water and landscape
AGUA y TERRITORIO

Urban land use and land cover mapping: proposal of a classification system with remote sensing

Mapeo de uso y ocupación del suelo urbano: propuesta de sistema de clasificación con teledetección

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ABSTRACT

The Brazilian urbanization process produced a complex urban space, with a variety of urban land use and cover as a result. The study of these forms through a classification system is essential, but most current systems don't capture this complexity, condensing it. Urban forms are difficult to distinguish and classify, resulting in the need for a system with a high degree of detail, for a more accurate urban planning. The objective of this work is to propose a classification system for urban land use and cover, which can demonstrate the multiplicities through remote sensing, using data from CBERS 04A satellite. The methodology surveys the visual elements of remote sensing images, through visual interpretation, relating them to each proposed use and cover class. With this, a classification system was developed that covers the urban space in 17 classes, being an effective way to raise information about the different urban forms.

KEYWORDS: CBERS 04A, Land use and land cover classification, Urban space, Remote sensing.

RESUMEN

El proceso de urbanización brasileño ha generado un espacio urbano complejo, con una variedad de usos y coberturas del suelo urbano. El estudio de estas formas a través de un sistema de clasificación es esencial, pero la mayoría de los sistemas actuales no capturan esta complejidad, condensándola. Las formas urbanas son difíciles de distinguir y clasificar, lo que resulta en la necesidad de un sistema con un alto grado de detalle para una planificación urbana más precisa. El objetivo de este trabajo es proponer un sistema de clasificación para el uso y cobertura del suelo urbano que pueda demostrar las multiplicidades a través de la teledetección, utilizando datos del satélite CBERS 04A. La metodología analiza los elementos visuales de las imágenes de teledetección a través de la interpretación visual, relacionándolos con cada clase propuesta de uso y cobertura. Con esto, se desarrolló un sistema de clasificación que abarca el espacio urbano en 17 clases, siendo una forma efectiva de recopilar información sobre las diferentes formas urbanas.

PALABRAS CLAVE: CBERS 04A, Clasificación de cobertura y uso del suelo, Espacio urbano, Teledetección.

Mapeamento do uso e ocupação da terra urbana: proposta de um sistema de classificação com sensoriamento remoto

RESUMO

O processo de urbanização brasileira produziu um espaço urbano complexo, com diversidade de uso e ocupação da terra. O estudo dessas formas com um sistema de classificação é essencial, mas a maioria dos sistemas atuais não captura essa complexidade, condensando-a. As formas urbanas têm difícil classificação, demandando um sistema com alto grau de detalhamento, para um planejamento urbano mais preciso. O objetivo deste trabalho é propor um sistema de classificação de uso e ocupação da terra urbana capaz de demonstrar as multiplicidades com sensoriamento remoto, utilizando dados do satélite CBERS 04A. A metodologia consiste no levantamento dos elementos visuais das imagens de sensoriamento remoto, por meio da interpretação visual, relacionando-os a cada classe proposta de uso e ocupação. Com isso, foi desenvolvido um sistema de classificação que abrange o espaço urbano em 17 classes, sendo uma forma eficaz de levantar informações sobre as diferentes formas urbanas.

PALAVRAS-CHAVE: CBERS 04A, Classificação de uso e ocupação da terra, Espaço urbano, Sensoriamento remoto.

Cartographie de l'occupation et de l'utilisation des terres urbaines: proposition d'un système de classification avec télédétection

RÉSUMÉ

Le processus d'urbanisation brésilien a produit un espace urbain complexe, avec une variété d'utilisations et de couvertures des sols urbains en résultat. L'étude de ces formes à travers un système de classification est essentielle, mais la plupart des systèmes actuels ne capturent pas cette complexité, la condensant. Les formes urbaines sont difficiles à distinguer et à classer, ce qui nécessite un système avec un degré élevé de détail pour une planification urbaine plus précise. L'objectif de ce travail est de proposer un système de classification pour l'utilisation et la couverture des sols urbains qui puisse démontrer les multiplicités par télédétection, en utilisant des données du satellite CBERS 04A. La méthodologie analyse les éléments visuels des images de télédétection par interprétation visuelle, les reliant à chaque classe proposée d'utilisation et de couverture. Ainsi, un système de classification a été développé, couvrant l'espace urbain en 17 classes, représentant un moyen efficace de recueillir des informations sur les différentes formes urbaines.

MOTS CLÉ: CBERS 04A, Classification de l'utilisation et de l'occupation des terres, Espace urbain, Télédétection.

