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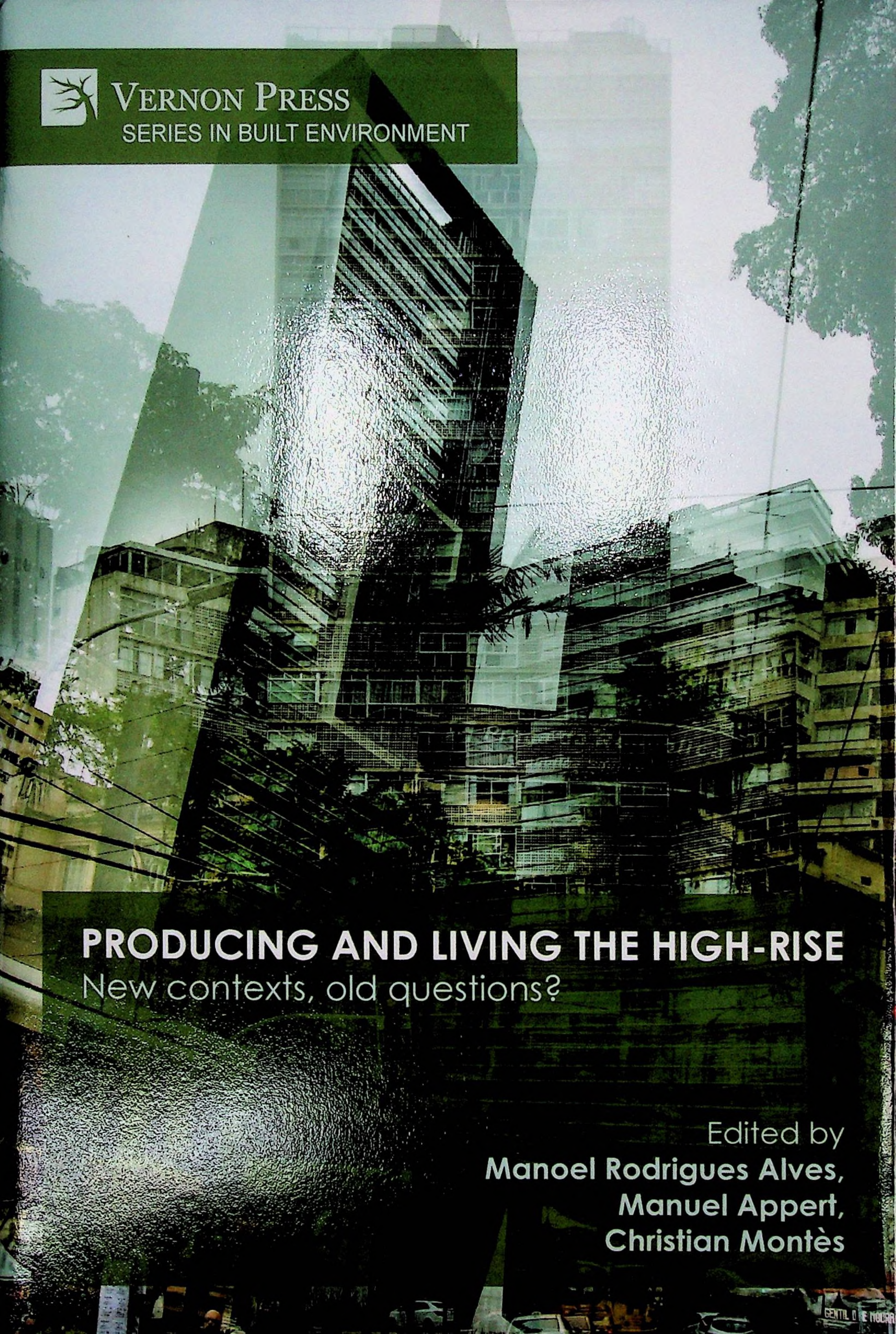

PRODUCING AND LIVING THE HIGH-RISE

New contexts, old questions?

Edited by
Manoel Rodrigues Alves,
Manuel Appert,
Christian Montès

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Chapter 16

Application of spectral mixing technique in remote sensing for analysis of skyscraper growth in São Paulo City

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Abstract

Remote sensing is a technique used to collect information about the Earth's surface through sensors installed on orbital or airborne platforms. The spectral mixing technique is one of the most used remote sensing techniques for satellite image analysis, allowing the identification of the spectral composition of each pixel of the image. The application of spectral mixing technique in remote sensing has been used in several areas, such as vegetation analysis, detection of changes in the Earth's surface, and analysis of urban morphoiogy. The objective of this study is to present the results of the application of the spectral mixing technique in remote sensing for analysis of the urban morphology of skyscrapers, associating this technique with different databases to identify and analyze processes related to urban morphology, land value, and socioeconomic issues. For this study, satellite images obtained through Landsat 8 sensors were used. The spectral mixing technique was applied to analyze the spectral composition of pixels corresponding to skyscrapers. In addition, other databases, such as the real estate registry, were associated with satellite images to identify land value and socioeconomic data were used to identify the characteristics of the population living in the urban area studied. The results obtained with the application of spectral mixing techniques allowed the identification of the urban morphology of skyscrapers and its association with different databases, allowing the identification of processes related to land value and socioeconomic issues. The results demonstrate the

effectiveness of the spectral mixing technique as a tool for the analysis of the urban morphology of skyscrapers.

Keywords: Remote sensing, skyscrapers, spectral mixing, urban morphology - land value

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Introduction

Remote sensing is an important technique for collecting information about the Earth's surface. Basically, it is the process of collecting information about an object, area or phenomenon from a distance, without being in direct contact with it. This is typically done using remote sensors, such as satellites or aircraft, which can capture images and data across the electromagnetic spectrum.

Among the various remote sensing techniques, spectral mixture analysis is widely used in satellite image analysis, allowing the identification of the spectral composition of each pixel in the image. This technique has been applied in various fields, including vegetation analysis, detection of changes in the Earth's surface, and analysis of urban morphology.

This text discusses the research development in the field of remote sensing regarding the "Highrise Living and the Inclusive City" project. The results of this investigation, which involves the sizing and analysis of the urban morphological evolution of skyscrapers using the remote sensing technique called spectral mixing, are presented. Spectral mixing is the result of the combination of different materials present in each pixel of the image, which results in the visual and spectral appearance of the pixel (Moreira 2007).

Spectral mixing is a common phenomenon in remote sensing images, where the spectral response of each pixel in the image is a combination of different materials present in the observed scene. Each material in the scene has a unique spectrum, which is a graphical representation of its reflectance or emissivity at different wavelengths.

For example, an urban area may be composed of materials such as asphalt, concrete, glass, and vegetation, each with a unique spectrum. When a remote sensor collects data from an urban area, the spectral response of each pixel in the image will be a mixture of the spectral responses of these different materials.

Spectral mixing can complicate the interpretation of remote sensing images, as the spectral response of a pixel may not correspond to a single material or material class. To overcome this difficulty, spectral mixing analysis techniques are used to unmix the mixtures and identify the materials present in each pixel of the image.

Spectral mixing analysis techniques are widely used in various remote sensing applications, including land cover classification, change detection, estimation of biophysical parameters, and others. Understanding spectral mixing is critical to correctly interpreting remote-sensing images and extracting useful information from them.

This study presents the results of applying spectral mixture analysis in remote sensing to analyze the urban morphology of skyscrapers. Additionally, the technique was associated with different databases to identify and analyze processes related to urban morphology, land value, and socio-economic issues. For the study, Landsat 8 satellite images were used, and spectral mixture analysis was applied to analyze the spectral composition of the pixels corresponding to the skyscrapers.

