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Planning sustainable urban-industrial configurations: relations amongst industrial complexes and the centralities of a regional continuum

Abstract

Production models flexibilization in capitalist economies, associated to metropolisation processes, have transformed industrial activities spatial organization in regional continua. Now placed in planned complexes located on cities' fringes, manufacturing firms often stand isolated from important regional routes of circulation, which may hinder their activities, resilience and long-term economical sustainability. Implications of these changes are imminent, as forthcoming "*Smart Manufacturing*" logistics will require efficient linkages between local and regional transportation modals. Such issues compel urban planners, economists and policymakers to develop approaches to evaluate industrial territories imprint on metropolitan dynamics and enact guidelines for future industrial strategies. Paper objective is to examine the role of road-circulation network centralities on industrial complexes' placement in a regional continuum, devising methods to assess industrial sites locational and agglomeration logics. Empirical studies comprise five Brazilian industrial complexes sited in *Porto Alegre's Metropolitan Region* (PMAR). Hypothesis is that road-circulation network centralities hierarches' (*closeness centralities* & *betweenness centralities*) have positive correlations with industrial placement patterns at regional scale, as well at inner-complex scale; and can inform regional contiguities dynamics amid discontinuous industrial spaces. Regional road-circulation networks configurational analysis, consequently, can unveil factors behind industrial complexes' development unevenness, recommending their incorporation in planning strategies for sustainable industrial environments.

Keywords: Urban Planning, Regional Planning, Industrial Complexes, Centrality, Space Syntax

INTRODUCTION

Regional expanses are still regarded as 'grey areas' concerning urban morphology. The understanding of how these environments were structured was hindered until early 2010s, due to computing power and processing methods limitations, which were deemed uncapable of analysing datasets comprising large extents of differentiated and complex territories. This not only caused lacunae in comprehending the role and properties of urban circulation networks at regional – and metropolitan – scale, but, as well, had repercussions on studies' accuracy in assessing relations among these territorial dimensions and the economic activities placed within its built structures, especially those relating to industrial production. Likewise, Economics, subdued by Keynesian-oriented regional theories, was rather unsuccessful in solving inner-complexes' spatial organisation issues, oftentimes failing to promote industrial development based on so-called 'local interdependencies', since, as mention Amin (2000), its policies favoured sectorial investments that take for granted territories and spatial configuration.

Approaches towards a sustainable[1] environment for industrial development in regional continua ought to consider, beyond assumed sectorial "local interdependencies", the social and collective factors underlying economical behaviour (AMIN, 2000), as firms' expectations and interactions with space, coupled with the economic specialisation emergent from territorial interactions, exhibit a reciprocal influence with the diffuse urban morphology, resultant from metropolisation processes. Regarding this territorial question, important advances in field of urban and regional morphology were made through active research, such as in Turner (2009), Serra & Pinho (2013), Braga et. al. (2017), Krenz (2017), Serra & Hillier (2018), Kaplan, Burg, & Omer (2019) and Lerman &

[1] Sustainability in this case is defined as the local-regional capabilities of maintaining a long-term economic dynamism (economic sustainability), as well assuring the efficient use of space and infrastructure (morphological sustainability).

Lebendiger (2019); whom proposed methods and models for constructing and evaluating road-circulation networks configurational properties of regional continua, accomplishing detailed visual representations of regional and even supra-regional territories, describing its urban morphology, network centralities properties and movement patterns at previously uncharted geographical scales.

Serra & Pinho (2013), nonetheless, recognized that, although innovative, current research in urban morphology tend to overall focus on the spatial dimensions of the territorial phenomena, Mention the authors (ibid, 2013), that beyond the innate difficulties of analysing regional networks, due to their sheer size as physical objects, the greater challenge remains representing them in conjunction with populational and socio-economic data which are periodical (Census), discrete and often a-spatial. Still, territorial interactions amid road-circulation networks configuration, population centres, built structures and the density and distribution of economic activities are, as stated by Kropf (2017), core aspects of urban morphology, consisting in reciprocal indicators that, only when apposed, can inform significant realities about metropolitan regions structuring and transformation. This is in accord with Economics, as new forms of territorial planning and governance, in conjunction with analyses of territorial local-regional logic, are a crucial prospect for forthcoming "*Integrated Industries*", as "*Smart Manufacturing*" autonomous logistics will require efficient linkages between local and regional transport modals[2]. As Thrift (2004) mentions: "what counts is connectivity", as the role of network configuration efficiency is bound to become an important part of future industries sustainable development.

Apropos, this is a pressing matter even when contemporary industrial activities are considered, as the recent flexibilization of production models in capitalist economies has changed this sector productive and spatial organization (PORTER, 1998). Once placed within main urban centres, these activities have been gradually *segregated* and moved to planned industrial complexes on metropolitan areas fringes, in a dynamic of "*concentred deindustrialization"* described by Rocassalva & Pluviano (2012), for Turin Metropolitan City in Italy. This dynamic, displayed a particularly severe emergence in some in-development countries, such as Brazil[3], as hinted by Alonso (1988) and discussed in Altafini (2018). In such countries, this *segregation* often means outright isolation from important regional circulation routes, being this a consequence of limitations – and political struggles – regarding urban policies execution at different territorial jurisdiction levels, since gestion autonomy and interests at regional scale, oftentimes are in conflict, and can restrict the implementation of these policies at municipality (city) scale and *vice-versa* (BRANDÃO, 2007). Complexes remoteness from main regional circulation impact on industrial firms' accessibility and can increase inner-complex and outer-complex transportation costs, which may compromise their dynamism, resilience and long-term economical sustainability (ALTAFINI, 2018).

Since industrial complexes became a popular planning tool at regional and municipality scales, any analysis intending to foresee and evaluate tendencies of chance in such territories must consider their interactions with road-circulation routes in regional continua as a first step to calibrate such strategies. Serra & Pinho (2013) list three fundamental conditions for a regional morphology descriptive and analytical methodology: accurately represent a territorial extent enabling to produce its details at any spatial scale; be suited for different geographical systems and contexts, allowing comparisons between distinct hierarchical relations; address socio-spatial processes, enabling to relate urban form (built structures) to urban functions (socio-economic aspects). Space Syntax (HILLIER, 2007) which consists of a set of theories whose methods can fulfil these conditions, enables researchers to assess

[2] Hoffman & Rüsch (2017) discuss logistics as being a major bottleneck in the diffusion of *Industry 4.0* production models.

[3] Morceiro & Guillhoto (2019) refer that Brazil exhibited the third highest retraction in industrial sector gross added value (GVA) among 30 countries, on a data series starting from 1970, being after only Australia and the United Kingdom. The authors (*ibid*, 2019) consider this a premature *deindustrialization*, since the productive structures weight on GDP began to decrease before the GDP *per-capta* could grow, an antithesis, when compared to other industrialised countries process.

the design of road-circulation networks at any scale, depicting its spatial configuration. Its resulting models are suitable as spatial datasets for enacting further geostatistical correlations, which unveil interactions among built structures (urban economic activities) and the circulation infrastructure centralities' hierarchies.

Based on urban and regional planning requirements, this paper focus in verifying if configurational properties of road-circulation networks can inform changes in trends of placement, organization and expansion of industrial activities in a regional continuum. The objective is to devise methods that can contribute to assess what spatial variables are meaningful in determining "optimal" locations for industrial complexes; and to evaluate which spatial features can favour or disfavour industrial agglomeration at region scale, supporting conclusions on territorial planning effectiveness. Empirical analyses encompass five Brazilian Industrial Complexes[4] at *Rio Grande do Sul* State, Brazil, sited in *Porto Alegre's Metropolitan Region* (PMAR), on the municipalities of *Alvorada, Cachoeirinha, Gravataí, Porto Alegre* and *Viamão*. Hypothesis is that movement potentials and flow probabilities informed by road-circulation network centralities' have direct and positive correlation to industrial placement patterns; and can establish cohesive connections between them, forming contiguities amid discontinuous industrial spaces that act as linkages between complexes areas, thus, favouring the interactions amid firms. The modelling combines Space Syntax' and spatial analyses methodologies to enable geostatistical correlations between road-circulation network centralities' and industrial structures (sites) placement.

Proposed network analyses enable urban planners and other decision makers to better access regional potentialities, giving them tools to evaluate the spatial component of industrial policies proposals, further imbedding them to the regional continua movement patterns. As well, these analyses can aid researchers to identify of why certain industrial spaces lack dynamism, ergo, contributing to regional development assessments about the sustainability of industrial areas in urban environments.

DATASETS AND METHODS

Evaluation of road-circulation network properties using centrality measures at regional scales, and further assessment of its relations with industrial complexes placement and zoning patterns in local, metropolitan and regional contexts, requites the apposition of two different datasets on a GIS suite (QGIS, 2019): *Porto Alegre's Metropolitan Region* (PMAR)[5] industrial complexes areas, comprising, as well, their built structures (industrial sites); and the regional road-circulation network, represented by a road-centre line map, built as a graph, then modelled using Depthmap X 0.5 (2015) software.

PMAR's industrial complexes database encompasses five areas, divided in two groups according to their territorial administration affiliation, and the applied rules regarding their land-use.

First complexes' group comprise three State planned Industrial Districts (ID's): *Alvorada-Viamão, Cachoeirinha* and *Gravataí*, whom land-use are restricted to industrial placement only. Enacted by mid-1970s regional development initiatives, these districts intended to spread manufacturing plants towards the fringes of *Rio Grande do Sul*'s capital, *Porto Alegre*, in order to increase occupation rates

[4] According to Proulx (2008) and Lévesque (2008) the industrial complexes concept provides an interesting frame for modelling territorial phenomena like industrial clustering, since it singles out the economic specialization of loose institutionalized zoning parameters.

