3D MODELING TO IDENTIFY AND QUANTIFY OBSTACLES IN AERODROME PROTECTION ZONE

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Abstract:

Aerodromes protection zones are defined by plans that are determined by three-dimensional (3D) limiting surfaces, which establish the airspace that must remain clear of obstacles, imposing some restrictions on land use. The objective of this paper is to generate 3D models of the surrounding area of Salgado Filho International Airport, considering the constructive altimetric limit established in the Aerodrome Protection Zone Basic Plan (PBZPA), to identify and quantify obstacles related to plots (urban land parcels) and buildings. The adopted methodology includes the analysis and selection of geospatial data, data modeling and performing spatial analysis on the generated 3D models. The results showed that out of a total of 106,838 plots, covering an area of 69.68 km², 4,826 plots (4.52%) exceeded the limiting surface and 1,054 plots (0.99%) represent critical areas where constructions may not be allowed. And, out of a total of 200,573 buildings, 26,418 of them (13.17%) exceeded the limit imposed by PBZPA's. Also, the methodology is valid for detecting and quantifying critical areas concerning the constructive viability of the plots, affected areas regarding the height of the plots and buildings, and for identifying obstacles to aerodromes according to their respective airspace laws.

Keywords: 3D Models; Obstacles; Aerodrome Protection Zone

1. Introduction

Mapping of aerodrome protection zones is necessary for urban planning and the economy of cities, as well as for the safety of the population living there. Violations of these protection zones represent highly complex problems as they may impede the expansion of aerodromes, limit the size of aircraft allowed to operate at them and also limit the provision of passenger seats and cargo hold space in the basements (Santos and Müller, 2014).

Aerodrome protection zones are defined by general, specific or basic plans. The set of three-dimensional (3D) imaginary surfaces established by the Aerodrome Protection Zone Basic Plan (PBZPA) delimits and establishes the airspace that must remain clear of obstacles, imposing restrictions on the land use within the aerodrome protection zone. These imaginary surfaces set the boundaries that objects can project into airspace without adversely affecting the safety and regularity of air operations (Brasil, 2015). The dimensions (width, distance, opening, length, gradient, radius) and elevations (related to aerodrome's height) of PBZPA's limiting surfaces are defined regarding the aerodrome's reference code, and can be seen on Table 3-4 of Ordinance No. 957/GC3 of the Air Force Command. The interpretation of PBZPA surfaces associated with the constructive limit established by the urban planning of the city results in land use and occupation issue. This issue can be assessed through spatial analysis that allows the visualization and detection of critical and obstructed areas, serving as a basis for decisions regarding the management of land use and occupation around the aerodrome.

Several kinds of research have been conducted to develop methodologies to identify obstacles to airports. Audu (2016) highlights that safety is an absolute prerequisite in air transport. The safety of aircraft near an aerodrome during the approach, takeoff and taxiing is a critical issue of great importance in flight operations. The correct identification of obstacles around airports is an important issue to ensure the safe takeoff and landing of aircraft (Pinelli and Veracini, 2015). About aviation safety, these authors evaluated the risk of obstacles and risk-mitigating operations and presented a methodology for detecting changes using orthorectified pairs of high-resolution multispectral satellite images acquired from the same geographical area and at different times. Parrish and Nowak (2009) developed and tested a methodology for detecting airport obstacles using LIDAR technology. The authors focused on improving the detection of vertical objects using full-waveform LIDAR data and on the efficiency of the airport obstacle identification process. The analyzes performed to verify the possible densification of the point cloud using the full-waveform data showed a 252% increase in the average number of points for the objects. As a result of the proposed methodology, the authors achieved 46% and 38% reductions, respectively, in computational processing time for obstacle identification and human time spent on manual analysis, compared to previous obstacle identifications using LIDAR data made by the National Geodetic Survey. Panayotov (2009) developed methods for high-resolution airspace modeling, proposing an approach to the development and generation of pseudo-3D models for airspace analysis. The proposed methodology, called the GIS-based Airspace Analysis Model (GAAM), allowed the automation and simplification of various airspaces analysis with the possibility of 3D visualization of the results. GAAM provided a 3D geometric interpretation of the Federal Aviation Administration (FAA) - Federal Aviation Regulation Part 77 - allowing the fast and accurate calculation of the 3D airspace set by FAA regulations. Wang, Hu and Tao (2004) presented a methodology to identify aerodrome obstacles through LIDAR data processing and model risks. Such modeling classifies obstacles into three risk levels by combining four risk factors into a multi-criteria evaluation to assist decision-making in managing aerodrome obstacles. As a result of this study it is presented in a risk rating map showing the high, medium and low-risk obstacles. Iescheck and Oliveira (2011) proposed a Geographic Information System (GIS) for zoning land use and occupation of the area around Salgado Filho International Airport. The purpose of this GIS was to enable rapid analyzes of the technical feasibility of construction projects in accordance with the limitations established by the Aerodrome Protection Zone Specific Plan (PEZPA).