Mappatura dell'uso e dell'occupazione del suolo urbano: proposta per un sistema di classificazione con telerilevamento

SOMMARIO

Il processo di urbanizzazione brasiliano ha prodotto uno spazio urbano complesso, con una varietà di usi e coperture del suolo urbano come risultato. Lo studio di queste forme attraverso un sistema di classificazione è essenziale, ma la maggior parte dei sistemi attuali non cattura questa complessità, condensandola. Le forme urbane sono difficili da distinguere e classificare, rendendo necessario un sistema con un elevato grado di dettaglio per una pianificazione urbana più accurata. L'obiettivo di questo lavoro è proporre un sistema di classificazione per l'uso e la copertura del suolo urbano che possa dimostrare le molteplicità attraverso il telerilevamento, utilizzando dati dal satellite CBERS 04A. La metodologia analizza gli elementi visivi delle immagini di telerilevamento attraverso l'interpretazione visiva, collegandoli a ciascuna classe proposta di uso e copertura. Con questo, è stato sviluppato un sistema di classificazione che copre lo spazio urbano in 17 classi, rappresentando un modo efficace per raccogliere informazioni sulle diverse forme urbane.

PAROLE CHIAVE: CBERS 04A, Classificazione dell'uso e dell'occupazione del suolo, Spazio urbano, Telerilevamento.

Introduction

The urban space as we currently know is manifested throughout cities with different hierarchical levels, which are commonly related to three expressions: the international, complex and chaotic city, the small and peaceful city and the intermediate city. However, this conception does not address the complex reality of the contemporary urban array, as it derives from an intense urbanization process and is driven by hegemonic capitalist forces[1].

An effective way of highlighting the contemporary urban complexity is through the anthropic morphology that lies in the Land Use and Land Cover (LULC) typologies, being buildings, road networks, urban green areas, and a diverse set of infrastructures. The analysis of how the different use and cover forms is manifested in the space is fundamental for the understanding of the urban reality, thus the detailed study of its classes and units is necessary[2].

Technological improvements have contributed to new approaches of LULC studies and, currently, its main basis relies on geotechnologies and remote sensing data, since they enable analysis with various goals. As an example, the application of a Geographic Information System (GIS) helps in the systematization, integration, identification, treatment and processing of data acquired from satellites and other remote sensing platforms, allowing a critical analysis of the (re)production of the geographical space[3].

Classifying urban forms in LULC classes is a process that has its challenges and requires specific approaches, because of the complexity of the current urban arrangement and the urbanization process itself. It demands a greater scale of detail, that allows urban forms to be identified and distinguished with accuracy, being a challenge to be overcome. Different methodological approaches and the technical improvements of remote sensors aid these difficulties, providing data with higher spatial, radiometric and spectral resolutions, but there are challenges still to be overcome[4].

The literature[5] reports several methodologies for spatial analysis, divided into digital and analogical approaches, however systems developed to classify the urban space are rarely mentioned. Urban LULC classifications usually aims on specific cases, focusing on the urban reality of a particular city or region, and other universal classification systems address the urban scheme in a broader way, failing to praise the real complexity that lies within this category of space.

Taking in consideration the global influence that cities have, regardless of their size, and the high rate of change to which urban centers are susceptible, a study and proposal of an urban LULC classification system is necessary. The availability of high-tech sensors and data supports the development of a study that follows this purpose, which was previously limited by factors such as the low resolutions of remote sensors. This would help territorial planning and the enhancement of urban socio-spatial phenomena, so that they are captured through remote sensors and expressed with cartographic content and geographical analyses.

Therewith, the objective of this paper is to propose a classification system for mapping the urban LULC with analogical techniques, based on visual interpretation, as a way of contributing to urban planning. The text is structured in four chapters: "*Theoretical Remarks*", the delimitation of the main theoretical references used in the development of the work; "*Methodological Procedures*", in which the methodological sequence adopted is demonstrated; "*Urban Land and Remote Sensors*", a segment of analysis and discussion of the results; then, a brief conclusion of the work will be made, followed by the bibliographic references used.

Theoretical Remarks

Authors[6] have discussions that contribute to the comprehension of the Brazilian urbanization process and the urban space characteristics. The contemporary urban reality was built by a diverse range of processes, among which the rise of the technical-scientific-informational environment had a great influence, producing a more fluid and clustered territory with the construction of new means of transport and a broader road network[7].

