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Unravelling urban typologies in Latin American cities: Integrating socioeconomic factors and urban configurations across scales

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ABSTRACT

The complex and multifaceted characteristics of urban expansion contribute to increasing challenges for policymakers in planning and managing metropolitan areas worldwide. Typologies have been helpful in better describing and understanding the differentiated paths of urban development. This research introduces a novel classification that integrates multidimensional growth and development components by employing hierarchical clustering analysis. We present urban typologies at the city and municipal levels for 18 Latin American metropolitan areas, with a total of 253 municipalities. Metrics include built-up area, urban density, fragmentation, compactness and types of new built-up land (infilling, edge extension and leapfrog) and several demographic and economic information. The investigated cities and municipalities revealed varying degrees of compactness or sprawl, with several implications for socioeconomic conditions. Three main types emerged: 1) compact, dense areas associated with wealthier socioeconomic conditions and a trend of sprawl (at the municipal and city levels), 2) dense, infilling areas with vulnerable socioeconomic conditions (at the city level), and 3) fragmented areas with vulnerable socioeconomic conditions (at the municipal and city levels). These types represent a unique combination of urban characteristics, allowing the understanding of the interlinkage of built-up changes with socioeconomic indicators, which can help to identify challenges and opportunities for managing Latin American cities.

1. Introduction

Urbanized areas are highly dynamic and complex systems that require a truly multidimensional understanding of the spatial configuration of built-up areas and socioeconomic characteristics (Krehl & Siedentop, 2019). Worldwide, metropolitan areas are expanding quickly, resulting in increasing suburbanization and peri-urbanization (Kluafus, 2010; United Nations, 2015) as well as densification and transformation of existing urban spaces (Cortinovis et al., 2022; Moreno-Monroy et al., 2021), exhibiting a differential combination of multidimensional drivers. Latin America and the Caribbean (LAC), acknowledged as one of the most unequal regions globally (UN-HABITAT, 2017), is home to a variety of urban typologies characterized by diverse patterns of urban configuration (Horn, 2020; Lemoine-Rodríguez et al., 2020; Piña, 2014) in combination with strong socioeconomic disparities (Bonduki, 2018; UN-HABITAT, 2017, Maricato, 2010). In this context, disempowered or marginalized groups often experience spatial, political, social, bioclimatic, and environmental segregation (Robbins, 2019; Abi Deivanayagam et al., 2023; Anguelovski et al., 2020). Social segregation stems from a complex historical process where injustices in access to urban spaces operate in cyclical and intersectional ways (Maricato, 2010; Kotsila et al., 2023). However, scientific knowledge remains limited regarding the complex multidimensional characteristics of various types of urban expansion (Klaufus, 2010; Shaw et al., 2020), particularly in understanding the spatial arrangement resulting from the intricate interplay between socioeconomic factors and urban configuration.

Urban geography has developed quantitative methods to describe the spatial patterns of urbanized areas by integrating spatial, morphological, social, economic, ecological and cultural factors (Taubenböck et al., 2020). These models classify cities by their centrality (mono- or polycentric) and compactness, and patterns of change, such as

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suburbanization and sprawl, and discuss their trade-offs for urban development strategies. Compact forms and higher densities are associated with higher resource efficiency and reduced travel costs, citizen well-being and social and cultural cohesion (Bibri et al., 2020; LeGates & Sout, 2011; United Nations, 2015). The compact city model has been discussed as a strategy to promote urban development and sustainability (Ahlfeldt & Pietrostefani, 2017; Bibri et al., 2020). Conversely, inhabitants of compact and extremely dense cities in LAC are increasingly exposed to the repercussions of severe climate conditions, such as heatwaves, flashfloods and air pollution, which frequently result in health issues and reduced well-being (UN-HABITAT, 2017). This may lead to inquiries about an optimal density and compactness threshold, particularly concerning major cities in the Global South. Nonetheless, research has documented an increase in land consumption per capita and urban sprawl globally (Behnisch et al., 2022) and in LAC (Inostroza et al., 2013; UN-HABITAT, 2017). Built-up areas are expanding at a faster rate than the population in most regions (Pierri-Daunt, Silva, 2019; Seto et al., 2012), frequently resulting in low-density development, monofunctional land development practices, and the appearance of new subcenters at peripheral locations (Krehl & Siedentop, 2019; Shaw et al., 2020). The highest amount of sprawl has been observed in peripheral areas and edge cities within metropolitan regions (Moreira et al., 2016; Moreno-Monroy et al., 2021). Urban sprawl has numerous socioeconomic and environmental impacts and leads to an overall increase in resource demand, and it is frequently driven by wealthier economic conditions (Behnisch et al., 2022; Jaeger & Schwick, 2014).

The understudied multifaceted characteristics of urban growth might increase the challenges for policymakers (Irazábal, 2015; Krehl & Siedentop, 2019; Shaw et al., 2020), especially in developing effective policies that aim to promote the concept of the "right to the city" (Lefebvre, 2012), spatial justice, human well-being and urban health (Abi Deivanayagam et al., 2023; Anguelovski et al., 2016,2020; Robbins, 2019). Rapid changes in urban configuration and its multidimensional characteristics profoundly impact a city's economic efficiency, social equity, and environmental quality (Wong et al., 2011), altering energy and material flows for critical services like housing, workplaces, and transportation (Seto et al., 2016; Brenner et al., 2024). Consequently, the well-being and health of urban citizens are affected differently by these multifaced characteristics (Anguelovski et al., 2016; Kotsila et al., 2023), especially in a context of socioeconomic disparities such as those found in LAC cities. This trend of rapid urban expansion is expected to continue, necessitating careful consideration of these challenges and inequalities in the region's urban development strategies (Irazábal, 2015; UN-HABITAT, 2017). Therefore, comprehending the intricate multidimensional aspects of a city, integrating both its physical form and socioeconomic characteristics, is crucial for devising informed policies that foster resource-efficient and just spatial arrangements in the future (Brenner et al., 2024; Domingo et al., 2023).

Urban typologies have recently been used to address the multidimensional nature of urban areas: The urban typology approach can help to better assess the complex gradient between urban centers, subcenters and peri-urban areas (Krehl & Siedentop, 2019; Moreira et al., 2016), monitor urban sprawl and intensification processes (Cutsinger et al., 2013), identify types of precarious settlements (Fonseca-Feitosa et al., 2021) and quantitatively describe and compare the patterns of changes in urban form (Hajrasouliha & Hamidi, 2017; Lemoine-Rodríguez et al., 2020; Taubenböck et al., 2020). However, more international comparative research is needed to provide a better understanding of changes in urban patterns (Heider & Siedentop, 2020; Krehl & Siedentop, 2019, Klaufus, 2010), and this particularly applies to LAC countries.

At this background, our study presents a typology that offers a multidimensional characterization of urban expansion patterns, integrating urban spatial metrics with socioeconomic and demographic characteristics. We address the following questions: How have patterns of urban configuration changed over time? What are the main patterns of urban configuration and how do they relate to socioeconomic conditions and demographics? Can we identify similar multidimensional patterns in different countries and cities in LAC and across the two scales of analysis (municipal and city levels)? To assess the general pattern of changes in urbanized areas in LAC, we statistically identified similar cities (city and municipality typology) through data-driven clustering of the combination of socioeconomic, demographic and spatial configurations of built-up areas.

