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Depicting routes and centralities: preparing and investigating Road Centre Lines for Angular Segment Analysis in two Brazilian cities

Representando rotas e centralidades: preparando e investigando Road Centre Lines para Análise Angular de Segmentos em duas cidades brasileiras

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Abstract

Axial and RCL (Road Centre Lines) models are street network representations used as base for space syntax Angular Segment Analysis (ASA) studies of centralities in cities. Although RCL is widely adopted for ASA, steps to treat RCL seem uncompleted. On the other hand, in Brazil many studies maintain axial models for ASA, despite standardization and updating limitations. Understanding models' importance as it affects results, and in order to advance more confidently in studies, this paper compares axial and different modes of Open Street Map RCL ASA for two medium-to-large sized north-eastern Brazilian cities (Joao Pessoa and Natal). Closeness and betweenness centralities (i.e., measures of integration and choice) are studied for the city and their old city centres, as well as interrelations between centralities for different scales. Although all models work differently, they capture city centralities and scale dynamics, pointing towards natural urban voids in both cities accentuating routes movement hierarchies. Understanding some limitations in RCL simplifications proposed so far, a further procedure is presented that yielded good results in terms of route depiction and highlighting city centralities reading, while allowing more standardized and easily updated city models, especially relevant for rapidly changing Brazilian cities.

Keywords: Cities centralities. Angular Segment Analysis. Space Syntax. OSM RCL models. Axial models.

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Resumo

Modelos axiais e de Road Centre Lines (RCL) são representações de redes de ruas usadas como base para estudos da sintaxe espacial de Análise Angular de Segmentos (ASA) sobre centralidades em cidades. Apesar do RCL ser amplamente adotado para ASA, passos para tratar RCL parecem incompletos. Por outro lado, no Brasil muitos estudos mantêm modelos axiais para ASA, apesar das limitações de padronização e atualização. Entendendo a importância dos modelos pois afetam resultados, e para avançar confiantemente em estudos, esse artigo compara modelos axiais e diferentes modos de Open Street Map RCL para ASA em duas cidades de médio-a-grande porte do nordeste Brasileiro (João Pessoa e Natal). Centralidades de proximidade e de intermediação (i.e., integração e escolha) são estudadas para a cidade e centros antigos, e inter-relações entre centralidades para diferentes escalas. Apesar dos modelos funcionarem diferente, capturam centralidades e dinâmicas da cidade, apontando para vazios urbanos naturais em ambas cidades acentuando hierarquias de movimento. Entendendo limitações nas propostas de simplificação de RCL até agora, um procedimento adicional é apresentado que produziu bons resultados em termos de capturar rotas e realçar centralidades na cidade, ao passo que permite modelos mais padronizados e facilmente atualizados, especialmente relevante para cidades Brasileiras em rápida transformação.

Palavras-chave: *Centralidades. Análise Angular de Segmentos. Sintaxe Espacial. Modelos OSM RCL. Modelos axiais.*

Introduction

There are many ways to study cities configuration based on ways streets are modelled forming a network (Marshall et al., 2018). Space syntax is an international theoretic-methodological field that developed analysis techniques understanding space as intrinsic to people's activities, and that topology and geometry strongly affect movement. City analysis advanced focusing mainly on closeness and betweenness centrality (respectively choice and integration values in space syntax field), processed by using manually-drawn axial lines models or Road Centre Lines (RCL) models. Understanding that selecting a network modelling is critical (Marshall et al., 2018) and should be made transparent as it affects results and interpretation, this paper studies angular segment analysis (ASA) for two Brazilian northeastern cities comparing performances for axial models and for Open Street Map (OSM) RCL models with different preparation steps.

Axial maps – here called axial models, as a type of street network representation - are movement permeabilities representations (Hillier & Hanson, 1984) formed by sets of the fewest longest lines reaching and connecting open accessible spaces in the studied network. Axial analysis, in turn, is performed analysing how axial model lines interconnect forming a system focusing on topologic accessibility: shallower lines connect easier with other lines demanding less steps or turns. Axial analysis main measure is closeness centrality which relates with network mean topologic depth (Hillier & Hanson, 1984), measured globally (Rn) or restricted to a topologic radius. Measures related with uses (Hillier, 2007) as areas with higher closeness centrality exhibited more movement and commerce. Local-global synchrony characterized legible neighbourhoods (Dalton, 2011) and Brazilian old city centres as more legible than newer areas (Medeiros, 2013).

As each axial analysis line represents a topologic depth, axial models are usually drawn coarsely. Thus, limits understood as scarcely affecting linear legibility – as roundabouts or parallel routes divisions – would not necessarily be drawn. Movement permeabilities and limitations perceptions might suffer, however, from individual reading, making axial models difficult to standardize. Another axial models' limitation (Batty & Rana, 2012; Dalton et al., 2003) is the labour-intensive manual modelling that hinder fast city model updates, and are more prone to representation errors.

On the other hand, axial analysis limitations, as long routes receiving a single centrality value and angularities being overlooked, engendered other types of analysis. Continuity maps transformed lines with little angle variation into one (Figueiredo & Amorim, 2005), fractional configurational analysis weighed angular deviations between lines (Dalton, 2001). There are yet other alternatives to axial maps and axial analysis studied through the years, as strokes as a spatial representation suitable for traffic flow studies and for handling curved routes (Thomson, 2003) and street-based topological representation and analysis found to be superior to conventional axial map in predicting traffic flows (Jiang & Liu, 2009). More recently, Stavroulaki et al. (2017) compared some of these types of representations and resulting graphs stemming from a common model. Segment analysis was proposed by splitting axial lines at crossings and removing stubs, creating a segment map pondering angular deviations (Turner, 2001, 2007), with measures addressed to these smaller spatial entities.

Segment analysis closeness centrality (space syntax integration measure) and betweenness centrality (space syntax choice measure) correlated strongly with actual flows in cities (Hillier & Iida, 2005). Betweenness centrality relates to information flows hierarchies configured by connections in a social network (Freeman, 1977), spatially representing potential movement through places, relating with the easiness of choosing certain segments as routes in different journeys. Closeness centrality relates with potential movement to places - relating with the proximity of places easier to be chosen as destinations. These measures could be processed considering different types of distances: metric, angular and topologic (Hillier & Iida, 2005). As studies found that least angle deviation related closely with flows (Hillier & Iida, 2005; Turner, 2009), angular distance became a recurrent segment analysis mode, i.e., ASA. For ASA spatial metric radii were used meaning “that the betweenness and closeness measures cover all journeys within a circle of the defined radius” (Turner, 2007, p. 545). Different metric radii were selected as capturing different movement dynamics, as that of the neighbourhood, city and regional scale (Serra & Pinho, 2013).

Because closeness and betweenness centrality can reach high numbers according to the number of spatial entities, normalized centrality measures were created to compare different-sized networks (Hillier et al., 2012), and to relate values between different-sized cities. These authors noted that normalized measures have yet to be more validated and noted problems for local normalized betweenness centrality in areas with incomplete urbanisation “(...) provided care is taken to account for the less consistent behaviour of systems at a radius of less than a kilometre.” (Hillier et al., 2012, p. 165).

Developments incorporating angular deviations enabled ASA to perform with RCL models, aiming at more automated models to overcome axial models’ limitations (Dalton et al., 2003, Turner, 2007). Turner (2007) highlighted the effectiveness to develop segmental analysis with Depthmap program with either axial or RCL models, and related centralities stemming from analysis with both models with actual flows in Barnsburry area, North London. Compared with axial models, RCL (from UK government-based EDINA supplied service) exhibited more and smaller spatial entities, impacting on ASA values; to adjust RCL results Turner (2007) proposed ASA weighted length centrality measures. Turner (2007) highlighted slightly different routes with high centrality measures in axial and RCL models, however analysis stemming from both models, especially betweenness centrality, maintained strong correlation with actual flows.

Other studies compared ASA for different RCL data-bases (ITN – Integrated Transport Network and OSM) without simplification to test readiness of use (Dhanani et al., 2012), comparing with axial models, with RCL model ASA weighed by segment length. For OSM these authors mentioned cleaning disjointed elements. In this case, total length and number of spatial entities were very different for the city system when represented by axial or by RCL models, but centralities at a suburban area were captured by both models. The authors underline more work to be done and the value of using accurate volunteered geographic information as OSM for space syntax analysis, as easing comparison with other spatialized built form information.

While some space syntax studies calibrated ASA for RCL, more recent studies performed RCL simplification to reduce segments and maintain the same ASA calculations for all tested models. Kolovou and colleagues (Kolovou et al., 2017) studied an area around central London comparing ASA from axial model with OSM RCL and Open Roads models, varying from: unsimplified, treated with Douglas-Peucker (DP) simplification algorithm and proposed modelling rules. Simplification was performed with 10-, 15-, and 20-meters thresholds, the latter model betweenness centrality value with modelling rules approximated more measures from the axial ASA. These authors stressed that centrality measures correspondences change with different metric radii, and RCL could be adjusted according to analysis scale. Krenz (2017, 2018) addressed OSM RCL for ASA presenting methods of checking and adjusting topological inconsistencies, dual line and road detail removal, and simplification using georeferenced proprietary platform ArcGIS. For simplification Krenz mentioned threshold distances between 2 and 20 meters depending on hierarchy street width. Both studies (Kolovou et al., 2017; Krenz, 2018) tried to approximate RCL model with the axial models', involving remodelling of road elements as erasing roundabouts and joining parallel lines.

