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An exploratory study on building, land change use, traffic and temperatures rising in Porto Alegre city - Brazil

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Abstract: Climate change is a global phenomenon that carries strong and sensitive effects at local scales, especially in cities, where more than 50% of world population is nowadays settled [1]. Urbanization is featured by intensive land change use, through building, specifically by edification density and shape [2, 3], as well as by high rates of vehicles circulation in cities [4], two dynamic systems whose combination can contribute for temperatures increasing in crowded areas, as registered by [5] and [6] and several other authors. We studied the situation of Porto Alegre, at the Southernmost Brazilian State, with 30°2'0" South and 51°12'0" West coordinates, regarding these aspects. Analyzing side by side city's satellite images of 1986, 1997, 2011, and statistical data of real estate local institution on building indexes, vehicles fleet and temperatures variation especially from the last two decades, it was possible to identify expressive rising in these variables. Satellite images show that urbanized area grew 19,65% from 1986 to 2011, and now represents 35,16% of the whole municipality area. Nevertheless, urbanization sprawl was slightly bigger from 1986 to 1997 (10,08%) than from 1997 to 2011 (8,69%). Observing satellite images, we realize that regardless this thin difference, South areas have shown a great scattering in the last 14 years, with some neighborhoods presenting conurbation with others. We also realize a significative vertical growth from 1998 to 2011 because the number of new edifications increased 40% in the city. Vehicle fleet has experimented an increase of 54,37% with respect to the number of circulating unities from 2000 to 2010. Annual average temperatures grew 0,39ºC between 2001 to 2010, compared with 1991 to-2000. Considering that the population of Porto Alegre is keeping an average growth rate of 6% from decade to decade since 1990, reaching to 1,4 million of indwellers in 2010, according [7], we can take population growth as not so relevant as the increase observed in urbanization and vehicles fleet for heating. We conclude that the pace of changing in land that underwent sprawl process kept itself almost constant since the middle of the 80's, but South areas has grown under a disorderly pattern if compared with overall. Although we have no better data for assessing densification than built unities, we can realize that the Urban and Environmental Master Plan targets, aimed at densification of Northeast and radial areas from the downtown to East, has been fulfilled but failed in the preservation of the South lands, which lacking infrastructure for supporting the burden of the fast expansion we visualize in images.

Keywords: urbanization, land change use, building, vehicles fleet, air temperature, urban planning.

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1. Introduction

Urbanization is regarded as a phenomenon with large and contradictory effects around the world. As one of the ultimate geographical stages of population agglomeration and radial links of mobility, cities increasingly demand a crisp view on how urbanization takes place, especially considering that high population density can often bring side effects as the long term rising of average yearly temperature [1, 4, 8]. Thus, it is mandatory studying the recovering of urbanization processes – mainly the patterns of changing in land using, building and transportation – in order to understand how they can entail changes in temperatures and therefore influence governmental decision making on urban development patterns.

In this paper we firstly discuss controversial issues linked to climate change and how they have been mirrored at local scales, mainly through urban heat island effect. Then we review studies on urbanization and temperature changes carried out in several cities of the world, and present the main aspects that characterize the structure of contemporary cities related to demographic distribution and growth, as well as mobility and transportation. Energy sources and consumption, although deemed as a relevant variable for assessing climate shifts in global and local scales, are eschewed of present debate due to the complex cause-effect chain it implies for urbanization. Rather than embrace the whole set of questions envisaged in complex urbanization evolvement, we focus on the evolution of land change patterns, mobility and temperatures shifts, gathered all together for the case of Porto Alegre, the Southernmost Brazilian metropolis of the country. Using Landsat satellite images captured in 1986, 1997 and 2011, geo-referentiated and processed with support of both Envi and AutoCAD softwares, we show that the city underwent an intensive process of urbanization that resulted in an entire neighborhood resized in Southeast direction, whose growth turned from radial sprawl, up to 1997, to a more scattered expansion that is nowadays featured as a new area of conurbation towards South. At the same time, we realize that Northeast neighborhoods experimented an expected advance in building, already provided by the Master Plan for Urban and Environmental Development. Urban patches found in images demonstrate that while Northeast and other nearer areas have grown accordingly planned by governmental authorities, the South of the city has now piecemeal patches of urbanization, and kept on reproducing disorderly expansion that characterizes the historic urbanization process of Porto Alegre. Satellite images, arranged in chronological order, also confirm increasingly density in downtown area from the middle of the 80's to nowadays. All these land changes were followed by a rising of 0.39ºC in average annual temperatures in the last decade (2001-2010), taking in account monthly variations, compared with the same measures of average temperatures of the ten years immediately past (1991-2000). This can be deemed as representative increase in heating, according to ANOVA tests carried out under 0.05 significance level. From data gathering and assessment, we can state that urbanization in Porto Alegre – understood as a complex outcome of population increasing, land use modification, as well as intensification in both building and traffic – has found citizens within a warmer environment in the last decade. Although a positive correlation between urbanization and higher temperatures cannot be stated through this research, we suggest that these results deserve more attention of public authorities in order to better align with the municipal master plan targets of orderly growth with real dynamics of citizen development in both natural and built environments.

2. Climate change and urbanization: where are we going?

Urbanization is perhaps the most remarkable process over daily people lives. It is running faster as long as the time goes by, and brings intensive effects. According [9], by 1800, Beijing was the only city to have more than 1 million of indwellers. In 1900, 16 other cities were in this condition, but in 2000 there were 378 cities reaching this number of inhabitants. By 2025, it is forecasted that almost 600 cities will be experiencing this situation. Since 2008 global population crossed the 50% mark as urban, and up to 2030, this average will reach 60% [1], with low income and middle income countries leading this rising. “More than 95% of the net increase in the global population will be in cities of the developing world” [8: 756).

[10] forecast that people living in cities will comprise 70% of the world population until 2050, and [11] estimate that there will be 3 billion people in urban centres until the middle of the present decade. This unprecedented human density has been followed by challenges in terms of quality of life that depends on several aspects to be managed, as mobility, land use, population growth, energy and goods production and consumption, water supply, sanitation, and wastes disposal.

Like complexes organisms, cities’ healthy evolvement depends primarily on a hierarchic arrangement that includes planning about infrastructure availability and using. In this sense, [8:756] state that “the form of cities follows the function of land-use patterns, leading to a diversity of land-use arrangements”, but in fact, population growth and settlement generally pressure planning. “Undoubtedly, urban centers, especially those in the developed world, are the primary source of greenhouse-gas emissions and thus are implicated in global climate change” [8: 758].

It is difficult to balance healthy and harmful effects of urbanization, as well as to take both types of effects in a weighing structure looking for a proper tradeoff. In a first sight there is no doubt that people concentration entails more greenhouse gases effect production and therefore temperatures increasing due to chain effect caused by human needs in large scale: “Urban areas, particularly in high income nations, are major sources of carbon dioxide emissions from industrial, transportation, and domestic consumption of fossil fuels that cause global warming. During the 20th century, temperatures increased significantly faster in cities compared to nearby rural areas due to the urban heat island (UHI) effect” [1: 127]. Nevertheless, a lengthy look at the way urban arrangements can be improved leads to another consideration: “Compact urban development coupled with high residential and employment densities can reduce energy consumption, vehicle miles traveled, and carbon dioxide (CO_2) emissions” [9: 168].

