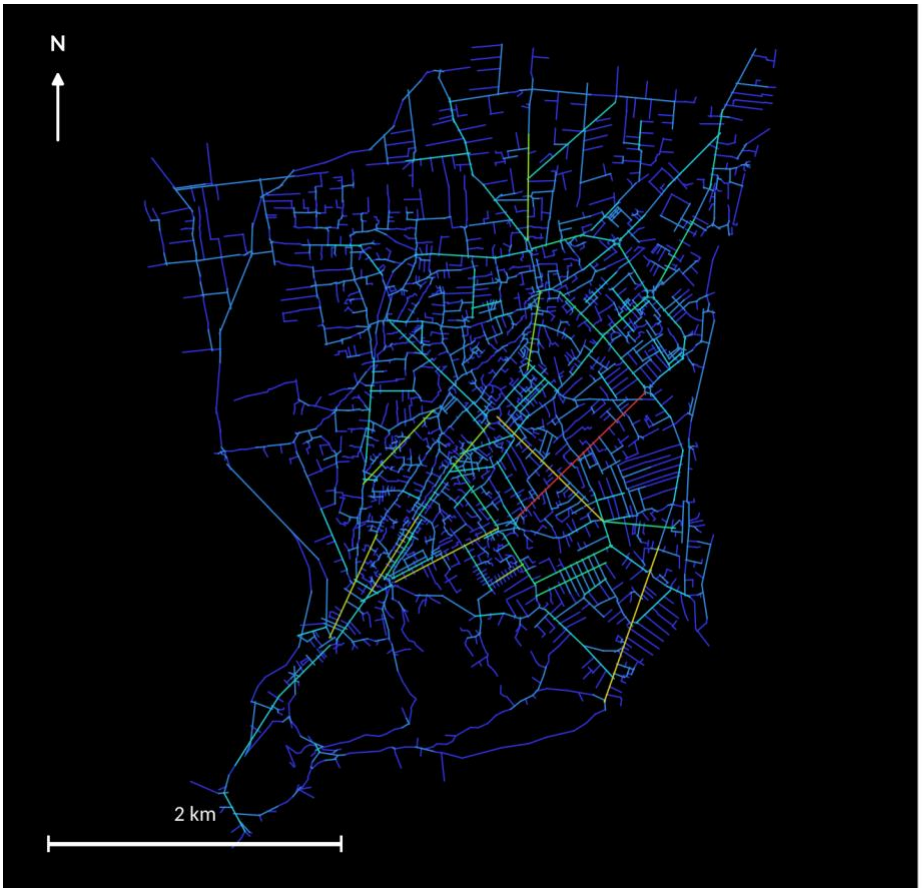
- Global measures are sensitive to the boundary of each model (edge effects). Lines near the edges appear more segregated than they would in a larger model.
- The axial representation ignores metric distance, slope and the quality of streets. Angular segment analysis and metric radii, which are closer to pedestrian behaviour, were not part of the project analysis.
- No observed movement data were available to calibrate the measures against pedestrian or vehicle flows.

4. Shkodër urban core

The Shkodër core model contains 3,608 axial lines with a total represented length of 252.1 km. Its largest connected component contains 3,471 lines, or 96.2% of the model. The remaining 137 lines form 60 smaller components. Of these components, 53 lie within 1 m of another component, with a median gap of 0.16 m. These short distances suggest geometric discontinuities requiring inspection rather than demonstrating physical barriers.

Within the largest component, mean connectivity is 2.44. Global integration ranges from 0.16 to 0.80, with a mean of 0.513, while mean depth ranges from 12.5 to 58.3, with an average of 20.1.

Map 1. Shkodër urban core: connectivity



Source: Wheels of Change space syntax analysis, depthmapX 0.27.b; colours as exported. Legend, scale bar and north arrow added by this study.

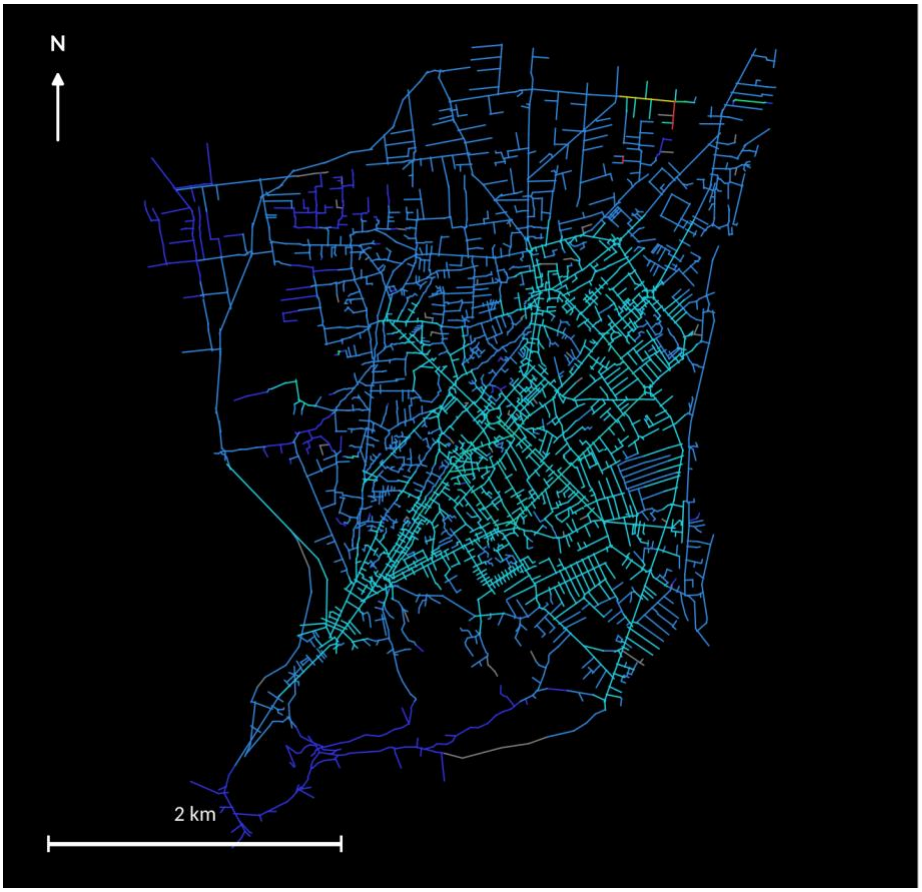
Connectivity is unevenly distributed. In the export, 2,377 lines intersect no more than two other lines, while 1,092 intersect between three and five. Only 107 lines reach the third colour band or above.

The highest values occur along long axial alignments associated with Rruga Marin Biçikemi, Bulevardi Skënderbeu, Rruga Shtatë Shaljanët, Bulevardi Zogu I, Bulevardi Mehmet Pashë Plaku and Rruga Ethem

Osmani. These alignments connect numerous shorter lines and form important local organising elements of the model.

Their high connectivity identifies locations where multiple network relationships converge. Assessing their role in inclusive mobility requires examination of junction design, crossing conditions and the continuity of routes along and across them.

Map 2. Shkodër urban core: global integration [HH]



Integration [HH], radius n

Shkodër urban core

Value range*	Lines
1.92–2.11	2
1.72–1.92	–
1.53–1.72	1
1.33–1.53	–
1.14–1.33	–
0.94–1.14	8
0.75–0.94	32
0.55–0.75	1,303
0.36–0.55	1,861
0.16–0.36	299
no value	70

Total 3,576 lines

Map: WOC export, depthmapX 0.27.b, colours unchanged. *Ranges are reconstructed by this study (10 equal bands). Legend, scale bar and north arrow added.

Source: Wheels of Change space syntax analysis, depthmapX 0.27.b; colours as exported. Legend, scale bar and north arrow added by this study.

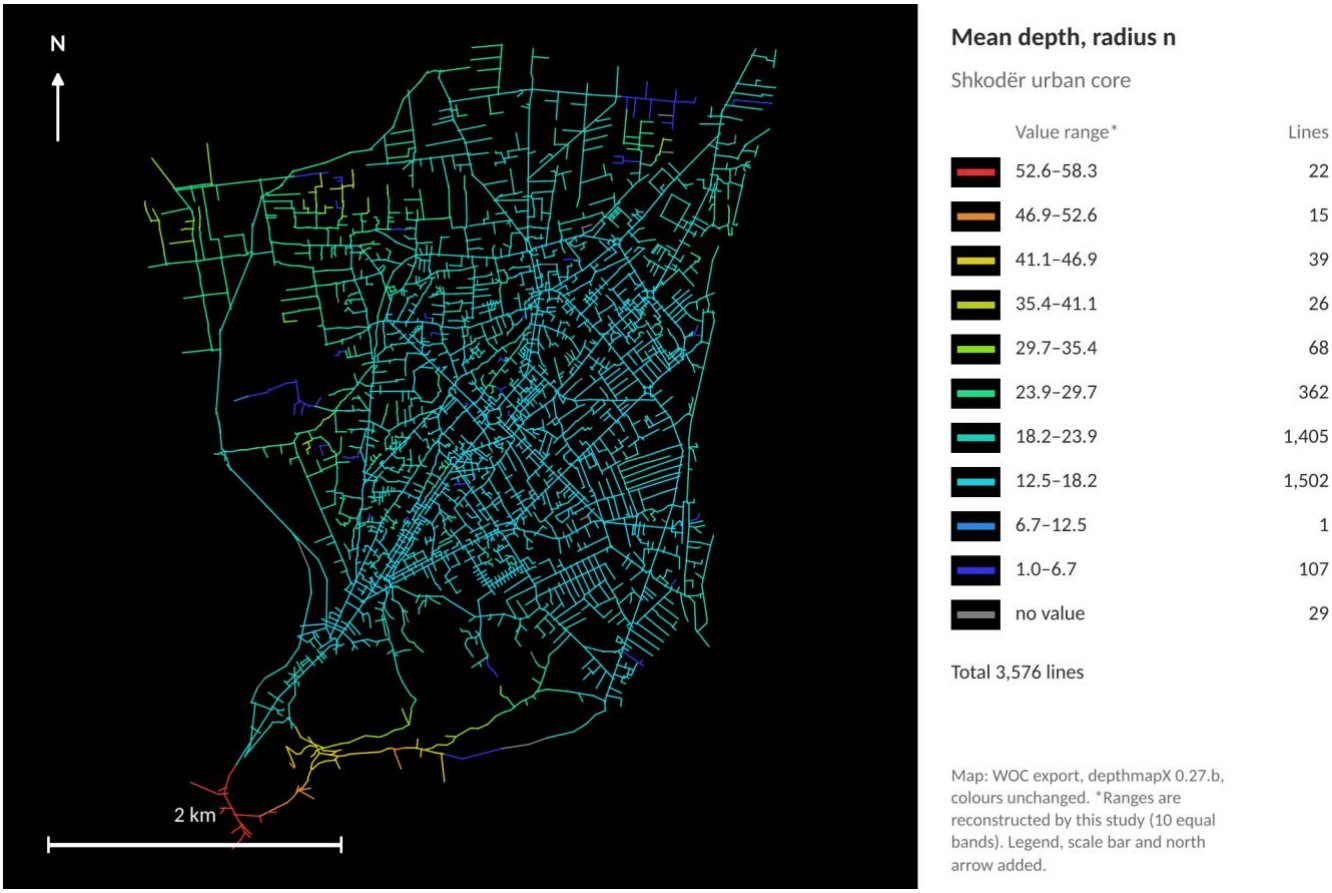
The main connected component occupies only the lower four bands of the exported integration scale. Higher bands are associated with small components whose values extend the displayed range.