To help integrate space syntax in georeferenced systems, the Space Syntax Toolkit (Gil et al., 2015) allows ASA performance through openly accessible georeferenced platform QGIS as a Depthmap interface. This tool performs axial analysis and ASA. ASA can be performed by (i) using an axial model transformed to segments usually erasing stubs. In this case unlinks (e.g., at viaduct) must also be uploaded, or (ii) using a prepared segment map, as axial transformation into segments happened elsewhere, as in Depthmap program or (iii) using an RCL model as base, for which this tool has a cleaning function, following some methods presented by Kolovou et al. (2017).

In parallel with space syntax developments, the volunteered geographic information OSM project increased range providing open RCL models worldwide, becoming more accurate in depicting location and road connections (Dhanani et al., 2012; Krenz, 2017, 2018; Minaei, 2020), facilitated by volunteer work, collaboration and developing techniques based on aerial and satellite images and Global Positioning Systems (GPS) speeding updates (Husain & Vaishya, 2018; Liu et al., 2019). OSM RCL provides road labelling easing inter-modal analysis; OSM database also locates built facilities, facilitating studying city complex dynamics (Eldijk et al., 2020).

Currently, many space syntax studies worldwide adopt RCL models for analysing potential movement, and ASA for urban space syntax analysis focusing mainly on betweenness centrality. Betweenness centrality facilitated building types comparison between cities in different European countries (Berghauser Pont et al., 2019), correlation with types of movement on nationwide road systems in England (Serra & Hillier, 2019) and understanding of inter-scale movement dynamics at Tuscany region (Italy), the latter focusing on normalized betweenness centrality measure (Altafini & Cutini, 2020). RCL was considered a rapid way to update models and analyse centralities to orient post-disaster decisions: normalized ASA was compared with axial, CTR (Carta Tecnica Regionale) and OSM RCL for Italian urban settlements (Pezzica et al., 2019). The latter study used Boeing (2017) proposed OSMnx python library to pre-process OSM RCL geometric models.

Meanwhile, many researchers in Brazil maintain axial models use either for axial analysis or ASA. Axial analysis was used to compare intelligibility in different Brazilian cities (Medeiros, 2013) and morphological centralities in Brasilia (Holanda, 2020). Other recent researches developed ASA from axial models, which helped read centralities in cities relating social divisions and residential location in Florianopolis, southern Brazil (Kronenberger & Saboya, 2019), and studying socio-spatial patterns at beaches in Natal, north-east Brazil (Donegan & Trigueiro, 2016). Although axial models' limitations in Brazil are partially tackled by nationwide collaboration and by Renato Saboya's configurational maps repository[1] - allowing shared information together with models – axial models are still updated slowly and

[1] http://urbanidades.arq.br/mapasconfiguracionais/, accessed May 2021.

have usually been changed by different people with different permeabilities interpretations; some maps were built without georeferencing, encumbering spatial data analysis. While axial analysis is valuable for some studies and might rely on axial models, ASA could be performed by RCL to deal with some axial models' limitations.

From what has been presented regarding RCL preparation for ASA we found, in our early studies and analysis, a mainly two-fold issue to be tackled. First, how to prepare better RCL so that the number of nodes (and segments) does not prejudice ASA scores and maintain a good match with RCL route depiction. The proposed simplifications presented by ASA researchers (Kolovou et al., 2017; Krenz, 2018; Altafini & Cutini, 2020) mentioned preparing RCL based mainly on geometric DP simplification with thresholds limitations. The DP simplification reduces the number of segments in a polyline according to a threshold, if the threshold increases much, corners are cut. The method does not account for other geometrical or street information to further reduce vertices without change to form. Secondly, recently shared RCL preparation methods used for ASA (Kolovou et al., 2017; Krenz, 2018) also assumed that some actions were necessary to approximate RCL with axial models. These actions defeat the purpose of an automated model, as transforming two close parallel lines into one - especially as a fix threshold to perform this is difficult to ascertain - and roundabouts without buildings in the middle should be crossed (Krenz, 2018). If remodelling is required as suggested (Kolovou et al., 2017), there might be inconsistent updates. Perhaps the motive the axial model is drawn more coarsely is more important for axial analysis, as for this analysis each line regardless of angular deviation represents a topological step. Before assessing if further remodelling processes are appropriate, more could be understood about RCL ASA with fewer shape changes, as it might help read subtleties impacting routes' legibility. Our reasoning resonates with earlier work of Dhanani and colleagues (2012) and Turner (2007), whose RCL map did not join parallel lines nor erased roundabouts. However, both studies balanced RCL ASA by segment length instead of model simplification.

To develop more confident shifts in modus operandi and understand better RCL adequacy for cities ASA, this paper addresses the questions:

(i) How does OSM RCL depict routes and ASA centralities in two cities in northeast Brazil and how does this differ from axial models?

(ii) Which automated steps can prepare RCL for ASA while maintaining routes depiction?

(iii) How studied models capture these cities and, a specific neighbourhood, ASA centralities?

(iv) Which limitations and potentialities RCL proposed preparation steps exhibit for these cities' ASA?

To answer this, this paper presents the case studies, the axial and RCL models datasets and RCL preparation methods. Analysis follows with models' representation differences and system sizes, then closeness and betweenness centralities at different scales for both cities and their old city centres. This paper finishes discussing results underlining models' limitations, potentialities and ways forward.

Datasets and methods

The studied cities Joao Pessoa (Paraiba) and Natal (Rio Grande do Norte) have recently updated axial models (available at Saboya's repository[1]). The cities have some similarities: both coastal, approximate in size, function and location country wise in northeast Brazil. Following Portugal's colonization, many Brazilian cities are coastal founded as ports protecting the territory and establishing commercial connections overseas. Portuguese Hereditary Captaincies divided the territory east-west resulting in some capital states located fairly close for Brazilian distances, expressed by north-eastern coast OSM road density (Figure 1).

Figure 1 – Brazil state divisions and OSM RCL-North-east Road network showing state capitals, highlighting studied cities. Source: Authors (2022) over IBGE base[2] (2020) and OSM RCL Goefabrik database[3] (2020).

Joao Pessoa and Natal are 165km road distance apart, both functional Regional Capitals by IBGE (Brazilian Institute for Geography and Statistics) with approximated population. Both cities initial settlements were established by a river, as calmer waters to dock with easy access to the sea, and expanded rapidly beyond this settlement as other Brazilian cities (Villaça, 2001), occupying valued coastal areas. Each city old centre was selected to study centralities in a smaller consolidated urban grid, opening a possibility to test Medeiros (2013) findings.

The city network models

For the axial models, lines were drawn in georeferenced platform considering a relation between limits and multi-modal city permeabilities. Joao Pessoa axial model updated in 2020, Natal in 2019. When the axial models were transformed to segments, stubs were removed representing up to 40% of the last crossing.

North-eastern Brazil OSM was downloaded in shapefile format from the Geofabrik database repository, with data stratified in layers. Then OSM roads layer was cropped for each municipality based on IBGE boundaries. As some spatial entities represent areas un-accessible to multimodal movement, the OSM RCL layer was cleaned. Also, when the following paths were not cleaned, ASA mal-functioned, as some polylines formed islands. Thus, the considered network in this study refers to routes open to mul-

[2] https://www.ibge.gov.br, accessed September 2020.

[3] https://www.geofabrik.de, accessed September, 2020.

ti-modal vehicular transport, encompassing modes of transport on a city scale. This scale relates with types of routes considered for the same cities drawn axial maps. For this study, the cleaning method – while checking routes functions - was to erase all features in the “fclass” column labelled “pedestrian”, “footway”, “steps”, “service”, “cycleway”, “tracks”. Some “unclassified” features were also erased when they were not official open routes. Another finer-grain representation including pedestrian paths could be performed in the future depending on research questions. Despite “living street” and “residential” features being mostly residential open areas forming a large part of the city, instances were found representing routes inside private estates, thus not openly accessible, and were erased case by case. This situation was particularly recurrent in Natal. For these RCL cleaned models in both cities no topologic inconsistencies were found.

Differently from some other space syntax RCL studies (Kolovou et al., 2017, Krenz, 2017, 2018), roundabouts were not removed and parallel lines were not joined. This decision followed a twofold reasoning: (i) to maintain automated RCL preparation steps and; (ii) existing permeabilities and barriers to movement. RCL models only represent two parallel lines for vehicular routes when there are physical barriers in the middle of the street or avenue, such as curbs, trees and/or light posts, perceived as actual barriers to vehicular movement. Streets without physical barriers in the middle – even when they have two traffic directions - are represented by RCL with a single line at the road centre. Thus, the reasoning to not join parallel lines is not due to traffic directionality. Roundabouts are also viewed as representing a limitation to vehicular movement. This reasoning aligns with Turner’s (2007) argument: “… if space syntax is to be used as a model of movement, then it ought to incorporate ideas from traffic modelling to make a fully coherent model of the built environment” (Turner, 2007; p. 540).

After this cleaning process ASA was performed needless to snap disconnected geometries, however distorted centrality values were found related with the high number of spatial entities, as reported by the literature, which led to simplification processes.

Model interoperability and polyline simplifications procedures

Interoperability with Computer Aided Design (CAD) was tested to further improve simplification actions, and a further process was made to adjust better the studied RCL models for ASA. The RLC cleaned models were submitted to polyline simplification processes in CAD system, using specifically Grasshopper (GH) visual algorithmic and parametric programming environment as a Rhinoceros CAD environment plugin. GH has add-ons as libraries for specific programming tasks. Shrimp add-on was used for functional interoperability components to read and store GIS shapefile data in a data-tree structure in GH, and write back a GIS shapefile. DeCoding Spaces add-on has functional components to process city models data, of which the non-inverse graph models and DP fashioned algorithm were used.

Figure 2 exhibits interoperability and proposed RCL polyline simplification algorithm procedures performed for each city. As shapefile data-table is imported as data-lists in GH, polylines with the same street name were filtered and joined, thus using OSM RCL tabular data to eliminate some vertices in the simplification process. Segments were then extracted from the polylines to build a non-inverse graph in order to identify road network intersection vertices.