Other databases, such as real estate records and socio-economic data, were associated with the satellite images to identify the characteristics of the population living in the studied urban area. The results obtained with the application of the spectral mixture analysis technique allowed the identification of the urban morphology of skyscrapers and their association with different databases, allowing the identification of processes related to land value and socio-economic issues.

The results of this study demonstrate the effectiveness of spectral mixture analysis as a tool for analyzing the urban morphology of skyscrapers. Furthermore, the use of different databases allowed for a broader and more in-depth analysis of issues related to urban morphology, land value, and socio-economic issues. This information can be useful for urban planning and decision-making regarding land use.

16.1. Methodological assumptions

The Landsat family of images is composed of a series of Earth observation satellites launched by NASA in 1972. These satellites collect data about the Earth's surface in a variety of spectral bands, allowing for the analysis of natural resources, land use changes, and the impact of human activities on the environment.

According to the National Institute for Space Research (INPE), "the mission of Landsat is the acquisition and distribution of high-resolution orbital images for applications in natural resources and environmental studies, including geology, mapping, forest management, agriculture, zoning, urban planning, defense, and environmental monitoring" (INPE 2021).

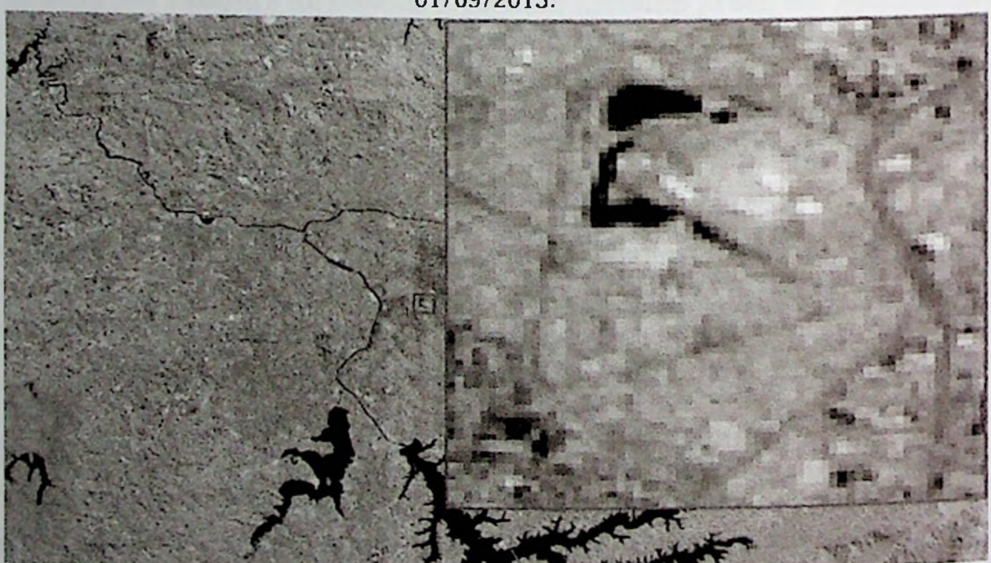
Since its launch, the Landsat family of images has been critical for environmental research and monitoring worldwide, providing valuable information for decision-making regarding land use and natural resources. One of the main characteristics of the Landsat family is its ability to collect high-resolution images in multiple spectral bands, allowing for detailed analysis of the Earth's surface.

Additionally, the longevity of the mission and the consistency of the data over time make Landsat images a valuable tool for long-term environmental monitoring. In summary, the Landsat family of images is a fundamental tool for environmental research and monitoring worldwide, with a long history of contributing to the understanding of natural resources and the environment.

The first approach of this study was to relate Landsat family image records with changes in surface materials in terms of composition and coverage, using image classification.

This was the first step to understanding the complex processes that led to these changes in the physical structure of this city. Using satellite images, it is possible to visualize these changes from an aerial perspective, considering an average of 700 km from sea level. And the question is: Is it possible to relate these physical records of the changes, accumulations, and ruptures in the urban space that the orbital images capture to the socio-political processes that direct them? How the changes in the spatial patterns of formal and informal housing over time in the São Paulo Metropolitan Region (SPMR) are detected and recorded by satellite images? (Figure 16.1).

Figure 16.1 The pixels of the Ibirapuera Park in São Paulo in a Landsat 8 image of 01/09/2013.



Adapted from Earth Explorer, 2013. (Growth of São Paulo, Brazil, 09/01/2013 - https://earthexplorer.usgs.gov/)

These changes can be used to estimate patterns of urban occupation into two common categories in Brazil, especially in the metropolitan area of São Paulo: formal and informal areas. Informal areas such as favelas will not be discussed at this time, but the focus will be on formal verticalized areas. The correct term for this is urban verticalization.

Before attempting to reach any conclusions about the presented questions, it is necessary to take a few steps back and think about how difficult it is to measure or map the spatial distribution of verticalization in a city, especially in São Paulo, which is a huge city with around 12 million people living there. If we consider the metropolitan area, it is even larger, with more people than in the entire country of Portugal.

A good example of this challenge is the work of professors Somekh and Gagliotti (2011). They analyzed how verticalization occurred in the city of São Paulo over the years from elevator installation permits, from the 1940s to 2011, in order to understand the distribution of buildings based on elevators installed by developers (Figures 16.2 to 16.4).

Figure 16.2 Verticalization in São Paulo based on the number of elevators installed between 1940 and 2011.

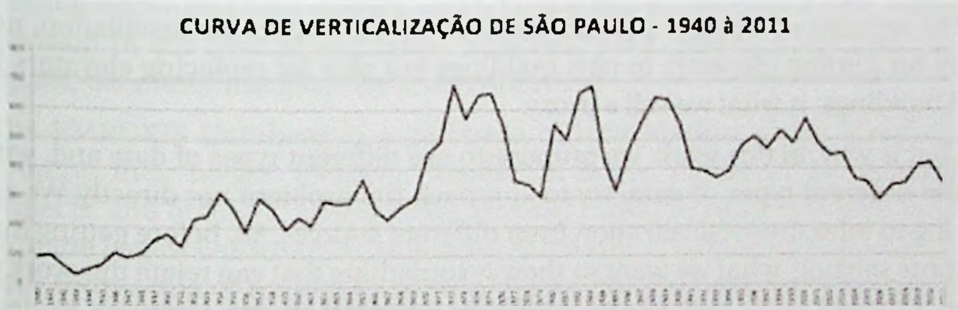
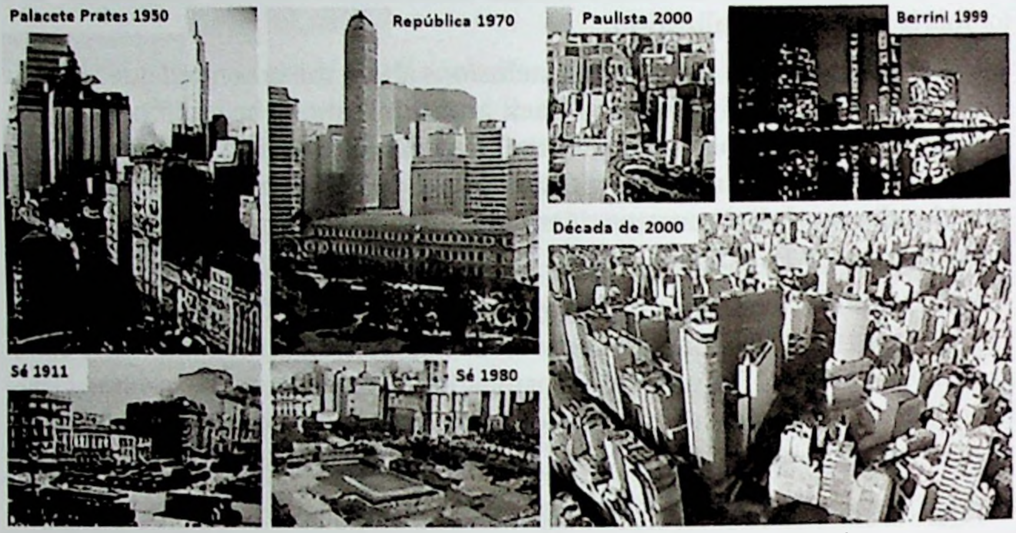


Figure 16.3 View of downtown São Paulo in 1940.