In 2015, all PEZPA were revoked by the Airspace Control Department (DECEA) and replaced by the PBZPA, according to Ordinance No. 957/GC3 of the Air Force Command. Also, there was a reformulation of the Urban and

Environmental Development Master Plan of the municipality of Porto Alegre and a photogrammetric and LIDAR aerial survey of the municipality provided more accurate and up-to-date geospatial data. These changes in the legal aspects regarding the aerodrome protection zone and the municipal master plan, together with the new accurate geospatial information, motivated us to improve this research.

Therefore, the objective of this paper is to generate 3D models of the surrounding area of Salgado Filho International Airport, considering the constructive height limit established in the PBZPA, to identify and quantify obstacles related to plots (urban land parcels) and buildings. The adopted methodology includes the analysis and selection of geospatial data, data modeling and performing spatial analysis. The innovation of this paper about the others is that besides identifying, the obstacles were quantified in terms of area and quantities involved. These obstacles correspond to areas of plots and buildings and areas considered critical, where constructions are not allowed. Also, it should be noted that the methodology employed is valid for any airport and any airspace legislation.

2. Study Area

The study area of this paper (Figure 1) comprises the northern zone of Porto Alegre, capital of the state of Rio Grande do Sul, and is limited by latitudes 29˚58'S and 30˚02'S and longitudes 51˚05'W and 51 ˚15'W. This region covers an extension of 127.57 km², which represents 27.04% of the area of the municipality. According to the 2010 census, there are 146,211 households and a population of 411,847 inhabitants in the region, which corresponds to 29.22% of the population of the municipality (ObservaPoa, 2016).
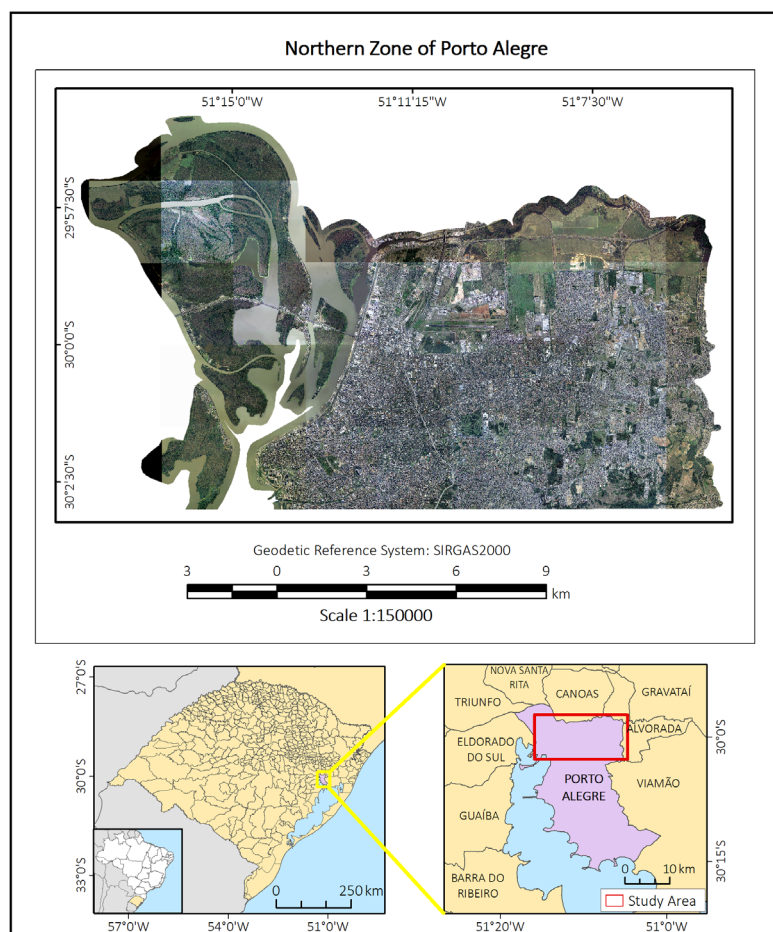

Figure 1: Location of the study area.

3. Methodology

The methodology of this work was divided into three stages. The first stage consisted of the analysis and selection of geospatial data at the Porto Alegre City Hall (PMPA). In the second stage, concerning the modeling of geospatial data, the digital model of the PBZPA was elaborated and the altimetric information was attributed to the plots and buildings. And in the third stage, spatial analysis, the airspace obstacles were identified and quantified by comparing the heights of the plots and buildings with the limiting surfaces of the PBZPA. This research was developed with ESRI ArcGIS software, version 10.0, along with the 3D Analyst and Spatial Analyst extensions. Figure 2 illustrates the flowchart of the methodology steps.
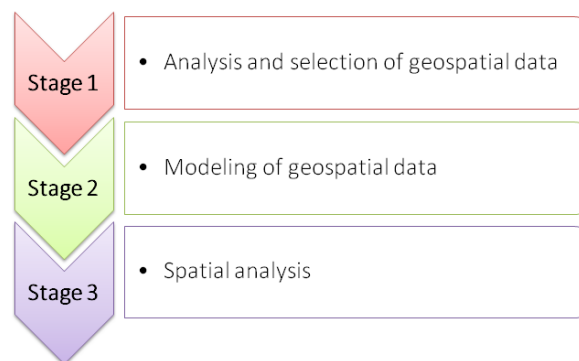