[5] *Porto Alegre's Metropolitan Region* is composed currently (2019) by 34 municipalities, however, these analyses use a road-centre line map comprising only the 14 municipalities that constitute the first PMAR iteration (1970). These cities were chosen because they exhibit higher conurbation indexes (RIGATTI, 2009), forming a more cohesive road-circulation network; and because they concentrate most of the Metropolitan Region industrial-dedicated areas. From these 14 municipalities, only five cities, which have industrial complexes possessing continuous planned territories, were analysed: *Alvorada, Cachoeirinha, Gravataí, Porto Alegre* and *Viamão.*

and enhancing the economic dynamism and integration of neighbouring municipalities, in the recently created Metropolitan Region (1974). Soares et al. (2015) mention that policies' goals were to minimize PMAR's uneven territorial development, as the incentive for industrial activities placement was deemed by Brazilian Federal Government policymakers[6] as an appropriated solution to increase overall income, employability, resident population, hence, spatial occupation throughout the region. Successful in some degree, these policies resulted in a substantial, but selective, urban growth of the municipalities displaying conurbation potential with the regional core, which achieved an important share in regional economy industrial sector during the successive decades (1980s and 1990s) However, the authors (*ibid,* 2015) point out that this trend has shifted after 2000, when industrial sector participation rates in PMAR's total Gross Value Added (GVA) suffered general decline, an aftershock of the 2007- 08 global financial crisis. From 2010 onwards, authors (*ibid, 2015*) refer that economic activities, such as retail & services, outdid manufacturing activities and even increased their participation in PMAR's economy, while industrial sector input to total production value remained stalled, indicating its lackluster resilience.

The remaining two complexes of *Corredor de Desenvolvimento* (*Development Corridor*) & *Parque Industrial da Restinga* (*Restinga Industrial Park*) are located within *Porto Alegre* municipality, and were enacted by early 1990s municipal urban policies. Being part of the most recent *Porto Alegre's* Master Plan (2010a), the polices intended to establish urbanistic guidelines for future housing, urban economic activities development[7], and to regulate overall expansion outside the city core, the areas differ, not only in sheer size, but also in purpose. While the *Development Corridor*'s main goal was to host a metropolitan industrial & logistics centre, whereas sprawling occupation rates throughout existent, but not yet consolidated, urban sprawl axes, as such, encompassing a large territorial expanse; the *Restinga Industrial Park* consists in a much smaller patch of industrial-oriented zoning, planned and enacted with the objective of developing a peripheral, rather unoccupied, location, in similar fashion as the State planned ID's (PMPA, 2010a). In this sense, this industrial complex consists of a partial application of a regional planning instrument inside an urban context.

Industrial sites' location data includes all industrial dedicated structures within selected complexes. Obtained through OpenStreetMap (2016a, 2016b), this spatial database was crosschecked through empirical data collected *in situ* (March –October 2017), excluding any defunct or non-operational industrial structures, further mapped altogether in a shapefile database. Data includes the built area of each structure, employed here as a weighting variable for Kernel Density Estimation Method (KDE) in geostatistical analyses (BAILEY & GATRELL, 1995). KDE is a comprehensive spatial measure that allows the estimation of industrial structures spatial agglomeration density (*heatmap*) drawing from influence spheres (*buffers*)[8] irradiating from each industrial structure centroid; and to establish spatial proximity correlations between industrial structures placement and different road-circulation network centrality measures.

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[6] Brandão (2007) mentions that centralized economic decisions during the Brazilian Military Government (1964-1985) established a clear pattern regarding urban development and industrial policies, where workforce expansion (rural-urban migrations) and total integration of national industrial production were the objectives. Therefore, even though the States were responsible for enacting these policies regionally, they invariably were thought as a part of a national development plan. In this sense, cities often had limited autonomy regarding their industrial districts planning and implementation.

[7] *Porto Alegre*'s Master Plan (2010a) classify these areas as mixed-use zones, thus, less restrictive regarding land-use than the State Industrial Districts. Still, most of the residential incorporations (social housing), retail & services activities in the area are industrial-oriented.

[8] The sphere of influence radius (*Kernel Buffer Radius*) for each structure is limited to 500m, stipulated as a maximum acceptable distance that a vehicle must travel to access a public road from the industrial structure.

Datasets used for configurational (network) analyses are based on Rigatti & Zampieri (2011) and Zampieri (2017) PMAR axial maps. Updated by Altafini (2018) to include road-infrastructure expansions and recent urban sprawl patterns, the metropolitan road-circulation graph map was also reconstructed using, instead of axial representation, a road-centre line representation. This depiction is better suited to conduct proposed Space Syntax' Angular Analyses (TURNER, 2005, 2007), since more than portraying road-circulation networks' morphology with greater precision[9], the angular weighted topological steps obtained from centre lines provide a finer depiction of *Choice* measures (*betweenness centrality*) (TURNER, 2001; 2007 important in the assessment of the predicted flow and *preferential routes* amid origin-destination nodes. As proven by Serra & Hillier (2018), when modelled for regional continua, Angular Analyses' *Choice* (*betweenness centrality*), provide very accurate vehicular movement and flow potentials depictions, which are deemed essential for industrial placement as they are proxies for evaluating transportation costs.

Configurational analyses draw from above mentioned Space Syntax' Angular Analyses, to depict different urban centrality hierarchies, applying two measures developed by Hillier, Turner & Yang (2012): Normalized Angular *Integration* (NAIN) and Normalized Angular *Choice* (NACH)[10]. NAIN denote *closeness* centralities in urban road-circulation networks, as it demonstrates the accessibility of a road segment relative to all other segments in the network (to-movement). It displays the network overall connectivity hierarchies based on the relative depth of each segment. Normalized Angular *Choice* (NACH) represents *betweenness* centralities in road-circulation networks, demonstrating the most probable crisscrossed routes within the network, based on the sum of times each segment crosses all origin-destination pairs (through-movement), representing *preferential routes* or the shortest paths across a system.

Based on the apposition of the described analyses – geostatistical and configurational – the tested hypothesis is that the road-network centrality hierarchies' values have a positive correlation with the industrial placement patterns both at local and regional scales. Therefore, industrial structures should be mostly clustered near road-network segments possessing elevated values for NAIN & NACH; At regional scale, road-network centralities also, constitute linkages amid different industrial complexes, guiding their expansion tendencies and reinforcing their relational capabilities, which may lead to better environments and interaction, ergo, improving overall industrial resilience.

In order to proof hypothesis and correlations, a statistical significance threshold was established by employing the Pareto Distribution Principle (PARETO, 1971), which states that: to be a significant correlation, at least 20% of causes – represented by the 20% of segments that have, in each individual angular analysis, highest values for *closeness* and *betweenness* centralities; needs to be responsible for at least 80% of the effects - represented by the proximity placement of industrial structures[11], which is informed by the KDE sphere of influence. These correlations will be calculated both for the regional road-networks and for the local inner-complex networks.

A second set of analyses assess how the road-network centralities connect and establish regional linkages amid industrial complexes areas, informing their contiguity patterns and expansion

[9] Angular Analyses provide a better depiction of movement potentials and flow probabilities in orthogonal and regular grids, as it can identify slight changes in topology direction interpreting them as weighted angular changes (TURNER, 2007). Orthogonal grids are the morphology typologies deemed to be prevalent in industrial zones.

[10] Angular *integration* and *choice* normalization processes developed by Hillier, Turner & Yang (2012) made possible accurate comparisons between different sized (in number of segments and area) urban networks – thus, with different depths. It matters because allows better depictions of *choice* routes distribution, as its calculus ponders each systems' Total Depth.

[11] If the industrial site sphere of influence determined by KDE (500m) is intersected by at least one segment within the establish centrality value of threshold (top 20%) there will be a spatial correlation.

tendencies through a 4km radius[12] *buffer* irradiating from each industrial complexes' inner-complex *preferential routes* (road-network *betweenness* centralities). The resulting area modeling of NAIN & NACH measures, depict the hierarchical structure of *closeness* (to-movement) and *betweenness* (through-movement) centralities between these spaces at regional scale.

Being proven, this hypothesis imply that road-network centralities in urbanized environments can be characterised as structures capable of exerting attraction towards certain types of economic activities, as hinted by Hillier (2000) and explored by Cutini (2001) and Altafini (2018), and also capable of indicating what should be industrial expansion axes, as suggested by Rocassalva & Pluviano (2012).

RESULTS AND DISCUSSION

PMAR's road network configurational analysis unveiled a system exhibiting high values for its Total Depth and Mean Depth relatively average-to-low values (Table 1), suggesting noteworthy contrasts circulation network at regional scale structuring and morphology.

Aforesaid depth differences can be visualized in Figures 1 & 2, as they demonstrate that metropolitan region territorial cut-out is fragmented and discontinuous. It possesses urban areas with a high density of short and medium length segments (*clusters*) with many interconnected nodes – higher Total Depth –, contrasting with large expanses devoid of urban occupation, traversed by few groups of long segments, possessing a small, although very definite, number node connections[13] – lower Total Depth. This reflects a dichotomy, often found in Brazilian metropolitan regions, as the compact nature of central metropolises diverge from the scattered nature of its urban sprawl towards lesser – but likewise compact – settlements in the metropolitan hierarchy where conurbation process is still incipient.

Such metropolitan morphology and its distinctive discrepancies in depth and connectivity portrait a road-circulation network spatial fragmentation that reproduces the fragmentation *status quo* of its own territory, further revealing an overall uneven territorial development amid rural and urban areas. Santos (2006) mentions that these spatial differences are outcomes from the accelerated nature of Brazilian metropolisation processes, a well observable characteristic of PMAR's spatial structure. Highlighting these urban form features is relevant, since most of the selected Industrial Complexes are imbedded to metropolitan fringes, remarking the spectre of these divides, being positioned on the transition zones that illustrate where the changes on regional continuum structure commence.

Table 1 – PMAR's road-circulation network configurational attributes, and attributes for Normalized Angular Integration (NAIN) (Figure 1 – A1. & A2.) & Normalized Angular Choice (NACH) (Figure 2 – B1. & B2.).

Map No.	Configurational Attributes	Values – Porto Alegre Metropolitan Region (PMAR)
	Total Metropolitan Area (km²)	4,203.42
	Segment Number (Total)	147,232.00
	Total Depth (Non-Norm.)	7,548,545.00
	Mean Depth (Non-Norm.)	2,541,696.00
	Configurational Analyses – Integration	
A1.	NAIN (Max.)	1.067
A1.	NAIN (Mean.)	0.666

[12] 4 km is the most commonly stipulated influence distance for regional facilities and services, industrial complexes akin.

[13] Described organisation of metropolitan road-circulation networks possess similitudes with Granovetter's (1983) concepts of *strong ties* – that would be the interconnected road-circulation network inside settlements; and *weak ties* – that would be characterised by the continuous highways, that connect the different settlements in the metropolitan system.