On the left, Tabatinguera street, the João Mendes Forum, and the Cathedral construction works. On the right, Rangel Pestana Avenue and the Carmo church. Source: Demographic History of the Municipality of São Paulo.

Figure 16.4 Imagens da verticalização de São Paulo entre as décadas de 1970 e 2000.



Source: Demographic History of the Municipality of São Paulo.

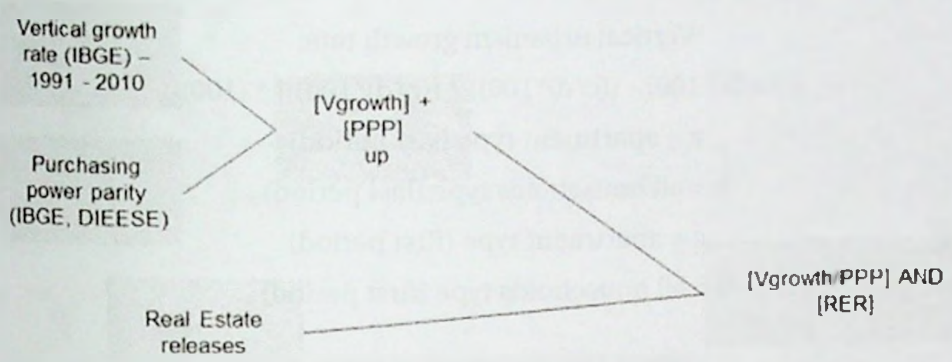
The amount of elevator permits received by developers for installation, not only for putting elevators in new buildings but also for replacing elevators in old buildings, is what we call a proxy.

That is why, in this work, we propose to use different types of data and, with these different types of data, try to approach the problem not directly. We are trying to infer the verticalization from different sources. So, before getting into remote sensing, what we want to show is something that can relate this work to the premises of a part of the problems involved in the high-rise project, especially in the Brazilian part of the High-rise Project.

16.2. Building a multilevel model to find study areas

To address the problem and try to associate what we are trying to see in the images with specialized data that can be used in Brazil to understand this phenomenon, it is important to address three different questions. The first one is the rate of vertical urban growth, how quickly some parts of the city are becoming vertical, and try to associate it with how much purchasing power has increased in other areas of the city. And if both things occur together and at the same time, are they spatially related or also occur in the same spots as the presence of real estate launches? Therefore, I can filter this in space, trying to simulate it with some mathematical models (Figure 16.5).

Figure 16.5 Filtering and simulation model based on selected data and mathematical models.



When you look at the set of this data, you can see where things are happening simultaneously in a certain direction, the central vector. In this case, we want to see where the city is becoming more vertical and at what rate, where the city is getting richer and how quickly, and whether this is associated with vertical expansion in the case of real estate launches, data coming from skyscraper projects, databases like Emporis and EMBRAESP.

The EMPORIS Database is a database of information about buildings, including their height, location, number of floors, construction materials, architects, and builders, among other relevant characteristics. It is considered one of the largest construction databases in the world, containing information about thousands of buildings around the world. This database is used by various sectors of the construction industry, as well as architecture and urbanism scholars for research and planning purposes (EMPORIS 2022).

The EMBRAESP database is an acronym for "Brazilian Company for Heritage Studies" and refers to a database that collects information about real estate developments under construction or already built in the city of São Paulo, Brazil. This information includes details about the size, location, and characteristics of buildings, as well as the number of residential and commercial units and other information relevant to the real estate market. The EMBRAESP database is a widely used reference source for real estate professionals, researchers, and urban planners for market analysis and urban planning (EMBRAESP 2022).

Just to understand what we mean by vertical urban growth, I am considering the data available over a 20-year period from 1991 to 2010, based on census tracts (approximately 250 households). And how quickly, compared to the most recent period, people in each census tract are seeking a specific type of housing, which is the apartment type. We are not looking at the buildings here because we do not have information on buildings in the census, but you have information on the apartment type, so the numbers are quite high, but I am applying a very high filter to consider high-rise buildings and see how fast verticalization occurs within a tract. It is a measure of speed, in fact, of acceleration, how fast it is growing(Figure 16.6).

Vertical urbanism growth rate:

$$\{[((a/b)*100) - ((c/d)*100)] / ((c/d)*100)]\} * (100)$$

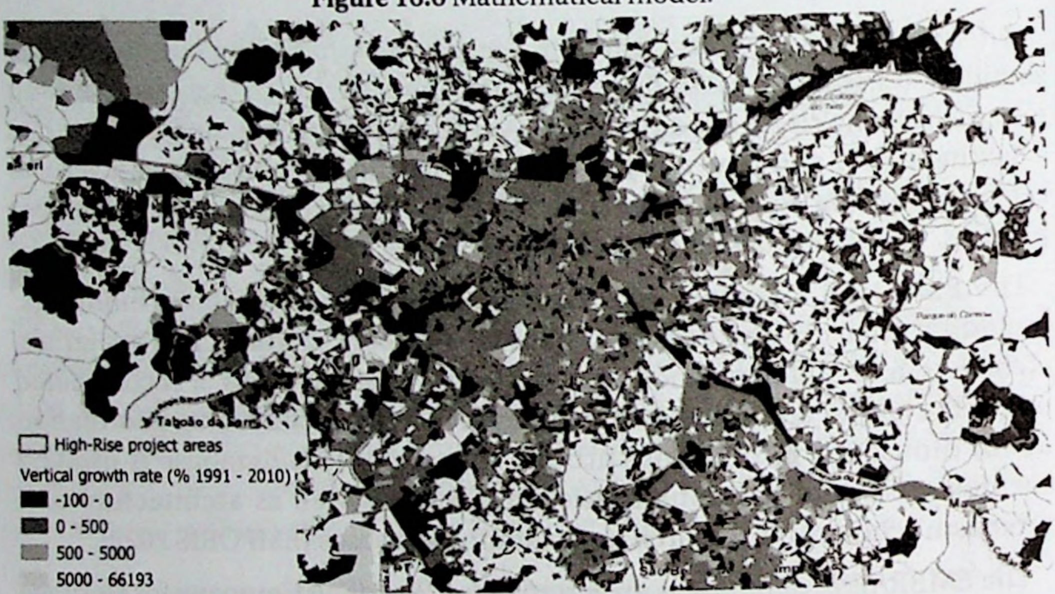
a = apartment type (last period)

b = all households type (last period)

c = apartment type (first period)

d = all households type (first period)