RCL network model intersection vertices were selected by the non-inverse graph and fixed to maintain all topological connections, then DP simplification were performed considering 5m, 10m, 20m and 50m threshold radius. Up to here, steps were similar to proposed by literature (Kolovou et al., 2017), with the adjustment of using street name as filters, which might prove more efficient for other situations depending on available tabular data.

The resulting ASA scores improved but not so much, as when models with larger simplification thresholds exhibited less segments (and approximated axial segment numbers), geometry distortions were found interfering with streets route representation. Further actions were sought to ensure street network information would not be lost, thus adding two proposed steps to select and fix other vertices before the DP simplification. Vertices fixed were polylines endpoints and points selected by angular threshold. Vertices connecting subsequent segments with more than three degrees deviation were fixed. Fixed polyline endpoints ensured street lengths and connectivity between polylines would not be lost. Fixed points with significant angle distortions meant unnecessary vertices of overall linear routes could be erased. By fixing these additional vertices, a larger threshold was searched for each city. This was at first sought by calibrating the city RCL mean and maximum segment values with those of the city Axial segment values. This exploration led us to realize that the simplification threshold could reach the model maximum RCL polyline length (300m for Joao Pessoa, 900m for Natal). These actions dealt with simplification geometry distortions creating this study RCL version (RCL-TS). Figure 3 shows main GH code parts used to perform interoperability, build non-inverse graph and polyline simplifications.

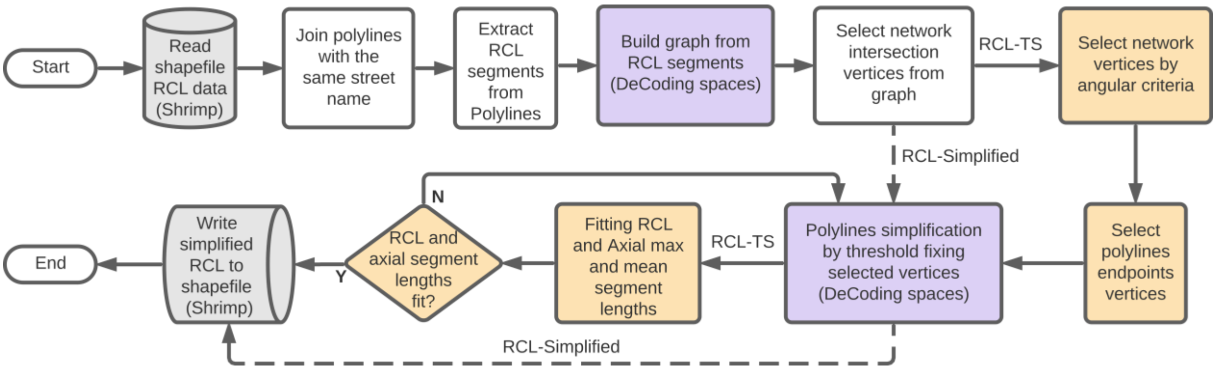

Figure 2 – Algorithm CAD-GIS interoperability and performed polyline simplifications flowchart. Source: Authors (2022).

The Shrimp GIS-CAD interoperability (Figure 3 – first row), uses an anchor point in CAD Cartesian Coordinate system related to the GIS geolocation, reading and storing the shapefile in a data-tree structure. To select the network intersection vertices, a network non-inverse graph was built (Figure 3 – second row). Decoding Spaces add-on stores each non-inverse graph node on a data-tree variable branch, related with the segments connected to it by its branch-index in an identical data-tree structure. The fixed vertices collection was separated in data-tree structure branches according to their polyline. Then the DP polyline simplification algorithm (Figure 3 – third row) should only have to consider a subgroup of vertices for each polyline, expediting the simplification processing. With all city model RCL polylines simplified, the Shrimp GH library was used to convert their geometry back to GIS shapefile (Figure 3 – fourth row), considering GIS and CAD coordinate systems relations.

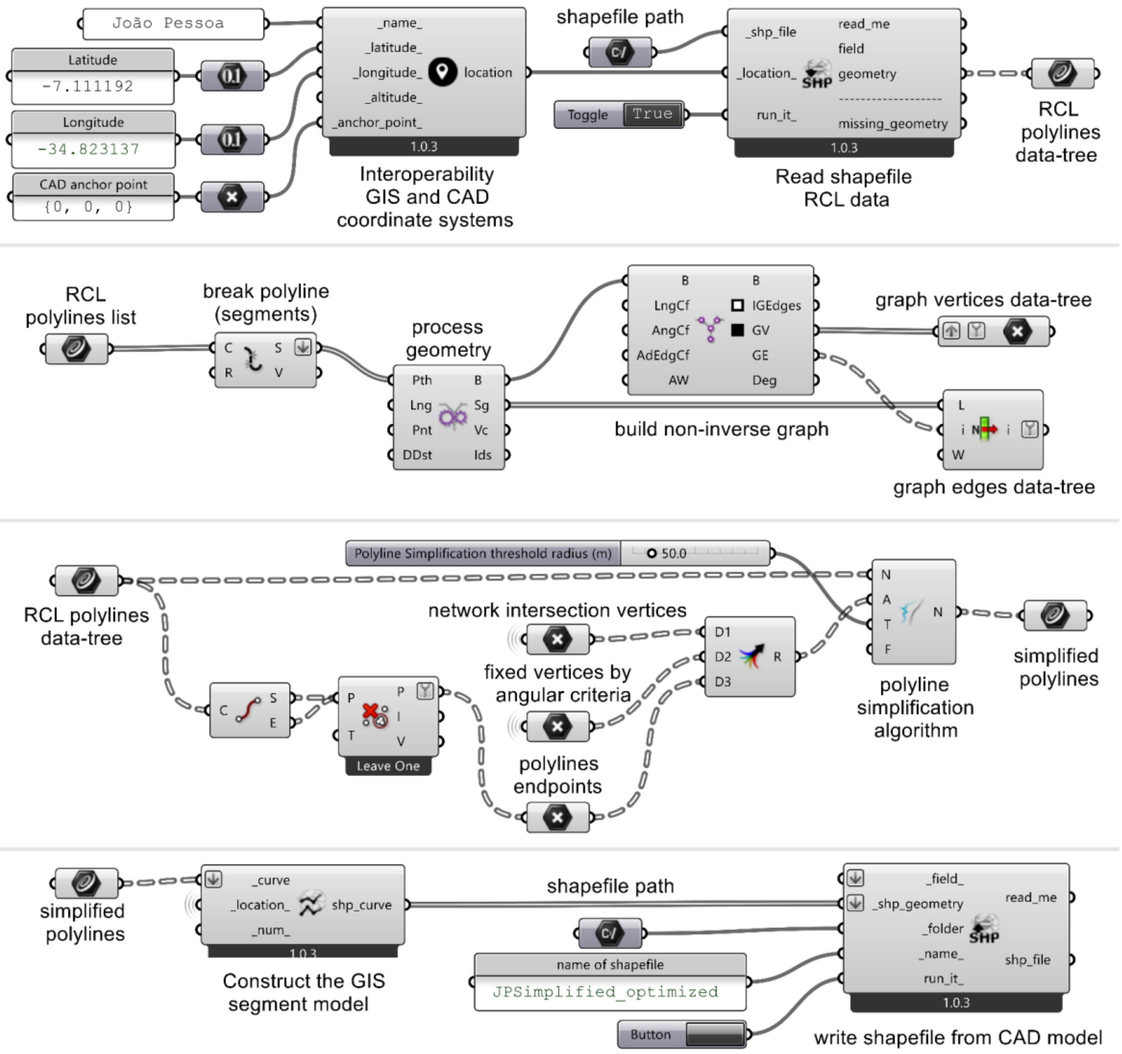

Figure 3 – Grasshopper main code parts used to perform simplifications. Source: Authors (2022).

Angular Segment Analysis Assumptions

Joao Pessoa and Natal georeferenced axial and RCL network models were processed for least angular depth (ASA) for various metric radii at DepthmapX 035 with the space syntax toolkit at QGIS 3.10.6. Betweenness and closeness centralities and their normalized values (Hillier et al., 2012), respectively NACH and NAIN, were processed. For further centralities scale analysis, metric radii representing different scale dynamics were focused: the very local scale 400m (representing a 5' walk), 1200m as a neighbourhood walkable scale (representing a15' walk), 5000m as the city scale, approximating scales highlighted in literature (Serra & Pinho, 2013), and n as the global scale. From all ASA models the old city centre - approximating the mid-19th century urban settlement location (Dias, 2013; Trigueiro & Medeiros, 2003) - was selected to read centralities in this area.

Centralities distribution in maps, and mean and maximum values for different metric radii were studied to compare centrality hierarchies. Centralities correlations (R^2) for different metric radii in each city and their old city centre were studied to explore areas and models local-global synchrony. Maps were visualized either separating specific values or through Jenks classification in colour bands from lighter grey for lower, to darker grey for higher, centrality values. Studied centralities for each dataset were analysed and visualized by plots with python script bokeh library.

In what follows, the studied models receive the acronyms: AX: axial segment map; RCL: unsimplified RCL; RCL-5: RCL simplified with a threshold of 5 metres; RCL-10: RCL simplified with a threshold of 10 metres; RCL-20: RCL simplified with a threshold of 20 metres; RCL-50: RCL simplified with a threshold of 50 metres; RCL-TS: RCL simplified with this study proposed steps.

Results

This section presents research results, first comparing models' sizes and road representation, then exploring models' betweenness and closeness centralities different scales mean and maximum levels for Natal and Joao Pessoa cities and their old city centres. The next section discusses results highlighting limitations and potentialities.

