

Population densities and real estate development on the alignment of São Paulo's Congonhas and Guarulhos airports' runways

Densidades populacionais e desenvolvimento imobiliário no alinhamento das pistas dos aeroportos de São Paulo – Congonhas e Guarulhos

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ABSTRACT

Urban development surrounding commercial airports is a conflictual factor that hampers their operations, prevents their expansion, and may lead to their closure. São Paulo has 22 million in its metropolitan area. It is served by Congonhas (Domestic) and Guarulhos (International) Airports (22 and 46 million passengers, respectively, in 2019). Congonhas is surrounded by urban development. The hypothesis of this study was to verify if a similar process is happening around Guarulhos. This study investigates population density on runway alignments and the trend of real estate development from 1985 to 2013 by using "heat maps" superposed to an "Alignment Radial Model" (ARM) comprising a central circle from 0-2 km and concentric radial rings at 2-4 km, 4-6 km, 6-8 km and 8-10 km radius. The 2010 population was computed in Census sectors within the ARM. Real estate development data of both runway-aligned and -dis-aligned was mapped in several years' periods over the ARM. Results show intense real estate development Northwest of Congonhas from 1985 to 2004, with a similar pattern the Western alignment of Guarulhos airport' runways since 2005. High population densities are noted in 2010 South of Congonhas and East of Guarulhos airports, where little or no real estate development occurred along 1985-2013, indicating informal dwellings. Evidence shows that the urban development conflicting with Congonhas airport is being replicated around Guarulhos airport, rendering both unable to expand their runways, restricting São Paulo's airports system capacity. This brings further challenges both for airport and urban planners to increasing airport capacity at São Paulo.

RESUMO

Desenvolvimento urbano no entorno de aeroportos atrapalha suas operações, impede seu crescimento e pode levar ao seu fechamento. A Região Metropolitana de São Paulo tem 22 milhões de habitantes, sendo servida pelos aeroportos de Congonhas (doméstico) e Guarulhos (internacional), com 22 e 46 milhões de passageiros, respectivamente, em 2019. Congonhas foi cercado por desenvolvimento urbano. Esse estudo objetiva verificar se um processo similar está acontecendo no entorno de Guarulhos. Investigou-se a densidade populacional nos alinhamentos das pistas e a tendência de lançamentos imobiliários de 1985 a 2013 usando "mapas de calor" superpostos a um "Modelo Radial de Alinhamento" (MRA) compreendendo um círculo central de 0-2 km e anéis concêntricos em raios de 2-4 km, 4-6 km, 6-8 km, e 8-10 km. A população censitária de 2010 teve seus setores superpostos ao MRA. Dados de desenvolvimento imobiliário foram mapeados para vários períodos de anos, alinhados e não alinhados com as pistas. Os resultados mostram que o desenvolvimento imobiliário concentrado a Noroeste de Congonhas entre 1985 e 2004 guarda similaridades com o observado a Oeste de Guarulhos desde 2005. Densidades populacionais elevadas também se notam a Sul de Congonhas e Leste de Guarulhos, onde não houve desenvolvimento imobiliário entre 1985 e 2013, indicando ocupações informais. As evidências mostram que o desenvolvimento imobiliário em conflito com Congonhas está se replicando no entorno de Guarulhos, deixando ambos incapacitados de expandir suas pistas, restringindo a expansão de capacidade aeroportuária em São Paulo. Isso traz novos desafios para planejadores urbanos e aeroportuários para expandir a capacidade aeroportuária de São Paulo.



1. INTRODUCTION AND BACKGROUND

1.1. Busy central airports

The increasing distance of new airports from the center of the cities they serve has been subject of a study in the past, both in the cases of a new airport replacing an older one, and in the cases of the new airport forming an airport system along with the original airport (Werneck de Oliveira, 2019). Many airport systems are formed by a hegemonic airport and smaller reliever and/or competing airports, such as London, Los Angeles, and Moscow. On the other hand, there are 14 airport systems in which a central airport movements more than 10 million passengers per year (MPax/y) and one or more complementing airports are less hegemonic in terms of passengers' yearly throughput, thus creating systems where the closure of one airport would probably drive the market to severe restriction. Thereby, these systems depend upon the operations of their central airports as well as the other airports on their system. Table 1 shows such systems, their cities, central and non-central airports with 2019 MPax/y compiled by the author based on airport authorities and/or country statistics sites.

Table 1: Airport Systems Depending on Central Airports and their Passenger Patronage (2019).

City	Central Airport	MPax/y	Non-Central Airport	MPax/y
Tokyo	Haneda	87.4	Narita	42.4
Shanghai	Hong Qiao	45.6	Pudong	76.2
Bangkok	Don Mueang	41.3	Suvarnabhumi	65.4
Paris	Orly	31.9	Charles De Gaulle	76.2
New York*	La Guardia	30.7	John F. Kennedy	62.3
Seoul	Gimpo	25.4	Incheon	71.2
Washington*	Reagan-National	23.2	Dulles	23.8
São Paulo	Congonhas	22.0	Guarulhos	46.2
Chicago	Midway	20.2	O'Hare	81.8
Osaka	Itami	16.5	Kansai	31.8
Dallas	Love Field	16.2	Dallas-Fort Worth	71.6
Tehran	Meharabad	14.3	Iman Khomeini	7.4
Houston	William P. Hobby	14.1	Georg Bush Intercontinental	43.8
Buenos Aires	Aeroparque Jorge. Newberry	12.3	Ezeiza-Ministro Pistarani	12.7

*New York's airport system also depends on Newark-Liberty (46.2MPax/y in 2019) and Washington's also depends on Baltimore-Thurgood Marshall (26.4MPax/y in 2019).

Out of these 14 airport systems, Tokyo and Tehran are the only ones with their non-central airports processing fewer yearly passengers than their older and more central airports. This has happened in recent years both at Buenos Aires' and at São Paulo's airports systems. Also, the airport systems of New York and Washington, DC, are formed by three airports, with the third one being rather important to tap their metropolitan markets. These systems' central airports are important players on their local markets but, as they were implemented many decades ago, their cities may have grown to surround them by urban development, hence creating conflicts with their neighbors (even if the airports got there first).

1.2. Urban planning and airports

According to Fishman (2016, p. 25) “[...] cities were never conceived of as blueprints for any actual project” (Brasília, in Brazil and Chandigarh, in India, are rare exceptions). As put by Lefèbvre (1991, p. 14), “[...] the division which keeps the various types of space away from each other [...] is far less important than the distance that separates ‘ideal’ space [...] from ‘real space’, which is the space of social practice”. Hence, cities grow as complex structures, more unplanned than planned.

