Planning Sustainable Urban-Industrial Configurations

The Influence of Industrial Complexes Morphology on Industrial Placement

by Diego Altafini, Andrea da Costa Braga & Valerio Cutini
University of Pisa, Federal University of Rio Grande do Sul, University of Pisa

Keywords: Urban Planning, Industrial Morphology, Industrial Placement, Centrality, Space Syntax.

Abstract: Forthcoming shifts towards network-integrated production models, such as Industry 4.0, may change industrial organisation and production. As these transformations advance, demands for methods allowing to foresee their effects on urban spaces increase. Urban road-network configurational properties′ analyses can depict changes in industrial placement tendencies under this new paradigm, enabling planners to design, evaluate industrial complexes' morphology and develop strategies that contribute to urban productive areas resilience and long-term sustainability. This study undertakes methods to perform these analyses using as empirical cases three Brazilian industrial complexes located in Porto Alegre's Metropolitan Region (PMAR) municipalities of Alvorada, Cachoeirinha Gravataí and Viamão. Hypothesis is that movement potentials and flow probabilities informed by urban road-network centralities' hierarchies have direct correlation to industrial placement patterns; therefore, higher movement distribution can improve endogenous firm-to-firm relations, favouring inner-complexes' clustering effects. Premises are verified through geo-statistical correlations between road-circulation networks centralities, constructed through Space Syntax Angular Analysis methodology, and industrial structures placement and agglomeration. Results demonstrate significant statistical correlations among structures and road-circulation centralities, indicating greater industrial clustering and occupation in complexes with more distributed movement potentials. Hence, complexes' morphology can inform industrial placement tendencies, and their analyses should be employed as planning tools for sustainable productive environments.

1. Introduction

Complexity of industrial activities' spatial organisation has increased in past decades, outcome of globalisation processes, the "Third Industrial Revolution" and subsequent flexibilization of production models in capitalist economies. Once integrated into urban centres, these activities were relocated from cities' cores and moved to planned industrial complexes scattered in metropolitan areas, following an urban deindustrialisation dynamic described by Rocassalva & Pluviano (2012) for Europe, likewise occurring in developing countries, such as Brazil, as stated by Alonso (2001), and further discussed, regarding spatial implications, by Altafini (2018).

As far as these deindustrialization effects from the "Third Industrial Revolution" still linger,

DOI 10.36158/978889295357439
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Hoffman & Rüsch (2017) mention that the rapid post-revolution technological progress in "*smart manufacturing*" and "*integrated industries*" may, in the near future, lead to another industrial paradigm shift, idea endorsed by Germany during early 2010's, following the *Industrie 4.0* (*Industry 4.0*) initiative. Its premises, as projected by Kagermann, Wahlster & Helbig (2013), will be based on flexible mass-production, automation, real-time coordination, optimisation of value chains, and reduction of process complexity, leading to the emergence of new production models. Hoffman & Rüsch (2017) advocate that major implications of this forthcoming shift will befall on logistics, as real-time tracking of material flows, and improved transport handling, both are crucial for providing envisioned *Industry 4.0* production systems required input factors at right steps of manufacturing processes and with consistent quality. In this sense, industrial complexes territorial planning should be able to cope with demands of transportation efficiency, as well integrating its conceived inner grid morphology to existent road-circulation networks of urban and metropolitan environments. Though now a rather unexplored topic in *Industry 4.0* studies, these subjects have potential to be a crucial part of future Industrial Economics and Urban & Regional Planning, since time-saving and synchronicity ought to be main issues in forthcoming production models, requiring specific sets of analyses, evaluating complexes' inner-morphologies and relating physical and virtual networks to optimal industrial placement and movement efficiency.

Henceforth, paper assesses methods to investigate if road-circulation networks configurational properties, such as centralities hierarchies, can inform trends about placement, clustering and organisation of industrial activities in urban spaces, and how the inner-complex morphology may favour or disfavour industrial relations and agglomeration processes. Space Syntax (Hillier, 2007) is a theory whose methods can fulfil these analyses, capable to abstract and represent morphological features of urban spaces, depicting configurational properties of road-circulation networks in multiple scales. Through its models, associated with geo-statistical analyses, it is possible to unveil interaction potentials amid built structures (economic activities) and circulation structures (movement network and centralities) also devising statistical correlations to support conclusions about urban design efficiency. Empirical analyses encompass three Brazilian Industrial Complexes located in *Porto Alegre's Metropolitan Region* (PMAR) of *Rio Grande do Sul State* municipalities of *Alvorada, Cachoeirinha, Gravataí, and Viamão.* Hypothesis is that movement potentials and flow probabilities informed by road-circulation network centralities' hierarchies have direct correlation to industrial placement patterns, and that a higher movement distribution can favour inner-complexes' clustering effects, improving important endogenous firm-to-firm relations, which may to lead to competitive and innovative environments, contemporaneous and forthcoming industrial models' quintessence. Premise is verified through geo-statistical correlations between road-circulation networks′ centralities, modelled through Space Syntax methodology, and industrial structures (sites) placement. These analyses empower urban planners and decision makers – both public and private – to better design and evaluate their proposals regarding industrial complexes construction and firm placement, imbedding them to road-network centrality structures, contributing to lower transportation costs, and improving development and sustainability of industries on urban environments, in adequacy to physical-virtual network integrated realities of future industrial activities.