A2.	NAIN 20% (Percentile Value)	0.798
	Configurational Analyses – Choice	
B1.	NACH (Max.)	1.566
B1.	NACH (Mean.)	0.720
B2.	NACH 20% (Percentile Value)	1.059

NAIN analyses (Table 1; Figure 1 – A1 & A2) depict how depth and connectivity differences shape *relative accessibility* distribution in PMAR road-circulation network. It can be observed that *Integration Cores* (NAIN 20%, Figure 1 – A2) are concentred around three main regional axes, corresponding to BR-116, BR-290, & RS-118 highways, which intersect to form a regional-wide *ring-road*, integrating the cities of *Porto Alegre, Cachoeirinha, Canoas* and *Gravataí*. A fourth regional axis – the BR-448, an alternative route to the heavily congested BR-116 – connects, through *Canoas* hinterland, *Porto Alegre* to *Vale dos Sinos* region. Although regionally relevant, to the point of even forming a secondary *ring-road* system with BR-116, it still possesses a lesser importance when compared to the other axes.

Beyond these structures, *Integration* values immediately suffer a decrease towards *segregation* levels, due to the increasement of system's Total Depth, which is not accompanied by a connectivity growth, as single and long rural roads tend to be prevalent, resulting in the road-circulation network structure fragmentation (Figure 1 – A1). This condition happens in all depicted main axes, apart from the northmost highway (BR-290), which begins in *Porto Alegre*, where the *Development Corridor* is located, and continues through the dense road-circulation network of *Canoas* towards the *Vale dos Sinos* region municipalities (Figure 1 – A2).

Regarding Industrial Complexes placement in the regional continuum, it is possible to distinguish their nearness to the mentioned transition areas, where the shift in *Integration* values initiates (Figure 1 – A1). Even though close to these *segregated* spaces[14], four of five complexes remain imbedded to regional *Integration Core* boundaries (NAIN 20%, Figure 1 – A2), which reach the innermost areas of *Alvorada-Viamão ID, Cachoeirinha ID, Gravataí ID* and *Development Corridor*, but do not spread towards *Restinga Industrial Park.* This complex remains *segregated* from the regional to-movement network, and that can be one of the causes for its relative industrial underdevelopment (Table 3).

While NAIN analyses demonstrates that regional *relative accessibility* is distributed along three main axes (BR-116, BR-290 & RS-118), forming a definite *ring-road* structure that connect metropolitan settlements and the imbedded Industrial Complexes, NACH analyses (Table 1; Figure 2 – B1 & B2), indicates that PMAR's *preferential routes* have a wider distribution in the road-circulation network, reflecting *betweenness centrality* linkage characteristics (Figure 2 – B1). Granting that aforesaid *Integration* axes function, as well, as main structures, when *preferential routes* are considered, it can be observed the inclusion of other urban avenues and regional highways that were not emphasised by the NAIN 20% restriction, such as RS-020, RS-030 & RS-040 (Figure 2 – B2). In fact, these roads and the remaining highlighted segments of NACH 20% restriction, depict the regional *super grid*, which structures the through-movement shortest paths in the regional continuum.

Concerning the Industrial Complexes placement relative to the *preferential routes*, NACH analyses shows that all them are encompassed by centrality structures, which reach even the previously seen as *segregated Restinga Industrial Park*, therefore, effectively interconnecting all complexes. It is important to remark that, even if the regional *preferential routes* reach all complexes innermost areas, their degree of inner-complex distribution is noticeably smaller, as the *betweenness centralities* tend

[14] Metropolitan settlements urbanisation, mustered by residential incorporations especially in *Cachoeirinha* and *Gravataí*, has encompassed the areas where the Industrial Complexes were placed (ALTAFINI, 2018). Hence, the complexes are now more integrated to the regional road-circulation network than when they originally conceived during the mid-1970's.

to be concentred in the main avenues that compose their road-circulation network, in opposition to the relatively concentred distribution logic verified for regional *Integration Cores*.

This explains the slight differences for the correlation degree between industrial sites placement and the road-circulation networks NAIN & NACH analyses (Table 2):

Table 2 – PMAR's correlational analyses between road-circulation network centralities and industrial sites placement for Normalized Angular Integration (NAIN) (Figure 1 – A2.) and Normalized Angular Choice (NACH) (Figure 2 – B2.)

Map No.	Industrial Complexes – PMAR	Number of Sites	Correlation - Sites x Network	(%)
	Industrial Sites Total	2782	-	-
	Industrial Sites within 500m Radius			
	Integration – Closeness Centrality			
A2.	NAIN 20%	2582	0.928	92.8
	Choice – Betweenness Centrality			
B2.	NACH 20%	2540	0.913	91.3

Geostatistical analyses uncovered that industrial sites placement possesses significant statistical correlations with both NAIN & NACH measures at regional scale. NAIN 20% restriction (Table 2; Figure 1 – A2), demonstrates that 92,8% of the industrial sites are located within 500m of at least one segment inside the established centrality threshold values (2582 of 2782 sites). Most of these sites are situated within the *Development Corridor, Cachoeirinha ID* and *Gravataí ID*, as the *Integration Core* only reaches the first half of *Alvorada-Viamão ID* and does not reach *Restinga Industrial Park* at all.

NACH 20% restriction correlations are slightly lower than those found for NAIN 20%, as 91,3% of the industrial sites are located within 500m of at least one segment inside the proposed centrality threshold values (2582 of 2782 sites). This weaker correlation value is justified by the inner-complex *Preferential Routes* distribution logic at regional scale since, in *betweenness centrality*, routes remain restricted to the main road-circulation structure, not reaching inner areas where some industrial sites are place. Hence, even considering the addition of *Restinga Industrial Park* structures, correlations remain weaker on *Development Corridor* and *Gravataí ID* where the majority of industrial structures is positioned in areas farther from main road-structures with highest centrality values.

Overall regional scale results suggest that centralities have a robust relation to industrial placement tendencies, ergo, valid variables to analyse in industrial planning strategies for location. Inner-complexes morphological analysis can give more clues about what determines placement, clustering and agglomeration dynamics for industrial activities.

Figure 1 – PMAR's configurational analyses for Normalized Angular Integration (NAIN) (A1); Restricted Normalized Angular Integration (NAIN 20%) (A2) and geostatistical correlations among regional circulation network and industrial complexes KDE values spatialization.

(INSERT FIGURE 1)

Figure 2 – PMAR's configurational analyses for Normalized Angular *Choice* (NACH) (B1); Restricted Normalized Angular *Choice* (NACH 20%) (B2) and geostatistical correlations between regional circulation network and industrial complexes KDE spatialized values

(INSERT FIGURE 2)

As significant correlations among regional scale road-circulation network centralities structures and industrial sites placement were proven, further investigations on inner-complexes spatial features are conceivable. In this regard, Kernel Density Estimations (KDE) goes beyond its intended main scope that is establish *buffer* radius for spatial correlations, being suitable, as well, to depict industrial sites agglomeration patterns at complexes innermost areas[15]. Heatmaps generated through these analyses, alongside Space Syntax measures, indicate how urban morphology can affect industrial placement.

Inner-complexes configurational attributes in Table 3, depict that KDE values (sites agglomeration index) are higher for *Cachoeirinha ID* (Figure 4) and for the *Development Corridor* (Figure 6). Both industrial complexes share similar urban morphology, where orthogonal grid design and *ring-roads* structures are prevalent. As centralities distributiveness tends to be broader in these less hierarchized typologies[16], industrial activities have a wider range of ideal placements options near to high value centrality measures segments (Figure 4 – A2; Figure 6 – A2), which leads to larger sites clustering, increasing overall KDE values.

Alvorada-Viamão ID (Figure 3), *Gravataí ID* (Figure 5) and *Restinga Industrial Park* (Figure 6) exhibit comparatively lower KDE values in opposition to the cases above (Table 3). This is attributed to the predominant linear structures that compose their inner-complexes road-circulation networks, which tends to restrict ideal placement options. which tends to restrict ideal placement options by creating "enclaves", *segregated* areas that are topologically far from the main centralities. Being spatially constrained by the single access routes, these spatial constrains limit wide-ranging industrial agglomeration.

Table 3 – PMAR's Industrial Complexes datasets, configurational analyses and correlational analyses between road-circulation network centralities and industrial sites placement for Normalized Angular Integration (NAIN) (A1. & A2.) and Normalized Angular Choice (NACH) (B1. & B2.)

Industrial Complexes Datasets - Configurational Attributes	Alvorada-Viamão ID	Cachoeirinha ID	Gravataí ID	Restinga Industrial Park	Development Corridor
	Figure 3	Figure 4	Figure 5	Figure 6	Figure 6
Total Industrial Sites	157	389	208	89	1,939
Total Area (km²)	3.50	10.98	3.73	0.80	36.49
Total Built Area (m²)	191,388.75	1,042,870.50	329,296.02	38,653.30	1,232,128.66
TBA/TA (%)	5.46	9.49	8.82	4.83	3.37
KDE (Highest Value - 500m)	3.22	29.60	2.90	0.66	31.58
Integration – Closeness Centrality					
A1. NAIN (Max)	1.556	1.089	1.139	1.217	1.703
A1. NAIN (Mean)	1.029	0.749	0.810	0.834	1.078
A2. NAIN 20% (Percentile)	1.236	0.891	0.952	0.946	1.285
Correlation (%)	59.2	92.8	85.6	100	84.5
Number of Sites	93	361	178	89	1,639
Choice – Betweenness Centrality					
B1. NACH (Max)	1.592	1.560	1.536	1.552	1.633
B1. NACH (Mean)	0.659	0.606	0.630	0.643	0.700
B2. NACH 20% (Percentile)	1.360	1.180	1.218	1.143	1.181
Correlation (%)	82.8	99.0	88.5	100	99.8
Number of Sites	130	385	184	89	1,936

[15] Since the industrial complexes are small in comparison to the regional area, only when assessed in higher resolutions (local scale analysis), that KDE heatmaps become discernible.
[16] The relations between urban morphology, network centralities distribution and industrial placement was evaluated in-depth by Altafini, Braga & Cutini (2019).

Additional analyses compare the inner-complexes road-circulation network centralities structures[17] with its regional-wide counterparts. This comparison objective is to understand how metropolitan scale centralities relate with the innermost local centralities' continuities of the industrial areas.

Alvorada-Viamão ID comparison for NAIN depicts that the regional *Integration Core* has a limited inner-complex reach, being the local centrality continuity responsible for structuring the to-movement within the area (Figure 3 – A1; A2). Mentioned linear morphology results in a concentration of high hierarchy centralities in a single group of segments, restraining clustering potentials. As consequence, most industrial sites are placed in *segregated* areas, which results in a low sites' correlation (59,2%). Due to several groups of industries being placed in enclaved spaces, far from the local *Integration Core,* this is the only case where there are no significant Paretian Correlations (Table 3).