Cities became metropolises with poor quality of life by the end of the 19th Century (Hall, 2016). Responses to this challenge came in the form of social rights and urban utopias. The first utopia was Ebenezer Howard’s “*Garden Cities*” – a low density neighborhood surrounded by gardens; the second, came from Le Corbusier’s “*Ville Radieuse*”, with dense high-rise buildings; the third was Frank Lloyd Wright’s “*Broadacre City*”, distancing people from each other (Fishman, 2016). These last two utopias were contemporary to the beginning of civil aviation. Two examples of naïve merging of cities and aviation are the main illustration of the “*Ville Radieuse*”, with an airfield amid high-rise buildings (Figure 1), and Fritz Lang’s movie “*Metropolis*”, based on the novel of Tea Von Harbou (2019), with biplane aircrafts flying between skyscrapers, as today’s helicopters (Figure 2).

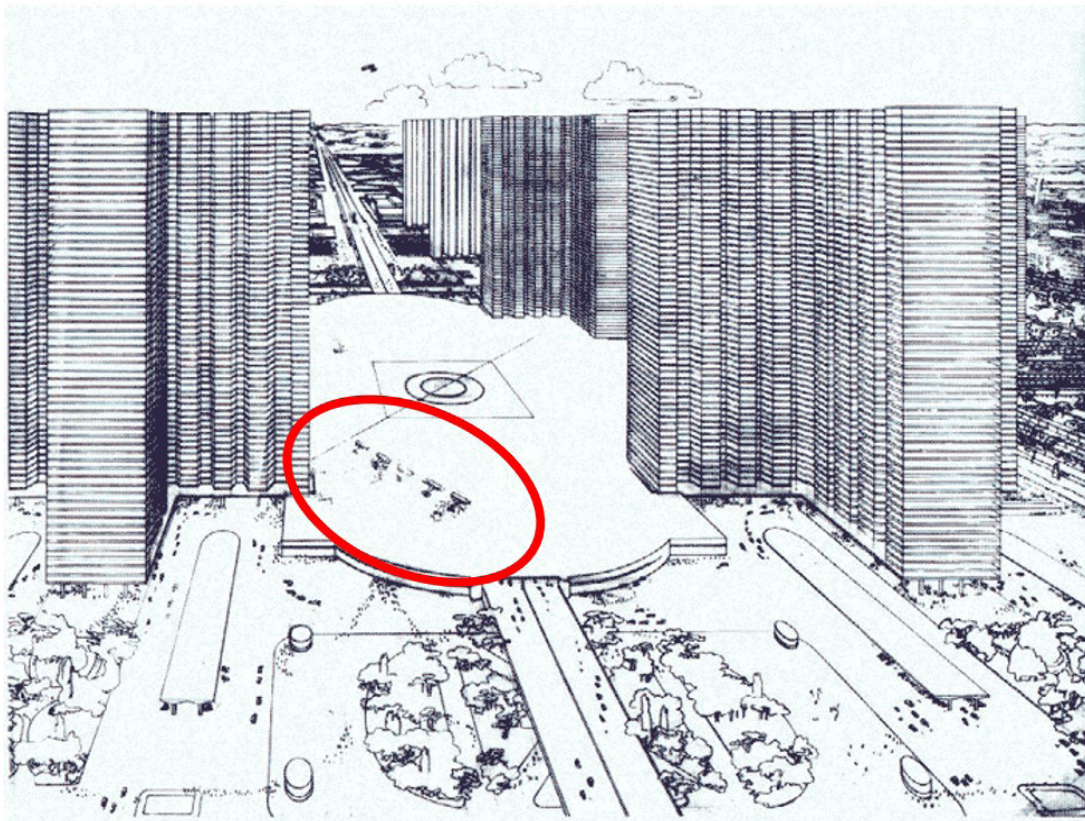


Figure 1. Illustration of Le Corbusier’s “*Ville Radieuse*”, with Aircrafts amid Skyscrapers [adapted from: Anthony, 1966].

The airports of the cradle of aviation were grass-covered circles allowing early aircrafts to land and take-off against the wind in whichever direction it was blowing (Blankenship, 1974). Soon enough, aircrafts like the Douglas DC-3 were heavier, faster, and safer, performing better in paved runways aligned with predominant winds. Early planners started worrying with the conflict of land requirements by ever-growing airports and the cities, such as the subdivisions of the rectangular townships’ system in the United States (Rau, 1930; Albers, 1940; Ascher, 1940). After World War

If the military transport surplus was made available to boost civil aviation calling for a revision of the concept of airports and their integration with urban planning (von Hausswolff, 1945). In late 1951 and early 1952 a series of accidents around Newark-Liberty airport claimed several lives – including people on the ground (ASN, 2022). An Airport Commission was formed by the United States President, and its report concluded that the main impact of airports in the coming years would be the need of much longer runways and flatter approach glides of jet aircraft rather than safety (Doolittle, Horne and Hunsaker, 1952). Many new airports were envisioned in North America and Europe, with an impending need to coordinate and integrate airport and municipal planning (Dinning, 1953).