Model characteristics and outputs

The models' sizes in terms of segment numbers and mean and maximum segment lengths approximate for both cities, although Natal has overall more RCL segments with lower mean sizes (Figure 4). Despite trivial rings formed by some axial lines intersections (Hillier, 2007) impacting on system numbers and length, AX, and RCL-50, have less segments and larger mean lengths. From RCL to RCL with larger simplification thresholds, there is a steady decrease in segment numbers and increase in mean lengths; RCL-TS has less segments than RCL-20 and more than RCL-50 in both cities, despite the higher simplification threshold radius: 300m and 1900m for Joao Pessoa and Natal, respectively, which were the networks saturation threshold from which improvements or modifications became irrelevant, showing that high RCL simplification threshold can be used elsewhere with this framework.

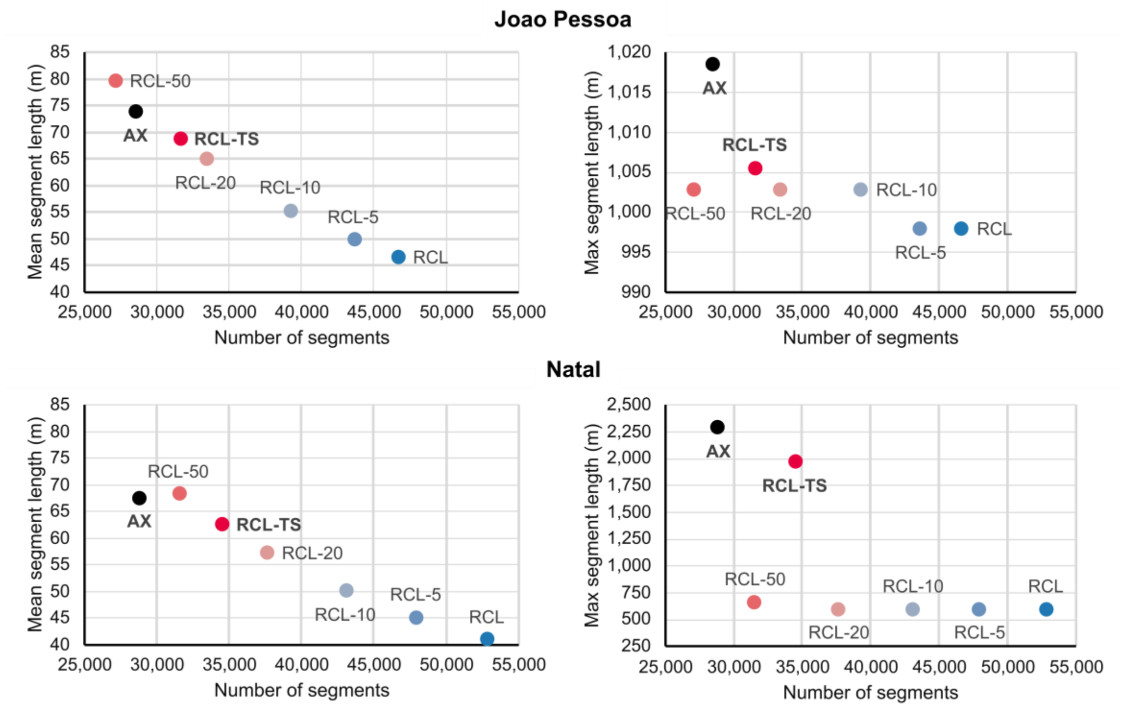

Figure 4 – Segments (number and lengths) for Joao Pessoa and Natal models. Source: Authors (2022).

RCL-TS approximates AX number of segments and mean length, especially in Joao Pessoa. For maximum segment lengths, raw RCL and simplified versions exhibited similar values for both cities. For both cities, AX was the model with the largest segment, followed closely - especially in Natal where maximum lengths between models vary more than in Joao Pessoa -, by RCL-TS. Less segments required less processing time, varying from 19 minutes for Joao Pessoa AX up to circa 1h22min for Natal RCL, using a I7 8th generation processor, 32GB RAM and SSD data-drive computer. For Joao Pessoa RCL-TS processing took 27 minutes, not far from AX processing duration.

Total road length for each city changes little in these models, although RCL exhibited more total length, attributed to roundabouts and two sides of some routes' representation, whereas few roundabouts and different road sides were drawn for AX models. Figure 5 exhibits AX model depicting only the larger roundabout; RCL exhibits two parallel routes for Epitacio Pessoa and Corinta Rosas avenues different traffic directions that are also separated by physical barriers (a thoroughfare curb with trees and street lighting posts). RCL exhibits a single line for other two traffic directions streets in Figure 5 that do not have physical separation; this reasoning follows overall.

Representation differences between models are visible in Figure 5 enlargement of a small roundabout connected with a curved street; AX cuts through the roundabout and lines passing the crossing are stubs removed when transformed to segments. RCL captures the whole roundabout circular format, and simplified versions maintain straight lines connecting five routes arriving at the roundabout. On the northern curved street corner, RCL-50 overcame the curve too abruptly slicing the urban block; similar situations happened elsewhere, sometimes erasing a whole street. On the other hand, RCL-TS, in this situation and elsewhere, maintains the main road alignment with few line segments. Considering route depiction and number of segments, close to AX, RCL-TS stands out as the most efficient treated RCL.

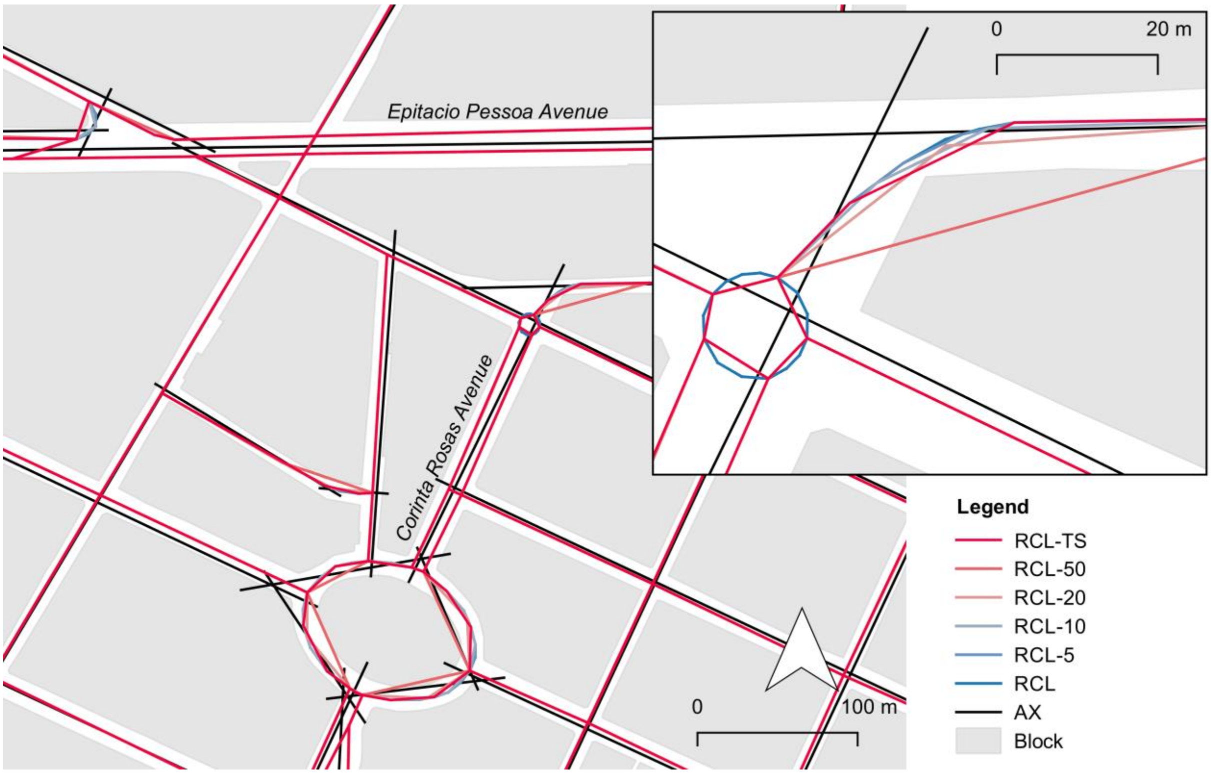

Figure 5 – Axial model and modes of RCL route representations. Source: Authors (2022) over blocks from Jampa em Mapas4 municipal website (2020).

[4] http://geo.joaopessoa.pb.gov.br/digeoc/htmls/, accessed September, 2020.

Centralities and scale dynamics in two cities

Figures 6 and 7 compare mean and maximum betweenness, closeness and normalized centralities (NACH and NAIN) ASA models values for, respectively, Joao Pessoa and Natal, centralities values were compared for radii 400m, 1200m, 5000m and correlations between scales.

Considering betweenness and closeness centrality mean and maximum, RCL-TS approximates more AX. Overall, NAIN global and intermediate radii mean and maximum values are higher for AX than RCL models, this also happens slightly for maximum NACH. RCL models reach higher values for smaller radii. On the other hand, mean NACH values are usually higher for RCL than AX models, characterizing RCL as more fragmented networks, except for RCL-TS 1200m, 5000m and n mean NACH in Natal, that juxtaposes with AX. Normalized values generally decrease as radii increase, the contrary happens for not normalized centralities, following reason of wider networks having more depth. RCL reaches higher normalized maximums for 400m radii, whereas for 1200m RCL-20 reaches highest maximums in both cities. For most other trends, all models conserve in general terms, similar trends in each city.