Figure 3 – Configurational analyses for Normalized Angular Integration & *Choice* (NAIN & NACH)); Restricted Normalized Angular Integration & *Choice* (NAIN 20% & NACH 20%); comparing PMAR's regional (A1 & B1) and *Alvorada-Viamão* ID (A2 & B2) inner-complex road-networks centralities distribution; and KDE values spatialization.

(INSERT FIGURE 3)

Regional *preferential routes* (NACH, Figure 3 – B1) reproduces part of the linear centrality structure observed in the *Integration Core*, however, local NACH have a more distributed, although still linear, *preferential routes* structure (Figure 3 – B2). A secondary linearity (north) provide limited access routes to previously *segregated* industrial structures, which increase overall centralities' correlation (82,8%). It can be observed that there is an overlap between regional and inner-complex centralities structures, remarking this structure importance as a high hierarchy *preferential route* at both scales.

Cachoeirinha ID road-circulation networks comparison reveals that inner-complex *Integration Cores* essentially overlap its regional counterparts (Figure 4 – A1 & A2). However, it is possible to observe that, at local scale, the industrial complex main access avenue possesses a lower centrality value than the crossroads which structure the central *ring-road.* Although this difference is negligible in value, it modifies significantly *Cachoeirinha ID* centralities hierarchies' configuration, remarking these as the system's most important roads in structuring local *accessibility* and also in structuring the main local *preferential routes* system, as highlighted in the NACH model (Figure 4 – B2).

Comparison between *Cachoeirinha ID* regional and inner-complex *preferential routes* (Figure 4 – B1; B2) evidence a slight overlap between segments with high centrality, especially in the northmost access avenue, which links the complex' consolidated and newly urbanised areas. Since most industrial structures are located around the aforementioned avenues, road-sites correlation results are very high, both for NAIN (92.8%) and for NACH (99,0%).

Figure 4 – Configurational analyses for Normalized Angular Integration & *Choice* (NAIN & NACH)); Restricted Normalized Angular Integration & *Choice* (NAIN 20% & NACH 20%); comparing PMAR's regional (A1 & B1) and *Cachoeirinha ID* (A2 & B2) inner-complex road-networks centralities distribution; and KDE values spatialization.

(INSERT FIGURE 4)

Gravataí ID share similarities with *Alvorada-Viamão ID*, as its morphology is fundamentally linear-based, with "enclaved" areas extending from main centrality cores. Still, the density of connections leads in a homogeneous distribution of the industrial sites, resulting in significant NAIN (85, 6%) and NACH (88,5%) correlations. Important differences regarding regional and inner-complex centralities are unveiled by NAIN analyses, as the avenue that structures local centrality – a RS-030 continuity –

[17] These inner-complex road-circulation networks are clipped from the main regional network and remodelled using Space Syntax measures (NAIN & NACH) and represented here by the 20% highest valued centrality segments.

is not highlighted at a regional scale (Figure 5 – A1 & A2), creating a gap of *segregated* area where some groups of industrial sites are located. NACH analyses, however, depict an almost total overlap between regional and inner-complex *preferential routes*, remarking the importance of the whole industrial complex road-circulation network as a regional linkage.

Figure 5 – Configurational analyses for Normalized Angular Integration & *Choice* (NAIN & NACH)); Restricted Normalized Angular Integration & *Choice* (NAIN 20% & NACH 20%); comparing PMAR's regional (A1 & B1) and *Gravataí ID* (A2 & B2) inner-complex road-networks centralities distribution; and KDE values spatialization.

(INSERT FIGURE 5)

Porto Alegre's Industrial Complexes exhibit, among themselves, central differences in their structure, regarding scale-wise centralities distribution. While the *Development Corridor* shows similarities in centralities disposition at both scales, and in both models (NAIN & NACH), the *Restinga Industrial Park*, displays a rather important distinction amid regional and inner scale (Figure 6).

Figure 6 – Configurational analyses for Normalized Angular Integration & *Choice* (NAIN & NACH); Restricted Normalized Angular Integration & *Choice* (NAIN 20% & NACH 20%); comparing PMAR's regional (A1, B1, A1.1 & B1.1.); *Development Corridor's* (A2 & B2) and *Restinga Industrial Park* (B2.1 & B2.2) inner-complex road-networks centralities distribution; and KDE values spatialization.

(INSERT FIGURE 6)

Development Corridor regional-wide *Integration Core* encompasses its whole area, reaching the most inner-placed industrial sites (Figure 6 – A1). Inner-complex road structure has a similar centralities distributiveness when compared to regional-wide NAIN, yet, in this inner scale, *Integration Cores* do not reach imbedded industrial sites at complex' center (Figure 6 – A2). Although this effectively *segregates* some of the innermost sites, overall correlation with road-circulation network is significative (84,5%), due to the nearness to BR-116 and BR-290 urban continuities. Inner-complex *Preferential Routes* are remarkable alike their regional-wide counterparts, therefore, exhibiting high industrial sites 'correlation (99,8%). As these routes structure through-movement towards the *segregated* areas they contribute to mitigate complex' bad *accessibility* effects.

Restinga Industrial Park on the other hand outstands the other complexes, since is not reached by any regional-wide *Integration Cores* (Figure 6 – A1.1). In this sense, at regional scale, *Preferential Routes* structures connections of this complex with the rest, while its inner *Preferential Routes* function as continuities of the regional system (Figure 6 – B1.1). NAIN & NACH inner centralities distribution are quite similar in configuration (Figure 6 – A2.1 & B2.1) and, due to compactness, have the highest correlation of sites to road-circulation networks (100%).

1:30.000

B1 B2

Regional contiguity analyses (Figures 7, 8 & 9) further investigate how different kinds of centralities can establish spatial proximity relations (linkages) amid the selected PMAR industrial complexes. These assessments complement previous-made comparisons between inner-complex centralities structures, and regional road-circulation network centrality structure.

Proposed analyses drawn inspiration on the Space Syntax' metric radius analysis (TURNER, 2008; HILLIER et.al, 2010), as to accomplish them, multiple spheres of influence (*buffers*), with 4km radius (equivalent to R4000), were constructed from selected road-segments, which represent the centrality cores – in this case, the *preferential routes* determined by NACH 20% measure - of each individual complex. From these spheres of influence, a portion of the PMAR segment map was sectioned, and the resulting restricted graph was further modelled using regular Angular Analysis (Rn). Through this method, it was possible to assess the immediate reach of the structural centrality axes of *Integration* (NAIN), depicting overall regional accessibility among industrial complexes, and depict *preferential routes* (NACH), that constitute the linkages through those complexes.

Figure 7 – Contiguity Analysis: PMAR's inner-complexes Normalized Angular *Choice* (NACH) centralities structures (A) and regional sphere of influence buffers (4km) spatialization.

(INSERT FIGURE 7)

NAIN analyses (Figure 8) reveals that only three of five industrial complexes display wide-ranging contiguity relations when *Integration* (*closeness centrality*) is considered. To-movement potentials concentrate on the national highway (BR-290), that function as the main structuring axis amid the three referred complexes, extending from the *Development Corridor* fringes towards *Gravataí ID*.

Figure 8 – PMAR's industrial complexes contiguity analyses for Normalized Angular Integration (NAIN) (A); and for Restricted Normalized Angular Integration (NAIN 20%) (B) encompassed by the regional sphere of influence buffers (4km).

(INSERT FIGURE 8)

Following this main axis, regional centralities split throughout two secondary axes, formed by State highways (Figure 8 – B): RS-040, and its urban continuities, extending form *Porto Alegre*, towards *Cachoeirinha* and *Gravataí*; and RS-118. In conjunction with BR-290, these axes constitute two *ring-roads*: at west, in *Porto Alegre*, encircling the *Development Corridor*, formed by the RS-040 (urban continuities) and the BR-290; and at east, extending through *Cachoeirinha* and *Gravataí* urban areas, being formed by the encounter of RS-040 (north) and BR-290 (south) with the RS-118, near *Gravataí ID*. Even though indirectly connected through secondary avenues to the *ring-road* highways, both *Cachoeirinha* and *Gravataí ID*'s take part in the *Integration Core*, thus, are contiguous. Although the *Resting Industrial Park* is entirely segregated from the main centrality structure, an attribute already evident on regional analysis (Figure 1 – A2), the non-contiguity of *Alvorada-Viamão ID* is, on the other hand surprising. Although highly accessible from a regional standpoint, industrial complex sphere of influence reveals its marginal position in relation to its metropolitan area counterparts. A relative *segregation* can be observed *since* the centrality core barely reaches this complex' fringes, undermining the potential for an effective contiguity within the internal core.

Figure 9 – PMAR's industrial complexes contiguity analyses for Normalized Angular *Choice* (NACH) (A); and for Restricted Normalized Angular *Choice* (NACH 20%) (B) within the regional sphere of influence buffers (4km).

(INSERT FIGURE 9)

NACH analyses (Figure 9) depict that through-movement potentials possess a wider degree of spatial distribution when compared to NAIN (Figure 8), as *betweenness centralities* (*Choice*) structures the contiguity relations amid four of five selected industrial complexes. *Preferential routes* are spread throughout the same main axes, composed by the highways BR-290, RS-040 & RS-118, displayed as being part of the *Integration Core* (Figure 8 – B), with the significant difference that they reach the inner-complex areas, overlapping, to a certain degree the local *preferential routes*, something which occurs, as well, when regional *preferential routes* structures are considered[18]. Once more, the *Restinga Industrial Park* is non-contiguous, although regionally connected regarding NACH, as depicted by Figure 2 – B2. Furthermore, the BR-290 and the RS-118 structures appear to function as regional road-circulation network *weak ties* (GRANOVETTER, 1983), as neither of them have a great number of connections on itself, nonetheless, serve as bridges, connecting groups of highly interconnected segments (*strong ties clusters*)[19], thus having an elevated NACH value.

[18] It is opportune to remark that the regional modelling for NACH (Figure 2 – B1 & B2) have a very high "visual similitude" degree when compared to the sphere of influence restricted modelling for NACH (Figure 9 – A & B).
[19] As suggested by the initial assessment about *Porto Alegre's* metropolitan region morphology.

This demonstrates that *Choice*, while less regionally correlated with industrial sites placement, has a more significant role than integration in establishing the connections amid the industrial complexes, both at a local and at a regional scale.