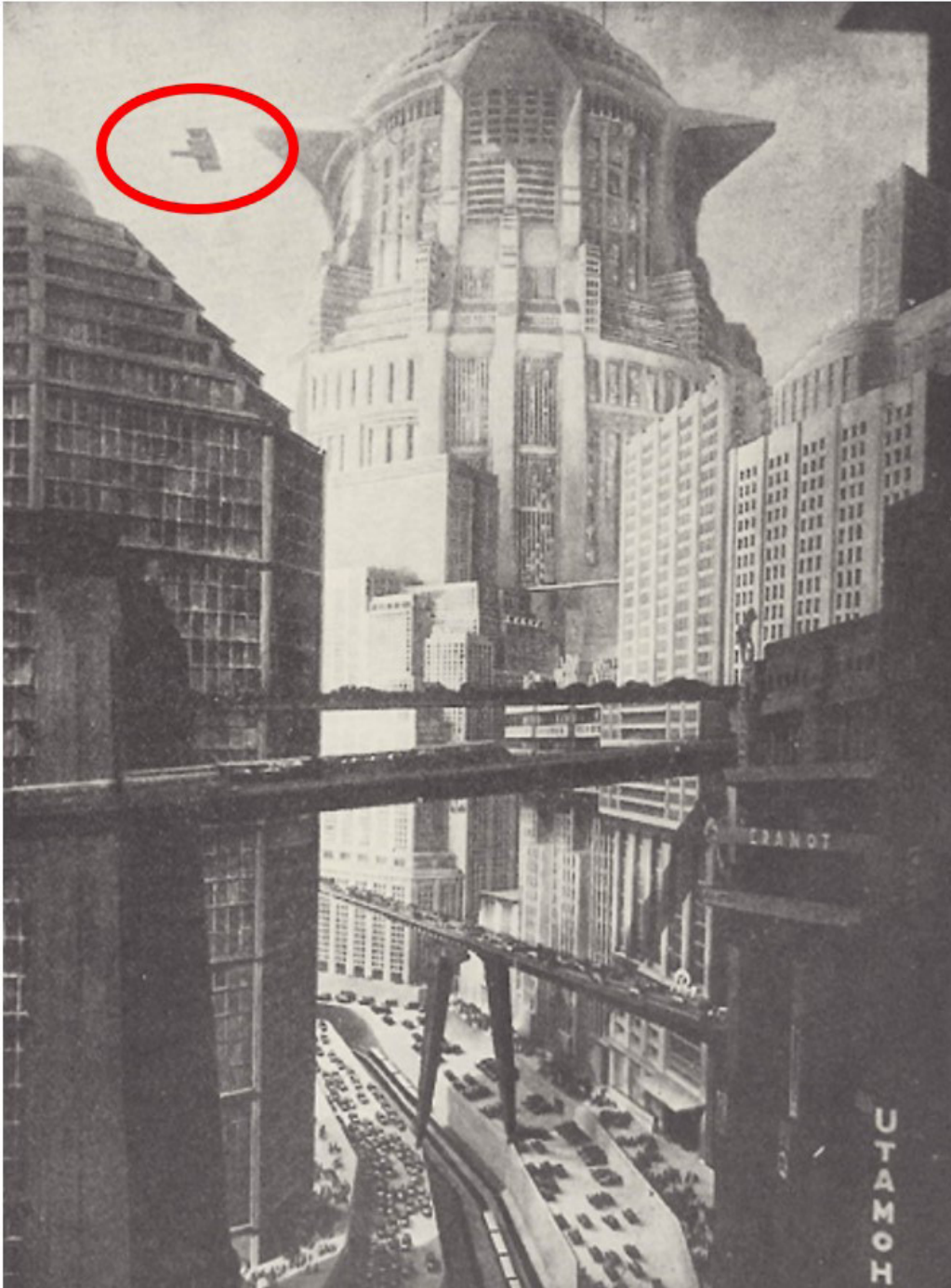


Figure 2. A Still Image from “*Metropolis*”, with an Aircraft Flying Between Skyscrapers [adapted from: von Harbou, 2019].

Several jet airports were developed serving many large cities, shedding light to the problem of noise and other airports' impacts (OECD, 1975), calling for further co-ordination with urban planning (Lichfield, 1980), which not always happened. Although airports are not magnet for money, large airports are very capital-intensive infrastructure elements (Fuller and Harley, 2004) and are important for economic development (Button and Taylor, 2000), but this is unable to suppress the conflict between airports and the cities they serve (Ayres, 2001). More recently, proposals for centering urban development around airports were presented (Güller and Güller, 2003; Kasarda and Lindsay, 2011), as well as criticized (Freestone and Baker, 2011). As airport planners influence urban planning and vice-versa, Ryerson (2016) offers a guideline of how to train planners to cope with the needs of airports (and vice-versa). As put by Fainstein and DePhilippis (2016, p. 2), "[...] planners do not just plan, and non-planners also plan".

1.3. The case of São Paulo airport system

São Paulo is the largest city in the Southern hemisphere. It has 12 million people, and its metropolitan area totals 22 million inhabitants (IBGE, 2022). The city's Gross Domestic Product (GDP) was US\$ 217 billion in 2015 (10.8% of Brazil's GDP), while the metropolitan area's GDP was US\$ 352.3 billion - 17.6% of Brazil's 2015 GDP (SEADE, 2018). Figure 3 shows a map of São Paulo's Metropolitan area with its two commercial airports.

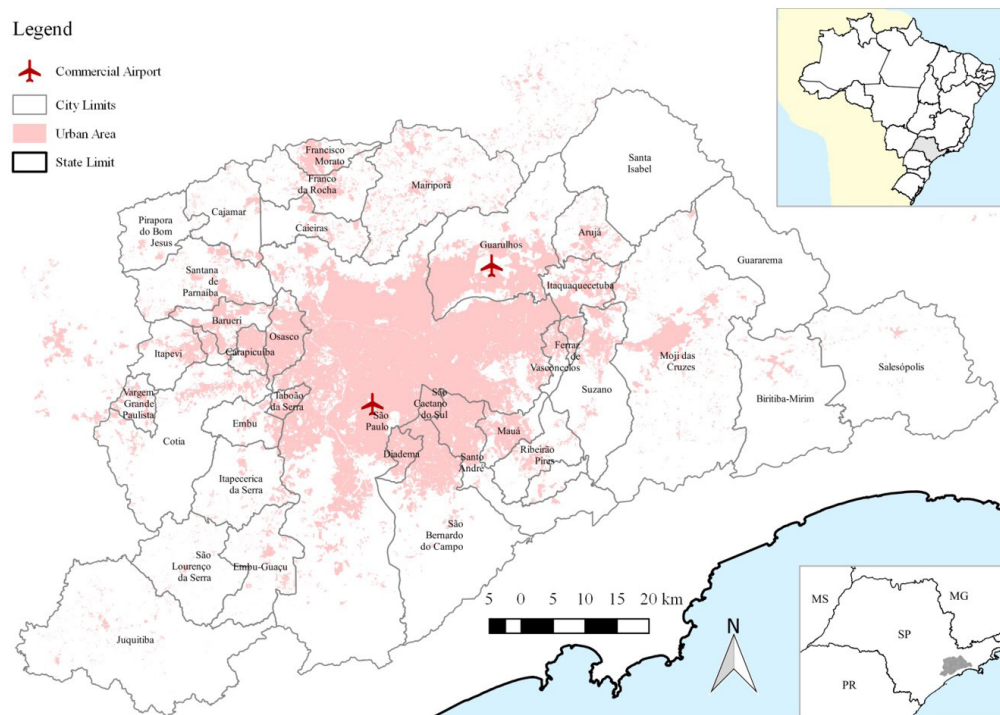


Figure 3. São Paulo Metropolitan Area and its Insertion in São Paulo State and Brazil.

