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Housing segregation in Rio de Janeiro: a dead-end street?

Analysing the impact of low-rise residential cul-de-sacs types on Rio de Janeiro's street network through Space Syntax

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ABSTRACT

The main objective of this study is to understand the impact of low-rise residential dead-ends on the movement to and through Rio de Janeiro's street network at local radii. More specifically, it compares *vilas* (a traditional terraced type along a gated alley), rowhouse cul-de-sacs, *favelas'* linear dead-end clusters and comb-like gated communities, focusing on the relationship between the housing units, the internal dead-end street or alley, the main public street and the local surroundings. The intention is to understand if, and through which spatial features, different types of low-rise residential dead-ends affect the connectivity and, thus, people's movement in the city's public space.

The paper first reassesses the historical progression of Rio's low-rise residential dead-ends since the backyard inline houses imported by the Portuguese into the modern row-house estates and gated communities. Then it compares the topological depth and micro-scale features of the selected types. Finally, it analyses their impact at local radii through the Space Syntax Angular Segment Analysis of Rio's RCL map.

The results show that: 1) *vila* type demonstrates that it is possible to have some degree of residential segregation without compromising the public streets' vitality and, therefore, safety; 2) *favelas*' dead-end clusters on flatlands and the traditional *vilas* are topologically identical and have a similar impact on the surroundings; 2) gated condominiums of row and detached houses are similar to the *vilas* layout but their complete lack of fronts permeability and increased topologic, and metric depth have a critical impact on the movement to and through the surroundings.

KEYWORDS

topological depth, connectivity, *favela* (slum), *vila* (rowhouses, terraced houses), gated communities

1 INTRODUCTION

"In an excellent location, gated condominium with a guardhouse, concierge, garage and intercom, here is a duplex in a *vila* house […]". "Excellent triplex house, [...]: You know that nice place, where you hear the birds singing, that airy place, with little movement, that exudes tranquillity? It's all you will find in this charming *vila* house!".

These are examples of how real estate advertisements describe *vila* houses in Rio de Janeiro. *Vilas*,[1] low-rise rowhouses along dead-end streets, are a traditional and popular type in the city for guaranteeing low-rise houses ('duplex', 'triplex') some segregation ('gated condominium', 'little movement', 'tranquillity') together with centrality ('excellent location').

This multifamily solution is the result of a typological evolution process that started in the second half of the 19th century, when the former Empire of Brazil and its capital government started supporting developers to replace the working class' precarious inline dormitories with 'hygienic' houses (Albernaz, 1985; Vaz, 2002). The city verticalisation process, which began in the 1930s with the emergence of armed concrete, slowed down their spread until the 1990s, when *vilas* became a sought-after type again by those who no longer appreciated or could not afford to live in medium and high-rise districts (Vaz, 2002; Wagner, 2010).

In the meantime, low-rise dead-ends spread was not limited to the *vilas* construction. On the contrary, cul-de-sacs have been a frequent feature of Rio's residential areas,[2] including low-rise gated communities and *favelas* (figure 1).[3] As a result of the literature review and field observation, the study aimed to compare Rio's low-rise multifamily dead-end street clusters (i.e., *vilas*, cul-de-sacs, *favelas*' dead-ends, and comb-like gated communities) based on the latent similarity of their layout. Specifically, the study focuses on the relation between the residential units, their communal dead-end street, the public street they connect with and the local area. This

[1] *Vila* in Brazilian Portuguese means (Michaelis, 2015):
1. A settlement of greater importance and rank than a village and smaller than a town.
2. The inhabitants of this village.
3. A country house, on the outskirts of Italian cities, suitable for recreation.
4. Elegant and exquisite house.
5. A group of houses, often alike, arranged along an alley or around a small inner square, with an exit to the street; (also called *avenida*).

[2] Among Rio's mapped residential groups, dead-end streets account for 25% of the gated communities' street network edges; 19,7% of the *favelas*; 13% of the irregular allotments; 11.9% of the medium-rise social housing complexes; and 43% of the new middle-rise housing developments MCMV. The remaining residential area of the city corresponds to the city's general average of 14% of dead-end edges over the total. This percentage, in turn, corresponds to 49% of total cul-de-sacs. This group includes *vilas*, of which there is no specific survey.

[3] Irregular allotments' dead-ends are not included as long as they are temporary expansion edges at the unconsolidated limits of the settlements (Cortado, 2018).

way, it seeks to shed light on how different low-rise inline dead-ends affect connectivity and, thus, people's movement in the city's public space.

To this aim, the study first compares the topological depth and micro-scale housing features of the selected types. Then, it analyses their impact at local radii through the Space Syntax Angular Segment Analysis of Rio's simplified RCL map. The study is based on three primary sources: 1) the literature (related to Space Syntax and housing in Rio de Janeiro); 2) the cartography (governmental; OpenStreetMaps-OSM); and 3) the direct field observation.

The outcomes of the analyses indicate that the earliest *vila* type and the *favelas*' dead-ends on flatlands demonstrate that some residential segregation is possible without compromising the public streets' vitality and, therefore, safety. On the other hand, the complete lack of fronts permeability (unconstitutedness) and increased topologic and metric depth of the gated condominiums of row and detached houses have a critical impact on the movement to and through their surroundings.

Figure 1. Examples of low-rise residential cul-de-sacs in Rio de Janeiro. Top (left to right): *vila* with semi-direct access to the housing units facing the street; cul-de-sac on a steep slope; *favela*'s dead-end on a steep slope. Bottom (left to right): gated community's dead-end; *vila* with direct access to housing units; *favela*'s dead-end on a flatland.

By this means, the study suggests that the constitutedness of gated communities and rowhouse cul-de-sacs are a critical architectural and urban feature to rule in order to improve the livability of their surroundings and, thus, the safety of local dwellers and strangers. Besides, the marked similarity between the *favelas*' linear dead-ends and the *vilas* pointed out that there is typological

osmosis between the favelas and the planned city. Thus, contributing to Licia Valladeres'(2005) questioning of the "specificity of favelas".

The paper is structured into four sections: contextualisation, datasets and methods, results, and discussion. The contextualisation reassesses the historical progression of the low-rise residential dead-ends since the backyard inline houses imported by the Portugueses (*ilhas*) into the modern rowhouses estates and gated communities in Rio de Janeiro. Next, in the datasets and methods, the stages and sources through which the analysis was developed are described. The following section reports the topological and angular segment analyses results and illustrates them by employing synthetic diagrams, complemented with maps and 3Dviews of representative examples. NaCh and NaIn sample maps are included to illustrate the impact of the different types of dead-ends at the local 400 and 5000 radii. Finally, the discussion section summarises and problematises the main results obtained, further discusses the conclusions outlined here, and frames potential future research.

2 CONTEXTUALISATION

This section briefly frames the emergence and evolution of multifamily housing on low-rise cul-de-sacs in Rio de Janeiro. Following Vaz (2002), it focuses on the interplay between five main issues, namely: economy (the real estate market, the economic inequality, the production system); institutions (the building laws, housing and zoning policies); territorial parcelling (dimension and location of the lots); technique (building technique, infrastructure and accessibility) and cultural conventions (the architectural types developers and city dwellers long for). The aim is to give a broader view of the different aspects that structured the spread of multifamily housing on low-rise cul-de-sacs as a popular residential solution.

