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State-of-the-Art and Framework for Identifying Urban Patterns by Remote Sensing Data

O Estado da Arte e um Modelo para Identificar Padrões Urbanos através de Dados de Sensoriamento Remoto

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Abstract: The increase in the spatial resolution of satellite imagery and the greater distribution of data have enabled the use of remote sensing for urban studies. However, there is still a lack of databases and cartographic publications for cities in the Brazilian Amazon. Thus, the following questions guided this work: what is the state-of-the-art in remote sensing to identify urban patterns in Brazil? Do these urban patterns equally cover all Brazilian regions? How to identify urban patterns in different contexts, such as the Amazon urban region? To this end, we conducted a review of publications that have identified urban patterns in Brazilian cities and put forward an identification model. For the most part, we observed that the works found analyzed small areas in São Paulo cities, using visual interpretation in private access and high spatial resolution imagery. To cover this gap, we propose a framework to identify Urban and Socio-Environmental Patterns based on remote sensing data, Voluntary Geographic Information data and census data. Although the framework can be applied in all regions of Brazil, the focus of the classification model is on Amazonian cities.
Keywords: Urban and Socio-Environmental Pattern. Intra-urban Scale. Urban Remote Sensing. Urban Fabric. Urban Settlements.

Resumo: O aumento da resolução espacial das imagens de satélite e a maior disponibilidade de dados possibilitam o uso do sensoriamento remoto para estudos urbanos. No entanto, ainda se percebe uma carência de bases de dados e publicações cartográficas para as cidades da Amazônia brasileira. Com isso, as seguintes perguntas guiaram este trabalho: qual é o estado da arte em sensoriamento remoto para identificar padrões urbanos no Brasil? Estes padrões urbanos abrangem igualmente todas as regiões brasileiras? Como identificar padrões urbanos em diferentes contextos, como o da região urbana da Amazônia? Para tal, realizamos uma análise das publicações que identificaram padrões urbanos em cidades brasileiras e propomos um modelo de identificação. Em sua maioria, observamos que os trabalhos encontrados analisaram áreas pequenas em cidades paulistas, utilizando a interpretação visual em imagens de acesso privado e de alta resolução espacial. Para cobrir esta lacuna, o propomos um modelo teórico para identificar Padrões Urbanos e Socioambientais com base em dados de sensoriamento remoto, dados de Informações Geográficas Voluntárias e dados censitários. Embora o modelo teórico tenha possibilidade de aplicação em todas as regiões do Brasil, o foco do modelo de classificação é a aplicação em cidades amazônicas.
Palavras-chave: Padrão Urbano e Socioambiental. Escala Intraurbana. Sensoriamento Remoto Urbano. Tecido Urbano. Assentamentos Urbanos.

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1 INTRODUCTION

In recent decades, remote sensing has been the main basis for urban mapping, especially in developing countries (ZHU et al., 2022). As an example, we can cite some initiatives that have emerged to map urban areas globally, such as the Global Urban Footprint (GUF) (ESCH et al., 2013), which provides a binary classification of urban and non-urban areas; the World Settlement Footprint Evolution (WSF-Evo) (MARCONCINI et al., 2020) which shows the development over time of GUF’s urban areas, and the World Urban Database, which provides climate zone maps for about 100 metropolitan areas around the globe (STEWART; OKE; KRAYENHOFF, 2014). According to Zhu et al. (2022), the studies reported by Esch et al. (2013), Stewart, Oke, and Krayenhoff (2014) and Marconcini et al. (2020) could not properly demonstrate the use of remote sensing for inner-city level analyses, although they have made significant contributions to urban mapping. This limitation can be associated with the lack of freely accessible very high resolution (< 5 m) satellite imagery with wide geographic coverage, as well as methodologically efficient and accurate algorithms.

To fill this gap, Zhu et al. (2022) identified morphological patterns on a global scale, which includes all cities in the world with a population greater than 300,000 inhabitants. Using data from Sentinel-1 and Sentinel-2 satellites, the authors classified urban morphology globally and identified 17 urban patterns with variations in land use, building density, and verticalization.

Recently, the Global Human Settlement Layer (GHSL) (SCHIAVINA et al., 2022) initiative produced global spatial information about the human presence on the planet over time using spatial data mining and automated processing. The GHSL uses data obtained from satellite imagery, particularly the Landsat and Sentinel series, and Volunteered Geographic Information (VGI). In the past, the GHSL has even used imagery from the China–Brazil Earth Resources Satellite CBERS-2B, with a spatial resolution of 2.5 m (PESARESI et al., 2013). The latest GHSL data package, released in 2022, includes detailed inner-city scale information, such as multi-temporal classification of built-up areas, identification of residential and non-residential areas, and average building height, among others.

Remote sensing data offers numerous opportunities for urban mapping and monitoring. It serves as the basis for physical, climatic, and socio-economic indicators, providing consistent quantitative data across time and space. These data complement traditional surveys, such as the census, and once processed into actionable information, they can greatly enhance urban planning (KUFFER; PFEFFER; PERSELLO, 2021).

At the international level, previous reports have already evaluated the effectiveness of applying remote sensing imagery for urban planning (NETZBAND; STEFANOV; REDMAN, 2007; WENG; QUATTROCHI, 2018). According to Almeida (2010), urban studies in Brazilian cities have used remote sensing data mainly in the following areas: (a) land use and land cover mapping (ALVES et al., 2009; DA COSTA et al., 2008; DE PINHO et al., 2012; KUX et al., 2011; KUX; NOVACK; FONSECA, 2009; PINHO; UMMUS; NOVACK, 2011; RIBEIRO, 2019); (b) determination of housing quality and housing sectorization (DENALDI et al., 2018; FEITOSA et al., 2021; FIDELIS-MEDEIROS; GRIGIO, 2019; OLIVEIRA; MANSO; BARROS, 1978; SANTOS; DE PINHO; DE JESUS, 2019); (c) socio-economic studies in population (BOGGIONE; SILVA; SILVA, 2019; MARINO JUNIOR, 2006); (d) inferences about the population and its distribution (AMARAL et al., 2005; ANAZAWA et al., 2020; CAMPOS et al., 2020; DÓRIA; AMARAL; MONTEIRO, 2016; GONÇALVES et al., 2006); (e) urban transport planning and management (MACHADO et al., 2014; MACHADO; DE ALBUQUERQUE NÓBREGA; QUINTANILHA, 2010; SOARES MACHADO; QUINTANILHA, 2019); (f) urban growth monitoring (ALMEIDA et al., 2005; ESPINDOLA; CARNEIRO; FAÇANHA, 2017; SPERANDELLI; DUPAS; DIAS PONS, 2013); (g) analysis of microclimate (ALVES, 2016; DE SOUZA; DOS SANTOS ALVALÁ, 2014; FUCKNER; MORAES; FLORENZANO, 2009; PERES et al., 2018; SILVA; DA SILVA; SANTOS, 2018; TEZA; BAPTISTA, 2005); (h) analysis of natural disasters and environmental hazards (GALERA et al., 2017; LU et al., 2004; NAKAZATO, 2018; SOARES et al., 2017); and (i) epidemiological and health policy studies (ARAUJO et al., 2015; BARCELLOS et al., 2009; BAVIA et al., 2005; CERBINO NETO; WERNECK; COSTA, 2009; CORREIA et al., 2004, 2007; COSTA et al., 2021; VASCONCELOS; NOVO; DONALISIO, 2006).