São Paulo has immense social disparities: 18.9% of the metropolis' dwellers lived in slums in 2010 (IBGE, 2013). It is among the largest cities hampered by severe housing deficit (Davis, 2006). On the other hand, it hosts the world's second largest helicopter fleet, which Graham and Marvin (2001) call "the ultimate commute". On the edge of the 20th century, it was an example of a networked city for the wealthy, resulting in social exclusion (Silva, 2000) of those who Harvey (2012) calls the "disadvantaged".

São Paulo opened its first airfield – Campo de Marte – on a floodplain close to the city center – in 1920. In 1929 a severe flood had it halt operations for four months. In 1932 a revolution attempt led federal forces to bomb it, resulting on its closure until 1934. At that time, state-of-the-art aircrafts such as the Junkers-52 and the Douglas DC-3 already called for paved runways (Mello, 2006).

Due to the constant flooding of Campo de Marte, in 1936 the privately-owned “Auto-Estradas” Real Estate Development Company opened a new, public aerodrome 9 km south of the city center. This new aerodrome, named Congonhas, was located atop a mild plateau (Ab’Saber, 1975). It soon received paved runways and was accessible by a paved toll road (also owned by “Auto-Estradas”). The company also had the right to develop most of the surrounding neighborhoods (Santos, 1985). The earlier zoning ordinances treated the airport itself as an exceptional case within local zoning, as its vicinities were dedicated exclusively for residential development (Feldman, 2005). Early, dispersed industries nearby Congonhas would later be replaced by high rise buildings of *Moema* neighborhood. Therefore, 30 years after opening, Congonhas airport was surrounded by urban sprawl, mostly with residential development (Beiguelman, 1996).

As Campo de Marte was dedicated to general aviation, until World War II Congonhas processed 50,000 passengers per year in 5,000 flights. In the 1950’s, the number of passengers increased to 1.5 million per year, with 91 thousand flights in 1959. In 1981 it processed 6.2 million passengers, 134.5 thousand flights and 69 thousand tons of cargo (Mello, 2006).

The combination of its relatively short runway (1,940 meters) and high elevation (802 meters) using all the available plateau prevented larger jets to operate long-distance flights. Most international passengers from São Paulo heading abroad had to fly to Rio de Janeiro to change planes to long-distance flights there, or had to use the Campinas-Viracopos Airport, operational since 1960, but located 90 km away.

Thus, an international airport was planned for the city as Congonhas’ runways could no longer be extended. After a poorly documented (Santos, 1985) but surprisingly pluralistic debate during military ruling in Brazil (CONDEPHAAT, 1978), the site adjacent to São Paulo Air Base in the neighboring city of Guarulhos was selected for the development of the current São Paulo-Guarulhos International Airport, which opened in January 1985, 25 km Northeast of São Paulo’s city center (GRU-Airport, 2022). Nevertheless, the city continued having two airports with commercial operations, which had their traffic systematically growing over the past three decades. Figure 4 shows the evolution of increasing passengers processed by São Paulo’s two commercial airports from 1971 to 2019.

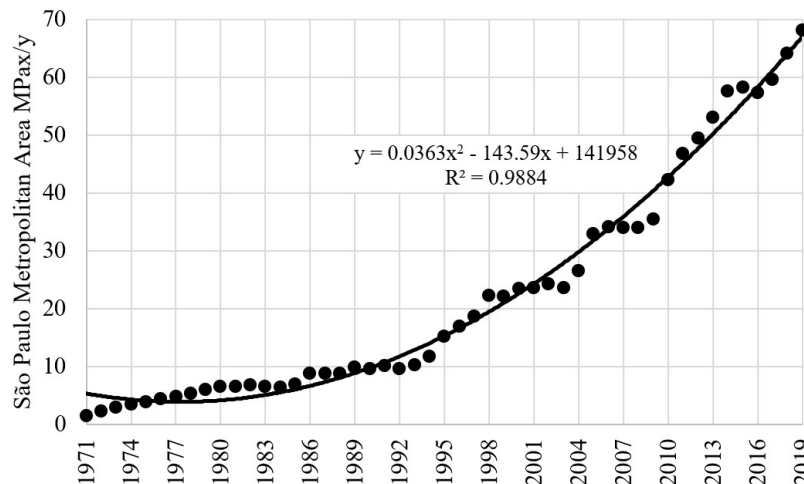


Figure 4. Passengers Processed by São Paulo’s Two Commercial Airports, 1981-2017.

It is worth noting that after the opening of Guarulhos Airport in 1985, most flights were transferred to it and Congonhas remained a rather idle regional airport for a few years. However, domestic flights to/from Congonhas were soon again scheduled to nearly all Brazilian major cities, allowing passengers flying from South to North or Northeast of the country changing planes at Congonhas instead of Guarulhos. As a result, from this domestic hub-like structure at Congonhas rather than at Guarulhos, from 2001 to 2007, the former’s throughput surpassed that of the latter. Figure 5 shows the evolution of passengers processed by both airports from 1971 to 2019 (1985 to 2019 for Guarulhos airport).

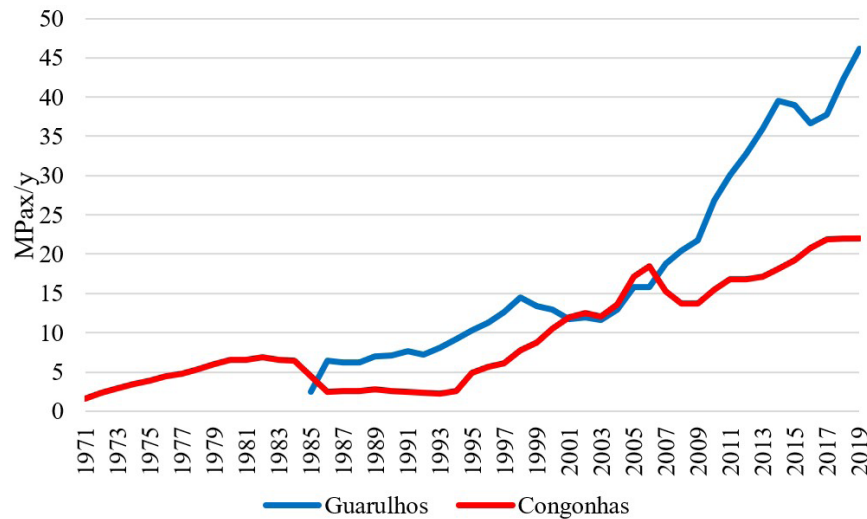


Figure 5. Passengers Processed by São Paulo’s Congonhas and Guarulhos Airports, 1981-2017.

