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STUDIES OF VOLUMETRIC RELATION BETWEEN VEGETATION AND BUILDINGS USING LIDAR DATA AND NDVI TO PROPOSE URBAN PARAMETERS

Estudos da Relação Volumétrica entre Vegetação e Edificações com Base em Dados LiDAR e Cálculo NDVI para Proposição de Parâmetros Urbanos

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ABSTRACT

The availability of high-resolution cartographic data is a trigger for the discussion about the quality of urban ambiance, as a result of comparison between indexes of vegetation cover and built area, aiming at the inclusion of new urban parameters in cities' management and planning. This paper aims not only to provide visualization about location and characterization of the vegetation cover but also to the evaluation of its role according to citizens' perception of their value. Pampulha's region, in Belo Horizonte, was adopted as a case study for its high-quality vegetation cover, which has been threatened by the expressive growth of the built-up area. The area is known been projected by Oscar Niemeyer, using as a value the equilibrium between natural and built landscape, what was recently recognized as cultural heritage by UNESCO. Belo Horizonte municipality has the privilege of having LiDAR data of 2007 and 2015, the last one also with high resolution infrared orthophotos. The methodology consisted in mapping the vegetation patches' projections from orthophotos and in calculating their volumes using LiDAR's points, as well as in calculating the buildings' volume using their footprints and heights also from LiDAR data, and comparing their volumetric indexes per block. As indexes classification must have references on local culture, in order to define the scale of "suitability", a research was done interviewing people from the place, using homogeneous areas as spatial units. As the research deals with quantitative approach

(volumetric indexes) and qualitative approach (perception of people from the place), it was also important to use an evaluation according to a technical approach, based on comparison of applied indexes from other zones of Belo Horizonte, to present a wider perspective about standards of the relation between building landscape and vegetation. The result is a contribution to support discussions about urban ambiance, based on volumetric values of vegetation and buildings, to be considered in urban parameters in Master Plans.

Keywords: Visualization, Urban Parameters, Citizens' Participation, LiDAR, NDVI.

RESUMO

A disponibilidade de dados cartográficos de alta resolução favorece que se inicie a discussão sobre a qualidade da ambiência urbana como resultado da relação entre índices de cobertura vegetal e volume edificado, com o objetivo de incluir novos parâmetros urbanísticos dessa natureza em processos de planejamento e gestão. O artigo visa não só promover visualização sobre localização e caracterização de cobertura vegetal, mas também a avaliação de seu papel segundo a percepção cidadã de seu significado. A região da Pampulha, em Belo Horizonte, foi adotada como estudo de caso em função de sua alta qualidade de cobertura vegetal, que se encontra em risco em função do expressivo crescimento da massa edificada. A área é conhecida por ter sido projetada por Oscar Niemeyer, usando como valor o equilíbrio entre paisagem edificada e natural, e recentemente foi reconhecida como patrimônio cultural pela UNESCO. O município de Belo Horizonte tem o privilégio de possuir dados LIDAR de 2007 e 2015, sendo que para o último ano há também ortofotos de alta resolução e captura na faixa do infravermelho. A metodologia consistiu em mapear as projeções dos fragmentos de cobertura vegetal com uso das ortofotos, e em calcular seus volumes usando dados LIDAR, assim como calcular os volumes edificados usando suas projeções e alturas também a partir de dados LIDAR, e em comparar seus índices volumétricos por quadra. Como a classificação de índices precisam ter como referência a cultura local, para se definir a escala de "adequabilidade", foi realizada uma pesquisa entrevistando pessoas do lugar, usando áreas homogêneas como unidades espaciais. Como a pesquisa lida com abordagem quantitativa (índices volumétricos) e abordagem qualitativa (percepção das pessoas do lugar), foi também importante usar uma avaliação segundo abordagem técnica, baseada na comparação de índices praticados em outras zonas de Belo Horizonte, para se apresentar uma perspectiva mais ampla sobre padrões na relação entre paisagem edificada e vegetação. O resultado é uma contribuição para dar suporte a discussões sobre ambiência urbana, baseada em valores de volumetria vegetada e edificada, para ser considerada em parâmetros urbanísticos em Planos Diretores.

Palavras-chave: Visualização, Parâmetros Urbanísticos, Participação Cidadã, LiDAR, NDVI.

1. INTRODUCTION

How can urban plans promote quality of life in the cities considering the equilibrium between green and built landscape? How can we calculate and analyze indexes of vegetation and buildings volumes, to give support to ideas about new urban parameters to be included in management and planning of cities? How can we evaluate and propose indexes, according to a reference of suitability, that can be a qualitative but also a quantitative approach, including citizens' opinion but also a technical point of view? These questions have initially faced this paper, with the goal to present a proposal of the methodological framework that can be applied to the characterization, visualization, analysis and discussion about urban parameters that considers green infrastructure in cities.

A recurrent subject of investigation in Brazil is the growth of urban population, that changed from slightly more than 56% in the 1970's to 84% in 2010 (IBGE, 2010), presenting a scenario that was predicted to the United Nations to be achieved by big centers only in 2050, when urban population is expected to be 90% and to present around 200 million people (UNO, 2014). In 50 years Brazil has changed from a rural country to an extremely urban condition, what resulted in several changes without the adequate improvement in infrastructure and not facing properly the importance green areas (MACEDO et al., 2003; VASCONCELOS, 2006; ONU, 2014; COSTA & FERREIRA, 2011).

Although urban growth has been experienced in the whole country, it was quite heterogeneous distributed. The most population who live in cities nowadays are concentrated in nine metropolitan regions, especially in the south-eastern portion of Brazil. Brito (2006) reports that in the 1970's half of urban population was already living in cities with more than a hundred thousand inhabitants, from which a third was living in those with more than five hundred thousand people. In 2000, about 60% of the urban population lived in cities with more than a hundred thousand inhabitants, what means that urbanization and concentration of population in the big cities were simultaneous processes in Brazil. Nowadays São Paulo has about 11 million inhabitants, Rio de Janeiro 6 million, Salvador 2.7 million and Belo Horizonte 2.5 million, considering the population in the capitals and not of metropolitan areas, that corresponds to 20 million, 11 million, 4 million and 5.7 million, respectively.

Due to accelerated growth and the lack of appropriate urban planning, the country has been characterized by a model of urban distribution with a tendency to spatial concentration and high-density building and verticalization. Brazilian Master Plans and Laws of Land Use are based on delimitation of morphometric references according to zone (floor area ratio, setbacks values, volumetric ratio, and so one). Urban laws not only accept but also incentivizes high volumetric indexes, as results of lack of infrastructure distribution and mainly due to market pressure (real estate speculation). Those laws are still very far behind in the discussion about green areas and its role in urban ambiance.

For urban ambiance, we use the concept proposed by Mascaró and Mascaró (2009). The authors present the idea of related to the morphology of the urban area, composed by the width of the street, the height of buildings and the presence of vegetation cover and its use in urban life. The quality of and urban ambient depends on this equilibrium of urban morphology and vegetation cover.

The landscape composed by big towers in urban areas contrasts with the empty spaces of the land occupation outside the cities, despite the vast territorial extension of the country (Figure 1A). This Brazilian way of land using has advantages and disadvantages when compared to other realities in the World. High concentration and verticalization with the lack of policies and projects about green infrastructure reduce the quality of urban ambiance, but in another hand, it preserves surrounding territories with a high concentration of green areas outside the cities.

Comparing this pattern of territorial use with European cities (Figure 1B), we understand that their distribution presents the morphology of a constellation, in a system of an integrated network. It`s the result of historical phases of urban core formation. By the 1950's, Europe had already 12 out of the 40 most populated cities in the World. Nowadays, this number has been reduced to 3. Vicari (2004) points that the growth of secondary centers formed an urban network, enabling the European cities to be distributed homogeneously along the territory.

This situation is probably due to the increasing demand for preservation of its historical centers and more strict construction laws, encouraging the expansion of big urban centers accompanied by a good infrastructure. Except for commercial and service areas of more recent character, or even to some examples of entrepreneurship and city marketing processes, the verticalization and the excessive volumetric concentration are not carried out and a moderate sprawl is perceived, shaped as a network of cities. According to Camagni (2003), the model is a consequence of a suburbanization or peri-urbanization with a low density of occupation.

Comparing to North American urban distributing, in the United States it is characterized by urban sprawl (Figure 1C). According to Laidley (2015), this development consumes excessive resources through real estate speculation and low-density dispersion, possibly favored by the local topography. According to the author, comparative researchers held between 2000 and 2010 demonstrated that the growth of buildings characterized by single-family unities is much bigger than the one with multi-family unities, what requires also the growth of infrastructure distribution.