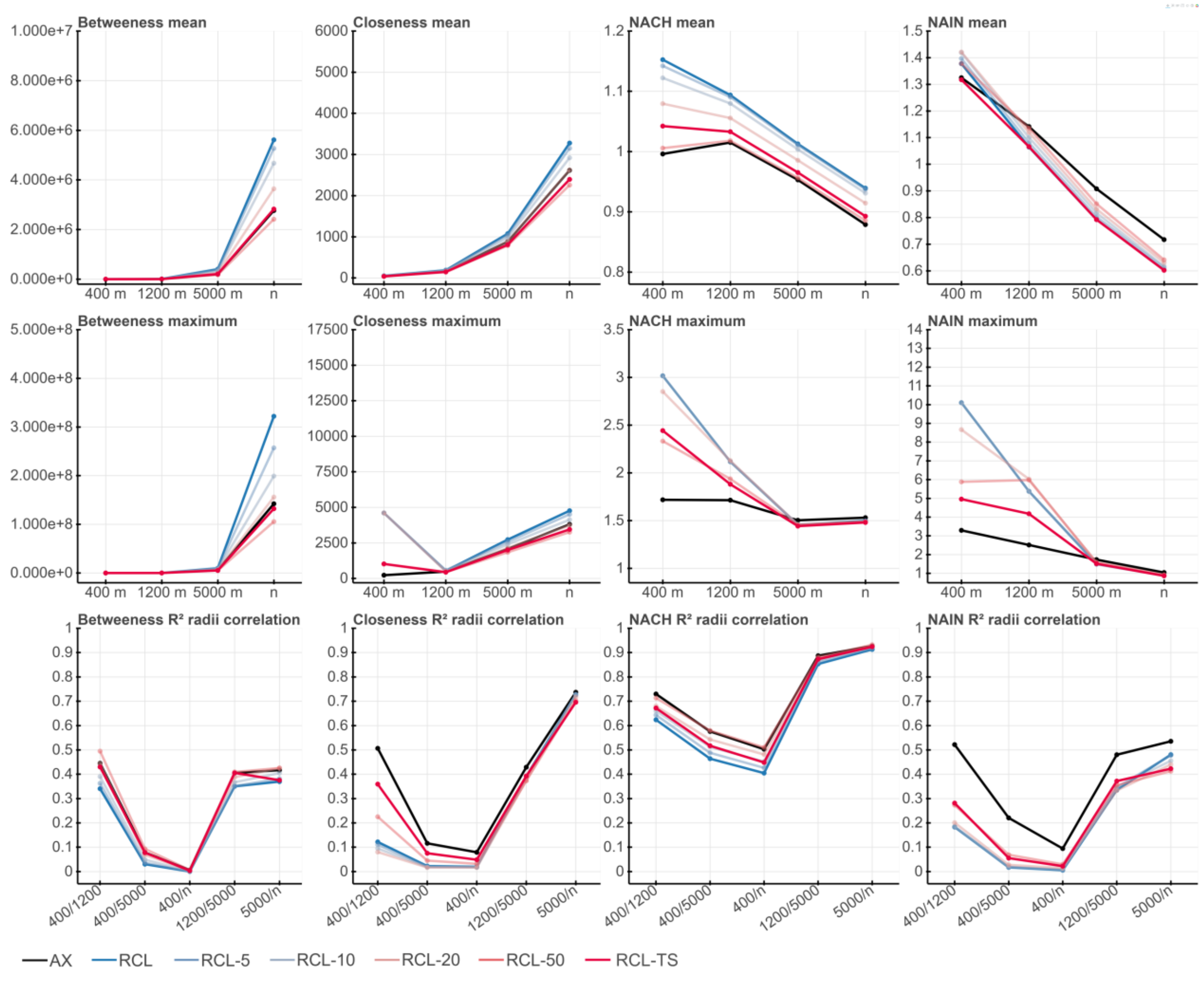

Figure 6 – Joao Pessoa models ASA results: centrality values for metric scales and their R² correlations.

Source: Authors (2022).

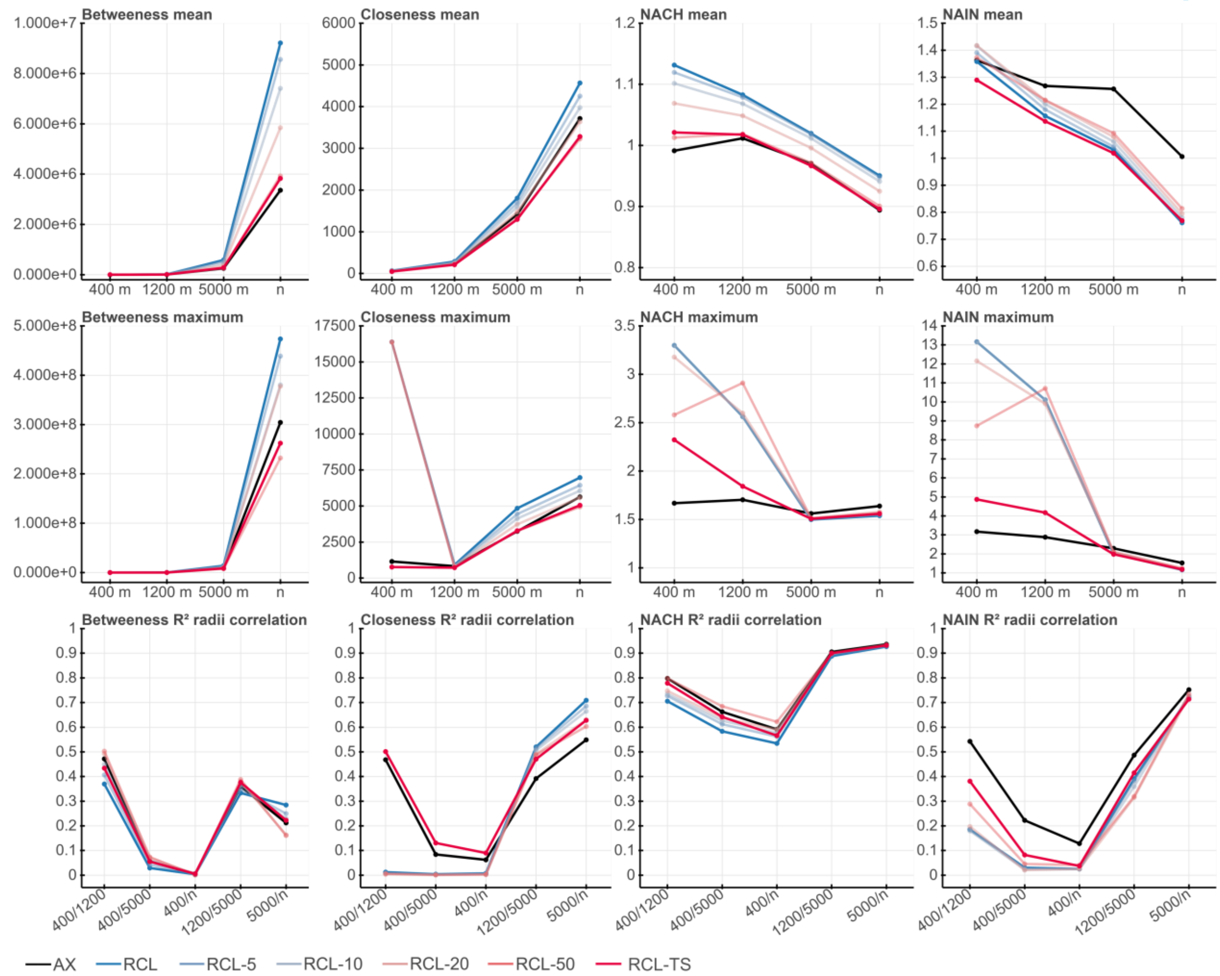

Figure 7 – Natal models ASA results: centrality values for metric scales and their R^2 correlations. Source: Authors (2022).

More ASA models' discrepancies are found in local scales, especially for NAIN and NACH, maximum measures accentuated with RCL. Some segments close to urban voids or municipalities' perimeter exhibit -1.0 closeness centrality value in R800m and, especially, R400 metres (following -1.0 Total Depth for that radius, avoiding division by zero in normalized formulas), they reach "1.0" NAIN as the only segments in that radius; this happened more for AX where segments can be longer. On the other hand, when two parallel segments represent one road for RCL and these segments are the only ones in that radii connected only with their continuous segments, values for local closeness centrality can become very high, whereas they exhibit low local betweenness levels and can also have low closeness centrality at larger radii. Additionally, very high NAIN and NACH values recur for local radii close to urban voids. Many NAIN 400m segments exhibit very high values in both cities (Figure 8) for all models, at sparser areas and many highways and viaducts in more central places. For 800m and 1200m radii models highlight segments close to urban voids in one area or another: (i) in Natal the bridges, routes closer to the southern perimeter and between large preservation area and the sea, and (ii) in Joao Pessoa for routes bordering, or close to, preservation areas, river paths, and sparser southern areas. While negative values should not chromatically hinder maps interpretation, high values mislead city centrality interpretations. For NAIN 5km some coastal areas with fewer neighbours also reach higher values in both cities than 5km closeness centrality. Overall, caution is needed for normalized ASA for local and even intermediate radii, especially when dealing with bridges, tunnels or single roads surrounded by voids.