So, there are controversial studies about the precise results of the relationships between urbanization and long term temperatures modifying: “If well-managed, the increasing concentration of population in urban centres can mean reduction in vulnerability to the direct and indirect impacts of climate change” [12: 2]. According [12], while low urban densities enable individual freedoms, they are also seen as wasteful in terms of space and resources consumption. In counterpart, high dense cities are compared to sick, claustrophobic places of squalor. “The goal of a city is to realize the benefits of dense population centers without compromising the ecological services or ecosystem health.” [13: 2426]. Therefore, is relevant to take care on how cities are designed, but “little is known about the interconnections among the changes and policies being considered” [10: 768].

Regardless the strength of these opposite arguments, the burgeon and long term sustain of a planned dense city, with high levels of infrastructure use based on healthy mobility, as collective transportation or cycling, also depends on cultural behavior and mainly on an equitable citizen average income. Economic concentration and exception underpin sick cities models. [14] highlight that metropolitan cities are characterized as global urban areas where economic polarization is a common feature. It entails an increasing centralized pattern of land using, mirrored in a real estate model that proper satisfy few groups. The result leads to the dualization of the space, where deprived and high income people got separated by the increasing offering of expensive networks of goods and services, addressed exclusively to the last ones.

Thus far, the most common pattern of cities’ growth is sprawled one: “Studies of urban morphology and rates of urban expansion show that contemporary urbanization is increasingly disperse and expansive” [9: 177]. This growing model started at the Second World War, in United States, where urban populations have moved further away from the urban centers, leading to a more expensive pattern of living due to increasing consumption of land, water and fossil fuels, with harm impacts to ecosystems. This so called peri-urban model, or “automobile-centric pattern of low-density suburban development” was replied to urban agglomerations of Canada, Australia, India, China, Mexico and Brazil [9].

A great amount of causes with unpredictable effects can unevenly threat people living in a disordered city, so it is becoming relevant to understand these complex relationships: “Local factors, such as climate, topography, heat-island magnitude, income, access to health services and the proportion of elderly people, are important in determining the underlying temperature–mortality relationship in a population” [15:7]. Several recent studies are looking into relationships between climate change and urban environments, trying to understand whether and how global change can affect cities and how far urban shape can impact global weather. These studies are focused on health effects and strategies for adaption to climate change [1, 16, 17], and on general issues about urbanization, population density, heating and climate change [4, 8, 9, 11, 12, 15, 18, 20, 21, 22]. Although common statements have been spread, divergences still stand. For instance, while [9: 185] advocate that “[u]rban areas contribute to climate change, and climate change is also a major threat for global urban areas”, [23: 290] says that “urban warming has not introduced significant biases into estimates of recent global warming” and defends that heating caused by urban building and shaping has actually stabilized [24].

We understand this debate as very difficult to get over and suggest more endeavour towards case specific assessments. Longitudinal studies are needed with multifaceted variables taken in account, aligning local, regional, and national strategies for urban planning. At the same time, meta-assessment indicators, as proposed by [25], can help to better address the reliability of isolated research.

2.1 The everlasting wrangle about climate change scale

The main difficult around debates on urbanization and global climate change is the lack of consistent studies to undoubtedly draw links between both phenomena [26]. While there are certainties about unfair harm effects of climate change – with underdeveloped regions and poor people being the most affected – there are also uncertainties on how to assess local level climate change [5]. As a matter of fact, [27: 284] state that the most crucial type of information for the climate science, on regional and local levels, is the least reliable because climate change models are based on General Circulation Models (GCM), "which represent physical processes in the global atmosphere, oceans, ice sheets and on the land's surface". The problem arises because such models generally have a resolution of about 1°–3° in latitude and longitude, which is not proper when translated into regional scales, giving coarse results. The scale issue is therefore an obstacle in attempts of linking investigations on urban temperatures changes and global climate research. Actually, recent studies have shown that climate change effects are practically unpredictable at small scales even in biological studies: "…models used to predict shifts in the ranges of species during climate change rarely incorporate data resolved to <1 km^2, although most organisms integrate climatic drivers at much smaller scales" [28: 666].

Another source of uncertainty lies on the idea that temperatures rising in urban centres are effects of [27] or cause of global warming [22]. [26: 286] argues that "[c]limate researchers have taken great care to correct for the impact of urbanization in temperature records by matching data from more-urban stations with data from rural ones". He adds that anomalies in temperatures occur in less populated areas around the world. [23:290] sustain that "globally, temperatures over land have risen as much on windy nights as on calm nights, indicating that the observed overall warming is not a consequence of urban development".

Although speculated links between climate change and urbanization are far from being unveiled, emerging local studies start to indicate that it is possible to systematize urban data as air surface temperature, as well as landscape descriptors automatically computed by Geographic Information Systems and remote sensing data for better understand the climate behavior in small scales [29]. [30:1] advocate the necessity of regional studies on climate change in order to understand "different geographical distributions of climate impacts within a country". Analysing climate data for Amazonas, São Francisco and Paraná rivers basins, they forecast a temperature increasing of 1° to 2° C for correspondent South America regions.

Finally, the wrangle on climate change scale cannot let behind the social approach of the problem. No matter through local, regional, national or global lens, demographic and socioeconomic processes cannot be overshadowed by statistical data of physical variables as temperature and rainfalls. So it is necessary to contextualize human circumstances in which people live and move to best climate dynamic frames [16].

2.2 Retrieving research on urbanization and heating

Studies on urban climate are not new, and they are usually focused on Urban Heat Island (UHI) phenomenon. [31: 1931] recovered ten researches on this subject, carried out from 1992 to 2007, and conclude that they "have experimentally or numerically elucidated the mechanisms and processes through which urbanization changes the local wind and air temperature fields". UHI is regarded as differences in air and surfaces temperatures of cities according they are taken in urban or rural areas, and in this sense, it is possible to say that "cities locally modify their own climate" depending on the landscapes' features considered [29: 2180].

According to [18:1],"[h]eat islands develop when a large fraction of the natural land cover in an area is replaced by built surfaces that trap incoming solar radiation during the day and then re-radiate it at night". Main recognized causes of UHI are vegetation suppression with subsequent coverage by impervious surfaces (concrete or asphalt); relative building heights, structures and proximity of each other, with consequent changes in radiative fluxes; heat released by human activity [32]. Therefore, UHI "is an urban climate phenomenon influenced by land use pattern" [33: 1382] and need to be investigated jointly with population dynamics [22].

Urban heating monitoring is becoming important because 78% of the carbon emissions around the world are attributed to cities [4, 8]. Nowadays, World Meteorological Organization (WMO) provides a method called Urban Climate Zoning (UCZ) for assessing urban temperatures that consider differences in cities' landscapes[29].