Within the main network, relatively high integration follows a central lattice associated with Marin Biçikemi, Skënderbeu, Don Bosko, 13 Dhjetori and 28 Nëntori, extending along several principal boulevards and central streets.

Approximate neighbourhood summaries identify higher mean values in Sarreq, Vasil Shanto, Ballabane, Tom Kola, Arra e Madhe and Qemal Stafa. Lower values occur in Ajasëm, Qafë, Kiras, Udhakryq and parts of the wider peripheral network, including Dobraç and Guerrile.

These differences describe relative topological centrality. They identify areas where access routes merit closer examination but do not establish service deprivation or social disadvantage without additional evidence.

Map 3. Shkodër urban core: global mean depth



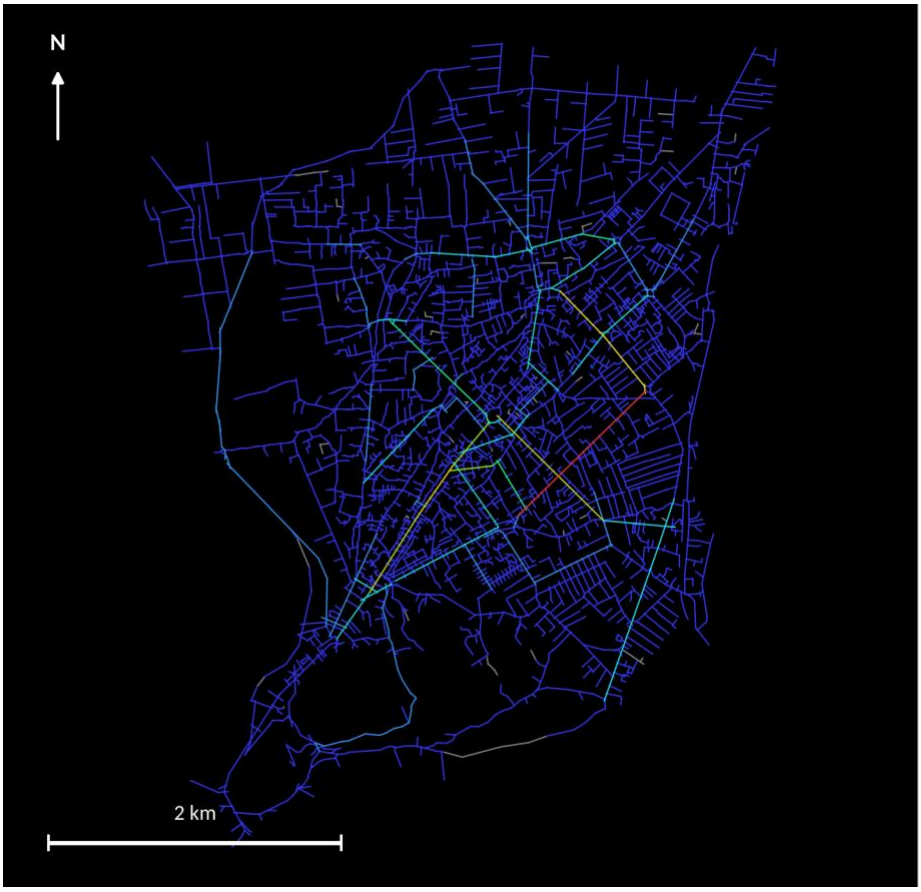
Source: Wheels of Change space syntax analysis, depthmapX 0.27.b; colours as exported. Legend, scale bar and north arrow added by this study.

Mean depth broadly complements the integration pattern within the main component. Central lines have shorter average topological relationships with the rest of the network, while deeper lines are concentrated around the southern and south-western edges and the castle area.

High-depth alignments include Rruga e Ajasmës, Rruga Bexhene, Rruga 9 Nuset, Rruga Selim Bushati, Rruga e Kalasë, Rruga Çun Mula and Rruga Mulla Hysen Dobraçit.

Their position indicates that reaching other parts of the represented network requires more transitions between axial lines. Whether this corresponds to longer or more difficult everyday journeys depends on metric distances, available destinations and street conditions.

Map 4. Shkodër urban core: global choice



Choice, radius n

Shkodër urban core

Value range* (thousands)	Lines
3,507–3,897	1
3,117–3,507	–
2,728–3,117	4
2,338–2,728	2
1,948–2,338	2
1,559–1,948	7
1,169–1,559	10
779–1,169	22
390–779	94
0–390	3,371
no value	63

Total 3,576 lines

Map: WOC export, depthmapX 0.27.b, colours unchanged. *Ranges are reconstructed by this study (10 equal bands). Legend, scale bar and north arrow added.

Source: Wheels of Change space syntax analysis, depthmapX 0.27.b export; colours as exported. Legend, scale bar and north arrow added by this study.

Choice is strongly concentrated. Approximately 94% of exported lines occupy the lowest band, while 142 lines occupy bands 2–10. These colour-band counts are distinct from the ranking of the highest 10% of lines.

Within the largest component, the highest-ranking 10% account for 75.2% of total choice, with a Gini coefficient of 0.835. A further 26.8% of lines have zero choice, meaning that they do not occur as intermediate lines on the shortest paths considered. This does not imply that they are unused or inaccessible.

High-choice alignments include Marin Biçikemi, Zogu I, Pogej, Lin Delia, Skënderbeu and the western bypass, alongside several other connecting routes. Overlap between high integration and high choice on Marin Biçikemi, Zogu I, Skënderbeu and Mehmet Pashë Plaku suggests that these corridors combine centrality with potential through-movement.

This overlap provides a basis for examining interactions between movement along the corridor, access to adjacent activities and pedestrian crossing needs. The bypass's combination of relatively high choice and lower integration indicates a different configurational role, which should be assessed alongside observed traffic and its designated transport function.

5. Shkodër and Shirokë

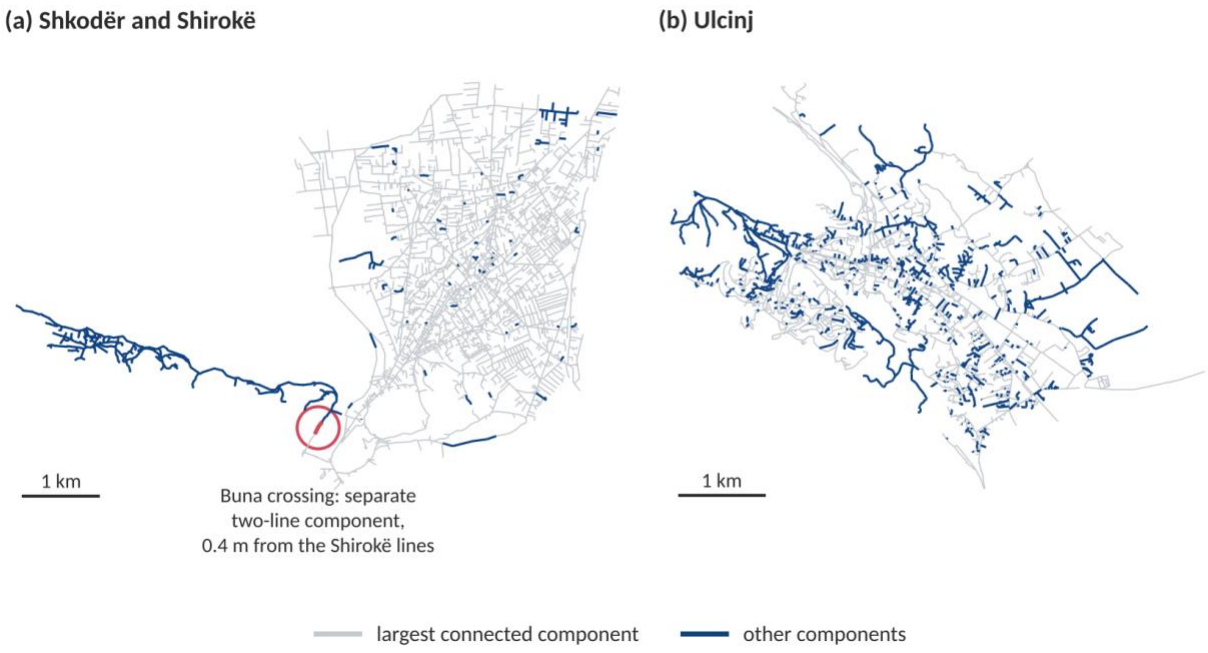
The extended model incorporates the lakeside road and Shirokë. It contains 3,967 analysed lines with a total represented length of 271.5 km, distributed across 65 components.

The largest component contains 3,468 lines, or 87.4% of the model. A separate component of 343 lines represents the Shirokë branch. Inspection identifies a gap of approximately 0.4 m between the crossing alignment and the lakeside network. The original model therefore does not represent a continuous connection between Shirokë and the city.

This distinction affects every global measure. Values calculated within the detached branch describe its internal structure and cannot be interpreted as measures of Shirokë's relationship with Shkodër.