Stage 1
- Analysis and selection of geospatial data

Stage 2
- Modeling of geospatial data

Stage 3
- Spatial analysis

Figure 2.: Methodology steps.

3.1 Geospatial Data

The geospatial data used in this research refer to plots, buildings, street centerlines, Digital Terrain Model (DTM), Digital Surface Model (DSM) and PBZPA. This data comes from topographic maps, orthophotos, LIDAR data and documents about the PBZPA.

The features related to plots, buildings and street centerlines were obtained from topographic maps, in 1:1,000 scale, in shapefile format. The digital models, DTM and DSM, have a spatial resolution of 1m and were generated from LIDAR data in tiff format. The orthophotos are rectified, having a spatial resolution of 12.5cm, a radiometric resolution of 8 bits and were generated from the photogrammetric aerial survey in tiff format. These orthophotos were used in this research to support the thematic and 3D representations. Altogether it took 38 DTM files, 39 DSM files and 39 orthophotos to cover the study area. All these data were made available by PMPA.

The information that describes, delimits and defines the Salgado Filho International Airport PBZPA can be found in DECEA Ordinance No. 22/ICA, on 14 July 2015. This ordinance provides a 1:60,000 scale plan and a kmz file representing the PBZPA. Besides that, the two-dimensional (2D) representation of PBZPA, in 1:1,000 scale, in shapefile format, available on the PMPA website (PMPA, 2016) were used. This file contains, as attributes, information about the limiting surface type, the description of the limiting surfaces, the location and the maximum allowable height for the properties entered on each limiting surface of the PBZPA.

3.2 Data Modeling

The geospatial data modeling stage aims to generate the digital model of the PBZPA and assign altimetric information to the plots and buildings. For this purpose, we performed graphical editing, conversion between data structures, an association of numerical attributes, and 3D representation of PBZPA ramps and limiting surfaces.

From the DTM and DSM modeling, polygon geometry files were generated that represent the terrain height and represent the heights of the terrain and the existing planimetric features, such as buildings, vegetation, streets, among others. To do this, we first converted the DTM and DSM files from the raster structure to the TIN (Triangular Irregular Network) vector structure. Then the TIN files were transformed into polygons and the altimetric attributes were set. DTM attributes include minimum and maximum heights and DSM attribute, maximum height.

The 3D representation of PBZPA ramps and obstacle limitation surfaces was made by complementing the 2D representation of the PBZPA in shapefile format. The airport runway, approach surface ramps – second section, the approach/transition surface ramps – first section and the runway ramps were included manually. For the design of these ramps, the information contained in Ordinance No. 22/ICA were observed. The ramps consist of several polygons drawn side by side, and for each ramp we assigned their mean heights. Thereby, the 3D digital model of the PBZPA (Figure 3) was generated.
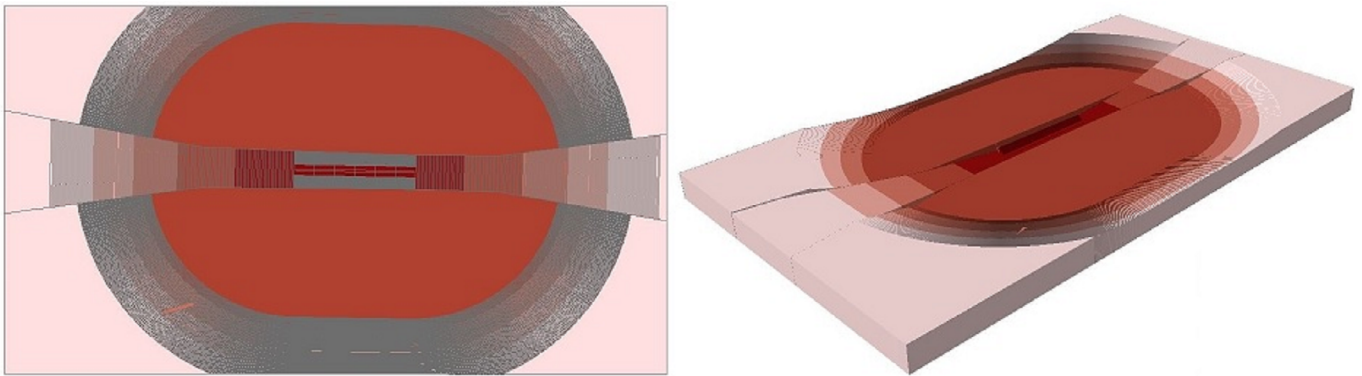

Figure 3: PBZPA 3D Digital Model.