2. Methodology

To evaluate inner-complexes morphology, and how road-circulation networks and its centralities patterns relate to industrial placement and agglomeration, two datasets were apposed on GIS

(Qgis, 2019): the *Porto Alegre Metropolitan Region* (PMAR)[1] industrial complexes, comprehending its area and industrial built structures; and their inner-complexes' road-network, represented by road-centre line maps, built as graphs and modelled through Depthmap X 0.5. (2015).

PMAR industrial complexes data comprises three expanses which have standardized rules for land-use. The complexes' of *Alvorada-Viamão*, *Cachoeirinha* and *Gravataí* are state planned industrial districts (ID's), dedicated for exclusive industrial placement; Spatial data regarding the ID's perimeters was acquired from *Rio Grande do Sul* state government (2017). Aforementioned areas were enacted as policies during the mid-1970's which intended to disperse industrial activities towards Rio Grande do Sul capital, *Porto Alegre*, boundaries, developing other municipalities of the recently created metropolitan territory (1974). Soares *et al.* (2015), state that the policies' goals were to minimize PMAR's territory uneven development patterns, as the placement of manufacturing activities was thought as a solution to increase spatial occupation, population, employment and income in the capital fringes. Successful in some degree, these policies resulted in a substantial growth both in cities' population and industrial activities participation in the regional economy during the 1980's & 1990's. However, the authors (*ibid*, 2015) point out that this trend has shifted during the late 2000's, as the industry general rate of participation on PMAR's economy has dropped, especially from 2008 onwards, indicating possible resilience problems concerning industrial activities, an aftershock of 2007-2008 global financial crisis.

Data regarding industrial sites' locations encompasses all industrial dedicated structures within selected complexes. Obtained through Open-Street-Map (2016a, 2016b), the spatial database was crosschecked through empirical data collected *in situ*, between March and October (2017), for functioning industrial structures and mapped in a single polygonal shapefile database. Spatial data contains built area information for each structure, employed as weighting variables in geo-statistical analyses. Analyses also employs Kernel Density Estimation (KDE) (Bailey & Gatrell, 1995), which allows to measure industrial agglomerations spatial density, to establish the sphere of influence[2] (*buffer*) for each industrial site, and to estimate proximity correlations between industrial structures and the road-circulation network different centrality measures.

Datasets for configurational analyses are based on a set of PMAR's axial maps organised by Zampieri (2017) and updated by Altafini (2018) to incorporate industrial complexes most recent urban expansions. Using these datasets and complexes' perimeter spatial data as guidelines, the inner-complexes' road-network was clipped from the regional map and reconstructed using, instead of axial representation, road-centre line representations, better suited for Space Syntax angular analysis (Turner, 2001, 2005). Such adaptation was made because the angular weighted topological steps provide a finer portrayal of *choice* (*betweenness* centrality), also refining slight differences in movement potentials for orthogonal and regular grids (Turner, 2007), morphological traits which are deemed to be prevalent in industrial zones.

Configurational analyses draw from Space Syntax theories, methods and tools, since they provide a group of measures (Normalised Angular Integration and *Choice*)[3], both depicting dif-

1. *Porto Alegre's Metropolitan Region* located at *Rio Grande do Sul* State is currently (2019) comprises 34 municipalities. Road-network analysis use only 14 municipalities which represent the first iteration of PMAR (1974), chosen due to higher conurbation indexes (Rigatti, 2009), that frame a cohesive road-network. These municipalities concentrate most of regional industrial production. Of these 14 municipalities, only four have continuous territorialized industrial areas, and thus were chosen as empirical cases for the research: *Alvorada*, *Cachoeirinha*, *Gravataí*, and *Viamão*.

2. The influence radius (Kernel Buffer Radius) is delimited in 500m, stipulated as a maximum travel distance value from industrial firms' structures to the main public roads.