The core reason for urban heating assessment is public health. With land changes, surface hydrology can also be modified, and floods become an additional threat [34]. "Excess morbidity and mortality related to extremely hot weather and poor air quality are found in cities worldwide", and there is scientific consensus that climate change intensify both air pollution and urban heating, harming especially vulnerable people as the elderly, very young, socially isolated, poor, and ethnic minorities [1: 126]. [18] warn that high temperatures increase the levels of secondary pollutants as ozone, worsening respiratory conditions. Besides, heating leads to increasing energy consumption for cooling environments in cities [35].

Although few studies on urbanization in developing countries are up to now provided [31], we summarize as follows results of available research on this subject related to heating, in both developing and developed countries.

Of our main concern is the research of [3]. He assessed effects of solar obstructions by building and vegetation, separately, in Porto Alegre, Brazil, collecting data from April 1985 to March 1986 in six meteorological stations placed in seven points of the city with different landscape features. He found positive co-relationship between building density and temperature rising, and concluded that building density strongly influenced temperatures: "The horizon obstruction by building seems to be the most relevant environmental variable on average of minimum temperatures where meteorological stations were placed" [3: 83].

[36] analysed mean temperatures of Istanbul and Ankara, in Turkey, in order to establish possible relationships between respective data and urbanization effects. They concluded that "[a] significant upward trend is found in the urban temperatures of Southern Istanbul, which is the most highly populated and industrialized part of the city compared to rural parts" [35: 3411].

Using statistical approach, [35] confirmed the correlation between air temperature variations and different urban land use in Göteborg, Sweden: "Measurements show intra-urban air temperature differences of up to

9°C in the urban district. The results show statistically significant temperature variations between different land use/land cover categories on a diurnal basis and for all weather conditions" [35: 135]. [18] analysed UHI in New Jersey, USA, using both satellite images and climate data and concluded that urban heating has several causes as architecture, meteorology, climatology, and land use change.

[2] provides several examples of urban health island studies which confirm temperature rising due building-side effects. He confirms different effects on average of temperature depending on the type (height and shape) of the buildings.

[37] compared data from daily temperatures and precipitation though 720 meteorological stations in China from 1970 to 2000 and concluded that "most parts of China experienced significant increases in temperature… although some of this warming may be attributable to the urban heat island effect in large cities" [36: 459]. Also in China, we highlight three other studies. [33] verified the influence of land use change on UHI in greater Guangzhou from 1980–2007 by analysing satellite data, meteorological records, and census data. "Examining the relationship between regional or local scale climate change and land use helped in understanding that the heat and energy transfer varied with land surface physical properties" [33: 1394]. [4] explored the relationships between urbanization and climate change regarding the region of the Yangtze River Delta, one of the larger and most urbanized China's areas. According to these authors, there were documented reciprocal influences between climate shifts and built environment. [38] investigated temperatures changes in Zhujiang River Basin, South China, from 1961 to 2007, in 192 weather stations, and found an increasing of 0,7°K. It was attributed to urban heat island phenomena due urbanization and industrialization: "…results demonstrate that rapid urbanization can substantially alter regional climate conditions in the Zhujiang River Delta" [38: 146].

[39] carried out a study on temperatures behavior in Brahain – a group of 36 islands placed in the Arabian Gulf – from 1947 to 2005. They found an average increase of 0,166°C in ten years. "The decade of 1991-2000 emerged as a period of conspicuous warming as well as increase in the occurrence of unusual mean temperatures and the number of months per year with above average temperature" [39: 269]. Temperatures rising were attributed to land change using, especially due to compactness of building patterns.

Studies carried out by [17] for assessing effects of climate change in African cities considered mean minimum and maximum temperatures as well as other variable as amount of precipitation, mean humidity, wind speed. Gradual rising temperatures were found in Mombasa, the second largest city of Kenya.

[31] analyzed the urban environmental growth of Jakarta and the simultaneous temperature average rising – 0,6°C from 1970 to nowadays: "The rapid urbanisation has been accompanied by land use modification in the area surrounding the old city of Jakarta" [31: 1939].

In USA, [40] compared population profile (demographic, socioeconomic, and health vulnerability) with GIS data all over the country. They concluded that for the past 30 years, "a relationship exists between increasing temperature variability and rates of morbidity and mortality" [40: 13].

[6] also found liable relationships between urbanization and temperatures rising in South Korea. Through multiple linear regression, they identified an increase of 1,37°C in temperatures from 1954 to 2008, and 0,77°C of this variation can be attributed to urbanization effect.

Above examples give evidences of the close relationships between urbanization and inherent processes (populational growth, transportation, mobility, land using) and changes in temperature patterns. It also paves the way for a more cautious sight about what is going on in Porto Alegre city, where contradictory aspects, as a well planned city, works for some areas but conflicts with disorderly growth in another characterized by peri-urbanization and slum formation. According [9] and [12], although considered anti-economic and environmentally harmful, the trend of reduced urban density under none or poor planning will probably continue in cities of developing countries, whose built-up areas can triple until 2030. It poses a real challenge in the perspective on better understanding of urbanization dynamics and it consequences.

3. Objectives, research methods and constraints

This research was performed as an exploratory case study [41: 18], because it "investigates a contemporary phenomenon in depth and within its real-life context". It aims to identify and jointly assess elements of urbanization that can be likely bonded to average temperatures rising in specific case of Porto Alegre city, the metropolitan area placed at the most Southernmost Brazilian territory. According similar studies reviewed in section 2.2, we selected the main aspects entailed in urbanization, as population growth profile, building and land use changing, and traffic, represented by vehicles fleet. We additionally brought elements of Urban and Environmental Development Master Plan and further mobility aspects that can complement respectively building patterns and urban transportation practices. Satellite images of Porto Alegre, captured by Landsat in June 1st 1986, July 1st 1997, and May, 5th 2011, were processed and geo-referenced with software Envi 4.5 (Environment for Visualizing Images), and respective urbanized areas were computed by each image, with support of AutoCAD.

Specific data of population, building, fleet vehicles traffic and average air temperatures were collected in demographic (Brazilian Institute of Geography and Statistics - IBGE, Economy and Statistic Foundation of Rio Grande do Sul - FEE/RS), civil building (Civil Building Union of Rio Grande do Sul – SINDUSCON), traffic (State Traffic Authority - DETRAN) and meteorological (National Institute of Meteorology – INMET) institutions. Some gaps have been filled through bibliographic research in both academic [42, 43, 44, 45, 46, 47] and not academic sources [48, 49, 50, 51, 52]. Data evolution was analysed side by side registers of the average temperatures considering a range of time between 1931 and 2010. In order to compare temperatures evolution we considered four time ranges (1931-1960, 1961-1990, 1991-2000, and 2000-2010). ANOVA test was performed with a 0.05 of significance level with the aim to assess whether the temperatures variations were statistically representative.

The research has not the aim of proofing co-relationships among determinants of urbanization and temperatures rising, although we have identified evidences of positive shifts for both phenomena. Rather than proof irrefutable links, we provide a set of well documented and articulated analysis for boosting the debate on urban planning in behalf of healthier strategies for the city and the indwellers.