This process also influenced the characteristics of the urban morphology, assembling it as a result of the production and reproduction of the space by hegemonic forces, being a clear reflection of these agents and its ideals. The constant urban changes build a complex

[1] Santos, 1993.
[2] Lamas, 2010, 37. Souza et al., 2020, 94.
[3] Matias, 2003, 28.
[4] Chowdhury, Bhaduri & Mckee, 2018, 94.
[5] Novo, 2008. Jensen, 2008.
[6] Villaça, 1978. Suzigan, 1988. Corrêa, 1989. Santos, 1993.
[7] Santos, Souza & Silveira, 1998. Sposito, 2000. Santos, 2013.

and diverse morphology, encompassing anthropic and non-anthropic objects, such as houses, buildings, vegetation, among others, and the study of this urban morphology is one of the starting points to understand urban conflicts, enabling the different urban realities to be highlighted[8].

The proposal of a LULC classification system that highlights the diversity of the urban forms with remote sensing data is relevant, aiding a more accurate classification of the urban array, thus contributing to the mitigation of a diverse range of issues that surround cities worldwide. In the past decades, significant advancements in urban remote sensing, including the development of new sensors and algorithms, have brought forth new possibilities for urban LULC classification, both in analogical[9] and digital approaches[10], thereby enhancing the need for a classification system.

For that matter a recollection is needed, regarding authors that discuss on the basic concepts of classification systems[11], the understanding of remote sensing concepts and applications[12] and those who help to comprehend the possibilities, limitations and challenges when studying urban LULC with remote sensing[13].

Methodological Procedures

To fulfill this paper's objectives, the methodological sequence was divided into five topics: (i) Definition of the Sampling Area, (ii) Data Acquisition, (iii) Image Processing, (iv) Visual Parameters and Interpretation Key, (v) Classification System.

For (i) Definition of the Sampling Area, was considered the discussion of the geographic space as the dimension of interrelationships and multiplicities, in which different stories and trajectories coexist and collaborate to produce a complex and constantly changing space, which is reflected in the different forms of LULC[14]. Based on that, and on the discussion that a larger population results in a greater space complexity[15], the city of Campinas, Brazil (Figure 1), was chosen as the sampling area, since its dense demographic scenario has potential to express the urban space's diversity and complexity.

In (ii) Data Acquisition, data was chosen from the sensor Wide Scan Multispectral and Panchromatic Camera (WPM), from CBERS 04A satellite, a sino-brazilian satellite launched in late 2019, imaging the entire globe with 3 different cameras. Images from 08/29/2020 were acquired, imaged at 1:30:36 pm and the bands 0 (Panchromatic), 1 (Blue), 2 (Green) and 3 (Red). This satellite emerges as a new potential for urban studies, the WPM sensor has a spatial resolution of 2 meters at the panchromatic band and 8 meters at the visible and near infrared (NIR) bands, meeting the basic criteria for urban analysis[16].