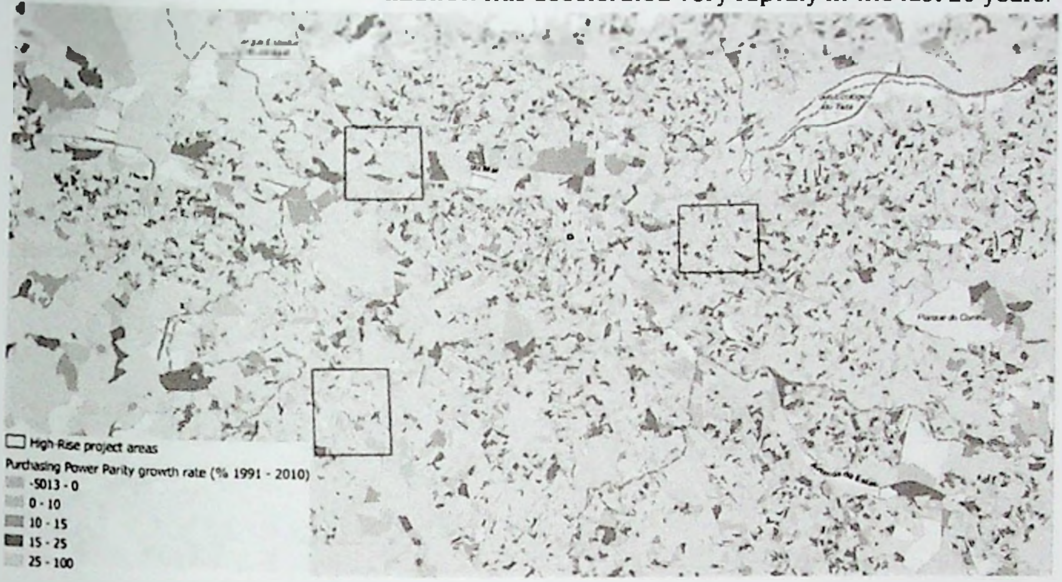
Figure 16.6 Mathematical model.



When we apply this statistic, this mathematical model to the metropolitan area of São Paulo, we can see that the yellow and green areas are where verticalization has accelerated very rapidly in the last 20 years, about five times faster than the rest of the city, or even 500 times or up to 5000 times greater in certain points than the rest of the city. It is a very fast pace of verticalization (Figure 16.7).

The second stage of this work was to construct the purchasing power parity growth rate, adapted from the Big Mac Index. The Big Mac Index (The Economist 2020) is a measure developed by The Economist magazine to compare the purchasing power of different currencies around the world. The index uses the price of a Big Mac, a fast food sandwich sold worldwide by the McDonald's restaurant chain, as an indicator of the cost of living in different countries. The idea is that the price of a Big Mac reflects local production costs and market conditions in each country, making it a reasonably accurate measure of the purchasing power of the local currency.

Figure 16.7 Areas where verticalization has accelerated very rapidly in the last 20 years.



During a long period of time in Brazil, during the hyperinflation period, we had different currencies resulting from distinct economic plans until 1991. In 1994, the Real currency was created and the period of inflation stabilization began, with this currency being used for the censuses of 2000 and 2010. Therefore, the minimum wage in Brazil is not comparable, as it has changed a lot due to currencies and inflation. In 1991, for example, the minimum wage changed three times in just one year and practically tripled at the end of the year compared to the beginning of the year. But, to be comparable over time, and in different spots within the São Paulo metropolitan area, we are taking as a reference the purchasing power of food and how many food parcels you could buy on average within the census tracts in different periods and how it evolved in this time series (Figure 16.8).

Purchasing Power Parity growth rate:

$$\{[((e/f) - (g/h) - (g/h))*100]\} * (-1)$$

e = total income of the Family chief (last period)

f = food parcel price (last period)

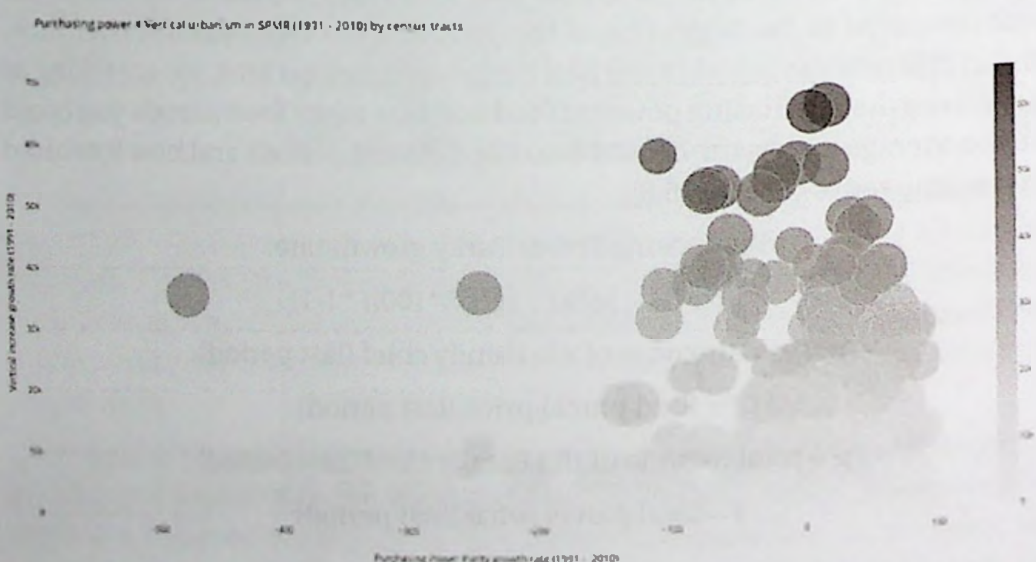
g = total income of the Family chief (first period)

f = food parcel price (first period)

Figure 16.8 Index similar to the Big Mac Index.

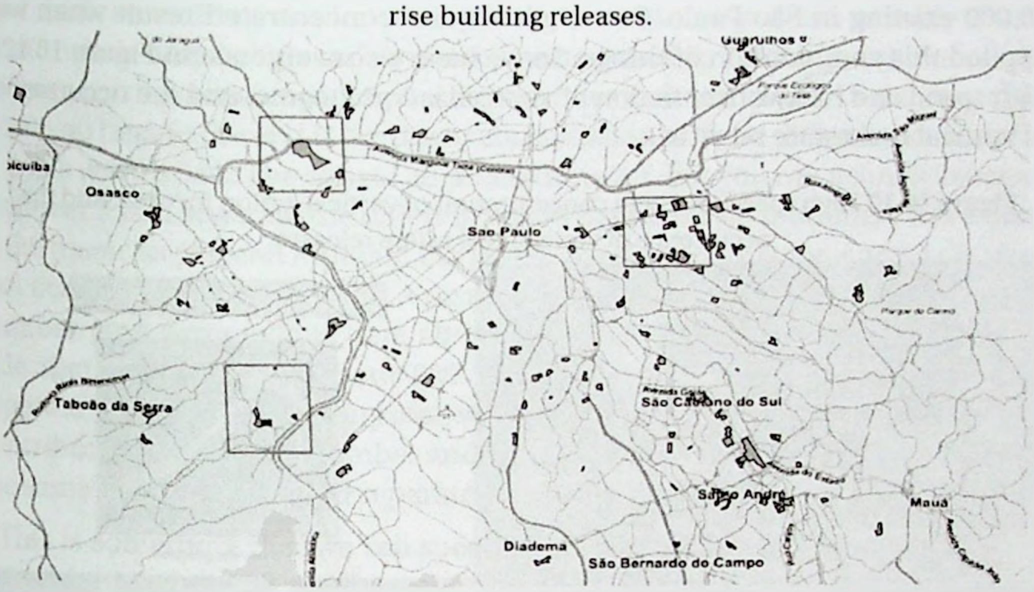
What we can see, especially in these blue areas, as a result of the calculation, is that the bluer the area, the more food packages people living there can buy compared to the past of the people who lived in this area. In some points, it is quite stable, as is the case with the white area, but the blue area is where income has really grown, considering the purchasing power parity (Figure 16.9).

Figure 16.9 Spatial result of the adapted Big Mac index mathematical model application.



