Urban volumetric capacity analysis in Brazil: a Pampulha case study

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Abstract
Since beginning of the implementation of Master Plans the Brazilian urban landscape is being shaped by morphometric parameters. Current regulations on those parameters establish additional coefficients obtained through financial compensation in order to reach two objectives: 1- make the property meet its social function; and, 2 - return to the government profits generated by real estate speculation as they are considered capital gains. This paper analyses the Floor Area Ratio and Coefficient of Utilization or Bulk to investigate the balance between stock and deficit in those parameters, using a 3D source based on Light Detection and Ranging (LIDAR). The goal is to analyse the quality and applicability of urban cadastres and defend 3D cadastres as well as discussing urban landscape morphometric modeling in Brazil. This study is illustrated by a case study of an important modernist neighbourhood, Pampulha in the city of Brlo Horizonte that was projected by Oscar Niemeyer.
Keywords: Volumetric Capacity Analysis; Urban Landscape; 3D Cadastre; LIDAR (Light Detection and Ranging).

1. INTRODUCTION

Collective management of landscapes is a desire since man has understood his part of a cultural group and began to imprint it through embodiment of housing values. Common interest is represented by the lot unit scale, which is the result of a synthesis of individual responses. In this way, the place's essence is established, depicting the values of the times from socioeconomic and geographic cultural references.

The history of urban settlement in Brazil oscillates between intentions of planning and occupations with no apparent logic. The latter were not even conditioned by the geography of the site. The questions one asks are: How is the urban landscape composed today? Are there ways of understanding the processes so that they are, in fact, a translation of collective values? What roles do urbanism and architecture have in this process?

Legal urban landscape could be generated by local 'urban surgery' ("*cirurgia urbana*" in Portuguese) or by parameters [1]. Surgeries occur as intervention projects in small temporal - and spatial - scale altering conditions, uses and variables of urban space. They are usually done by government associations in partnership with private entrepreneurs, who generally finance the processes. According to Harvey [2, 3] this process generates entrepreneurial cities, or in the original term, "entrepreneurship".

According to the zoning definition, parameters represent the application of planning rules in a city, regulating its carrying capacity and load conditions. In addition, they indicate how each lot should be occupied. The process of identifying urban and landscape changes, as a sum of the alteration made by human beings, takes a long time. Usually, local communities do not notice the gradual impact of planning rules, but do perceive overall change.

In colonial Brazil the first parameter dates from the time of the gold cycle. According to Reis Filho [4], Brazil's urban evolution had a very significant moment in that era thanks to the search for gold, which led to permanent urban settlements. Few rules were established for the construction of urban occupations, which brought on the creation of axis roads that respected geographical constraints and joined the small villages to their parishes. These were territorial units that could be related to neighborhood units or surroundings and they began from mining sites. Urban networks shaped urban settlement as well as the connections that united these small villages [5]. Moreover, at the time, the landscape was regulated by the Royal Letters and Ordinances of the Portuguese Kingdom. They were normative and defined the layout of buildings' alignments to the front without any setbacks. Would this first parametrization be solely responsible for the urban design notably featuring the settlement composition? Note the heterogeneity among homogeneity, so, each built unit was an architectural response, but there was something uniting them and, in this way, they formed a whole. There were practically no propositions related to facades' rhythm, elements' dimensions, little was said about an architectural language, but would the simple front clearance parameter be able to ensure a composition of the set?

After that, Brazil has been through many economic and political cycles that brought architectural and urban phases related to positivism, as examples, Aarão Reis's design of Belo Horizonte (1894) and Pereira Passos's reform in Rio de Janeiro's central area (1903). During this phase, Agache's plan in Rio de Janeiro (1930) and Curitiba (1943) represent significant marks. His intention was to define constraints of landscaping possibilities on buildings as to the individual responses of lots. The Agache Plan for Rio de Janeiro [6] is considered the first Brazilian Master Plan and it was aimed at scenic modeling, the beautification of the city, and it established orchestrated rules to a geometrically harmonious city within the positivism logic.