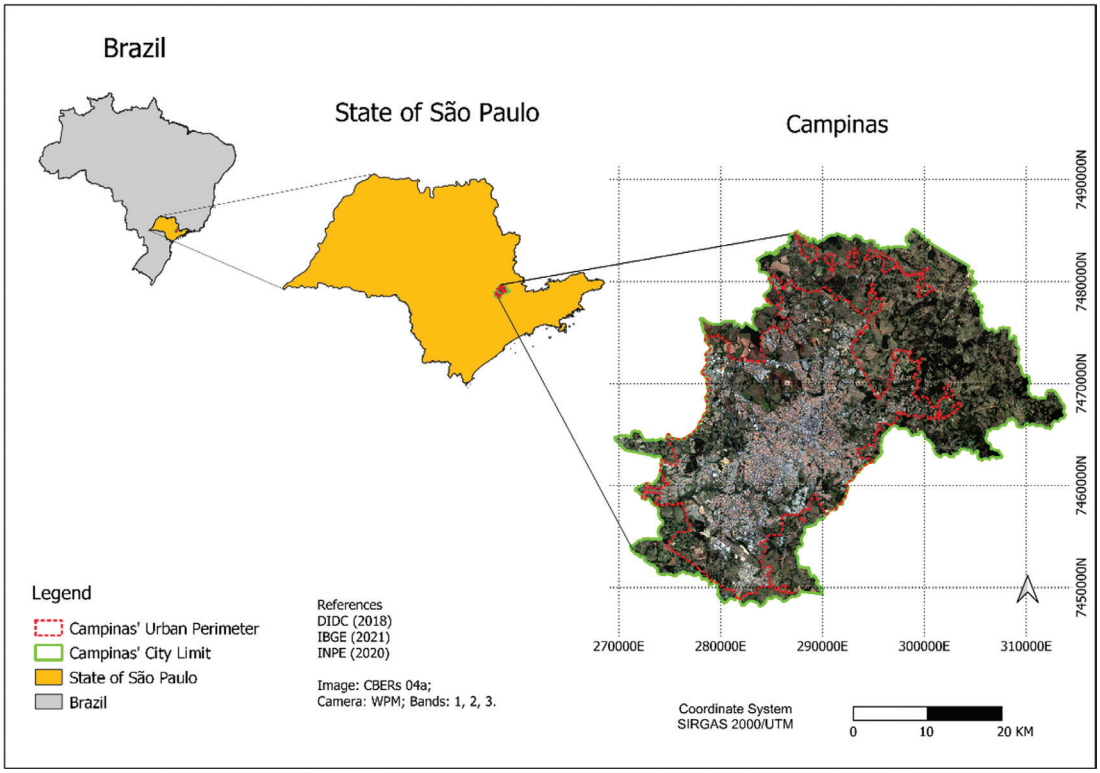
Regarding the topic (iii) Image Processing, the atmospheric correction and band compositions were made, being produced a true color image (Bands 3, 2 and 1) and a false color image (Bands 3, 2, 1 and 4)[17], in which a pansharpening processing was made. The two images resulted from the band composition allowed the visual interpretation of color, shadow and the differentiation among urban forms, the panchromatic image based the interpretation of the elements size, texture, pattern and shape, whilst the combined analysis of the three images helped to analyze the site, situation and association. This topic was developed aiming an analogical image classification of the two compositions, true and false colors.

In the topic (iv) Visual Parameters and Interpretation Key the visual elements, their variations and the composition considered were defined (Table 1) and the interpretation key was settled[18]. The interpretation and analogic classification of the final image assumed that the characteristics of certain types of LULC follow trends that can be observed in visual elements. This provided a basis for the development of interpretation keys, through which the classification process is less subjective and more precise.

Lastly, in (v) Classification System, the spatial scale was set to 1:10.000, and the urban LULC classification system was finished. The classes nomenclature was adapted from systems already mentioned by the specialized literature[19], being produced a classification system with two levels of detail (Table 2) and fixed the definition of each class (Table 3), aiming an analogical image classification.

[8] Massey, 2004. Lamas, 2010.
[9] Riegel et al., 2019.
[10] Huang et al., 2018.
[11] Anderson et al., 1979. Heymann, 1994. Instituto Brasileiro de Geografia e Estatística (IBGE), 2013.
[12] Novo, 2008. Jensen, 2008. Meneses & Almeida, 2012.
[13] Rogan & Chen, 2004. Ribeiro & Kux, 2009. Rashed & Jurgens, 2014.
[14] Massey, 2004.
[15] Santos, 1993, 95.
[16] Rogan & Chen, 2004, 307.
[17] Crosta, 1992.
[18] Araújo, 2015, 51.
[19] Anderson et al., 1979.

Figure 1. City of Campinas Location Map



Source: Elaborated by the Authors.

Table 1. Visual Elements, their Variations, and Compositions for Interpretation

Visual Element	Composition	Variations
Color	RGB and RGB + NIR	Definition of colors according to those in greater quantity in the objects, varying according to RGB and RGB + NIR compositions.
Size	Pancromatic	Very Small, Small, Medium and Large
Texture	Pancromatic	Smooth, Coarse, Intermediate and Mixed
Pattern	Pancromatic	Random and Sistematic
Shape	Pancromatic	Dotted, Linear, Retangular, Square, Triangular, Circular and Amorphous
Shadow	Pancromatic	With (Yes) or Without Shadow (No)
Site, Situation and Association	RGB, RGB + NIR and Pancromatic	Description and relationship of the object's physical characteristics with the scene and its surroundings. As an example, a mining area is associated with extensive exposed soil, surrounded by access roads, small administrative structures, and specific machinery (such as tractors and large extraction machines).

Source: Adapted from Jensen (2008).