In addition to the applications already mentioned, remote sensing in Brazil has been increasingly used in urban areas. The increase in the spatial resolution of satellite imagery and the greater availability of data encourage the use of remote sensing in subjects that were previously studied only through the visual interpretation of aerial photographs (DE ALMEIDA, 2010; KURKDJIAN, 1993; MAHABIR et al., 2018). Although there are rich and significant publications about the Amazonian urban, public policy makers have not yet included these studies in the public policy agenda. In addition, there is a lack of databases and cartographic publications in Amazonian cities (CARDOSO et al., 2020).

With this background, this work asks the following questions: What is the State-of-the-Art in remote sensing to identify urban patterns in Brazil? Furthermore, do the urban patterns identified by remote sensing cover all the Brazilian regions equally? Finally, how can we identify urban patterns in different contexts, such as the Brazilian Amazon urban region, based on remote sensing data? Based on these questions, this work has two aims: (i) to review the bibliographic publications on the use of remote sensing to identify urban patterns in Brazilian cities and to present the methodological and technological advances reported in the literature, and (ii) propose a framework for identifying **Urban and Socio-Environmental Patterns** (**USEPs**) based on remote sensing data, VGI data, and census data. The paper is organized as follows: first, we present the methodology of the bibliographic review, and then we discuss the results of the review. In the penultimate section, we present the framework for identifying USEPs, and finally in the last section, we present the concluding remarks.

2 REVIEW METHODOLOGY

The bibliographic review was structured to assess data sources, determine the motivation and geographic location of the mapping, and characterize the methodological approach. Initially, a manual search was carried out for publications in the *Portal de Periódicos da CAPES* (*Coordenação de Aperfeiçoamento de Pessoal de Nível Superior* in Portuguese, which translates to Coordination for the Advancement of Higher Education Personnel in English). This portal, affiliated with the Brazilian Ministry of Education, is a prominent scientific reference search engine in Brazil, offering access to over 49 thousand full-text journals and 455 databases with diverse content, including references, patents, statistics, audiovisual materials, technical standards, dissertations, books, and other types of works.

To begin, it is necessary to establish a clear definition of an urban pattern. In the context of this paper, urban pattern is defined as an area with homogeneous environmental, urban morphological, and socioeconomic conditions, when analyzed at the level of the inner-city space.

For the review, we conducted searches using the following keywords: *urban pattern*, *urban settlement* and *urban fabric* in combination with *remote sensing* or *mapping* or *geoprocessing* and *Brazil* (Table 1). We also searched for publications in Portuguese using the corresponding terms: *padrão urbano*, *assentamento urbano* and *tecido urbano*, combined with *sensoriamento remoto* or *mapeamento* or *geoprocessamento*.

Table 1 – Number of publications according to the search criteria.

Character string	Number of publications
(urban pattern AND *remote sensing* AND *Brazil)*	118
(urban pattern AND *mapping* AND *Brazil)*	108
(urban pattern AND *geoprocessing* AND *Brazil)*	18
(urban settlement AND *remote sensing* AND *Brazil)*	50
(urban settlement AND *mapping* AND *Brazil)*	52
(urban settlement AND *geoprocessing* AND *Brazil)*	7
(urban fabric AND *remote sensing* AND *Brazil)*	4
(urban fabric AND *mapping* AND *Brazil)*	3
(urban fabric AND *geoprocessing* AND *Brazil)*	1

Source: The Authors (2023).

It is important to note that the objective of this literature review extends beyond merely identifying different classes of urban land use and land cover (LULC) or LULC within urban areas. While the combination and distribution of various LULC classes contribute to the formation of urban patterns, our intention is to explore specific studies that delve deeper into the analysis, moving beyond the simple identification of LULC. Furthermore, we conducted the keyword search without using quotation marks, allowing for different combinations of the keywords themselves. Consequently, the combination of the terms 'urban' and 'remote sensing' may encompass additional relevant terms used by authors, even if they were not explicitly mentioned in the search.

Furthermore, we thoroughly examined the bibliographic references of the publications obtained from the search engines. We specifically reviewed the abstracts that addressed the use of remote sensing data for analyzing urban patterns in Brazilian cities. Studies that did not primarily focus on this aspect were not included in this paper.

We considered scientific publications in journals, books, articles in proceedings and conference proceedings, and reports and technical notes sponsored by government agencies. Master's dissertations and doctoral theses were also considered - provided that the educational/research institution had already approved them. Similar publications by the same authors, where the methodological approach or the field of study did not change, were counted only once. The subsequent section presents the results obtained from this review.

3 RESULTS AND DISCUSSION

In total, we found 41 publications identifying and classifying urban patterns in Brazilian cities using remote sensing techniques. The publications date from 1986 to 2022. Figure 1 shows the keywords used by the authors in the publications, with a predominance of the words "urban" (cited 18 times) or "*urbano*" (cited 6 times) and "remote sensing" (8 citations) or "*sensoriamento remoto*" (9 citations). Interestingly, "pattern" or "*padrões*" are cited only 5 and 2 times, respectively. The analysis of the 41 publications is presented in the subsections.

Figure 1 – Keywords of the publications we found in our review. More commonly used keywords are emphasized.

Source: The Authors (2023).

3.1 Data sources

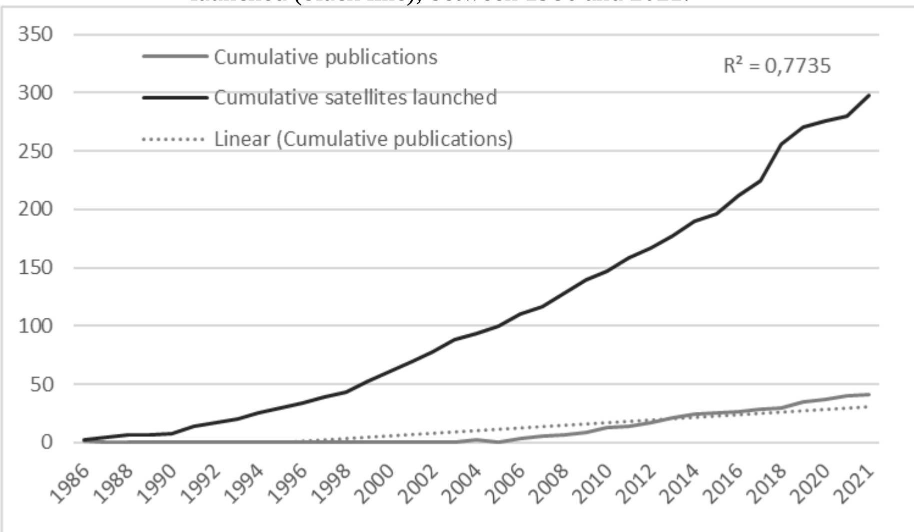
The first work that we found that identified urban patterns in remote sensing data was by Kurkdjian (1986). The author identified urban patterns in São José dos Campos, São Paulo, based on the Homogeneous Residential Zones (HRZ) [1], by visually interpreting aerial photographs taken in 1978 at a scale of 1:10,000 by

[1] Homogeneous Residential Zones are areas (or zones) that have a homogeneous texture in remote sensing data. In Brazil, Oliveira et

the camera RC-10 installed in a Bandeirante aircraft of the National Institute for Space Research. The author used only a magnifying glass with scale and a stereoscope to interpret the aerial photographs and performed the city sectorization to estimate the population size.