2. Latin American and the Caribbean context: case studies selection

LAC, the world's second most urbanized region, with more than 80% of its population residing in urban areas (World Bank, 2020), faces significant challenges related to informal housing, spatial segregation, access to service and rapid urban expansion (UN-HABITAT, 2017). The rapid expansion of urban areas on city peripheries, both informal and formal, has resulted in densely populated neighborhoods often lacking essential services, health care, and transportation due to limited state presence and public policy shortcomings (UN-HABITAT, 2017). Issues such as waste management, water security, and sewage services have prevailed in LAC (Di Giulio et al., 2017; Teixeira, 2018) requiring monitoring to support policymaking. In general, LAC urban peripheries are home to diverse, often racialized and marginalized populations, including self-identified Afro-descendants, indigenous peoples, women, and immigrants (UN-HABITAT, 2017). In contrast, wealthier socioeconomic conditions are associated with less dense and more fragmented urban forms, often characterized by lower population densities and better service provision (Horn, 2020; Piña, 2014). The narrated complexity of patterns of urban expansion in LAC cities – encompassing rapid expansion, densification, sprawling, diverse socioeconomic characteristics, and the unequal provision of basic services – poses significant challenges for public policy in the region (Irazábal, 2015; Di Giulio et al., 2017; Teixeira, 2018). In this research, we introduce a classification system for LAC cities that integrates these multidimensional components to delineate urban typologies at both the city and municipal levels.

To analyze the variety of socioeconomic characteristics that reflect inequalities and injustices of LAC cities (UN-HABITAT, 2017), we selected population density, percentage of racialized people, sex (Anguelovski et al., 2016; Kotsila et al., 2023), and indicators of human development (Behnisch et al., 2022) and social inequality (Piña, 2014.) as variables. Within the context of social construction, racialized individuals experience vulnerability due to social processes, implying that vulnerability is an outcome (Macdonald et al., 2022). For this reason, we use the term "vulnerabilized" to describe the racialized population in LAC. In addition to socioeconomic data, the provision of basic services is a determining factor in both the quality of life of inhabitants and in identifying urban typologies for LAC realities (Di Giulio et al., 2017; Teixeira, 2018).

In terms of urban configuration, Lemoine-Rodríguez et al. (2020) proposed that LAC cities underwent a combination of compact and fragmented patterns of urban expansion. Studies concentrating on LAC metropolitan areas have consistently revealed noticeable increases in land consumption, urban fragmentation, and the proliferation of urban sprawl (UN-HABITAT, 2017; Horn, 2020; Inostroza et al., 2013; Piña, 2014; Pierri-Daunt, Silva, 2019). Given this variety of urban forms in LAC cities, it is crucial to understand the changes over time in urban compaction, saturation, and fragmentation.

Metropolitan areas can usually be characterized by a densely populated city center and commuting zones, such as satellite towns and semi-urban areas, where the major city often wields a significant socioeconomic influence over the broader region (Moreno-Monroy et al., 2021, OECD, 2022). The OECD (2022) categorized urban areas as follows: Metropolitan areas encompass populations of 500,000 or greater, and medium-sized urban areas fall within populations ranging from 200,000 to 500,000.

We selected all 18 metropolitan areas situated in LAC from the Atlas of Urban Expansion dataset (Angel et al., 2016), along with two medium-sized cities of regional economic significance (Table 1): Leon, the capital of Nicaragua, and Palmas, Brazil. Our sample covers 11 countries across South, Central, and North (Fig. 2A, left) America and hosts 253 municipalities, offering a comprehensive overview of urbanization outcomes in LAC. The case studies were chosen to represent diverse urban configurations and socio-economic realities across various geographies in LAC. This selection includes South American megacities, medium-sized metropolises, and recently urbanized cities in Central America: at the city scale, large metropolitan areas (>1.5 million inh.), i.e., Bogotá, Mexico City, Belo Horizonte, and São Paulo, are expected to be classified as saturated and dense, while exhibiting a trend toward urban sprawl at the edge. In contrast to most LAC megacities, the urbanization process in Central American countries (represented by Guatemala City, Leon and San Salvador) took place at a later stage, with the region predominantly becoming urbanized only in the late 1990s. We expected these Central American cities to be more fragmented and/or sprawled and to have lower levels of basic service provision. At the municipal scale, central municipalities are expected to have greater density, compactness, and better services than satellite municipalities at the edge of metropolitan areas, which may vary widely in density and public service quality.

3. Methods

Data-driven approaches with spatial metrics and comparative research can support the comprehension of urban configuration and functions (Cortinovis et al., 2022; Jehling & Hecht, 2021; Moreira et al., 2016). To assess the multidimensional character of urban expansion in LAC cities, we combined socioeconomic, demographic and spatial configurations of built-up areas. The complete dataset used in this study is available for viewing and free download at: https://doi.org/10.34810/data1851. We assessed the multidimensional character of 18 LAC cities at two scales of analysis (Fig. 2), a city–regional scale (metropolitan) and a municipal scale, aiming to classify, compare and identify cities and municipalities with similar typological features. For this study, we employed the definition of 'city' provided by the Lincoln Institute of Land Policy (LILP) as a settlement with 100,000 or more inhabitants with metropolitan boundaries defined by 'agglomerations of contiguous urban areas (and the open spaces in and around them) that may contain a large number of municipalities' (Angel et al., 2016). Similarly, the UN Statistical Commission (United Nations, 2020) proposed a method to delineate "cities" to facilitate international comparison, which includes densely populated areas beyond municipal (administrative) areas. The same document defines a metropolitan area as "a city and its commuting zone, which consists of suburban, peri-urban and rural areas economically and socially linked to the city".

3.1. *Spatial characterization*

3.1.1. *Built-up configuration dimension*

We used the Atlas of Urban Expansion database provided by the Lincoln Institute of Land Policy (Angel et al., 2016) to characterize the land cover changes in the LAC cities, as well as the new built-up growth and landscape metrics. This dataset includes several metrics for cities distributed globally, derived from cloud-free Landsat images (30 m resolution) from circa 1990, circa 2000 and circa 2015 (Table 2). The UN Statistical Commission endorsed a global definition of cities to facilitate international comparison (United Nations, 2020).

The geographical extent of the studied cities was identified following the Roman tradition of defining a city by the edge of its built-up area (Angel et al., 2016). We calculate the absolute and percentage of changes for both total added area and extent variables. We used three metrics to assess the levels of fragmentation and compactness of the studied cities (only at the city scale).

- Saturation (ranging from 0 to 1: When values are close to 0, cities have more open spaces and, consequently, are more fragmented, or saturation is at a maximum when the urban extent contains no open space);
- the openness index (ranging from 0 to 1: When values are close to 0, cities have less open space and, consequently, are less fragmented);

Table 1
Selected cities and main characteristics. Abbreviations: Central America (CA), North America (NA), South America (SA), human development index (HDI), hectares (ha). Source: Atlas of Urban Expansion database provided by the Lincoln Institute of Land Policy (Angel et al., 2016) and National Census data from each country (see Table 3 and Table A.1 in the Supplementary Material for more information). *Official data published by each country collected at the city level.