On July 17, 2007, a fully loaded and fueled Airbus A-320 overshot Congonhas’ wet and slippery, recently resurfaced runway when landing and crashed onto a building adjacent to the airport, claiming the lives of 187 people on board and 12 on the ground (ASN, 2022). This led to new restrictions regarding the use of the runway length, maximum payload, with the prohibition of connections and long-distance domestic flights to/from Congonhas. Thus, several mid- and long-range flights to/from São Paulo area were moved to Guarulhos Airport.

During Brazil’s civil aviation growth period from 2004 to 2013 Guarulhos Airport took the lion’s share in São Paulo’s area while Congonhas maintained growth at lower pace. Due to the Brazilian economic demise since 2015, however, Guarulhos’ patronage literally diminished, while Congonhas was the country’s only airport recording yearly growths.

Brazil’s economy recovered slightly in the following years, and aviation kept growing, especially the passenger and aircraft movements of São Paulo’s airports. While experiencing economic and airports’ patronage growth, real estate development in the cities they serve also grew. The impact of the Sars-Cov-2 (COVID-19) Pandemics from April 2020 onwards was devastating to most airports in the world but both Congonhas and Guarulhos airports have practically recovered the pre-pandemics levels of passenger’s patronage.

Given that Congonhas airport was built in order to boost sales of urban plots around it, the main objective of this study was to evaluate if indeed a culture of building residences around airports has been established in São Paulo, by comparing commercial real estate development indicators with formal and informal self-construction and shanty towns (slums) both in the alignment and off from the alignment of São Paulo’s two Commercial airports – Congonhas and Guarulhos International.

2. METHODOLOGY

For São Paulo's Congonhas and Guarulhos airports, population densities both in their runways' alignment and off from it were surveyed based on the Brazilian 2010 (most recent currently available) official Census (IBGE, 2010). The evolution of new housing, real estate development set for sale from 1985 to 2013 was based on a database by the Center for Studies of the Metropolis (CEM, 2018). Such data does not include self-constructed houses nor shanty or even brick-built subnormal slums which housed 18.9% of the metropolitan population in 2010 (IBGE, 2013).

Mapping was applied around São Paulo's Congonhas (central) and Guarulhos International (non-central) airports' sites. It was decided not to map the city's general aviation airport (Campo de Marte) due to its relatively smaller size and its relative proximity with both Congonhas and Guarulhos airports.

For the mapping, an Alignment Radial Model (ARM) was developed and applied, evolving from a previous methodological test (Werneck de Oliveira, 2018) but employing Geographical Information Systems (GIS) tools and considering runway alignment, as aviation's main negative impact – aircraft noise – is more linear along flight paths than radial. Hence, the ARM was phased on a 45° angle from the runway alignment, thus forming two “bowtie” shapes: one set (two quarter of circles) aligned to the runways (both headings); the other set (two converse quarter-circles) dis-aligned (sideways) to the runways.

Off from the center of each airport site a series of concentric circles were drawn at every 2 km, from the center up to 10 km (named “rings” R1 to R5). Each circle and/or ring was divided in 3.14 km² “iso-areas”. The inner circle/first ring (0-2 km) has 4 “iso-areas”, the second ring (2-4 km) has 12, the third ring (4-6 km) has 20, the fourth ring (6-8 km) has 28, and the fifth and last, outer ring (8-10 km) has 36 “iso-areas”.

This totaled 100 “iso-areas” or sectors with 3.14 km² for each airport, half aligned to their runway headings and half sideways to it. Congonhas' runways current headings are 17/35 and Guarulhos' are 09/27. Both airports have two parallel runways, but too close to each other, not allowing independent and/or simultaneous operations. The ARMs were thereby centered amid their runways, in their mid-point.

Brazilian Civil Aviation Regulation (RBAC) #161 (ANAC, 2019) suggests a buffer “area of influence” where noise levels up to 75 dB and 65 dB are tolerated and hence indicate compatible and non-compatible land uses within them. This was, however, dropped as this regulation includes somewhat small areas within noise restrictions (*e.g.*, less than 1 km from each runway end for 65dB). The same regulation requires the development of “Specific Noise Zoning Plan” (PEZR in Portuguese) for Brazil's busiest airports, including Congonhas and Guarulhos. Both developed their noise contours in 2019, but neither employ continuous noise monitoring. As the focus herein is to evaluate how formal real estate urban development has evolved both on the alignment and off-alignment of these airports' runways, the number of people living within these areas under 75 dB and 65 dB was not quantified.

Specific layers were developed on Geographical Information Systems (GIS) software (ArcGIS version 12 for “cuts and joins” and QGIS version 2.18.21 for mapping) using SIRGAS 2000 (UTM23S) reference for the airports' site limits, their runways' alignment, their coordinates in latitude and longitude, and the ARMs with the “iso-areas”.

Geo-referenced data from the Brazilian Population Census of 2010 - population per Census District (IBGE, 2010) generated another layer, while data from the CEM (2018) regarding new residential market real estate development from 1985 to 2013 generated yet another layer (weighted for

total residential units rather than for total enterprises set for sale in the market, as these include many high-rise buildings, with multi-family residential units in one enterprise). Unfortunately, no similar georeferenced data from 2014 onwards has been published.

The number of residential units set for sale in the market was grouped and analyzed using dynamic tables' tool at MS Excel® spreadsheets with binary coding (1 = aligned; 0 = dis-aligned to runways). It is friendlier and faster to group data in the aligned and dis-aligned "iso-areas", allowing faster decision-making for the mapping. Real estate development data were gathered in periods as follows: 1985-1989, 1990-1994, 1995-1999, 2000-2004, 2005-2009, and 2010-2013 (the only group with 4 years instead of 5).

Finally, to illustrate the evolution of new residential units set for sale by real estate developers along these quasi-five-year periods and how they geographically distribute between the surroundings of Congonhas and Guarulhos airports, the ARM was superposed to the heat maps which weighted the number of total residential units year by year, gathered in these periods, with a buffer rendering of 3 km from the densest points of the geo-referenced residential enterprises. They were classified in five density levels, arbitrarily defined for the purposes of providing visually friendlier maps.

3. RESULTS

Figure 6 shows the yearly distribution of number of residential enterprises and residential units reaching the market from 1985 to 2013, showing often coinciding peaks and valleys. The average number of residential units per enterprise is 57.07, with a Standard Deviation of 11.69 units.