4. Porto Alegre city: building and traffic as remarkable challenges

In the next subsections we present the profile of urbanization in Porto Alegre according natural and historical evolvement of the city, and correspondent temperatures behavior during the last 80 years.

4.*1 Natural features and demographic evolvement*

The Southernmost Brazilian metropolis, Porto Alegre is the capital of Rio Grande do Sul, placed at Central Depression of the State. It has as geographical coordinates 30°02'0" South and 51°12'00" West (Fig 1). According [7], the city occupies 496.82 Km^2, and has a population of 1,409,351 inhabitants, with a density of 2,836 indwellers/km^2. Gross Domestic Product (GDP) per capita reached US$ 15,125 in 2008 [7]. The city is placed at first in State ranking of GDP among the State 496 municipalities. Life expectancy of the city's population reaches 71.6 years.

Fig 1 – Localization of Porto Alegre in Brazil

Porto Alegre has a heterogeneous relief, with mountains and hills at East and South, plains in central and North areas, and low land and coastal area at West [46]. The city was firstly established in 1772, became a village in 1810. Underwent massive migration waves from 1820 to 1890, and industrialization took place from 1890 to 1945. Although intensive harbor activity has characterized the capital until the 19 century, Porto Alegre mobility has developed through roads as it main transportation modal. Territorial occupation occurred firstly in granitic hills – in lowlands, at the edge extension of Guaiba Lake, where downtown is nowadays placed.

Under subtropical climate, Porto Alegre suffers influences of both maritime tropical and continental systems. It averages temperatures ranges from 20°C to 23°C [47].

[43] classifies the vegetation of Porto Alegre as native forest, degradated forest, shrubs, grasslands, plated, and managed fields. Almost all the city's vegetation was replaced by anthropic occupation during the urbanization process. Nevertheless, Porto Alegre still keeps 24,1% of it original vegetation – of this amount, 13,9% are forest coverage and 10,2% are underbrush. The main areas of original vegetation coverage are placed at the South of the city (neighborhoods of Tristeza, Assunção, Belém Novo) and at legally preserved area of Jacuí Delta – a hydrographic set of 16 islands, channels, swamps and marshes placed at Northwest, which results from the meeting of Gravataí, Sinos, Caí and Jacuí rivers, which forms Guaiba Lake, one of the main sources of water supply in the whole metropolitan area [43].

The city has sprawled from the downtown in radial shape. South of the city keeps the most expressive original landscapes strips, and even with recent occupation, presents low impermeabilization rates in comparison with downtown and nearer neighborhoods, where soil is almost all paved. Around the hills, in East side of the city, there is high concentration of irregular occupation as well as often flood episodes.

Considering that cities has two basic paths for development – one which prioritizes economic dimension, and another one which gives emphasis on ecological processes – we can classify Porto Alegre as well as another Brazilian metropolis under the first model, of capitalist concentration [44].

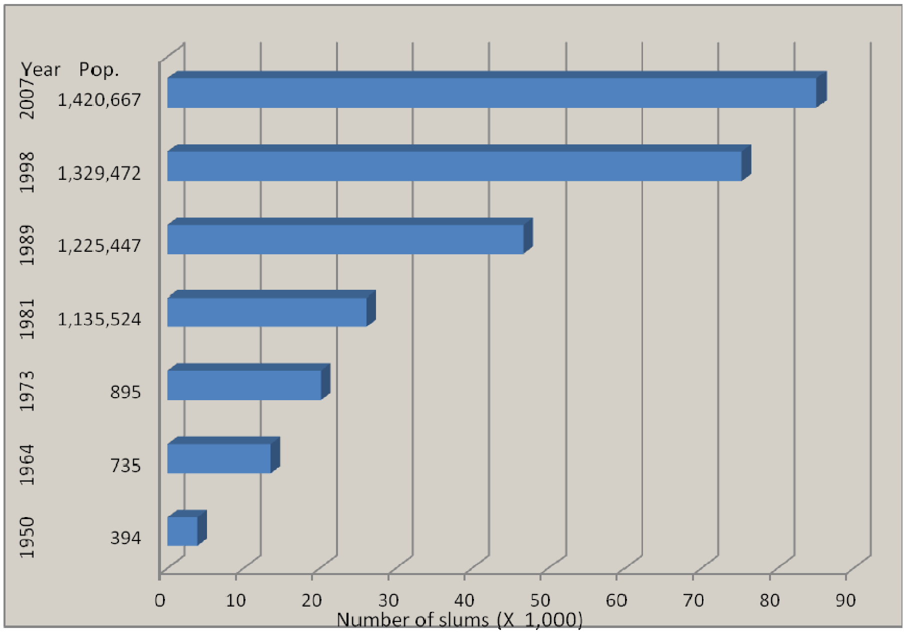
The city's population did not exceed the mark of 200,000 habitants up to 1920, but underwent intensive growth from 1950 to 1990 [46]. Since the last decade, there is a tendency to enter in a steady demographic state, with average growth of no more than 6% per decade.

According [44], Porto Alegre had a population boom from 1900 to 1960, when population grew from 73,000 indwellers to 635,000 indwellers. This increasing remained in the following years, and from 1970 to 2000, population has grown 86,4%, but from 2000 on there is a trend of steady growth. While from 1940 to 1960 the population of the city grew 133,8%, this increasing dropped to 39,4% (from 1960 to 1970), to 27,1% (1970 to 1980) and to 10,9% (1980 to 1990). In the last decade (1990-2000), Porto Alegre had a population growth of 9%.

[46] reviewed several studies that highlight the complexity of populational growth and the semicircular shape that took place in population sprawling of Porto Alegre. She attributes to public policies regulation – as low income habitational policies – some type of population dispersion which occurred in the last decade. Soil impermeabilization has risen side by side popular residential areas and high income (horizontal) residential condominiums. Occupation shows accentuate increasing in fluvial plain lagoon and in hills specially from 2011 on, with an average of 80% of increase. According [46], urban patches in municipality grew from 40% to 45% of the whole area, although population has not shown high average growth.

According [44], 5,1% of the whole Porto Alegre population lived in slums up to 1950, and this percentage grew to 11,3% in 1981, represented 17,11% in 1988, and 22,11% in 1998. It reached to 23,38% of the whole indwellers of the city in 2007 – 332,158 indwellers. Porto Alegre had 124 sub habitational cores 35 years ago, and now has 479. Since 1998, Porto Alegre's whole population and population living in poor condition have grown in moderate rates. Fig. 2 presents demographic evolution of Porto Alegre since 1950, with respective sub-habitation evolvement (drawn bars).

Fig 2 – Demographic evolvement of Porto Alegre with respective sub-habitational growth



4.2 Building and land use change: criticism on Urban and Environmental Development Master Plan

Urban spaces refer to patterns of occupation and land using – economic activities concentration as industries, services, commerce, infrastructure. They mirror the way society organizes itself in a dynamic which includes transportation and zoning planning [42]. Real estate is a mainly urban activity, and it follows the market rules of capital concentration. It is a powerful pressure for urbanization, because it stratifies offering conditions of habitational units and often contributes to inequalities in housing that lead to a deep imbalance between low and high income people.