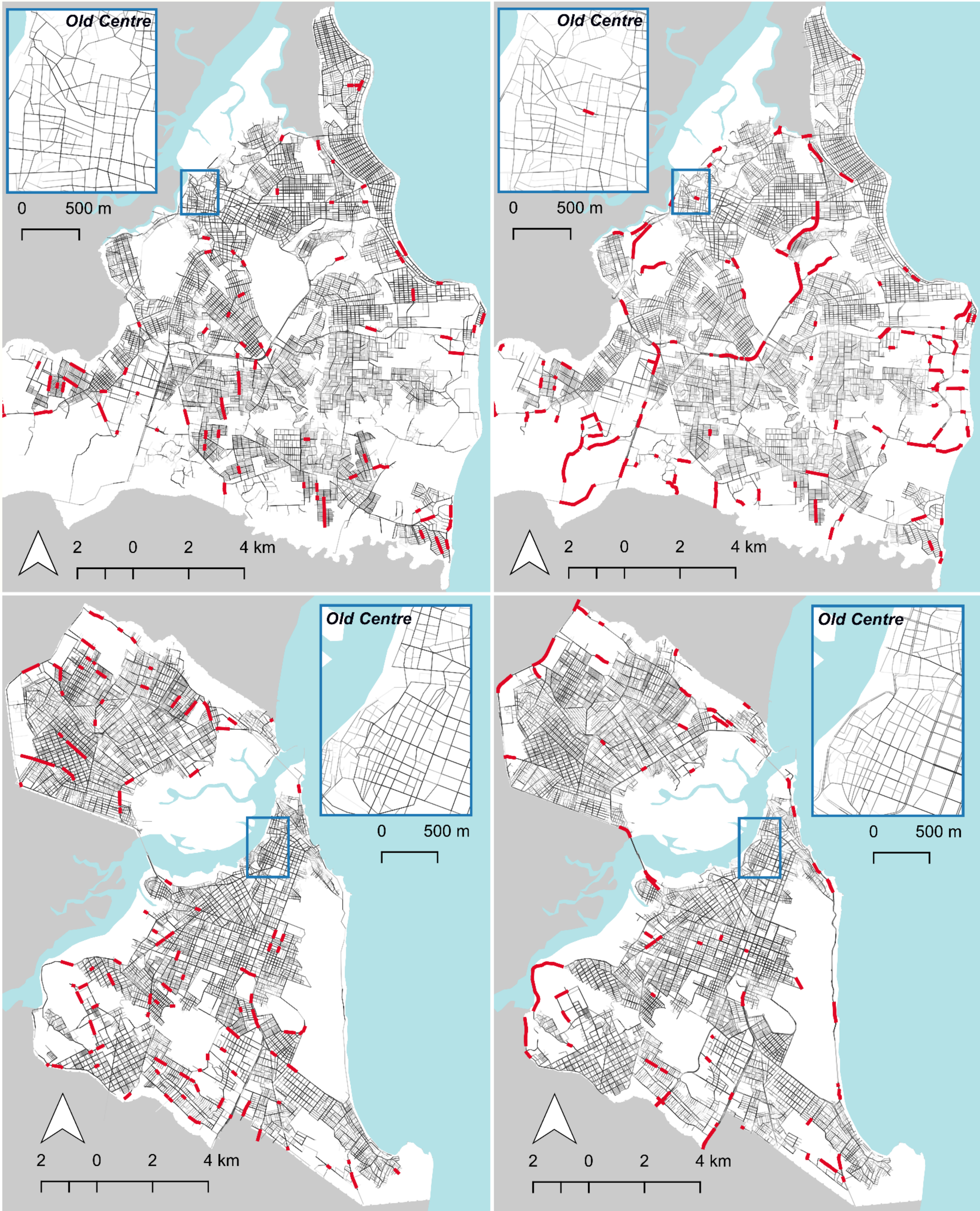

Figure 8 – NAIN R400m highlighting segments with 2.2 or higher values for Joao Pessoa (up) and Natal (down), for AX (left) and RCL-TS (right). Source: Authors (2022).

Local values discrepancies were barely found for more occupied and consolidated old city centres areas; although neighbouring the river, on three sides they connect continuously with streets. Figures 9 and 10 exhibit old city centres centralities' values, both exhibit higher global mean closeness centrality and NAIN than their respective city, although not highest levels. For metric scales correlations, only Natal old city centre reaches significantly high correlations, especially with 400m radius, pointing to some synchrony between scales corroborating Medeiros (2013) findings. For Joao Pessoa weaker inter-correlation can be due to recent interventions that pedestrianized some streets and newer tunnels and viaducts were encompassed in studied models, thus the old settlement was not integrally captured.

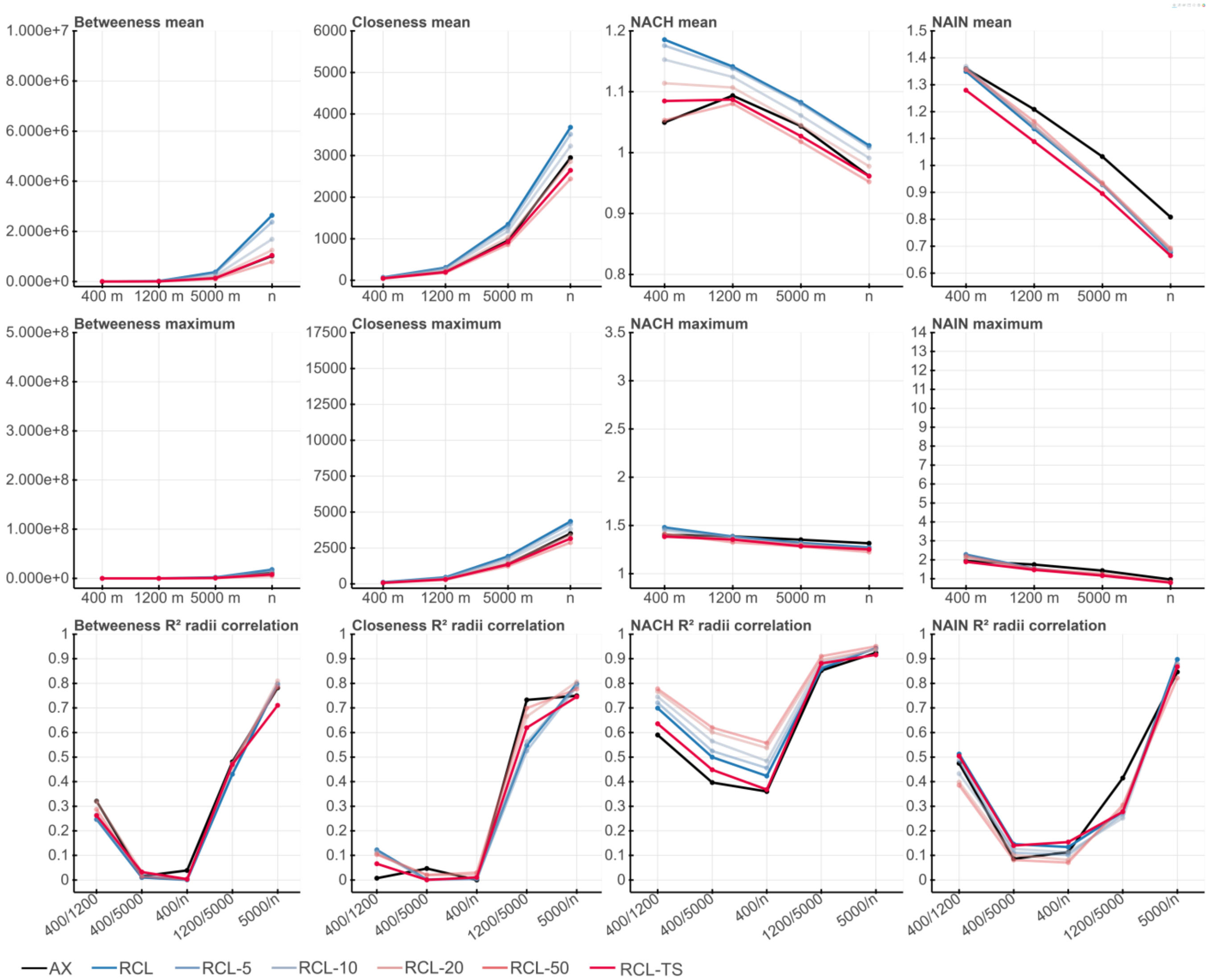

Figure 9 – Joao Pessoa old city centre models ASA results: centrality values for metric scales and their R² correlations. Source: Authors (2022).

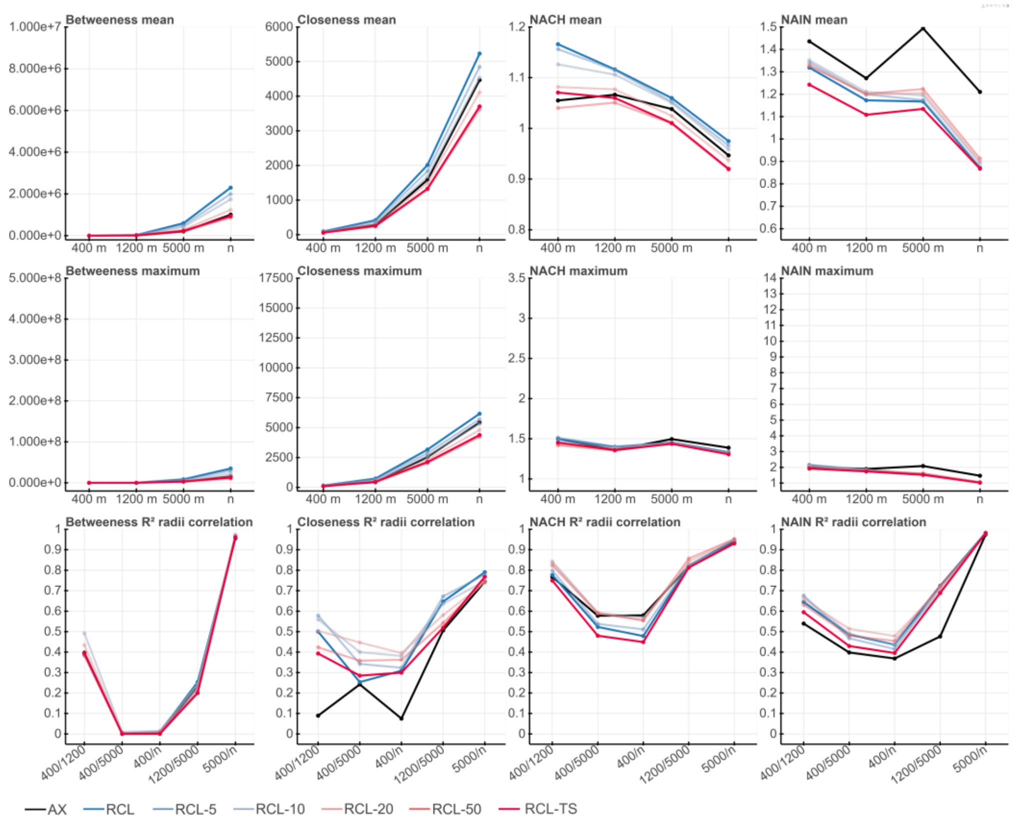

Figure 10 – Natal old city centre models ASA results: centrality values for metric scales and their R^2 correlations. Source: Authors (2022).