City name	Country	Region	Population*	Munic. nº	Urban extent (ha) (2015)	Total Built-up (ha) (2015)	Women %	Indigenous %	Afro-descendants %	Absence of service %	HDI	GINI
Belo Horizonte	Brazil	SA	4372302	11	64551.51	48701.34	51.22	0.14	11.875	5.31	0.738	0.500
Bogota	Colombia	SA	8045222	5	39723.3	31895.37	51.44	0.30	0.900	0.86	0.776	0.443
Buenos Aires	Argentina	SA	12700331	30	193393.62	147305.52	51.43	1.88	0.380	19.75	0.837	0.410
Caracas	Venezuela	SA	2901918	5	24202.35	16351.56	52.02	0.10	47.600	12.12	0.757	0.343
Cochabamba	Bolivia	SA	1141094	7	26294.58	16735.5	51.46	26.69	NA	22.22	0.695	0.485
Cordoba	Argentina	SA	1652943	3	35486.73	24542.19	51.98	1.55	0.280	21.57	0.828	0.371
Curitiba	Brazil	SA	2856866	11	64026.63	44527.32	50.37	0.16	3.362	5.312	0.737	0.461
Florianopolis	Brazil	SA	826584	4	15849.99	10209.78	51.10	0.423	4.563	16.32	0.788	0.451
Guadalajara	Mexico	NA	5079762	6	68815.89	51624.72	50.42	0.52	1.853	0.334	0.780	0.375
Guatemala City	Guatemala	CA	2963609	15	37565.55	26506.44	51.42	16.6	0.207	17.59	0.733	0.514
Leon	Nicaragua	CA	174051	1	2254.77	1543.86	52.55	6.46	NA	15.53	0.745	0.534
Mexico City	Mexico	NA	22081048	60	210019.5	161821.26	51.54	1.38	1.936	1.322	0.782	0.364
Palmas	Brazil	SA	228332	1	6172.11	4228.29	50.58	0.18	9.480	15.36	0.788	0.591
Ribeirao Preto	Brazil	SA	604682	1	15043.95	10916.55	52.01	0.09	6.330	0.825	0.800	0.546
San Salvador	El Salvador	CA	1590438	20	23858.55	16888.59	52.86	0.17	NA	23.76	0.756	0.409
Santiago	Chile	SA	6627012	40	76107.87	60380.91	51.39	10.25	NA	3.813	0.616	0.450
Sao Paulo	Brazil	SA	19388870	31	211907.61	172427.94	51.13	0.11	6.454	6.636	0.758	0.510
Tijuana	Mexico	NA	2049413	2	36542.61	28626.21	49.43	0.79	2.330	2.043	0.783	0.370
Total selected LAC cities			95284477	253.00	1151817.12	875233.35	–	–	–	–	–	–
Average selected LAC cities			10029944.95	26.63	121243.91	92129.83	51.35	3.77	6.97	10.59	0.761	0.452

Table 2
Urban configuration dataset. Land use and cover data (LULC), landscape metrics and new built-up areas were acquired from the Atlas of Urban Expansion (Angel et al., 2016), available at http://www.atlasofurbanexpansion.org/data. Observations: Only the second period (from 2000 to 2015) and the indices calculated for 2015 were used for cluster analysis.

Variable	Abbreviation	Information/description	Unit	Dates	Dates for cluster	Scale
Land use and cover: landscape metrics and new built-up growth						
Total added area	built	Percentage and total of increase in total built-up added area	% and ha of increase	1990–2000 and 2000–2015	–	City
Urban extent	extent	Percentage and total of increase in total urban extent	% and ha of increase	1990–2000 and 2000–2015	–	City
Saturation	fsat	The ratio of the built-up area within the urban extent of the city and its urban extent.	Index between 0 and 1	1990, 2000, 2015	2015	City
Fragmentation: openness index	foi	The average share of open space pixels within the walking distance circle (a circle with an area of 1 km2 and a radius of 564 m) of every built-up pixel within the urban extent	Index between 0 and 1	1990, 2000, 2015	2015	City
Compactness: cohesion index	cci	The ratio of the average beeline distance of all points to all other points in the equal area circle and the average beeline distance of all points to all other points in the urban extent.	Index between 0 and 1	1990, 2000, 2015	2015	City
Compactness: proximity index	cip	The ratio of the average beeline distance of all points in the equal area circle to city hall and the average beeline distance of all points in the urban extent to city hall.	Index between 0 and 1	1990, 2000, 2015	2015	City
Percentage of new built-up pixels classified as						
● Percentage of urban infill	infill	All built-up pixels added in the new period that occupy urbanized open space within the urban extent of the earlier period.	%	1990–2000 and 2000–2015	2000–2015	Municipal and city
● Percentage of urban edge-expansion	edge	Consists of all built-up pixels added in the new period that constitute contiguous urban clusters that are attached to the urban extent of the earlier period.	%	1990–2000 and 2000–2015	2000–2015	Municipal and city
● Percentage of urban leapfrog	leap	Consists of all built-up pixels added in the new period that constitute new contiguous urban clusters that are not attached to the urban extent of the earlier period or to new extension areas.	%	1990–2000 and 2000–2015	2000–2015	Municipal and city

- the cohesion index and the proximity index (ranging from 0 to 1: higher values correspond to urban extents that are closer in shape to a circle, indicating more compact patterns) (Angel et al., 2016).

The LILP dataset classified the new built-up pixels (added pixels) into three classes of built-up expansion: infill, edge expansion and leapfrog. We calculated the percentage of each class per city and municipality. To describe how the built-up configuration has changed over time, we quantified the absolute and the percentage of change for all metrics in Table 2.

3.1.2. Socioeconomic dimension

We accessed information on socioeconomic and demographic conditions as well as basic service provision through national census databases (Table 2) for years ranging between 2010 and 2020, complemented by other sources (Table A.1 in the supplementary material). The data were collected at the municipal scale, and the overall average was calculated at the city scale, except for the GINI index, which was not available at the municipal level.

We calculate the percentages of women, Afro-descendants, and several indigenous ethnic groups. For reasons of international comparison, we combined all indigenous ethnicities into a single group, and we calculated the percentage at the city and municipal scale. As some countries present a clear distinction between mixed ethnicities, or absence of information about Afro-descendants, we combined all racialized communities and often marginalized minorities (indigenous and Afro-descendants) to provide a general characterization of ethnically vulnerabilized people.

To address differences in measurement units, including indices, proportions and densities per unit area, all variables were normalized and standardized from 0 to 1. We computed Pearson correlations between all pairs of variables for both scales of analysis (city and municipality) and discarded the *proximity index* as a measure of compactness, as it showed a correlation coefficient above 0.8 and very similar values to the *cohesion index*, which is also a metric of compactness (Angel et al., 2016).

3.2. Cluster analyses

Hierarchical cluster analysis (HCA) is an unsupervised learning technique utilized to cluster objects based on their similarities and it has gained popularity in various applications due to its interpretability and deterministic nature (Shi et al., 2022). To statistically identify similar development trajectories of cities and municipalities, the following steps were performed: 1) Principal component analysis (PCA) was used to reduce the complexity of our metrics, and we retained variable scores at the nine first PCs (cumulative proportion of 75% of explained variance). PCAs were performed employing the PCA function present in the “FactoMineR” package in R (Lê et al., 2008) in the environment for statistical computing R (R Core Team, 2020). 2). We relied on a set of validation measures to select the optimal clustering number (between three and six) and the best method among Hierarchical Clustering, K-Means Clustering, and K-Medoids (PAM) (Brock et al., 2008) in R (R Core Team, 2020). Hierarchical Clustering, K-Means, and K-Medoids are examples of distinct clustering methods. Hierarchical Clustering builds a hierarchy, starting from individual data points and merging them until all are in a single cluster, making it suitable for small datasets where the number of clusters isn’t predefined (Shi et al., 2022). K-Means divides data into a fixed number of clusters (k) by iteratively updating centroids, making it ideal for larger datasets. K-Medoids, similar to K-Means, represents clusters using actual data points, known as medoids, with the most widely used method being Partitioning Around Medoids (PAM) (Kaufman & Rousseeuw, 1990). Based on the results, we selected the hierarchical cluster (HCA) method and three classes of clusters, as it offered the best inertia gain (See Supplementary Material for the graphical representations of the PCA and dendrogram) 3) HCA: We used hierarchical clustering analysis (HCA) to classify the cities and municipality’s types of urban expansion. We calculated a distance matrix between values of the nine retained PCs (z-scores), employing Euclidian distance and Ward’s agglomeration method (Ward, 1963). Ward.D’s agglomeration method is effective for small datasets in hierarchical clustering, as it minimizes within-cluster variance, producing balanced, well-separated, and homogeneous clusters (Murtagh; Legendre, 2014;