In the areas designated for multifamily dwellings, by 2022, Rio de Janeiro's Building Code (Rio de Janeiro, 2019) allows the construction of complexes (*grupamentos*) of buildings or buildable lots on the same plot of land, allotted for autonomous units. By this means, the bill differentiates multifamily from the other two residential categories, i.e., single and two-family housing.

Actually, multifamily housing appeared as a juridical category in Rio de Janeiro in the 19th century, responding to the city's urban fabric densification. Multifamily was designated in opposition to detached and temporary housing and on the growing levels of equipment collectivisation, being also called 'collective housing'(Vaz, 2002). According to Rio's Building Code in effect by 1892, a multifamily dwelling hosted different families in independent unities under the same roof or within the same land/property. Later, in 1925, norms defined multifamily as a building or part of a building that permanently hosted different families.

Rio's city centre hosted both work and residential functions by the end of the 19th-century and the beginning of the 20th-century. Indeed, since the beginning of the 19th-century, employers

provided accommodation (mostly dormitories) to workers within the workplace. At the same time, in the city's countryside, the *senzala* - the enslaved people's dormitories at the sugarcane and coffee plantations - was the architectural solution that materialised the relation between housing and working under the slavery production system (Vaz, 2002).

In the modernisation process - with the end of slavery and the beginning of industrial production – the housing supply did not respond adequately to the rapid population growth caused by internal and external migrations (Abreu, 2006). Furthermore, factories settled down by occupying some of the housing lots in the central area, worsening the housing supply shortage, especially for the poorest, the broader part of the city dwellers. The immediate consequence was a fast multiplication of collective housing by subdividing the city centre's remaining houses or lots into smaller units (Albernaz, 1985; Vaz, 2002). This process moulded distinct types: *estalagens, casas de cômodos* and, later, *avenidas*.

Estalagens were inline clusters of tiny ground-floor houses (*casas terreas*), single room dwellings with one door-and-window façade, with shared toilets. They were accessed and structured by an elongated patio or a corridor (figure 2). As a solution to the reduced area of the units, dwellers used to perform their daily and leisure activities in this communal exterior part. This type started in the first half of the 19th century, sprawled by 1850 and became illegal during the same century.

Colonisation was at the root of this type, which find its ancestor in the *ilhas* (Portuguese for islands, lit.) of the city of Porto, in Portugal, an inline succession of low-quality built small rooms, poorly illuminated and ventilated, occupying lengthwise the narrow and elongated parcels that structured the urban fabric (figure 2). The Portuguese civil construction workers, collective housing landlords and renters exported this model from Portugal to Brazil. Similarly to the dormitories for enslaved people working in the plantations on the city's outskirts, the aim was to offer the minimal condition for workers to rest before another working day (Vaz, 2002).

Lately, at the end of the 19th century, the room-for-rent-houses (*casas de cômodos*) emerged as collective houses interiorly subdivided into tiny units. So, lots and houses were "*encortiçados*", that is transformed respectively in *estalagens* and *casas de cômodos*. These two different types were both classified under the broader category of *cortiço* for being characterised by shared equipment (toilets, water deposit, patio) and being the result of the same housing production system. Landlords, often aristocrats, lent their properties to developers, generally Portuguese merchants, who invested in building *cortiços* to rent the housing units and explore the shop (*taberna*) facing the street (Albernaz, 1985; Vaz, 2002).

Quickly, the *cortiços*' extreme population density became to be considered a potential threat to social and health control (Vaz, 2002; Abreu, 2006). In response, by 1856, the government

established ‘hygienic’ rules and imposed construction licenses. Later, in 1873, it forbade the construction of new *estalagens* in the city centre, extending the prohibition to all the city and renovations by 1893. The aim was to implement a new ‘hygienic’ typology by forbidding and disqualifying the most common type in use.

Figure 2 Typological evolution from Porto’s *ilhas* (top left, Aurélio da Paz dos Reis, 1899, CPF) to Rio de Janeiro’s *estalagens* on the rear of a lot in the city centre (top right, Augusto Malta, n.d., AGCRJ), *vilas operárias* next to the new factories (bottom left, n.d., AGCRJ) and *vila* (bottom right, the author, 2022).

Houses should be ample, enlighted, aired, and less dense to guarantee order, morality and discipline. The new ‘hygienic’ houses also differ from the old typologies by enhancing the private over the collective equipment. Every unit was supposed to have a patio, a w.c. and independent water provision. Instead, service areas and toilets could be common (Vaz, 2002).

Besides ruling the collective housing standards, in 1875, the government started supporting developers for building ‘hygienic’ and cheap houses for the proletariat and workers. By dismantling the *cortiços*, the city made space to construct the new houses. Some landlords invested in transforming on-site the existing precarious *estalagens* into ‘hygienic’ inline, tiny

houses, according to the new standards. *Correr de casas* and *avenidas* surged as types during this renovation process. They consisted respectively of one or two-row of houses facing an interior alley or elongated patio (Albernaz, 1985).

This process reduced at the same time the population density and the number of housing units in the city centre, making rentals grow and pushing factories and workers to the nearest countryside, which was still structured in large rural possessions. The most common solution adopted by the entrepreneurs to solve the housing problem in a poorly infrastructured and rapidly growing city was to build *vilas operárias* in the new factories' surroundings (see figure 2).

The name *vilas operárias* recalled the village model and scale (see note 1) while designating modern and 'hygienic' low-rise terraced social housing developments for the new industrial working class (*classe operária*). This housing production system changed again with the construction and expansion of modern collective transport connecting Rio's city centre to its countryside, making housing and factories sprawl along its main tentacular lines (Abreu, 2006).

Meanwhile, a large part of the city dwellers was impoverished and factories could not provide employment and housing to the fast-growing population of the capital. Among the insufficiency of public policies for low-income dwellers, many of the former inhabitants of the demolished *cortiços* started to occupy with auto constructed shacks the hillside areas of the city, which were in little demand on the real estate market. Later, this kind of settlement, called *favela*, sprawled following the city's formal expansion as a bottom-up solution to the chronic lack or poor quality of social housing construction (Abreu, 1994, 2006).

In the first decades of the 20th century, the introduction of reinforced concrete structures made the real estate market shift its focus to constructing multi-storey apartment buildings. To make space for the medium and high-rise multifamily housing solution the legislation gradually pushed the *vila* type into the background, literally. In 1937, a decree established that *vilas* could only be built as inline rowhouses along a cul-de-sac on the rear lot portions while prohibiting their construction in various parts of the city.

Subsequently, this type was fiscally discouraged until 1993, when new urban policies regularised their construction and stimulated the renovation of the existing *vilas* and the production of new ones (Wagner, 2010). Lately, Rio's Building Code (Rio de Janeiro, 2019) defined *vila* as a low-rise residential complex (*grupamento*) of single-family or two-family buildings of juxtaposed or superimposed units with independent access through an uncovered common area (*via interna* or *rua de vila*).

In the former rural areas of the city, this type became especially attractive due to the large availability and cheaper value of the land. These conditions allowed a high return on developers'

investment and more affordable prices for dwellers than multi-storey apartment buildings (Wagner, 2010). Moreover, following the densification of the city's most expensive area (the southern zone facing the Guanabara Bay and the Atlantic Ocean), the growing economic inequality and the worsening crime rate, the *vila* type returned in vogue within the middle class, eager to live in less dense and greener areas, still widely available in the city countryside (Vaz, 2002).

