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Spatializing inequality across residential built-up types: A relational geography of urban density in São Paulo, Brazil.

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ABSTRACT

Overcrowding in informal housing is a core problem in international development debates, whereby slum upgrading is viewed as a dominant policy to integrate formal and informal areas. Conceptually, challenges to socio-spatial integration are associated with unbalanced development processes of urban de- and re-densification beyond the housing level. However, a lack of empirical understanding of these processes limits the case for redistributive land use policies to complement slum upgrading. To address this gap, our study adopts an exploratory approach, applying GIS-based techniques to population census and open data on land use in São Paulo, Brazil, in order to analyze the distribution of population densities across residential built-up types in informal and informal areas, although there are constrains related to small-scale spatial data sources on urban density. This shows that informal settlements are indeed the densest residential built-up type in the city while revealing the underlying spatial inequality between informal settlements and low-rise, high-standard residential areas. We suggest that more emphasis be placed on the design and implementation of redistributive policies to avoid spatialized forms of inequality associated with uneven urban development. This will ensure the spatial and social integration of urban areas.

1. Introduction

The UN's Sustainable Development Goal 11 aims to make cities and human settlements inclusive, safe, resilient and sustainable (United Nations, 2015). The first target towards achieving this goal proposes slum upgrading as a spatial and social policy option to redress urban poverty in cities with large housing deficits. Broadly understood, slum upgrading entails a bundle of policies such as tenure regularization as well as the renovation of housing and physical infrastructure upgrading. Compared with large-scale resettlement housing schemes, slum upgrading is a cost-efficient investment which can reduce the social disruption caused by relocations/evictions and avoid the economic fallout when informal dwellers are removed from their places of employment (Patel, 2013; UN-Habitat, 2003; van Horen, 2000). Additionally, slum upgrading has environmental benefits associated with climate change adaptation and mitigation (Núñez Collado & Wang, 2020; Satterthwaite et al., 2020).

In general, the goal of slum upgrading is to address the problem of insanitary and overcrowded housing. Since the 1970s, examples of slum upgrading in the context of international development have focused on building and connecting basic physical infrastructure to dwellings through renowned programs such as the Jakarta's Kampung Improvement Program (Devas, 1981), the Slum Networking in Indore (Dewan Verma, 2000), or the Favela-Bairro program in Rio de Janeiro (Handzic, 2010). The focus on household-level targets has been progressively sharpened at the dawn of the 21st century, accompanied by the drafting of the United Nations' Millennium Development Goals and its operational definition of slums. Specifically, the UN conceives the provision of physical infrastructure and land regularization within slum upgrading as a counterpoint to informal settlements, which are defined as areas that lack basic physical infrastructure (clean water, sewage and electricity) and where substandard and overcrowding housing or insecure housing tenure are prevalent (UN-Habitat, 2003, p. 11). This housing-centered view has been up-scaled from piecemeal project-based improvements to a citywide approach to slum upgrading (CWSU), thereby increasing the scale, synergies, comprehensiveness and responsiveness of slum upgrading (UN-Habitat, 2015). In CSWU, the focus on housing improvements or relocation is broadened to basic infrastructure provision, the removal of environmental hazards, the construction of community facilities, and the creation of incentives to community management or

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the development of social support programs.

Since both piecemeal and citywide slum upgrading interventions occur within the geographical boundaries of informal settlements, they are a form of land-use policy that contribute to land use efficiency (Mao et al., 2020). In the context of land scarcity – a typical problem in many growing megacities – these efficiency increases may however exacerbate 'land sufficiency' problems, namely the urban dimensions of space scarcity and overcrowding in informal areas. Such urban-scale overcrowding not only results in poor access to open, green and pedestrian spaces in informal settlements, but also spatializes the existing social segregation between formal and informal areas. The lack of empirical data on overcrowding at urban scale limits the potential support for redistributive land use policy decisions to complement current slum upgrading initiatives in their effort to achieve the socio-spatial integration of informal and formal urban areas. To address this gap, our paper presents a statistical and spatial analysis of the distribution of urban scale overcrowding across formal and informal areas.