Ward, 1963). Having chosen HCA and working with a relatively small quantitative sample, we deemed Ward's method appropriate for producing homogeneous groups with low internal variability, ensuring greater similarity between cities and municipalities in each cluster. We computed the HCA with three clusters employing the HCPC algorithm present on the "FactoMineR" package in R (Lê et al., 2008), following Husson et al. (2010). 4). We calculate the overall average and standard deviation of all variables for each cluster class. To evaluate the uniqueness of each cluster, we computed a V test assessing the difference between each cluster's average and the overall average for each variable. We repeated this procedure at the municipal scale, especially for validation, as we tested the optimum number only for the hierarchical clustering algorithm, as we judged that it would be more appropriate to use the same method applied at the city scale.

4. Results

4.1. Changes in urban configuration (1990–2000–2015)

Urban landscapes in LAC are diverse and have changed considerably over a recent 25-year period: We quantified an increase of 60% in built-up areas from 1990 to 2000 and 33% from 2000 to 2015. The urban extent increased by 45.02% and 32.31%, respectively. Overall, cities are becoming more saturated and less fragmented (Fig. 1A and B), and this pattern is more clearly observed from 1990 to 2000. We observed some outliers from 2000 to 2015: Cochabamba and Guadalajara became more fragmented, and Ribeirao Preto, Cordoba, Santiago and Cochabamba became less saturated. Conversely, urban population density decreased in most cities, and several cities became slightly less compact (Fig. 1C and D), possibly indicating a sprawling trend (or an early stage of a sprawling). In addition, population growth seems to be an important factor that drives built-up growth Regarding new built-up growth (Fig. 1E), the infilling and edge expansion types were equally the most dominant patterns, with shares of 49.8% and 48.9%, respectively.

4.2. Multidimensional patterns at the city scale

We found three clusters representing groups of cities in terms of urban configuration, demographics, socioeconomic characteristics and basic service provisions:

Cluster 1 (saturated and well-serviced cities): This cluster comprises three Mexican cities and Santiago, Chile (Fig. 2A). These cities showed a notable decrease in population density (−8.4%) from 2000 to 2015 (Table 4). They also had the lowest percentage of the population without basic services (1.9%) and the highest proportion of leap-frog urban growth (2.9%), although this was relatively low. These cities are the most saturated on average (0.77). Although not statistically significant, Cluster 1 exhibited the lowest GINI index (0.39), indicating lower income inequality and the lowest percentage of vulnerabilized populations (4.8%). They also had the highest proportion of urban extension growth (59%).

Cluster 2 (vulnerabilized and dense cities): Seven cities were grouped in Cluster 2, including five Brazilian cities, Caracas, and Bogota (Fig. 2A). These cities experienced the greatest increase in population density (6.6%) (Table 4). They hosted the highest percentage of vulnerabilized people (42.8%) and the highest proportion of infilling built-up growth (60.2%). Although not statistically significant, these cities showed the highest income inequality (Gini index = 0.48).

Cluster 3 (low-service and fragmented cities): This cluster comprised seven cities, three from Central America and four from South America (Fig. 2A). These cities had the highest percentages of women (51.8%) and indigenous people (7.7) in their populations (Table 4). They also had the highest proportion of the population lacking basic services (19.5%), specifically water provision (29.3%), and were the most fragmented (0.25%), although this indicator was not significant. Despite this, these cities presented a decrease in population density (−8.3%), as also found in Cluster 1, and primarily exhibited infilling and extension development patterns. They were characterized by fragmented urban development with limited access to services.

4.3. Multidimensional patterns at the municipal scale

Due to data limitations in certain municipalities, some were excluded, resulting in a consideration of 213 municipalities out of the initial 253 at the city level. Data for municipalities in the Buenos Aires, Cordoba, and Caracas metropolitan areas were inaccessible at the municipal level and, therefore, not included at this scale. Overall, the patterns at both scales showed general similarities with a few distinctive characteristics. In the cities of Clusters 1 and 2 (city-level), the core city (or city) falls into Cluster 4, and commuting municipalities are mainly represented by Cluster 5. Conversely, in cities in Cluster 3 at the city level, commuting municipalities are classified under Cluster 6 (Fig. 3).

Cluster 4 (central, infilling, dense and well-serviced municipalities): The municipalities belonging to Cluster 4 presented the highest population density (84 persons/hectare), the highest percentage of women (52.1%), and good service provision (Table 5). In terms of urban configuration, these municipalities presented the highest percentage of the infilling urban growth type (79.2%) and the lowest percentage of the extension (19.9%) and leapfrogging patterns (0.9%), which are typical features associated with central areas. Dense patterns seem to support better services, and still, the vulnerabilized population seems to constitute a small proportion of the municipalities in these types of cities (see Table 5).

Municipalities in Cluster 5 (building up at the edge and vulnerabilized) present the greatest increase in the percentage of new built-up areas (30.5%), which is dominantly an extension pattern (50.7%). This cluster also shares some similarities with Cluster 4, as it presented a low proportion of the population without basic services (Table 5), and with Cluster 6, presenting a high percentage of the vulnerabilized population (22.5%) and a high percentage of new built-up area classified as leapfrogging (23.1%). Municipalities categorized as Cluster 5 were frequently situated in the commuting zones of Clusters 1 and 2 or were the main unique patterns in Florianopolis, Leon, Palmas and Tijuana.

The municipalities in Cluster 6 (expanding, marginalized and low-density) were characterized by the highest proportion of indigenous people and the second highest proportion of vulnerabilized people, as well as the highest proportion of absent basic services, the lowest HDI and the lowest population density (Table 5). Regarding urban configuration, these municipalities present the highest proportion of extension patterns (52%), the lowest infill, and the highest proportion of leapfrogging (25.4%), similar to Cluster 5, although not significantly. Municipalities categorized as Cluster 6 are frequently located in the commuting zones of Cluster 3 cities or at the outskirts of Cluster 1 at the city level.

5. Discussion

Regarding our first question *(how have patterns of urban configuration changed over time?*), our findings indicate that built-up areas experienced more and faster growth from 1990 to 2000 than from 2000 to 2015. This is in line with Taubenböck et al. (2024) who found decreasing growth rates of urban areas in different world regions over a period of 30 years. Across LAC cities, there is an increasing trend toward greater compactness, primarily driven by extension and infilling urban growth types. However, population density is decreasing in most cities, which may indicate an increase in land consumption per capita and the emergence of a sprawling trend, as observed in several South American cities (Horn, 2020; Inostroza et al., 2013; Piña, 2014, Pierri-Daunt and Silva, 2019, and globally (Xu et al., 2020).