The Brazilian way of orchestrating the urban landscape, built from the lot unit since the 1930s, is morphometric and parameters have been more widely used in urban planning and have introduced new concepts related to constructive feedback.

Parametrization in Brazil, even today, is morphometric, because it presents a very two-dimensional geometric modeling rule of maximum envelopes that affects the architectural response. Based on setbacks, occupancy rates and, above all, the use of coefficients, the logic behind what is considered the ideal condition of unit occupation is the reproduction of the lot, also understood as the created soil. It is argued that, traditionally, a lot should use one as coefficient, which means that the same lot's area is acceptable for the sum of the constructed plans. Going beyond coefficient 1, which means 100% of the lot area divided the sum of overlapping horizontal planes, already starts to create an additional soil and land speculation of the territory's use.

The current regulation of those parameters is the Statute of the Cities (Federal Act 10,257 of 2001), establishes additional coefficients allowed with financial compensation to attain two objectives: make the property meet its social function and return to government values produced by real estate speculation considered capital gains obtained from real estate profits. [7]

This paper proposes to analyze the TO (*Taxa de Ocupação*/ FAR – Floor Area Ratio) and CA (*Coeficiente de Aproveitamento*/ Coefficient of Utilization or Bulk). It proposes to broaden an investigation on the balance between stock and deficit of those parameters using a 3D source based on LIDAR (Light Detection and Ranging) of *São Luiz* and *São José* neighborhoods in the Pampulha Region in Belo Horizonte, Minas Gerais, Brazil, to perform a critical analysis of the resulting urban landscape after parameter applications. Its goals are to analyze the quality and applicability of urban cadastres and defend 3D cadastres. In this way we discuss morphometric modeling of urban landscape in Brazil, as illustrated through a case study.

Investigations of parameters' balance are needed because of cadastre updating, irregularities' control, analysis of the land's investment potential and needs. Understanding how different rules applied in other places such as rules on density, volume, sight view, the environment and others issues could bring insights to improve Brazilian regulations and increase public participation based on the idea that management of the land is a community achievement.

Good architecture should provide balance and proportion, even though the language varies (modern, baroque, neoclassical). We notice a loss of architectural quality over the years in Brazil with the creation of the volumetric envelopes promoting a change in the architect's role (when there is one) from designer to envelope filler to satisfy real state greed. We suggest that leveling of this knowledge would ease the process of avoiding illegalities.

The *São Luiz* and *São José* neighborhoods in the Pampulha Region in Belo Horizonte, Minas Gerais, were chosen to develop a case study, as they are very important areas of modern architecture and urban planning, designed by Oscar Niemeyer. They are located in a strategic axis of growth, in a place with very good infrastructure and accessibility, good urban services and quality of life, beautiful landscape and good environmental conditions. Most lots are big (an average of 600 to 1000 square meters), presenting single-family residential buildings, and constructed by previous generations, which means risk of transformations due to the market's interest in buying lots and in this way destroying the present landscape to impose a landscape based only on morphometric aspects supported by the law. The point is: How do we analyze the carrying capacity of the area not only taking morphometric aspects into consideration? The first challenge is to deal with the law that is already in place and analyze the area according to current rules and present a portrait of reality.

2. MATERIALS AND METHODS

The methodological approach was based on two main steps: 1 - check the difference between official 2D and generated 3D cadastres, and 2 – analysis of authorized volumetric landscape.

The first step was to create a database to set up a 2D and 3D cadastre. Substantial work had to be done to adjust topological problems in 2D representations of lots and buildings. The second step was to build an analysis of volumetric landscape: as authorized by law and how it is done in reality, to identify areas of stock or deficit of volumetric use, which means new buildings or bigger constructions.

A 3D cadastre was generated using LIDAR (Light Detection and Ranging) information to create a digital terrain model and a digital surface model to state the height of the land and buildings' surface. It also had a layer of the building area as well as zoning code according to the city's master plan favoring the 3D model creation and balance between stocks and deficits, according to local stated regulations. The data base used was provided by Belo Horizonte's City Hall. The use of that information, especially LIDAR, favored the operational procedure making it reasonably fast, if compared to other procedures of cadastre creation with great analysis potential.