2. Spatial segregation and inequality

The spatial manifestations of social segregation, inequality and informality have been widely studied in urban geography and urban history from the early analysis of cultural and racial segregation in Chicago's North Side (Zorbaugh & Chudacoff, 1929), to the land grabs typical of informal land tenure in early industrial cities (Fischer, 2008), to the decay of urban renewal sites in the US (Martin et al., 2015), or indeed to recent studies on the links between violence, segregation and exclusion in global cities (Chhabria, 2019; Davis, 2006; Wacquant, 2010), to cite only a few. These analyses belong to the broader politicization of the discourses on space appropriation, revolving around concepts such as territorial social justice (Dikeç, 2001), spatial justice (Soja, 2010) and redistributive planning justice (Dadashpoor & Alvandipour, 2020) as well as around the critique of 'spatial fixes' produced by the crises of capital accumulation (Harvey, 1981; Schoenberger, 2004) and spatial inequality (Kanbur & Venables, 2005; Warf & Cao, 2010). This is highly significant in the context of Brazil, where, especially since the mid-20th century, economic growth has been coupled with massive rural-urban migration and a rapid, indeed drastic, transformation of its cities, especially São Paulo (Reid, 2015; Rohter, 2010). As a consequence, the spread of informal urban development in Brazilian cities throughout the 20th century can be taken to represent the particular problems and discontents of such trends (Caldeira, 2012; Fahlberg & Vicino, 2016; Perlman, 2010).

Hitherto, the analysis of spatial inequalities has been limited to describing the effect of socio-economic realities in spatial regions, as in the case of residential segregation and income inequality in European cities (Tammaru et al., 2019), or the relationship between urban morphological patterns and racial, ethnic and household characteristics in the US (Talen et al., 2018). However, urban space is not only a manifestation but also a cause of social and environmental inequalities, realized through processes of urban re-densification and de-densification (McFarlane, 2020). Such 'intrinsically spatial' inequality implies a relational geography of place, space and social dynamics (Graham & Healey, 1999; Jones, 2009) that is especially jarring in urban development and policies affecting informal settlements. These include physical 'avoidance' mechanisms institutionalized in urban development, such as the occupation by affluent populations of terrains with few residential units and low dwelling density, which in the context of urban land scarcity implies the overcrowding of housing areas with liminal areas of public space (Nakano, 2015). 'Avoidance mechanisms' are particularly visible in the case of gated communities in developing contexts (Caldeira, 2012), and in the visual juxtapositions of wealthy/poor and formal/informal residential urban areas (Hooton, 2014; Pomerantz, 2019; Vieira, 2017).

Unfortunately, discussions on the de- and re-densification of informal areas and the urban 'politics of density' remain highly conceptual. Empirical research on housing density in cities with informal areas still show overcrowding as an outlier of the urban system and not as integrally constitutive of the logic of uneven urban development. The gap between theoretical and empirical spatial analyses of uneven urban development limits the application of this concept within policy and practice. Our paper addresses this gap by presenting a relational geographic analysis of urban densities in residential areas in São Paulo, which is taken as a representative example of urban development in the Global South, and where a large housing deficit has been absorbed through informal urbanization. In the accompanying research, we carried out a citywide, statistical and geospatial analysis of population density and distributions of residential built-up types, enabling us to describe the relative prevalence of overcrowding across different built-up types, and the extent to which population densities in informal areas are outliers within the city system. In the following sections, we discuss the relevance of the city of São Paulo as a case study before describing the selection of data for the spatial and statistical analysis of population density, including some methodological limitations. The research workflow is then outlined, followed by a presentation and discussion of results, including key findings, the contribution to the existing literature, policy implications, study limitations and the scope for future research.