3. Angular integration and *choice* normalization processes were developed by Hillier, Turner & Yang (2012) to allow more accurate comparisons between different sized urban networks, thus, with different depths. It is also important because it betters the depictions of *choice* routes distribution, as it considers for calculus systems' total depth.

ferent urban centrality hierarchies', and evaluating distinct properties of movement potentials in the road-network, at local scale (with limited step or radius) and at global (whole network) scale. Normalised Angular Integration (NAIN) denote *closeness* centralities in an urban system. It establishes the accessibility of a single segment relative to all other road-network segments (to-movement). Normalised Angular *Choice* (NACH) reveals *betweenness* centralities in an urban system. It describes the most crisscrossed (preferential) routes in the road-network from all origin-destination pairs (through-movement). It is tested if centralities hierarchies represented by high NAIN & NACH values (high movement and flow potentials) are correlated with industrial placement and if that these centralities' hierarchies distribution, influenced by complexes' inner-morphology, favours agglomeration, also facilitating labour and transport relations among firms in an industrial complex. Hence, urban centralities can exert attraction towards economic activities, in a spatial process hinted by Hillier (2000) and explored by Cutini (2001), and later by Roccasalva & Pluviano (2012); and these centralities distribution will result in more efficient inner-complex connections, improving closeness amid firms, a factor that, as stated by Porter (1990, 1998) may lead to a better environment for competitiveness, innovation, development and resilience of industrial agglomerations.

On this premise, a group of configurational analyses is apposed to industrial spatial data, in order to assess if any correlations between high movement potentials denoted through NAIN & NACH and industrial placement exist. The statistical significance threshold is determined through the Pareto Distribution Principle (Pareto, 1971), which states that: to have significant correlations, at least 20% of causes – represented by the 20% highest segment values for angular analysis (centralities) – needs to be responsible for at least 80% of the effects – the placement of industrial structures[4]. Synergy correlations are employed to further investigate relations between industrial agglomeration, centralities and movement distribution on industrial complexes. Synergy is a Space Syntax measure that correlates the global (Rn) and local (R3) measures of integration, thus, assesses movement potentials and its tendencies of distribution within a network. Higher values for Synergy correlation will denote a concentration of movement potentials in a few same groups of segments along the network, thus the centralities will be represented the same segments in both scales. Lower Synergy correlation values will be found on networks that exhibit more distributed movement potentials within the network, with centralities being in different groups of segments within the network[5], indicating that local movement gathering structures are more distributed resulting in a more beneficial condition for industrial activities placement and, above all, for firm-to-firm relations to happen.

3. Analysis

Configurational analyses reveal a dichotomy amongst the selected industrial complexes inner-morphologies, which possess quite opposing road-circulation network configurations and significant structural differences:

4. If the industrial site sphere of influence (500m) intersects with at least one part of segment within the establish centrality threshold value (top 20%) there will be a valid spatial correlation.

5. Synergy correlation interpretations here are counter-intuitive to Hillier (1996) original proposition, in which high synergy values denote the *control* of some segment groups over the whole network (movement potentials concentration). From the social point of view this is desirable as it produces co-presence, since the *to-movement* relations are centred, in both scales, to same groups of segments. This, for industrial activities, mean a hindrance to reach by road transportation other firms, as local *to-movement* structures do not lead to local areas, but to main regional road-circulation networks.

Alvorada-Viamão ID (Figure 1) and *Gravataí ID* (Figure 3) both exhibit linear-based morphologies, differing on linearities number and internal disposition. *Alvorada-Viamão ID* (Figure 1), is constructed over an avenue with direct access to a regional highway (east), forming a long continuous segment group that represents both *centrality core* (Figure 1.2) and *preferential route structure* (Figure 1.4). From this *core-structure* branches of long linear segments give access to where most of industrial sites are placed. It can be noticed that few regular blocks are formed, as roads are often discontinuous; *Gravataí ID* (Figure 2) is built on three linearities, two (north & east) are regional highways continuities that constitute *centrality cores* (Figure 3.2). From roundabouts placed on these *cores*, branches of short road-segments lead to enclosed industrial sites placement areas. It can be observed that these enclosed areas seldom form continuous regular blocks, being characterized as *cul-de-sacs*. Connected to the national highway (south), these regional routes form complex's *preferential route structure* (Figure 3.4). It is important to remark that, although *Gravataí ID preferential routes* inner-morphology seem to constitute a *ring-road*, there is no direct linkage between segments other than the southeast interchange, being the northeast road a bypass, which is extended from a secondary highway service road.

Cachoeirinha ID (Figure 2) differs from the remainder industrial complexes since it possesses an orthogonal-grid inner-morphology, formed by apposition of several different sized regular grids. Although characterized by this regularity, *Cachoeirinha ID* exhibits a clear division constituting two areas with diverse features. Southmost area represents the complex first iteration, concentrating most industrial sites. Constructed over a bifurcation of two urban avenues, this area is crisscrossed by roads forming regular blocks and a central *ring-road*. It can be observed, however, that a few of these roads form *cul-de-sacs*, comparable to those found in *Gravataí ID*. Nevertheless, the emerging enclosed structure is accessible from multiple directions (Figure 2.1). South of central *ring-road* structure locates another *ring-road* encompassing an expanse of undeveloped land, that houses a few numbers of agroindustries unconsidered for this research. The central *ring-road* and regular grids form an overlapping *centrality core* (Figure 2.2) and *preferential route structure* (Figure 2.4), that extends towards northmost emplacements, where recently urbanised sectors of *Cachoeirinha ID* are located. Consisting of small unoccupied groups of blocks (east), and several long linearities (west) that occasionally form blocks with sparse industrial sites occupation, this area is connected to the neighbouring municipality of *Canoas*. Compared to remainder of the complex, this sector possesses a distinct linear-based morphology, with features similar to those depicted on *Alvorada-Viamão ID*.