2.1. Topological and cadastral corrections

Problems observed, that could be problems from cadastre registration data or from representation in digital cartographic data, were:

- Lots that were not divided and were used by different buildings without been a condominium. More than one building with same identification field in the lot. (Figure 1)
- Lots that were not unified and were used by one building, projected on both lots. (Figure 2)
- Buildings in more than one lot, representing topological problems or representational problems.

(Figure 4)
- Significant differences from the area calculated by geometric tools in the software and the area registered in the official database, presented in alphanumerical tables associated in the polygons.

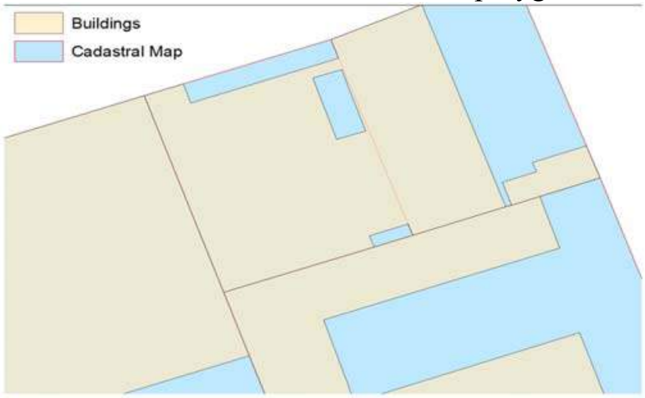

Figure 1 – Many buildings on the same lot. **Figure 2 -** Example of a building that is bigger than the lot, meaning that more than one lot was used by the owner, but in the cadastre the lots were not unified (integrated).

a) The first step was to check the difference from the lot area, in square meters, that registered in the alphanumeric table linked to the cartographic representation in comparison to the area calculated by the software, according to geometric values of polygons. Comparisons that presented a difference higher than 10 m2 were selected, as some differences can occur because of natural differences between reality and registration database values. These incongruities were 0.55% of the total of lots and the majority of these areas were very big lots in public use or public service.

It was observed that the majority of these lots were very big and because of that the difference of 10 m^2 was not so important as it is in single private lots. It was also observed that the majority of these big lots with differing values were public lots, that according to Brazilian urban laws (Municipal Master Plans), are classified as special zones and don't have to respect the same urban parameters as private lots – the projects are proposed and approved according to the logic of "urban surgeries", as explained in this paper's introduction.

Lots with recognized differences were deleted so as not to interfere in the analysis, but were maintained in a different layer to be considered in the future, because LIDAR data can contribute to the controlling of incongruities in cartographic databases. (Figure 3)

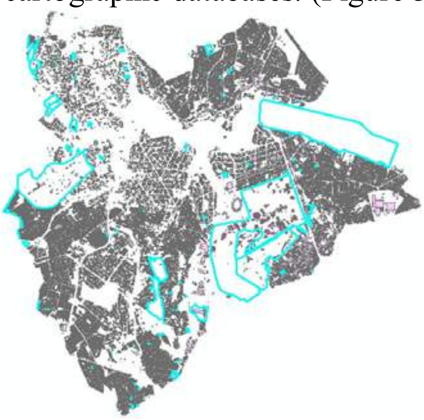

Figure 3 – Incongruities in areas calculated by geometric tools in a cartographic representation in comparison to database representation in alphanumeric data linked in the layer.

b) The second step was to correct topological problems or registration problems, or even problems of land regularization.

In order to face the many problem in land regularization in Brazil, the Ministry of Cities published Norm 511 in 2009. In it, they set guidelines as to the creation, maintenance and updating of the Multipurpose Territorial Cadastre (MTC or in Portuguese, "CTM – *Cadastro Territorial Multifinalitário*") [8]. The MTC has the goal to map information about actual land use and support a diagnosis on land problems, characterizing properties and possession of lots. One of its main characteristics is to include registration data in a unique database to be shared with different public sectors, and to use the reference of the "parcel" to register lots and properties.