After Kurkdjian (1986), there appears to have been a gap in new publications on the topic. Our review reveals that it was not until 2004 that studies re-emerged, focusing on delineating urban patterns in Brazilian cities using remote sensing techniques. These studies were primarily related to population estimation by HRZ (GONÇALVES et al., 2004). The publication of new studies showed a strong linear correlation with the number of satellites launched ($R^2 = 0.77$, including only the earth observation satellites), as depicted in Figure 2. This finding aligns with the global temporal pattern found by Kuffer, Pfeffer and Sliuzas (2016), who identified a correlation ($R^2 = 0.75$) between the number of new satellites launched and publications on slum identification[2].

Figure 2 - Relationship of cumulative publications (gray line) to the cumulative number of earth observation satellites launched (black line), between 1986 and 2021.



Source: Adapted from ITC (2021).

As for the data sources used in mapping, we can divide them into 3 types: (a) aerial photographs; (b) base maps (a geographic background with the content to be displayed) from Geographic Information Systems (GIS); and (c) images from multispectral sensors. Besides Kurkdjian (1986), only Brito et al. (2008) have used aerial photographs. In the Brito et al. (2008) experiment, orthorectified aerial imagery with a spatial resolution of 0.16 meters and the blue, green, and red bands were used to detect morphological patterns in Salvador, Bahia.

In four of the papers, no digital image processing was performed (DENALDI et al., 2018; FEITOSA et al., 2021; FRIESEN et al., 2019; WURM; TAUBENBÖCK, 2018). In these cases, the authors used only the information available in the base maps of the GIS software, and differences between settlements were visually determined.

In the other 34 studies, satellite imagery was used incrementally, representing 85% of the base maps studied. In almost all these cases, the imagery came from multispectral sensors using only the visible and near-infrared bands, except for Lapola et al. (2019) which used Landsat-8 Operational Land Imager (OLI) thermal bands. Table 2 shows the sensors used in the published literature accessed by the present study [3].

al (1978) and Manso et al (1978) defined a methodology to determine this HRZ to estimate the population of São José dos Campos, São Paulo.

[2] In the case of Kuffer, Pfeffer and Sliuzas (2016), the authors specifically focused on earth observation satellites with a spatial resolution of 5 meters or less.

[3] Homogeneous Residential Zones are areas (or zones) that have a homogeneous texture in remote sensing data. In Brazil, Oliveira et al (1978) and Manso et al (1978) defined a methodology to determine this HRZ to estimate the population of São José dos Campos, São Paulo.

QuickBird imagery is the most commonly used in these studies, accounting for approximately 43% of the works. QuickBird, launched by MAXAR (formerly DigitalGlobe) in 2001, had a spatial resolution of 0.61 m in the panchromatic module and 2.44 m in the multispectral mode (NOVO, 2008). Unfortunately, the satellite ended its mission in 2015 after re-entering the Earth's atmosphere over the South Atlantic Ocean near southern Brazil (EMBRAPA, 2018).

The Optical Sensor Assembly images from the Ikonos-II satellite ranked second in terms of frequency of use, appearing in 23% of the reviewed papers. Until its deactivation in 2015 by the operator GeoEye, Ikonos-II provided panchromatic images with a spatial resolution of 1 m and multispectral images with a spatial resolution of 4 m. It is worth mentioning that QuickBird and Ikonos-II, the two most used satellites, had respective operational periods of 14 and 16 years. Despite being paid, which made access difficult for researchers, these two satellites were the first to offer high spatial resolution images.

Table 2 – Frequency, access mode and spatial resolution of satellite imagery used for identifying and classifying urban patterns in Brazilian cities (OLI = Operational Land Imager; TM = Thematic Mapper; MSI = Multispectral Instrument; WPM = Multispectral and Panchromatic Wide Scan Camera; Pan = Panchromatic).

Satellite	Frequency	(%)	Access to data	Spatial resolution
QUICKBIRD	15	43%	Private	0.61 m (pan) - 2.44 (multispectral)
IKONOS-II	8	23%	Private	1 m (pan) - 4 (multispectral)
LANDSAT 8 (OLI)	4	11%	Public	15 m (pan) - 30 (multispectral)
RAPIDEYE	3	9%	Private	5 m (multispectral)
LANDSAT TM (5)	2	6%	Public	30 (multispectral)
WORLDVIEW-2	2	6%	Private	0.45 m (pan) - 1.85 (multispectral)
WORLDVIEW-3	2	6%	Private	0.31 m (pan) - 1.24 (multispectral)
SENTINEL-2A (MSI)	2	6%	Public	10 m (multispectral)
CBERS-2B	2	6%	Public	2.7 m (pan)
CBERS-4A (WPM)	1	3%	Public	2 m (pan) - 8 m (multispectral)
GEOEYE-1	1	3%	Private	0.5 m (pan) - 2 m (multispectral)
SPOT-5	1	3%	Private	2.5 m (pan) - 10 m (multispectral)
PLANET	1	3%	Private	3 m (multispectral)

Source: The Authors (2023).

Also noteworthy is the WorldView satellite series, ranking third and being utilized in 12% of the articles. This satellite series is newer compared to QuickBird and Ikonos-II. WorldView-2, launched in 2009, features a panchromatic sensor with a spatial resolution of 0.45 m and multispectral resolution of 1.85 m. WorldView-3, launched in 2014, possesses a panchromatic sensor with a spatial resolution of 0.31 meters and multispectral with a spatial resolution of 1.24 meters. WorldView-2 was the first commercial satellite equipped with a sensor capable of capturing eight multispectral bands, ranging from blue to near-infrared. In the case of WorldView-3, additional bands were included to improve cloud, water vapor, ice, and aerosol detection in the Earth's atmosphere, as well as to provide atmospheric correction data to enhance the satellite's high-resolution imagery. Unlike the QuickBird and Ikonos-II satellites, WorldView-2 and -3 satellites are still operational.

According to Novo (2008), the very high spatial resolution sensors enable the acquisition of images of the Earth's surface up to 5 meters. About 78% of the reported studies used very high spatial resolution images. Therefore, we can say that very high spatial resolution was the key criterion in selecting the sensor for this type of study, as it allows for the identification of inner-city features and differentiation of settlement patterns.

In general, very high spatial resolution presents certain conflicts that researchers must consider. These trade-offs include the reduction of temporal, spectral, and radiometric resolution, as well as the size of the images. The intensity of the signal to be measured must be sufficiently large to be registered by the orbital sensor, which requires longer integration time during image acquisition by the satellite, wider spectral bands, and greater challenges in signal quantization (AL-WASSAI; KALYANKAR, 2013). Although recent publications have mitigated some of these trade-offs, higher spatial resolutions also result in a larger volume of data to be transmitted, stored, and computationally processed, potentially incurring higher financial costs when acquiring images from private companies.