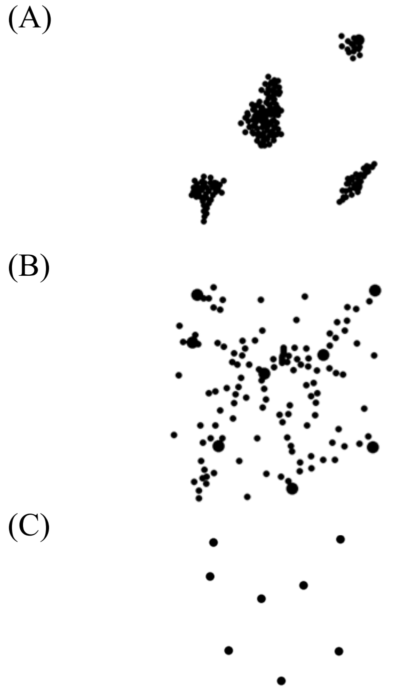

Fig. 1 - Land use and distribution of population: (A) Brazil; (B) Europe; (C) USA. Source: Produced by the authors, from bibliography interpretation.

The exponential growth of the cities in Brazil requires planners to rethink urban spaces, seeking to guarantee overall quality of life and quality of the environment, providing what can be defined as an "urban ambiance". The references for this important equilibrium, that is the level of suitability in land use composed by built and natural landscape, must consider cultural values. This means the importance of understanding genius loci of the place (qualitative approach), but also technical references (quantitative approach).

The concept of green infrastructure is defined by an interconnected network of green area that reserves the values and functions of natural ecosystems to harmonize the relation between man and nature, in which green urban areas play different roles (ROTTENBACHER & CASSIDY, 2014; EUROPEAN COMMISSION, 2013; ANDERSSON et al., 2014). Green areas are related to aesthetic quality, spaces for socialization and leisure, protection of biodiversity, protection against geotechnical risks, protection of aquifers and springs, or even the maintenance of environmental balance related to the climate, environment humidity, air quality and acoustic control (LOBODA et al., 2005; COLDING & BARTHEL, 2013; GODDARD et al., 2010). To identify possible vocations of each fragment of vegetation cover, it is necessary to map and characterize them, using spatial analysis models. In this sense, technologies of geoinformation play an important role in the use of remote sensing, digital image processing and geographic information systems (MOURA, 2005).

1.1 The sense of urban environmental quality

Since the 1960's, studies are been developed to investigate the relationship between man and environment, as a multidisciplinary topic of interest in several sciences (MACHADO, 2012). Bechtel (1997) affirms that the studies about environment-behavior have an interdisciplinary basis and aim to understand needs and satisfaction according to people of the place, measuring their relations to the quality of the physical environment. The author points out the "five pioneers" who developed studies on this topic, that was the psychologist Roger Barker, the anthropologist Edward Hall, the psychologist Robert Sommer, the architect Christopher Alexander and the town planner Kevin Lynch.

Lynch (1960) had a very important contribution to studies in urban scale, focused on human perception and how good city form could be materialized in the design and reshape of the cities, mostly in an intra-urban scale. In addition to his studies, Jane Jacobs (1961) presents important criticism about the quality of life in the cities, even though she didn't arrive to design proposals. Jacobs discusses the importance of the connection of people with their, place, defending the use of sidewalks to promote interaction. She points out some values as mixed uses, small blocks, mixing old and new buildings, urban density accessibility and the existence of limits and borders. In the same year, Cullen (1961) presents his idea of townscape and introduces the idea of spatial cognition, based on the importance of the relations between citizens and the way they understand their urban areas. In the 80's, the contributions of geographer Yi-Fu Tuan helped understanding the environment and the aspirations of individuals regarding environmental quality, such as topophilia (emotional ties between people and environment) and topophobia (fears, aversion to the place) (TUAN, 1980; TUAN, 1983). , the architect and scholar Vicente del Rio (2002) went deeper in the studies of perception and of cognitive processes, affirming their importance for comprehending our inter-relations with the environment.

If everyone perceives, interacts and reacts in a different way in an environmental experience, the way people use space is a result of perceptions (individual or collective), cognitive processes, judgments and cultural expectations. To face this qualitative approach, it`s important to propose studies based on the analysis of what people of the place understand as the quality of life, that means also the quality of urban ambiance. Nevertheless, there are still few studies focused on qualifying urban ambiance from the point of view of the pedestrian, especially on the topic of green urban areas. Generalist indexes, that measure the green areas per inhabitant by square meters, are frequently prioritized in comparison to more detailed scale. Recently, the group from Ratti (LI et al., 2015; SEIFERLING et al., 2017) presented studies about green view index (GVI), calculated using Google Street View, in which they compare some cities in the World according to the visibility of vegetation along the streets.

This paper's aims to purpose a local index, regarding the neighborhood, using the block as a territorial unit, with the goal to give support to discussions about the balance of urban vegetation and built volumes in the cities, as the existing indexes are very generalists. In addition, the method results in the possibility of classifying typologies of vegetation patches, creating data and information that can be used in future studies based on Landscape Ecology (FORMAN & GODRON, 1986), what means the discussion about their shapes, importance, and possibilities of uses.

1.2 LiDAR and NDVI data

Nowadays, some Brazilian cities have resources to invest in collecting good resolution data that triggers deeper analyses and support to urban management and planning. The use of high-resolution spatial data (up to 20 centimeters) and automated classification based on spectral bands (e.g. the possibility of working with the infrared range) contributes to automation of classifications, making the results quicker and more accurate.

LiDAR (Light Detection and Ranging) technology added new possibilities in spatial analysis. This technique relies on active sensing and enables the acquiring of accurate information in a short time-span with the use of a laser beam, to obtain three-dimensional point clouds. Each point presents information about the position, X, Y and Z coordinates, but also the intensity of the reflection and the echo number (return pulses). The majority of studies about the use of data captured with this technology presents applications about the construction of Digital Terrain Model (DTM) and Digital Surface Models (DSM) (GIONGO et al. 2010; RIBAS et al., 2014).

NDVI (Normalized Difference Vegetation Index) relies on the spectral signature of a target's behavior applied to the vegetation cover, which has specific responses related to the amount of water contained in the leaf structure. The plants' cells reflect more strongly in the near infrared region. The portions absorbed in the red and reflected in the infrared vary according to the plants' conditions. The calculated NDVI can then be associated with other normalized indexes so as allow for correlations to be made and to verify the ambiance of the studied location, facilitating the city planning and management (ROUSE et. al., 1973; MYNENI, 1995; FREIRE & PACHECO, 2005). In the last years, several studies on urban vegetation cover it was also developed using high spatial resolution imagery and LiDAR data. Davis et al. (2016) evaluated the effects of green areas' volume in the air temperature. The authors made use of a similar methodology as the one presented in the paper, employing LiDAR data to estimate the vegetation's volume and high-resolution imagery to map and calculate the vegetation cover's area with the aid of the spectral NDVI (Normalized Difference Vegetation) index.

Ramírez-Núñez et al. (2015) employed the association of LiDAR data with the NDVI to map vegetation cover extracts associated to anthropogenic land use and the characteristics of the land surface slope, associated with the classification and the dynamic changes in landscape units in the lower course of Coatzacoalcos river in Mexico.

The association of LiDAR data with the NDVI has also been employed as a means of estimating biomass of forest and prairie areas, such as in the studies of Schaefer and Lamb (2016), Greaves et al. (2015) and Li et al. (2015). Rafiee et al. (2016) employed LiDAR data, without associating them to the NDVI, to estimate the volume of trees to calculate its impact in the formation of heat islands in Amsterdam during the night.

The advent of new technologies of relief measuring and high-resolution imagery has enabled methodological experiments, new possible analyses and knowledge acquisition in different fields of expertise. Hereby, we present a methodological framework for the case study of the Pampulha's region in Belo Horizonte (Minas Gerais, Brazil).

1.3 Case study

The Pampulha's Region in Belo Horizonte hosts the main landscape intervention in the history of the city, which valued the maintenance of free spaces and green areas in the planning of the buildings (Figure 2).

Due to its very good infrastructure, strategic position in the city, environmental characteristics (low slope values) and cultural relevance, Pampulha (fig.03) has become known on the north side of Belo Horizonte (Brazil), attracting investors of the private sector and real estate professionals, resulting in a dynamic ever-changing conformation of the landscape (CARSALADE & CASTRO, 2011). Such dynamics have raised a series of environmental, urban, architectural and cultural issues that have become crucial in the last years.