CONCLUDING REMARKS

Urban & regional science and economics ought to ponder about current and forthcoming industrial complexes spatial organization in regional continua. Since logistics implications tend to increase, as a consequence of "*integrated industries*" requirements, an (in)efficient regional governance regarding the spatial dimension of industrial placement can contribute to a straightforward decay or resilience and long-term sustainable development at regional scale. As discussed, metropolitan and regional road-circulation networks configurations – and the centralities distributiveness that emerges from it – are variables capable of informing aspects regarding industrial placement "optimality", as it considers how territories' infrastructure can promote or hinder clustering and interactions amid firms, important factors for their production chains efficiency. In this aspect proposed analyses can serve as base for public policies considering different territorial framings to be enacted, enacting possibilities for territorial development.

Challenges remain, however, in precising the so-called "optimal locations" in regional continua, since current methodologies have problems in handling the analysis of extensive territorial networks, as well, in considering the multitude of factors that can have effects on industrial complexes' placement logics. In the same way, trans-local governance remains as an issue in order to meet development goals at different institutional levels. This paper, in this sense, is a contribution, with objective of uncovering some spatial factors that can inform aspects supporting the identification of these spatial networks "optimalities", by apposing different approaches.

Qualitative approaches using Space Syntax methodology evidenced that road-circulation networks properties, such as centralities hierarchies' differences, can inform structural aspects of regional movement potentials, as well the systems' *preferential routes*, depicting interconnection among areas where industrial complexes are imbedded. It was revealed that being located on metropolitan regions' transitional areas, where *Integration* decreases towards *segregation* levels, in fact, does not outright characterize a hinder to industrial placement, if there are present proper connections between the industrial complexes and Regional *Core* centralities segments of the network. Linkages through *preferential routes* can mitigate spatial *segregation* by structuring contiguities at regional scale. However, it is noted that the absence of *accessibility* and a lower number of connections is one factor that can lead to limited territorial occupation, as being *segregated* will detach the area from the main centrality structures, effectively isolating it from other industrial complexes, rendering possible interactions costly and inefficient. This is verified, as well, for inner-complex road-circulation networks, as the linear and "enclaved" morphology can isolate and limit local interactions amid firms.

Quantitative geostatistical approaches confirmed that both *closeness* and *betweenness* centralities are relevant to industrial activities placement at regional scale, with correlations surpassing established *Pareto* threshold of significance (80%). At local scale (inner-complex), and regarding the regional contiguity of the industrial areas, however, it has been evidenced that *betweenness* centralities have greater importance, as they engender linkages between local and regional road-circulation networks, also presenting overall higher correlations with industrial sites placement. Agglomeration, on the other hand, appears to be more related to the industrial complexes' inner morphology, than just to the centralities' hierarchies since, as indicated by the KDE analyses, the complexes possessing greater centralities distribution, have a higher degree of clustering.

Overall results, therefore, indicate that there are significant relationships between "optimal" positioning of industrial complexes and regional continua centralities' structures. Henceforth, regional morphology should be onwards regarded on pair with most often approached economic dimension in Urban & Regional planning strategies focusing industrial sustainable development and resilience, as well, consider the empirical, practical and conceptual dimensions of network analyses in designing policies and governance at metropolitan scale.

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Figure 1 – PMAR's configurational analyses for Normalised Angular Integration (NAIN) (A1); Restricted Normalised Angular Integration (NAIN 20%) (A2) and geostatistical correlations among regional circulation network and industrial complexes KDE values spatialization.

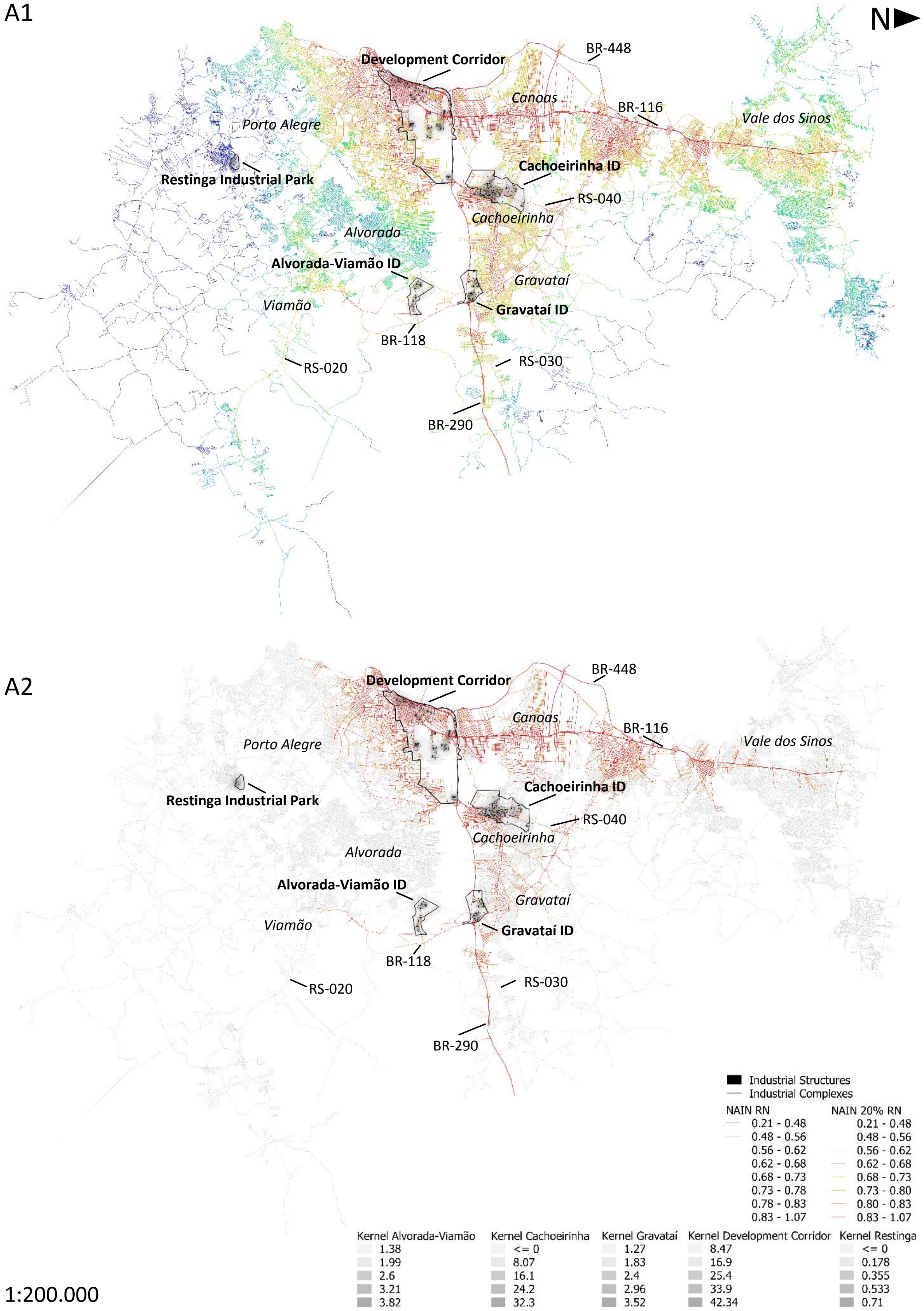


Figure 2 – PMAR's configurational analyses for Normalised Angular *Choice* (NACH) (B1); Restricted Normalised Angular *Choice* (NACH 20%) (B2) and geostatistical correlations between regional circulation network and industrial complexes KDE spatialized values

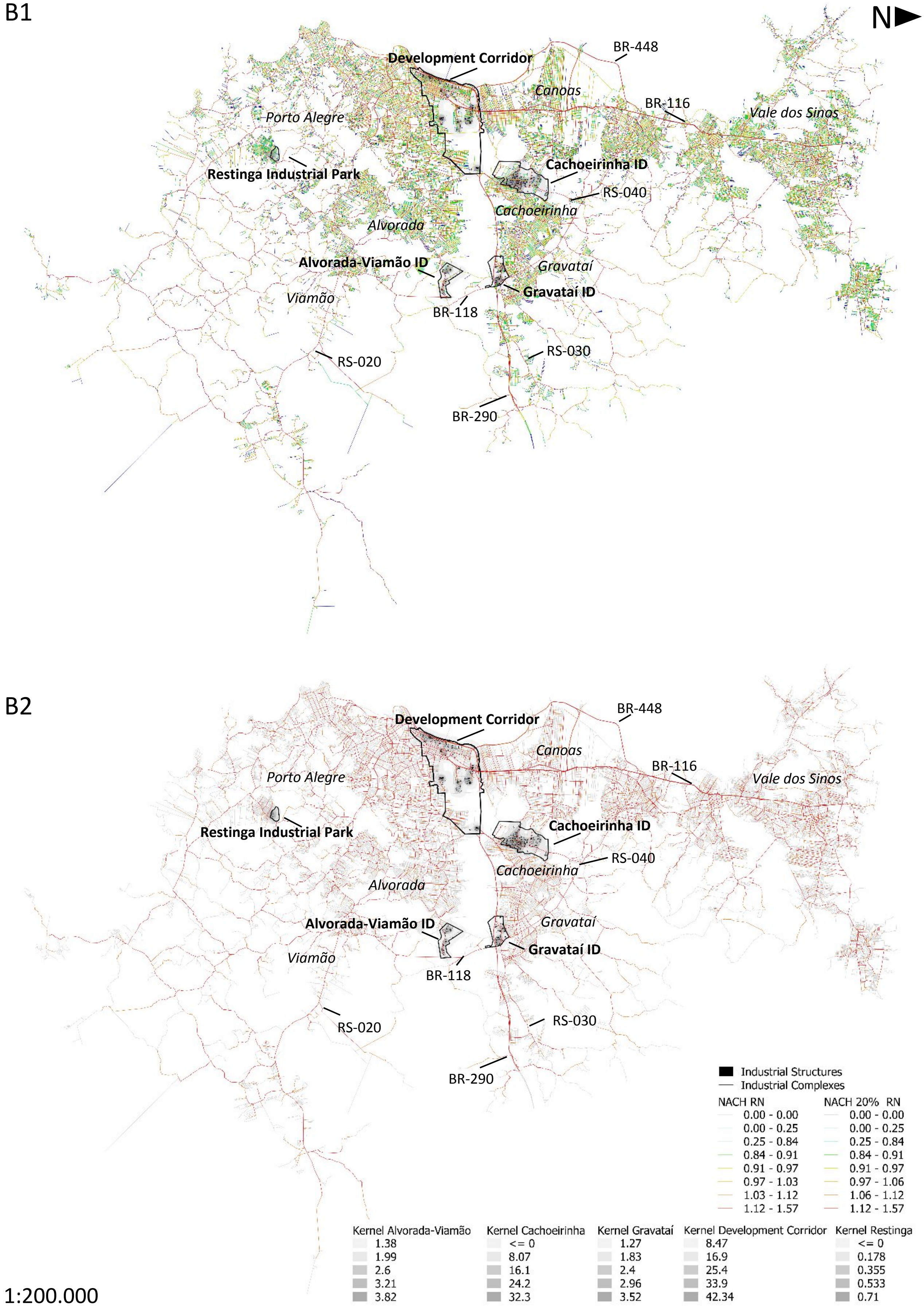


Figure 3 – Configurational analyses for Normalised Angular Integration & *Choice* (NAIN & NACH)); Restricted Normalised Angular Integration & *Choice* (NAIN 20% & NACH 20%); comparing PMAR's regional (A1 & B1) and *Alvorada-Viamão* ID (A2 & B2) inner-complex road-networks centralities distribution; and KDE values spatialization.