3.2 Applications

In terms of applications, most mapping is related to urban planning (68.3%), with studies ranging from monitoring occupations in areas with environmental risks (ESDRAS, 2012; LEITE et al., 2013; LEITE; BRITO, 2012; MARTINS; LEITE, 2015), population inference (ALMEIDA et al., 2009; DE MARCELHAS et al., 2007; GONÇALVES et al., 2004, 2006; KURKDJIAN, 1993), and measuring the housing deficit (FEITOSA et al., 2021). Additionally, a smaller portion of the studies (7.3%) focused on mapping for public health purposes, such as identifying urban typologies associated with leptospirosis in a suburban region of Salvador, Bahia (BRITO, 2010; BRITO et al., 2008), and assessing the occurrence of dengue in Rio de Janeiro (REIS, 2010). Another study explored the urban climate in six Brazilian capitals (LAPOLA et al., 2019). The remaining applications (22%) were centered around Digital Image Processing, involving experiments on the analysis of various high-resolution satellite images and classification techniques (BARROS et al., 2013; ESTEVAM; SILVA, 2010; GUEGUEN, 2014; HOFMANN et al., 2008; KUX; NOVACK; FONSECA, 2009; MUSCI et al., 2013; REUSS, 2017; SANTOS; DE PINHO; DE JESUS, 2019; STARK et al., 2020).

The identification and characterization of precarious settlements in Brazil have emerged as a new and growing area of research in remote sensing. Precarious settlements encompass various typologies but are predominantly residential areas inhabited by low-income populations, characterized by numerous deficiencies and inadequate housing conditions. These settlements include tenements, slums, informal settlements, irregular low-income properties, and degraded housing estates (BRASIL, 2005, 2010; DENALDI; ROSA, 2010). Regarding the analyzed database, 51.2% of the studies explicitly focused on the classification of precarious settlements.

3.3 Delineating and identifying urban patterns methodologies

To represent urban patterns, it was observed that most of the reported studies (51%) adopted city blocks or the boundaries of the settlements themselves. The second most common approach (20%) involved delimitation by non-regular segments, created through a process of unmediated segmentation. Some studies (17%) utilized the image pixels themselves as a form of representation, employing pixel-by-pixel classification. Finally, a portion of the studies (12%) opted for a representation using regular cellular grids.

Visual identification was the form of classification chosen by 46% of the authors. In 30% of the cases, the authors used manual decision trees or thresholds for classification. In 15%, a machine learning algorithm was used for classification; 3% used statistical models, and only one (2%) used deep learning as a classification method. In all studies, texture assessment was crucial for delimiting the areas of interest.

The Geographic Object-Based Image Analysis (GEOBIA) approach was used in 46% of the studies. In general, the authors used GEOBIA techniques to integrate data from different sources into geographic objects and then create thresholds or use machine learning algorithms to identify and classify urban patterns.

The first study that identified urban patterns using the GEOBIA approach was proposed by Hofmann et al. (2008). Using a QuickBird image of the city of Rio de Janeiro, the authors introduced and popularized the technique, which later became one of the most widely used methods worldwide for identifying patterns using high spatial resolution satellite imagery (KUFFER; PFEFFER; SLIUZAS, 2016). The work of Hofmann et al. (2001) also inspired Kohli et al. (2012) to develop a slum ontology that conceptualizes the physical characteristics of these inadequate residential areas and serves as a reference for identifying precarious areas through remote sensing.

Using visual identification, statistical models, and manual decision rules, Feitosa et al. (2021) elaborated the Integrated Methodology for Mapping and Classifying Precarious Settlements (IMMerSE), in which they identified settlements in the Baixada Santista and Grande ABC, São Paulo, and classified them into urban fabric typologies based on occupation characteristics. This work is distinguished by the fact that it was developed jointly by the academia and the public sector and led to the measurement of housing deficit and inadequacies inside and outside the precarious settlements.

According to Kuffer, Pfeffer and Sliuzas (2016), the studies that used machine learning algorithms showed higher accuracy in identifying precarious areas. However, in the studies conducted in Brazil, machine learning techniques for describing urban patterns, in general, have not yet gained acceptance, as the use of these classification algorithms does not even represent 20% of the above database.

In terms of methods, however, some articles classified inner-city land cover in high spatial resolution imagery and, although they did not focus on delineating urban patterns, they enabled the expansion of remote sensing applications for this purpose. For example, studies that developed mappings of the elements that compose urban land cover such as concrete, different types of roofs, water and vegetation (ALVES et al., 2009; DA COSTA et al., 2008; DE PINHO et al., 2012; KUX et al., 2011; RIBEIRO, 2010, 2015).

3.4 Location and characteristics of the study areas

The Brazilian Southeast Region concentrated more than 70% of the study areas (Table 3), with the state of São Paulo standing out with almost 48% of participation. The Northeast Region appears in second place with seven publications (14.6%), distributed among the cities of Salvador, Bahia (BRITO, 2010; BRITO et al., 2008; HACKER et al., 2013), João Pessoa, Paraíba (DA PENHA PACHÊCO et al., 2014), Natal (LAPOLA et al., 2019), and Mossoró (FIDELIS-MEDEIROS; GRIGIO, 2019), both in Rio Grande do Norte.

Table 3 – Location (Region, State, and City), scale, and frequency of the study areas (AM = Amazonas; BA = Bahia; ES = Espírito Santo; MG = Minas Gerais; PA = Pará; PB = Paraíba; PR = Paraná; RJ = Rio de Janeiro; RN = Rio Grande do Norte; RS = Rio Grande do Sul; SP = São Paulo)[4].

Region	State	Study sites	Scale	Frequency
Northeast (14.6 %)	BA (10.4%)	Salvador	Neighborhood	3 (6.3%)
			Entire city	1 (2.1%)
	PB (2.1%)	João Pessoa	Neighborhood	1 (2.1%)
	RN (4.2%)	Natal	Entire city	1 (2.1%)
		Mossoró	Entire city	1 (2.1%)
North (6.3 %)	AM (2.1%)	Manaus	Entire city	1 (2.1%)
	PA (6.3%)	Altamira, Belterra, Cametá, Itaituba, Jacareacanga, Marabá, Novo Progresso, Placas, Rurópolis, São Felix do Xingu, Trairão e Santarém	Entire city	3 (6.3%)
Southeast (70.8 %)	ES (2.1%)	Vitória	Entire city	1 (2.1%)
	MG (8.3%)	Montes Claros	Neighborhood	4 (8.3%)
	RJ (12.5%)	Rio de Janeiro	Neighborhood	2 (4.2%)
			Entire city	4 (8.3%)
	SP (47.9%)	São José dos Campos	Neighborhood	7 (14.6%)
		São Paulo	Neighborhood	3 (6.3%)
			Entire city	3 (6.3%)
		Taboão da Serra	Neighborhood	1 (2.1%)
		Estado de São Paulo	Statewide	1 (2.1%)
		Baixada Santista, Grande ABC Paulista, Região Metropolitana de São Paulo, Região Metropolitana de Campinas, Litoral Norte	Regional	8 (16.7%)
South (6.3 %)	PR (4.2%)	Ponta Grossa	Entire city	1 (2.1%)
		Curitiba	Entire city	1 (2.1%)

[4] The sum of the percentages in Table 3 is greater than 100% because some works applied the methodology in more than one study area.