A first overview regarding road-network centralities distribution is possible when Complexes' Configurational Attributes are analysed (Table 1):

Cachoeirinha ID (Figure 2), even though possesses the highest number of road segments, exhibit the lowest NAIN (Maximum & Mean) values found in selected industrial complexes, an indication that connectivity may have a wider distribution within its road-system. This alludes that there is no single segment that overly concentrate *closeness centrality*, feature that is depicted in Figure 2.2. The opposite logic is observed in Alvorada-*Viamão ID*, which, despite the lowest number of segments, exhibit the highest values for NAIN & NACH (Maximum & Mean) denoting movement and flow concentration tendencies in a single group of long segments, as depicted on spatial iconography (Figure 1.2 & 1.4). *Gravataí ID* (Figure 3), regardless of a linear-based morphology, exhibit values closer to *Cachoeirinha ID*, denoting that simple Configurational Attributes analyses are not enough to unveil all characteristics about centralities distribution, aspect that is better observed through Synergy Correlation Analyses (Figures 1.5; 2.5; 3.5; Table 3).

Correlations amid selected complexes Industrial Sites and NAIN & NACH values reveal strong correlations amongst urban centralities and Industrial Activities Placement (Table 2), with all complexes attaining Paretian Significances (Over 80%) for NACH, and all but one for NAIN:

Alvorada-Viamão ID (Figure 1) is the only industrial complex that does not abide to established significance threshold for NAIN (Figure 1.1), as 59,2% of its industrial sites (93) are located within 500m from a top 20% *centrality core* (Figure 1.2). This result is explained by the urban grid morphology, depicted on Figure 1.2, as urban centralities concentrate on a single long linearity that does not reach the most internal placed industrial sites. The correlation for NACH, however, has statistical significance, with 82,8 % of the industrial sites (130) being placed within established range of a *preferential route* (Figure 1.4). It is noticeable that NACH is mostly concentred in the same linearity as NAIN, and that these segments correspond for majority of complex *to* and *through movement*.

Cachoeirinha ID (Figure 2) possesses the highest correlation between Industrial Sites Placement and NAIN & NACH values. 92,8 % of the industrial sites (361) are located within 500m from a top 20% *centrality core* (Figure 2.1), while 98,9% of the industrial sites (385) are placed at same range threshold for a *preferential route* (Figure 2.4). Industrial sites are concentrated in areas

Table 1. *Selected Industrial Complexes Configurational Attributes.*

Nº	Industrial Complexes	Alvorada-Viamão ID	Cachoeirinha ID	Gravataí ID
-	Number of Road Segments	128	726	509
NAIN				
1.	NAIN (Max.)	1.556	1.089	1.139
1.	NAIN (Mean)	1.029	0.749	0.809
NACH				
3.	NACH (Max.)	1.591	1.559	1.536
3.	NACH (Mean)	0.659	0.606	0.630

Table 2. *Selected Industrial Complexes Total Number of Industrial Sites, Number of Sites within 500m from a road-network segment of NAIN (1.) and NACH (2.) restrictions of 20% (2. & 4.); and Sites Placement Correlation.*

Nº	Industrial Complexes	Alvorada-Viamão ID	Cachoeirinha ID	Gravataí ID
	Industrial Sites Total	157	389	208
NAIN				
2.	Industrial Sites Total (Restriction)	93	361	178
2.	Industrial Sites Placement Correlation	0.592	0.928	0.856
2.	Placement Correlation (%)	59.2	92.8	85.6
NACH				
4.	Industrial Sites Total (Restriction)	130	385	184
4.	Industrial Sites Placement Correlation	0.828	0.989	0.885
4.	Placement Correlation (%)	82.8	98.9	88.5