The parcel is defined as the smallest polygon in the cadastre, presented in a contiguous representation and under a unique legal regime (private or public property), being a unique property or a unique possession with a unique ID (identifier) in local cadastre [9]. If a building is partially constructed in a lot that belongs to a private owner and partially constructed on a public lot, it must be represented in two parcels and land regularization must be done, as there is a problem in its legal regime. If a building is constructed in different lots belonging to different owners, it is also represented in two parcels and land regularization must be done as there are problems as to property and possession.

In the example of Figure 4, a correction in the cadastre should verify if the problems were in representation or reality; if topological corrections were needed, corrections in registration or land regularization. For the objectives of this paper, a topological correction was done, maintaining the drawing of the building only in the main lot, but keeping the original values of the area's dimensions (Figure 4) to avoid it being counted on all lots. Problems like that must be confronted by public administrations in the future.

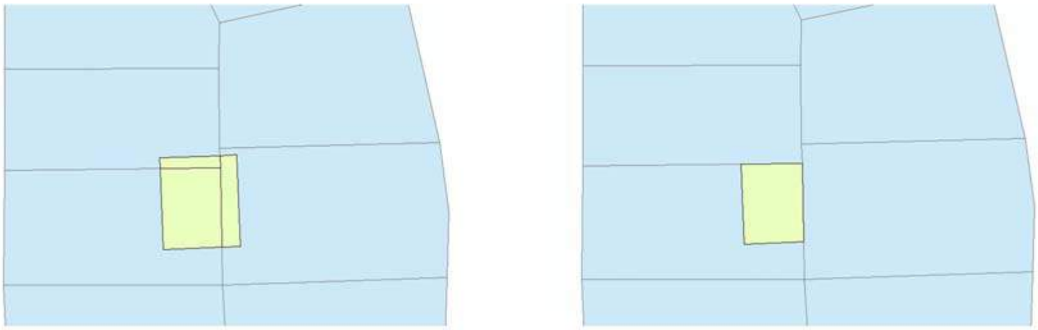

Figure 4 – Topological corrections of buildings and lots.

2.2. Join by Spatial Location of Lots and Buildings Layers

It was important to integrate data from lots and buildings in just one database in order to calculate urban taxes: Using the values of Lot Area (presented in the lot layer) and Building Floor Area or Lot Coverage (presented in buildings layer), it was possible to calculate the FAR (floor area rate), and volumetric rate (defined by the Bulk – an envelope that is produced by the height a building can reach considering the sum of areas constructed in each floor of the building).

Topological problems caused many difficulties in joining the two layers by spatial location. Some tests were done using the centroids (Figure 5a), but it was observed that some buildings' centroids were not exactly in its corresponding lot. The solution was to convert buildings' polygons to points, defining that points should be inside the building (Figure 5b), but maintaining all the data in the table linked to the point (number of floors per building, building floor area, and so on). Then the spatial join by location was done, followed by summarizing values registered in points in limits of the lot so as to face the situation of more than one building on the same lot.

Figure 5 – a) The use of centroids to join the buildings and lots; b) The use of central points to join features by spatial location.

2.3. Analysis of Volumetric Landscape: As Authorized by Law and as Done in Reality

Brazilian urban parameters, that define what can and cannot be constructed on each lot, are absolutely morphometric. They are established as: setbacks, floor area ratio, ratio of permeable land on the lot and volumetric rate, defined as CA (coefficient of utilization).

In this point of the research, the goal is to face these parameters in order to understand how they work and the logic of volumetric control. The future goal will be to consider the carrying capacity of urban use, proposing non-morphometric variables. However, to arrive at this point of innovation it is important to understand the situation. In this sense, a comparison between the volumetric landscape already constructed and the volumetric landscape as authorized by law was carried out. To do this, we compared the CA (coefficient of utilization, volumetric coefficient) already constructed with the CA as authorized by law according to zoning and the urban parameters' table presented in the Master Plan. If the CA constructed is larger than the CA authorized, it is possible to say that there is a deficit and if the CA constructed is smaller than the CA authorized, it is possible to say that there is a stock.