	RS (2.1%)	Porto Alegre	Entire city	1 (2.1%)

Source: The Authors (2023).

For the Southern Region, there is only the work of Matias and Nascimento (2006), which identified areas of irregular settlements in the city of Ponta Grossa, Paraná, and the work of Lapola et al. (2019), which identified urban heat islands in Curitiba, Paraná and Porto Alegre, Rio Grande do Sul. Lapola et al. (2019) also applied the methodology in Manaus, Natal, Vitória and São Paulo, respectively in the States of Amazonas, Rio Grande do Norte, Espírito Santo and São Paulo. We did not find any publication that adopted a city in the Brazilian Midwest as a study site.

According to our research, São José dos Campos, São Paulo State, was the municipality with the largest number of specific studies, with a total of seven publications (14.3%). This predominance can be attributed to the fact that the National Institute for Space Research is headquartered in São José dos Campos, and all publications related to the municipality include at least one researcher from the Institute.

Regarding the scale of the study areas, the following categorization can be made: a) Neighborhood: where only a part of the city is selected for the experiment, usually a neighborhood known for its diversity of urban patterns; b) entire city: the experiment is carried out in the entire city; c) regional: a group of city in urban agglomerations, such as the experiments in metropolitan regions; d) Statewide: the experiment is carried out in all cities of the state.

The study areas categorized as "neighborhood" represent more than 53% of the conducted mapping. However, Kuffer, Pfeffer and Sliuzas (2016) shows that small areas of analysis are common in remote sensing applications for delineating urban patterns. The limitation in study area size is primarily due to the financial costs associated with acquiring high spatial resolution imagery and the size of the scenes themselves.

However, there has been a recent trend to develop research in larger areas. All studies with a regional scope, accounting for 17.1% of the total, were published in the last five years, starting in 2018. It is noteworthy that all of these studies selected some region within São Paulo State as their study area (DAUNT; SILVA, 2019; DENALDI et al., 2018; ESCH et al., 2013; FEITOSA et al., 2021; FRIESEN et al., 2019; PASQUOTTO et al., 2018; REUSS, 2017; SANTOS; DE PINHO; DE JESUS, 2019).

Mahabir et al. (2018) state that the launch of new satellites with high spatial resolution and no fees for image use has facilitated the expansion of urban remote sensing applications to larger areas. Based on the analysis conducted, all studies with a regional extent utilized imagery with free access or geographic information system (GIS) software base maps in their methods.

The study by the São Paulo State Government deserves highligh because of the size of the area studied. In 2016, the São Paulo State Government commissioned the *Fundação de Ciência, Aplicações e Tecnologia Espaciais* (FUNCATE), to delineate the Homogeneous Units of Land Cover, Use and Pattern of Urban Settlement (UHCT) (SÃO PAULO, 2014). The UHCTs represent a planning and land-use planning tool that is applied in state and municipal policies for urban-environmental management.

The UHCTs result from the sectorization of urban areas throughout the state of São Paulo, resulting from the visual interpretation of remote sensing products with high and medium spatial resolution in areas with similar characteristics in terms of physical aspects of shape and texture. Orthorectified SPOT satellite imagery (spatial resolution of 2.5 m), RapidEye imagery (spatial resolution of 5 m), LANDSAT -5 TM sensor imagery (spatial resolution of 30 m), and orthophotos (spatial resolution of 1 m or less) provided by the Environment Secretariat of the State of São Paulo were used in the delineation of the UHCTs.

A hierarchical, multilevel, and multiresolution classification procedure was used to identify the UHCTs, dividing the area into three levels of analysis. The first level is the land cover classification, which identifies the urban or built-up areas. The second level attempts to differentiate the urban area in terms of land use by identifying residential, commercial, and service areas, among others. Finally, the areas identified as residential, commercial or service areas are classified again, but now according to the physical patterns of use. This considers the aspects of building density, settlement maturity, and level of development.

In identifying urban patterns in the Northern Region, only the work of Dal'Asta et al. (2012), Gonçalves et al. (2021), and Dos Santos et al. (2022) was found, representing only 6.3% of the total. Dal'Asta et al. (2012) identified typologies of human occupation in western Pará through visual interpretation of CBERS-HRC panchromatic images (5 m spatial resolution) and CBERS-CCD multispectral images (20 m spatial resolution). As a result, the following urban patterns were identified: a) dense settlement: consisting of residential and commercial areas with high building density; b) spatial settlement: consisting of residential areas with low building density and vegetation between residences; c) expansion areas: consisting of widely separated residences with low building density; d) large nonresidential buildings: consisting of large buildings such as gymnasiums, community centers, factories, and others; and e) access roads: consisting of undeveloped areas around highways and rivers.

Gonçalves et al. (2021) analyzed the urban extent found in seven general mapping bases for 2010 supported by remote sensing data. Six cities in Pará State were analyzed. The authors analyzed the consistency and agreement between the databases using a regular grid. The highest agreement between databases was found in areas with medium and high inner-city density, where the agreement between databases was over 90%. The largest discrepancies between bases were observed in the low-density inner-city patterns.

Dos Santos et al. (2022) also identified inner-city patterns in Amazonian municipalities when they identified typologies of precarious settlements in the cities of Altamira, Cametá, and Marabá in Pará. The authors used GEOBIA and data mining techniques on WPM images from the CBERS-4A satellite (2 m spatial resolution for the panchromatic band and 8 m for the multispectral bands). To support the classification, the authors used biophysical indices, Gray Level Co-occurrence Matrix (GLCM) metrics, context metrics, and neighborhood metrics.

4 A FRAMEWORK FOR CLASSIFYING URBAN AND SOCIO-ENVIRONMENTAL PATTERNS IN AMAZONIAN CITIES

After reviewing and analyzing the publications, we can note: i) the predominant use of very high spatial resolution images from private multispectral sensors such as QuickBird, Ikonos- II, Planet, and WorldView 2 and 3; ii) the concentration of studies in the Southeast Region of Brazil and the absence of methodologies at the municipal or regional scale; and iii) the absence of automated classification techniques, such as the use of statistical or machine learning models.

Based on these findings, we have developed a framework for classifying USEPs with the following main guidelines: i) the use of satellite imagery with high and medium spatial resolution and with open access; ii) ensuring the application of the methodology beyond the Southeastern region of Brazil, especially aiming to apply it in Amazonian cities; and iii) the use of automated classification techniques that do not depend on previous classifications or monitoring. In addition, the framework is based on two assumptions:

- Distinctive urban patterns can be observed within a city based on the environment, socioeconomic factors, and urban morphology.
- The combination of remote sensing imagery, demographic census, and Volunteered Geographic Information (VGI) is suitable and sufficient for depicting the dimensions of analysis and classifying urban patterns.