Our study supports a better understanding of spatial arrangements from the interplay between socioeconomic factors and urban configuration dimensions across the two scales of analysis: Cities and

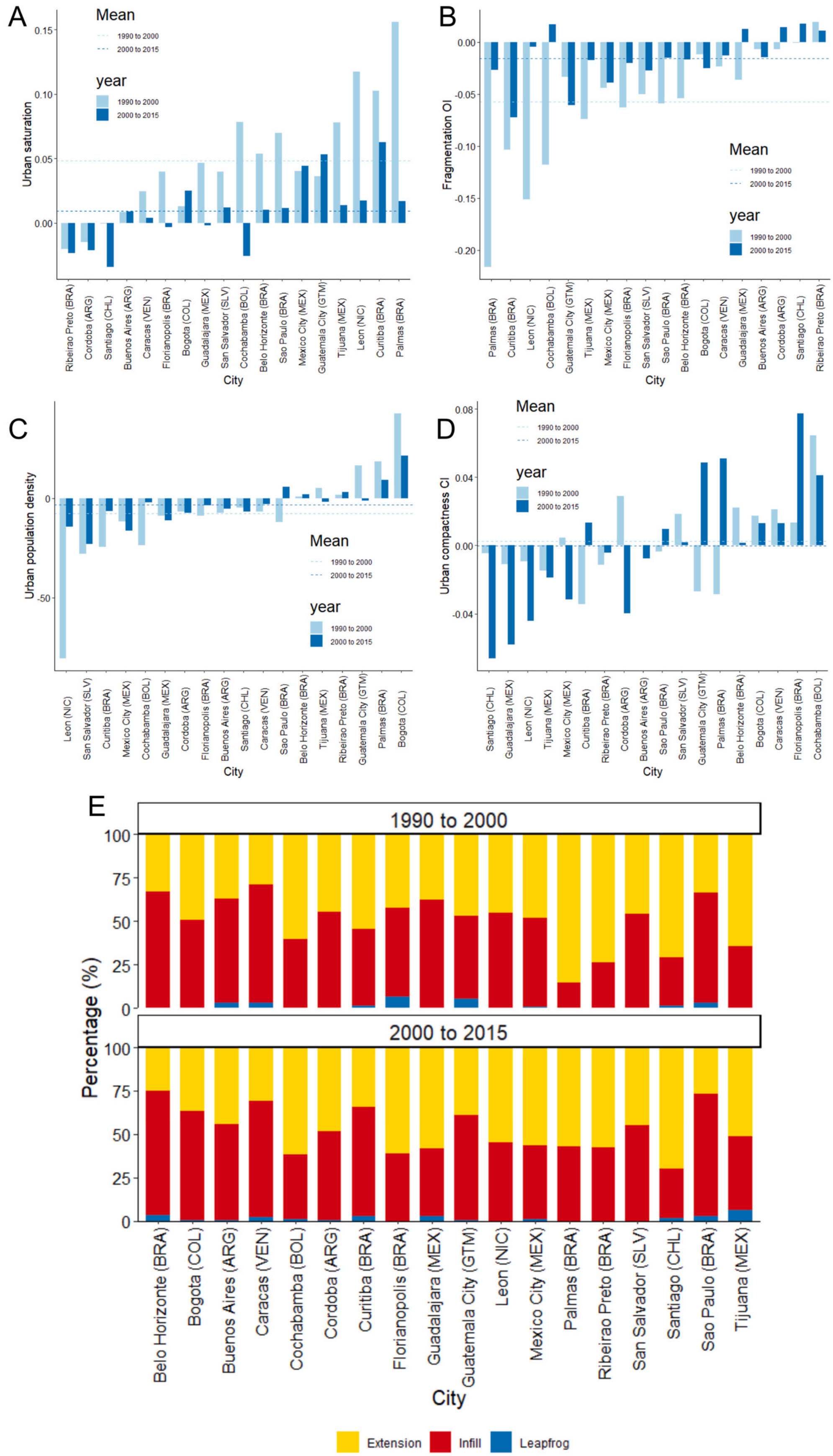

Fig. 1. Built-up configuration. A) Saturation, B) fragmentation, C) urban population density, D) urban compactness (cohesion index), and E) percentages of new urban growth.

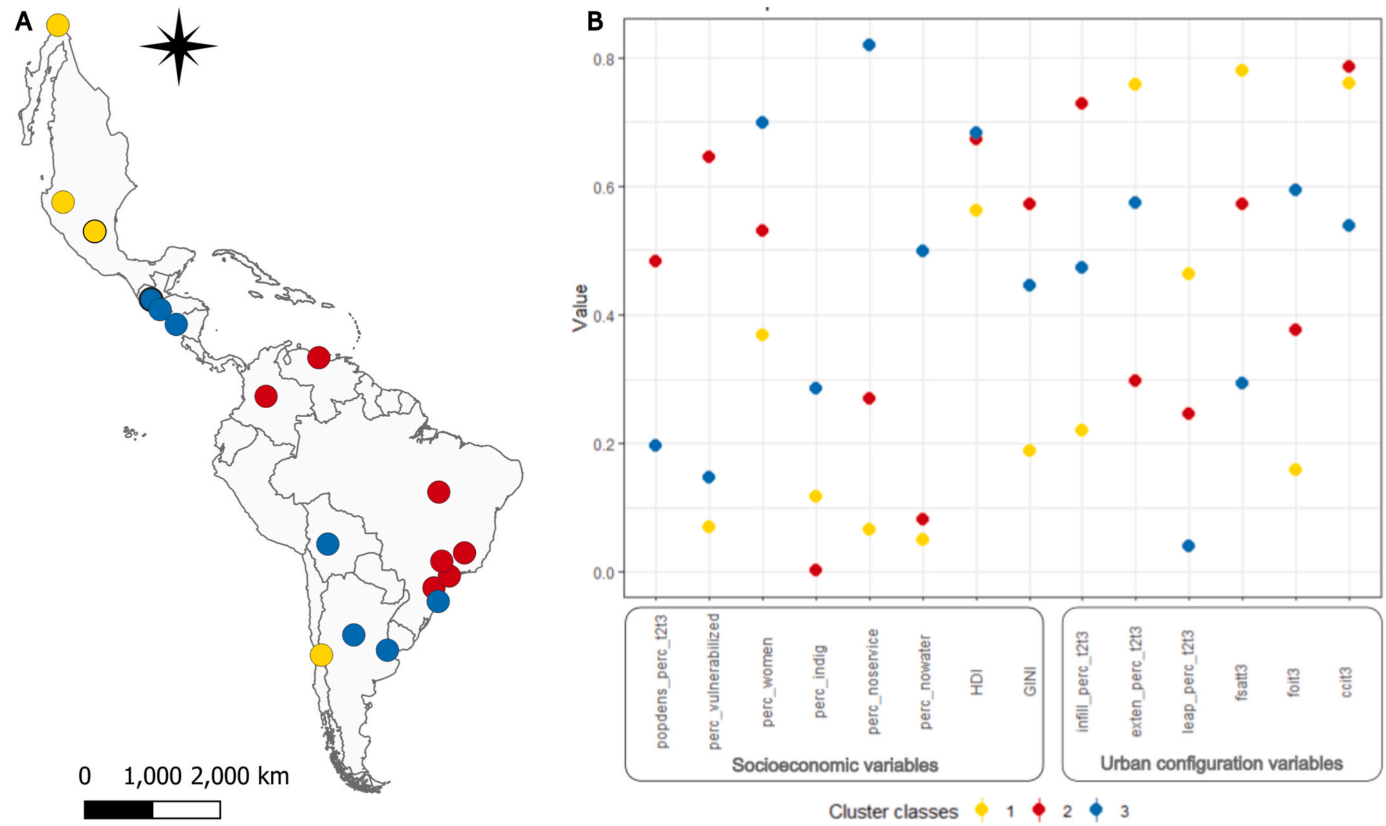

Fig. 2. Studied cities classified using hierarchical cluster analysis (left); The overall average of the variables per cluster class (right). The values were normalized and standardized (from 0 to 1). Variables for which the points are close to each other are less discriminant than those for which one or two of the points are separated from the rest.