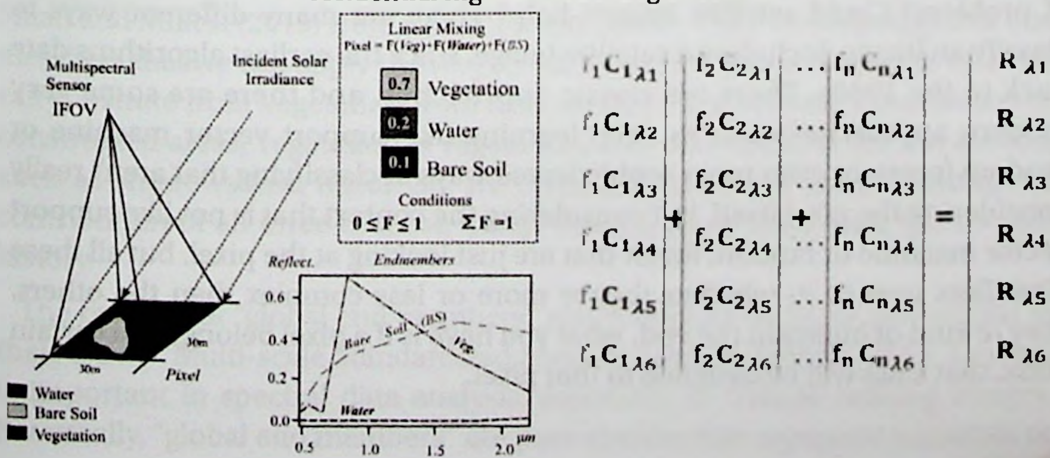
These areas mapped by the Highrise project bring many vertical residential high-rise buildings. This is part of the project's database and analysis and has revealed well-known areas of segregation and gentrification that are expected to be more gentrified areas, like Vila Anastácia, Vila Andrade, and Tatuapé (Figure 16.10).

Figure 16.10 Areas mapped by the Highrise project with many vertical residential high-rise building releases.



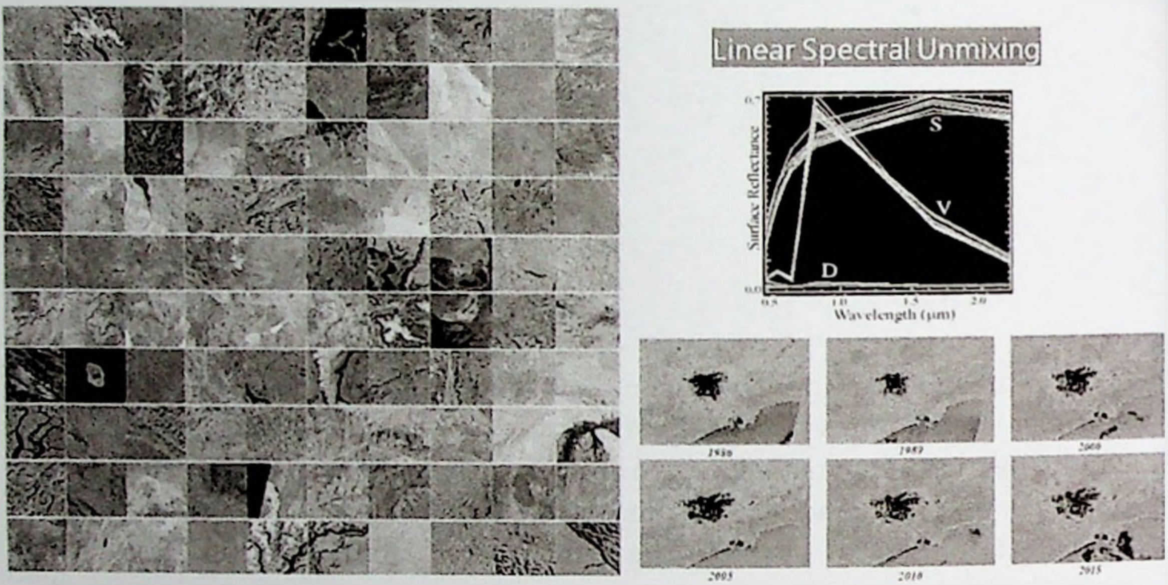
The interesting thing is that when you combine both things and, of course, consider the data provided by the real estate market, this is what you expect to see on the map when using the two mathematical models. Areas where vertical growth is very high and, at the same time, purchasing power is also very high. If real estate releases occur in the same area, I can consider that area as a potential study area. This was a very demanding field within the project, which means that the choice of study areas considered that vertical growth must be at least five times higher than that of the city, and purchasing power must be 25% higher than that of other parts of the city. At the same time, there must be at least one real estate release in the same period of time. (Vertical Real Estate: Total points count by census tracts; Vgrowt >= 500 AND PPP >=25 AND RER > 1) (Figure 16.11).

Figure 16.11 Graphic of areas mapped by the Highrise project with many vertical residential high-rise building releases.



The result was the selection of about 250 census tracts out of approximately 30,000 existing in São Paulo. So we got a quite concentrated result when we applied this combination of things. So we have a convergence in Figure 16.12, high speed and high concentration of verticalization income, and the occurrence of vertical real estate releases.

Figure 16.12 High speed and high concentration of verticalization income, and the occurrence of vertical real estate releases.



16.3. Building a model to understand the evolution of verticalization with remote sensing

What we have shown in the last chapter involves tabular data and field-collected data by agencies such as the Brazilian Institute of Geography and Statistics, asking people over a large time series. This allows for the construction of a multilevel model to understand the differences.

And if you don't have this type of information, how can we approach this kind of problem? Could satellite images help? There are many different ways to classify an image, including a satellite image, since the earliest algorithms date back to the 1960s. There are classic approaches, and there are some very modern approaches such as deep learning like support vector machine or random forest, or even more sophisticated ways of classifying that aren't really considering the pixel itself, but considering the context that is not like support vector machine or random forest that are just looking at the pixel, but all these classifiers next to it, whether they're more or less complex than the others, they're kind of binary in the end, what you have is if a pixel belongs to a certain class, that class will be assigned to that pixel.

Or we can also look at this process in a different way; you can look at the pixel and think something similar when you hear music, so you can actually think about who's here in the series when you hear music; it's the combination of different instruments together, so they are linearly fused mostly in the case and what you hear in the end is the linear combination of those different waves into a single wave exists. The sum of all different waves, but you can actually reverse engineer it and separate the different waves that make up that single wave that is the music as you can separate the guitar, the piano, the voice, and so on; you can actually do the same with a pixel. If you look at the pixel, a pixel is just a number. And we're talking here about a pixel of Landsat 8 image, on the lens side that has 30 by 30, about 900 square kilometers, but you can actually separate if you tell the computer what the things you think are inside and contributed to form that number and how much they contribute are, it's exactly the same thing, if you could separate the instruments of a music.