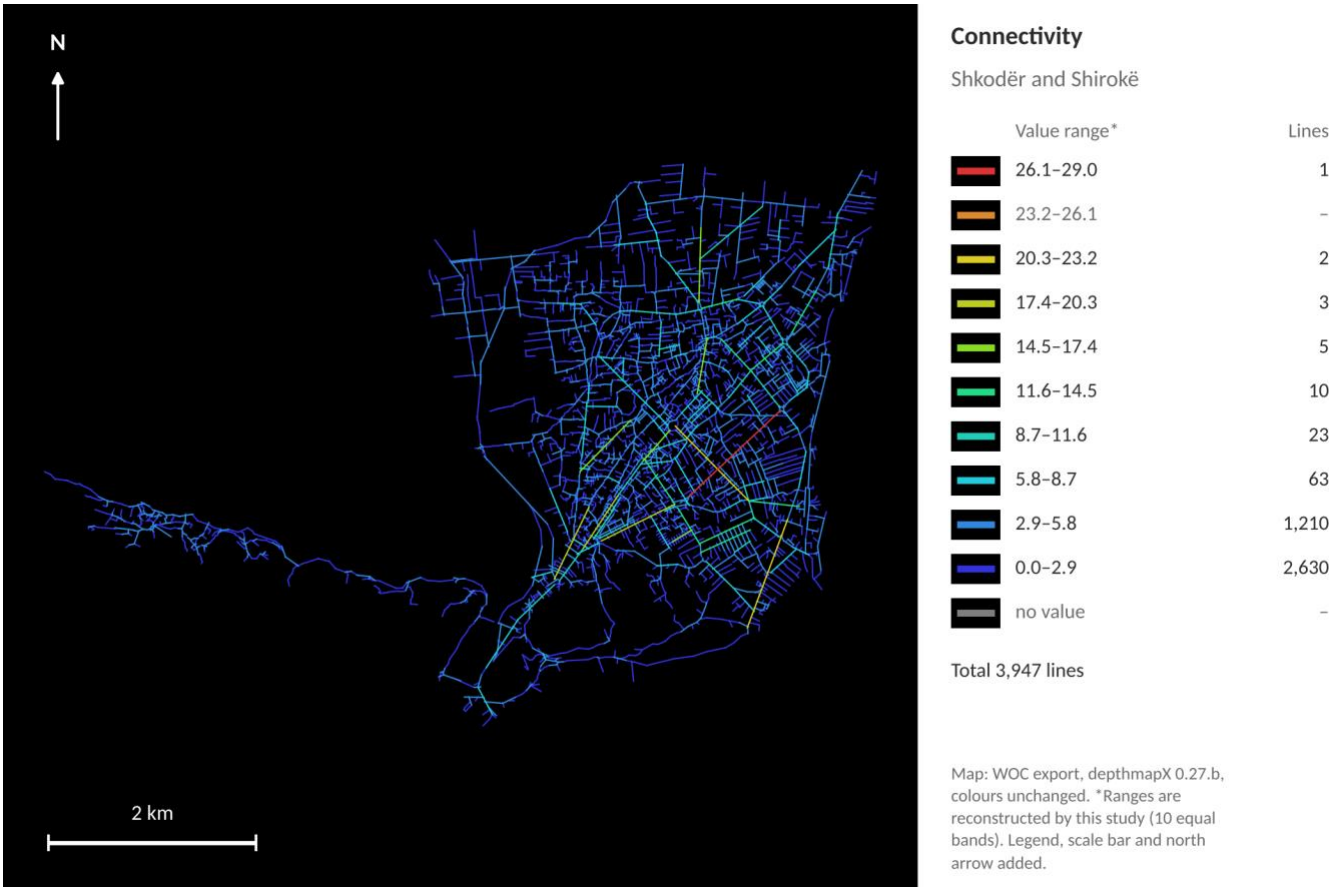
The exports also differ in line count and drawing scale. Connectivity contains 3,947 exported lines, compared with 3,777 in the other three maps. These discrepancies reinforce the need to document the model version associated with each export.

Figure 1. Connected components of the axial models of Shkodër and Shirokë (a) and Ulcinj (b)



Source: Axial models supplied by Wheels of Change; computation by this study.

Map 5. Shkodër and Shirokë: connectivity

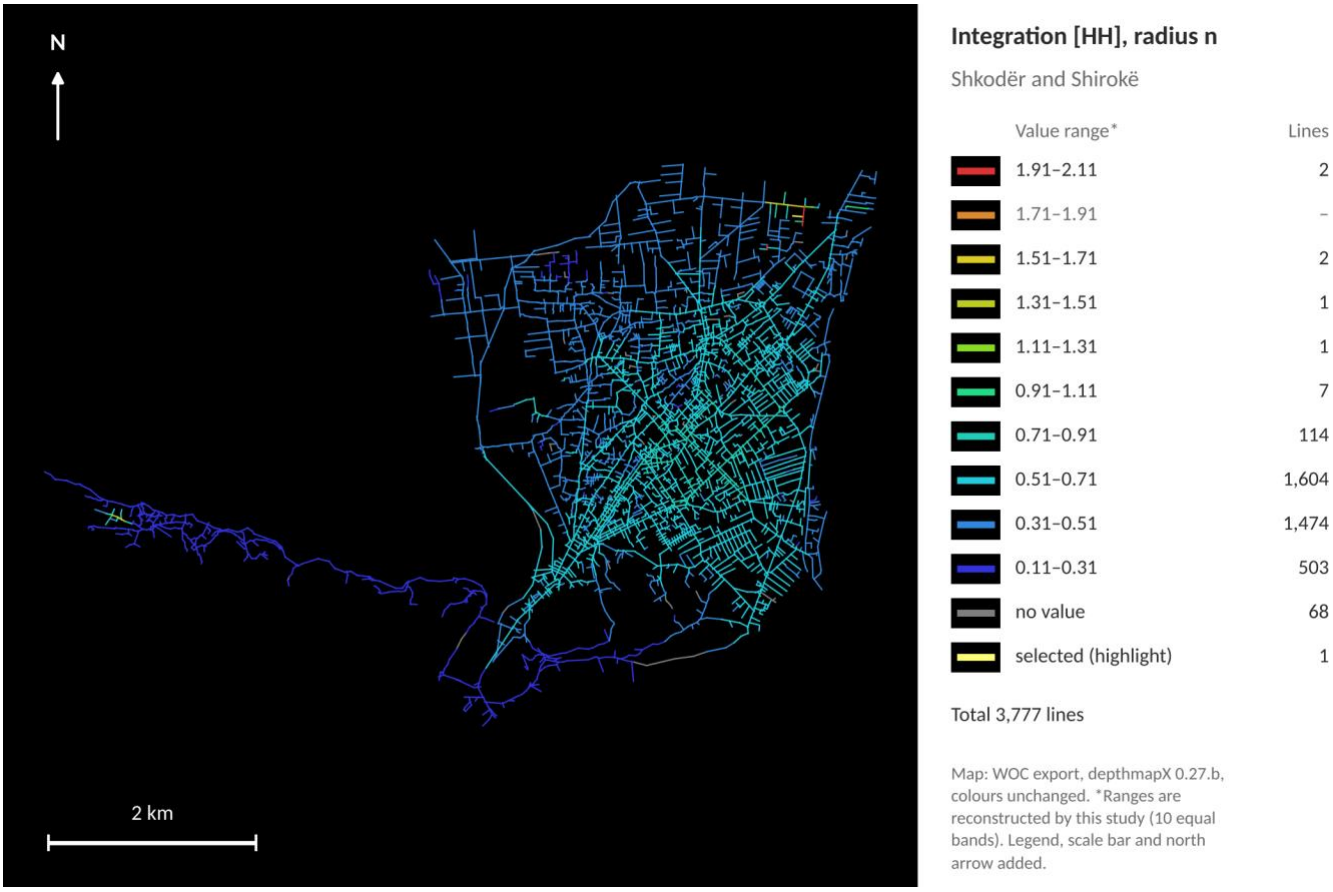


Source: Wheels of Change space syntax analysis, depthmapX 0.27.b; colours as exported. Legend, scale bar and north arrow added by this study.

The city portion broadly reproduces the connectivity pattern of the core model. The Shirokë branch is represented predominantly by a sequence of lines with few direct connections.

This pattern reflects the linear and curving geometry of the represented lakeside route. It indicates limited branching within the model, although the extent to which it captures all pedestrian and cycling alternatives requires verification.

Map 6. Shkodër and Shirokë: global integration [HH]



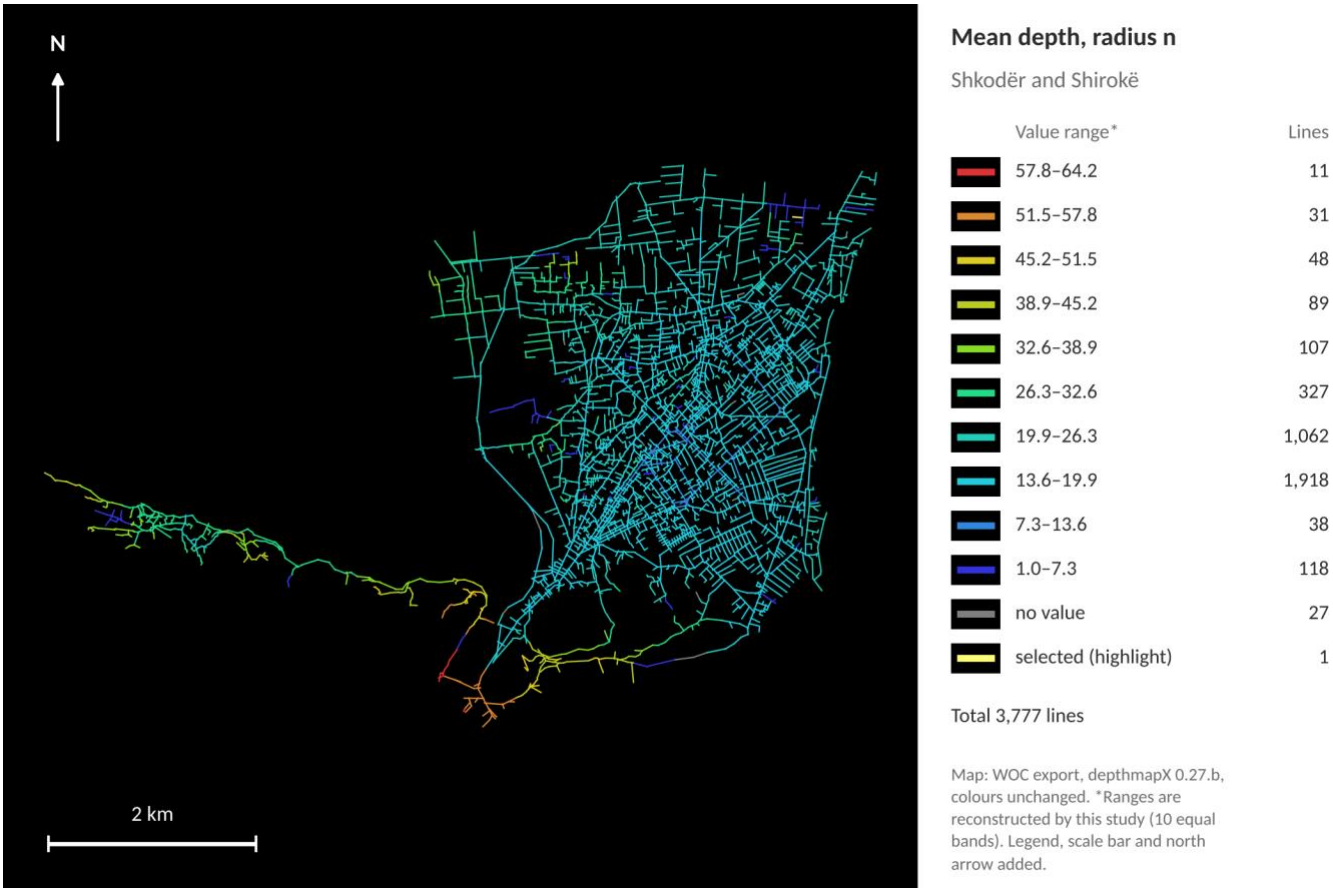
Source: Wheels of Change space syntax analysis, depthmapX 0.27.b; colours as exported. Legend, scale bar and north arrow added by this study.