With the terrain altitude representation (DTM) and the plot representation with the same polygon geometry it was possible to associate the altimetric information to the plots. This association is based on the spatial relationship between the features and is intended to ensure that each plot receives the respective altimetric information regarding the maximum and minimum heights. This was done by the geometric intersection of the DTM with the plots, through the Identity tool, which allows attributing to a file or level of information, named identified, the attributes of another file or level of information, named identifier. From this procedure a new batch file (identified) containing the altimetric attributes of the DTM (identifier) was generated. Subsequently, the average height of each plot was calculated.

Figure 4 represents the study area plots classified according to their average heights. It is noticed that the plots with the highest average heights are concentrated in the southern portion of the study area, extending to the eastern portion of it. And, around the Salgado Filho International Airport, northwest, north and northeast portions are the plots with the lowest average heights.
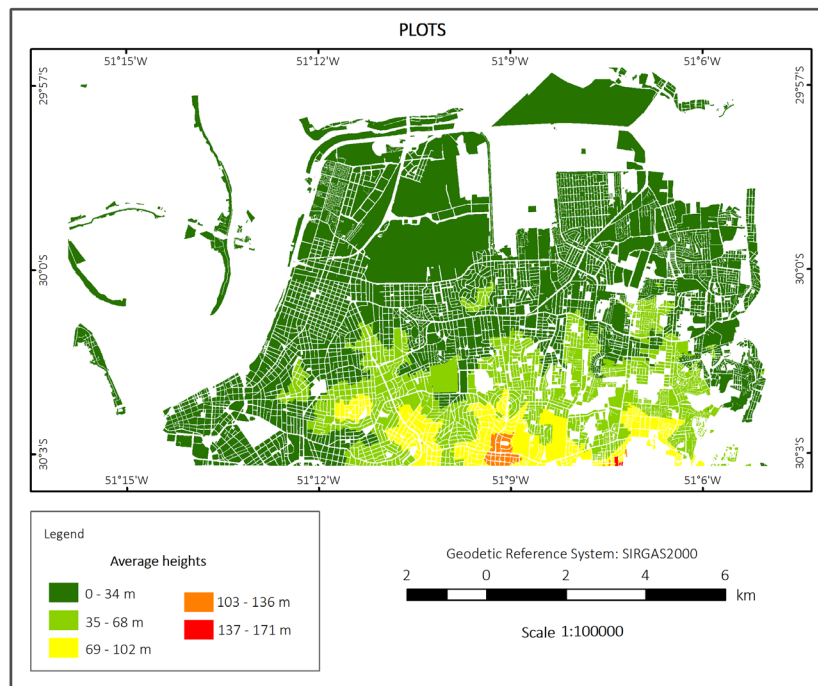
Figure 4: Plots classified by average height.

Then, the altimetric information regarding the maximum height was assigned to the buildings. This association, as in the case of plots, is based on the spatial relationship between the features and is intended to ensure that each building in the study area receives the respective altimetric information.

In this paper, the DSM was the file identifier and the buildings the file to be identified. Although some buildings have different heights throughout their structure, we decided to represent each building with a single maximum height to enable the altimetric comparisons between the buildings and the PBZPA, and the 3D representation of the buildings.

Figure 5 represents the buildings of the study area classified according to their maximum height. As in the case of plots, it is clear that the tallest buildings are concentrated in the highest regions of the study area (south portion, extending to the east portion) and around the airport are the lower buildings.
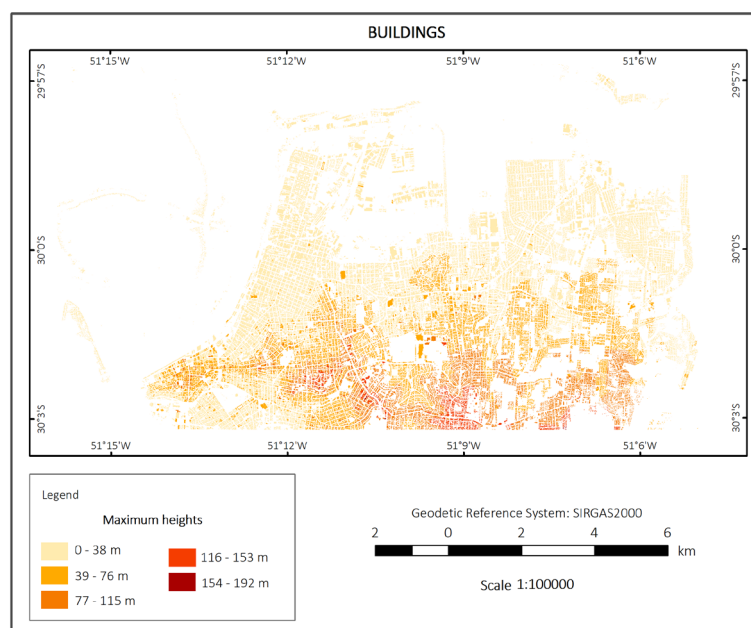

Figure 5: Buildings classified by maximum height.