3. Methodology

3.1. Study area: São Paulo city

The case study city of São Paulo has a large deficit of formal housing. This shortfall is met through informal urbanization and – despite institutional efforts to overcome precarious housing conditions – through slum upgrading and redistributive policies. According to surveys, approximately 30% of São Paulo's 12 million residents live in precarious housing (Barda, 2011, p. 10), while approximately 11% reside in favelas, which are "precarious human settlements resulting from the invasion of both public and private urban areas" lacking in "almost every element of urban infrastructure and collective equipment" (Lall, 2006). Currently, the metropolitan area of São Paulo has an absolute housing deficit of 331,000 units, the second highest deficit in the country after Rio de Janeiro (FJP, 2021; Furtado et al., 2013).

Since the 1970s, the municipality has developed a plethora of mutual-help housing solutions (*mutirões autogestionarios* in Portuguese) (Arantes, 2002), as well as social housing and slum upgrading programs. In the period 2008–2013, a citywide slum upgrading program in São Paulo (the largest such initiative in Brazil) included the intensive construction of social housing projects, with prominent examples in the districts of Paraisópolis (see Fig. 1) (Pisani & Bruna, 2014), Heliópolis (CAU/BR, 2018) and Cantinho do Ceu (ArchDaily, 2013). Currently, significant less funding has been allocated for slum upgrading programs; however a number of legislative measures such as São Paulo's 2015 Master Plan (Lei no 16.050, Municipality of São Paulo, 2014) and the current zoning law (Lei no 16.402, Municipality of São Paulo, 2016) have ushered in measures aimed at addressing the housing deficit through spatial redistributive policies. In particular, the Master Plan introduces provisions to: a) earmark a share of its urban development fund (FUNDURB) for the acquisition and transformation of buildings in prime locations to social housing; b) double the provision of special zones of social interest (ZEIS) for the establishment of social housing in different regions of the city; and c) create a Solidarity Quota, a development counterpart mechanism that allocates 10% of large housing developments for the promotion of social housing. Additionally, the plan increases floor area ratios (FAR) in ZEIS and in low-rise areas in prime locations, and introduces land value capture mechanisms by introducing tradeable certificates of additional construction potential (*Certificados de Potential Adicional de Construção* or CEPAC for short) in selected areas of Consociated Urban Operations (where urban transformations are promoted by the government in partnership with the private sector).

Fig. 1. Aerial photograph of the favela of Paraisópolis (São Paulo) with social housing projects in the foreground.
Source: Fabio Knoll

Despite such redistributive initiatives, speedy implementation has so far been hindered by budgetary constraints, market pressures and other political priorities, so that affordable housing stocks are not expanding sufficiently to meet the current housing deficit. The city's poor, therefore, are still forced to rely on informal housing.

3.2. Spatial/statistical data and methods

In our analysis we applied standard geostatistical methods to portray the spatial implications of socio-economic inequalities (Todes & Turok, 2018; Zechin & Holanda, 2018). In contrast to other studies, however, population density was taken as a spatial input to describe such inequalities. This enables us to describe the distribution of residential