Meanwhile, part of the wealthiest population considered the gated communities with shared leisure facilities under construction in the new neighbourhood of Barra da Tijuca, a convenient multifamily solution to urban congestion and unsafety compared to single-family residential units. Barra's plan was designed in the latter 1960s by Lucio Costa according to modernist principles, with high-rise buildings surrounded by greenery and terraced or detached house communities set in a still untouched sea and lakeside landscape (figure 3). The architect later distanced himself from many of the solutions implemented because they misinterpreted his initial idea in order to address the real estate market demand (Rezende and Leitão, 2014).

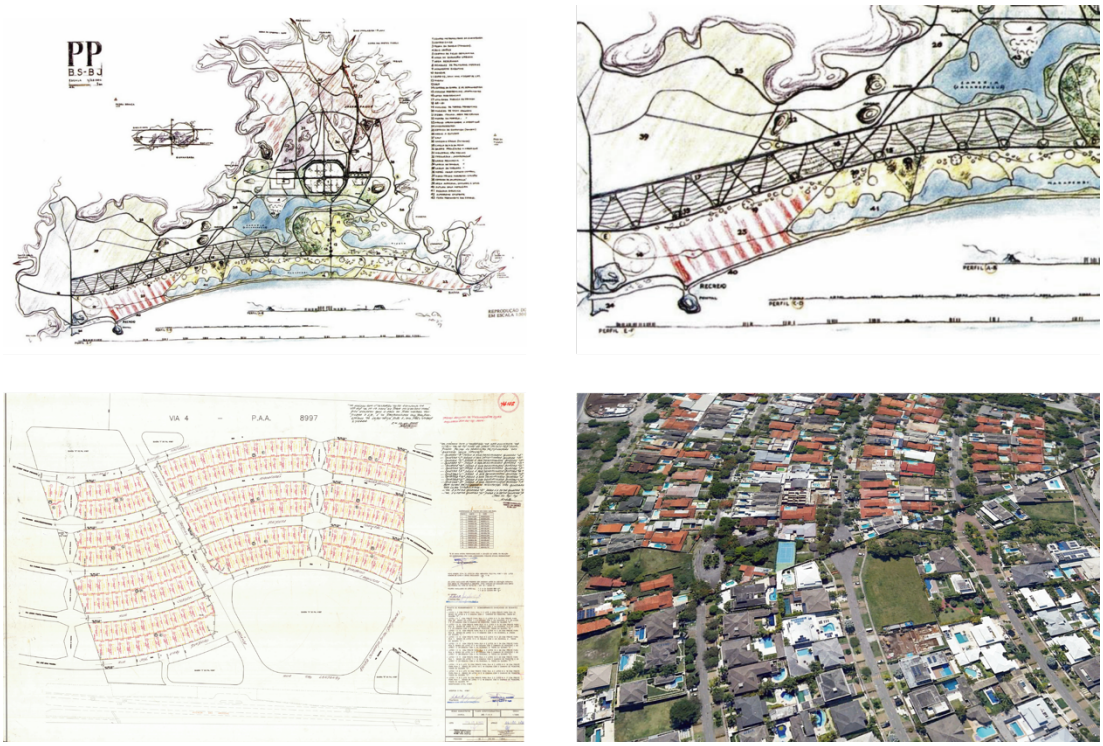

Figure 3 Top: (left) Lucio Costa, Plan for Jacarepaguá and Barra da Tijuca lowlands, 1969; (right) zoom on Barra da Tijuca's street network design.
Bottom: (left) *Plano Aprovado de Loteamento* (approved allotment project) – PAL n. 46102, 2003 (http://www2.rio.rj.gov.br/smu/acervoimagens/imagenspaa/PAL%20DATAVIX/79/0/245.jpg); (right) view of a wall between two gated communities interrupting the continuity of the planned street grid (GoogleMaps). The wall corresponds to the allotment's left border in the previous image (bottom left).

A remarkable example is the division of the neighbourhood into gated areas, some of which correspond to the former rural properties. Indeed, during the plan's implementation process, the

boundaries of private lands got the better of the plan's design (Rezende and Leitão, 2014), fragmenting the continuous public street grid into comb-like structures divided by walls, railings and water canals (see figure 3). Most of these roads are still public, but private security companies control their access, as dwellers' safety is intentionally pursued through segregation.

Cul-de-sacs or comb-like structures seem to respond, indeed, to the residents' desire to exclude strangers from the immediate local movement, i.e., to be a spatial strategy for living in a safe but low-density location directly connecting to the ground floor.

The study will next explore how, to some extent, these objectives are pursued by similar spatial structures in the *vilas*, cul-de-sacs, gated communities and *favelas'* dead-ends. Indeed, while the literature explored in-depth the typological process that took place between the *estalagens*, *avenidas* and *vilas* (Albernaz, 1985; Vaz, 2002; Wagner, 2010), no studies were founded over similarly structured low-rise formal and informal cul-de-sacs in the city of Rio de Janeiro. Furthermore, there is virtually no literature exploring the impact of these dead-end residential groups on the movent to and through their surrounding areas.

3 DATASETS AND METHODS

According to Rio de Janeiro's street network (data.rio and OpenStreetMap) and land use (data.rio) datasets, by 2022, dead-ends represent 14% of the city's residential edges (see note 2). Based on the literature review, cartography and fieldwork, this study analyses and compares the ones that structure low-rise inline complexes, i.e., *vilas*, cul-de-sacs, and dead-ends in gated communities and *favelas.*[4] The aim is to understand through which features these different types achieve different degrees of topological depth and how they influence the movement to and through their surroundings.

For each type, the study focuses on the relation between the residential units, the dead-end street, the road it connects to, and the local area. In this way, it seeks to compare low-rise inline cul-de-sacs by how they affect the connectivity and thus people's movement in the city's public space. To this aim, the analysis is twofold. First, it focuses on the spatial relation between the public and private space at the residential cluster scale through topological depth, constitutedness and micro-

[4] *Estalagens* and *avenidas* with shared service areas are left aside from this comparison, as they are collective buildings and not complexes of single-family or two-family buildings. As pointed out in the 'Contextualisation' section, the typological evolution from *estalagens* to *avenidas* and *vilas* preserved the schema of one or two-row low-rise units facing an internal elongated patio or alley, while progressively integrating collective w.c., toilets and kitchens into the single houses. Whereas the *vilas*' internal cul-de-sac is a communal semiprivate space, *estalagens*' and *avenidas*' patio or alley are 'collective-private' areas that host the communal kitchen and serves as corridor between the single rooms/tiny apartments and the shared facilities. Indeed, according to the report of the Observatorio das Metropoles and Central de Movimentos Populares (2019) what still defines a *cortiço* (i.e., *estalagens* or *casa de cômodos*) is the social relation between dwellers daily sharing the service areas and the landlord or renter who administrates the building.

scale spatial features analysis. Secondly, through SpaceSyntax Angular Segment Analysis, it compares the Normalised Choice (NaCh) and Integration (NaIn) of the surrounding areas at larger local radii (400, 800, 1200, 1600, 2000, 3000, 4000, 5000).

With regard to the topological depth, the study analyses the features that structure the spatial relation between the public and private space. By this means, the diagrams in the next section (see left plans in the figures 4, 5, 6, and 7) schematically synthesise the most representative variations of the dead-end types under study, resulting from the direct field observation and the broader analyses already present in the literature (Drummond, 1981; Albernaz, 1985; Abreu, 1994, 2006; Vaz, 2002; Wagner, 2010; Rezende and Leitão, 2014). A map extract (data.rio) and 3d view (GoogleSatellite) complement every diagram with an illustrative example retrieved in the literature or during the fieldwork.