Global centralities overall distribution was captured for both cities in RCL and AX models, although RCL-TS accentuated more centralities in both cities than other RCL models. RCL-TS betweenness centrality in Joao Pessoa highlighted more than AX a more continuous circuit of routes connecting different areas (Figure 11) as those encircling the Botanical Garden, a large preservation area geometrically centrally within the municipality, as BR-230 highway at Botanical Garden's east, and routes reaching north from this circuit connecting with Epitacio Pessoa Avenue, a long linear West-East route expanding from the old city centre towards the sea. These routes and their surrounding areas also reached high closeness centrality (Figure 12). Betweenness centrality is also more visible at the old city centre for RCL-TS, capturing continuous routes used to reach and cross the neighbourhood. Some spatial hierarchies not addressed by AX were captured by RCL, as changes between two sides of BR-230 highway. As U-turns are sparse and transversal movement difficult, sides do differentiate.

Centralities' distribution in Natal accentuates areas leading to the southern bridge over Potengi river from its northern side and, especially, its southern side (Figure 11), a system reaching higher betweenness centrality than Joao Pessoa (Figures 6 and 7). RCL-TS captured main routes more prominently than AX, with high betweenness centrality expanding throughout the city, as the role of Bernardo Vieira Avenue leading linearly from the south towards the southern bridge, at its east connected perpendicularly with Salgado Filho Avenue, also highlighted in measures, stretching north-south close to *Parque das Dunas* large preservation area that limits the city expansion further east towards the sea. Areas surrounding these routes have also reached high closeness centrality; the old city centre maintains high closeness centrality following its continuous grid expanding east and south, however distant from high betweenness centrality.

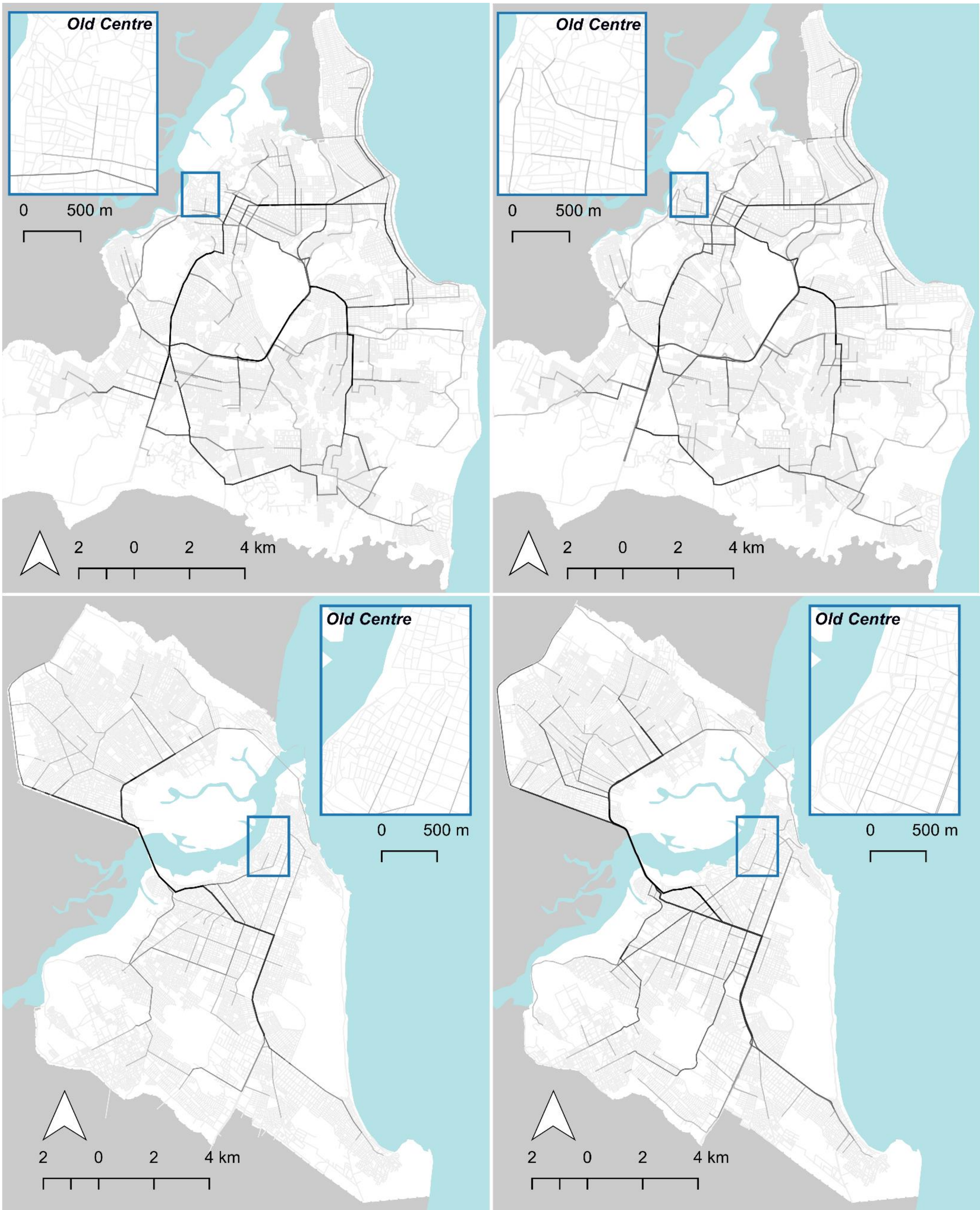

Figure11 – Betweenness centrality for Joao Pessoa (up) and Natal (down) for AX (left) and RCL-TS (right) models. Source: Authors (2022).

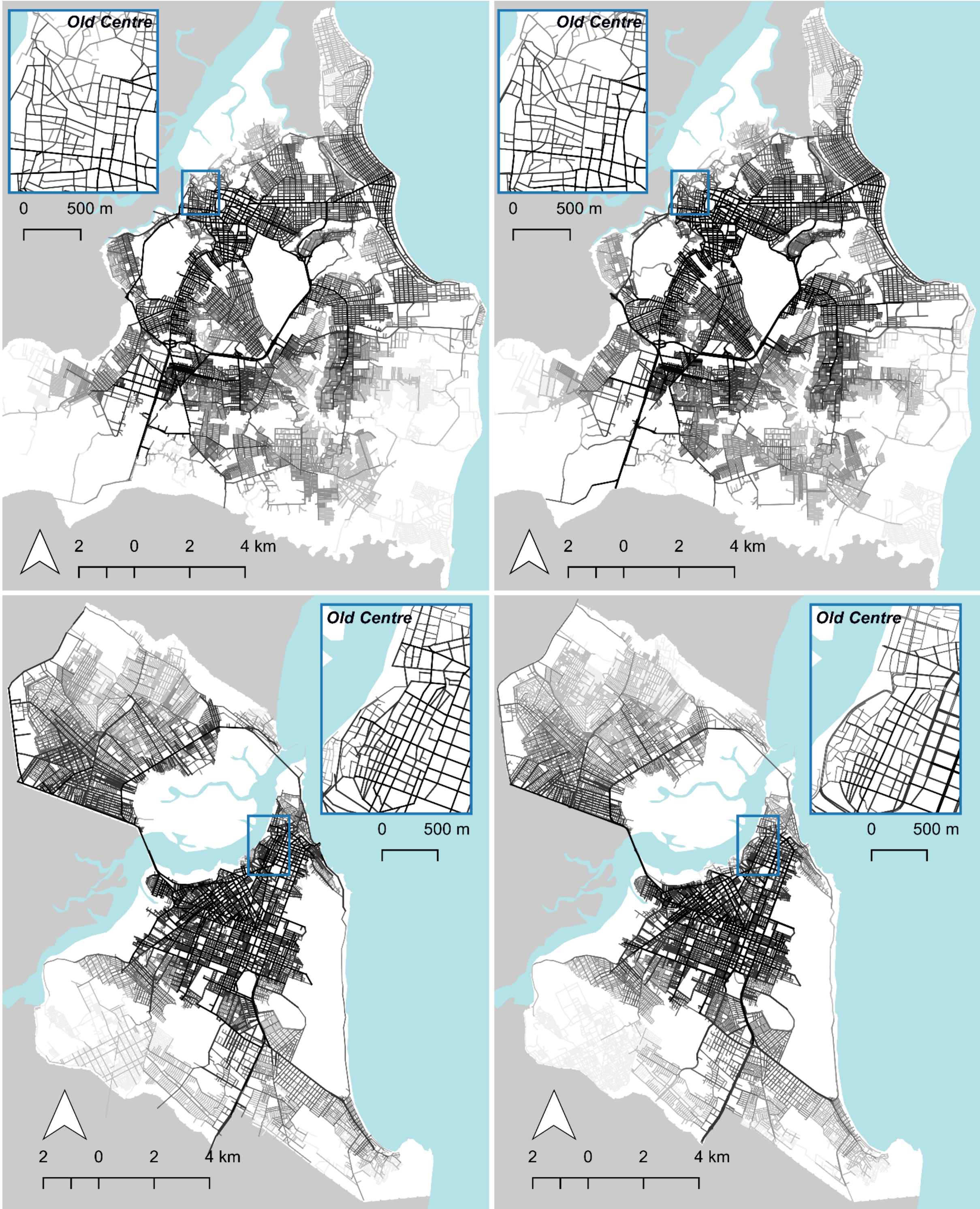

Figure 12 – Closeness centrality for Joao Pessoa (up) and Natal (down) for AX (left) and RCL-TS (right) models. Source: Authors (2022).