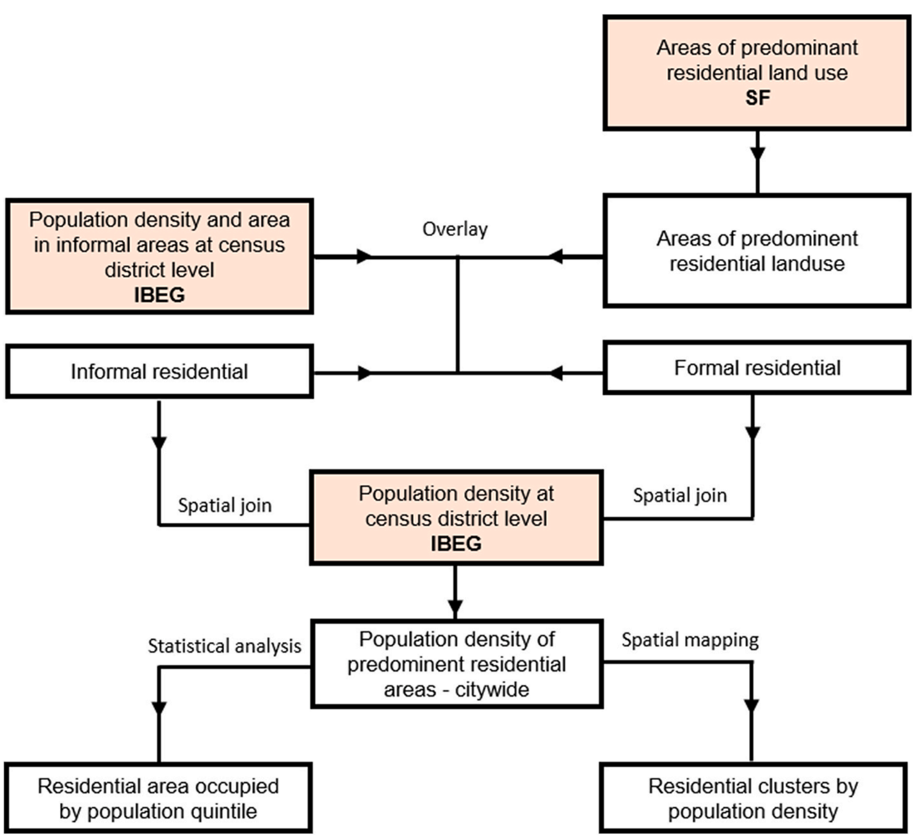

Fig. 2. Data processing and analysis workflow.

space across different residential built-up types. The analysis is two-pronged: first, we conducted a statistical and geospatial analysis to determine the distribution of population densities in different residential land types as well as for informal/formal classifications of residential land (see Fig. 2); and second, we realized a statistical analysis of population densities and residential land use types population density per population quintiles, represented by a Lorenz-curve.

Data on population density in São Paulo was accessed from the freely available geoservices (i.e. WFS) of the Brazilian Institute of Geography and Statistics (IBGE), corresponding to the most recent national census (2010). This dataset contains information on density (specified as the number of inhabitants per hectare) for enumeration districts (*setores censitários*). Additionally, IBGE has a more detailed population density dataset for so-called 'subnormal' agglomerates (*aglomerados subnormais*), which correspond to favelas (ibge.gov.br/geociencias/organizacao-do-territorio/15788-aglomerados-subnormais.html).

Data on residential land use in São Paulo was accessed through two sources. For informal settlements, we obtained spatial data through IBGE's subnormal agglomerates dataset; for formal areas, residential land uses at urban block level were accessed through the open spatial municipal portal Geosampa (geosampa.prefeitura.sp.gov.br). The open geospatial consortium (OGC) standard web feature services (WFS) allow users to download the land use map of an entire municipal area, prepared according to a systematic mapping approach of predominant land use functions, i.e. residential, commercial, etc.

3.3. Key assumptions for data processing

The following criteria were applied when selecting data on land use and built-up areas:

a) Residential built-up types in formal areas were characterized according to São Paulo's predominant land use fiscal cadastral map (Município de São Paulo, 2014), created by the city's Municipal Treasury Department (*Secretaría Municipal da Fazenda* or SF). This identifies 16 forms of land use occupying at least 60% of each identified fiscal unit; in particular, the map features four predominant uses of residential land, which are the focus of this paper. These residential land uses differentiate between residential property types and construction standards, which are used in this paper as proxies for building types and socio-economic sectors. The horizontal and vertical types of residential property on the land use map reflect a municipal decree (Decreto N^{o} 45.817, 2005) that broadly identifies low-rise buildings (with typologies similar to single-family houses) and high-rise buildings (corresponding to apartments in multi-family buildings or independent residential towers). In addition, the SF land use map differentiates between low and medium-high residential standards (*padrões residenciais*). These standards are a composite value used by the Brazilian construction industry (ABNT, 2006) to assess construction cost baselines per square meter *(custo unitario basico*) by taking account of the building area, quality of finish, the presence of elevators, leisure uses and technical infrastructure. This classification was adopted as a proxy for low, medium and high standard socio-economic tiers.
b) Informal areas in São Paulo (the favelas or subnormal agglomerates in this paper) are categorized as containing low-rise buildings. Commonly, more than one family live in the same building, which in many areas have three to five floors (Pedro et al., 2020).
c) Informal areas are categorized as predominantly residential, given their high population density. While the ground floor of some buildings may be used for commercial purposes, the upper floors are generally dwellings.