Habitational density in Porto Alegre corresponds to 3.01 person by housing unity [46]. According the 14th census of Real State in Porto Alegre, released in August 2011, the number of unities offered has increased 40% since 1998 to nowadays [53]. The years of 2008 and 2009 were atypical due to global financial crisis, and the best results for civil building were registered in 2005, with 470 unities offered against 270 in 1998 – an increasing of 174%. Main offer is nowadays placed in North East neighborhoods as well as in some South neighborhoods of the city.

Another source of civil building activity is given by the amount of jobs it offers. According [46], the number of people employed in civil building has more than doubled in the last 25 years, changing from grew from 15,533 workers in 1985 to 34,926 workers in 2010.

The fast process of urbanization which took place in Porto Alegre especially since 1970 brought severe shifts in topographic profile of occupation as well as in vegetation [45, 46]. Slope of hills in East areas of the city testified high density of irregular building, as a result of governmental planning lack. As a matter of fact, authorities failed in providing proper infrastructure for supporting rapid urban growth. According [42], 19.07% of Porto Alegre dwellers live in inadequate building – such as more than one family dividing the same place or occupying under-rented places. This situation reflects socioeconomic inequality: a range of

47.49% of Porto Alegre residents has a monthly income of US$ 1,600, but the civil building is planned to finance residential unities for people with monthly income above US$ 3,255 (25.3% of the citizen's residents, according [54].

As consequence of disorderly growth, natural landscape underwent severe losses, and the city keeps just 24% of the natural vegetation covering [43]. [45] highlights dramatic vegetation suppression in the South areas of Porto Alegre, markedly in Cristal and Espirito Santo neighborhoods. According her, from 1966 to 2008, Cristal has lost 64.6% of green areas, while Espirito Santo lost 39.4%. These two neighborhood have now high rates of impermeabilization.

[42] identifies a recent trend in housing behaviors of Porto Alegre citizens: people with high income levels are moving from the old town (already urbanized) to horizontal buildings placed at peripherical areas almost all placed in neighbourhood municipalities or at the South neighborhoods. And besides its internal population pressure, the city is also overwhelmed by the fast growth of the Metropolitan area, a set of 32 surrounding municipalities whose population has experimented a demographic growth of twice of the capital's growth in the last decades [44].

Data from City Hall [51] inform that Porto Alegre became the first capital in Brazil to have a Master Plan – it happened in 1914. Until 1938, the city's Master Plans were focused on transportation and road conditions, but it started to change in 1959, when a new plan covered housing, work, leisure and circulation issues. The more recent master plan is from 1979, it was launched as Master Plan of Urban Development, whose name has changed in 1999 to Master Plan of Urban and Environmental Development. It contemplates edification rates, minimum space between buildings to be constructed since then, as well as introduced the concept of "created soil" (as vertical building) in order to contemplate the need for urban growth through densification mainly in Northeast and radial areas from the downtown to East side of the city. Actually, the last version of the Master Plan (Municipal Law 434/1999) is driven by density control of the cities' spaces – so local urban development is addressed according the size of the population which has access to infrastructure. It is aimed at redistribute the opportunities of housing in order to attain people with lowest income.

According the Master Plan [44], Porto Alegre is divided in the following areas:

- Radicocentric City – zone placed in the middle West part of the city, with well defined roots and good infrastructure services;

- Development Corridor – placed at the extreme North of the city, where there is good access to freeways and airport services but not so good infrastructure, with empty places generally occupied by low income families;

- Chess City – placed at the Northeast of the city, with increasing occupation since the 1980's and with development characterized by commercial activity, especially shopping centers and alike commercial firms. It has some empty places but also transition roads which facilitate moving from one part to another of the city;

- Transition City – placed immediately after the downtown, towards the Southeast of the city. It has residential features, with lots of popular villages. It is characterized by population with low income, and high violence rates, where the natural landscape has suffered high impact;

- Garden City – comprises the extreme South of the city, with low population density, but with a situation of transition in the last years because of horizontal condominiums placement;

- Pinheiro Hill and Restinga – comprises a set of neighborhoods with the more irregular housing situation of the whole city, that show increasing disorderly urbanization in the last years;

- Rural City – placed between the Garden City and the Pinheiro Hill/Restinga – has urban cores and rural places side by side – like the Garden City, it has changed it profile with increasing occupation.

Porto Alegre Master Plan is designed for giving priority to social function of property, with democratic participation and decentralization. It is settled on principles of income distribution and environmental qualification through transportation and land using. [50] confirms that Porto Alegre's Master Plan is addressed towards urbanization density since 1993. It legally introduced the concept of "created soil" in order to maximize investments in public infrastructure. [49] highlight the following features of the Porto Alegre Master Plan: land division, pattern of public way characterized by public communitary equipment, viary system, and environmental preservation care (including landscape and cultural assets).

Nevertheless, according [49], informality keep on the main feature of conflict between private and public interests. Some authors as [48] state that Master Plan of Porto Alegre is complicated, spendthrift, anachronic and not flexible because it has actually low effectiveness in real dynamics of populational occupation. Porto Alegre satellite images of 1986, 1997 and 2011 can partially confirm some success of the Master Plan and at the same time it failure. Figs. 3, 4 and 5 below present the urban metropolitan perimeter assigned in light blue color inside the dark line, which circumvents areas of the shore, from Guaiba Lake (dark blue area), to the East of the city.

Urban areas accounted from 2011 image (Fig. 5) inform that urbanized area of the city corresponds to 35.16% of the whole municipality area – an increasing of 19.65% since 1986 (Fig. 3). From 1986 to 1997 (Fig. 4), urbanized area has grown 10,08%, but this growth has shown a little drop since then, staying at 8.69% from 1997 to 2011.

Arrows placed in each image allow us to realize that Southeast (1) and South areas, specifically Restinga neighborhood (2) experimented significant expansion from 1986 to 1997 (Figs. 3 and 4). This horizontal growth was more dramatic from 1997 to 2011 (Fig 5), despite the whole urbanized area has grown not so much during these years than from 1986 to 1997. Nevertheless, considering that the difference between the growths of 1997-2011 and 1997-1986 is of 1.39 percent, we can state that horizontal expansion of the whole metropolis has kept a steady state in the last 25 years, at the same time that vertical expansion was more remarkable. We can also realize that horizontal sprawl is more accentuated at the Southeast and South areas, with Restinga neighborhood (2) practically in conurbation with other South neighborhoods (3) in recent satellite image. This situation arises as problematic because while the Master Plan provides a forecasted and planned growth for Northeast areas, designing the created soil in order to densify these areas, it has no equal provisions for Southeast and South areas, which have been target of irregular occupation and real estate speculation.