Table 2. Proposed Classes and Levels

Level I	Level II
1. Urban Area	1.1 Agricultural Urban Area
	1.2 Commercial and Services in Medium Lots
	1.3 Commercial and Services in Large Lots
	1.4 Industrial
	1.5 Mining
	1.6 Vertical Residential in Private Lot
	1.7 Vertical Residential in Private Condominium
	1.8 Informal Residential Lots
	1.9 Horizontal Residential in Private Lot
	1.10 Horizontal Residential in Private Condominium
	1.11 Road Network
	1.12 Airport
	1.13 Cemetery
	1.14 Urban Equipment
	1.15 Vacant Lot
	1.16 Vegetal Cover
	1.17 Water Bodies

Source: Elaborated by the authors.

Table 3. Definition of the Proposed Classes

1.	**Urban surfaces, containing mostly buildings, structures, interventions, or anthropic uses.**
1.1	Areas destined to the cultivation of vegetables, fruits, grains, and other inputs, located in the urban limit.
1.2	Structures built to sell products and offer services, located on lots of up to 2 hectares, such as markets, hotels, services of the financial, administrative and construction sectors, schools, medium-sized, pharmacies and related forms.
1.3	Structures built to sell products and offer services, located on lots larger than 2 hectares, corresponding to large centers such as shopping malls, universities, hospitals, hypermarkets and related forms.
1.4	Areas with a concentration of industrial activities, such as processing (mechanical, chemical and thermal) and manufacturing (assembly of automobiles, ships, heavy machinery, manufacturing and electronics).
1.5	Area with a concentration of extractive industrial activities, such as open pit, underground and dam mining.
1.6	Residential units structured vertically, with three or more floors; residential buildings distributed in private lots, located in blocks.
1.7	Residential units structured vertically, with three or more floors; residential buildings distributed in private condominiums.
1.8	Informal residential; informal lots, slums, and squatters.
1.9	Residential units in individual private lots, structured horizontally, with up to two floors; small, medium, and large houses, distributed in blocks or areas with road access.
1.10	Residential units in private condominiums, structured horizontally, with up to two floors; small, medium, and large houses.
1.11	Transportation network, such as highways, railways, avenues and streets.
1.12	Area related to airports and its structures, such as airstrips, aircrafts garages, and parking.
1.13	Area related to cemeteries and its structures, such as tombs and administrative structures.
1.14	Recreational areas, destined to include the population in the urban space and green areas; recreational structures, such as parks, squares and gardens.
1.15	Lots without human construction, private or public, with a predominance of exposed soil or low vegetation.
1.16	Areas with vegetation located in urban areas; conservation areas, swamps and large shrub concentrations.
1.17	Water bodies, such as lakes, rivers, oceans and glaciers.

Source: Elaborated by the authors.

The Urban Land and The Remote Sensors

The urban space has a fragmented and articulated aspect, the reorganization made by hegemonic agents and the consequent ascent of a diverse array of LULC types fragments the space, but its individual parts are still connected, being codependent to one another, creating the articulated spectrum[20]. In this scene, the urban space is a social determinant and an expression of the capitalist interests, thereby the contemporary city becomes a complex arena of conflicts, housing disputes for the same space, among divergent multiplicities[21].

This conflicting space demands interferences and the urban planning must answer them through planning instruments and methodologies, among which the analysis of LULC is one of the main tools, as it gathers information about the distribution of urban forms, provides mathematical data about the urban array, and others, supporting a critical analysis of the space. The use of remote sensing for urban planning purposes have grown in the past years, the technological advancements enable the use of remote data to a more adequate planning, that embraces the space's multiplicities and realities[22].

The great range of classification systems verified currently cannot grasp the complexity of the urban array, approaching it in a plain and indirect way, diminishing vital information for the urban planning. There are systems developed to classify the urban space, but they have very specific goals, aiming local or regional analysis, and have no cohesion when evaluated altogether, making them unable for broader applications. As an example, the system developed to analyze the Brazilian city of Nova Hamburgo, aiming at a more sustainable urban planning, making this a vital contribution on a local scale, but not holding possibility of

[20] Corrêa, 1989, 7.
[21] Lefebvre, 2006, 70.
[22] Massey, 2004. Barreto, Silva & Cassol, 2016, 298.