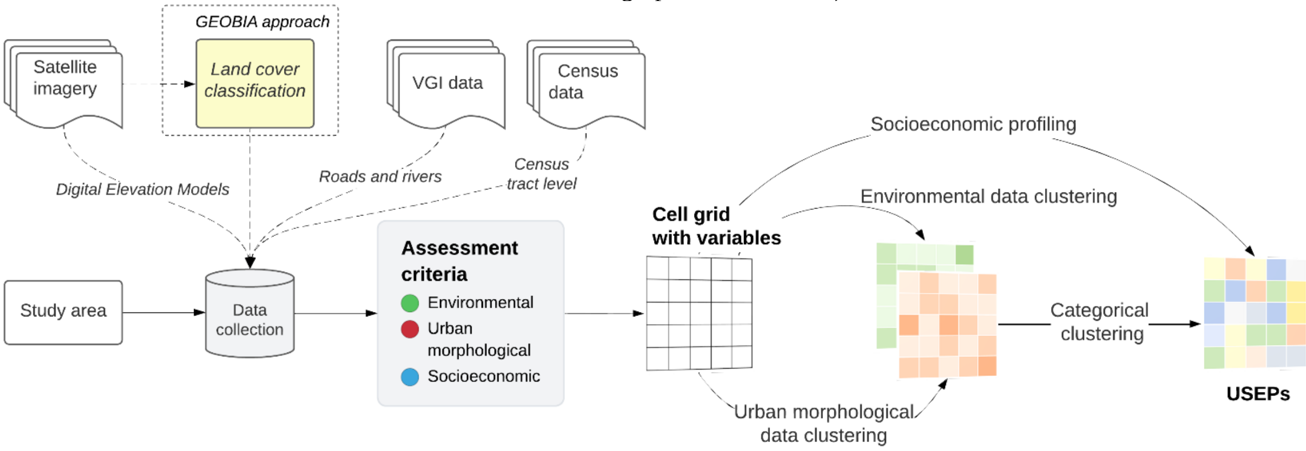
We have developed a framework for identifying USEPs using remote sensing and machine learning techniques. This framework is structured around the analysis of three analysis dimensions: environmental, urban morphological, and socioeconomic. The selection of these dimensions is based on the availability of spatial data that can be used to construct assessment criteria and variables for each dimension. In contrast to previous methods that focus solely on either urban morphology or socioeconomic factors, our approach aims to integrate both dimensions and incorporates an environmental perspective. By considering all three dimensions, we can gain a more holistic understanding of USEPs in Amazonian cities.

For each dimension (environmental, urban morphological, and socioeconomic), we have defined specific assessment criteria. These criteria outline the key aspects that should be evaluated within each dimension, taking into account the unique characteristics of Amazonian cities. Based on these assessment criteria, we obtain a set of variables that capture relevant information for each dimension.

We can summarize the USEPs model classification methodology in six steps (Figure 3). The first step is the delimitation of the study area. The second step of the methodology is to classify a land cover base at the intra-urban level. The third step involves creating the variables for the assessment criteria of each dimension. The fourth step consists of integrating all variables into a cellular grid. The fifth step consists of obtaining clusters generated through unsupervised classifications and identifying the USEPs. Finally, in the sixth we use socioeconomic indicators and a decision tree algorithm to characterize the USEPs.

The initial step involves delineating the study area, and we suggest selecting only the area where the population of the municipality or region is residing. To define this area, one approach is to utilize night light images, which often serve as indicators of developed areas extending beyond the boundaries of the urban center, thereby identifying the inhabited regions by the population (AMARAL et al., 2005). Using night light imagery allows for the identification of study areas without being limited by the conventional urban-rural classification employed in census data.

Figure 3 – Framework schema for identifying USEPs (USEPs = Urban and Socio-Environmental Patterns and VGI = Volunteered Geographic Information).



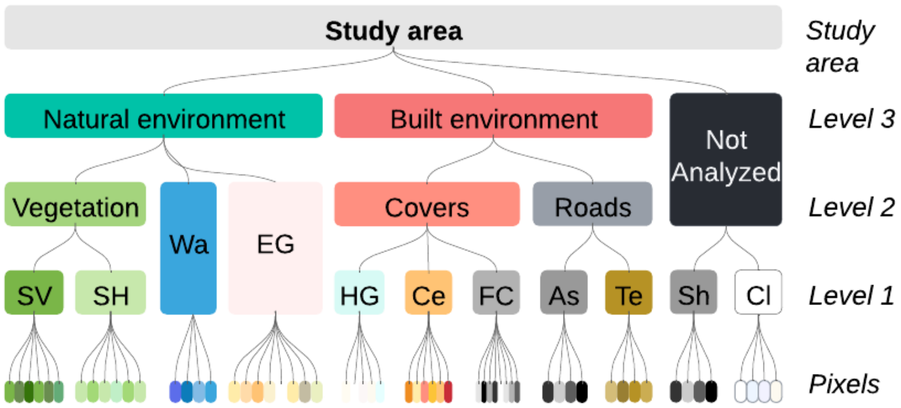
Source: The Authors (2023).

Once the study area is defined, the second step of the methodology is to classify a land cover base at the intra-urban level. The land cover database allows the creation of variables for the three dimensions of the analysis. For this purpose, the GEOBIA approach is a good alternative for identifying inner-city land cover classes, such as different types of roofs and streets. For example, Santos et al. (2022) used imagery from the CBERS-4A satellite's WPM sensor, as well as GEOBIA and data mining techniques, to obtain a land cover classification for the cities of Altamira, Cametá and Marabá, all of them located on Pará state, in the Brazilian Amazon.

Similarly, Dos Santos et al. (2023) employed the land cover classification methodology introduced by Santos et al. (2022) for the city of Santarém, also located in the Pará state. In both cases, the authors defined the classes of interest based on visual interpretation of the WPM image to identify prominent features within the urban landscape, obtaining the land cover classes: “Shrub Vegetation” (SV), “Herbaceous Vegetation” (HV), “Water” (Wa), “Exposed Ground” (EG), “High Gloss Cover” (HG), “Ceramic Cover” (Ce), “Fiber Cement Cover” (FC), “Asphalt Road” (As), “Terrain Road” (Te), “Cloud” (Cl) and “Shadow” (Sh).

In both cases, the segmentation followed a bottom-up approach, where the initial focus was on identifying lower-level classes, which were then gradually merged or aggregated to form higher-level hierarchical classes. Level 1 aimed to map the land cover classes at a detailed scale, while Level 2 aim to generate land cover maps at a grosser scale without differentiating the existing vegetation types and the materials of roofs and roads. Finally, Level 3 separates the physical environment, represented by vegetation, water, and exposed soil, from the anthropized environment, represented by the built-up areas on different roofs and roads (Figure 4).

Figure 4 – Semantic network for land cover classification.



Source: Santos et al. (2023).

After obtaining a land cover classification for the study area, we began developing variables for each dimension, starting with the environmental dimension. This dimension helps identify urban patterns with peri-urban characteristics, typically located at the periphery of the consolidated urban area. These areas often have lower population density and serve as land reserves for future urban expansion. Moreover, this dimension aims to address the limitations of morphological analysis methodologies, originally designed for urban-industrial cities in the global North. In the case of the Amazon, the environmental dimension allows for the identification of two competing patterns: one associated with the traditional knowledge of indigenous peoples, and the other related to the urban-industrial practices, modernist ideas, and significant environmental degradation introduced in the region after the 1960s.

The land cover classes of the physical-natural environment are represented differently in Amazonian cities. In the case of settlements with a traditional origin, it is expected that they will be situated closer to rivers, exhibit a greater presence of vegetation, and have more permeable areas within the settlements. The layout of these settlements is also expected to be influenced by the terrain, with minimal changes to the topography during their establishment. This traditional pattern contrasts significantly with settlements following urban-industrial rationality, where alterations to the topography are common, and higher building densification occurs.