The values of lot area, total area of building summarizing the area on each floor, building floor area or lot coverage were presented or calculated when the features of lot and building were joined by spatial location. The result is the calculation of stock and deficit.

It is also important to analyze if these areas that have deficit, or a negative coefficient as all the volumetric possibilities were already constructed, were the result of specific laws in the past as the urban landscape of the city of Belo Horizonte has been modeled by 3 main Master Plans, published in the years of 1976, 1985 and 1996. Some changes were also proposed in 2000 and 2001. Below we provide maps based on each different law:

- Municipal Act 2662, of November 29, 1976 – Master Plan - Land Use and Urban Activities.
- Municipal Act 4034, of March 25, 1985 – Master Plan - Land Use and Urban Activities.
- Municipal Act 7166, of August 27, 1996 – Master Plan - Land Use and Urban Activities.
- Municipal Act 8137, of December 21, 2000 – Changes zones defined in Act 7166/1996.
- Municipal Act 8254, of November 12, 2001 – Changes zones defined in Act 7166/1996.
- Municipal Act 9,959/10, of July 20, 2010 - Changes zones defined in Act 7166/1996.

3. RESULTS AND DISCUSSION

This paper provides results and discussions on the importance of the multipurpose territorial cadastre with base maps and information to support analyses and representations of urban parameters. It was possible to observe that the first step is to identify and characterize the differences between real land use and cadastral information. The problems may be of representation such as topological problems, but may also be conflicts between the real use of lots and the register of this use at public offices. Using LIDAR data can be an important source of data to produce information and update land use data. This paper also presents a discussion on the results of representing the coefficient of utilization (volumetric coefficient) observing the use of a 2D logic instead of a 3D logic in working with this urban parameter.

3.1. The Use of LIDAR Data and Volumetric Analysis

LIDAR data was very important in constructing the 3D cadastre, representing the envelopes of already built buildings. A methodology developed by Ribas et al. and Fonseca et al. [10, 11] was applied to transform DEM and DTM points in to information on the buildings' height and the terrains' elevation and to get the value of buildings' height. With this information, the value of height was divided by 3, because it is the average value of a floor building in order to get the number of floors in each building.

At this point, it was possible to understand a great difference in Brazilian urban parameters and to observe that even when they deal with heights and volumetric coefficient, based on CA (coefficient of utilization), the logic is still 2D. This is because the rules regulate how much can be built as a rate or a percentage of the lot area. For example, if the CA is 1.0, building 100% of the value of the lot dimension is allowed, but as a summary of all the floor, considering each floor area. If the lot has 400 m2, and the Floor Area Ratio is 0.5 (50%) the building floor area or lot coverage can be a maximum of 200 m^2. If this value is used, it means that the building can have 2 floors. However, if the project proposes floor area or lot coverage of 100 m^2, the building can have 4 floors.

In Brazil, parameters limit total constructed area, but not exactly volumetric construction because a floor can have from approximately 3 to 4.5 meters of height. This means a difference of more than 50% in the final height. Using the same example, the final building could have a height between 12 meters and 18 meters and the final volume is quite different (33% bigger) (refeer to Figure 6).

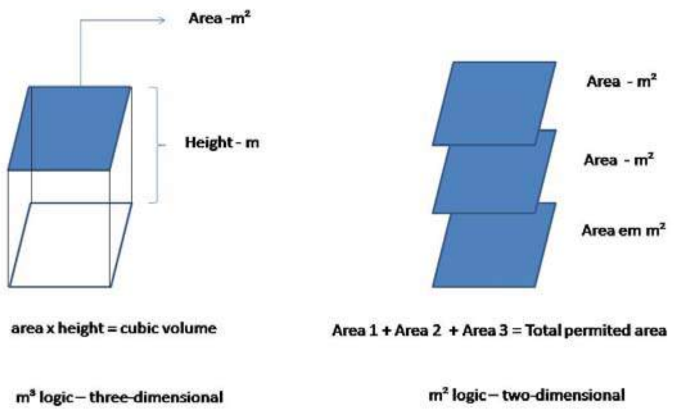

Figure 6 – The logic of bi-dimensional values controlling volumetric aspects.