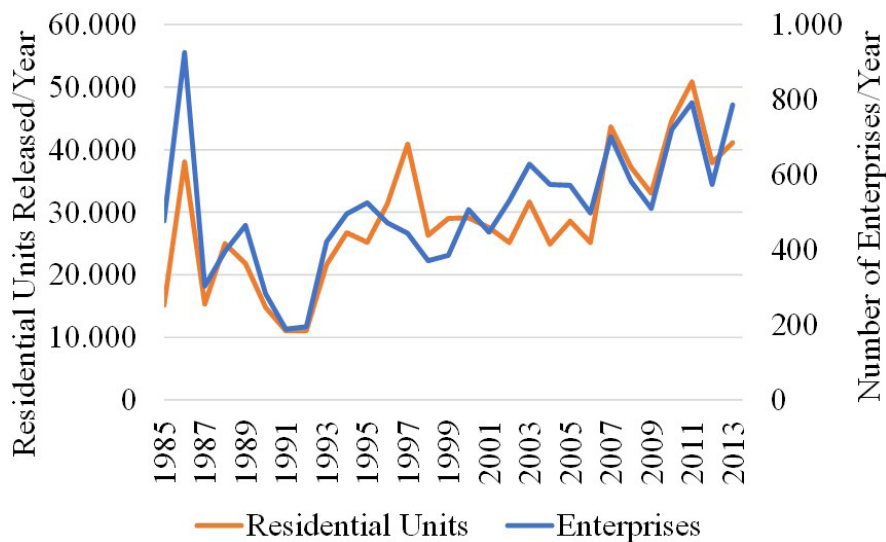


Figure 6. Annual Evolution of New Residential Enterprises and Units in São Paulo's Two Airport's Influence Areas, 1985-2013.

The overlay of the ARM and population density data from official Census (IBGE, 2010) allows verifying if this variable depends on the runway alignments of these two airports. These overlays are illustrated in Figure 7, which shows the densities of the Census' Districts (practically always smaller than the "iso-areas", thereby resulting quite high density peak-values often surpassing 200 inhabitants per hectare).

The aligned and dis-aligned "bowties" and the ARM shows how population density varies with runway alignment and distance (0-10km) from each airport site center, by "iso-areas"

and Census Districts. In the case of Congonhas, high population densities are observed on both headings of the runways, with more isolated spots in the Northwest than in the Southeast (where a park larger than the airport site is an empty exception), whereas dis-aligned to the runways, higher population densities are verified in the Northeast and in the far Southwest of the airport. In the case of Guarulhos airport, high density population is observed West of the airport site, with more isolated high density areas East of the site, both aligned to the airport's runways. Dis-aligned from the runways, on the other hand, the population densities vary significantly: São Paulo's municipality East-end form a very densely populated continuum South of the airport, while the Cantareira hills prevent high density urban development towards North of the airport site.

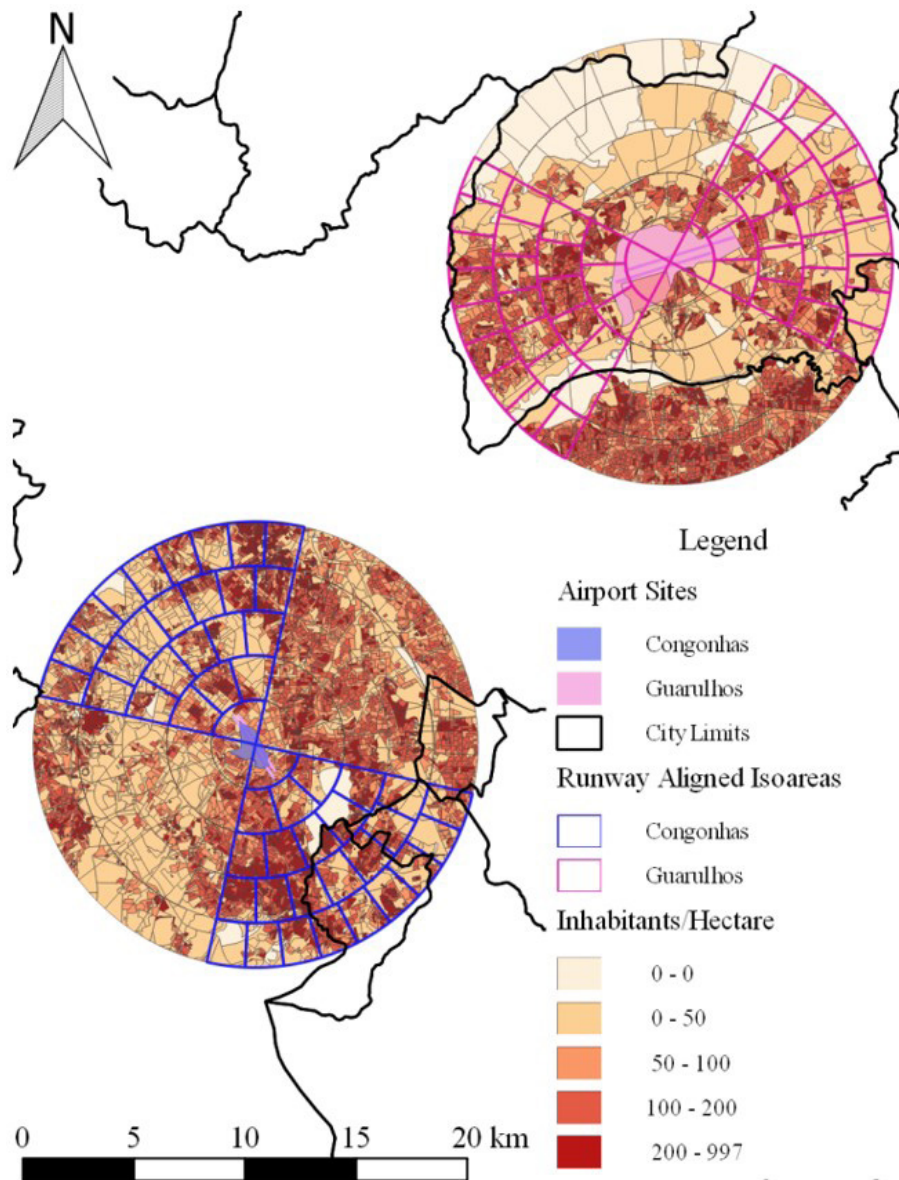


Figure 7. Overlay of ARM and Population Densities per Census Districts Aligned and Dis-Aligned with Congonhas and Guarulhos Airports' Runways.