Criteria to extract a consistent sequence of steps from the public road to the entrance of the housing units in the abovementioned diagrams were established as follows: discontinuity between the entrance and the main street line (i.e., gate set back from the main street); the presence of gates or barriers; direction change towards a secondary service road; use of semi-private spaces (e.g., verandas or gardens, stairs, walls or fences separating the units from the outer space). Finally, to complement the topological depth analysis, the study includes other spatial features that influence the micro-scale of the public-private relationship (Van Nes and Lopez, 2018): constitutedness, controlled access, type of cul-de-sac (public, semi-public, private), houses typology (terraced or detached).

Next, in the second part, the study analyses Rio's Road Center Line (RCL) map through the SpaceSyntax Angular Segment Analysis run on DepthMap to understand the impact of the selected dead-end types within their local network. Due to the lack of a comprehensive updated survey of Rio's irregular areas, to set up the dataset for the analysis, the OSM map[5] integrated Rio's governmental RCL map (data.rio) in the areas where it proved to be more accurate. Once the integrated dataset gave a sufficiently complete representation of Rio de Janeiro's street network for the purposes of this study, it was simplified accordingly to Kolovou *et al.* (2017) and Ena, Beirão and Serdoura (2019).

The segment map analysis was run at different local metric radii, including the immediate proximity up to a walking distance of about one hour (400, 800, 1200, 1600, 2000, 3000, 4000, 5000). The results examination focused on Normalised Choice (NaCh) and Integration (NaIn) for three main reasons: 1) they allow to compare different scales (Hillier, Yang and Turner, 2012); 2) NaCh corresponds well to simple segment connectivity (Al_Sayed, 2018); 3) metric integration (in this case normalised, i.e., NaIn), by reflecting the "universal distance", i.e., the distance from

[5] Topologically corrected and downloaded using OSMnx (Boeing, 2017)

one point to all others on the map, provides a consistent representation of the network edges' rates of movement (Hillier, 1999; Hillier, Yang and Turner, 2012).

4 RESULTS

This section is divided into two main parts. The first explores the spatial relations between the public and private housing space by analysing the main variants of the low-rise dead-end clusters under study. Next, through the Normalised Choice and Integration results obtained by running the Angular Segment Analysis of Rio's simplified RCL map, it assesses the different dead-end cluster's impact on their local surroundings.

4.1 The Spatial Relation Between Public and Private Space

As far as *vilas* are concerned, the study sticks to the current definition given by Rio's Building Code (Rio de Janeiro, 2019): a low-rise residential complex (*grupamento*) of single-family or two-family buildings with juxtaposed or superimposed units with independent access through an uncovered common area (*via interna* or *rua de vila*). Indeed this definition allows for the inclusion of both earlier *vilas* and later variations.

The *vilas*' public-private connection is exemplified by three diagrams: a) the *vila* with direct access both to the units facing the internal dead-end and the units facing the street (figure 4, a.); b) the *vila* with semi-direct access to the internal units and the ones facing the street (figure 4, b.); c) the *vila* occupying the rear of a lot of a multi-storey building facing the street (figure 4, c.).

The shallowest is the *vila* with direct access to the units on either the outer or inner street (figure 4, a.). The topological depth increases as the access is set back through a transitional space (e.g., veranda, porch, front garden) on the main street and the internal dead-end (figure 4, b.). The units' depth grows further as the whole *vila* sets back at the bottom of a multi-storey building's lot, as it is necessary to pass through a greater sequence of spaces (covered, uncovered, gated) to reach the units (figure 4, c). In all three cases (figure 4; a, b, c), the street fronts remain active.

However, they differ in terms of adjacency and permeability, depending on whether there is direct or semi-direct access to the residential or commercial units facing the main street. Thus, while the *vila* with direct access (a) is constituted, i.e., it has both door and windows facing the street, the *vila* with semi-direct access to the units facing the street (b) is unconstituted. Differently, the *vila* on the rear lot portion (c) is uncostituted, but the lot is constituted as the commercial units of the building facing the street have direct access to the ground floor. Finally, in all cases, the internal dead-end is semi-private, i.e., for the exclusive use of the housing units. A gate usually blocks the access, thus reducing the movement to and through the dead-end alley to inhabitants and visitors only.

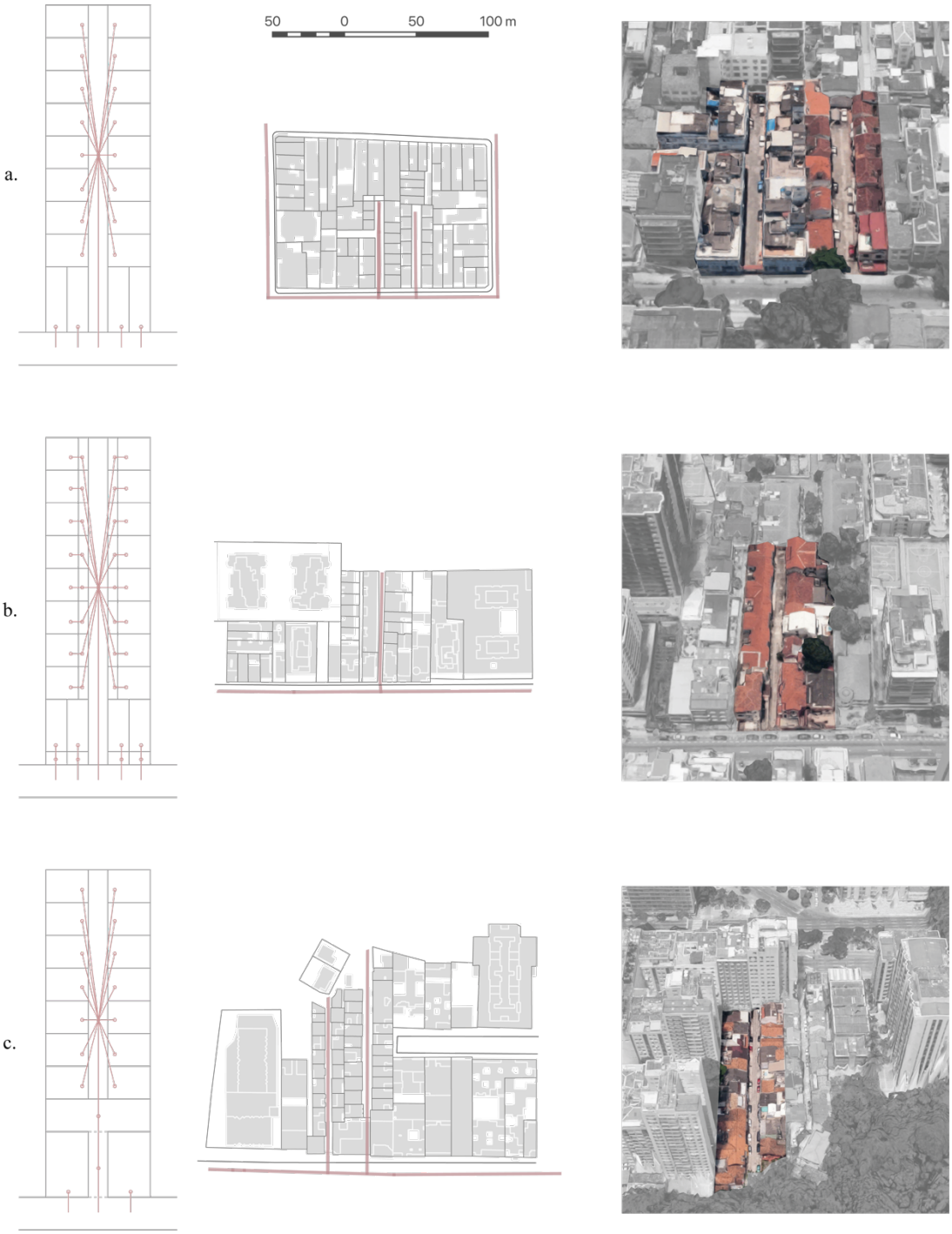

Figure 4. Topological depth of *vilas*: a) *vila* with direct access both to the internal units and the units facing the street; b) *vila* with semi-direct access to the internal units and the ones facing the street; c) *vila* occupying the back of a lot of a multi-storey building facing the street. (Images elaborated with datasets from data.rio and GoogleMaps 3d view)