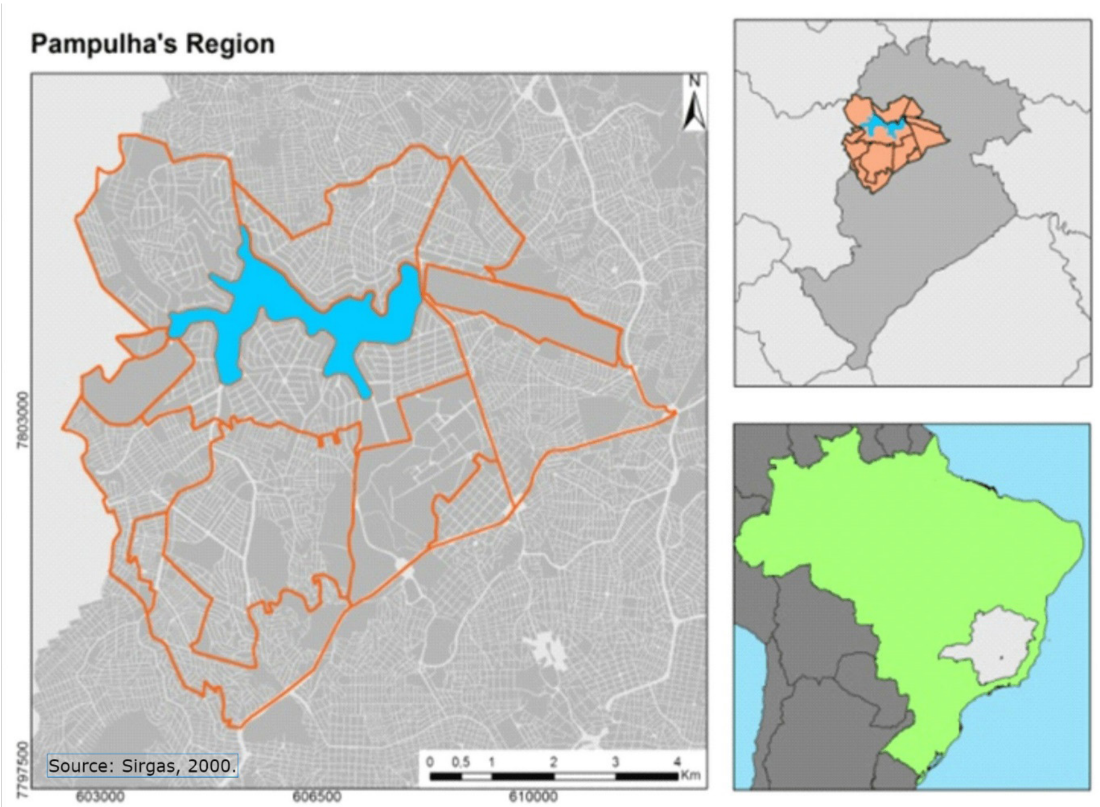

Fig. 2 - A case study - Pampulha, Belo Horizonte – Brazil. Source: Geoprocessing Laboratory / EA – UFMG.

Fig. 03: Pampulha, Belo Horizonte. Source: Breno Pataro – media.licdn.com

Furthermore, the region had just received the title of World Heritage by UNESCO, as it represents a masterpiece of human creative genius, due to modernist architecture and to the works of Oscar Niemeyer, Portinari, Burle Marx, Ceschiatti and Paulo Werneck (CARSALADE, 2015).

In the dossier presented to UNESCO (IPHAN, 2014), the importance of Pampulha is recognized as "The strong Ensemble perception revealed in relation to the landscape and with the assets built up, these also featuring great expressive relations and of architectural language among themselves" (p. 14). More than that, when the dossier talks about the buffer zone, the area of interest in the surroundings of the monuments, proposed based on the Modern Ensemble protection inserted in a specific urban landscape, it calls attention to its characteristics as: "The horizontal pattern and low construction densities that characterize the occupation of surrounding areas and give homogeneity to urban landscape composed of volumes built in low altimetry, discontinuous, spaced and interspersed by massive arboreal vegetation." (CARSALADE, 2015 p. 40).

The vulnerabilities and attractiveness in Pampulha make it an area of conflicts of interests, because of environmental and cultural values, but also an area with all conditions to attract real estate speculation. It is characterized by the expressive presence of vegetation cover in public, but also in private properties. In addition to that, in the dossier of cultural and heritage protection established that as requirements for protection and management, it will be important to review the regulatory dimension through the revision and updating of the urban standards applicable, we believe that parameters related to vegetation cover must be planned. In this sense, this paper is a contribution to the city, characterized by very dense building conditions, that has few areas of good quality of green cover to be protected, but that can improve its urban ambiance proposing vegetation volumetric parameters in the Master Plan and Law of Land Use (Fig. 04).

Fig. 4 - Central region of Belo Horizonte. Source: http://www.brasil247.com/images/cms-image-000461701.jpg

It is easy to understand that Pampulha is an anomalous region in Belo Horizonte, due to its favorable presence of vegetation cover, that composes the genius loci of the place. It`s also a zone characterized by single-family units in most the area, but that is been replaced very rapidly by high buildings.

This configuration of low-density housing and green landscape should be maintained and mirrored, and not transformed according to the interests of expansion and urban concentration as observed in other regions of Belo Horizonte.

2. METHODOLOGY

The methodology was based on organizing data, applying spatial models to produce information, promoting interviews with people from the place to get their opinions, to calibrate analysis based on a comparison of some spatial references, to discuss the first results and to propose possible future developments of the studies.

The methodology consisted of working with four axes of ambiance variables and their analysis: Building volumes (2.1); Vegetation Volumes (2.2); Comparative studies (2.3); and Interviews (2.4).

The first objective was to use good quality data to provide information about the existing reality, not in the sense of cadastral data, but in the sense of promoting visualization. With the improvement of visualization, the second objective was to get from people of the place their opinions about the limits of acceptability of the relation between green and built landscape, to define the limits of suitability. In this sense, visualization opened the possibility of constructing critical participation. As a third objective, after receiving an opinion from people of the place about the suitability conditions to a good urban ambiance, the existing conditions were analyzed, with the goal to propose future new urban parameters related to green infrastructure.

2.1 Building Volumes

In the first step of the study, the goal was to produce data and information about building volumes, resulted from LIDAR data, orthophotos, and cadastral database. (Figure 05).

The orthophotos used in the study were provided by the Municipality of Belo Horizonte (PBH – Prefeitura de Belo Horizonte) and captured through an aero photogrammetric survey with digital camera A3 Edge/Visionmap, comprising the visible spectrum (RGB) and the near infrared (NIR), in a spatial resolution of 20 cm.

As one of the interests were to control urban growth, images and LiDAR data from 2007 and 2015 were used. The new orthophotos, from 2015, was compared to footprints of 2007 to the identification of new constructions. It`s important to register that the process was not a cadastral update or register because it was not the goal of the study, but only the draft drawing of new footprints, with no interest in better resolution. Just to identify new buildings and to calculate, in the expeditious study, the volume of new buildings.

Once having the footprint of the buildings, partially provided by the cadastral of 2007 from the municipality and updated in draft drawings based on the images of 2015, the next step was the use of LIDAR data to calculate the height of buildings. LIDAR data were used for the digital modeling of the surfaces in 2015, which enabled the cross-check of new footprints, but mainly for the measurement of buildings' heights, in order to estimate their volumes (RIBAS et al., 2014, FONSECA at. al, 2016)

The result was information about built-up volumes, enabling the calculation of volume per building, per lot and per block.

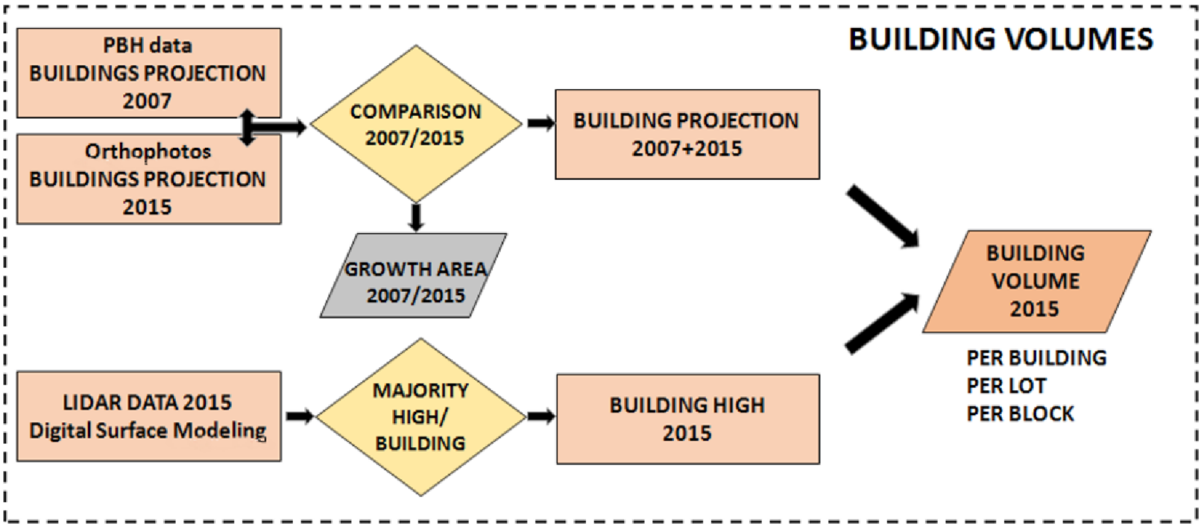

Fig. 5 - Building Height and Volumes framework.

2.2 Vegetation Volumes

The Vegetation Volumes framework represents the step of modeling data and producing information about vegetation cover, not only in bi-dimensional representation but as 3D analysis, in Pampulha's region (Figure 6).

Orthophotos from 2015 were used and the data went through pre-processing in preparation for their processing on ArcGIS/ESRI© software. The first step was to composite bands to produce an image based on visible bands (from 400 to 700 nm), but the most important composition was based on the use of infrared band (from 700 to 1000 nm), that allows the highlighting of vegetation cover. Due to the use of infrared data, it was possible to produce the NDVI (Normalized Difference Vegetation Index) composition, categorizing different conditions of the vegetation cover.