In deriving results, our study takes into account the limitations of the empirical data. In particular, it is important to note that the IBGE's enumeration districts are bigger than SF's fiscal districts, incorporating areas not used for residential purposes such as large open areas, roads, water bodies and buildings with alternative uses. While this does not affect the census of households, it can influence the estimation of density values, especially in informal areas (Pedro, 2016). In an attempt to avoid this problem, we considered using an alternative spatial dataset, namely the base map of São Paulo's Secretary of Housing (SEHAB), which identifies different informal housing types. Both the SEHAB and IBGE datasets focus on irregular conditions of land ownership, a disorderly urban layout, and the lack of infrastructure and services. However SEHAB and IBGE show certain discrepancies when favela and subnormal agglomerates Basemaps are overlaid: while SEHAB's delimitation of favelas is clearly more accurate (Pedro & Queiroz, 2019), IBGE's dataset provides more accurate population figures in subnormal agglomerates (SEHAB merely estimates the number of households). These conditions limit the accuracy of population density calculations in informal areas and show the relevance of integrating both datasets (Pedro & Queiroz, 2019). Bearing these limitations in mind, we decided to adopt the IBGE data because, firstly, its subdivision into enumeration districts is also applied in other datasets used in this study; secondly, it is the prevalent dataset for scientific research on the spatial distribution of income-based inequalities at municipal level (Zechin & Holanda, 2018); and, thirdly, it provides the empirical data on density required for our analysis. At the same time, it should be noted that the results here represent changing population densities and *not* absolute population figures in São Paulo.

3.4. Data processing and analysis

The distribution of population densities in built-up types of predominantly residential land usage was calculated as follows:

a) A point matrix of IBGE spatial population density data was applied to the formal residential land use areas of the SF map. Several alternative methods were tested here, including the creation of centroids; of these, the point matrix proved the most consistent. At this stage, geometrical overlaps and errors below 0.01 ha were removed from the final selection to avoid misinterpretation of data.
b) A spatial join of IBGE population density data and subnormal agglomerates (with common geometrical codes) provided consistent figures for population density along with the residential built-up types *informal* (low-rise buildings) and *formal* (both low-rise or high-rise buildings, and belonging to low or medium-high residential standards).
c) After creating a joint dataset of population densities in residential built-up types across informal and formal residential areas, a spatial Lorenz-curve was drawn using statistical analysis. To realize this, the *per capita* area (inhab/ha) of residential boundaries was distributed across equal quintiles of the residential population. Each quintile represents the share of the population living in informal and formal areas as well as in horizontal and vertical property types.
d) Finally, predominant formal and informal residential areas were plotted in population density segments corresponding to the population quintiles.

4. Study findings and analysis

4.1. Spatial distribution of population density for residential built-up types

An initial analysis of population densities at municipal level (Table 1) shows the heterogeneity of population densities across built-up types and socio-economic tiers: 16.7% of the population live in subnormal agglomerates of São Paulo, 31.2% live in low-standard formal areas, and 52.1% in medium-high standard formal areas. Informal areas, with an average population density of 435.9 inhab/ha, are significantly more crowded than formal residential ones, although this depends on the built-up type. High-rise residential buildings show a relatively lower density than subnormal agglomerates (317.8 inhab/ha); further, low-

Table 1
Population densities in predominantly residential land uses in the city of São Paulo according to construction standard and built-up type.