The other variable herein studied – the number of new residential units (houses and/or apartments) set for sale on the local market from 1985 to 2013 – has its overall statistics shown

in Table 2. In this period, approximately half a million (495,087) new dwellings were built and set for sale on the local real estate market within a 10 km-radius influenced by São Paulo’s two commercial airports (85% around Congonhas and 15% around Guarulhos Airport).

Table 2: Number of New Residential Units (Houses and Apartments) Built and Set for Sale in the Market within the 10 km Radius from São Paulo’s Commercial Airports, 1985-2013.

Airport	Runway	Distance from City Center	Period						Total
			1985-1989	1990-1994	1995-1999	2000-2004	2005-2009	2010-2013	
Congonhas	Aligned	R1 0-2 km	2,140	705	833	801	1,566	745	6,790
		R2 2-4 km	10,103	6,086	8,086	7,017	4,978	6,101	42,371
		R3 4-6 km	6,413	5,151	8,360	7,058	5,363	6,386	38,731
		R4 6-8 km	8,379	4,180	11,327	9,445	6,349	5,515	45,195
		R5 8-10 km	7,457	5,397	8,747	8,384	8,570	13,350	51,905
		Subtotal	34,492	21,519	37,353	32,705	26,826	32,097	184,992
	Dis-Aligned	R1 0-2 km	1,522	1,014	2,142	1,106	2,166	2,350	10,300
		R2 2-4 km	6,211	4,470	6,418	6,514	5,870	6,604	36,087
		R3 4-6 km	8,872	6,899	10,919	10,356	13,184	9,041	59,271
		R4 6-8 km	4,856	4,731	9,308	8,265	17,612	10,597	55,369
		R5 8-10 km	8,334	7,230	9,508	12,308	15,570	22,136	75,086
Subtotal		29,795	24,344	38,295	38,549	54,402	50,728	236,113	
Congonhas Total			64,287	45,863	75,648	71,254	81,228	82,825	421,105
Guarulhos	Aligned	R1 0-2 km	0	0	0	0	0	0	0
		R2 2-4 km	0	0	244	188	500	370	1,302
		R3 4-6 km	512	414	4,827	2,206	2,794	3,601	14,354
		R4 6-8 km	994	562	2,738	2,277	5,572	10,140	22,283
		R5 8-10 km	380	1,282	2,291	2,702	4,073	9,538	20,266
		Subtotal	1,886	2,258	10,100	7,373	12,939	23,649	58,205
	Dis-Aligned	R1 0-2 km	0	112	512	0	0	0	624
R2 2-4 km		0	0	68	198	0	0	266	
R3 4-6 km		0	0	0	0	29	1,002	1,031	
R4 6-8 km		0	239	1,648	819	722	889	4,317	
R5 8-10 km		418	949	3,049	1,182	1,810	2,131	9,539	
Subtotal		418	1,300	5,277	2,199	2,561	4,022	15,777	
Guarulhos Total			2,304	3,558	15,377	9,572	15,500	27,671	73,982
Grand Total			66,591	49,421	91,025	80,826	96,728	110,496	495,087

Figure 8 shows the series of heat maps illustrating how the number of new residential units set for sale by real estate developers evolved along the several quasi-five-year periods, and how they geographically distribute along the surroundings of Congonhas and Guarulhos airports, considering the “bowties” aligned and dis-aligned with their respective runways within the ARM.

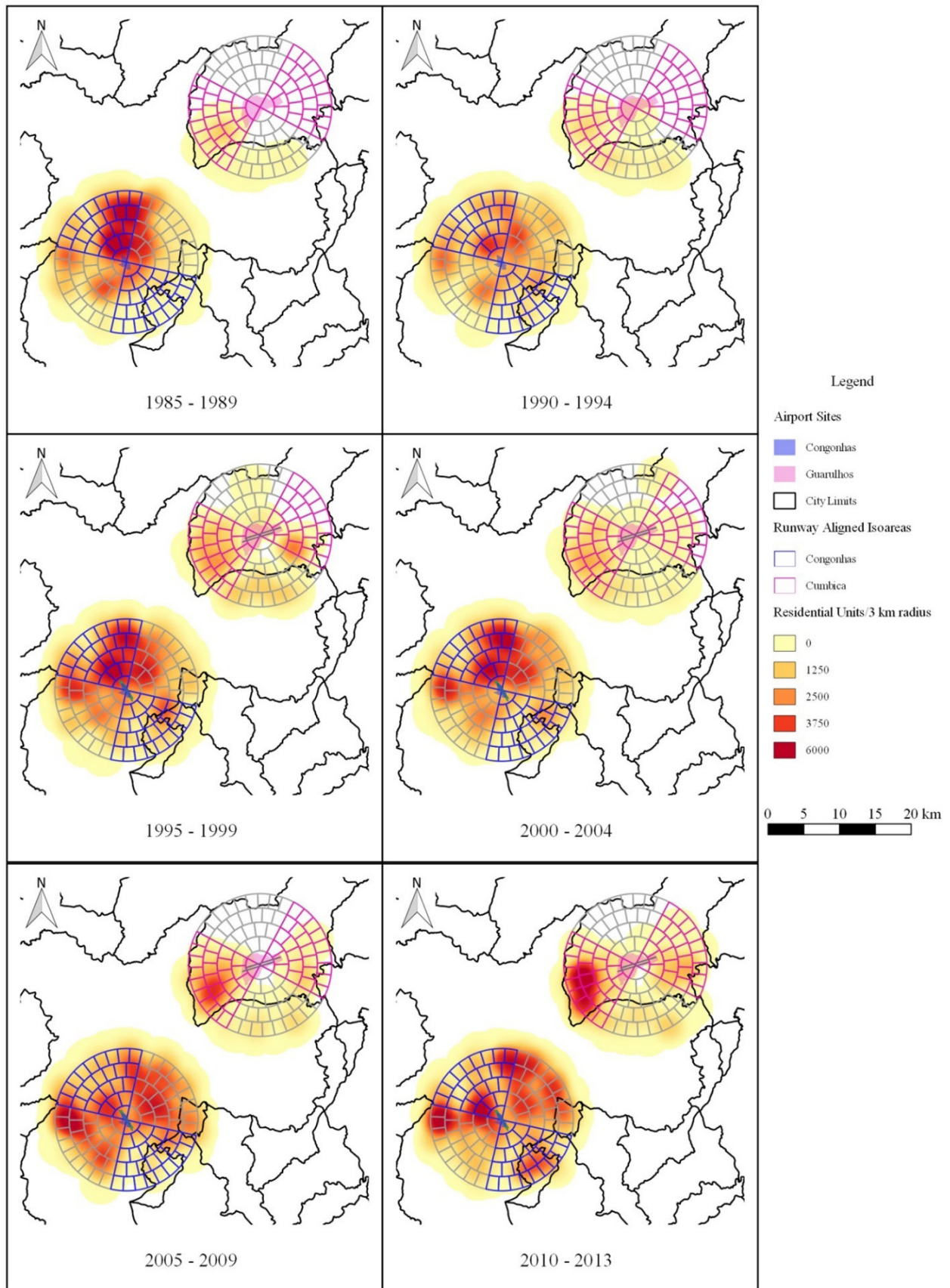


Figure 8. Evolution of Heat Maps of New Residential Units (5-year Periods) Overlay to the ARM for São Paulo’s Congonhas (Central) and Guarulhos (Non-Central) Airports.