The original export places the Shirokë lines within the lowest integration band. Because the branch is disconnected, these values describe centrality within that branch alone.

After joining nearby line ends, the sensitivity test connects Shirokë to the city. Its reported mean integration is then 0.144, compared with approximately 0.43 for the remainder of the connected system. Shirokë consequently occupies a relatively peripheral topological position in the extended network.

This finding supports further investigation of the continuity and quality of the lakeside connection. It does not independently establish travel time or transport service adequacy.

Map 7. Shkodër and Shirokë: global mean depth

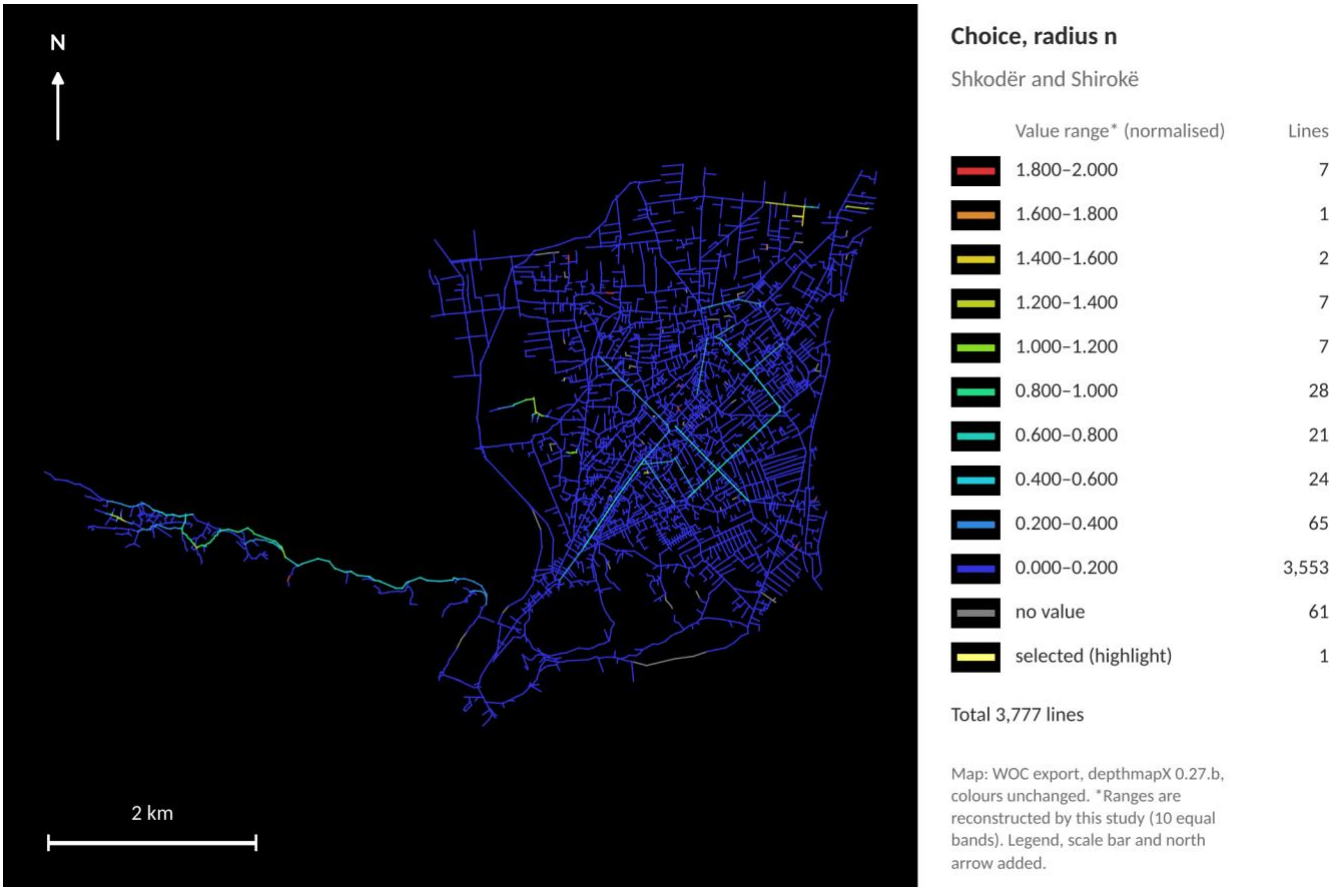


Source: Wheels of Change space syntax analysis, depthmapX 0.27.b; colours as exported. Legend, scale bar and north arrow added by this study.

In the original branch, mean depth averages 34.2. The result reflects the sequence of axial transitions along the curving lakeside network.

Once connected to the city, the branch's relationship with the wider system changes. The original branch-only values should therefore not be used to describe journeys between Shirokë and central Shkodër. The sensitivity analysis provides a more relevant basis for examining that relationship, subject to verification of the joined connections.

Map 8. Shkodër and Shirokë: global choice (normalised)



Source: Wheels of Change space syntax analysis, depthmapX 0.27.b; colours as exported. Legend, scale bar and north arrow added by this study.

This export represents normalised choice. Relatively prominent values along the lakeside route indicate its importance within the detached branch.

The map does not capture shortest paths between Shirokë and the city because these parts are disconnected in the original graph. Its interpretation must therefore distinguish the internal role of the lakeside route from its potential function within the complete extended network.

For planning, the principal issue is the dependence of the represented branch on a restricted connecting corridor. Assessing this dependence requires the combined examination of physical continuity, crossing arrangements, route alternatives and public transport provision.

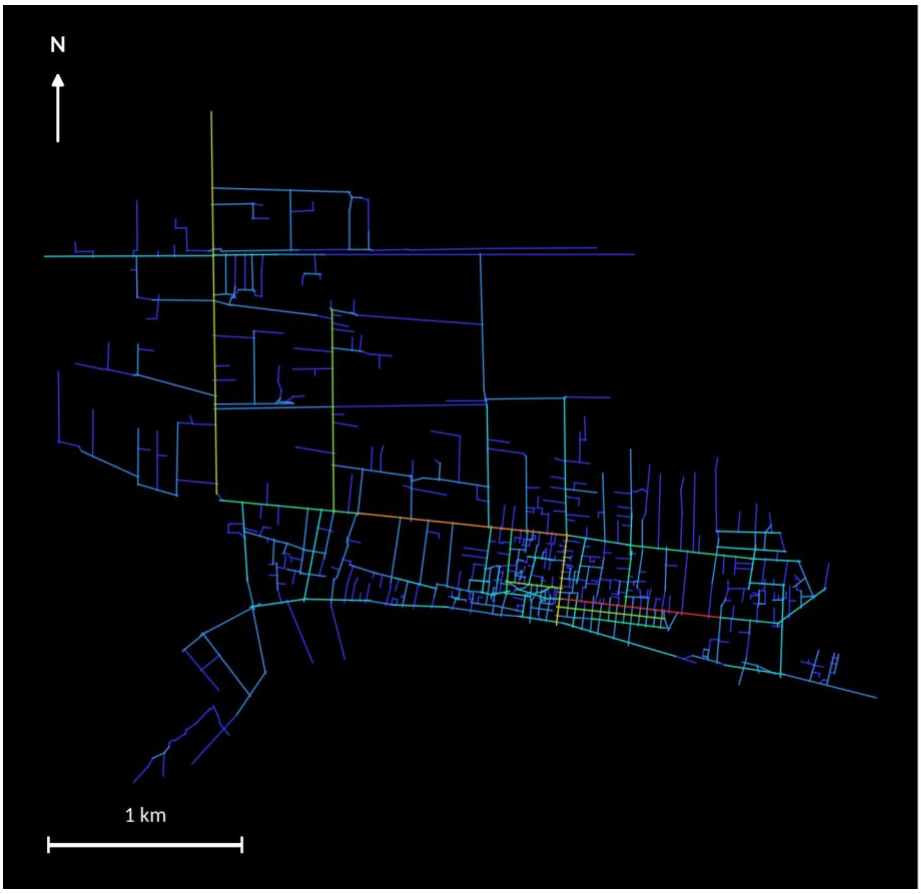
6. Velipojë

Velipojë is the smallest model, containing 720 lines with a total represented length of 83.5 km. The largest component includes 715 lines, or 99.3% of the network.

The representation contains comparatively long axial lines, with a reported mean length of 115.9 m. Its regular street pattern produces shorter topological relationships than those observed in the other supplied models. Mean depth in the largest component is 8.8, while mean global integration is 0.948.

These characteristics indicate favourable configurational conditions for direct movement. Their practical significance depends on actual distances, street provision, seasonal demand and the distribution of destinations.

Map 9. Velipojë: connectivity



Source: Wheels of Change space syntax analysis, depthmapX 0.27.b; colours as exported. Legend, scale bar and north arrow added by this study.

Most lines have limited immediate connectivity: 439 intersect no more than two others, and 228 intersect between three and five. A smaller number of long alignments connect multiple streets within the grid.

The highest reported values are associated with the alignment named Shtëpia e Peshkatarëve in the General Local Plan road layer, the beach access route from the Gjon Lulit bridge, and Selita.

These alignments organise local connections and warrant attention to junction conditions and the distribution of access across the grid.

Map 10. Velipojë: global integration [HH]



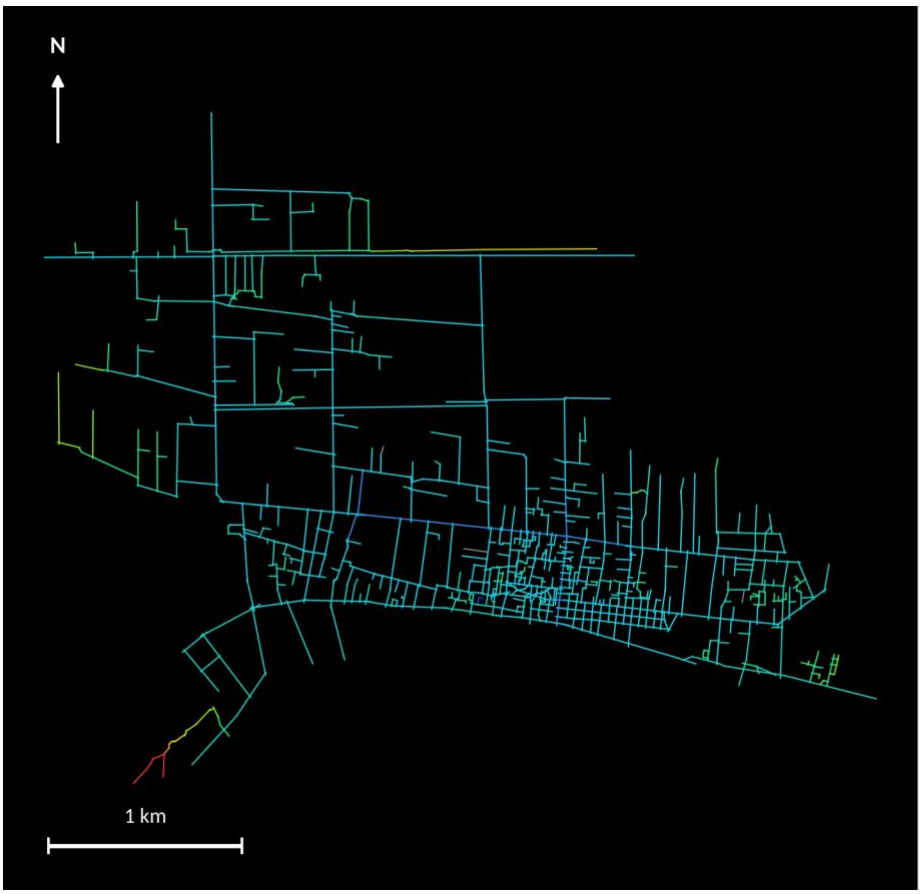
Source: Wheels of Change space syntax analysis, depthmapX 0.27.b; colours as exported. Legend, scale bar and north arrow added by this study.