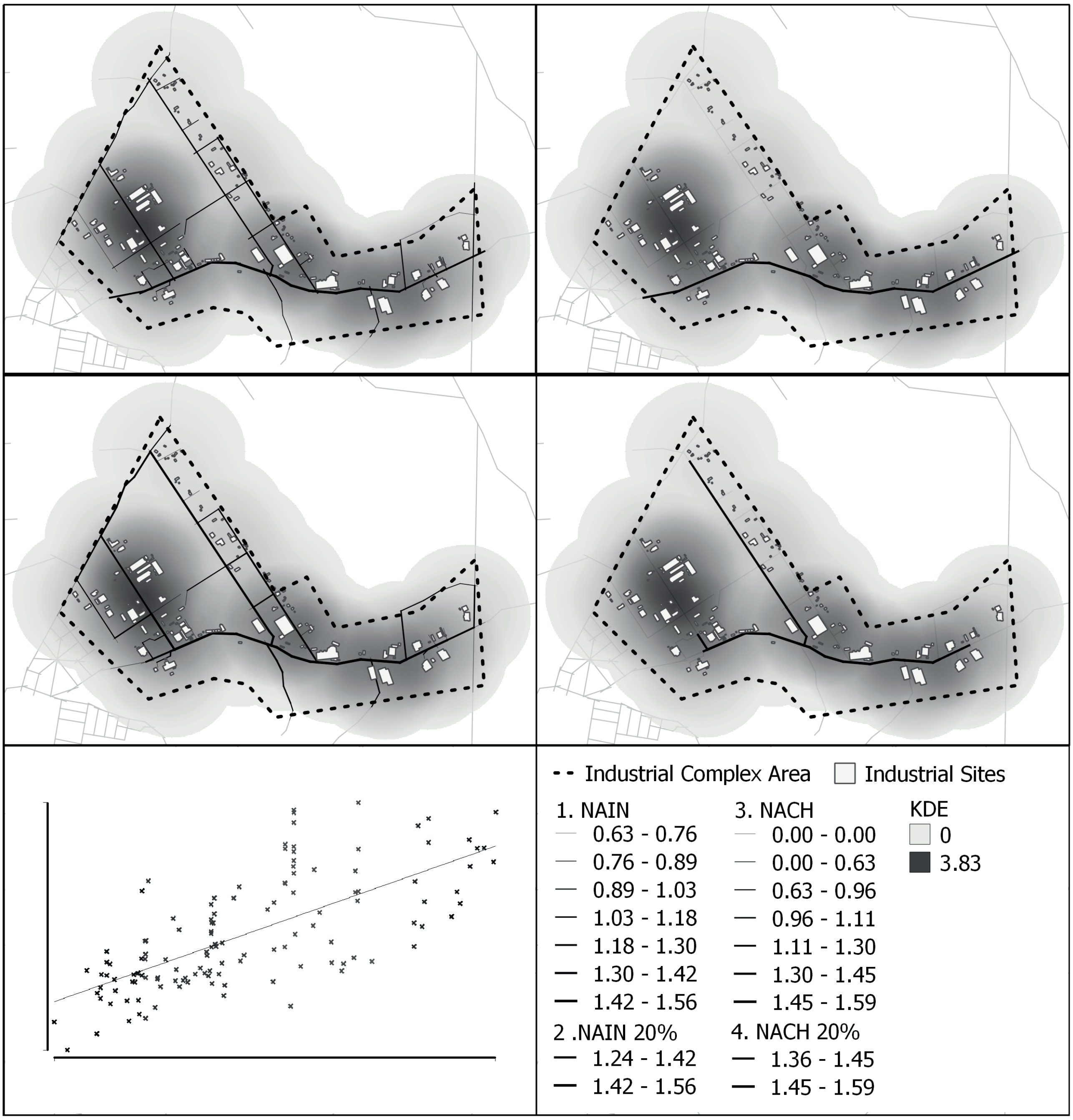

Figure 1. *Alvorada-Viamão ID spatial correlations between Industrial Sites Placement (KDE), and inner-complex road-network centralities represented by NAIN (1.1) and NACH (1.3) restrictions of 20% (1.2 & 1.4); and Synergy Correlation graph between Integration Rn and R3 values (1.5).*

that dispose of more options of *to* and *through movement*, around the two main axes with higher *closeness* and *betweenness* centralities values. It is noticeable that, contrarily of what happens on *Alvorada-Viamão ID*, the regular and *ring*-based morphologies promotes higher connectivity, even to expanses around *cul-de-sacs*, giving access to more areas than branched single linearities. This feature not only can explain the observed higher occupation degree, when compared to other ID's, but also its own internal industrial organisation differences.

Although possessing a linear-based morphology comparable to *Alvorada-Viamão ID*, *Gravataí ID* correlation results differ, unveiling Paretian significances amid industrial placement