4. DISCUSSION

It is noteworthy that this data refers to real estate developers and does not include self-construction, neither in normal, urbanized urban plots by privateers, or self-construction of new shacks in slums. Formal real estate development concentrates on the central alignments of the runways of both airports (São Paulo's city center is North of Congonhas airport and Guarulhos city center is West of Guarulhos airport).

It is also important to note that there are high population densities on the peripheral alignments of both airports' runways (Southeast of Congonhas and East of Guarulhos) but, as these do not coincide with formal real estate developments shown on Table 2 and Figure 8, the evidence showing that these areas were densely populated in 2010 (see Figure 7) and simultaneously having nearly no commercial real estate development since 1985 throughout 2013 indicate the presence of informal and eventually subnormal dwellings (slums) rather than "normal" houses in both these more peripheral runway alignments.

The population density within the 3.14 km² "iso-areas" show dense areas aligned with Congonhas' runways (Figure 7). There is a dense "iso-area" just 2-4 km Northwest of the runway, which is due to vertical, multiple-stories buildings in *Moema* neighborhood, while in the South, the higher density reflects intense partitioning of plots into small areas for single- or multi-familiar sub-normal housing, often in self-constructed shacks in slums or shantytowns from 2 km to 6 km south of Congonhas airport. Evidence shows that low-income subnormal areas develop over smaller and more fractioned land plots, thus resulting higher population densities than formal real estate development, even when verticalized in blocks of multi-stories buildings. The dense "iso-areas" 6-10 km North of Congonhas coincide with vertical housing development in the expanded city center, surrounding "Paulista Avenue", which spreads towards East (into the "bowtie" dis-aligned with Congonhas' runways) in lower densities. Both shown smaller densities than the South of Congonhas' runways.

Guarulhos Airport neighborhood has low density within 2-4 km aligned with its runways because its site is significantly larger than Congonhas'. West of the runway, though, there is a high-density "iso-area" due to slums, close to Guarulhos' city center, where moderate densities were observed in 2010. East of the runway there are low to medium density "iso-areas" due to urban segmentation caused by the airport itself. The higher density "iso-areas" in the south (dis-aligned to the runways, 6-8 km, and 8-10 km radius) are due to a mix of slums and vertical urban development in West-end of São Paulo – a clear urban expansion area (unrelated to the airports). North of Guarulhos airport site lays an environmentally protected area ("Serra da Cantareira" forested hills) not yet encroached by urban development – but threatened by urban expansion with subnormal housing of low-income families.

Regarding the heat maps (Figure 8), it is noteworthy that Congonhas' Northwest runway alignment had much more residential development built and set for sale from 1985 to 2004. The period from 1990 to 1994 coincides with a hyperinflation period in Brazil, when real estate industry was severely impacted. Along these multi-year intervals, there was very little real estate development on either runway headings of Guarulhos airport's runways. On more recent analytical periods of 2005-2009 and 2010-2013 however, formal real estate development spreads off from the alignments of Congonhas airport, with densest areas moving towards West, East, and North of the airport site, although with some heat remaining precisely within the 2-4 km and 4-6 km Northwest alignment of its runways. Strikingly, while there was very few real estate development set for sale within either alignments of Guarulhos airport's runways until 2004, these two more recent periods (2005-2009 and 2010-2013) show a fairly intense growth of formal real estate development West-Southwest from the airport site, coinciding both with the center of Guarulhos municipality but as well as with this airport's

alignment of runways 09-27, reproducing the conflictual fate of the neighborhood relations that in the past started limiting Congonhas airport ability to expand its capacity.

5. CONCLUSIONS

The use of the ARM suits the purposes of this study to allow visualizing land use up to 10 km radius from the airports' centers as evidence shows for both Congonhas and Guarulhos airports, in São Paulo, Brazil. It is a clear means to compare densities and heat maps of new housing development aligned and dis-aligned to the airports' runways. Imaginary straight lines from the runways allows considering fully and moderately aligned "iso areas", providing subsidies for air traffic controllers to develop Noise Abatement Departure Procedures (NADP) in optimized routes (although every route out of Congonhas airport flies overpopulated areas). It also contributes for urban planners to better regulate zoning in order to prevent increasing residential densities in noise-sensitive areas aligned with these large airports' runways.

Evidence shows that an urban sprawl process very similar to that which surrounded São Paulo's older and more central Congonhas airport was being replicated at the vicinities of newer and more peripheral Guarulhos international airport from 2005 to 2013, when such data availability ceased.

Evidence supporting such finding is two-fold. First, from mapping the evolution of formal real estate development illustrated by consecutive quasi-five-years periods with heat maps, especially towards cities' centers alignments of both airports' runways (Figure 8). Second, from mapping population densities based on the 2010 Census indicating high population densities also at the opposite runway alignments towards the peripheral areas of São Paulo and Guarulhos municipalities, where self-constructed and eventually subnormal urban development predominates (Figure 7).

On one hand, this obviously prevents both airports to expand their runways (Guarulhos airport master plan anticipated the construction of a third runway, but since the turn of the century this is considered not feasible from social point of view, as it would require the involuntary resettlement of no less than five thousand families). On the other hand, allowing continuous augmentation of population densities aligned with these airports runways tends to fuel more conflict, as the number of people affected by aircraft noise increases substantially. Thereby, such evidence indicates that the conflictual fate around Congonhas airport may well be replicated around Guarulhos international airport, putting additional challenges both for airport operators and for city planners at São Paulo and Guarulhos municipalities, eventually limiting the prospects of capacity expansion of the São Paulo Metropolitan Area airports. Expanding the survey to newer-than-2013 data (unfortunately so far unpublished) could reinforce this conclusion.

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