Considering the height observed of each building in accordance to LIDAR, 3 meters as the average height of each floor and using the projection of the buildings provided by the cadastre, we calculated the average of floors and the final coefficient of volumetric utilization. The volumetric use in each lot was compared to the volumetric use allowed by law and the result is the map of volumetric stocks and volumetric deficits. It can be observed that the region still has a great amount of stock. (Figure 7).

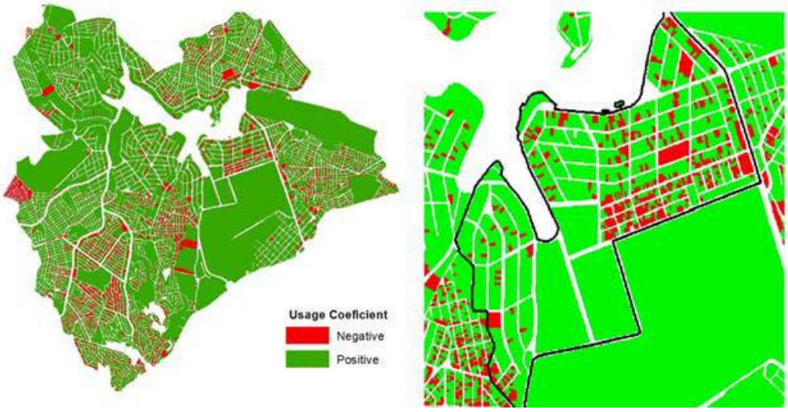

Figure 7 – a) Stock and Deficit – Negative and Positive Usage of Volumetric Coefficient. b) Details of São Luiz and São José neighborhoods.

The questions asked are: Is the law too permissive in the area and is the reason there is stock for new constructions? The answer is probably yes because the area is very fragile and presents conflicts of interest: cultural landscape, environmental resources, fragility in drainage services, accessibility, public transport [12]. Observing the area of interest, the São Luiz and São José neighborhoods (Figure 7b), our analysis is that the area has already been heavily transformed and stocks have been significantly used.

3.2. Analysis of Existing Master Plans

The question made is if the use of the region and, especially of the neighborhoods under analysis, is the result of parameters proposed in three Master Plans, published in 1976, 1985 and 1996 and for which some changes were proposed in 2000 and 2001. The Master Plan and Law of Land Use and Urban Activities of 1976 and 1985 presented the same proposal to both São Luiz and São José: Inside the neighborhood (São Luiz) there was to be residential made up by uni-familiar and low volumetric uses (ZR1) and for the São José area there was also to be residencial use, but with higher volumes (ZR2) and in the area's main street, a ZR3 was proposed that authorized vertical buildings for multifamily use. The greatest impact caused by this law, presented in 1976 and again in 1985, was commercial concentration on the neighborhood's frontiers or edges, which caused the main transformation and resulted in changes in the landscape and volumetric use (Figure 8).

Figure 8 - Act 4034, of March 25, 1985. Land Use and Urban Activities according to Master Plan – zoom in São Luiz and São José neighborhoods.

The analysis of the law proposed in 1996, Act 7166 of August 27, indicates that the logic of zoning of uses was changed to the logic of capacity to receive land use as the zones were classified as "preferred density zoning", "zoning with restricted density" and so on. According to this law, the São Luiz area was to be more controlled as it was classified as "ZP-1 – Protected Zone", but theSão José area was classified as ZAP - Preferred Density Zoning – which caused significant transformations and interfered in the area's volumetric density (Figure 9a). Changes proposed by revisiting the law in 2000 and in 2001 (Acts 8137 and 8254) did not directly affect the neighborhood, but a change proposed for the region can catalyze significant transformation in Pampulha: the definition of an area to the region's south as ZE. This can lead to receiving a very high volumetric coefficient and new uses, which could interfere by increasing real estate speculation and interest in transforming the region (Figure 9b).