Next, low-rise cul-de-sacs are represented by two primary schemes (figure 5): d) on flatlands and e) on steep dead-end streets. Including topography in the analysis is essential to account for Rio's

peculiar morphology and street grid. In fact, many dead-end streets sprout at the edge of the flat areas, like fringes running up the city's hillsides. The dead-end street in these cases can be public or semi-public, with free or controlled access through gate barriers and security booths. The housing units may respect a single repeated style or be articulated as a succession of different designs. They can be terraced or detached, with façades set back or aligned with the street front.

Scheme (d) is widespread in the areas under consolidation in the city's western area. In this case, the street is semi-private, as it is only accessible to residents and visitors. Scheme (e) is more common at the base of the hillsides in the city's south and central area, often running along a public dead-end street, open to pedestrians but with vehicular access controlled by a guardhouse and a barrier gate. These cul-de-sac schemes have a low depth, similar to the *vilas*. In the cases when commercial or mixed-use buildings occupy the lots facing the main road, the cul-de-sac diagram is similar to the *vilas* occupying the rear portion of a lot (figure 4, c). In turn, they differ from *vilas* as long as the whole cluster faces the internal street, while the main street fronts are blind or only windowed, i.e., unconstituted (figure 5, d).

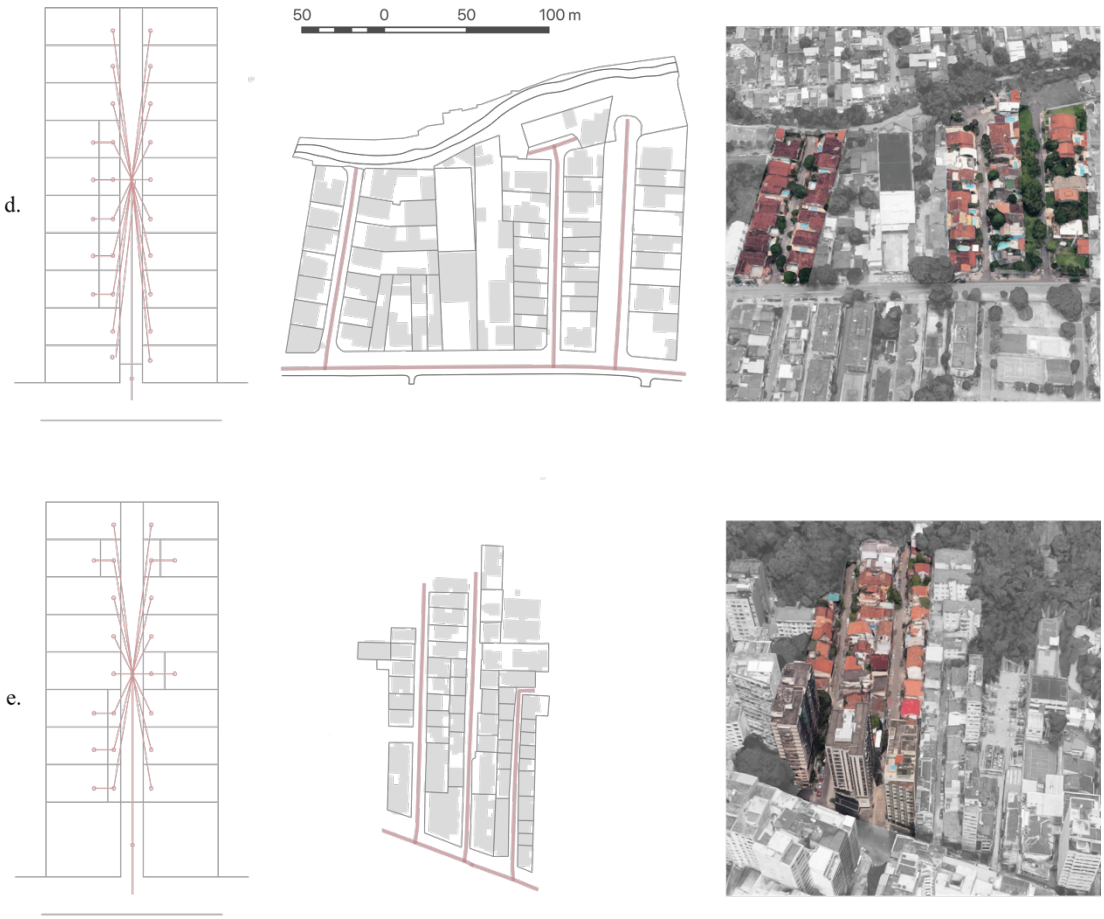

Figure 5. Topological depth of low-rise cul-de-sacs: d) on flatlands and e) on a steep slope. (Images elaborated with datasets from data.rio and GoogleMaps 3d view)

The clusters structured along dead-end streets in *favelas* (figure 6) are also divided into: f) flat areas and g) steep areas.[6] In the latter case, the dead-end is a path running up perpendicularly to the contour lines, articulated as a succession of staircases. The diagram of *favelas'* dead-ends on flatland (figure 6, f) repeats in full the topological solution of the *vila* with direct access (figure 4, a) but with smaller lots and a narrower internal alley. On the other hand, the *favelas*' dead-ends on a steep slope (figure 6, g) have an occupation pattern of the hillsides similar to the low-rise cul-de-sacs on steep slopes (figure 5, e) but are structured along a succession of narrow stairs.

Also, in *favelas*' dead-ends, the housing units are not uniform but present common features, such as the narrow main front facing the stairs, with direct or semi-direct access (through further stairs or a transition space). Furthermore, when lots are subdivided, the housing unit on the rear lot portions has greater depth, as a secondary path/corridor connects it to the dead-end street. Commerce can be found both on the main street and dead-end, often as small businesses occupying the houses' ground floor.