Table 4. Urban Land Use and Land Cover Classification System

Classes		Visual Elements								CODE	Color of Representation (RGB)
		Color		Size	Texture	Pattern	Shape	Shadow	Site, Situation and Association		
		RGB	RGB NIR								
Urban Area	Agricultural Urban Area	Brown and Green	✖	Medium or Large	Smooth	Systematic	Linear, Oval or Square	No	Presence of exposed soil and areas for cultivation, located in peripheral areas of the urban limit.	1.1	C5E0B4
	Commercial and Services in Medium Lots	Brown, Grey and White	Brown, Grey and White	Medium	Intermediate	Systematic	Rectangular	Yes	Alike structures, in an area of easy access, usually larger than surrounding houses and with different roofing materials	1.2	C00000
	Commercial and Services in Large Lots	Grey and White	Brown and Grey	Large	Intermediate	Systematic	Circular, Elliptical, Rectangular or Square	Yes	Large shopping or service areas, with different structures, large parking and easy access.	1.3	FC9E9E
	Industrial	Grey and White	Grey and White	Large	Varied	Random	Rectangular	Yes	Large areas, with large and spaced infrastructures, parking lot and close to residential areas.	1.4	94888D
	Mining	Brown and Grey	Dark Brown and Light Blue	Large	Coarse	Random	Amorphous	Yes	Areas of exposed soil arranged in levels (excavation), with small establishments at its limits, usually with visible machinery. Located in peripheral areas of the urban limit.	1.5	000000
	Vertical Residential in Private Lot	Grey	Black and Dark Blue	Medium	Coarse	Systematic	Square	Yes	Tall buildings with large shadows, located in blocks divided by road networks. Allocated in blocks, with heterogeneous roofs.	1.6	FFC000
	Vertical Residential in Private Condominium	Grey and Orange	Black and Dark Blue	Medium	Intermediate	Systematic	Rectangular or Square	Yes	Groups of buildings in an area surrounded by walls, with a unified entrance. Buildings that follow the same structural and roof pattern.	1.7	BF9000
	Informal Residential Lots	Light Brown and Grey	Black, Blue and White	Small	Coarse	Random	Amorphous	No	Small lots in peripheral areas, with the predominance of unpaved roads and gray roofs (as seem in the true color image)	1.8	FFE699

(continued)

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Table 4. Urban Land Use and Land Cover Classification System *(continued)*

Classes		Visual Elements								CODE	Color of Representation (RGB)
		Color		Size	Texture	Pattern	Shape	Shadow	Site, Situation and Association		
		RGB	RGB NIR								
	Horizontal Residential in Private Lot	Orange	Blue	Small	Coarse	Systematic	Linear or Rectangular	No	Set of houses distributed in blocks and divided by road network.	1.9	A9D18E
	Horizontal Residential in Private Condominium	Orange and White	Blue and White	Small	Varied	Random	Linear or Rectangular	No	A set of houses, spaced out in an area delimited by walls, with a unified entrance and paved roads.	1.10	70AD47
	Road Network	Grey	✖	Medium	Smooth	Systematic	Linear or Rectangular	No	Concrete laid out in well-defined linear areas, or linear exposed soil.	1.11	D9D9D9
	Airport	Grey and White	Blue, Grey and White	Large	Varied	Systematic	Rectangular	Yes	Large structures, usually arranged next to a large runway, easily accessible and with planes in the area.	1.12	7030A0
	Cemetery	Brown or Green	Blue and White	Very small	Coarse	Systematic	Dotted	No	Area with undergrowth vegetation or exposed soil, with very small objects and few establishments.	1.13	C28ABA
	Urban Equipment	Green and White	Black and White	Medium or Large	Varied	Random	Random	Yes	Green parks in the urban area, with lakes, walking paths and small establishments.	1.14	416529
	Vacant Lot	Brown and Green		Varied	Intermediate	Systematic	Rectangular or Square	No	Surfaces that break with the pattern of their surroundings, with access by road network, covered by low vegetation or exposed soil.	1.15	FFFFFF
	Vegetal Cover	Green	✖	Varied	Coarse	Random	Amorphous	Yes	Surfaces with vegetation, without a defined distribution pattern and absence of buildings in their area.	1.16	00B050
	Water Bodies	Dark Green or Black	✖	Varied	Smooth	Random	Amorphous	No	Smooth surfaces, surrounded by vegetation or exposed soil.	1.17	0070C0

Source: Elaborated by the authors.

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applications on other scenarios, since it considers a specific urban space, and not the visual elements of the urban morphology[23].

The development of classification systems for a local purpose has the goal to highlight a specific morphology, whilst the ones aiming broader goals, diminish important information for urban planning. A resolution for this issue would be a system with more detailed classes, as the one proposed by NASA and USGS[24] but this raises other challenges since the high level of details cannot be evidenced in most multispectral remote sensing images[25].