municipalities revealed varying degrees of compactness or sprawl, with several implications for socioeconomic conditions. Surprisingly, the patterns at both scales were generally similar, with a few idiosyncrasies. This led us to identify three primary categories that guided our discussion, which were found in both scales of analysis: 1. Compact and dense forms with a trend of sprawling and wealthier socioeconomic conditions (Clusters 1 – city and 4 – municipal), 2. infilling and dense forms with vulnerable socioeconomic conditions (Cluster 2, city-level), 3. fragmentation with vulnerable socioeconomic conditions (Cluster 3 – city and Clusters 5 and 6 – municipal). Our study thus challenges the narrative of global "homogenization" of urban configurations (see also Taubenböck et al., 2020), showing that LAC cities experience mixed processes that combine both compact and fragmented patterns of expansion (Lemoine-Rodríguez et al., 2020).

Clusters 1 (saturated and well-serviced), 2 (vulnerabilized and dense cities), and 4 (central, infilling, dense, and well-serviced) included more compact and dense cities and municipalities, each with varied socioeconomic characteristics. In Cluster 1 and 4, compact patterns supported better service provision, lower inequalities a higher HDI. As introduced, compact and dense urban forms are suggested as a model to promote greater resource efficiency and reduce travel costs, citizen well-being and social and cultural cohesion (Bibri et al., 2020; LeGates & Sout, 2011; United Nations, 2015). Conversely, better socioeconomic conditions (indicated here by higher HDI values) have globally been associated with the sprawling process (Behnisch et al., 2022), urban expansion (Piña, 2014) and increased land consumption per capita (Inostroza et al., 2013, Pierri-Daunt, Silva 2019). While the percentage of leapfrogging patterns is proportionally low at the city scale but not at the municipal scale, some cities are expanding on their outskirts, and population density has decreased. For this reason, Cluster 1 may be witnessing the beginnings of a sprawling process in the outskirts of the three Mexican cities (Cluster 5) and Santiago, Chile (Cluster 6). This implies that oversaturated high-cost metropolitan areas may be experiencing expansion and sprawling processes. Nonetheless, vulnerabilized populations still existed in much lower percentages in Clusters 1 and 4. Research focusing on cities in the Global South has consistently demonstrated a discernible trend characterized by increased land consumption, urban fragmentation, and sprawl (UN-HABITAT, 2017, Horn, 2020; Inostroza et al., 2013; Piña, 2014; Pierri-Daunt & Silva, 2019).

Cluster 2 consists of compact cities that are densifying, such as the five Brazilian cities, Caracas, and Bogota, which mainly exhibit infilling and extension built-up type. These cities have the highest concentrations of vulnerabilized populations and inequality indices. Most likely, these cities are experiencing densification of preexisting urban peripheries or edge municipalities (cluster 5), both informal and formal settlements. Moreover, recent urban studies (Benach, 2021) have pointed out that areas that were once referred to as 'urban peripheries' are no longer situated at the city's edge. Contrary to the expectations of the urban compactness model discussed above, limitations to social, political, and accessibility to urban resources persist in these areas. Across cities in LAC, the coexistence of a substantial vulnerabilized population and pronounced income inequalities, measured by the GINI index, is well documented (Piña, 2014). This phenomenon is prevalent in LAC, recognized as one of the most unequal regions globally (UN-HABITAT, 2017), with countries such as Colombia and Brazil often leading in inequality rankings.

Conversely, fragmented and leapfrogging clusters (3, 5 and 6) appear to exhibit fewer affluent characteristics than compact Clusters (1 and 4) based on the metrics applied in our study. The three Central American cities and Florianópolis (Cluster 3) showed increasing compactness despite the highest fragmentation degree, which was driven by extension and infilling in built-up areas. These cities had poor service

Table 3
Socioeconomic dimension. The demographic, sex, ethnic group and basic services data were acquired from the National Census of all eleven countries. *All data from the National Census refer to permanent inhabitants, and the date of the National Census varied from country to country (see Table A.1 in the supplementary material for details regarding the sources and dates). **Basic services provision: As we could not access all the services for every city, we grouped them into an average measurement to allow comparison. *** HDI and GINI were acquired from several sources and dates (see Table A.1 in the supplementary material). Variables with missing data were excluded from the analysis: Percentage of Afro-descendants, waste, sewage and electricity service provision.

Variable	Abbreviation	Information/description	Source/data origin	Scale
		Demographic includes sex, ethnic proportions		
Total population	tot_pop	Total inhabitants per municipality and city	National Census*	Municipal and city
Urban population density	popdens_perc	The ratio of the total population of the city and its built-up area, measured in persons per hectare. We calculate the percentage of change	Atlas of Urban Expansion (Angel et al., 2016)	City
Population density	pop_dens	The ratio of the total population of the municipality and its municipality area, measured in persons per hectare	National Census*	Municipal
Percentage of women	perc_women	Percentage of women	National Census*	Municipal and city
Percentage of indigenous	perc_indig	Self-declared member of an indigenous ethnic group	National Census*	Municipal and city
Percentage of Afro-descendants	perc_afro	Self-declared Afro-descendants	National Census*	Municipal and city
Percentage of vulnerabilized communities and minorities	perc_vulnerabilized	Average of all vulnerabilized communities and minorities (indigenous people and Afro-descendants) per municipalities and city	National Census*	Municipal and city
		Basic services **		
Waste service provision	perc_nowaste	Percentage of the population without waste service provision per municipality and city	National Census *	Municipal and city
Sanitation (sewage) service provision	perc_nosewage	Percentage of the population without sanitation (sewage) service provision per municipality and city	National Census *	Municipal and city
Water service provision	perc_nowater	Percentage of the population without water service provision per municipality and city (threated and piped water)	National Census *	Municipal and city
Electricity service provision	perc_no_eletricity	Percentage of the population without electricity service provision per municipality	National Census *	Municipal and city
Public service provision	perc_noservice	Average over all services	National Census *	Municipal and city
		Socioeconomic ***		
Change in human development index	HDI	HDI per municipality and city	National Census *	Municipal and city
Gini coefficient	GINI	GINI (distribution of income across a population) per municipality and city	See Table A SM	City

Table 4
Average per cluster, overall average, and standard deviation of the variables within each cluster class. Red: variables for which a cluster has a significantly higher average than the overall average; Blue: variables for which a cluster has a significantly lower average than the overall average. We show the unstandardized values to allow better interpretation. We applied the V-test with the variables normalized and standardized from 0 to 1. P-values were determined by applying a V–test for P < 0.05*, P < 0.01** and P < 0.001***. Table 1 shows the variable descriptions.