3.3 Spatial Analysis

The spatial analyses were performed using the 3D models of the plots, buildings and PBZPA. To identify and quantify plots, buildings and critical areas, we compared plots heights and buildings heights with PBZPA limiting surfaces.

Initially, PBZPA information regarding the type, description, location, observation, message and height of the limiting surfaces was assigned to the plots. This was done through the geometric intersection of PBZPA with the plots, using the Identity tool, with PBZPA being the identifier file and the plots being the file to be identified. The comparison between the heights was made by subtracting the limiting surface heights from the average heights of the plots.

The same procedure was performed with buildings, with PBZPA being the identifier file and buildings being the file to be identified. The comparison between the heights, in turn, was made by subtracting the heights of the limiting surfaces by the maximum heights of the buildings.

4. Results and Discussions

The results of the spatial analysis allowed us to identify and quantify the obstacles in the Salgado Filho Airport airspace, based on the constraints established by PBZPA limiting surfaces. These obstacles concern plots, buildings and areas considered critical, where no buildings are allowed. The analyses were performed using the 3D models of the plots, buildings and PBZPA. Initially, the heights of the plots were compared with the PBZPA and then the heights of the buildings with the PBZPA.

Figure 6 shows the comparison between the mean heights of the plots and the limiting surface heights of the PBZPA. In this Figure it is possible to identify, in red, the areas where the terrain height already exceeds the limiting surfaces. These are critical areas in which buildings should not be allowed. Also, the yellow areas are at the edge of the protection zone and require more detailed analysis and field confirmation before defining their constructive viability. In blue are represented plots or fractions of these which are not reached by the limiting surfaces and thus allow for building.
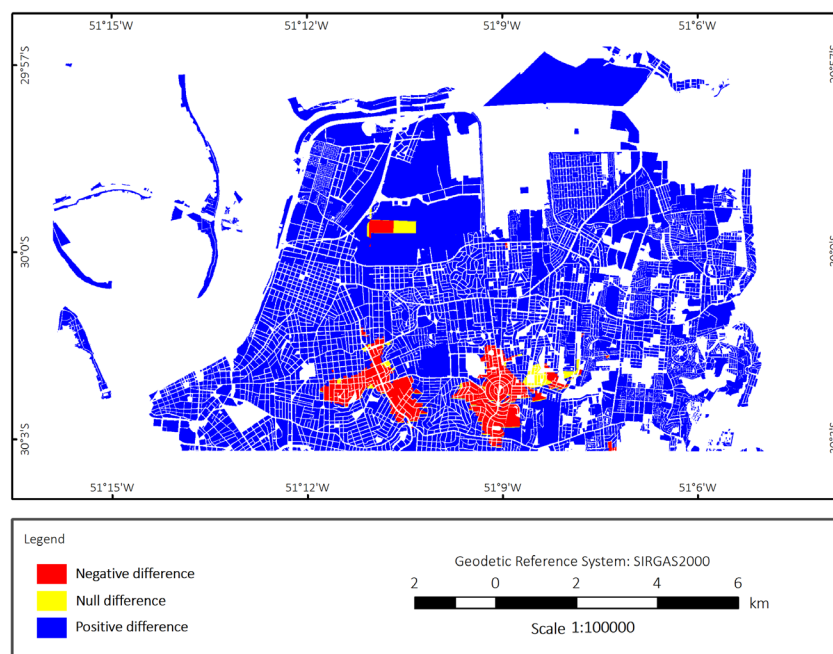

Figure 6: Plots classification according to PBZPA.

For the quantification of affected plots and critical plots, 106838 plots were considered, representing an area of 69.68 km². Table 1 presents the area of the plots reached in percentage and km², the number of plots reached, totally and partially, and the number of plots that are in the limit of the protection zone (critical plots), considering the accuracy of 0.5m.

Table 1: Information of the identified plots

Plots Area	69.68 km²		Plots Number		106838	
Plots reached	3.32 km²	4.76 %	Total (T)	Partial (P)	T + P	(%)
			4615	211	4826	4.52
Critical plots	0.58 km²	0.84 %	636	418	1054	0.99

Looking at Table 1, it is noted that out of a total of 106838 plots, 4826 exceed the PBZPA limiting surfaces, of which 4615 totally and 211 partially exceed, which is equivalent to 4.52% of the total plots. These plots correspond to an area of 3.32 km², i.e., 4.76% of the total area, which is 69.68 km². Also, 1054 plots, 0.99% of the total, represent critical areas in which buildings should not be allowed, and 636 plots having their entire area on edge and 418 plots being partially reached. This corresponds to an area of 0.58 km² which equals 0.84% of the total area.