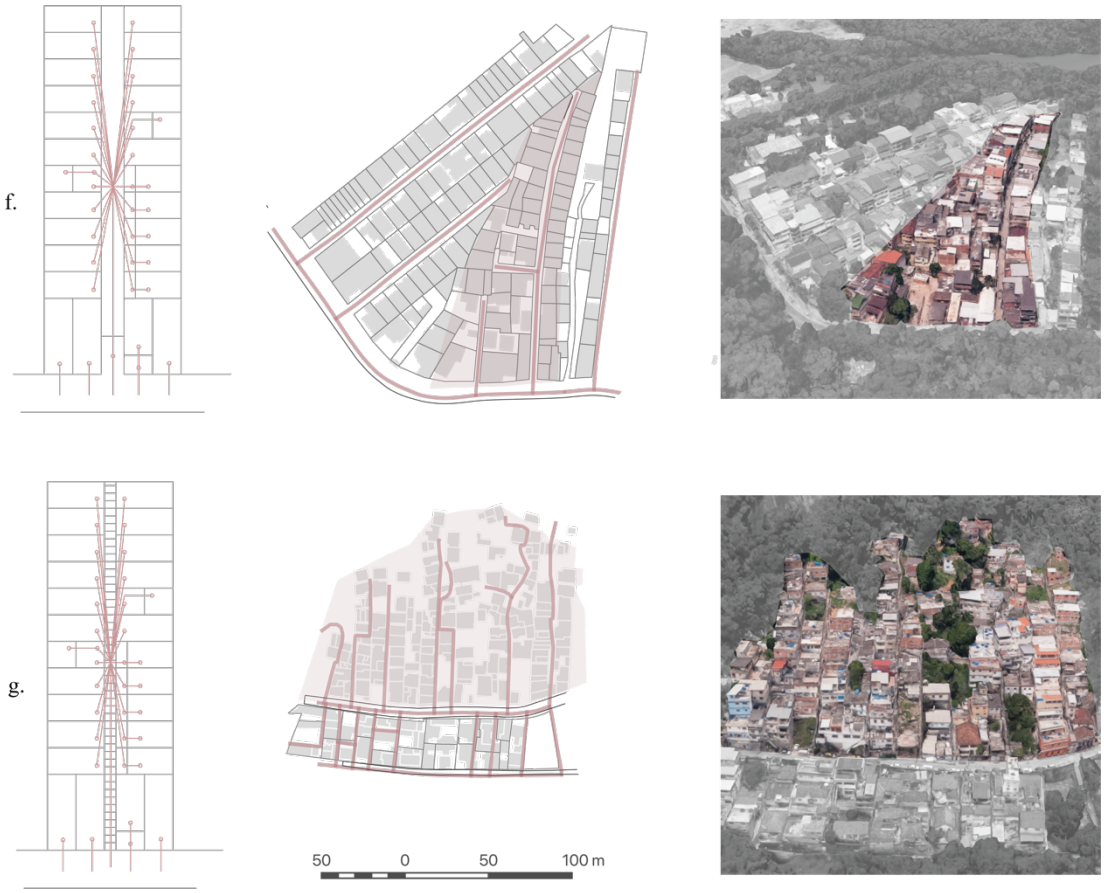

Figure 6. Topological depth of *favelas'* dead-ends: f) on flatlands and g) on a steep slope. (Images elaborated with datasets from data.rio and GoogleMaps 3d view)

[6] Nonrectilinear dead-end streets are common in Rio's *favelas*, as well. This type of dead-end deviates from this study's specific topic. Further specific syntactic analysis will allow to compare nonrectilinear with the rectilinear cases analysed here.

Finally, to analyse dead-ends in low-rise gated communities (figure 7), the study focuses on two recurrent patterns: h) the comb pattern with one entrance and i) the comb pattern with two entrances. These residential clusters differ from the previous examples in urban scale and topological depth. Also, unlike the other analysed types, these complexes have exclusive leisure spaces for residents (e.g. football pitch or tennis court, party hall).

Social and spatial segregation are pursued through fragmentation of the public street network into comb-like structures employing fences, water canals, and vehicular and pedestrian access check-points. Houses are not necessarily aligned, freely occupying the lot within the constraints established by the plan. Walled or fenced private areas mould the street line continuity but increase the topological depth of the single units, configuring unconstituded streets. Instead, when the street network is private with exclusive access for residents and visitors, the entrance door of the houses can directly face the street but is set back from the sidewalk.

Figure 7. Topological depth of cul-de-sacs in gated communities: h) the comb pattern with one entrance, and i) the comb pattern with two or more entrances. (Images elaborated with datasets from data.rio and GoogleMaps 3d view).

4.2 Angular Segment Analysis: Normalised Choice and Integration

Zooming out to get a broader view, as could easily be guessed, the local Angular Segment Analysis pointed out that all dead-end types have NaCh values below 0.8 on all radii. However, significant differences between types can be appointed when looking at the local surroundings. In the case of the *vilas* and low-rise cul-de-sacs, at radii 2000, 3000 and 5000, the streets on which they directly connect have a value higher than 1.2. This value rises to 1.4 when considering smaller local radii (400, 800, 1200). Such results are mainly obtained when several vilas or cul-de-sacs connect to the same street. When they are an exception to the surroundings, the values of the connecting road are lower (see figure 8, a and b; and figure 9, a).

As far as dead-ends in gated communities and *favelas* are concerned, distinctions need to be made. At higher local radii, when comb-like gated communities with more than one entrance (figure 9, b, top side of the image) and *favelas'* dead-ends connect directly to a continuous network (figure 8, c), the values are similar to those observed in *vilas* and cul-de-sacs. The closer these urban clusters are to the pattern in figure 8a (i.e., several segments directly connecting to a continuous network), the higher the NaCh values at local radii.

In gated communities with only one access (figure 9, b, bottom side of the images) or *favelas'* dead-ends that are distant to the "formal" network, i.e., in discontinuity with it (figure 8, b, top left of the images), the streets dead-ends connect to have lower NaCh values at higher local radii and higher NaCh values at smaller local radii. These results effectively represent the fragmentation of movement at smaller local radii.

As can be observed in figure 9-b, the foreground street network connecting the gated communities is almost excluded from movement at radii 400, despite its high integration values (NaIn) at the same radii (figure 11, b). Again, gated communities and the *favela* on a steep hillside represented in figure 10-b share a marked difference between integration values at 400 and 5000 radii.

Actually, the analysis of NaIn (figures 10 and 11) pointed out that, in all analysed cases, the integration values increase as the radius decreases. At radius 400, all types have good integration (> 0.8). This value decreases at higher radii. Nevertheless, there are noticeable differences. The most segregated are the gated communities, and the *favelas* with few entrances settled on a steep hillside (figure 10, b). On the contrary, integration values increase the closer dead-ends are to a local centrality and the more similar the urban pattern is to the one in figure 10-a.

5 DISCUSSION

Although this study is only an initial exploration of a vast topic, it is possible to discuss some relevant points based on the results obtained. First of all, the presence of dead-end streets in Rio at around 14% of total street edges reflects the discontinuity of the city's urban network. Indeed, the more significant the dead-end percentage, the lower the network connections and, hence, the connectivity degree of the whole. Various issues can be investigated regarding the causes of these discontinuities. Among others, topography, hydrography, legal constraints, the extensive presence of unplanned or irregular areas, and the sprouting of gated communities in response to crime - actual and perceived (Caldeira, 2000).

This paper first investigated Rio's low-rise dead-ends by the typological evolution process that started with the *estalagens*, then focused on the impact of the different low-rise dead-end clusters on Rio's local movement through syntactical analysis.