In 2010, according to the Act 9959, the definition of ZAP (Preferred Density Zoning) for São José was reviewed and it was proposed that it be classified as ZAR-1 (Zoning of Restricted Density), which means a reduction in volumetric coefficients and this is the reason why a deficit of stocks is observed in the area. In 1996, it was classified as Preferred Density Zoning and in 2010 was re-classified to Zoning of Restricted Density, which is much more suitable to landscape conditions. However, the area is constantly under threat of transformation because of real estate speculation interests and urban surgeries.

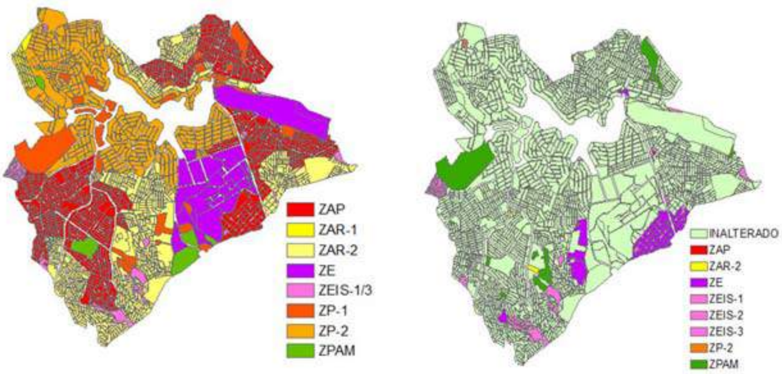

Figure 9 – a) Act 7166/1996 , b) Act 8137/2000.

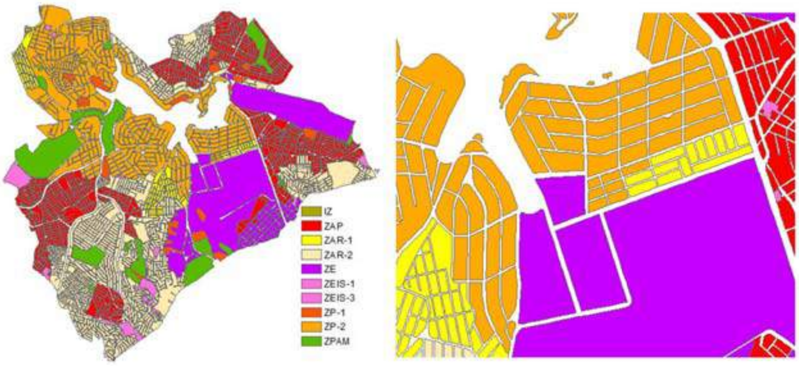

Figure 10 – a) Act 9959/2010, b) Detail of São Luiz/São José

4. CONCLUSIONS

Urban parameters shape the city. They determine its configuration, shapes and physical and three-dimensional development. It is fundamental to recognize that morphometric parameters, related to shape and position of build’s, which have been used since the first master plans in Brazil working in two-dimensional logic lack in advancement. Our expectation is that this study reached continuity to review urban parameters, although morphometric, points to a three-dimensional logic, and get closer, for instance, to the Italian principle of "*capacità insediativa residua*". The development of methodologies of volumentric load capacity, transformation and urban density carrying capacity methodologies should introduce new forms of landscape modeling by achieving new parametrization supported by those previous studies.

It is important to address the appropriate picture of reality through Territorial Cadastre Register with the use of LIDAR through recent capture technologies and the effort to build a three-dimensional registration for land regularization and urban landscape management.

It is valuable for future developments to investigate what is the ideal standard volume for a landscape and how different countries establish their regulations. How do they define/reach the standard volume? What would an ideal standard be? Do they use other parameters? Where do the parameters come from? Does it take the landscape in consideration? Does it consider context? How is it done in other countries? Is there an index?

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