Fig. 3 – Satellite image of Porto Alegre taken by Landsat in June 1st 1986

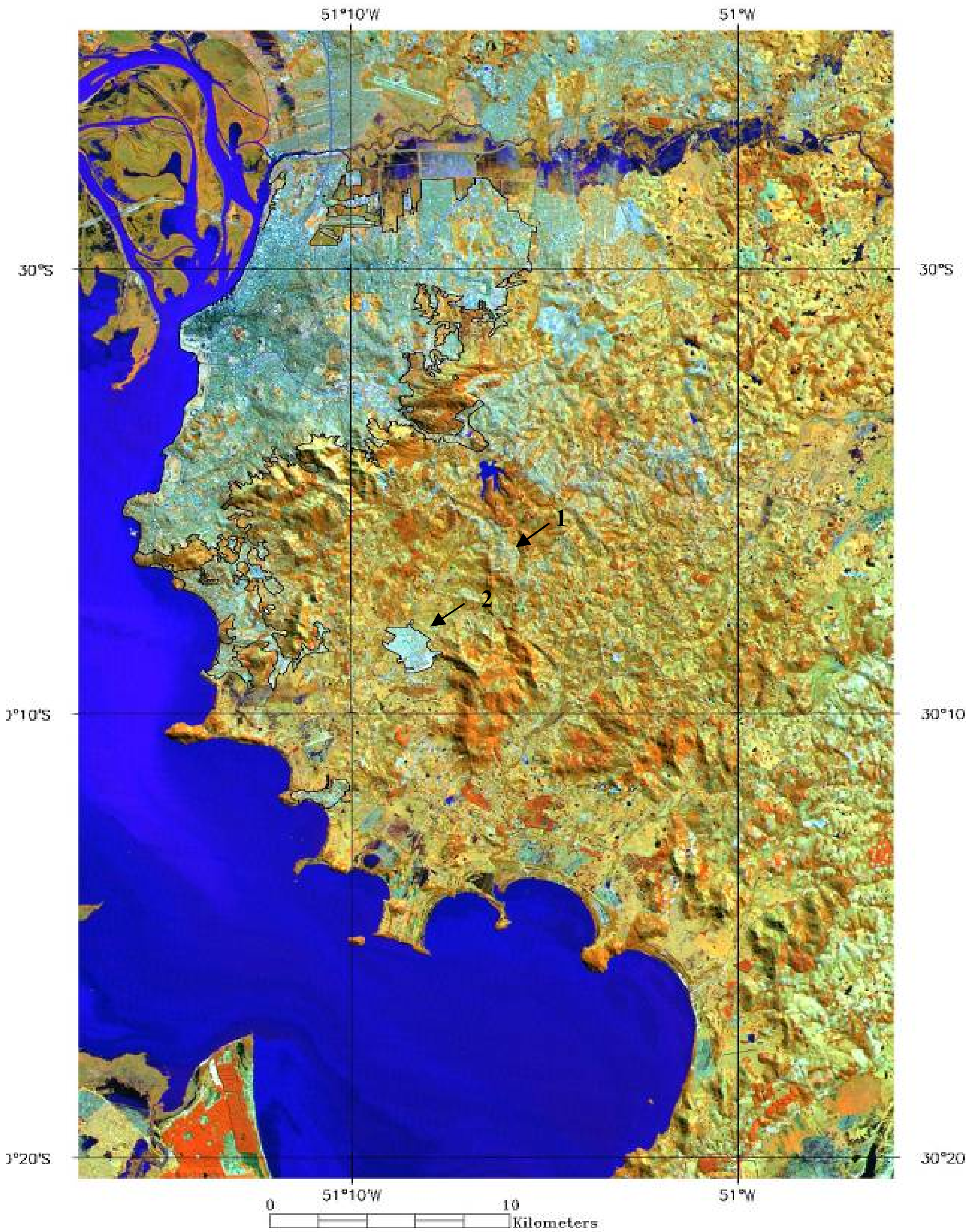


Fig. 4 – Satellite image of Porto Alegre taken by Landsat in July 1st 1997

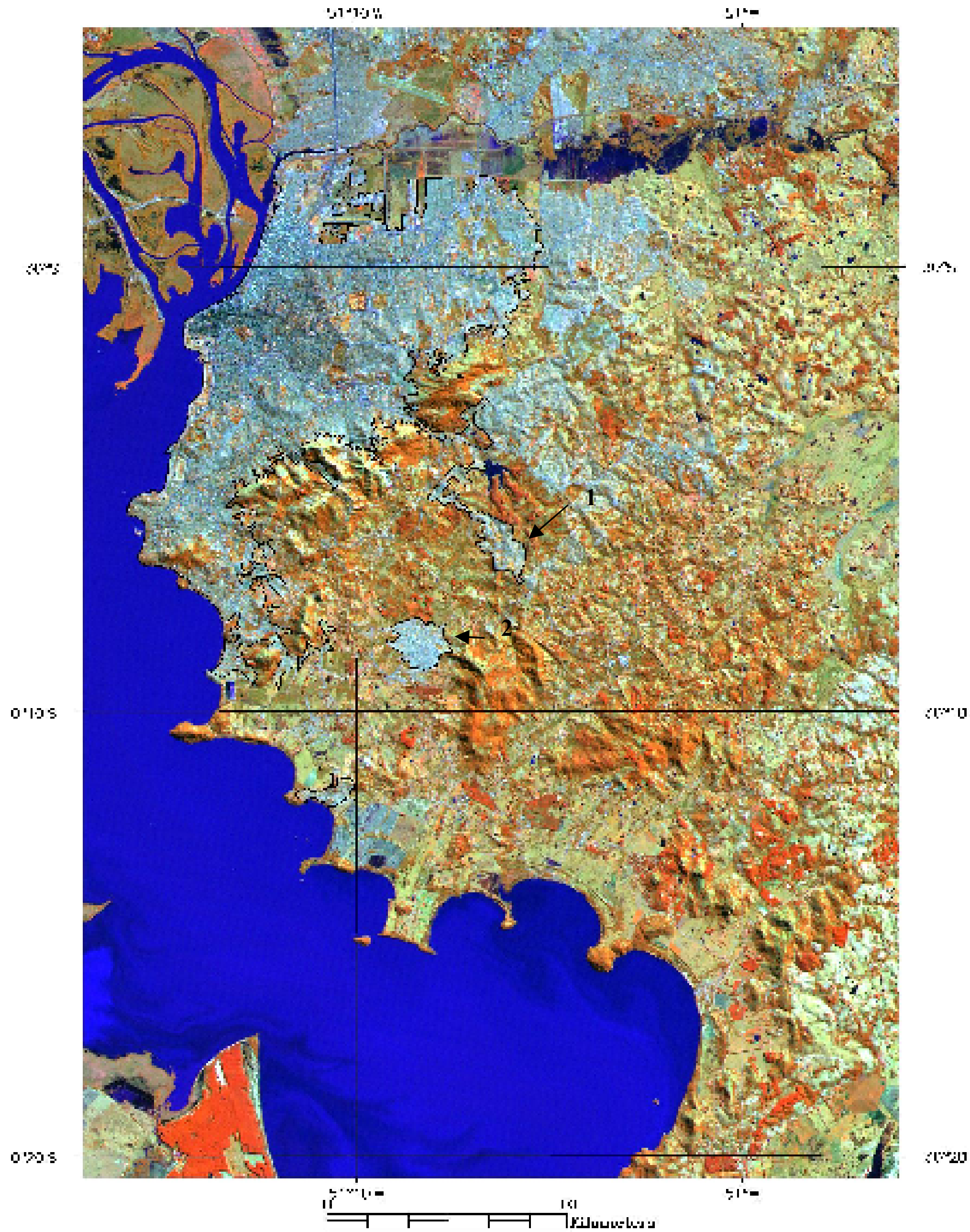
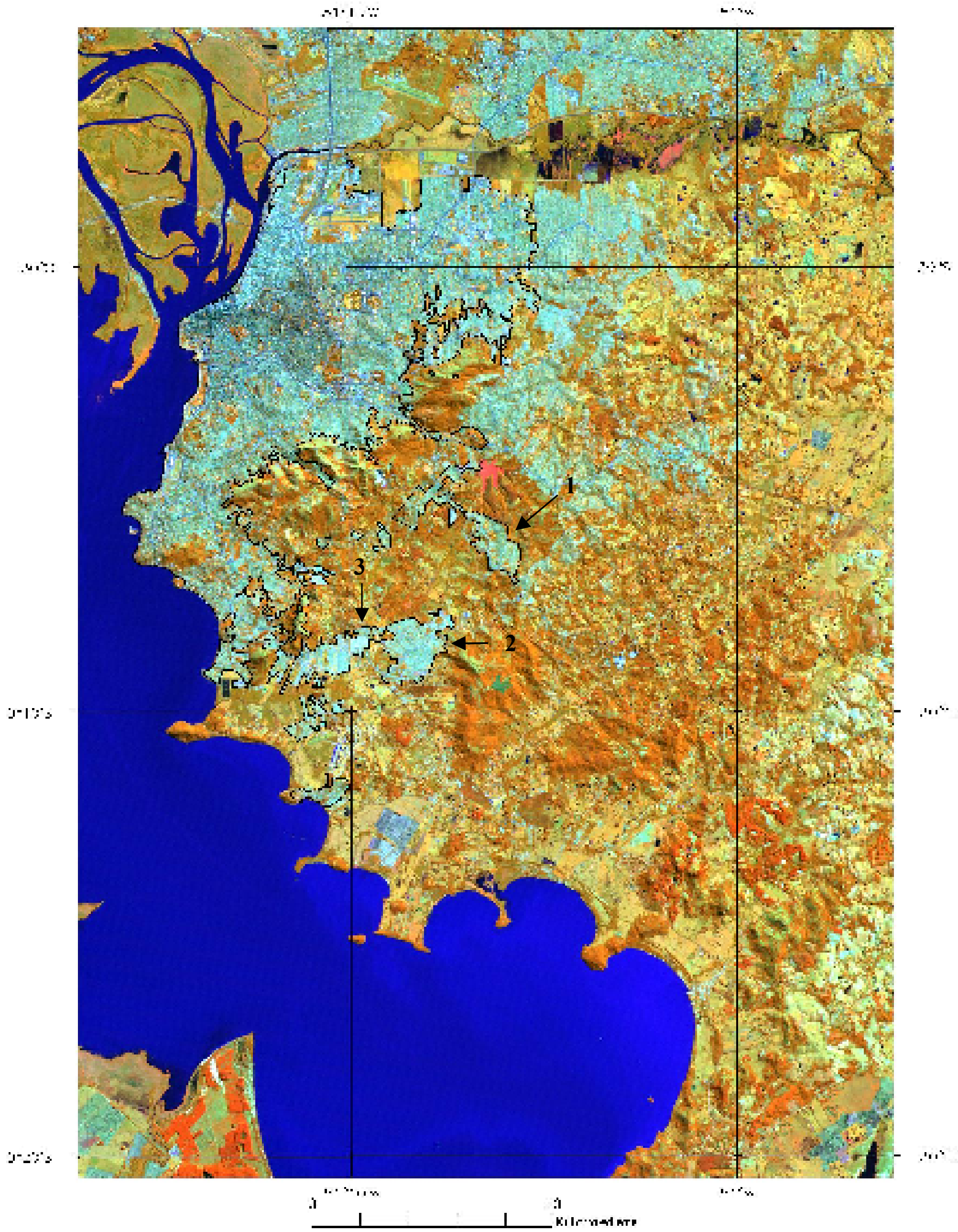


Fig. 5 – Satellite image of Porto Alegre taken by Landsat in May 5th 2011



4.*3 Traffic and mobility*

Planned demographic density for urban centres can be seen as contradictory. It gives opportunities to people change behaviors in terms of mobility, increasing the use of walking, cycling and public transportation. Nevertheless, with bad public services provision and unplanned public transportation, demographic density can maybe trigger more problems than solved intended ones. It is well documented the harmful externalities vehicle emissions can bring to public health [21, 55]. On road emissions contributes for