Integration is distributed across a broader portion of the displayed colour range than in Shkodër or Ulcinj. Small disconnected components have less influence on the integration scale.

The highest value, 1.69, occurs along the beach access alignment from the Gjon Lulit bridge. Other relatively integrated routes include Bregu i Detit, Fran Matusha, Rrok Preka, Rrahi i Axhes, Selita, Shtëpia e Peshkatarëve and Nikollë Lucajt.

Lower integration occurs towards the north-western boundary and the south-western extension of the model. These patterns should be interpreted with attention to boundary effects.

Map 11. Velipojë: global mean depth



Source: Wheels of Change space syntax analysis, depthmapX 0.27.b; colours as exported. Legend, scale bar and north arrow added by this study.

Most of the main component has relatively low topological depth. The reported results place 603 lines between approximately 5.8 and 10.6 steps from the rest of the component on average. Only 13 lines exceed 15.4.

The pattern indicates comparatively direct relationships within the represented network. It does not establish that all destinations are within comfortable walking distance, because topological proximity and metric proximity are different properties.

Map 12. Velipojë: global choice



Source: Wheels of Change space syntax analysis, depthmapX 0.27.b; colours as exported. Legend, scale bar and north arrow added by this study.

The highest choice values follow a restricted set of alignments connecting the principal access route with the beach area. These include the beach access road, Shtëpia e Peshkatarëve, Selita and Rrok Preka.

The highest-ranking 10% of lines account for 70.8% of total choice, with a Gini coefficient of 0.819. The overlap between high integration and high choice indicates that central access functions and potential through-movement converge along parts of the same corridor.

This convergence identifies locations where seasonal traffic, parking, pedestrian activity and cycling should be assessed together. The parallel grid may offer opportunities to distribute access and provide alternative routes, subject to verification of continuity and suitability.

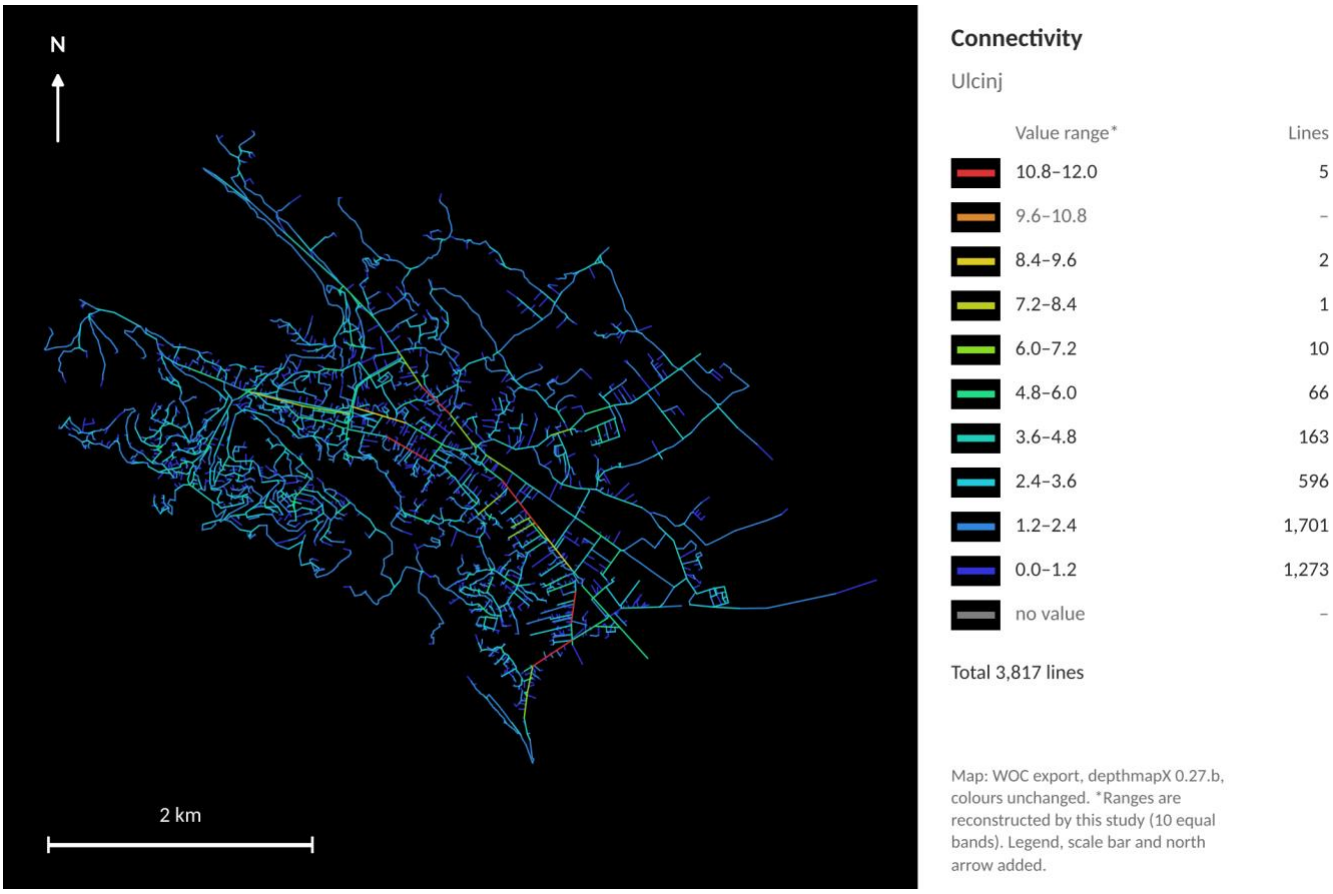
7. Ulcinj

The Ulcinj model contains 3,837 axial lines with a total represented length of 176.1 km. Its comparatively short lines reflect the representation of a curving street network.

The original graph contains 478 components. The largest includes 2,354 lines, or 61.4% of the model. The remaining 1,483 lines form 477 smaller components, of which 474 lie within 0.1 m of another component.

These discontinuities substantially affect settlement-wide interpretation. In the original model, global values are calculated separately within components, and relationships between disconnected parts are omitted. The original exports consequently describe a fragmented representation rather than a fully connected urban network.

Map 13. Ulcinj: connectivity

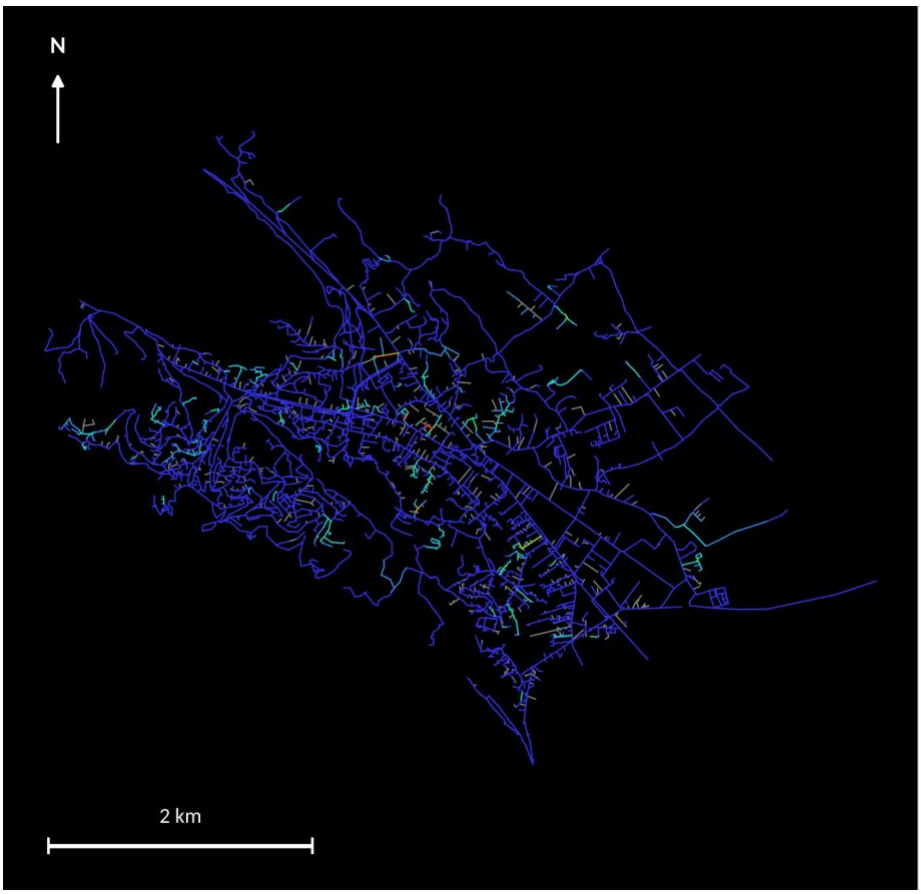


Source: Wheels of Change space syntax analysis, depthmapX 0.27.b; colours as exported. Legend, scale bar and north arrow added by this study.

The connectivity distribution contains a substantial share of lines with zero or one direct connection. This reflects both the geometry of the representation and the effects of discontinuities.

Higher values occur along Rruga Simon Filipaj, Rruga e Turizmit, Bulevardi Teuta, Rruga Fiqri Hasanaga, Gjerana 30 and Bulevardi Nëna Terezë.The map identifies locally prominent alignments within the supplied model. Their connectivity values should be reconsidered after geometric continuity has been verified.

Map 14. Ulcinj: global integration [HH]



Integration [HH], radius n

Ulcinj

Value range*	Lines
2.30–2.55	1
2.06–2.30	4
1.81–2.06	–
1.57–1.81	2
1.33–1.57	2
1.08–1.33	10
0.84–1.08	93
0.59–0.84	111
0.35–0.59	214
0.10–0.35	2,883
no value	497

Total 3,817 lines

Map: WOC export, depthmapX 0.27.b, colours unchanged. *Ranges are reconstructed by this study (10 equal bands). Legend, scale bar and north arrow added.