The calculation of the NDVI was made according to the following formula:

$$NDVI = (\rho ivp - \rho v) / (\rho ivp + \rho v) \qquad (1).$$

Where ρivp is the reflectance in the near infrared; ρv is the reflectance in the red.

After calculating the NDVI, the result was categorized to separate the values into ranges, according to the robustness of to vegetation. This study took into consideration the vegetation of arboreal size (woody) with values above 0,16 in NDVI. It`s important to say that the index presents relative values that go from absence of

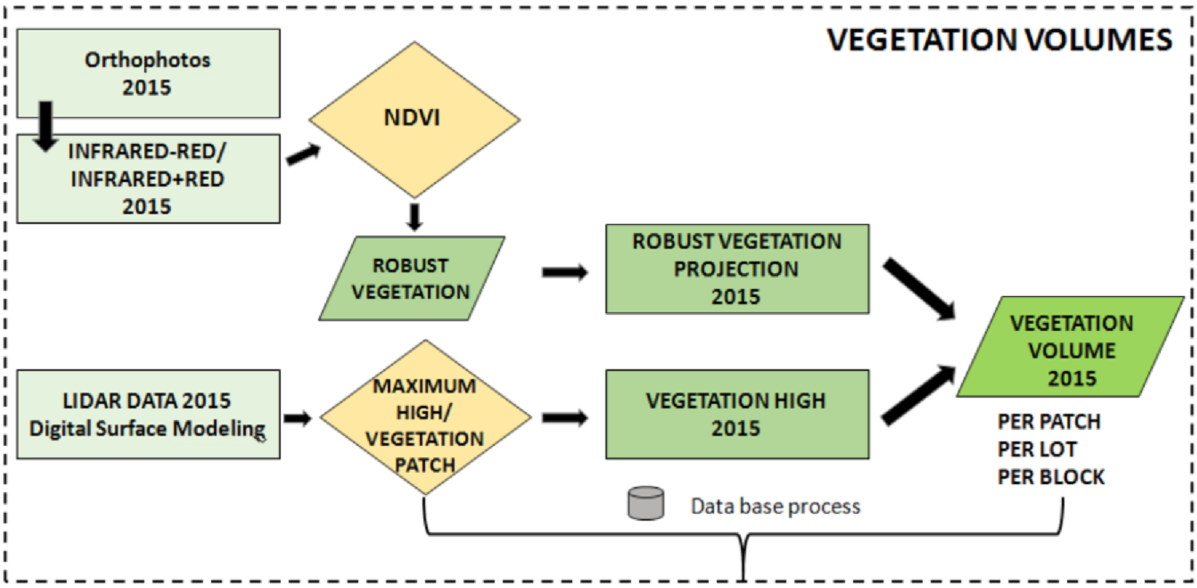

Fig. 6 - Vegetation Volumes framework.

vegetation to very dense vegetation, in the place. This means that we cannot propose the use of this same value in other case studies, but it must be tested according to local conditions and to the objective of the research. (Fig. 07).

The value was defined based on calibration to local conditions, using expert knowledge about the area (field observations and visual control using composition in the visible and in the infrared bands). In the case study, we were more interested in robust vegetation (woody), because it is more effective in environmental quality and ambiance, but studies about the rate of permeability, including all vegetation types, could also be developed.

The use of LIDAR data followed the same methodology applied in the studies of buildings volumes: footprints from vegetation cover were obtained by NDVI, and the footprints were associated with cloud points from LIDAR data (Figure 9).

In the case of buildings, from the collection of points associated with each footprint, it was selected the value of "majority", what means the altimetry most observed, that corresponds to the base of the tiling roof or the roof slab (Fonseca et al., 2016). In the case of vegetation altimetry, it was also calculated selecting the points cloud correspondent to the polygons of the footprint of trees, but in instead of getting the "majority" of the values, it was selected the highest point. The reason for that is the great variability of values, as the tree is a very complex volume, and the representation of the highest point could tell about their volumetric influence in the urban ambiance.

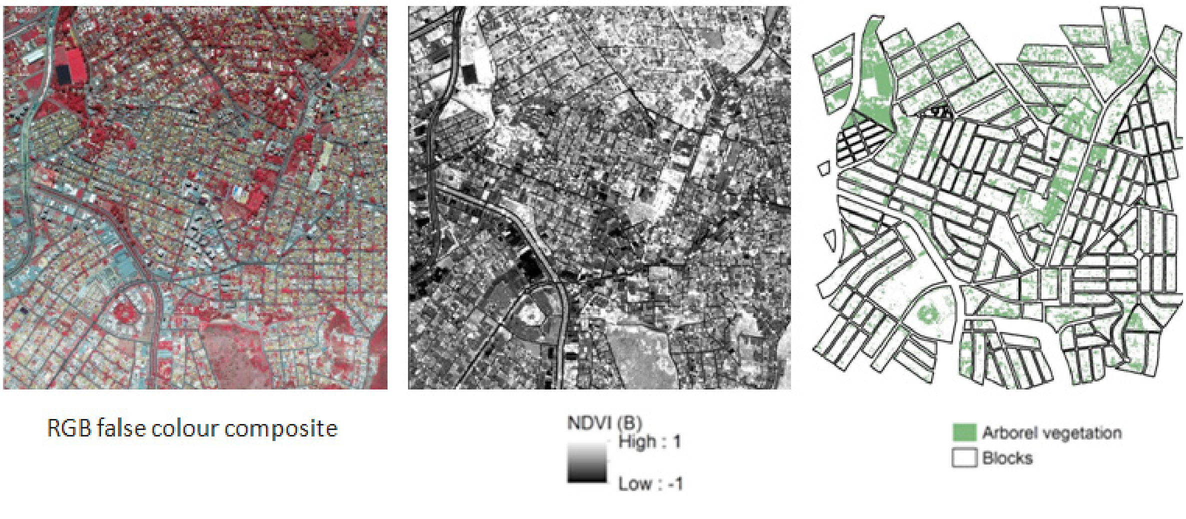

Fig. 7 - RGB Composition/ NDVI and NDVI per block.

As the procedure requires significant machine processing, a database was used and a script was created to the steps from identifying the footprints, then associating the points to each footprint, to compare the points and getting the highest in each polygon, and associating this value to the polygon.

The Urban ambiance is related to insolation, micro temperature, air quality and so one (MASCARÓ & MASCARÓ, 2009), characteristics that are quite correlated to the high, volume and shadow produced by the trees. In this sense, the representation of a volume going from the top to the base, without eliminating the area under the treetops, was adequate to the specific study about the relation between the volumes from green areas and volumes from buildings areas. (Figure 8 and Figure 9).

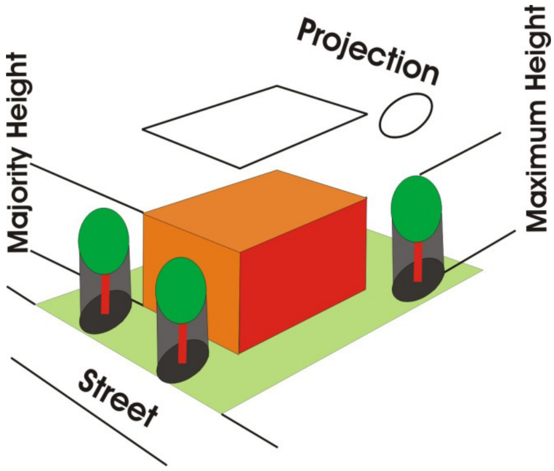

Fig. 8 – Logic of vegetation volumes. Source: Designed by the authors.

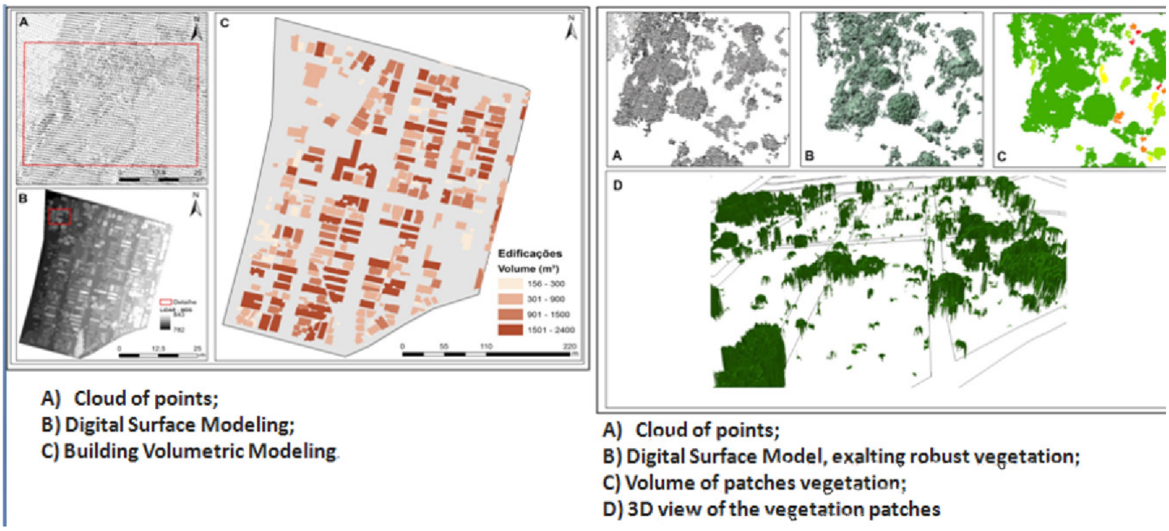

Fig. 9 - Cloud of points.