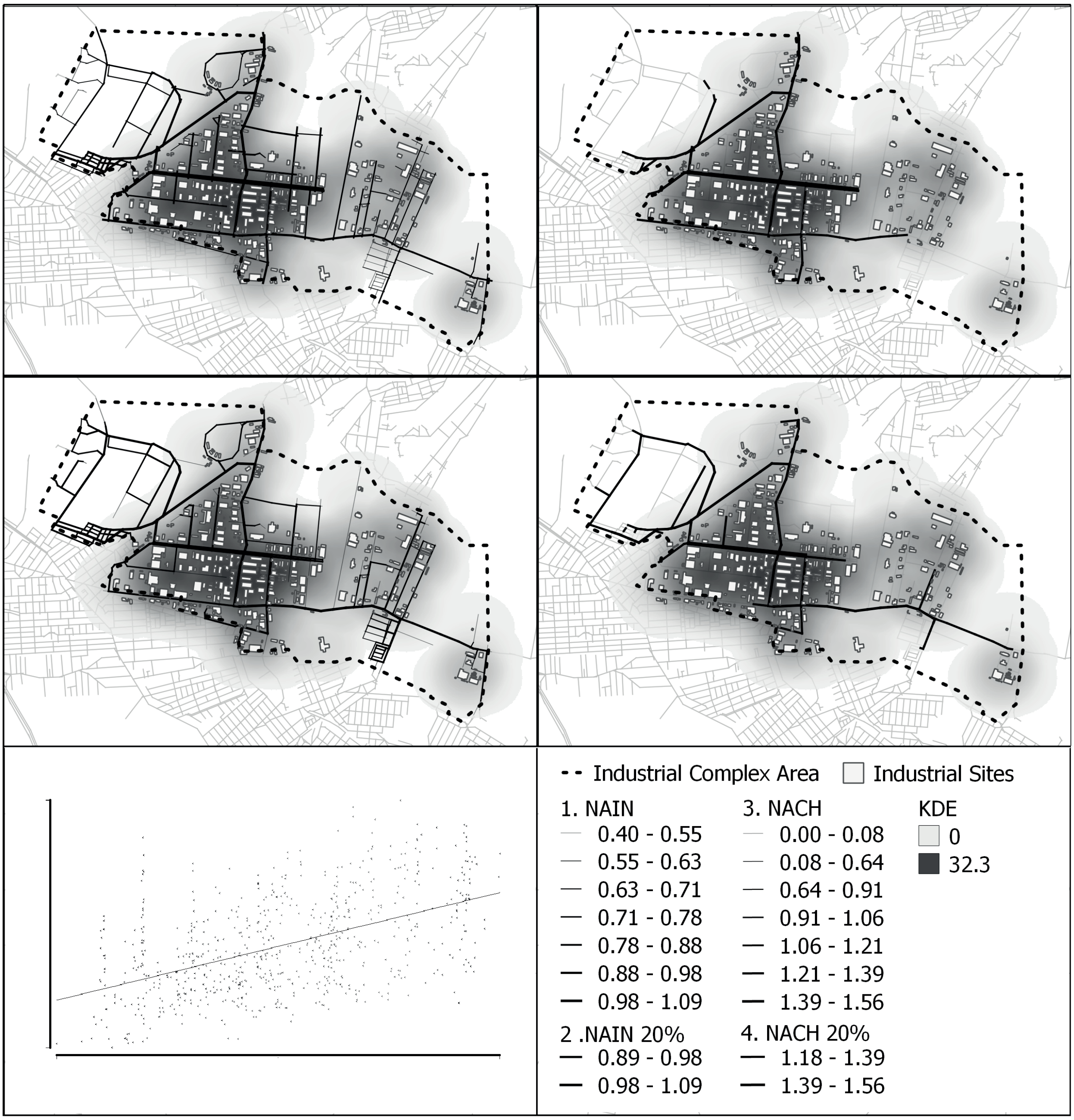

Figure 2. *Cachoeirinha ID spatial correlations between Industrial Sites Placement (KDE), and inner-complex road-network centralities represented by NAIN (2.1) and NACH (2.3) restrictions of 20% (2.2 & 2.4); and Synergy Correlation graph between Integration Rn and R3 values (2.5).*

and road-circulation networks for both NAIN & NACH. 85.6% of its industrial sites (178) are located within at least 500m from a top 20% *centrality core*, while 88.5% of its industrial sites (184) being place at the same range from a 20% *preferential route*. Once again inner-complex morphology explains attained results. Even though *core-structure* segments do not extend to areas where industries are place, these segments short lengths make placement areas closer to the main centralities structures, feature reinforced by the *quasi ring-road*. In terms of logistics, inner-complex transportation needs to move through less depth to access other areas, resulting in a more accessible system.

Comparing Synergy Correlation values (Table 3) for industrial complexes it is observed that *Cachoeirinha ID* (Figure 2.) exhibit far lower values for R^2 than the remainder of selected PMAR complexes. This indicates a low correlation among global (Rn) and local (R3) central-