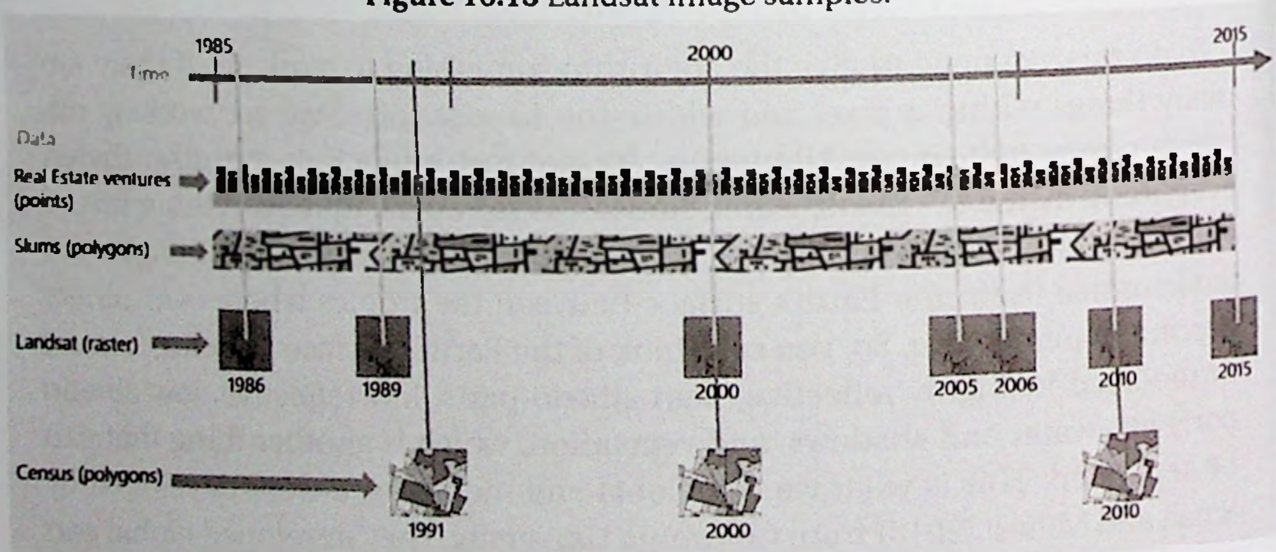
This is something that we call spectral mixing, and we can deconstruct this spectral mixing model within each pixel. In this example, it's a decomposition of a pixel, that is, how the percentage of vegetation, water, and various types of soil contribute to the number registered in this pixel. This is important because it's a dimensionality reduction, and we can reduce many dimensions into simple dimensions to track them over time.

To do this, we need to give the algorithm something to work on. If there are many things within a pixel and within the Landsat pixel we are working on, which covers 900 square kilometers, it's not just a block or a house; there's everything inside it - rivers, water, houses, skyscrapers, and everything mixed together. But we can simplify the land surface into at least three things - the land surface itself, the Earth's surface between the tropics where over ninety percent of people live. So, you can think of the Earth's surface as being formed or modeled by highly reflective, high albedo parts, low reflective, low albedo parts like water and shadows, and vegetation, which is another thing that can be separated. This is what we call global end members, a work developed by Small and Millesi (2013) from Columbia University. They developed global end members that we can apply to every city in the world. We can separate what we call substrate from vegetation from dark surfaces. The substrate can be soil or constructed areas, vegetation is vegetation, and dark surfaces are low albedo, such as shadows and water. So, we can easily estimate the percentage of contribution of all three of these things in each pixel. Each pixel has its own history.

The concept of "global end members" was proposed by Small and Millesi in their article "Multi-scale Standardized Spectral Mixture Models." This concept is important in spectral data analysis, especially in remote sensing images. Essentially, "global end members" are pure spectra that represent materials or classes of materials that appear in an image. They are called "global" because they are spectra that are considered representative of the entire dataset in question. These spectra are often used as a reference for analysis of pixel mixtures, where each pixel in the image can be considered as a mixture of various different materials. "Global end members" are different from local "end members," which are pure spectra that are specific to a region or specific location in the image. While local "end members" can vary from pixel to pixel, depending on the specific characteristics of the area, "global end members" are considered more stable and representative of the entire dataset. The identification and use of "global end members" is important for spectral data analysis because it can help improve accuracy in image classification, detection of land cover changes, and other remote sensing applications (Small and Millesi 2013).

At the beginning of this chapter, census data and location points for new real estate developments were worked on. Now, we are going to include a new layer here, which is orbital remote sensing. I am using some samples of Landsat images, and the choice of data is related to the sun's position and ensuring calibration between different times (Figure 16.13).

Figure 16.13 Landsat image samples.



Landsat is a series of Earth-observing satellite missions jointly operated by the US Geological Survey (USGS) and NASA. The Landsat program provides high-quality, multispectral, and thermal data that are valuable for a wide range of applications, including agriculture, forestry, land use and land cover change, and natural resources management.

When choosing Landsat images, several factors should be considered, such as the spectral bands required for the analysis, the cloud cover, the temporal frequency of the images, and the spatial resolution. Landsat data are available at different spatial resolutions, ranging from 15 meters to 60 meters. Higher spatial resolution images provide more detailed information but cover smaller areas.

The position of the sun during the acquisition of the Landsat images is also important to consider. The Landsat satellites are in a sun-synchronous orbit, which means that they pass over each location on Earth at the same time of day. This ensures that the illumination conditions are similar for all images of the same location, allowing for more accurate comparisons of the data over time.

Another important aspect of using Landsat data is the need for calibration. Landsat images are subject to different types of distortions that affect the radiometric and geometric accuracy of the data. Radiometric calibration is the process of converting the raw digital numbers (DN) obtained from the satellite sensor into physical values such as reflectance or temperature. Geometric calibration corrects distortions caused by sensor and platform orientation and atmospheric effects.

The USGS provides calibrated and georeferenced Landsat data for free download, but it is important to note that some level of pre-processing may still be necessary, depending on the specific application. Overall, Landsat data are a valuable resource for a wide range of Earth observation applications and require careful consideration when selecting and processing the images.

So, by decomposing all the pixels for the different years in the metropolitan area of São Paulo and correlating these values, we can observe the black line in Figure 16.14, which shows the shadows that I can extract from the pixels correlated with the types of apartments that I can extract from census information. Most of the correlations are positive, meaning that the greater the increase in apartment types in the census data, the greater the increase in shadows in the image. Part of this can be explained because we lose the detection of the substrate, which would be the built area, but tall buildings if they are too tall, the shadows start to cover what should be detected as a different type of land cover. This largely explains this strange positive correlation.

Figure 16.14 Correlations between the extracted Endmembers and apartment-type houses (aggregated by census tracts): 1986 – 2015.