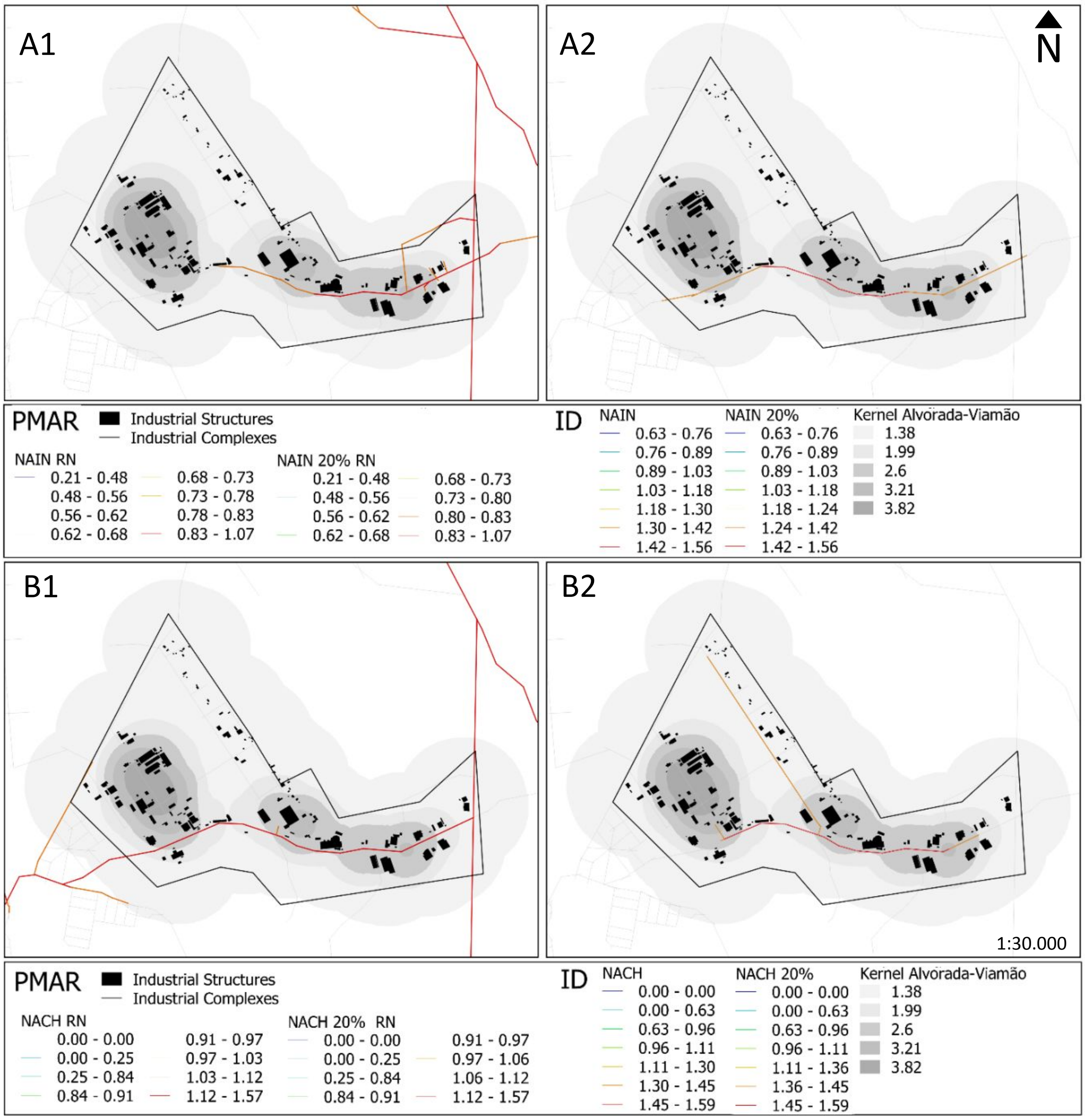
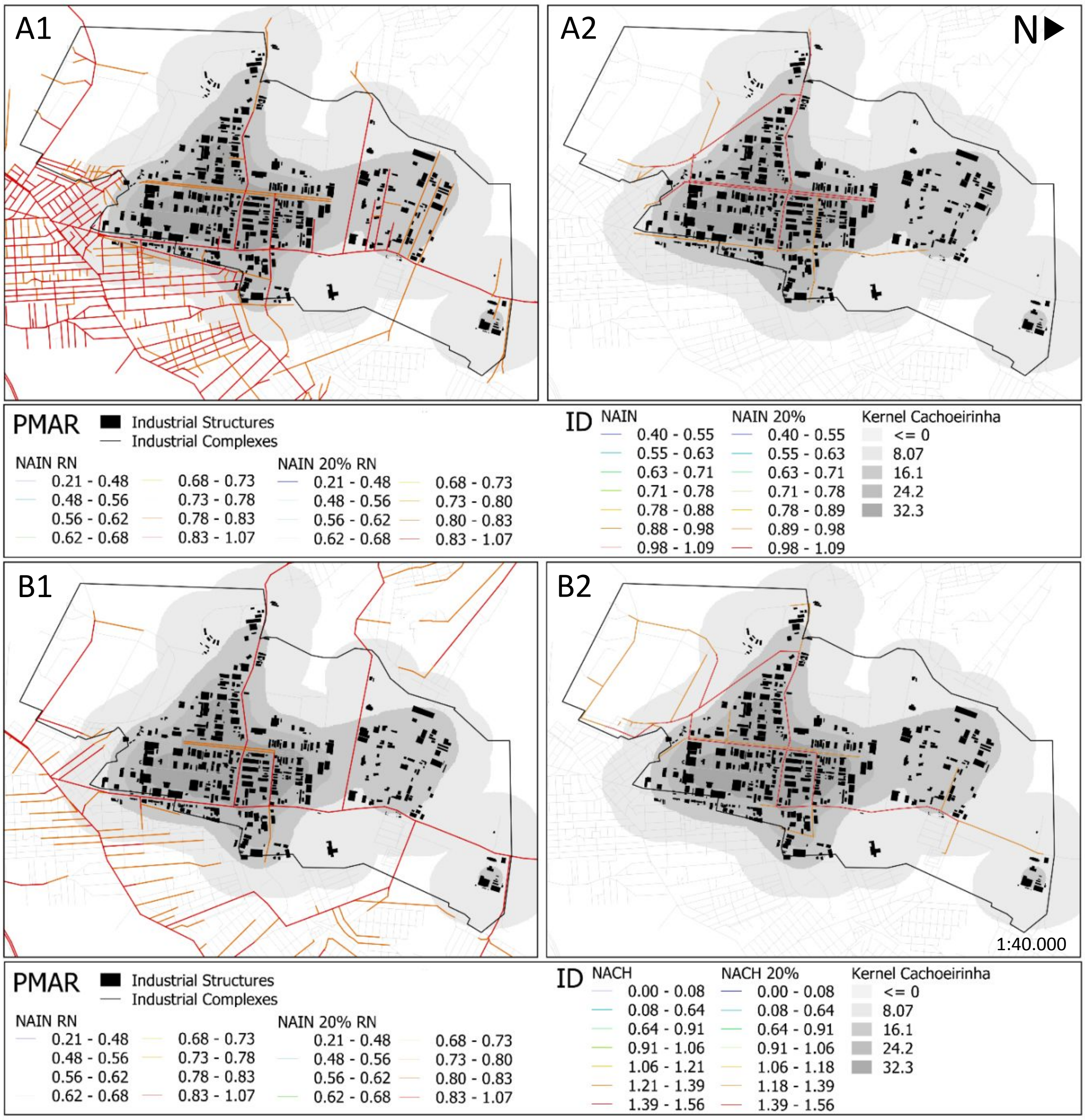


Figure 4 – Configurational analyses for Normalised Angular Integration & *Choice* (NAIN & NACH)); Restricted Normalised Angular Integration & *Choice* (NAIN 20% & NACH 20%); comparing PMAR's regional (A1 & B1) and *Cachoeirinha ID* (A2 & B2) inner-complex road-networks centralities distribution; and KDE values spatialization.