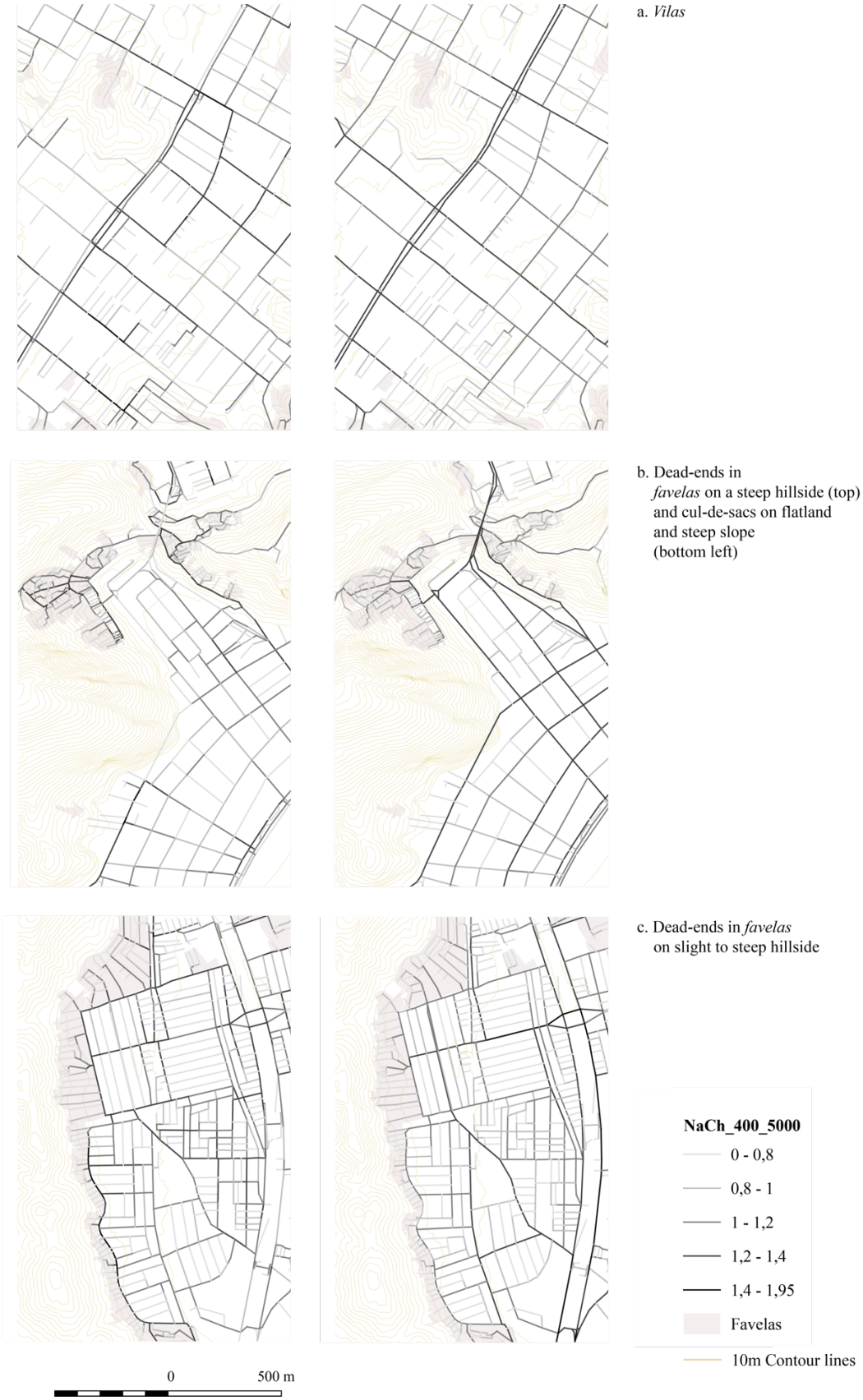

Figure 8. NaCh: radius 400 (left) and 5000 (right)

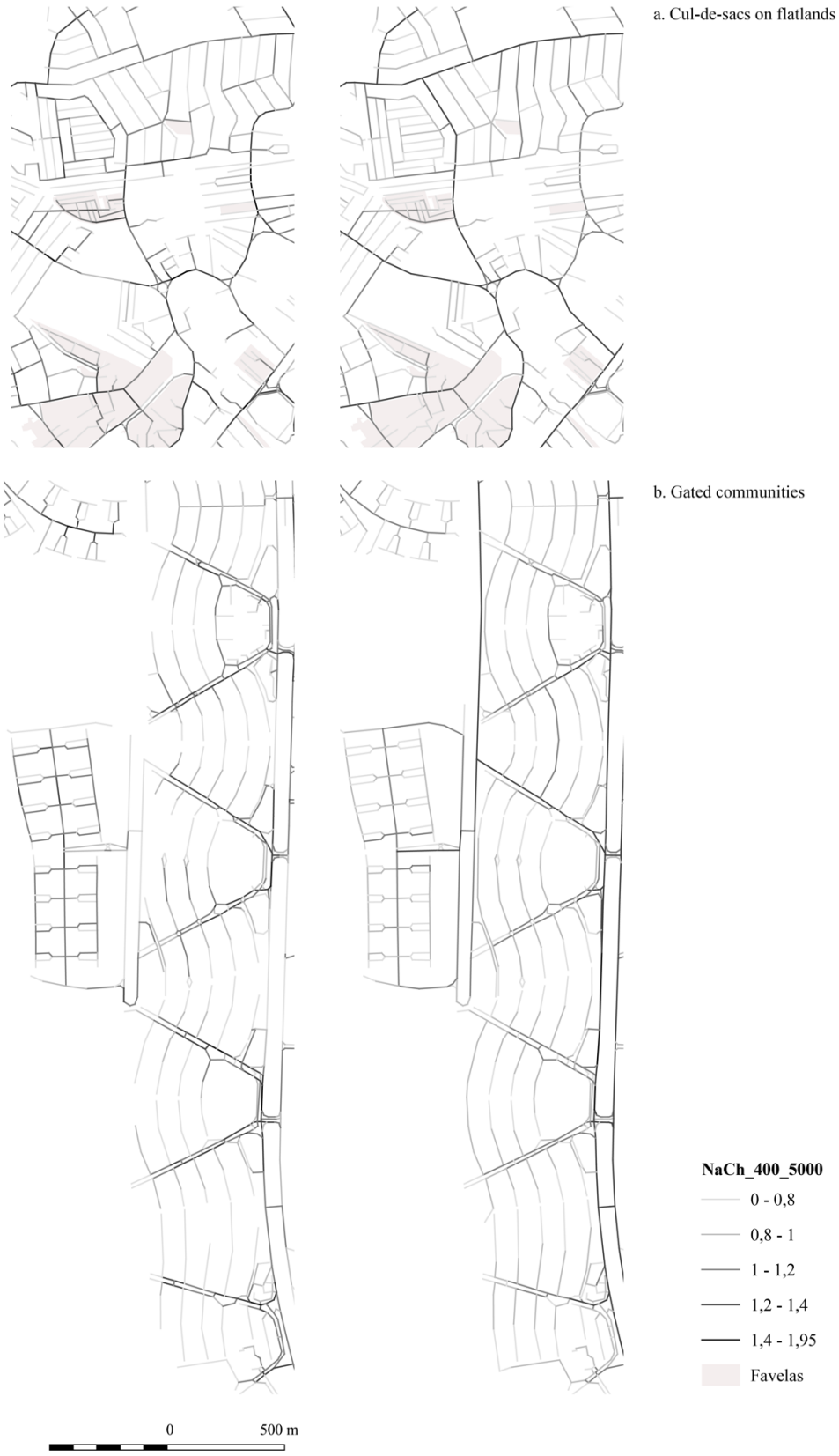

Figure 9. NaCh: radius 400 (left) and 5000 (right)

Figure 10. NaIn: radius 400 (left) and 5000 (right)