		Population (inhab.)					Area (ha.)					Pop. Dens.(inhab./ha.)
		Max.	Mean	Stdv.	Var.	% Total	Max.	Mean	Stdv.	Var.	% Total	Average
Informal residential areas												
Subnormal conglomerates		3183	644	433	187,166	**16.7**	106.07	2.12	4.47	19.96	**10.4**	**435.9**
Formal residential areas												
Low-rise	Low construction std.	6249	134	174	30,402	23.8	165.13	0.81	1.79	3.21	27.2	183.8
buildings	High construction std.	11,422	101	145	21,040	22.6	86.87	0.94	1.25	1.56	39.8	119.6
High-rise	Low construction std.	26,252	845	2134	4,553,742	7.4	45.06	2.21	3.57	12.73	3.6	317.8
buildings	High construction std.	25,032	502	1184	1,402,464	29.5	59.39	1.70	2.63	6.92	18.9	247.1

Source: authors' own preparation using data from IBGE, Geosampa.

rise building types in formal areas have significantly lower densities, particularly for medium-high standard areas, where the average density is almost a quarter that of informal areas (107.3 inhab/ha). Most importantly, the data indicates that informal areas are denser than any other residential built-up type, including high-rise buildings.

Given that the process of estimating these average population densities requires the disaggregation and re-aggregation of spatial data, the results are subject to a degree of uncertainty. In the geospatial sciences, such statistical uncertainty – known as the "modifiable areal unit problem (MAUP)" – is much debated (Madelin et al., 2009; Sikder et al., 2019; Viegas et al., 2009; Zhang & Kukadia, 2005). It appears, for example, if we contrast the figure for average population density of subnormal agglomerates calculated in our paper, namely 436 inhab/ha, with the average population density of favelas determined in a previous study, i.e. 297 inhab/ha (Pasternak & D'Ottaviano, 2016). While acknowledging this methodological problem, we will not discuss it further given that GIS is here applied as an exploratory method to spark a policy debate.

Mapping the distribution of the population density quintiles across São Paulo, we note the prevalence of low-density formal residential areas and high-density informal areas (see Fig. 3). While informal areas have in average densities above 435.9 inhab/ha, with the clear examples of Paraisópolis and Heliópolis around the city center, lower density areas, particularly in the lowest quintile (below 141 inhab/ha), are for the most part formal residential areas. As with informal settlements, such low density areas are spread around the city center, and thus are close to public services.

Fig. 3 also reveals some large peripheral areas of low-density informal housing in São Paulo. As mentioned earlier, this can be attributed to the fact that some subnormal agglomerates contain large and unpopulated open areas, which can be observed through satellite imagery (see Fig. 4). If such open areas were discounted from the analysis, the average population density of informal areas would increase. This bias justifies the exploratory nature of the present study, and indirectly supports our results by indicating a lower threshold for the imbalance of population densities between informal and informal areas.