2.3 Comparative studies

To make the comparison between the volume of vegetation and the volume of buildings (in cubic meters), it was necessary to propose references to justify the evaluations, what means to define from "not adequate" to "adequate" in the relation between vegetation and built-up area. These references were carried out through two methods: interviews with people of the place and comparative studies with other regions in Belo Horizonte. To the first method, we interviewed some citizens in the streets, searching for residents, workers, and visitors of each area, using as spatial units of analysis the homogeneous sectors in Pampulha. To the second method we selected neighborhoods mentioned by people of the place as examples of good urban ambiance according to green infrastructure, and the neighborhoods from Belo Horizonte mentioned were: Lourdes, Sion, Santa Tereza and Cidade Jardim.

2.3.1 Interviews with people from the place

Questionnaires were applied to people of the place, that was separated in residents, workers, and visitors of the zone. The zone was divided according to homogeneous sectors (data provided by the municipality PBH) and one person by category was interviewed. From 10 homogeneous sectors, we interviewed 40 people (a minimum of 3 people per territorial unit) because we excluded the areas of the airport, of UFMG and of the Zoo. Those areas were not considered because it is public land, and the alteration of those green areas is not controlled by real estate speculation, while the rest of the green areas are conditioned to the processes of urban growth and the remodeling of the urban space.

The number of questionnaires was not big, but it was followed the method of Lynch (1960) that proposed to interview a minimum of 15 people to get the essence of perception from the place.

The goal was to understand their values about the essence of their place as well as their expectations and values to a future landscape and land use. They were asked to analyze pictures from the place, extracted from the view of the road and from an aerial view (Google Earth and Google Street View), but in positions, they could clearly understand the relation between buildings volumes and vegetation cover (Figure 10).

They have presented three pictures with different levels of volumetric building and vegetation cover, and they were expected to recognize the streets in which each picture was captured, because they were supposed to understand we were talking about three different levels of vegetation cover and build-up landscape. Observing the three pictures, they were asked about their expectations or even their level of acceptability to the future of the built landscape in that zone. They had to choose one of the pictures, because the idea was to establish an index among vegetation and buildings according to the expectations of people from the place, using homogeneous areas as references.

The method was based on indirect visual selection, which consists of a prior image selection applied through forms (MACHADO, 2012). According to Sanoff (1991), environmental images/messages express the values and experiences of the people who appreciate a certain place. The visual cues are inspired by techniques that employ visual attributes with the purpose of identifying what pleases and bothers the user according to previously selected images that are relevant to the research.

According to Rheingantz et al. (2009), the application of this method enables the identification of the added values and meanings of the researched environments. Since it is an instrument based on the analysis of several images made by the users, it is a contributing factor to identifying their preferences, which were already evidenced through the comparison of the images. The success and accuracy of the reality's representation demand nevertheless some care in the selection of the images (MACHADO, 2012; RHEINGANTZ et al. 2009).

Besides that, the application of this instrument aimed at identifying the positive and negative aspects, that is, the selection of images

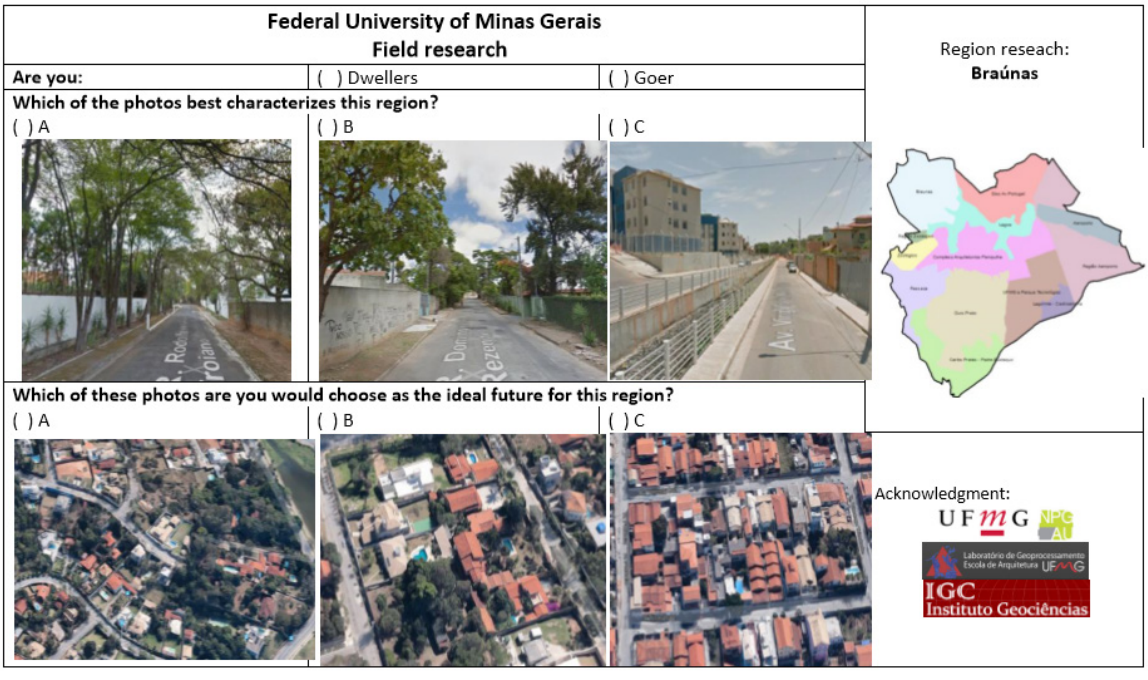

Fig. 10 - Vegetation-Building ratio per block – Residents' opinion.

with good, medium, little or no vegetation cover.

The results of the interview were divergent because most people indicated areas with less vegetation as an acceptable future landscape. It was clearly the effect of "NIMBY" (not in my backyard) because people were declaring the green areas were important, but they wanted more buildings to the place.

To do a cross-check analysis, we also asked them to mention a region or a neighborhood in Belo Horizonte that they considered of good quality of urban ambiance, according to the relation of green infrastructure and buildings. These suggestions were used to compose references of suitability in the relation between vegetation volumes and building volumes.

2.3.2 Using mentioned neighborhoods as references

In the interviews, people mentioned the neighborhoods of Lourdes, Cidade Jardim, Santa Tereza and Sion as areas of good equilibrium between vegetation cover and buildings creating good urban ambiance. From these areas, it was calculated the volume of buildings and the volume of vegetation in a sector of 6 blocks in the core of each neighborhood.

In Lourdes neighborhood, the relation between vegetation and buildings per block was of 1.83%, that is, for each 100 m³ of total volume (i.e. built-up volume plus vegetation volume), 1.83m³ consists of the vegetation. In Sion neighborhood, vegetation volume represents 3.53% of the total volume, whereas in Santa Tereza neighborhood it represents 4.5% and in Cidade Jardim neighborhood 3.7%. The criteria to define ranges were established by natural breaks using the values from the four areas. They were respectively: 0 to 0.99%; 1 to 1.99%; 2 to 3.49%; 3.5% to 4.99%; 5% and above. (Figure 11).

We consider this method a technical approach because the references to decide from "adequate" to "not adequate" was based on existing conditions. It was a way to calibrate the opinions people gave in the direct interviews. Both results were presented, method of interviews (definition of high, medium and low) and method of technical analysis (5 levels of proportions, observed in spatial references).

3. RESULTS

After the processes of preparing data and getting information to have a reference of suitability in the balance vegetation and buildings, it was possible to make analyses about spatial distributions of values of indexes.

The first maps produced were the absolute and relative values of building volumes per block, and vegetation volumes per block, what means the indexes of built and vegetated volumes per block. From these values, it was possible to construct the map of the relation between