The map in Figure 7 shows the constructive viability of the plots. The classes indicate the maximum height of the buildings that can be built in each plot. Considering the accuracy of 0.5m for the height of the plots the constructive viability was divided into 5 classes. The approximate number of floors was estimated based on the legislation and the master plan of the municipality. In class < 0m no buildings are allowed, as the terrain already exceeds the limiting surfaces of the PBZPA. Classes from 0.0 to 12.0m show plots with constructive viability of up to 4 floors, from 12.1 to 30.0m are plots with constructive viability of 5 to 10 floors, from 30.1 to 60.0m are plots with constructive viability of 10 to 20 floors, and > 60.0m are plots with constructive viability above 20 floors.
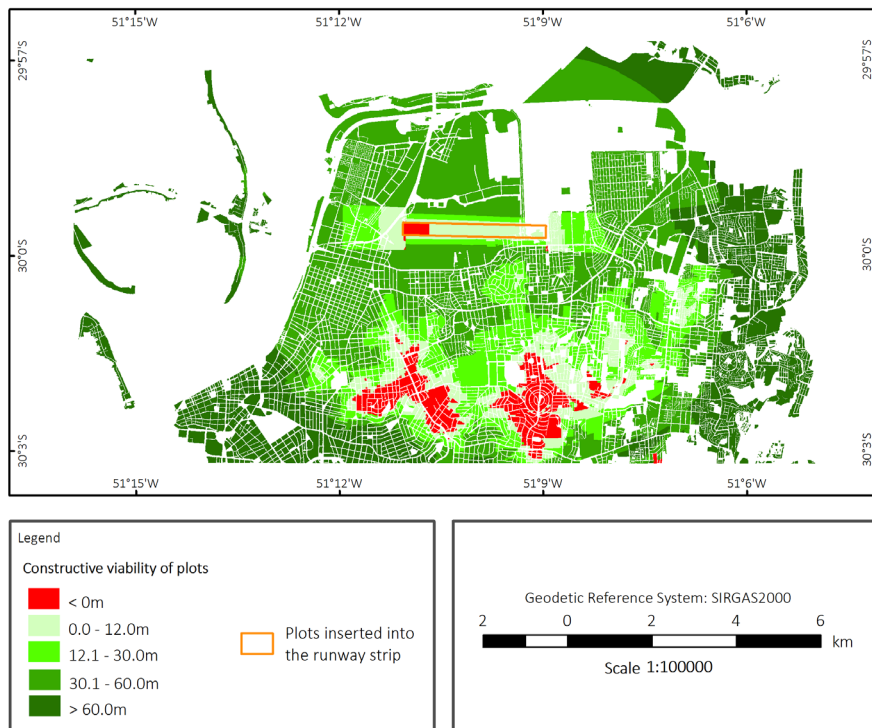

Figure 7: Constructive viability of plots.

By comparing the 3D models of buildings and the PBZPA it was possible to identify and quantify the obstacles related to buildings. Figure 8 shows the 3D representation of buildings projecting, wholly or partially, into airspace. And Figure 9 shows, in detail, an area near the airport where you can view buildings that exceed limiting surfaces of PBZPA.
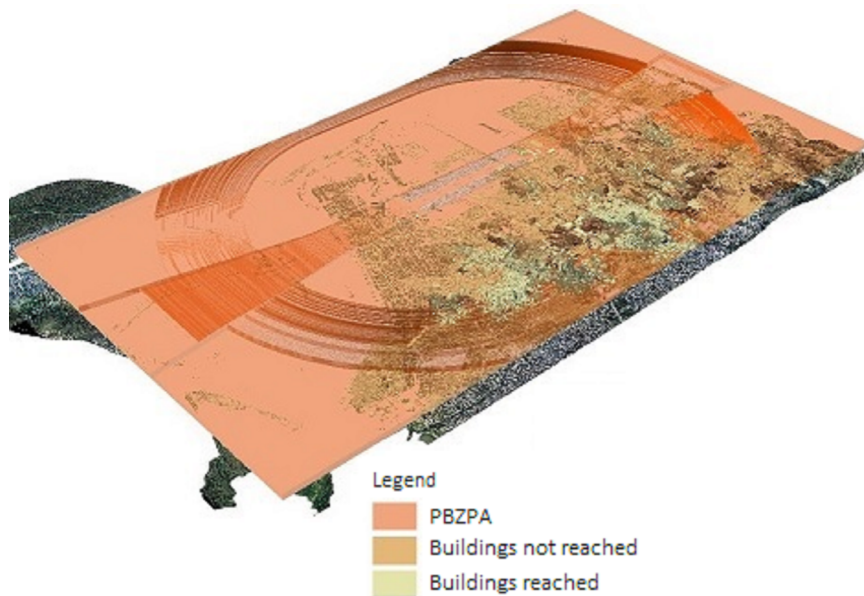