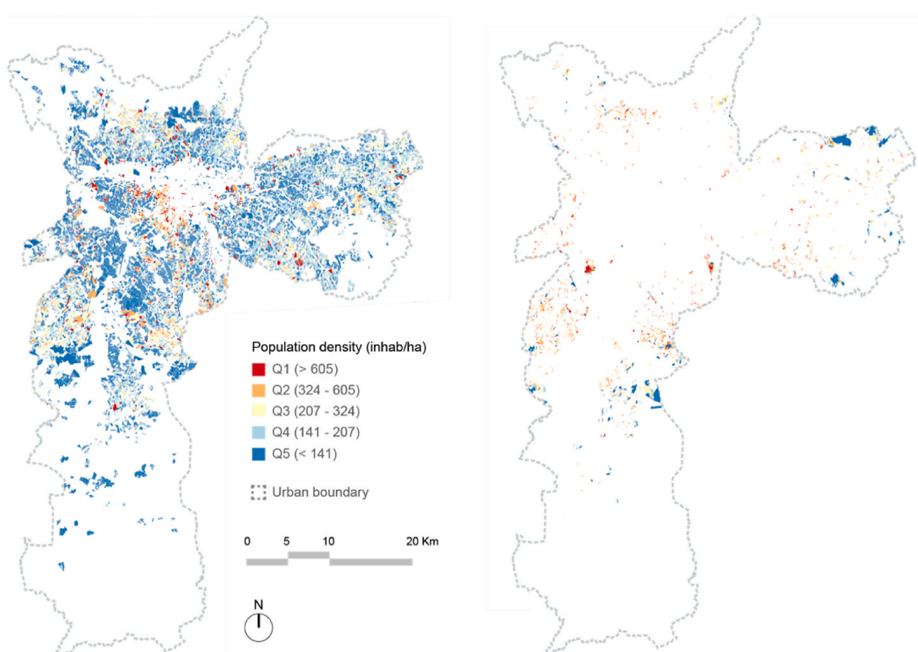

Fig. 3. Population densities of formal/informal residential land uses in São Paulo
Source: authors' own preparation using data from IBGE, Geosampa.

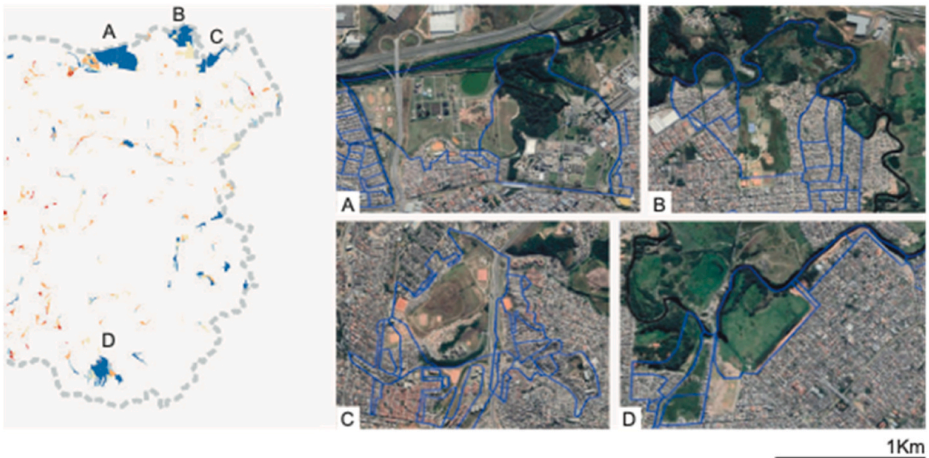

Fig. 4. Location of four IBGE subnormal agglomerations in the northeast of Sao Paulo (left) and satellite images of the clusters with their embedded green areas (right).
Source: authors' own preparation using data from, IBGE, Geosampa, Googlemaps.
Copyright: IOER, Decreto No45.817 no. 45.817, 2005. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

4.2. Inequalities associated with population density and residential land use

Inequality in the distribution of residential space is revealed by the relative proportions of the built-up types in each population quintile ordered by population density (Fig. 5). Informal areas and low-rise buildings with low construction standards cover a wide range of population densities, while low-rise buildings with high construction standards are mostly present as very low density residential areas. This trend is clearest in the case of high-standard, low-rise buildings, which occupy 39.8% of total residential land and is clearly the major building type in the highest population quintile.

The Lorenz-curve in Fig. 5, which represents deviations from equal residential space distributions, shows that the lowest population quintile occupies 3.9% of the total predominantly residential land, while the highest population quintile occupies 50%. This inequality in the distribution of space for residential land is largely predicated upon the prevalence of high-standard, low-rise buildings in this quintile. While this built-up type occupies 28.6% of the total residential land, it houses only 11.2% of the total residential population. In contrast, while informal settlements house a similar population (11.4%), they only take up 4.11% of the total residential land. Thus the land occupation of low-rise, high-standard residential areas is approximately 4 times higher than informal areas.