Thus, there is a demand for a classification system based on a level of detail that follows the advances and limitations of open access remote sensing data. In view of these considerations, Table 4 presents the proposal for a LULC classification system, with the 17 proposed classes, the visual elements that represent each class, the numbering code and the representation color of each class (with the respective RGB code). This system is initially developed for precise analogical classifications, with further analysis required for digital classification, considering the diverse range of algorithms available and how the 17 proposed classes can be classified using automatic or semi-automatic techniques.

Final Considerations

Since the start of the Brazilian urbanization process, the production of the urban space follows hegemonic guidelines, which organizes the space to sustain the demands of capitalism, directly or indirectly. One of the most relevant methodologies to the study and planning of urban space is the classification LULC, as it raises important data to support urban planning. Considering this, the proposal for a classification methodology of the urban LULC arises, to support the gathering of information and to provide a basis for a new way to perceive the complexity of the contemporary globalized city, through remote sensing.

The system proposed here presented two levels of detail, considered sufficient for an analogical classification, in which the visual elements of remote sensing images were described according to the respective classes of use and occupation. Furthermore, the system should be tested with digital classification techniques, applying different algorithms, assessing the accuracy within the 17 classes.

A city with a high population density, such as Campinas, would be an ideal space for further analysis on digital classification techniques, given its complex urban array that exhibits distinct morphologies. On the other hand, the application of this system in other municipalities is also necessary, to evaluate how the proposed classes are distributed, determine if they are sufficient for classifying other urban patterns, and identify potential other urban LULC classes.

Like the other systems mentioned, the one proposed does not encompass all the plurality of morphologies in each class, requiring a third level of detail for this. There may be exceptions regarding urban forms that do not fit the description of visual elements, but this was expected, since the classification is based on generalization, made in small doses in this work. Thus, the most abundant elements of each class are the ones necessary to support an efficient classification system and, as for exceptions, collateral information is necessary, so that they are correctly identified.

The analysis and results obtained demonstrate the potential that remote sensing has, allowing to highlight socio-spatial issues that permeate the studies of geography and urban planning. The system proposed here is effective at the scale of detail aimed, with the possibility of expanding to another level of detail, which would require collateral information in addition to the remote sensing images. In this way, it is concluded that the classification based on visual elements is effective up to a certain level, considering that the more detailed the classification, the more collateral information would be needed. Finally, it is worth mentioning that the use of automated techniques for mapping and classifying the LULC is a well-founded methodology, especially when considering the technological advances of remote sensing systems, which allow more accuracy in distinguishing between objects in the urban space.

References

Anderson, J.; Hardy, E.; Roach, J. & Witmer, R. 1979: *Sistema de classificação do uso da terra e do revestimento do solo para utilização com dados de sensores remoto.* Rio de Janeiro (Brasil), SUPREN.

[23] Riegel et al., 2019, 380.
[24] Anderson et al., 1979, 32.
[25] Herold & Roberts, 2014.

Araújo, A. S. 2015: *Cobertura da terra intraurbana para inferências sobre a qualidade de vida na cidade de Marília / SP Cobertura da terra intraurbana para inferências sobre a qualidade de vida na cidade de Marília / SP*, dissetação de mestrado, Universidade de São Paulo, São Paulo (Brasil).

Barreto, J. R.; Silva, L. F. & Cassol, R. 2016: "A Aplicação das Geotecnologias na Fundamentação de um Planejamento Urbano*". Anais do XI Colóquio Internacional Sobre Comércio e Consumo Urbano*, 6 (5), 298-306.

Chowdhury, P. R.; Bhaduria, B. & McKee, J. 2018: "Estimating urban areas: New insights from very high-resolution human settlement data*". Remote Sensing Applications: Society and Environment*, 10 (2018), 93-103. https://doi.org/10.1016/j.rsase.2018.03.002

Corrêa, R. L. 1989: *O Espaço Urbano*. São Paulo (Brasil), Ática.

Crosta, Á. P. 1992: *Processamento Digital de Imagens de Sensoriamento Remoto*. Campinas (Brasil), Unicamp.

Herold, M. & Roberts, D. 2014: "The Spectral Dimension in Urban Remote Sensing", Rashed, Tarek; Jürgens, Carsten. *Remote Sensing of Urban and Suburban Areas*. London (England), Springer, 67-84.

Heymann, Y. 1994: *CORINE land cover: Technical guide*. Luxemburgo, European Comissions.