Variable code	Cluster 1	Cluster 2	Cluster 3	Overall average	Overall standard deviation
popdens_perc	-8.40	6.63**	-8.34	-2.53	11.68
perc_vulnerabilized	4.76	42.76**	9.91	21.54	23.64
perc_women	50.70	51.25	51.83	51.35	0.82
perc_indig	3.24	0.16	7.68	3.77	7.23
perc_noservice	1.88*	6.63	19.54***	10.59	8.46
perc_nowater	3.03	4.92	29.31**	13.98	19.00
HDI	0.74	0.76	0.77	0.76	0.05
GINI	0.39	0.48	0.45	0.45	0.07
infill_perc_t2t3	38.07*	60.15*	49.02	50.92	12.88
exten_perc_t2t3	59.02	38.31*	50.73	47.74	13.19
leap_perc_t2t3	2.91*	1.55	0.25*	1.34	1.69
fsatt3	0.77*	0.74	0.69*	0.73	0.05
foit3	0.17	0.21	0.25**	0.22	0.06
ccit3	0.84	0.84	0.78	0.82	0.07

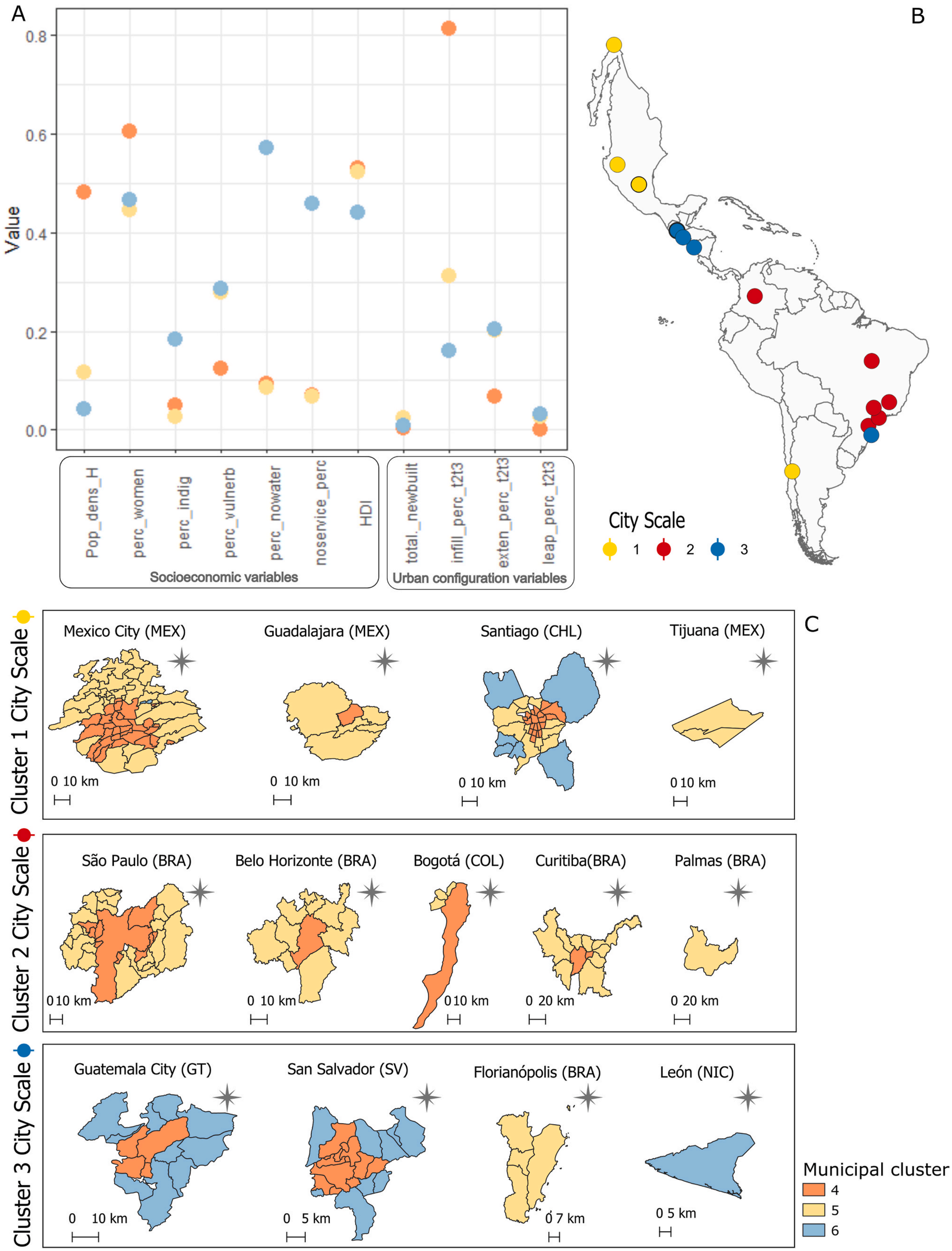

Fig. 3. A) The overall average of the variables per cluster class at the municipal scale. The values were normalized and standardized (from 0 to 1). B) Location of city-level typology. C) Municipal-level typologies: examples of LAC metropolitan areas organized by typologies at the city level.

Table 5
Average per cluster, overall average, and standard deviation of the variables within each cluster class. Red: variables for which a cluster has a significantly higher average than the overall average; Blue: variables for which a cluster has a significantly lower average than the overall average. We show the unstandardized values to allow better interpretation. We applied the V-test with the variables normalized and standardized from 0 to 1. P-values were determined by applying a V–test for $P < 0.05^*$, $P < 0.01^{**}$ and $P < 0.001^{***}$. Table 1 shows the variable descriptions.

Variable code	Cluster 4	Cluster 5	Cluster 6	Overall average	Overall standard deviation
pop_dens	83.58**	18.93**	7.40***	36.64	41.06
perc_women	52.08	50.93	51.31	51.44	0.59
perc_indig	3.58	2.00***	14.55***	6.71	6.84
perc_vulnerb	11.54**	22.53**	16.60*	16.22	5.67
perc_nowater	4.36**	2.77***	25.23***	10.79	12.53
noservice_perc	6.56***	6.06***	46.72***	19.78	23.33
HDI	0.752	0.741	0.695**	0.730	0.03
total_newbuilt	6.35	30.43*	12.99	19.42	17.22
infill_perc_t2t3	79.26**	30.43**	19.68***	43.12	31.75
exten_perc_t2t3	19.85**	50.70**	52.05**	40.87	18.21
leap_perc_t2t3	0.89**	26.15*	25.36	17.47	14.36

provision and a high proportion of indigenous populations. A common thread across Central American cities arises from sociospatial divisions within cities and late and rapid urbanization. Factors such as land markets, insecurity, mobility, and income inequality have led to contrasting neighborhoods, perpetuated poverty cycles and territorial inequality, limited access to the city's rights and worsening social disparities in Central America (UN-HABITAT, 2017).

Regarding internal patterns in metropolitan areas, the fastest changes in built-up areas and population growth have been observed in commuting areas, such as peri-urban settlements and edge municipalities (Moreira et al., 2016; Moreno-Monroy et al., 2021). Unlike central municipalities (Cluster 4), the municipalities categorized as Clusters 5 and 6 are situated on the outskirts of cities (Fig. 3), where built-up areas primarily expand through extension and leapfrogging. These municipalities hosted the highest proportions of vulnerabilized people and exhibited the poorest public service and the lowest HDI (Cluster 6), indicating a significant socioeconomic core-periphery gradient. Historical disparities in opportunities for women and indigenous and Afro-descendants populations may have led to their spatial, social and political exclusion (Bonduki, 2018; Maricato, 2010; Robbins, 2019). As a result, we observed that cities and municipalities with greater proportions of vulnerabilized populations had the lowest rates of service provision, highest income inequalities (Gini), and lowest HDIs and were often more fragmented and/or that urban expansion was characterized by extension and leapfrog development patterns. These patterns appear at both the city (Cluster 3) and municipal levels (Clusters 6 and 5), more pronounced in the municipalities in Cluster 6 on the edge of Cluster 3. However, it is essential to note that these populations are not necessarily concentrated exclusively in the outskirts areas without services, as we did not test the relationship spatially.