As variables for the environmental dimension, we propose the following: (a) the area of land cover classes related to the physical environment (such as arboreal vegetation, herbaceous vegetation, water, and exposed soil); (b) the slope (in percent), and a base for vertical curvature (numeric) obtained from Topodata (VALERIANO; ROSSETTI, 2012) or another Digital Terrain Model with higher spatial resolution; and (d) the Height Above the Nearest Drainage (HAND) (RENNÓ et al., 2008). Table 4 describes the reason for choosing these variables for the environmental dimension.

Table 4 – Variables of the environmental dimension and reason for choice.

Variable	Reason
Area (ha) of land cover classes	The presence of vegetation in urban areas offers many ecosystem services, such as the supply of food and raw materials, regulation of erosion, floods, microclimates and pollution, which directly or indirectly impact human health. In addition, the areas of exposed soil and vegetation areas indicate higher infiltration of rainwater (BRAGA JR et al., 2005). Rivers, in turn, are related to the formation process of many Amazonian cities and play an essential role in the lives of traditional communities through their capacity to provide food and as a means of transportation (CARDOSO; LIMA, 2006).
Slope	According to Cardoso, De Melo, and Do Vale Gomes (2016), informal settlements in Amazonian cities occupy environmentally sensitive areas on the peripheries of cities, such as floodplain regions and riverbanks. Slope can indicate areas with a higher propensity to flooding, costly urbanization and other limitations to urban settlements (SOUZA; MONTERO; LIESENBERG, 2007).
Curvature	According to Galera et al. (2017), the analysis of terrain curvature assists in interpreting and understanding erosive and hydrological processes (natural or anthropic) that act on hillside orientations. Hillside geometries indicate the direction of water flows and can be categorized into concave, convex, and rectilinear. Associated with HAND, the curvature of the terrain allows identifying wetland areas that present environmentally sensitive characteristics for occupation, referring to flood risks and structural

	instability of civil construction (VARALLO et al., 2018).
Variable	**Reason**
HAND	Some settlements, traditional or not, are located in areas of lower elevations (CARDOSO; DE MELO; GOMES, 2016). However, when it is not the traditional populations, the dwellings tend not to be well-prepared for flooding from seasonal floods.

Source: The Authors (2023).

The urban morphological dimension, on the other hand, allows for the characterization of the various physical forms of the city, including the patterns of buildings, streets, lots, and blocks. It also enables the identification of actors and processes that have played a role in city formation. For the analysis of urban morphology, we propose adapting the methods of Conzen ([1960] 2004) and *Morpho* (OLIVEIRA, 2013).

Adaptation is required to create metrics for morphological assessment from remote sensing data and other spatial data. Furthermore, adaptation is essential because urban design tools and spatial syntax were formulated for societies with a high degree of urbanization and industrialization and with a solid cadastral tradition, very different from the Amazonian context (CARDOSO et al., 2020). The hybrid characteristics of Amazonian cities, landscape diversity, complex social formation, and peculiarities in the formation process demand adaptations in the traditional morphological analysis. Therefore, we propose the construction of variables based on the following elements of analysis:

- **Accesses:** the intersection between road infrastructure, routes, and rivers - as the latter two are used by the population as "paths" to get around. The roads and rivers can be obtained from the Open Street Maps dataset (OSM, 2021).
- **Blocks and Occupation Areas:** inclusion of occupation areas as a morphological element for places where there is no block boundary. The blocks and occupation areas result from the cut of the study area by the road network and the rivers. The methodology for identifying blocks and occupation areas was developed by Feitosa et al. (2021).
- **Roofs:** replaces the morphological element “building”, often used in traditional morphological analyzes, due to the difficulty of obtaining the buildings themselves from high spatial resolution images (≤ 5m).

Some initiatives have made building footprints datasets available for various countries worldwide, such as the efforts by Google (SIRKO et al., 2021) and Microsoft researchers (MICROSOFT, 2021). In the case of Google researchers (SIRKO et al., 2021), they developed a deep learning model to detect buildings across the entire African continent using satellite images with a spatial resolution of 0.50 meters[5]. Their model successfully identified approximately 516 million buildings on the continent. Currently, the initiative is conducting detection experiments in Asia. On the other hand, Microsoft (2021) extracted building footprints using a deep neural network technique to segment Maxar images captured between 2020 and 2021[6], including Brazilian cities in its methodology.

Utilizing a building footprint dataset can serve as a viable option for creating variables related to the urban morphological element "roofs." Several metrics can be derived from such datasets, including building density within blocks and occupation areas, average area of building footprints, and even a measure to evaluate the arrangement of building footprints within blocks. However, it is worth noting that none of the studies identified in this review have utilized these datasets for the identification of urban patterns.

The last dimension, the socioeconomic dimension, characterizes the conditions of the households, their surroundings, and the resident population. This dimension utilizes the socioeconomic indicators proposed by the Brazilian Institute of Geography and Statistics (IBGE, from the Portuguese *Instituto Brasileiro de Geografia e Estatística*) (IBGE, 2017). These indicators have been evaluated and adapted as they serve as a reference for the characterization of inner-city Brazilian cities (MIRANDA, 2019; SILVA; O’NEILL; SOUZA, 2019). The objective of the IBGE (2017) survey was to present differences in the living conditions of the population in the largest urban areas in Brazil. To enhance the understanding of these cities, the IBGE

[5] There is no mention of the type of sensor used, nor of the dates of the images.
[6] Microsoft does not detail the other information in the images used.

presented the results at a more detailed level than the municipal level, using weighted areas as the territorial unit.

In general, a weighted area is formed by the combination of several census sectors, creating an intermediate spatial unit between the census tracts and the municipal boundary. However, particularly for small and medium-sized municipalities, weighted areas do not divide cities into numerous parts, making it challenging to capture variations at the scale of the inner-city space. Therefore, we propose using the aggregated census universe data at the census tract level. Additionally, adjustments are necessary because the concept of inadequate infrastructure for Amazonian municipalities should not be the same as the one typically applied to other regions.