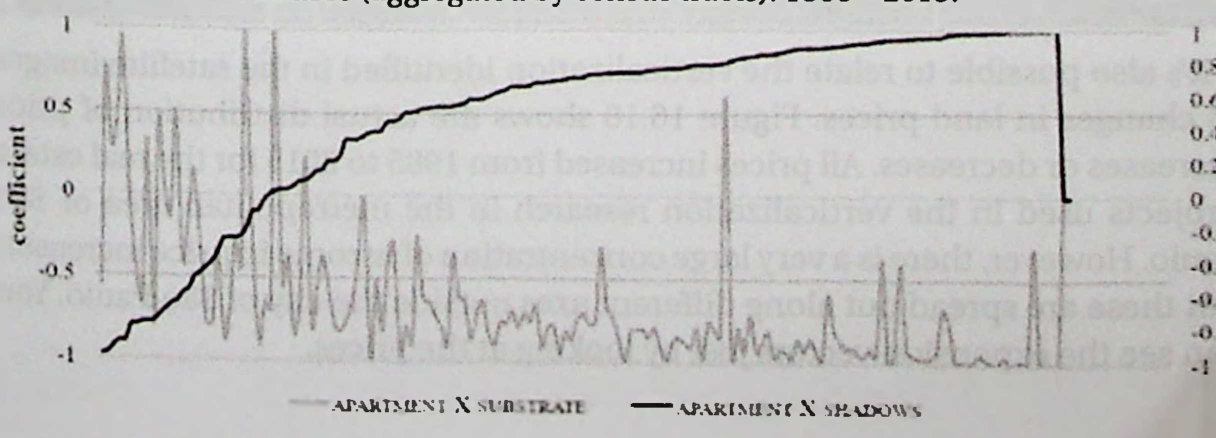
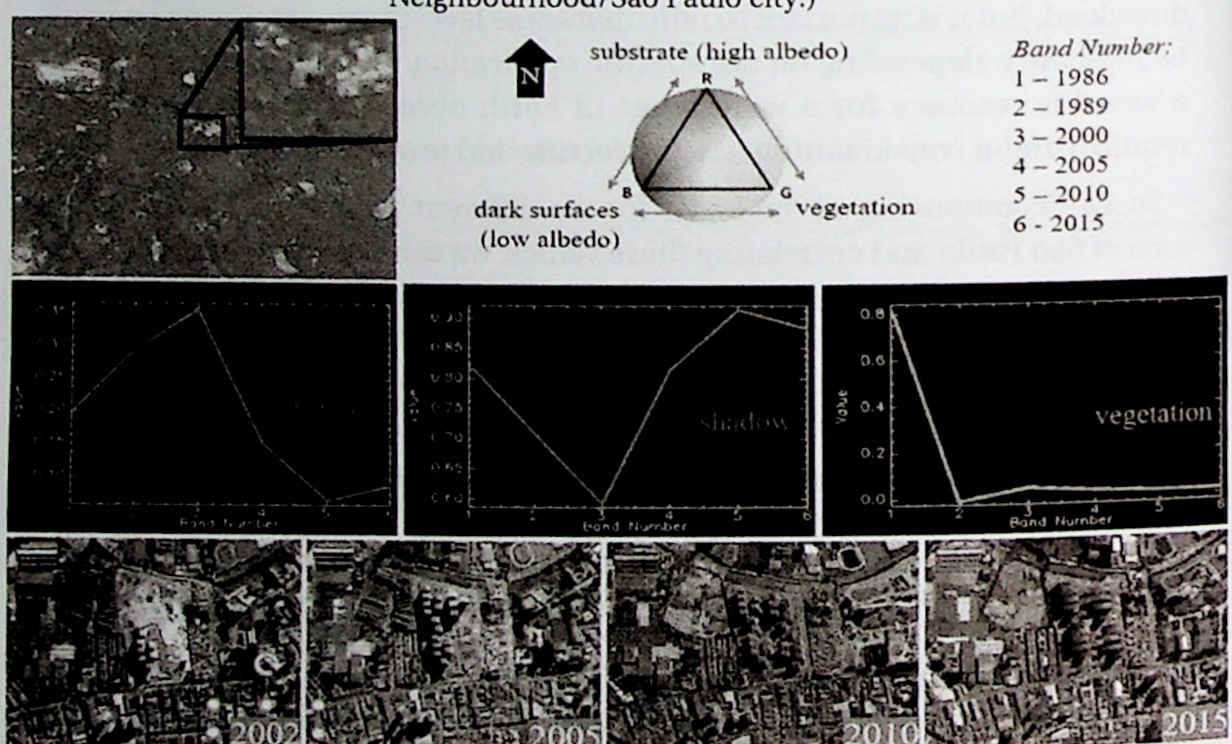


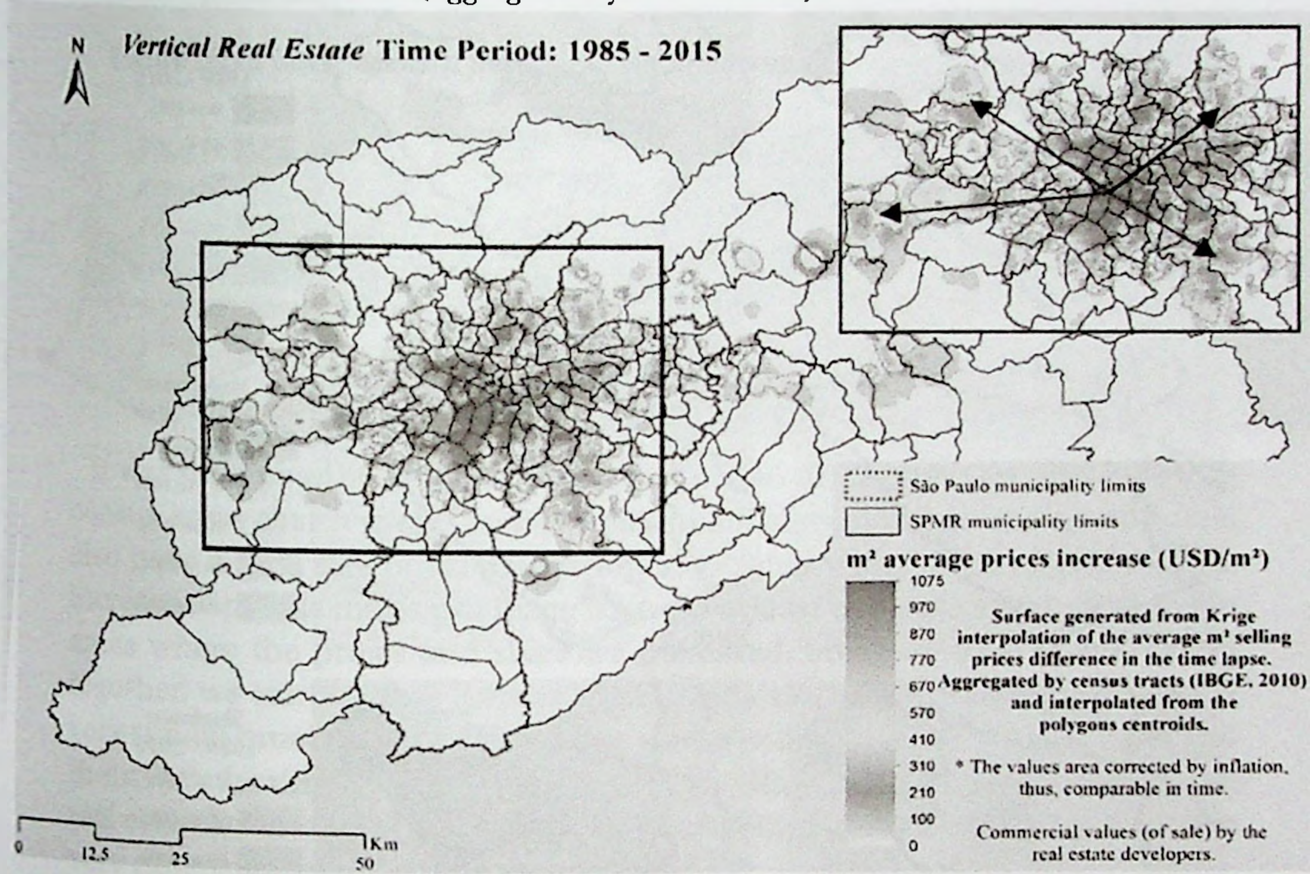
Figure 16.15 shows, as an example, an area in the metropolitan region of São Paulo, in the Maria Zélia neighborhood, from a construction site in 2002, 2005, 2010, and 2015. This is what we can call the trajectory of the pixels, in this case, a few pixels in this area. The substrate at the beginning is a bit of substrate, a bit of shadow, and a lot of vegetation in the 1985 image. It is possible to observe that the substrate at some point increases because the vegetation was good up until the start of construction, and then at some point, the substrate starts to decline, but the shadows start to increase. And, of course, the vegetation never comes back and probably will never come back, but what we can see in Figure 16.14 is a kind of trajectory, but we can consider it as a space-temporal signature of a verticalization process. Look at a time series in a satellite image. This is derived from a time series that was calculated using the number of members, how much the substrate changes over time, how many shadows change over time, and how much the vegetation changes over time.

Figure 16.15 Fractions variance profile in a verticalization area (Maria Zélia Neighbourhood/São Paulo city.)