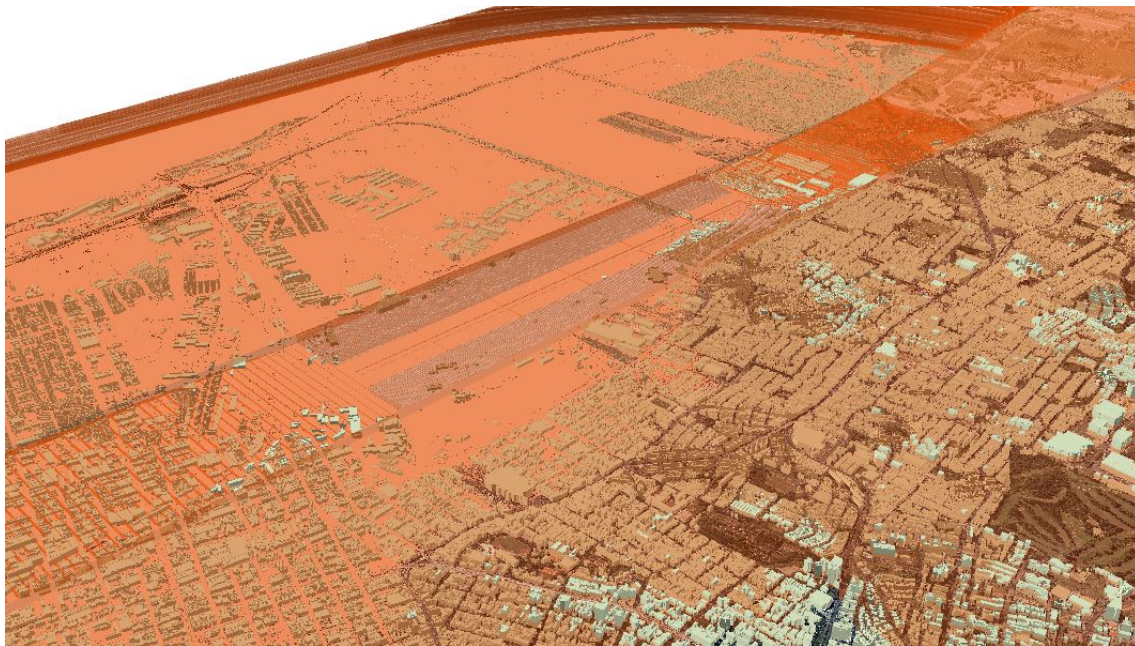**Figure 8:** 3D representation of buildings reached or not by the PBZPA.

Figure 9: Detail of buildings reached by PBZPA.

The quantification of the affected buildings and critical buildings was performed considering 200573 buildings, which represent a built area of 27.86 km^2. Table 2 shows the area of buildings reached in percentage and km², the number of buildings reached, totally and partially, and the number of buildings that are in the limit of the protection zone (critical buildings), considering the accuracy of 0.5m.

Table 2: Information of identified buildings

Buildings Area	27.86 km²		Buildings Number		200573	
Buildings reached	4.33 km²	15.54 %	Total (T)	Partial (P)	T + P	(%)
			26077	341	26418	13.17
Critical buildings	0.22 km²	0.80 %	1529	609	2138	1.07

The values in Table 2 show that 26418 buildings reached by the limiting surfaces of the PBZPA were identified, of which 26077 are reached throughout their area and 341 buildings are partially reached. The sum of the total and partially reached buildings represents 13.17% of the buildings of the study area, which corresponds to 4.33 km² and reaches 15.54% of the total built area. Critical buildings correspond to 2138 buildings, 1.07% of the buildings, of which 1529 buildings are fully and 609 buildings are partially on the limiting surfaces. The 2138 critical buildings amount to 0.22 km² of the built area, which corresponds to 0.80% of the total built area.