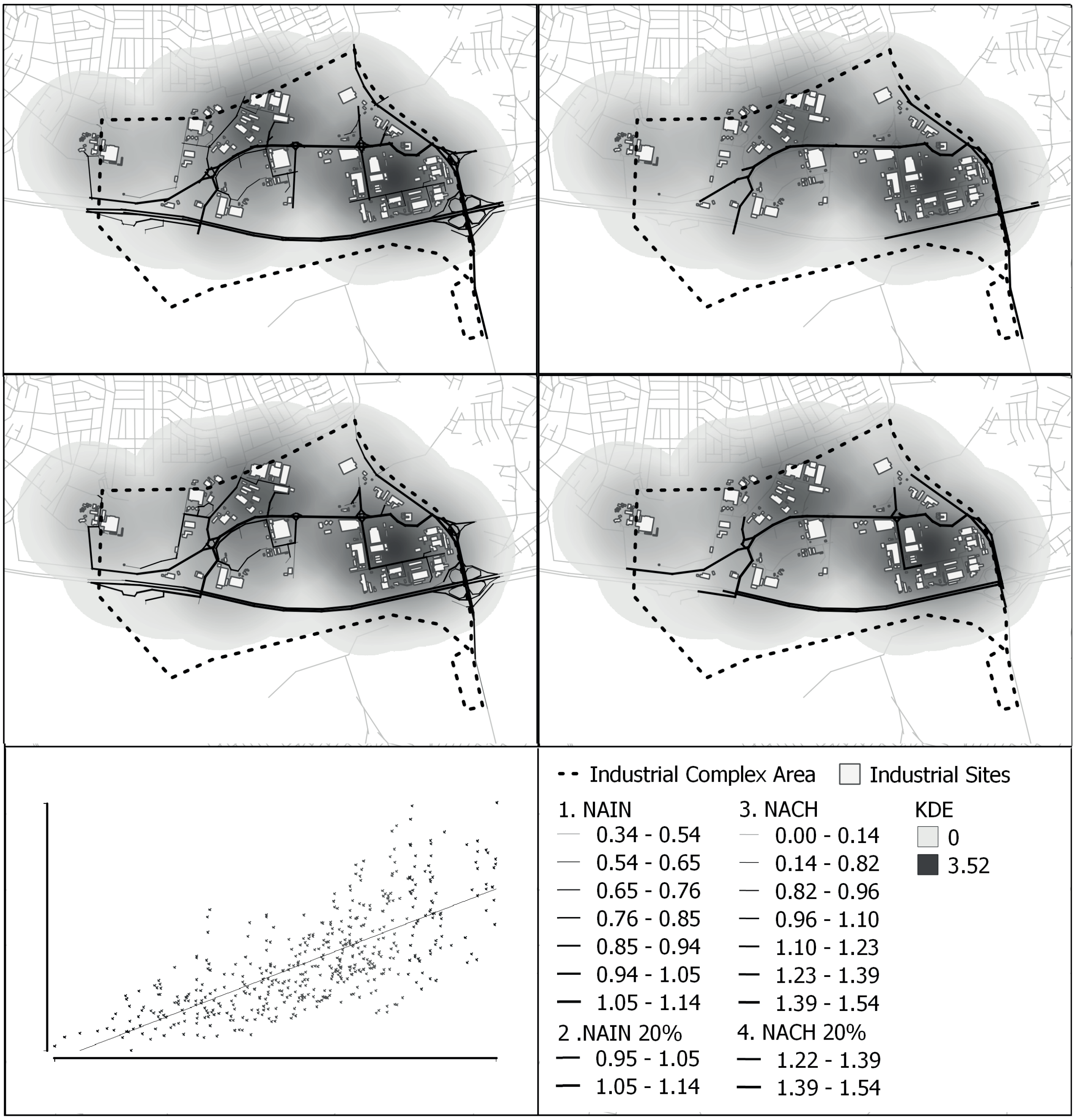

Figure 3. *Gravataí ID spatial correlations between Industrial Sites Placement (KDE), and inner-complex road-network centralities represented by NAIN (3.1) and NACH (3.3) restrictions of 20% (3.2 & 3.4); and Synergy Correlation graph between Integration Rn and R3 values (3.5)*

ities, hence, convey that their movement potentials are more segment-wise distributed in the whole system. Once this is valued alongside configurational analyses (Figure 2.1 & 2.2) it becomes noticeable that this complex possesses a road-circulation morphology that allows better movement distribution along the road-network, as orthogonal grids and the *ring-road* structure form a higher number of non-hierarchical connections – segments with low angular integration differences – and create additional options of *to-movement* routes. Such morphological features ensure a greater degree of accessibility and spatial connection amid inner-complex firms, which may explain industrial complex' higher occupation rate (9.49%) as indicated by the built area proportion (Table 3). KDE measures (Table 3) reinforce this assessment, as they demonstrate that *Cachoeirinha ID* (Figure 2) have a considerable degree of industrial sites agglomeration (32.30), far higher than those found in the other complexes. Sites are placed, above all, in the *ring-road* structure inner and bordering areas, close to segments that represent centrality cores (Figure 2.1). Despite local connections, the orthogonal grid set located north of the complex exhibit lower agglomeration of industrial sites, which can be explained due to its relative *segregation* from the centralities system formed by the *ring-road*, as it is accessible through one route only (Figure 2.2) resulting in a distinct hierarchical differentiation amid these areas. Nevertheless, this area agglomeration degree is on par with those found for the remainder PMAR industrial complexes, suggesting that orthogonal grids can promote better movement conditions for industrial placement. Although only verified qualitatively, these results regarding patterns of industrial activities agglomeration and morphological properties advocate that there are relations between closeness to urban road-network centralities and densification.