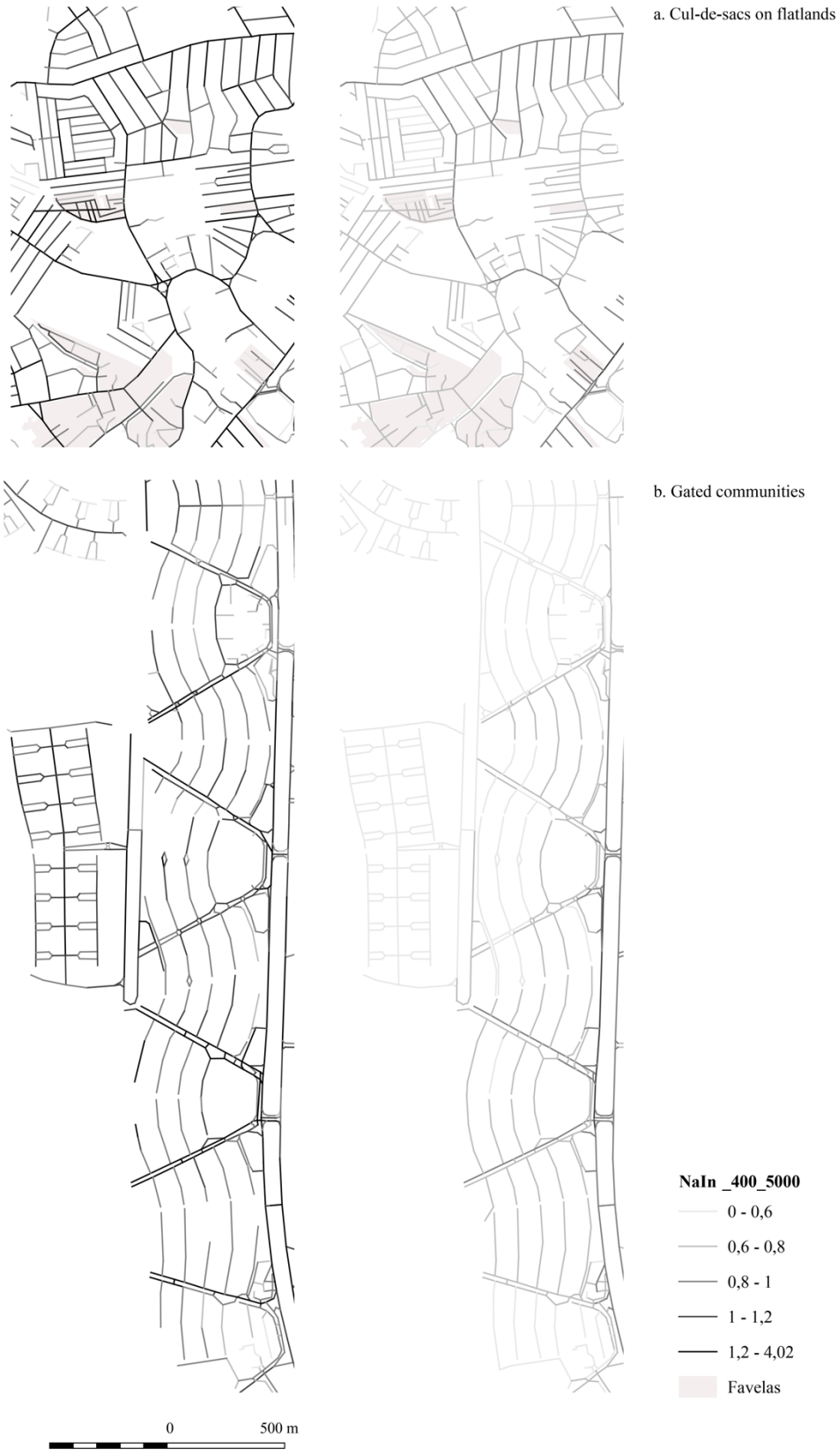

Figure 11. NaIn: radius 400 (left) and 5000 (right)

The outcomes of this study suggest that there is a topological similarity between the analysed housing clusters. As Vaz (2002) pointed out, the *vila* type echoed, even in its name, the myth of life in the countryside (*vila* as village) as opposed to the overcrowded, dirty, chaotic and dangerous industrial city. The *vila* represented a desirable model until the 'arrival of modernity', with the medium and high-rise apartment buildings. Subsequently, Rio's urban densification reinverted the pattern (Vaz, 2002). It made it desirable to return to the low-rise, row or detached house with a garden and, preferably, segregated from the dangerous outer city (Wagner, 2010).

High-income gated communities represent the ultimate realisation of this desire. They are designed as a scaling-up of *vilas*' layout (e.g., lots and housing units dimension, green areas, parking lots) and topological and metric depth. If proof were needed, this model adaptation demonstrates that the city's architecture continually creates new spatial hybrids.

In continuity with the previous point, this study shows a substantial similarity between the topology of linear dead-end clusters within *favelas* and the *vilas*. This result contributes to questioning the idea of the *favela* as a unitary, solid category and spatiality and, above all, as a place with its own specificity (cf. Valladares, 2005; Krenz *et al.*, 2016). Furthermore, this similarity shows that the inhabitants of the self-built areas have a clear idea of the house and neighbourhood they aspire to live in. This idea is shaped by observing both their immediate surroundings and the architectural and urban spaces outside the *favelas* (Holston, 1991).

The Angular Segment Analysis clearly shows that the gated communities' dead-ends fragmented the urban network in segregated comb-like structures directly connected to the foreground network. Their topological and metric depth implicitly design a "defensible space" (Hillier, 1996) that helps to restrict the movement through and to large urban areas to inhabitants and visitors.

This planning strategy is precisely the opposite of what Hillier (1996, p.146) defined as "the formula for urban safety", i.e., designing patterns of the probabilistic interface between strangers and residents. The recurrent use of security systems (e.g., high fences with barbed wire and CCTV cameras) to protect the single housing units inside the gated communities confirms that urban segregation does not guarantee the security residents sought after.

Another critical point that emerged from this study is the permeability of the main street frontages of dead-end residential clusters, which is intentionally omitted in the gated communities of row and detached houses and the gated cul-de-sacs and *vilas* built in the city's western zone in the last decades (cf. Wagner, 2010). Older *vilas* and *favelas* still preserve their constitutedness mainly through commercial street frontages. Nevertheless, during the fieldwork, it was possible to observe (but not quantify) that many *vilas*' housing units facing the public street were vacant.

Besides, gates closing the access to dead-end streets in *favelas* are widespread in the city's western zone. The spread of walled and gated dead-end residential clusters, both formal and 'informal', confirms that a high degree of segregation is a sought-after housing feature in Rio de Janeiro (Wagner, 2010; Rezende and Leitão, 2014). The study shows that *vilas* allow for residential segregation without compromising the public streets' vitality and, therefore, safety. The constitutedness of the street frontages mainly influences these characteristics.

Given the broad structuring impact of gated dead-end clusters (*vilas*, cul-de-sacs, *favelas* and gated communities) in the city's western area, the analysis suggests that by guaranteeing the street constitutedness through commercial, public street frontages, streets vitality can be improved while preserving the residential segregation Rio's dwellers long for.

Finally, the analysis outcomes suggest that further research could explore the relation between dead-ends and block density. Besides, given the high percentage of dead-ends in Rio's *favelas* (19,7%), a comparative analysis of the linear and non-linear ones could shed light on the relation between private and shared spaces in auto-constructed settlements.

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