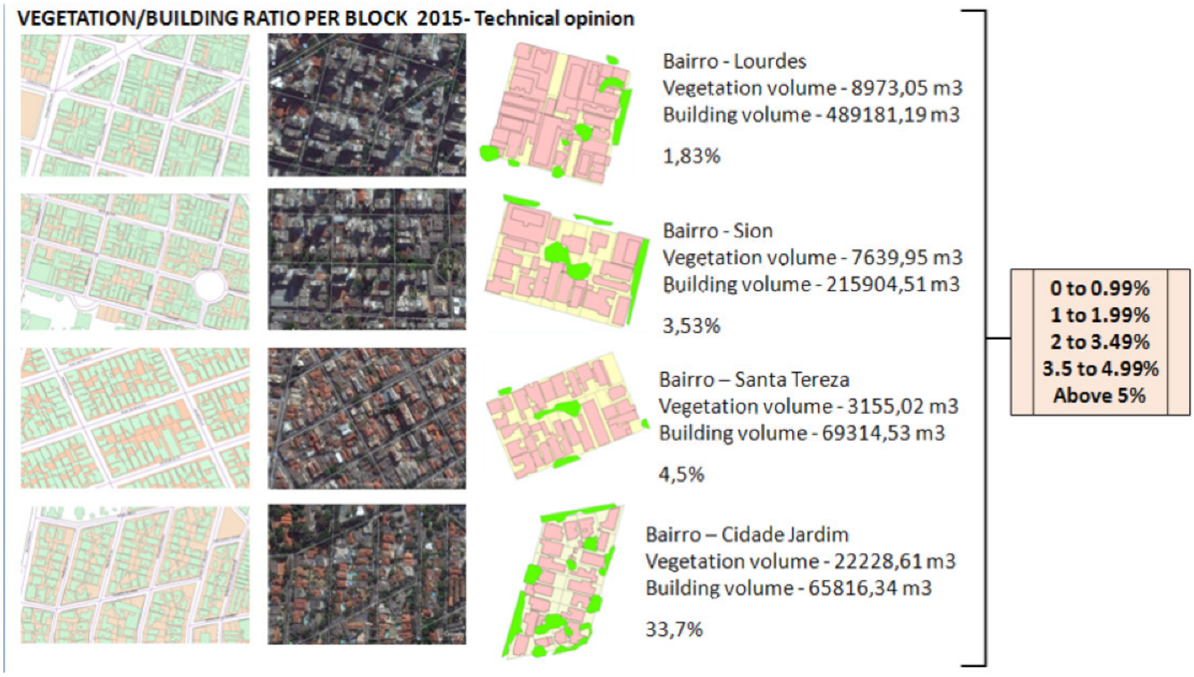

Fig. 11 - Ratio per block Vegetation/ Building – Technical opinion – Details as examples of the places.

vegetation and buildings per block.

To understand the condition of the index vegetation & buildings, two analyses were developed. First, we interviewed people to verify what they wanted for the future of the areas: to have high, medium or low vegetation cover. In another hand, we classified the rate of the relation between vegetation & buildings according to technical analysis of defined neighborhoods in Belo Horizonte, divided in a range of 5 values from low to high index of vegetation/buildings (Figure 12).

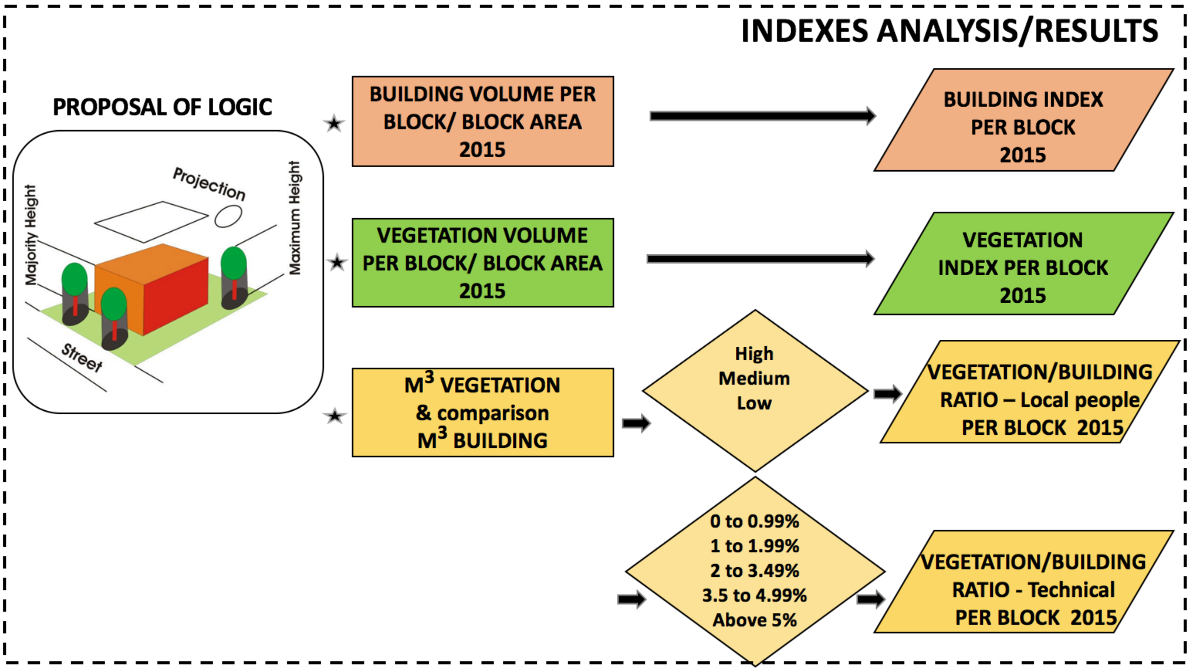

Fig. 12 - Index analysis (vegetation, buildings, vegetation & buildings) and results.

3.1 Growth area

An output of the studies was the comparison of footprints of buildings from 2007 and 2015, what means the growth of the built-up area.

It`s important to register that the objective of the study was not to update the cadastre of the region. From the orthophotos of 20 cm of resolution, it was possible to compare with footprints from 2007 and to generate some expeditious drawings of new buildings. Just with the objective of calculating general volumes of this new buildings. For this specific goal, the low-resolution vectorization can be accepted.

New buildings are highlighted in red on the map, while pre-existing constructions are highlighted in gray (Figure 13).

As it can be identified on the map, the region with the highest rate of new constructions is in the southwestern portion of Pampulha. To get a more accurate idea of the growth in the region, an area with new constructions (in red) and the existent constructions (in yellow) was simulated in the current topography (Figure 14). It is possible to notice the changes in the template standards, favored by the current law that allowed higher buildings, transforming the thus far prevailing landscape.

3.2 Growth of Buildings per Block

The map that presents the results of the growth of building volume per block shows in dark gray the areas in Pampulha that had significant growth of building volumes (Figure 15).

It`s possible to observe the concentration of new volumes along a north-south axis close to UFMG, and the limits southeast, that is a very industrial area, with huge sheds. In the limit northwest there is also an area of concentration of buildings, due to a new occupation, an area of social fragility that it's not vertically.

The highest concentration of new buildings is in the central-west part of the zone. It's the area around the neighborhood Ouro Preto, that is the main reference for services and commerce in the zone, where new very high buildings are being authorized. This is already a problem, because they can be seen from the lake and, what is worst, from the area declared of interest as cultural and heritage by UNESCO.

Pampulha is still characterized as low-density area, and the region around the work of Niemeyer, protected by UNESCO (around the lake, and especially in the south of the lake), presents very good conditions of low density. This is a value to be maintained, as it`s under pressure of transformation.

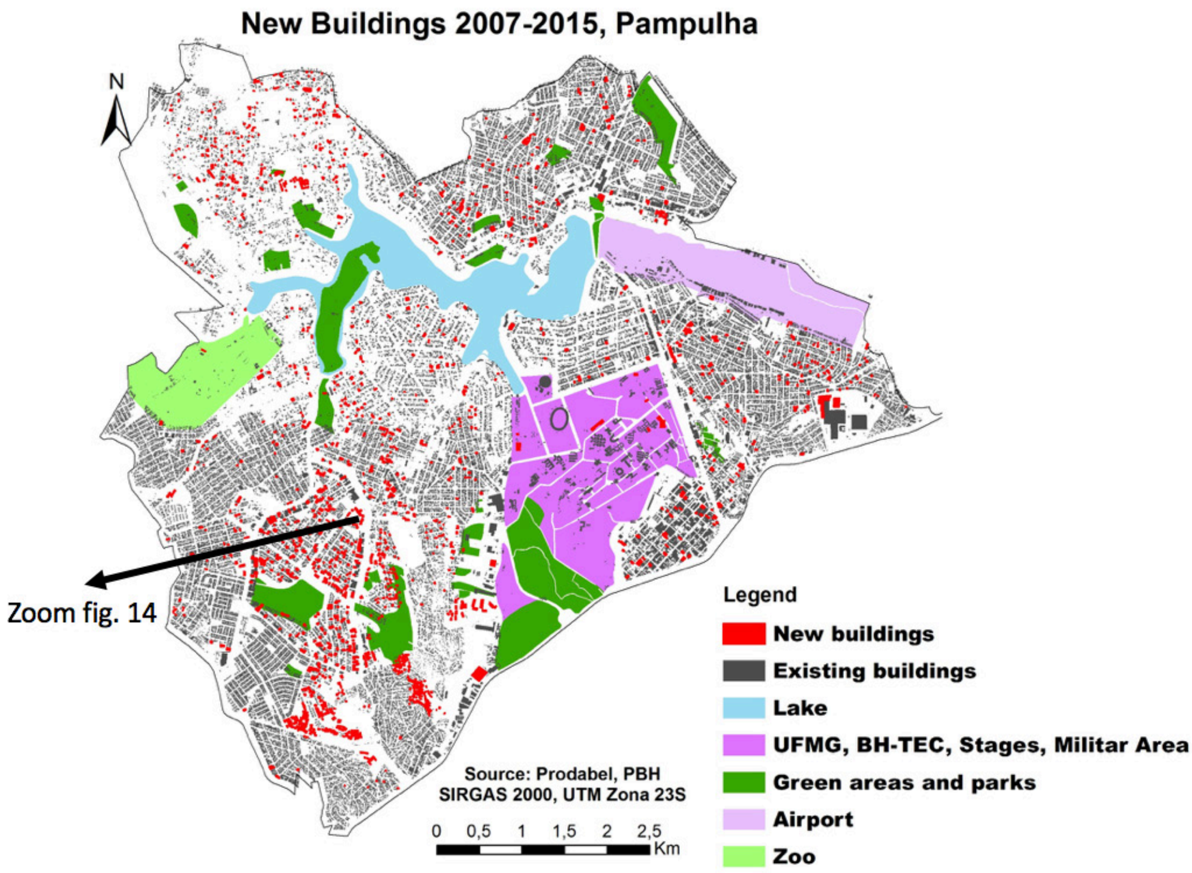

Fig. 13 - Building growth2007/2015.