23% of the total emissions around the world, according [10]. Besides, traffic injuries are the second cause of death in young people all over the world (ages from 5 to 29) [10].

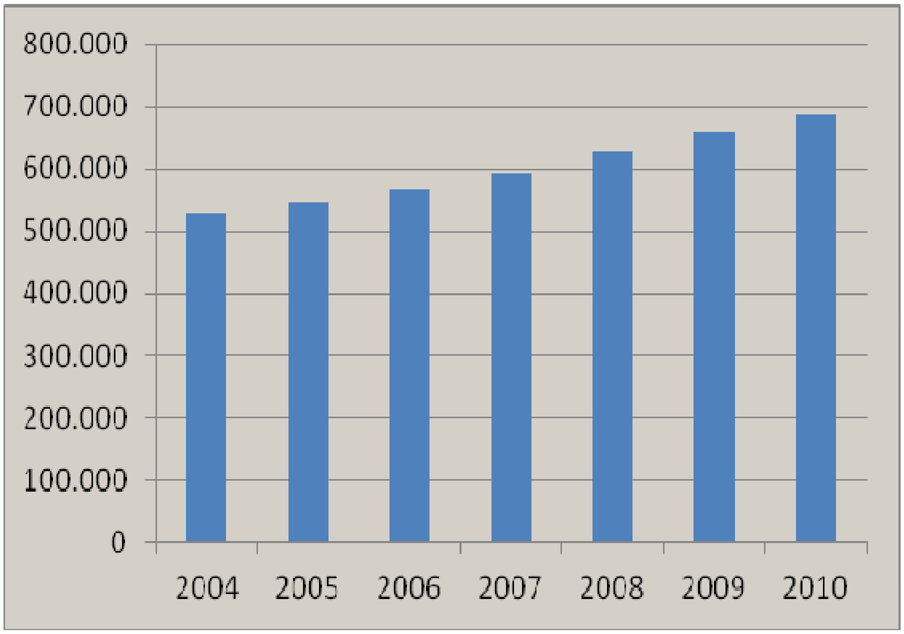
So, impacts of transportation systems in cities' emissions depend on models adopted in each area. According [20: 10], "the relationship between urban areas and climate change has been relatively less explored than other areas of research on global warming". Few are known about the consequences of public policies addressed to encourage clean transportation [19:1]: "Aside from injury reduction measures, there is very little empirical data on the impact of road transport interventions". While building accounts for 7.9% of the global average of greenhouse gases emissions, transportation is responsible for 13.1% [20].