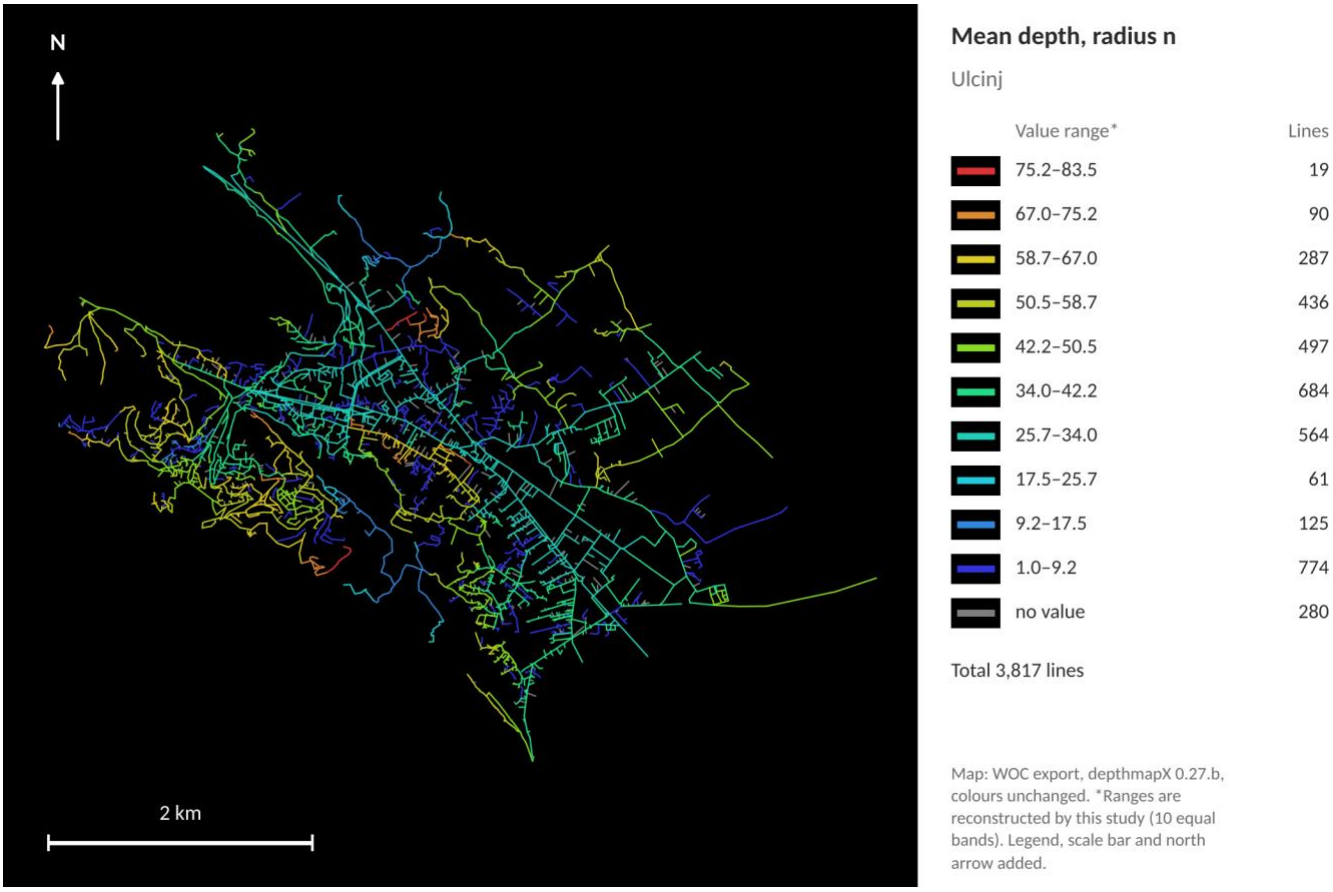
Source: Wheels of Change space syntax analysis, depthmapX 0.27.b; colours as exported. Legend, scale bar and north arrow added by this study.

The main connected component occupies predominantly the lowest part of the displayed range. Higher colour bands are associated with smaller components, whose integration values extend the scale.

The original export therefore provides limited visual differentiation of centrality across the principal network. Within the largest component, relatively integrated alignments include Simon Filipaj, Sami Frashëri, Skënderbeu, Nëna Terezë and Teuta.

Figure 4, 8.4 presents the sensitivity-test result after nearby line ends are joined. It offers a more coherent basis for examining wider relationships, while remaining dependent on verification of those connections.

Map 15. Ulcinj: global mean depth



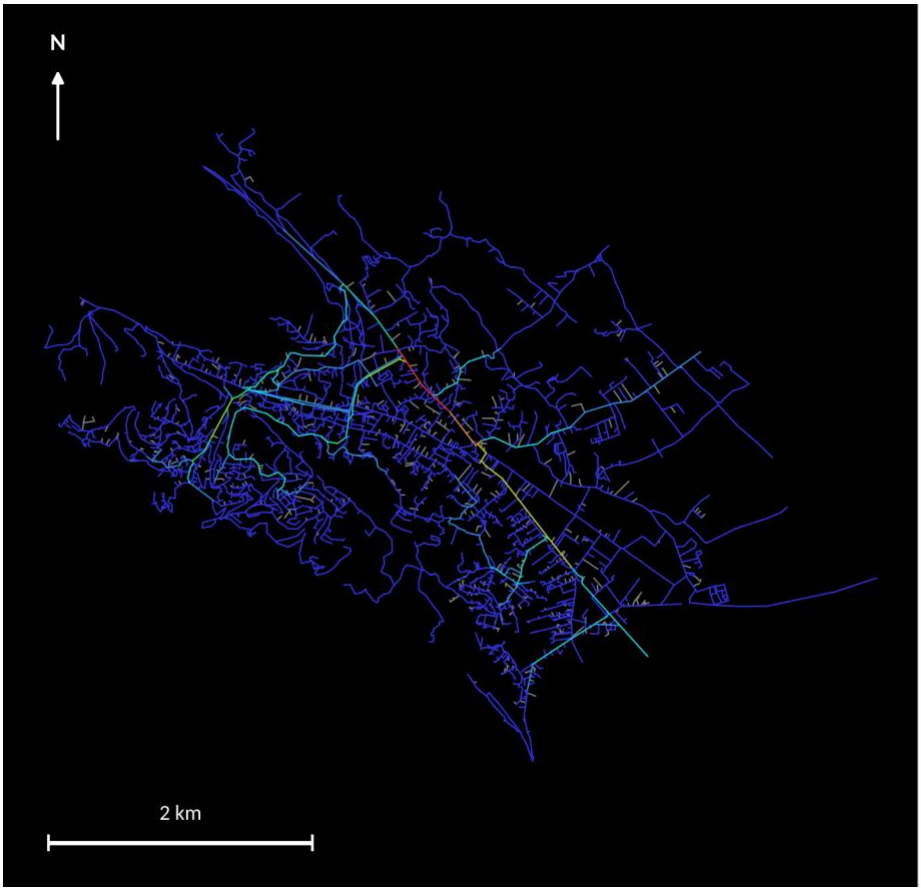
Source: Wheels of Change space syntax analysis, depthmapX. Legend, scale bar and north arrow added by this study.

This export has weaker agreement with the recomputed colour bands than the other maps. Interpretation should therefore focus on broad spatial tendencies rather than precise line-level distinctions.

Approximate area summaries identify higher depth in Pylli i Pishave, Limani, Meterizi, Pinjeshi and the Old Town, with lower values in Mahala e Re, Meraja and Totoshi.

These results describe the original model and are affected by its fragmentation. Physical constraints such as slope and the location of traversable connections require separate investigation before conclusions are drawn about journey difficulty.

Map 16. Ulcinj: global choice



Source: Wheels of Change space syntax analysis, depthmapX 0.27.b; colours as exported. Legend, scale bar and north arrow added by this study.

High-choice alignments within the largest component include Simon Filipaj, Rruga e Kosovës, Teuta, the Teuta bridge, Hafiz Ali Ulqinaku, Sami Frashëri, Gjerana 12 and Voja Lakčevića.

The highest-ranking 10% of lines account for 71.8% of total choice, with a Gini coefficient of 0.824. These values describe concentration within the analysed component.

Because the original graph excludes paths between disconnected components, it may omit important relationships or assign them to alternative sequences within the remaining network. Detailed corridor priorities should therefore use a verified model.

8. Comparative analysis

Table 2 compares the largest connected components of the original models. Their differing shares of the total networks must be considered when interpreting the results. In particular, the original Ulcinj component represents a substantially smaller proportion of its model than the components used for Shkodër and Velipojë.

The two Shkodër models also share most of their urban network. Their similar original statistics partly reflect the exclusion of the disconnected Shirokë branch from the largest component of the extended model.

Table 2. Comparative statistics of the four systems (largest connected component)

Measure	Shkodër core	Shkodër and Shirokë	Velipojë	Ulcinj
Lines (largest component)	3,471	3,468	715	2,354
Share of all lines	96.2%	87.4%	99.3%	61.4%
Mean line length, m	69.9	68.4	115.9	45.9
Mean connectivity (maximum)	2.44 (29)	2.44 (29)	2.73 (27)	2.23 (12)
Mean depth: mean (range)	20.1 (12.5–58.3)	20.4 (12.7–64.2)	8.8 (5.1–24.9)	43.4 (25.5–83.5)
Integration [HH] radius n: mean (range)	0.513 (0.16–0.80)	0.508 (0.15–0.79)	0.948 (0.29–1.69)	0.219 (0.10–0.35)
Integration [HH] radius 3: mean	1.258	1.259	1.503	1.049
Intelligibility, R^2	0.048	0.047	0.137	0.014
Synergy, R^2	0.266	0.261	0.596	0.070
Choice: share of top 10% of lines	75.2%	75.4%	70.8%	71.8%
Choice: Gini coefficient	0.835	0.835	0.819	0.824
Lines with zero choice	26.8%	26.7%	25.7%	26.0%

Analysis by this study, from the axial models supplied by Wheels of Change.