Synergy correlation values (R^2) (Table 3) for the industrial complexes of *Alvorada-Viamão ID* (Figure 1) and *Gravataí ID* (Figure 3) are far higher than those observed for *Cachoeirinha ID* (Figure 2), attesting that these systems have greater correlations between global (Rn) and local (R3) centralities. This denotes that movement potentials are concentrated in few same segments that form long non-hierarchical connections in the system, a trait that becomes clearer when results are confronted with complexes' configurational analyses (Figure 1.2 & 3.2). It can be distinguished then, that movement potentials are concentrated in linearities, which act as main linkages among the industrial complexes' expanses, restricting *to-movement* options and *segregating* whole areas, reachable only through less-integrated secondary road segments which branch from the main centrality core. These morphological features engender sparse groups of low-hierarchical spaces or "*Enclaves*", where industries are to be placed. Such characteristics also disclose an outer-complex-oriented industrial dynamic in *Alvorada-Viamão ID* and *Gravataí ID*, as firms have a close connection to the main linear structures

Table 3. *PMAR's Industrial Complexes total area, total built area, built area proportion, Synergy Correlation Values (R^2) and KDE (500m) highest values for agglomeration.*

Industrial Complex – PMAR	Total Area (km^2)	Total Built Area (m^2)	TBA/TA (%)	Synergy (R^2 – Rn x R3)	KDE (500m)
Alvorada-Viamão Industrial District	3.50	191,388.75	5.46	0.485685	3.83
Cachoeirinha Industrial District	10.98	1,042,870.50	9.49	0.257894	32.30
Gravataí Industrial District	3.73	329,296.02	8.82	0.530853	3.52

of global centrality – which represents a regional preferential route – but disconnected amid themselves due to the "*Enclaved*" nature of complexes' inner-morphology. This may, as well, elucidate the low degree of Industrial Complexes' occupation visualised for *Alvorada-Viamão ID* (5.46%), as industries have limited ideal placing locations alongside the highest road-network centrality values, that are concentred in a single linear structure. The assessment that industrial sites tend to be clustered close to road-centralities is backed by KDE measures (Table 3). It can be observed that on *Alvorada-Viamão ID* the agglomeration patterns tend to extend along the main linearity towards an "*Enclave*" with higher agglomeration, reached only by a preferential route (Figure 1.2 & 1.4). A similar logic can be witnessed for *Gravataí ID*, where industrial sites are agglomerated along the main centrality core, with higher agglomeration being verified inside the low-hierarchical spaces, accessed through secondary lower integrated routes (Figure 3.2). The "*Enclaves*" internal structures in this complex differ from the *Alvorada-Viamão ID*, being closer in form to an orthogonal grid, supporting the statement that this morphology indeed favours industrial agglomeration.

4. Conclusions

Urban Planning and Economics ought to ponder about quintessential tendencies of current and forthcoming industrial complexes spatial organization. Urban form – and the distribution of centralities that emerge from road-circulation networks configuration – as proven by the results, is a factor that can favour or disfavour interactions amid firms and production chains. Since logistics implications tend to increase due to requirements of "*integrated industries*", an (in)efficient spatial design can lead to industrial straightforward decay or to its resilience and long-term sustainability. Hence, industrial complexes morphology should be onwards regarded on pair with most often approached questions of Industrial and Urban & Regional studies.

Evaluation of inner-complexes spatial structure, as herewith proposed, depicted how urban morphology can influence industrial sites distribution. It was statistically confirmed that these economic activities tend to locate closer to areas exhibiting higher degrees of road-circulation network centralities, due to externalities related to transport efficiency and endogenous connectivity. Linear-based morphologies, while may favour industrial interactions with regional and nationwide territories, can diminish possibilities of ideal industrial placement, as these linearities tend to concentrate centrality in single groups of segments. This may hinder inner-complex transportation efficiency, as well, impair firm-to-firm relations, and due to such accessibility constrains, lead to agglomeration diseconomies. It was found that orthogonal-grid morphologies, as regular blocs and *ring-roads*, promote better inner-movement distribution, through the diffusion of local centralities, opening more possibilities of ideal industrial placement, which have positive effects on industrial agglomeration, as displayed by KDE measures. Hence, integration, connectivity, proximity to preferential routes, and spatial distribution of centralities contribute to even firm's locational choices, creating a built environment capable of promoting efficient interactions among different industrial activities and their material networks.

Henceforth, the diffusion of *smart manufacturing* on current and forthcoming 4.0 industrial complexes will require application of strategies focusing, not only on economics and logistics, but that, as well, on practical and conceptual dimensions of spatial morphology and urban design.

5. Acknowledgements

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001, and in part by the Università di Pisa.

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