Porto Alegre, as any Brazilian metropolis, experiences increasing traffic bottlenecks. The city has 2,761 kilometers of roads for collective and individual transportation vehicles, and 722,078 vehicles in circulation [52]. It implies one car by 2.7 indwellers. Public road transportation through bus, although more or less well distributed along the city, do not offers satisfactory conditions for people to travel in. At the same time, bicycle paths comprises just 3.2 kilometers all over the city, and this extent is not continuous. In 2011, municipal administration delivered more 4.6 kilometers of bicycle paths, and the total bike path is estimated to reach 17.4 kilometers up to 2013.

Considering the costs of public transportation to people, deaths in traffic by 100 indwellers, bike pathways extension, and the ratio between individual car travels and public (bus) travels, Porto Alegre is at 7th place on the national capital ranking of urban mobility – this ranking considers now just 9 Brazilian capitals. Porto Alegre is better positioned than just two other capitals – Cuiaba and São Paulo. One of the main problems of Porto Alegre is the high rates of casualties of urban traffic – 10 deaths by 100 mil indwellers [52].

While urban road system remained practically at the same size in the last decade, vehicle fleet has increased 54.37% from 2000 to 2010 [56]. The city has 686,142 circulating vehicles – this amount considers just vehicles charted in Porto Alegre, and leaves behind the immense amount of fleet from outside – especially from Metropolitan Region – which every day goes around the city. Historically, the vehicle fleet of Porto Alegre shows an annual increase of 3% to 4%, but since 2007 this media is getting higher, as we can realize from Fig. 6.

Fig. 6 – Yearly vehicle fleet increase in Porto Alegre since 2004



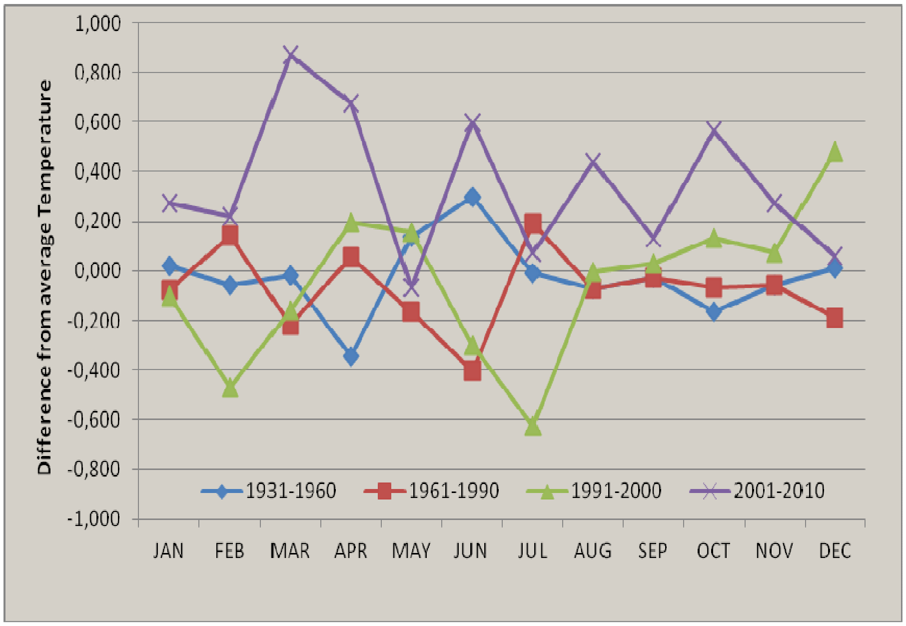
4.4 Temperatures rising: the hottest decade since the 60's

According [47], an analysis of the climate of Porto Alegre between 1930 and 2007 shows that the average of minimum temperatures has increased at the same time that the average of maximum temperatures have shown a small decrease. If we compare 1961-1990 and 1931-1960, we will find, respectively, 25ºC and 24.8ºC for the maximum average and 15.2ºC and 1.6ºC for the minimum. Linear and polynomial analyses of the average temperatures, considered along each month of the year, for 1930 to 2007, all over Rio Grande do Sul State, confirm the decrease of the differences between maximum and minimum average temperatures. Cold cores were reduced all over the State.

We analysed especially the average monthly temperatures from 1930-1960, 1961-1990 (30 years for each range), and 1991-2000, 2001-2010 (10 years for each range).

Taking in account the temperatures observed in the four time ranges (1931-1960, 1961-1990, 1991-2000 and 2001-2010), we applied the ANOVA and a multiple comparison procedure to determine which periods have shown significant differences compared with the others. Using a 0.05 significance level, statistical results show that 2001-2010 temperatures are significantly higher than those observed for 1931-1960, 1961-1990, and 1991-2010. The differences registered for the last decade are of 0,367ºC (compared with 1931-1960), of 0.417ºC (compared with 1961-1990) and of 0.392ºC (compared with 1991-2000). We can state that the last 10 years has been hotter than the 30 years comprised between 1961 and 1990, and this trend has kept practically steady in the recent decade up to 2010. Fig. 6 shows the variations of average monthly temperatures for the considered ranges.

Fig. 6 – Variations of average monthly temperatures of Porto Alegre for 1931-60, 1961-90, 1991-2000 and 2001-2010. Results expressed in ºC



5. Discussion and conclusions

Cities hold more than 50% of the global population, and this rate is expected to quickly grow in the next decades. Land use – with disorderly building and vegetation suppression – side by side to vehicles traffic, are regarded as remarkable outcomes of urbanization in developing countries, where these features are especially problematic.

Although there are not conclusive research about the direct linkage between urbanization and climate change, mainly due the difficult for translating global change models into smaller scales, several studies on urban climate change have revealed positive relations between urban land change and heating [4, 6, 17, 22, 31, 32, 33, 35, 36, 37, 38, 39, 40].

In Porto Alegre city, the Southernmost Brazilian metropolis, focus of our research, [3] found positive co-relationships between building density and temperatures rising. Analyzing side by side land change use with the aid of real estate data and satellite images across a range of 25 years (from 1986 to 2011), as well as traffic variation and average temperatures of Porto Alegre, taken from 1931 to 2010, we conclude that the pace of changing in land that underwent sprawl process kept itself almost constant since the middle of the 80's, but South areas has grown under a disorderly pattern if compared with overall. Although we have no better data for assessing densification than built unities, we can realize that the Urban and Environmental Master Plan targets, aimed at densification of Northeast and radial areas from the downtown to East, has been fulfilled but failed in the preservation of the South lands, which lacking infrastructure for supporting the burden of the fast expansion we visualize in images.

We also registered an average increase temperature of almost 0.4ºC in the last decade, compared with the ten years immediately before. Although we cannot surely state that the temperature growth is a direct outcome of urbanization phenomenon, we deem relevant to warn public authorities to take a better look to this whole set of gathered data in order to rethink the way urban Master Plan has been implemented. We consider especially the patterns of land use and mobility aspects as worthy of replanning for achieving better levels of wellbeing and social justice in the city.

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Conflict of Interest

The authors declare no conflict of interest.

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