8.1 Integration

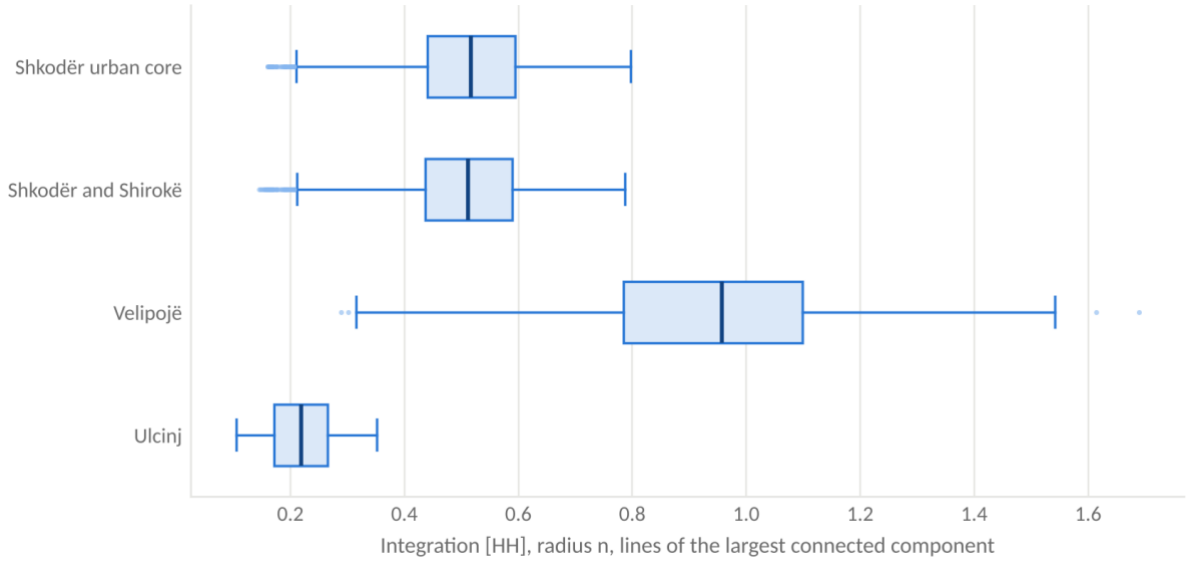
Velipojë has the highest reported mean integration in the original models, at 0.948, followed by the Shkodër core at 0.513, extended Shkodër at 0.508, and Ulcinj at 0.219.

This ordering is consistent with differences in network geometry and model construction. Velipojë's comparatively small, regular representation produces fewer axial transitions, whereas the other models contain more extensive or curving networks. Ulcinj is additionally affected by substantial fragmentation.

After nearby line ends are joined, Ulcinj's mean integration rises to 0.329. Its value remains the lowest of the four sensitivity-test models, but the magnitude of the change demonstrates the influence of geometric discontinuities.

The comparison describes configurational centrality under the adopted representations. It should not be presented as a general ranking of mobility performance or pedestrian accessibility.

Figure 2. Distribution of global integration [HH] in the four systems



Source: Axial models supplied by Wheels of Change; computation by this study.

8.2 Intelligibility and synergy

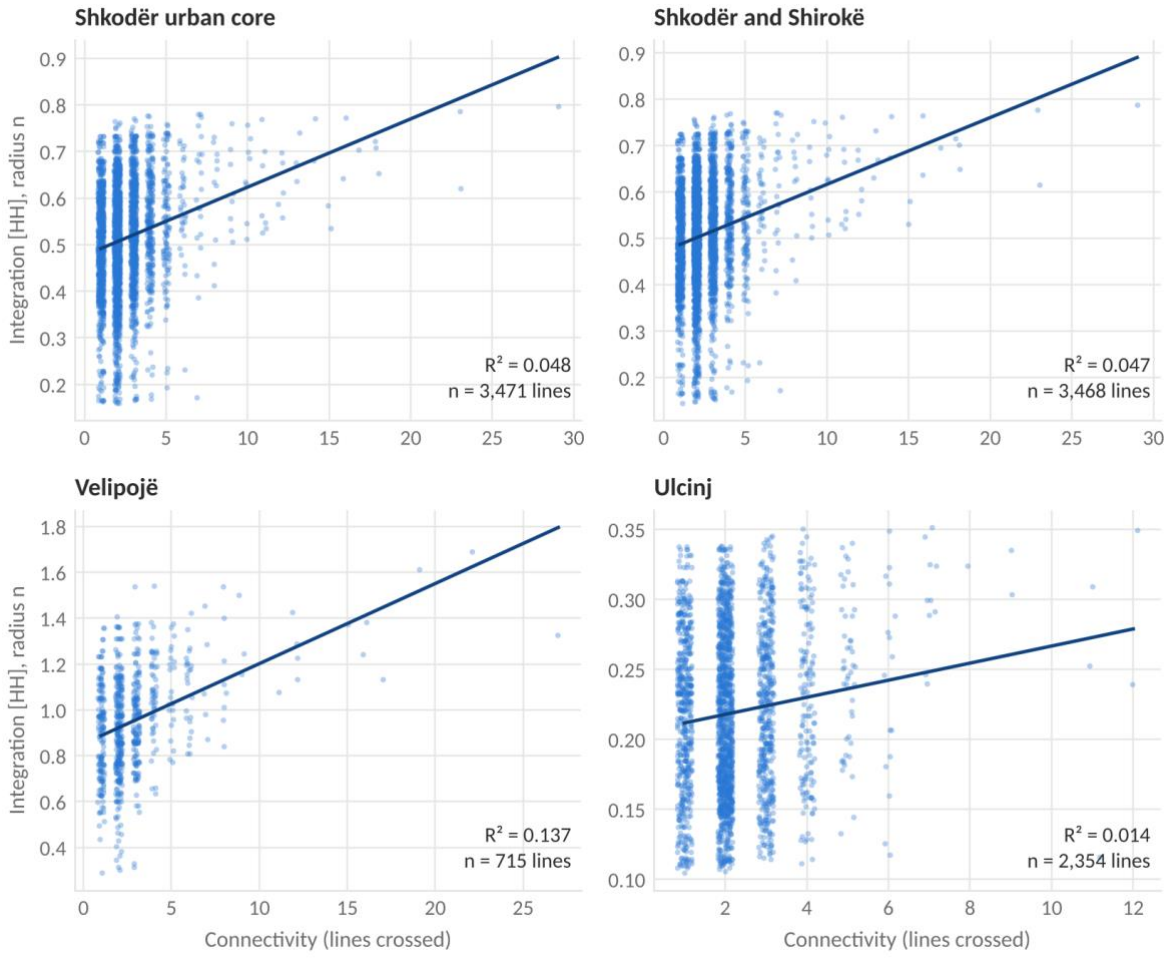
Intelligibility is weak across the original models. The reported (R^2) values are 0.048 for the Shkodër core, 0.047 for extended Shkodër, 0.137 for Velipojë and 0.014 for Ulcinj.

These values indicate that immediate connectivity explains only a limited proportion of the variation in global integration. They do not directly demonstrate that users find the settlements difficult to navigate.

Synergy shows a stronger relationship between local and global integration in Velipojë, at 0.596, than in the Shkodër core, at 0.266, extended Shkodër, at 0.261, or Ulcinj, at 0.070. Local and global centrality therefore align more closely in the Velipojë model.

For planning, these results support investigation of how principal routes, landmarks and information systems assist orientation. Wayfinding recommendations should also draw on users' reported difficulties and observed route choices.

Figure 3. Intelligibility: connectivity against global integration [HH], largest connected component



Source: Axial models supplied by Wheels of Change; computation by this study.

8.3 Concentration of choice

The highest-ranking 10% of lines account for 70.8–75.4% of total choice across the original models. Gini coefficients range from 0.819 to 0.835.

This concentration indicates that a restricted part of each graph carries a large proportion of modelled shortest-path through-movement. It does not imply that the same share of observed journeys uses those lines.

Approximately one quarter of lines have zero choice. These lines may still serve as origins, destinations and local access routes. Zero choice identifies the absence of an intermediate role under the model's shortest-path assumptions.

Concentration provides a basis for selecting corridors for further assessment. It does not establish which intervention would produce the greatest benefit without evidence on actual use, existing conditions and user needs.

8.4 Connectedness of the models and sensitivity

Joining nearby line ends produces different effects across the models.

In the Shkodër core and Velipojë, the rank ordering of integration remains comparatively stable, with Spearman coefficients of 0.978 and 0.993 respectively. Aggregate integration nevertheless changes, particularly in Shkodër, demonstrating that stable rankings do not imply identical numerical values.

In extended Shkodër, joining connects the Shirokë branch to the city. Mean integration decreases from 0.508 to 0.402, while mean depth increases from 20.4 to 27.9. The comparison involves an expanded connected population, rather than a deterioration in the physical network.

Ulcinj shows the greatest sensitivity. The number of components decreases from 478 to four, and the largest component increases from 61.4% to 99.9% of model lines. The integration rank correlation is 0.704, indicating substantial changes in relative position.

In the joined Ulcinj model, the integration core follows Fiqri Hasanaga and the principal boulevards, including Nëna Terezë, Skënderbeu, Simon Filipaj, Sami Frashëri, Teuta and Mehmet Gjyli. Of the lines in its highest integration decile, 26% were outside the largest component of the original model.

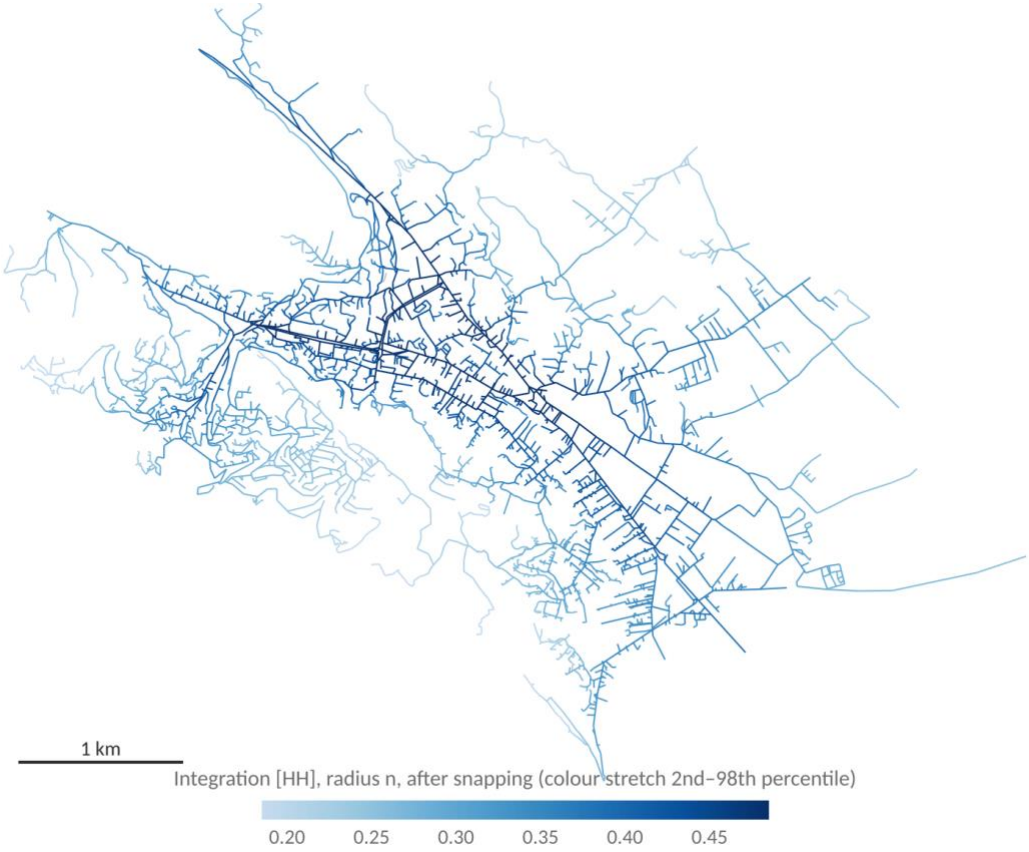
The sensitivity test demonstrates the analytical consequences of small gaps. It should inform geometric inspection and model correction, rather than substitute for verification of real connections.