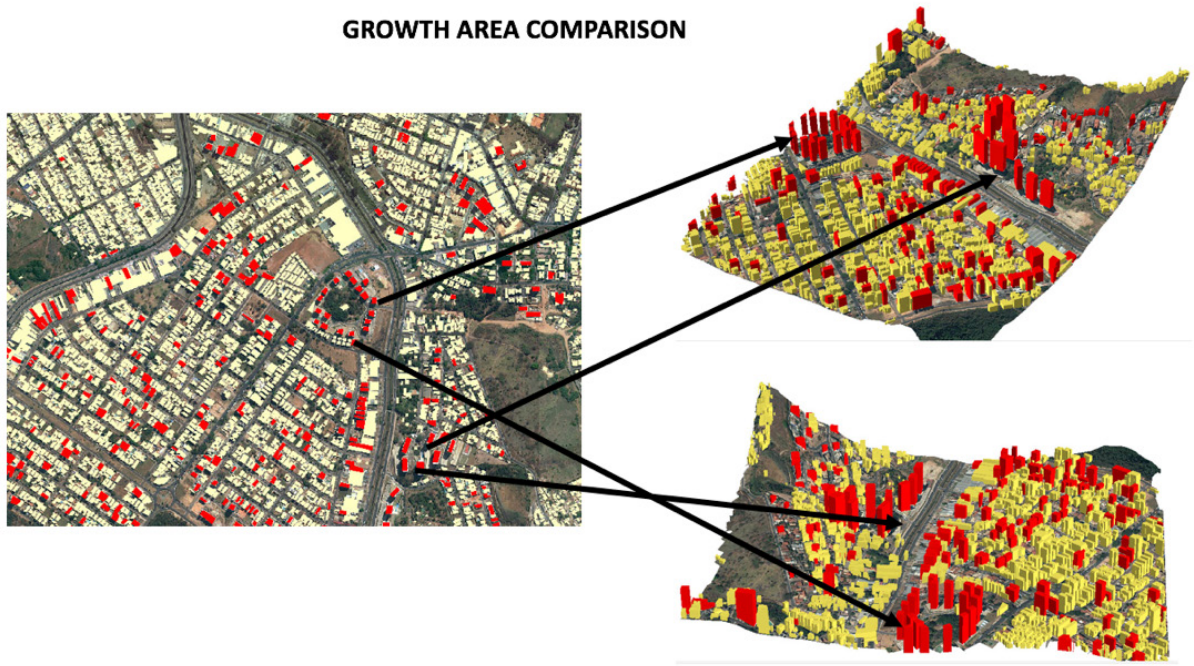

Fig. 14 - Growth area comparison. Zoom in the area of more concentration of growth.

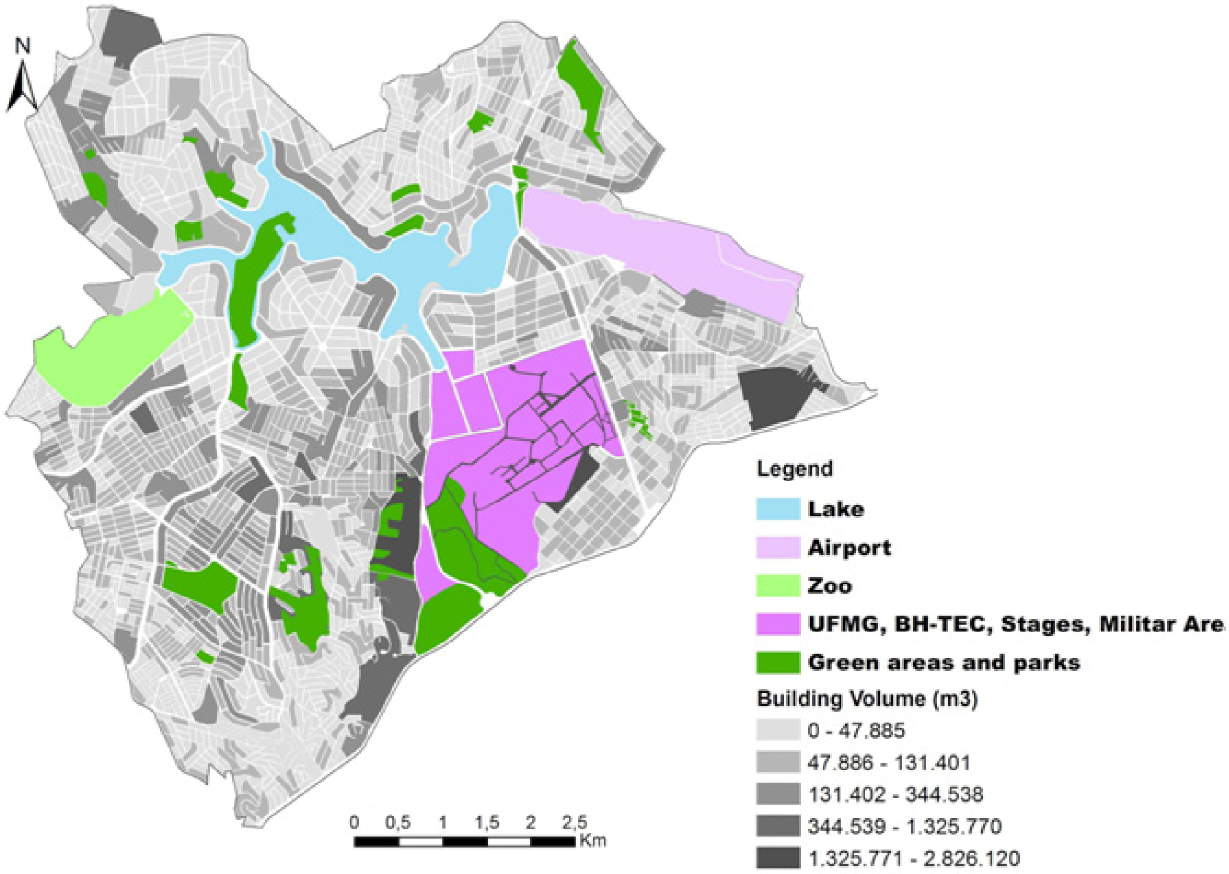

Fig. 15 - Building Volume per block 2015.

3.3 Built-up area Index per Block

The map of building index per block shows the spatial concentration of built-up areas in the southwestern portion of the region. Furthermore, one can observe that there is a slight tendency to grow in the north-eastern region, probably because of its proximity to the Federal University of Minas Gerais, what generates a great circulation of people and the needs of urban equipment in the place (Fig. 16).

In the north from the Pampulha lake, there is a spatial concentration of high building index areas around the neighborhoods of Santa Amélia and Santa Branca, distinguished mostly by two-story-plus and multi-family buildings. In the west and south of Pampulha Lake, there is a concentration of low building volume areas. These areas correspond mainly to the neighborhoods of Enseada das Garças and Braúnas, in the west, and São Luis and Bandeirantes in the south, characterized by one or two-story single-family houses.

The most concentrated build-up area is in the center-south of the zone, in the surroundings of Ouro Preto neighborhood, an area characterized by the commerce and services that attract high buildings.

3.4 Vegetation Volume per Block

The map of vegetation volume per block shows that the place has a significant vegetation cover, that is an important part of the genius loci of the place. The current vegetation is peculiar to this landscape, as it is perceived along the roads and in the backyards since the region is distinguished by large lots, low typologies and the ubiquitous presence of gardens. (Figure 17).

Doing simple comparisons of the maps of vegetation cover and built-up volumes, it is noticeable that this landscape is going through changes enabled by the current law. The current urban legislature allows a volumetric coefficient that results in high buildings and greater soil sealing in areas that would normally be destined to gardens and vegetation cover. The vegetation index per block map shows that the areas with the biggest concentration of vegetation are located along Pampulha lake and its surroundings.