Huang, B.; Zhao, B. & Yimeng, S. 2018: "Urban land-use mapping using a deep convolutional neural network with high spatial resolution multispectral remote sensing imagery". *Remote Sensing o the Environment*, 214, 73-86. https://doi.org/10.1016/j.rse.2018.04.050

Instituto Brasileiro de Geografia e Estatística (IBGE). 2013: *Manual Técnico de Uso da Terra*. Rio de Janeiro (Brasil), IBGE.

Jensen, J. 2008: *Sensoriamento Remoto do Ambiente: Uma Perspectiva em Recursos Terrestres*. São José dos Campos (Brasil), Parentese.

Lamas, J. R. G. 2010: *Morfologia urbana e desenvolvimento da cidade*. Lisboa (Portugal), Fundação Calouste Gulbenkian.

Lefebvre, H. 2006: *A Produção do Espaço*. United Kingdom, Blackwell.

Massey, D. 2004: *Pelo Espaço: uma nova política da espacialidade*. São Paulo (Brasil), Bertrand.

Matias, L. F. 2003: "Sistemas de Informação Geográfica (SIG): ainda a questão do método". *GEOUSP – Espaço e Tempo*, 13, 21-33. https://doi.org/10.11606/issn.2179-0892.geousp.2003.123791

Meneses, P. R. & Almeida, T. 2012: *Introdução ao processamento de imagem de sensoriamento remoto*. Brasília (Brasil), CNPq/UNB.

Novo, H. L. 2008: *Sensoriamento Remoto: Princípios e Aplicações*. São Paulo (Brasil), Blucher.

Rashed, T. & Jürgens, C. 2014: *Remote Sensing of Urban and Suburban Areas*. London (England), Springer.

Ribeiro, B. M. G. & Kux, H. J. H. 2009: "Classificação Orientada a Objeto para Mapeamento do Uso do Solo – Métodos de Análise de Expansão Urbana". *Anais do XIV Simpósio Brasileiro de Sensoriamento Remoto*, 7893-7900.

Riegel, R. P.; Alves, D. D.; Birlem, L. E.; Roque, D. C.; Oliveira, G. G.; Haetinger, C.; Osório, D. M. M.; Rodrigues, M. A. S.; & Quevedo, D. M. 2019: "Classificação do Uso e Ocupação do Solo com Ênfase em Áreas Urbanas". *Anuário do Instituto de Geociências – UFRJ*, 42 (3), 377-386. https://doi.org/10.11137/2019_3_377_386

Rogan, J. & Chen, D. 2004: "Remote sensing technology for mapping and monitoring land-cover and land-use change". *Progress in Planning*, 61 (4), 301-325. https://doi.org/10.1016/S0305-9006(03)00066-7

Santos, M. 1993: *A Urbanização Brasileira*. São Paulo (Brasil), Hucitec.

Santos, M. 2013: *Técnica, Espaço e Tempo: Globalização e Meio Técnico-Científico Informacional*. São Paulo (Brasil), Edusp.

Santos, M.; Souza, M. A. & Silveira, M. L. 1998: *Território: Globalização e Fragmentação.* São Paulo (Brasil), Hucitec.

Souza, C.; Shimbo, J.; Rosa, M.; Parente, L.; Alencar, A.; Rudorff, B.; Hasenack, H.; Matsumoto, M.; Ferreira, L.; Souza-Filho, P.; Oliveira, S.; Rocha, W.; Fonseca, A.; Marques, C.; Diniz, C.; Costa, D.; Monteiro, D.; Rosa, E.; Vélez-Martin, E.; Weber, E.; Benti, F.; Paternost, F.; Pareyn, F.; Siqueira, J.; Vieira, J.; Neto, L. F.; Saraiva, M.; Sales, M.; Salgado, M.; Vasconcelos, R.; Galano, S.; Mesquita, V. & Azevedo, T. 2020: "Reconstructing Three Decades of Land Use and Land Cover Changes in Brazilian Biomes with Landsat Archive and Earth Engine". *Remote Sensing*, 12 (17), 2735. https://doi.org/10.3390/rs12172735

Sposito, M. E. B. 2000: *Capitalismo e Urbanização*. São Paulo (Brasil), Contexto.

Suzigan, W. 1988: "Estado e Industrialização no Brasil". *Revista de Economia Política*, 8 (4), 5-16.

Villaça, F. 1978: *Uso do Solo Urbano*. São Paulo (Brasil), Fundação Faria Lima.