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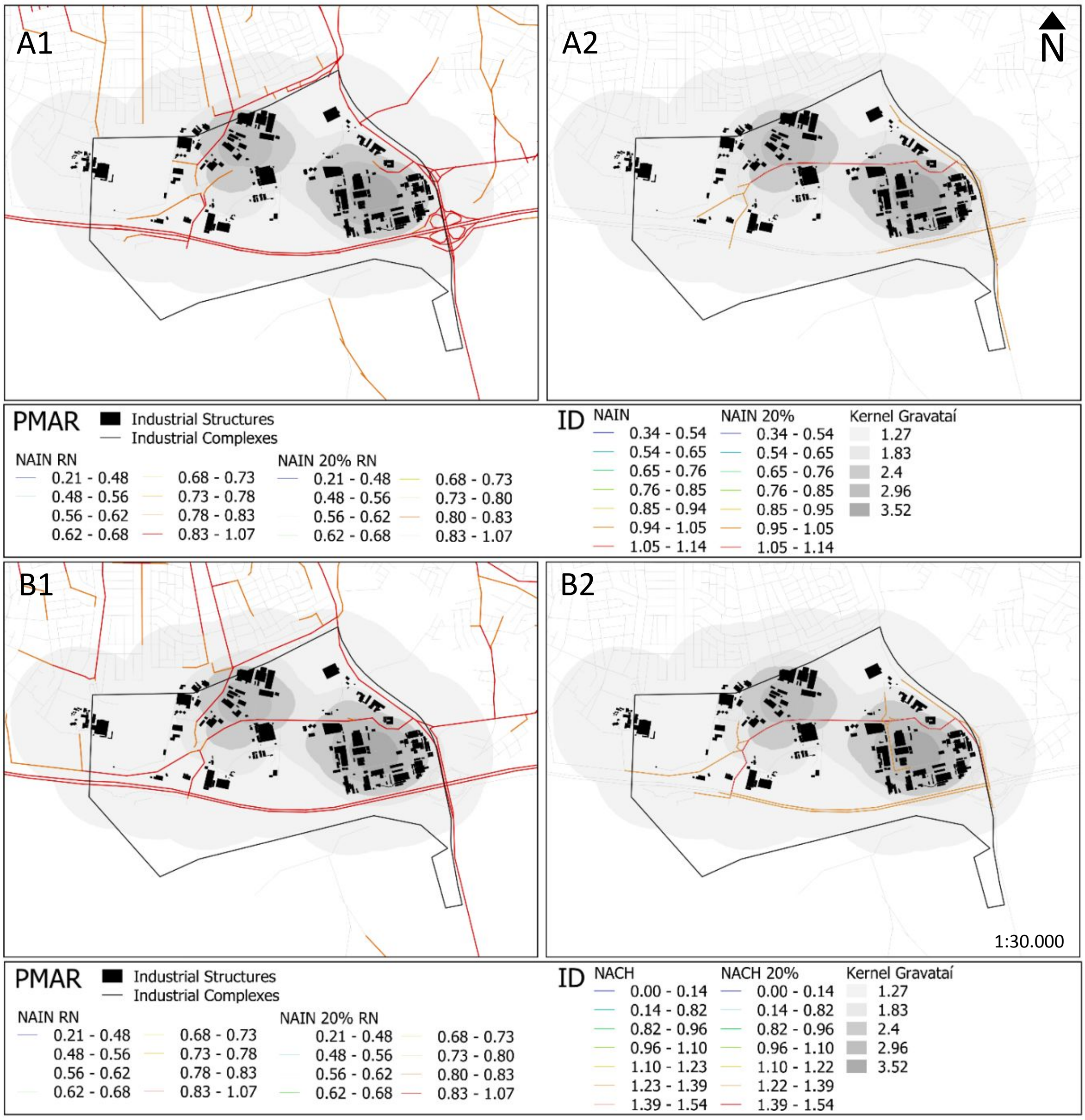

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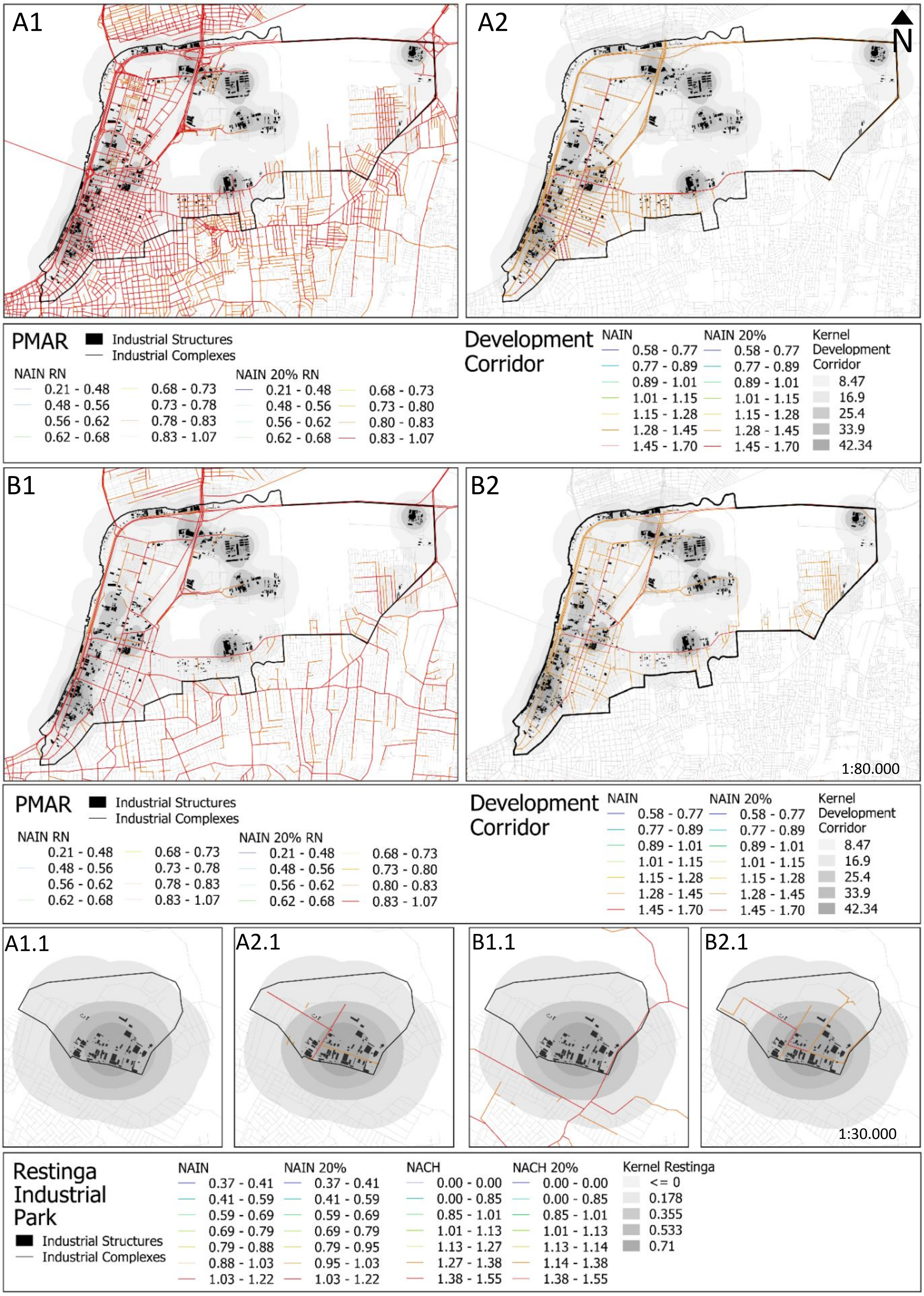

Figure 7 – Contiguity Analysis: PMAR's inner-complexes Normalized Angular *Choice* (NACH) centralities structures (A) and regional sphere of influence buffers (4km) spatialization.

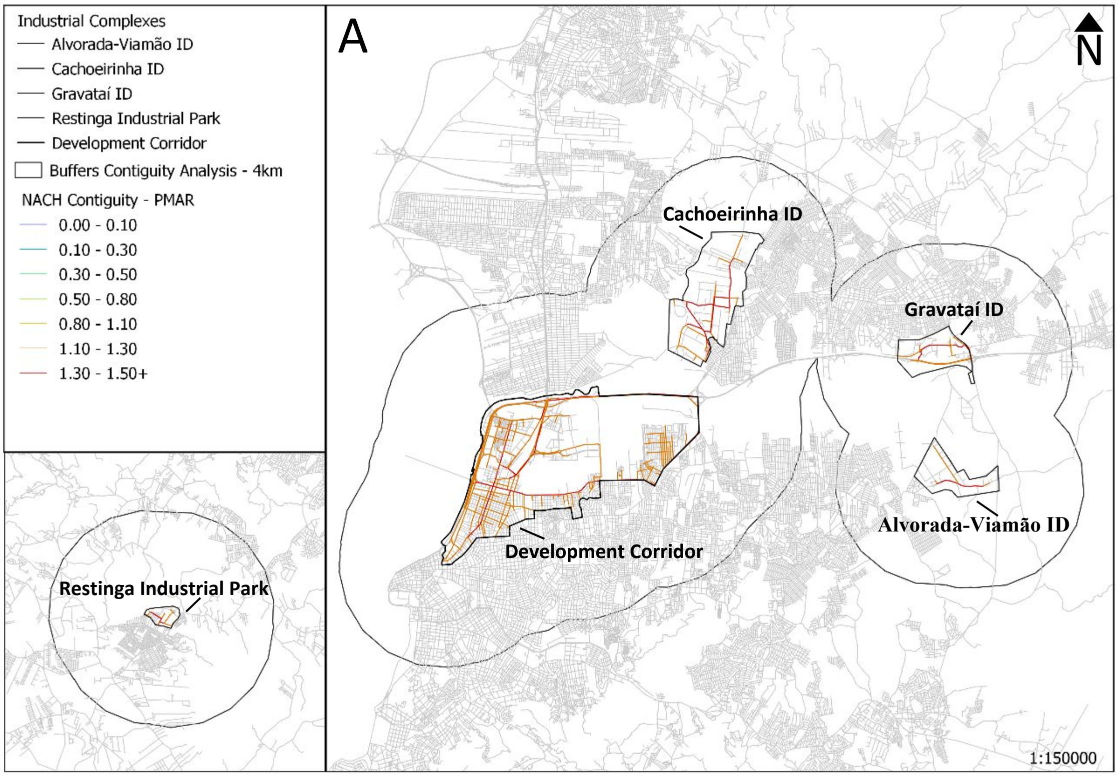

Figure 8 – PMAR's industrial complexes contiguity analyses for Normalized Angular Integration (NAIN) (A); and for Restricted Normalized Angular Integration (NAIN 20%) (B) encompassed by the regional sphere of influence buffers (4km).