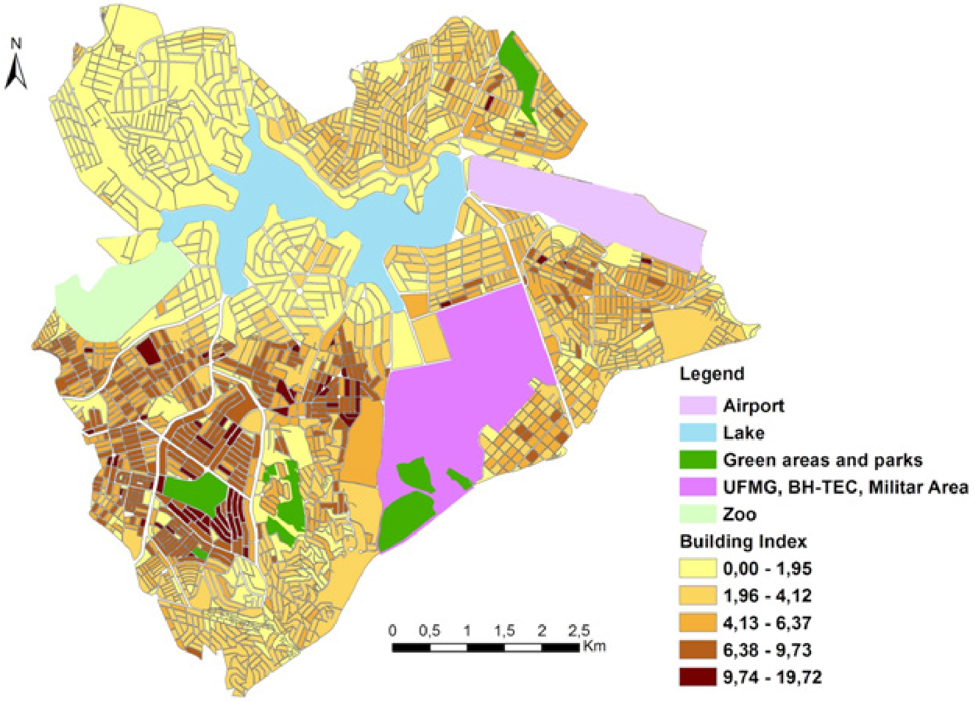

Fig. 16 - Building Index per block 2015.

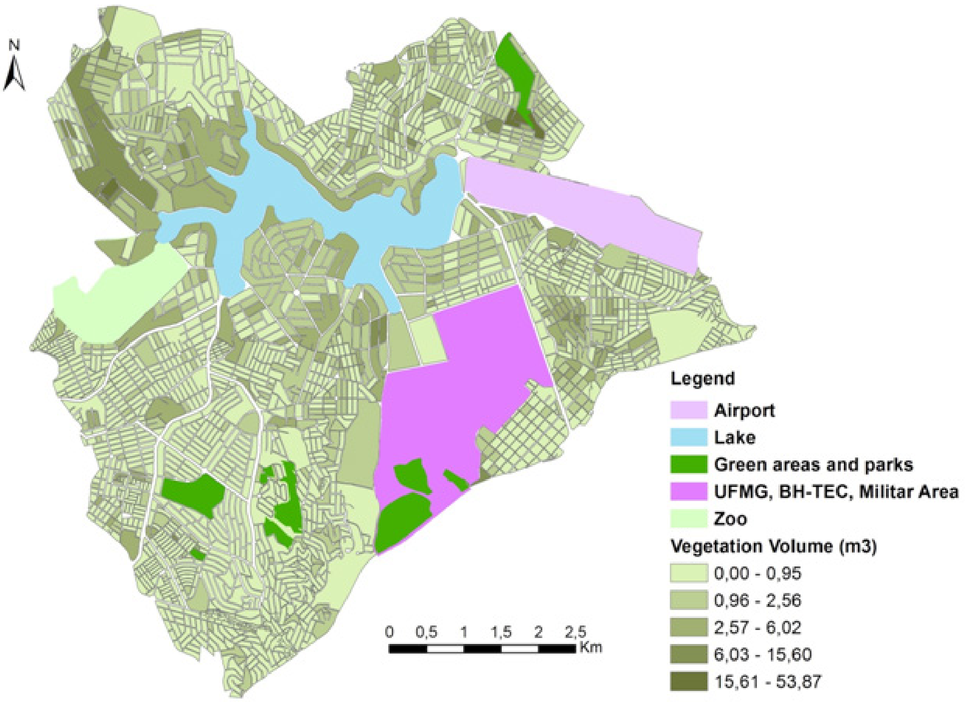

Fig. 17 - Vegetation Volume per block 2015 in m3.

3.5 Vegetation & Building Ratio per Block

The values of the relation vegetation & building ratio per block were classified in 5 levels from low to high proportions, according to technical studies of areas used as references.

To compare this results with the expectations of people from the place, it was also constructed a map to make possible to identify the areas in which people voted for promoting low density of vegetation cover in comparison to buildings, medium density, and high density (Figure 18)

When people of the place were questioned about the ideal future for the zone, a considerable number of them opted for the image with less quantity of green infrastructure and highest buildings. When asked about their decision, it was correlated to the idea of economic value, of dynamicity, of been interesting to real estate market. The problem is that they just don't understand that in a close future this will be a problem to their quality of life.

This arises the discussions of the limits of participatory processes, in which technical information must be presented to people to make them understand the results of their decisions. It's a clear example of NIMBY – not in my backyards.

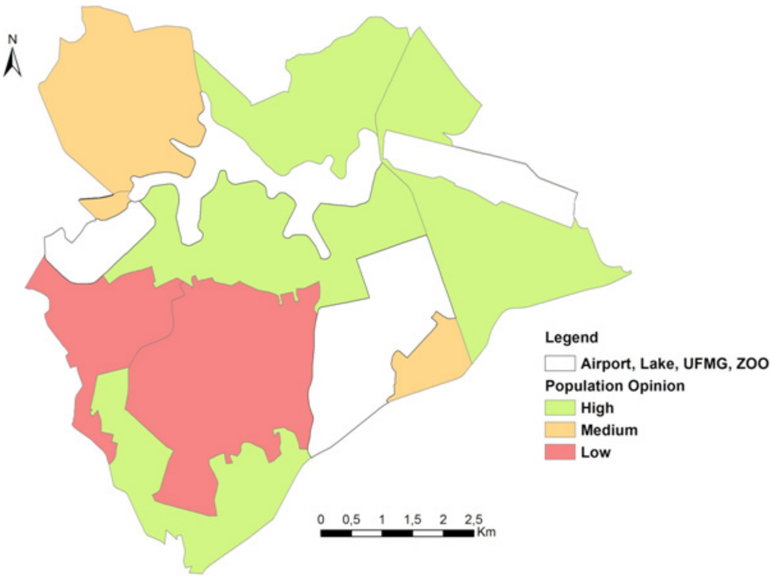

Fig. 18 - Expectation of Vegetation & Building ratio per block, according to the interviews.

The map of the distribution of the relation between vegetation and buildings in Pampulha shows the region is still very characterized by green areas. The presence of this very good conditions is due to its historical formation because the zone was initially destined to leisure farming and after that to very big lots with low-density housing (Fig. 19). The ranges from high to low, as it was already explained, used the references of areas in Belo Horizonte that are considered of the high quality of urban ambiance.

However, the area is been affected by expansion and speculation process, and this quality is already quite reduced in some parts. This is changing the genius loci of the place and must be considered in master plans and specific policies to the area.

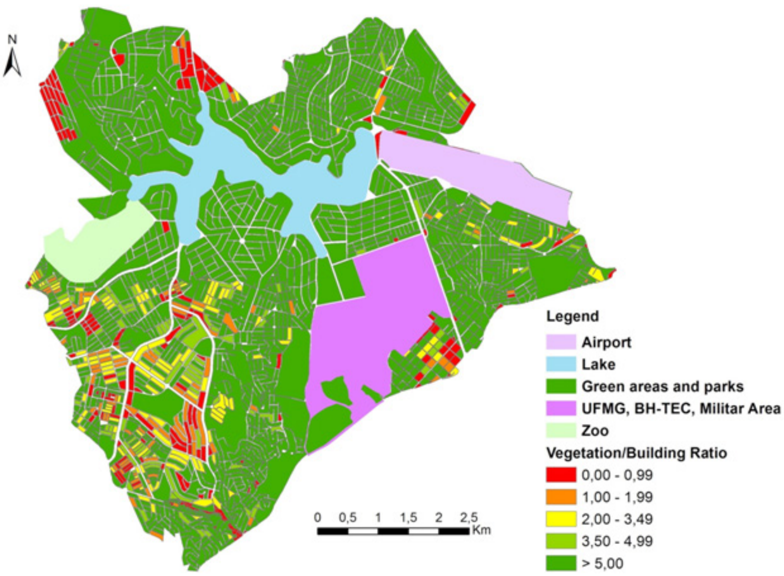

Fig. 19 - Vegetation & Building ratio per block – technical classification according to references of good quality of urban ambiance.

4. CONCLUSIONS

The application of remote sensing and geoprocessing techniques in high-resolution data was presented as a flexible way to construct of landscape urban indexes, which gave support to a consistent spatial representation and to allow the elaboration of modeled scenarios.

Using the Pampulha region as a case study allowed the perception of the pressure of urban growth from pertinent legislation and real estate speculation, as well as the necessary attention to the conservation of the landscape, which had its tipping as UNESCO world heritage.

The interviews, initially used for the calibration of the indices presented, also showed a tendency towards public opinion. This detail helped to raise questions about citizen participation in urban plans and the barriers between technical knowledge and daily life.

The possibility of presentation of the indexes from 3D modeling can serve as a geovisualization tool, transposing technical scientific analyses to a more intuitive language, which can contribute to the dissemination and citizen participation in the issues of urban ambiance.

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