Table 3. Sensitivity of the measures to joining line ends within 0.5 m (analysis by this study)

System	Components (original → joined)	Largest component share	Integration [HH] mean	Mean depth, mean	Intelligibility R^2	Rank correlation with original
Shkodër core	61 → 13	96.2% → 99.4%	0.513 → 0.562	20.1 → 18.2	0.048 → 0.062	0.978
Shkodër and Shirokë	65 → 14	87.4% → 99.4%	0.508 → 0.402	20.4 → 27.9	0.047 → 0.030	0.970
Velipojë	5 → 4	99.3% → 99.4%	0.948 → 0.956	8.8 → 8.7	0.137 → 0.137	0.993
Ulcinj	478 → 4	61.4% → 99.9%	0.219 → 0.329	43.4 → 31.3	0.014 → 0.024	0.704

Rank correlation (Spearman) of global integration between the original and the joined model, for lines with a value in both.

Figure 4. Ulcinj: global integration [HH] after joining line ends within 0.5 m (analysis by this study, not a Wheels of Change export)



Source: Axial models supplied by Wheels of Change; computation by this study.

9. Discussion

9.1 Implications for inclusive mobility

Shkodër's central network combines relatively high integration with several high-choice corridors. This overlap identifies locations where wider movement relationships and access to central activities may coincide. Marin Biçikemi, Zogu I, Skënderbeu and Mehmet Pashë Plaku warrant particular examination of pedestrian continuity, crossings, cycling conditions and interactions with motorised traffic.

Lower integration and greater depth occur in several peripheral areas, including Kiras, Qafë, Ajasëm, Dobraç and Guerrile. The project's accessibility study also identifies access and service concerns in some of these areas. Where the findings overlap, they provide a stronger basis for investigating whether network structure and service distribution jointly constrain everyday journeys. The configurational results alone do not establish the scale or social distribution of those constraints.

The extended Shkodër model highlights the importance of the lakeside connection to Shirokë. Once the model gap is joined, Shirokë occupies a comparatively peripheral position within the wider network. Its linear representation offers limited alternatives. This supports examination of route continuity and transport provision along the corridor, particularly for users who cannot readily substitute private car travel.

Velipojë combines relatively short topological relationships with concentration of integration and choice along its principal access corridor. The grid offers potential alternatives, but their usefulness depends on continuity, infrastructure and the location of destinations. Seasonal assessment is necessary to understand whether parking and vehicle movements reduce the practical advantages of the network structure.

Ulcinj requires particular methodological caution. The joined model suggests a central structure along the main boulevards and less directly connected coastal areas. These patterns should be examined alongside terrain, street conditions and available transport services. They cannot independently establish the accessibility of routes for older people, wheelchair users or people travelling with children.

Across the study areas, the relevance to women and young people depends on the relationship between network position and actual journeys. Linking model findings with reported destinations, route avoidance, transport dependence and perceived safety would allow more specific conclusions about unequal mobility conditions.

9.2 Application in planning

The first requirement is a verified and documented network model. Small gaps should be inspected against appropriate spatial evidence, with attention to whether apparent intersections represent traversable connections. Model preparation should preserve genuine barriers and differences between transport modes.

Integration and choice should then be interpreted together. Corridors with high values in both measures are candidates for examining the relationship between local access and through-movement. High choice with lower integration indicates a different network role, but does not automatically justify a traffic designation. Likewise, low centrality does not establish that a street is residential or determine its appropriate speed regime.

Configurational analysis can support the comparison of planning scenarios. Potential links, changes to route continuity and modifications to access arrangements can be represented and compared with an agreed

baseline. Such testing should evaluate consequences across the network and should be followed by assessment of feasibility, environmental conditions and user needs.

Further analysis could incorporate segment representations, angular distance and metric radii relevant to neighbourhood journeys (Hillier and Iida, 2005; Turner, 2007). These approaches would extend the current analysis, while still requiring complementary information on street conditions and destinations.

Calibration with observed movement would strengthen interpretation. Counts and route observations should cover different network positions, times and seasonal conditions. Where appropriate, the survey design should also examine differences between user groups rather than assuming that a single aggregate pattern represents all mobility experiences.

9.3 Cross-border relevance

The comparative value of the study lies in identifying common analytical questions across different urban contexts. Concentration of potential through-movement, peripheral network positions and the relationship between route structure and practical accessibility are relevant to both municipalities.

Cross-border cooperation can support shared methods for collecting movement data, documenting user experiences and evaluating improvements. Comparable indicators would allow future assessments to distinguish changes in network structure from changes in infrastructure, services and travel behaviour.

The present models represent separate local systems. They do not establish the connectivity or performance of a cross-border transport network. Recommendations at that scale require additional information on interurban services, transfer arrangements and the complete journeys undertaken between destinations.

10. Conclusions

The space syntax analysis identifies distinct patterns of connectivity, centrality and potential through-movement within the supplied models. Shkodër contains a relatively integrated central network and less directly connected peripheral areas. The extended model places Shirokë in a comparatively deep position once the lakeside branch is connected. Velipojë has shorter topological relationships within a regular network, while the Ulcinj results are particularly sensitive to geometric discontinuities.

Choice is strongly concentrated across all four original models. A limited proportion of lines accounts for most modelled shortest-path through-movement. Where this concentration overlaps with high integration, the results identify corridors for closer assessment of access, crossing needs and competing demands on street space.

The methodological checks demonstrate close agreement between stored and recomputed values for Shkodër and substantial agreement with most exported colour bands. They also show that computational reproducibility and suitability for urban interpretation are separate questions. Small disconnected components influence the colour scales, while gaps in the Shirokë and Ulcinj models materially affect global relationships.

The findings provide a basis for identifying locations and questions for further investigation. They do not independently determine street safety, physical accessibility or the distribution of mobility disadvantage. Their contribution to inclusive planning depends on integration with the project's surveys, accessibility studies, consultations and field evidence.

Priorities should therefore emerge from the convergence of configurational findings and documented user needs. This approach allows network analysis to support decisions about pedestrian continuity, cycling connections, access to public transport and wayfinding while maintaining a clear account of the evidence and its limitations.

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Annex A. Method and validation note

A.1 Reading the depthmapX EPS exports

Each EPS file starts by filling the page in black. It then lists the lines grouped by colour. Within each group, the lines are added to the current path, and the group ends with the colour, given as three values from 0 to 1, and the command that draws the path. In PostScript, the colour that applies to a path is the colour current when the path is drawn. Each colour therefore belongs to the group of lines written before it. The first colour in each file, black, draws an empty path; no line is drawn in black. The files end with a scale bar labelled in model units.

Read in this way, every map uses grey for lines without a value and the ten colours of the depthmapX scale for ten equal intervals between the minimum and maximum value. In the extended Shkodër model one line in each of three exports has a pale yellow colour, which depthmapX uses for selected lines; these lines were selected when the maps were exported.

A.2 Display ranges and band agreement

Table A1. Display range, band width and agreement between exported colour bands and recomputed values

System	Measure	Display range	Band width	Lines in export	Grey (no value)	Same band	Within one band
Shkodër core	Connectivity	0–29	2.9	3,576	0	100.0%	100.0%
Shkodër core	Integration [HH]	0.160–2.112	0.195	3,576	70	100.0%	100.0%
Shkodër core	Mean depth	1.0–58.3	5.7	3,576	29	100.0%	100.0%
Shkodër core	Choice	0–3,896,714	389,671	3,576	63	99.9%	100.0%
Shkodër and Shirokë	Connectivity	0–29	2.9	3,947	0	99.9%	100.0%
Shkodër and Shirokë	Integration [HH]	0.106–2.112	0.201	3,777	68	99.8%	100.0%
Shkodër and Shirokë	Mean depth	1.0–64.2	6.3	3,777	27	99.9%	100.0%
Shkodër and Shirokë	Choice (normalised)	0.000–2.000	0.200	3,777	61	99.9%	99.9%
Velipojë	Connectivity	0–27	2.7	719	0	99.9%	100.0%
Velipojë	Integration [HH]	0.289–1.690	0.140	719	5	100.0%	100.0%
Velipojë	Mean depth	1.0–24.9	2.4	719	3	100.0%	100.0%
Velipojë	Choice	0–297,584	29,758	719	5	99.9%	100.0%
Ulcinj	Connectivity	0–12	1.2	3,817	0	99.0%	100.0%
Ulcinj	Integration [HH]	0.105–2.547	0.244	3,817	497	97.7%	99.7%
Ulcinj	Mean depth	1.0–83.5	8.2	3,817	280	80.1%	92.5%
Ulcinj	Choice	0–3,081,681	308,168	3,817	452	96.6%	99.8%

Display range: minimum and maximum over all lines with a value, including lines in small components. For mean depth, lines in two-line components have a mean depth of 1, as in depthmapX. Agreement is measured on the exported lines matched to model lines.

A.3 Replication of the values of the project

Table A2. Shkodër core: values stored by the project compared with values recomputed by this study (3,608 lines)

Measure	Comparison	Result
Connectivity	Identical values	100% of lines
Mean depth, radius n	Largest absolute difference	2.2×10^{-6}
Integration [HH], radius n	Largest absolute difference	9.6×10^{-8}
Choice, radius n	Pearson / Spearman correlation	0.9996 / 0.9988
Normalised choice	Ratio of stored to recomputed value (median)	2.000

The stored values for radius 500 equal the global values, because no topological path in the model is longer than 500 steps.

A.4 Gaps between components

Table A3. Small components and their distance to the nearest line of another component (analysis by this study)

System	Small components	Lines in small components	Median gap, m	Gap < 0.1 m	Gap < 0.5 m	Gap < 1 m
Shkodër core	60	137	0.16	22	48	53
Shkodër and Shirokë	64	499	0.16	23	51	57
Velipojë	4	5	0.65	1	1	3
Ulcinj	477	1,483	0.00	474	474	474

Most small components are separated from the network by less than half a metre. They are gaps in the drawing, not barriers in the city.

A.5 Software and reproducibility

The analysis used Python 3 with shapely (geometry and spatial index), networkx (graph measures), geopandas and matplotlib. The graph rule, the formulas and the conventions for choice follow depthmapX 0.27.b, as confirmed by the comparison in Table A2. The recomputed values for all lines, with the band read from each export and the values after joining line ends, were stored in a GeoPackage with one layer per system in UTM zone 34N, so that the maps and tables of this report can be reproduced and the models can be repaired and analysed again.

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