Analysis and Discussion

To study how OSM RCL depict routes and ASA centralities, models were studied for two closely-sized north-eastern Brazilian cities compared with AX, exploring mean and maximum centrality values for different metric radii and their inter-relations. Results show approximations in both cities for all models as scales where measures reach higher or lower values, capturing overall cities dynamics, while pointing towards an RCL-TS and AX approximation, reinforcing trends perceived visually with maps.

In terms of spatially capturing centralities dynamics, while AX captures areas in Joao Pessoa accentuating routes expanding from the old city centre towards the sea (lead mainly by Epitacio Pessoa Avenue), RCL-TS highlighted, especially with betweenness centrality, a more continuous network connecting this circuit with routes encircling Botanical Garden preservation area (Figure 11), and more continuous routes used by inhabitants to pass through and reach the old city centre.

Natal`s municipality cut by Potengi River with few north-south connections accentuates a polarization highlighted elsewhere (Donegan & Trigueiro, 2016); main centralities concentrate by the southern bridge underlining the newer northern bridge not well connected with the network. This fragmented network is highlighted by overall higher betweenness centrality maximum and mean values for Natal (Figure 7) than for Joao Pessoa (Figure 6) as the south bridge has a strong ability to control movement. RCL-TS depicted more clearly routes with high betweenness centrality (Figure 11) leading straight towards this bridge (Bernardo Vieira Avenue) and of north-south routes connected with it.

Considering scale dynamics, correlations between radii n and 5km betweenness and closeness centralities values are lower for Natal than for Joao Pessoa for all models (Figures 6 and 7), relating with global centrality in Natal shifting from routes closer to the bridge to 5 kilometres centralities either north or south of Potengi River. Natal's old city centre is captured by this southern centrality reaching high mean 5km closeness centrality and NAIN (Figure 10).

Both cities were established by the river and expanded rapidly from mid-19th century, centralities shifting rapidly as with many Brazilian cities (Villaça, 2001). Nonetheless, however close to network limits, old city centres maintain some closeness centrality especially in Natal, although high betweenness routes do not pass by (Figure 11). Centralities scales inter-correlation was strong for Natal old city centre, relating with Medeiros (2013) axial local-global synchrony analysis characterizing old centres as legible areas, also captured with ASA; whereas for Joao Pessoa old city centre weaker synchrony might be due interventions pedestrianizing routes, disregarded here.

Studied models' characteristics connected with limitations and potentialities are synthesized in Table 1. Main axial model limitations were addressed in literature (Batty & Rana, 2012; Dalton et al., 2003) and drove this research, especially as it is currently still often used in Brazil. Although axial models allow axial analysis, for ASA RCL proved positive. RCL have overall more georeferenced accuracy, continual route updates and standardized representation. ASA RCL processing without simplification captured centralities highlighting main roads, reinforcing Dhanani and colleagues (2012) argument allowing OSM RCL use only with the cleaning step. However, RCL closeness values were quite lower and betweenness centrality values much higher than AX, and processing time much longer. Values distortions also happened for normalized values.

Procedures to prepare RCL before ASA are appropriate. The first simplification process - similar to those presented by other researchers (Kolovou et al., 2017; Krenz, 2018), adjusted in terms of filtering polylines by street name-, entailed that when the number of segments did decrease approximating AX, accurate street depiction was lost (Figure 2). A further action was employed, fixing vertices by angle criteria and polylines endpoints, enabling larger thresholds. While for this study the axial segment map offered parameters to adjust thresholds, it is not necessary to have an axial model to adjust other cities models. After fixing these vertices, it is enough to adopt a larger simplification threshold as long as the studied city RCL longest polyline. This study RCL-TS models provided accurate route representation approximating AX in terms of segments numbers and sizes, and accentuated ASA centralities in both cities. RCL-TS could prove useful to explore network centralities and distances in general, beyond ASA. RCL roundabouts and parallel lines were not erased and provided centrality hierarchies insights, as accentuating differences in connections between two sides of a highway in Joao Pessoa that might relate with actual movement. To use RCL models for ASA can help take advantage of traffic modelling ideas and representation (Turner, 2007) to help further understand cities complexities impacting on mobility.

Local, and even intermediate, scale ASA limitations are stressed for local NACH for areas with incomplete urbanisation, as mentioned by Hillier and colleagues (2012), but also for NAIN and closeness centrality in centrally located and established areas close to urban voids (e.g., bridges over Potengi River in Natal and routes close to the Botanical Garden in Joao Pessoa). These places are unlikely to change in time, and cannot be cut out from analysis. ASA could be adjusted in the future for local radii measures to relate with spatial and functional hierarchies for sparser routes recurrent in contemporary cities, especially in Brazil.

Table 1 – Main limitations and potentialities of studied axial and RCL models for ASA

MODELS	LIMITATIONS		POTENTIALITIES
AX	- Labour-intensive drawing; - Suffers individual interpretation; - Need to unlink viaducts; - Trivial rings; - Less accurate route representation.		- Less processing time;
OSM RCL	All	- Cleaning process needed;	- Continuous road updates; - Alphanumeric attributes; - Standardized modelling; - Bridges and viaducts already unlinked;
	Unsimplified	- More processing time; - Network fragmentation; - Distorted ASA values.	- Routes georeferenced accuracy;
	Simplified	- Additional treatment needed; - Route accuracy up to a threshold value.	- Less network fragmentation; - Less processing time; - Additional treatment is automized.
	TS	- Two additional treatments needed;	- Less network fragmentation; - Less processing time; - Additional treatments are automized; - Routes georeferenced accuracy; - ASA centralities accentuated.

Source: Authors (2022).

OSM RCL data-base for north-eastern Brazilian cities exhibited good quality and accurate location; some problems underlined earlier as topological inconsistencies (Dhanani et al., 2012; Kolovou et al., 2017; Krenz, 2018) were not found with the cleaned layer maintaining routes accessible by car. The attribute data allowed GIS-CAD interoperability thus joining both systems capabilities; this also helped clean the model by road types, and street name data helped filter spatial entities for simplification. However, further OSM RCL label improvement could facilitate pre-processing steps: in the “type” column specify private residential roads (facilitating the cleaning process), and the “name” column could differentiate labels for roundabouts and for roads connecting to them, and different road sides, facilitating simplification.

While Kolovou and colleagues (2017) compared axial and RCL treated basis finding that simplification with 20 threshold was best suited approximating results from the axial model, they also proceeded with a different RCL treatment with remodelling erasing roundabouts and joining parallel lines. Roundabouts and parallel lines do not seem problems themselves, especially when their representation is simplified most, and as they might impact movement. The main issue found after DP simplification were vectors that still exist in a straight route line that the limited threshold does not erase and impact ASA centrality values without purpose. This issue was partially tackled by filtering streets by route name and especially by larger simplification thresholds feasible by fixing vertices by polyline endpoints and by angular criteria. This RCL-TS model reached a good balance between system size and route depiction for our cities, and captured more accentuated centralities than other models. More can be explored in the future comparing models for other cities besides north-east Brazil to further validate the proposed preparation steps.

Conclusion

As RCL ASA Natal and Joao Pessoa cities results proved solid, sharing these steps attempts to contribute to more reliable, automated, standardized and easily updated city analysis, especially relevant in rapidly changing Brazilian cities. This facilitates spatially accurate city dynamics studying, comparing cities, and broadening studies regionally, as developed elsewhere (Serra & Hillier, 2019; Altafani & Cutini, 2020), that can be performed in future.

While axial models are still useful for space syntax axial analysis, advantages of using OSM RCL bases for ASA are clear. Some RCL preparation issues as unclear preparation procedures, lack of further comparison between proposed models ASA for whole cities analysis, and little communication about availability and quality of RCL, might have contributed to the maintenance of axial models for ASA in Brazil, and elsewhere. This study endeavoured to tackle this gap, by exploring how manually drawn and automated models depict routes and ASA centralities in two closely-related cities in north-east Brazil, and by sharing methods to clean, simplify and further prepare RCL for ASA. RCL explored in this study without remodelling approximates axial models ASA centralities, while addressing other subtleties, as differences in centrality between two sides of a highway.

Steps to prepare RCL here were performed with GIS-CAD interoperability, and can be further explored with other more recent processing tools at QGIS or directly with python script to provide openly accessible processing, and will be this research next steps.

With the proposed process, analysis can encompass other routes as pedestrians and cyclists, to explore how centralities change in specific scales or areas, as in Joao Pessoa old city centre. RCL centralities can be related with other spatial data, as facilities distribution and built form, broadening our many avenues for future research, as comparison with actual flows in the city, and further validate steps taken.

Data availability statement

The dataset that supports the results of this paper is available at SciELO Data and can be accessed via https://doi.org/10.48331/scielodata.VMBYJL

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