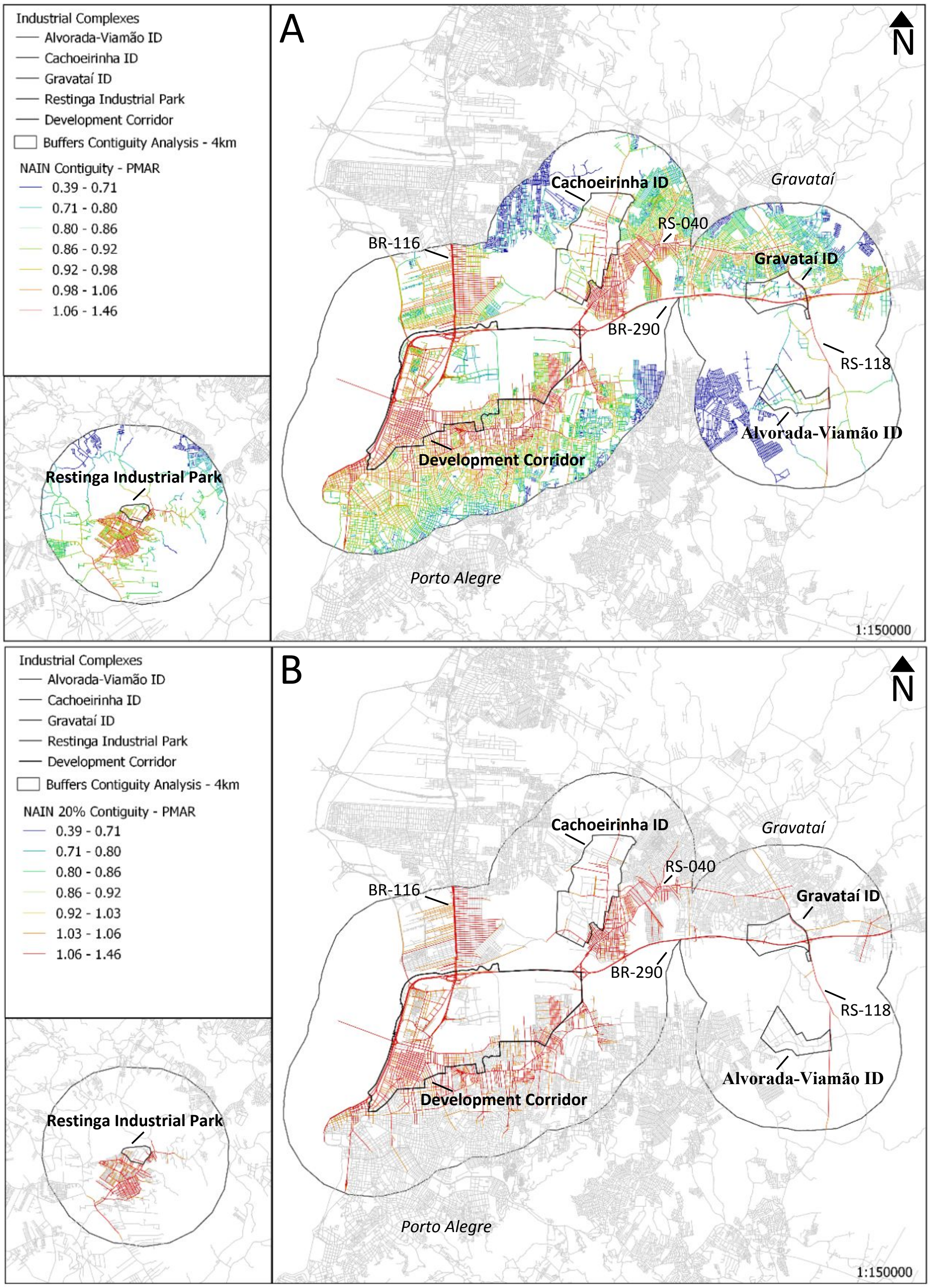

Figure 9 – PMAR's industrial complexes contiguity analyses for Normalized Angular *Choice* (NACH) (A); and for Restricted Normalized Angular *Choice* (NACH 20%) (B) within the regional sphere of influence buffers (4km).

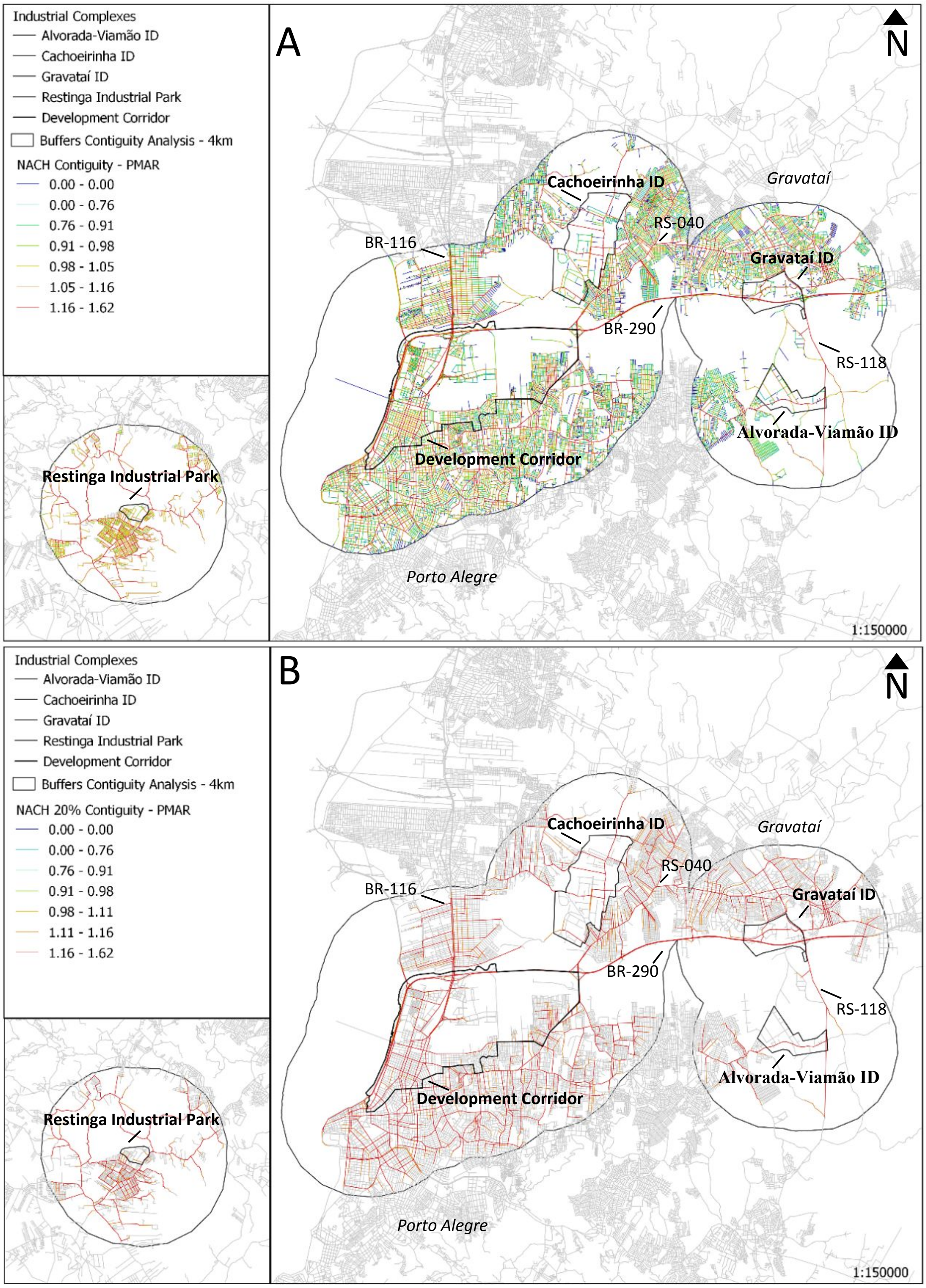

Table 1 – PMAR's road-circulation network configurational attributes, and attributes for Normalised Angular Integration (NAIN) (Figure 1 – A1. & A2.) & Normalised Angular Choice (NACH) (Figure 2 – B1. & B2.).

Map No.	Configurational Attributes	Values – Porto Alegre Metropolitan Region (PMAR)
	Total Metropolitan Area (km²)	4,203.42
	Segment Number (Total)	147,232.00
	Total Depth (Non-Norm.)	7,548,545.00
	Mean Depth (Non-Norm.)	2,541,696.00
	Configurational Analyses – Integration	
A1.	NAIN (Max.)	1.067
A1.	NAIN (Mean.)	0.666
A2.	NAIN 20% (Percentile Value)	0.798
	Configurational Analyses – Choice	
B1.	NACH (Max.)	1.566
B1.	NACH (Mean.)	0.720
B2.	NACH 20% (Percentile Value)	1.059

Table 2 – PMAR's correlational analyses between road-circulation network centralities and industrial sites placement for Normalised Angular Integration (NAIN) (Figure 1 – A2.) and Normalised Angular Choice (NACH) (Figure 2 – B2.)

Map No.	Industrial Complexes – PMAR	Number of Sites	Correlation - Sites x Network	(%)
	Industrial Sites Total	2782	-	-
	Industrial Sites within 500m Radius			
	Integration – Closeness Centrality			
A2.	NAIN 20%	2582	0.928	92.8
	Choice – Betweenness Centrality			
B2.	NACH 20%	2540	0.913	91.3

Table 3 – PMAR's Industrial Complexes datasets, configurational analyses and correlational analyses between road-circulation network centralities and industrial sites placement for Normalised Angular Integration (NAIN) (A1. & A2.) and Normalised Angular Choice (NACH) (B1. & B2.)

Industrial Complexes Datasets - Configurational Attributes	Alvorada-Viamão ID	Cachoeirinha ID	Gravataí ID	Restinga Industrial Park	Development Corridor
	Figure 3	Figure 4	Figure 5	Figure 6	Figure 6
Total Industrial Sites	157	389	208	89	1,939
Total Area (km²)	3.50	10.98	3.73	0.80	36.49
Total Built Area (m²)	191,388.75	1,042,870.50	329,296.02	38,653.30	1,232,128.66
TBA/TA (%)	5.46	9.49	8.82	4.83	3.37
KDE (Highest Value - 500m)	3.22	29.60	2.90	0.66	31.58
Integration – Closeness Centrality					
A1. NAIN (Max)	1.556	1.089	1.139	1.217	1.703
A1. NAIN (Mean)	1.029	0.749	0.810	0.834	1.078
A2. NAIN 20% (Percentile)	1.236	0.891	0.952	0.946	1.285
Correlation (%)	59.2	92.8	85.6	100	84.5
Number of Sites	93	361	178	89	1,639
Choice – Betweenness Centrality					
B1. NACH (Max)	1.592	1.560	1.536	1.552	1.633
B1. NACH (Mean)	0.659	0.606	0.630	0.643	0.700
B2. NACH 20% (Percentile)	1.360	1.180	1.218	1.143	1.181
Correlation (%)	82.8	99.0	88.5	100	99.8
Number of Sites	130	385	184	89	1,936