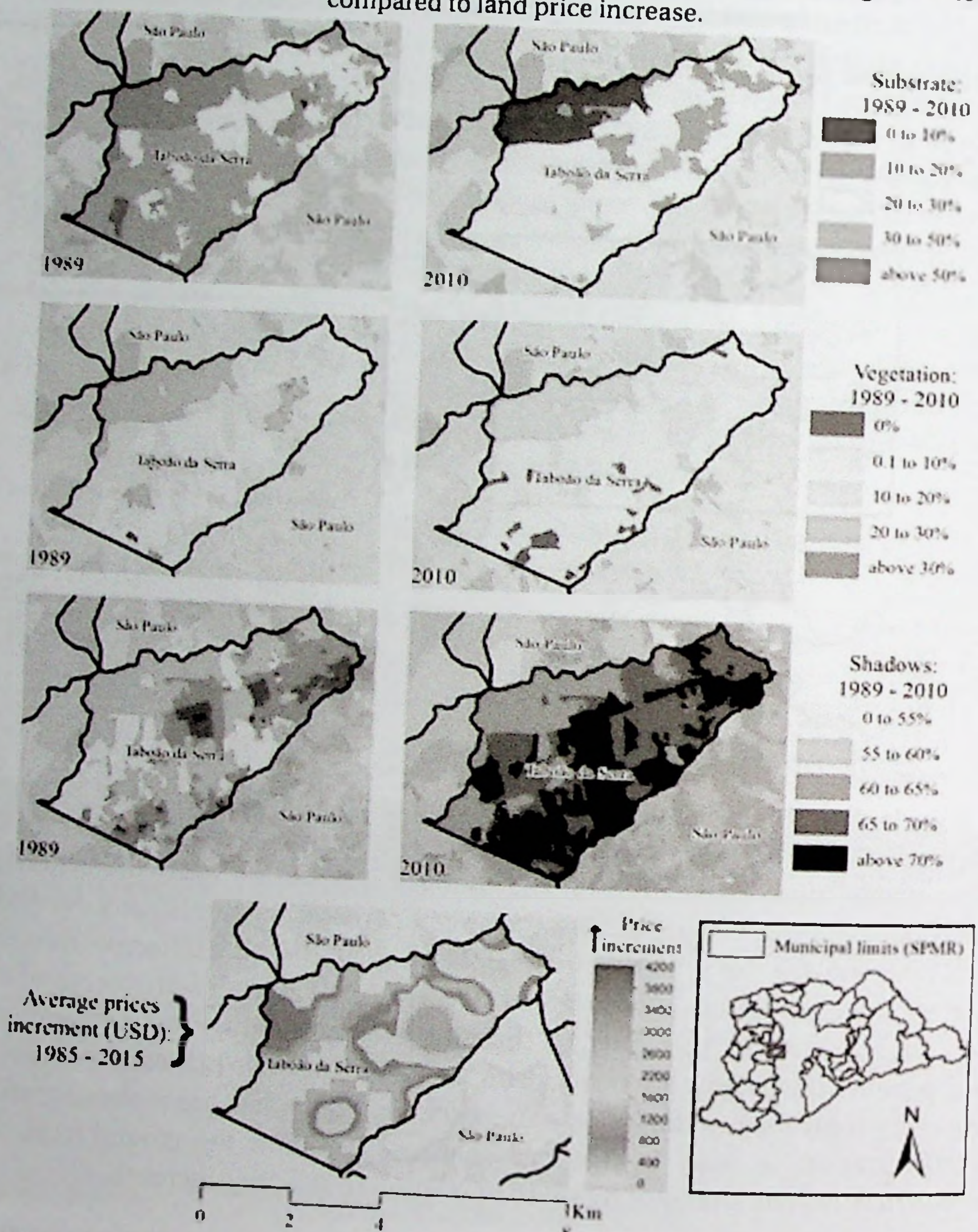
It's also possible to relate the verticalization identified in the satellite images to changes in land prices. Figure 16.16 shows the actual distribution of price increases or decreases. All prices increased from 1985 to 2015 for the real estate projects used in the verticalization research in the metropolitan area of São Paulo. However, there is a very large concentration of income in price increases, but these are spread out along different axes outside the city of São Paulo. You can see the expansion vectors just by looking at the prices.

Figure 16.16 Correlations between the extracted Endmembers and apartment-type houses (aggregated by census tracts): 1986 – 2015.



If we look at this price distribution, taking as an example the city of Taboão da Serra (Figure 16.17), a very small city close to the modern and sophisticated area of São Paulo, we can observe the changes. It is possible to see the shadows increasing in the same period that the prices increase, and this is a process. And when we look at the material change, it also increases on a different scale, of course. We are talking about a very large pixel, but it allows us to observe what is concentrated in this part of the city just by looking at the shadows. Supposedly, if we know the relationship between these two processes very well, we can simply look at the images and argue that the prices are increasing with verticalization, at least in this case, because we know the ground truth to confirm it. So, the shadows increase in relation to the price increase.

Figure 16.17 Taboão da Serra town example: fractions alteration along the time compared to land price increase.



The price increase map shows the movement of the real estate speculation process. This trend showed a strong spatial correlation with the construction of high-rise buildings. This also explains the increasing trend of evicting slums to increasingly peripheral areas. Satellite images can also tell this story. As stated, the verticalized areas show an inverse correlation between substrate and shadow fractions and, at the same time, illustrate spatial correlation to the increased price areas. Therefore, the urban structural change shown in the imagery reflects social and political alteration and variability, displaying them in urban space (Figure 16.18).

Figure 16.18 Correlation of price increase, shadows and construction of high-rise buildings.

It was then possible to observe that in Taboão da Serra, there are also some census areas that respond to this mathematical model that was created. You also have a high rate of verticalization associated with a high rate of income increase of people moving or living there, in at least two points very close to the areas where the prices and shadows increased. So, if we look at everything together, we can see that there is a price increase, and the image will show a very similar process. I'm looking at the shadows because I'm trying to associate them with the verticalization. This is how I model it, and we have a lot of vertical real estate releases that investors put into buildings in this area, and at least two very expensive ones are related to this part.

Conclusion

In conclusion, the chapter highlights the importance of modeling and detecting the process of verticalization and gentrification using mathematical models and remote sensing techniques. While the task of modeling gentrification is challenging, it is crucial to better understand this complex process and its impact on urban landscapes.

Verticalization and gentrification are terms often associated with urban development and social change.

Verticalization refers to the increase in population density in urban areas, resulting in the construction of taller buildings. This is generally associated with urbanization and economic growth but can also be a result of real estate pressures and government policies.

On the other hand, gentrification refers to the process of social and economic change where previously degraded or less favored neighborhoods are occupied by individuals or groups with higher purchasing power. This often leads to urban renewal, increased real estate value, and displacement of low-income residents.

Although verticalization and gentrification are often discussed together, they represent distinct phenomena. Verticalization can occur without necessarily resulting in gentrification, and gentrification can occur in areas without necessarily involving verticalization.

However, it is common for verticalization and gentrification to occur together in urban areas, especially in large cities. As demand for housing increases, property prices rise, making central and well-located areas inaccessible to many people. This can lead to a process of gentrification, where people with higher purchasing power move to these areas, contributing to verticalization and displacing low-income residents.

Understanding these phenomena is important for urban planning and public policies aimed at ensuring access to quality housing for all layers of the population. Additionally, detection and monitoring of verticalization and gentrification can be done through remote sensing techniques, such as satellite image analysis, to identify changes in the urban landscape and the evolution of real estate prices.

The chapter presents a simple model that focuses on the increase of vertical range and concentration gap of money, which is multiplied and expanded by the real estate market over time. However, it is important to note that this model does not consider state intervention or the role of the state in creating opportunities for gentrification.

Furthermore, the chapter emphasizes the significance of physical characteristics in remote sensing and how they can be used to characterize processes over time. For example, in the case of São Paulo, the increase of shadows in certain areas can be linked to specific physical changes in the urban landscape associated with verticalization.

Overall, the chapter encourages researchers and policymakers to continue exploring the relationship between mathematical models, remote sensing techniques, and urban processes such as gentrification. By doing so, we can gain a better understanding of these complex phenomena and develop more effective strategies to address them.

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