Our analysis suggests that urban development in LAC follows cyclical patterns, making it crucial to understand both scales of analysis. More compact cities (Cluster 1) tend to spread out, while fragmented, recently urbanized cities (Cluster 3) and municipalities (Clusters 5 and 6) tend to densify. Compact cities span edge municipalities, which have different socioeconomic characteristics and densify over time. Central municipalities in LAC cities (Cluster 4) have higher densities, better socioeconomic conditions, and better service provision than peripheral ones. Our findings raise a fundamental question regarding the drivers and consequences of urban sprawl and fragmentation in the LAC region, as these configurations potentially pose greater challenges for service provisions and citizen's well-being in the future (UN-HABITAT, 2017). It also reiterates the discussion about the trade-offs of the compact urban development model, given that compact clusters differ significantly in demographics, socioeconomics, and service provision. Although we were not able to explain the causes of these urban development patterns in detail, possible explanations can be suggested by analyzing the interactions between urban configuration, socioeconomic factors, and service provision. Global sprawl in high-density, compact areas (Cluster 1) is driven by favorable socioeconomic conditions (Behnisch et al., 2022; Inostroza et al., 2013). High land prices (and associated housing costs) in central areas may exclude certain populations, and favorable economic conditions might attract investments, influencing land markets and increasing peripheral built-up land (Jia et al., 2020). In contrast, the expansion followed by densification of disadvantaged, fragmented settlements (Clusters 5, and 6) results from historical processes (Maricato, 2010; Horn, 2020) where disparities in access to central and well-served areas persist through cyclical and intersectional dynamic (Maricato, 2010; Kotsila et al., 2023).

Previous research highlights the necessity for more international comparative studies on urban spatial structure and typologies (Klaufus, 2010; Krehl & Siedentop, 2019; Heider, Siedentop, 2020; Taubenböck et al., 2020). Our study addressed this gap by offering an international and continental comparative typology that guided our identification of three narratives at both city and municipal scales, potentially shaping continental actions toward shared objectives for LAC cities. However, the scale of analysis poses limitations, as socioeconomic data were aggregated at the municipal level, potentially masking intermunicipal inequalities. While most research investigating these internal patterns of urban typologies has been conducted in Europe (Brenner et al., 2024; Domingo et al., 2023; Krehl, Siedentop, 2019), the focus has primarily been on urban configuration alone. Limited research has been conducted in LAC, especially in terms of integrating urban configurations with socioeconomic data. This creates an opportunity for further research to explore these typologies at the local neighborhood scale.

The national context can influence urban typologies (Heider, Siedentop, 2020; Taubenböck et al., 2020), as seen with the placement of Mexican cities in Cluster 1 and Brazilian cities in Cluster 2, which may reflect differences in census data variables such as ethnic proportion, human development index, GINI, and basic service provision. We mitigated these differences through meticulous preprocessing, class aggregation, and percentage calculations for compatibility, as detailed in the methodology. Additionally, incorporating additional variables, such as sprawling indices (Brenner et al., 2024; Jaeger & Schwick, 2014), vertical patterns of built-up expansion (Domingo et al., 2023), and income (Bayón & Saraví, 2013) or employment distribution metrics (Heide; Siedentop, 2020), could yield alternative typologies. However, our focus on international and continental comparisons led us to utilize existing official data.

Although most LAC cities have overcome the rapid change phases driven by rural–urban migration and rapid natural population growth, challenges inherited from this period of rapid growth persist, and new challenges are imposed to ensure quality of life, access to basic services and sustainability, increasing governance complexity (Bonduki, 2018; Maricato, 2010; UN-HABITAT, 2017). On the other hand, this recent and ongoing demographic shift, marked by a deceleration in population growth, offers a significant opportunity for a structured and sustainable urban transition in LAC (UN-HABITAT, 2017). Typology studies serve as an effective methodological tool for analyzing complex urban phenomena, facilitating comparisons and elucidating interaction effects without oversimplification.

Moreover, the discussed typologies offer unique insight into the interlinkage of built-up changes with socioeconomic indicators, providing a deeper understanding of urban dynamics that can help to identify challenges and opportunities for managing LAC cities. The implications of these interconnected patterns for residents' well-being and policymaking vary significantly. For instance, spatial planning strategies for Clusters 1 and 4 should aim to avoid sprawl, while Clusters 2, 3, 5 and 6 require policies promoting access to urban services, well-being, and justice. Furthermore, similar findings and typologies are anticipated in other LAC urban areas, thereby supporting policymakers in addressing key priorities (Cohen et al., 2019; Inostroza, 2017). In this sense, our results could also provide a basis for regional and municipal planning. Examples include the development of upgrading plans for disadvantaged neighborhoods and planning strategies for effective densification to increase infrastructure efficiency and social integration. Typology approaches could also help to establish location-specific development agendas or funding schemes that can be used to respond more precisely to the "typical" framework conditions, challenges and potentials of certain urban areas. Finally, a multi-criteria typology of cities and neighborhoods can be a component of a comprehensive socio-spatial monitoring approach. Such monitoring can serve both to observe the performance of a specific type (cluster) over time and to interpret transitions of a city/neighborhood from one type to another in terms of the need for political action.

6. Conclusions

Regarding our goal to describe whether patterns of urban configuration have changed over time, our study indicates that LAC cities, which are generally compact, are experiencing a decrease in overall density. We could suggest that the urbanization process can be cyclical, as we found compact clusters with a trend of sprawling and fragmented clusters with a trend of compacting and densifying. Recent demographic studies have pointed to a stabilization of the population in LAC and a significant increase in land consumption and sprawl, and different processes may alter the patterns we have identified here in the future.

One of the main findings of our study is that the analysis and evaluation of changes in urban structure and form must not be separated from socio-spatial developments. Cities and municipalities with a greater proportion of vulnerabilized people tend to have fewer basic services available, lower human development indices and/or greater income disparities and are more often fragmented and/or expanding. While social disparities also exist in compact cities, wealthier compact cities seem to be experiencing sprawl. In LAC, the way in which cities develop outwards and inwards is inherently linked to issues of spatial justice, in particular access to housing and urban infrastructure for different social groups, showing that socio-spatial segregation in access to central and well-served areas persist through cyclical and intersectional dynamics. In this respect, our study has contributed to filling the gap between "urban sprawl" analyses and the debate on the "right to the city".

The lessons learned from past processes in the region can guide new challenges that will arise during the next decade for LAC cities: our study prompts the question of whether the compactness model is the most suitable approach for planning cities in LAC, suggesting that specifically avoiding sprawl, limiting the increase in land consumption per capita in order to balance the overall city population density and guarantee the access to well-served areas, could be a better strategy to move towards more spatially just cities and adequately promote the right to the city.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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CRediT authorship contribution statement

Ana Beatriz Pierri-Daunt: Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Stefan Siedentop:** Writing – review & editing, Writing – original draft, Conceptualization.

Declaration of AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT, DeepL and Grammarly (free versions) to improve the readability and language of the manuscript. After using these tools, the authors reviewed and edited the content as needed and took full responsibility for the content of the publication.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.apgeog.2024.103460.

The complete dataset and results are available for download at https://doi.org/10.34810/data1851.

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