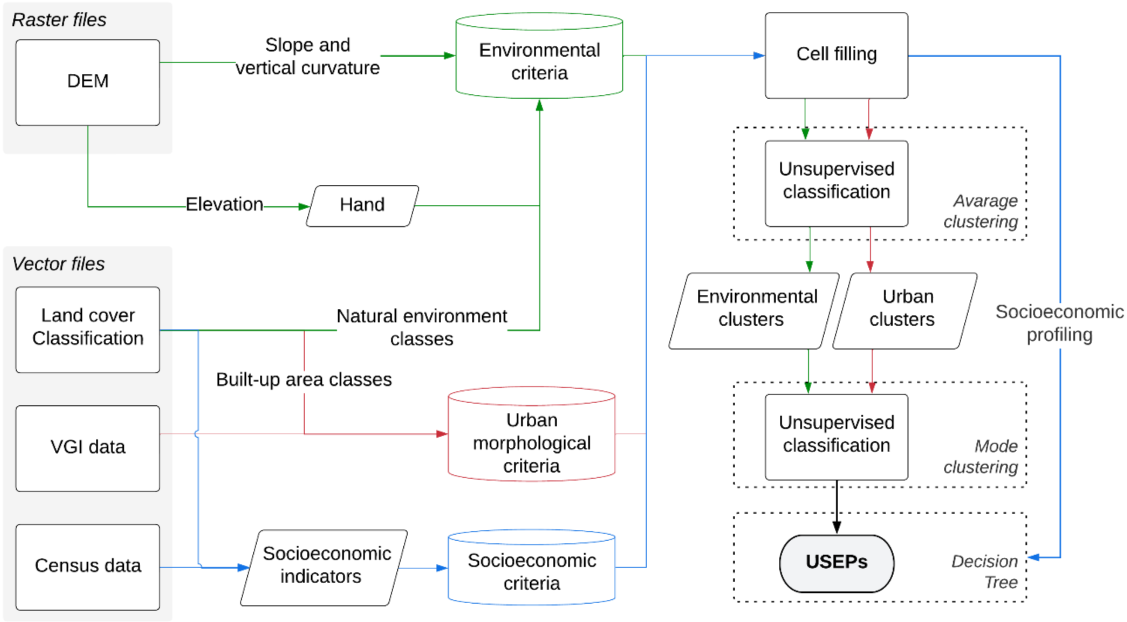
After the identification, adaptation, and construction of the variables of all dimensions, they are integrated into the geographic space. For this, it is proposed to use a cellular grid consisting of 100x100 m square cells with an area of 10,000 m². These cells serve as spatial units for aggregating data from different types and sources. We established this cell size based on studies that identified patterns in Brazilian cities using cell grids (FEITOSA et al., 2021; GONÇALVES, 2018; SANTOS et al., 2022; SANTOS; DE PINHO; DE JESUS, 2019) and because 100 m facilitates integration with the IBGE statistical grid (D'ANTONA; BUENO; DAGNINO, 2011). Moreover, this cell size allows the differentiation of neighbors without compromising the visualization of internal patterns. For the variables of the socioeconomic dimension, we indicate a method to disaggregate the information only for the cells with built-up areas, such as a dasymetric method or an area-weighted interpolation.

Having the cell grid with all variables, we start the urban pattern identification process applying specifics unsupervised classifications for the environmental and urban morphological dimensions, obtaining clusters for each dimension. We propose the application of separated unsupervised classification methods using the variables of each both dimensions, using average-based algorithms like k-modes, hierarchical clustering, or Self-Organizing Maps. The separate clustering of the environmental and urban morphological dimensions enables a meaningful explanation of the USEPs. Following the UHCTs (SÃO PAULO, 2014), these two analysis dimensions are used as levels of information compartmentalization, where the clusters of each dimension represent these levels and provide information about the environment and urban nature of the study area. Utilizing unsupervised classification methods is crucial in the absence of comprehensive databases and prior mappings in Brazilian Amazon cities, revealing distinct patterns in the data. Additionally, separating these two dimensions explicitly highlights the environmental characteristics of these Amazonian cities.

Subsequently, another unsupervised classification is applied using only the two categorical variables related to the clusters of the environmental and urban morphological dimensions. Since these variables are categorical, a mode-based algorithm like k-modes is necessary. This process creates a new type of cluster that combines environmental and urban information, synthesizing the two dimensions of analysis. The number of clusters to be created must be determined based on visual analysis, but techniques like the Elbow method (THORNDIKE, 1953) can help in determining the optimal number of clusters.

Finally, we use the indicators from the socioeconomic dimension to characterize the final clusters. Victoriano et al. (2020) have used a decision tree to characterize the socioeconomic clusters that result from an unsupervised classification. The decision tree offers the advantage of deriving profile characterization through simple, explicit, binary partitions, which is why it is sometimes referred to as a white-box model. Similar to Victoriano et al. (2020), we consider the urban environmental clusters as categorical dependent variables, while the socioeconomic indicators serve as independent variables that define the corresponding partitions. Consequently, the outcome of the decision tree is a partition of the sample into terminal nodes, which indicate the socio-economic profile of each cluster. This way, the USEPs combine the urban environmental clusters with the socioeconomic indicators. Figure 5 presents an expanded scheme of the framework, showing how the different data mentioned in our methodology are related to each dimension and to the unsupervised classifications.

Figure 5 – Expanded scheme of the framework for identifying USEPs (DEM = Digital Elevation Model; USEPs = Urban and Socio-Environmental Patterns, and VGI = Volunteered Geographic Information).



Source: The Authors (2023).

Since the patterns were derived from an unsupervised classification technique, it is important to ascertain the semantic significance of each urban pattern. When discussing unsupervised classifications, it is challenging to make direct State-of-the-Art (SOTA) comparisons. The reason is that unsupervised classification methods do not rely on labeled training data or predefined classes. Instead, they aim to identify patterns and structures in the data without prior knowledge of the classes or categories. Evaluating the performance of unsupervised classifications usually involves assessing the quality and coherence of the identified clusters or patterns rather than comparing them to specific benchmarks or SOTA approaches. We suggest investigating the potential for the analytical explanation of the USEPs and their capacity to represent the various typologies in each study area based on extant literature or classification methodologies.

5 FINAL CONSIDERATIONS

This work has evaluated the State-of-the-Art of remote sensing in the identification and classification of urban patterns in Brazil and has presented a framework for identifying Urban and Socio-Environmental Patterns, focusing on its application in Amazonian cities. We have reviewed forty-one publications from various fields of knowledge, published between 1986 and 2022. The remote sensing studies that map urban LULC are many and were not inventoried in this work. However, we have found that specific studies discussing the classification of urban patterns in Brazil at the intra-urban scale, according to our definition, are still relatively limited.

After analyzing the publications, we realized that most of them are studies that use visual identification as a delineation technique. More than 70% of the studies used high spatial resolution imagery from private multispectral sensors. According to our results, work on identifying urban patterns by remote sensing covers relatively small geographic areas, mostly in the Southeast region of Brazil.

Some studies deserve to be highlighted for different reasons. For example, the study of Hofmann et al. (2008) presented avant-garde by using GEOBIA techniques. The work of Feitosa et al. (2021) enabled the calculation of the housing deficit for the municipalities of Baixada Santista. São Paulo. Moreover, Dal'Asta (2012), was the first study that identified urban patterns in Amazonian cities.

The application of those methodologies currently indicated in other regions is limited or hampered by the acquisition costs of commercial images. In this context, we proposed a framework for automated classification of Urban and Socio-Environmental Patterns with the possibility of application in all regions of Brazil, with a focus on application in Amazonian cities, using high spatial resolution images and other spatial data with free access.

The mapping of urban patterns carried out exclusively in loco is time-consuming and has a high financial cost, requiring the mobilization of a large amount of specialized labor. The use of remote sensing can be a convenient alternative or a complement to the work carried out by the municipalities to face such limitations and can help identify the various types of settlements in the city.

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Author Contributions

Conceptualization, B.D.d.S., M.K., C.M.D.d.P., A.P and S.A.; Investigation, B.D.d.S.; Data curation, B.D.d.S.; Writing – original draft, B.D.d.S., C.M.D.d.P., M.K., and S.A.; Supervision, M. K., C.M.D.d.P., A.P. and S.A.; Writing – Review e Edition, B.D.d.S, M.K., C.M.D.d.P., R.M.R., A.P and S.A. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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