5. Discussion and policy implications

In this paper, we have examined how population densities are distributed across residential built-up types in São Paulo in order to pinpoint spatialized forms of inequality across the city. Our geo-spatial and statistical analysis of built-up types and population densities revealed overcrowding in informal areas at urban scale and demonstrated the existence of uneven allocations of land to different socio-economic sectors. Low-rise informal areas were found to have the highest average population densities of any residential built-up type, including high-standard and high-rise residential areas (with buildings of up to 20 floors), which on average have only around half of the population density of informal areas. High-standard, low-rise residential areas, on the other hand, occupy almost 40 per cent of all residential land, and are the predominant built-up type of the population quintile

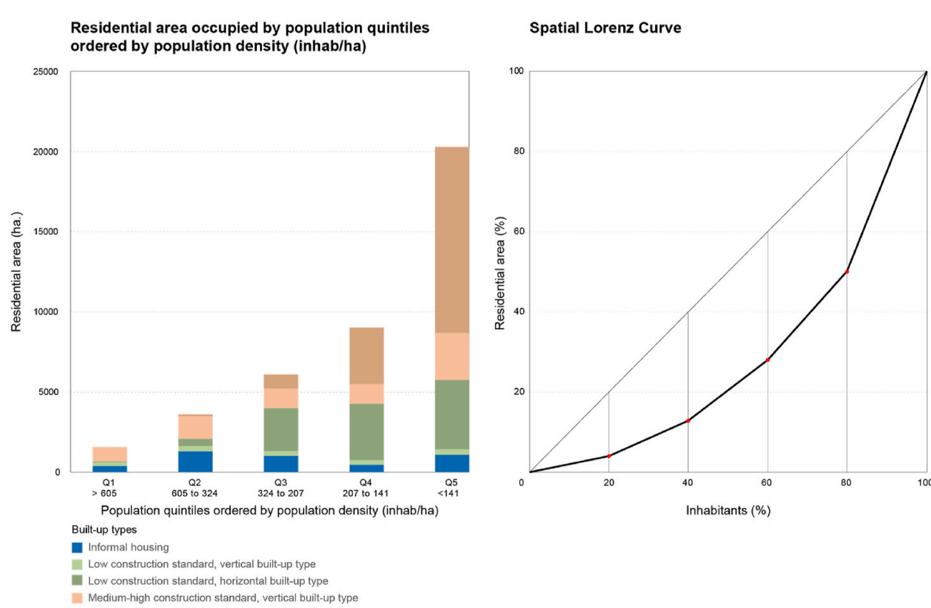

Fig. 5. Areas occupied by residential built-up types in population quintiles (left) and spatial Lorenz curve (right)
Source: authors' own preparation using data from IBGE, Geosampa.
Copyright: IOER, Decreto No45.817 no. 45.817, 2005.

with the lowest population density. These spatial forms of inequality are statistically represented in a spatial Lorenz-curve as a large deviation in the equal distribution of residential space towards high-standard low-rise buildings. This empirically confirms the presence of socio-spatial segregation patterns discussed by Caldeira (2012) and McFarlane (2020).

There is no doubt that the upgrading and regularization of slum areas as well as in-situ social housing programs cannot fully address the spatial segregation suffered by residents of informal areas; nor are high-standard, high-rise buildings able to absorb sufficient numbers of people to reduce the extreme population densities. Instead, our findings point to the need for the local authorities to design and implement spatial redistributive policies aimed at resolving the problem of land scarcity and large housing deficits in São Paulo as well as in similar cities. This is especially urgent given the current low level of political action and small state budgets allocated for policy actions to address uneven urban development and spatial inequality. To reduce the marginalization of informal areas, citywide redistributive land use policies can incentivize a population shift from highly dense, informal areas to less dense, low-rise residential areas, where urban infrastructure is already in place and (in many cases) is underused. The existence of large and well served residential areas with low population densities presents a potential for such redistributive spatial policies. To avoid the poor implementation of such policies, further research is needed to study the institutional and economic implications of redistributive urban planning measures. The analysis of such transformative scenarios and redistributive spatial policies could help practitioners design complementary tools to meet the overarching goal of socio-spatial integration and social justice as well as ascertain how slum upgrading interventions and social housing programs can best address the problem of uneven urban development even beyond the poor availability of small-scale spatial data sources on urban density.

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