In Figure 10 it is possible to perceive the comparison between the maximum building heights and the limiting surface heights of the PBZPA. In blue the buildings, or fractions thereof, are shown to have a positive difference, i.e. those that are not reached by the limiting surfaces and therefore are not considered obstacles to the airport. In red, the buildings that present negative difference, that is, those that are completely or partially reached by the limiting surfaces, because the height of the top of the building is above that allowed by the PBZPA. And, in yellow, the critical buildings are represented, that is, those that show no difference between the height of the PBZPA surfaces and the maximum height of the building, and so are unreached buildings, but which are at the height limit allowed.
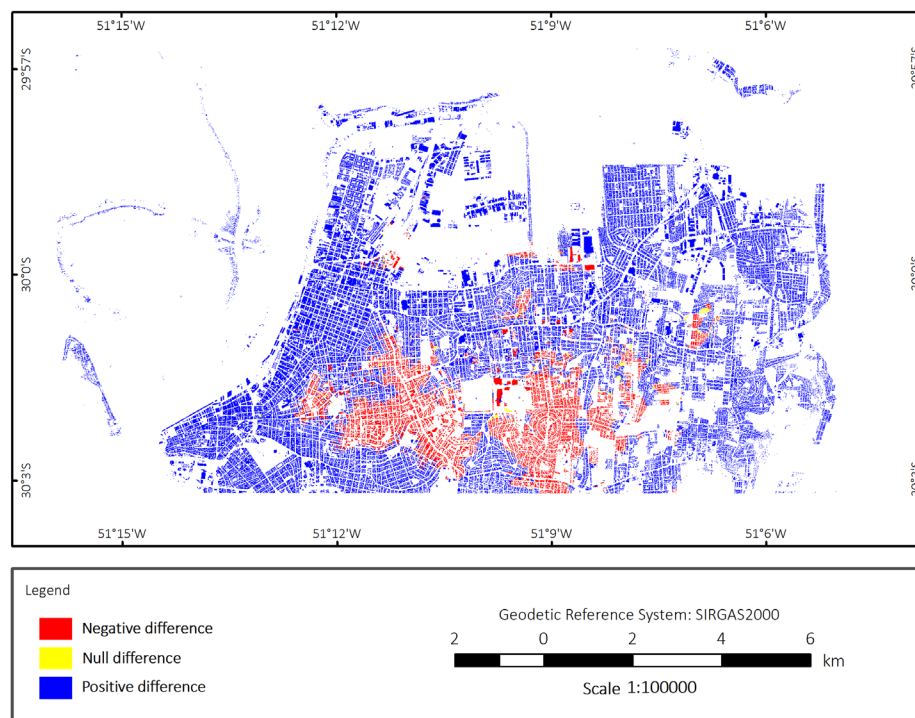
Figure 10: Classification of buildings according to the PBZPA.

Looking at Figure 10, it can be seen that most of the buildings in the study area are in the blue class, with differences between heights ranging from a few meters to over 155 meters. Similarly to the one identified in the analysis of the plots heights with the PBZPA heights, it is noted that the largest number of buildings identified as obstacles are concentrated in the higher parts of the study area, which are inserted on the inner horizontal surface,

on the conical surface and on the outer horizontal surface of the PBZPA. There are also affected buildings that are inserted into the first section of approach/transitional surface of the PBZPA. Such buildings are considered more worrying obstacles to the operation of the airport than buildings inserted into the inner horizontal surface, the conical surface and the outer horizontal surface. This is because obstacles on or near the takeoff and landing axis of aircraft can, for example, diminish landing aircraft alternatives, forcing the aircraft to make a longer lap to land, and even canceling a landing procedure. Obstacles located outside the takeoff and landing axis, otherwise, are more likely to be circumvented by aircraft. Therefore, buildings identified as obstacles, located on and near the landing and takeoff axis, must undergo a process of adaptation to the imposed situation.

5. Conclusion

In this paper, 3D models were created to identify and quantify obstacles around Salgado Filho International Airport. Spatial analyzes were performed by comparing the heights of the plots and the heights of the buildings with the limiting surfaces of the PBZPA. The quality and timeliness of the geospatial data used in analyzes directly influence the generated products.

The results show that the study is valid for detecting and quantifying critical areas, such as the constructive viability of the plots, the areas reached by PBZPA limiting surfaces, the height of the plots and buildings, and also to identify obstacles to aerodromes, according to the restrictions established by their respective airspace laws. In addition, it is possible to verify the constructive viability of the plots and to monitor the buildings in the northern area of Porto Alegre, regarding the altimetric limits imposed by PBZPA surfaces, with an accuracy of 0.5m. This serves as a basis for making decisions regarding land use and occupation management around the Salgado Filho International Airport, as it makes it possible to answer most questions related to the construction viability of the protection zone.

In addition to serving as a tool for urban users and managers, it also serves the authorities responsible for airspace legislation as it allows for the control and supervision of existing and future buildings within the aerodrome protection zone. Airports less susceptible to interference from obstacles become safer, since the risk of changing or canceling landing procedures, reducing runway length, impacting on the size of aircraft allowed to operate, or even disabling aerodrome operations are minimized. Besides that, the smaller the restrictions imposed on airports due to obstacles, the greater operating capacity and the possibility of the aerodrome expansions of the airports, which contributes to the development and economy of the regions served by them, and for the safety of the population.

The PBZPA addressed in this paper was revoked in September 2016 and replaced by DECEA Ordinance No. 260/ICA, which redrafted the restrictions imposed on the use of properties located within the protection zone of Salgado Filho International Airport. Nevertheless, the methodology employed in this work is valid for any airport and airspace legislation. The sequence of this research, already in progress, is related to the update of the PBZPA, according to current legislation, and the classification of the different types of risk obstacles to the safety and regularity of air operations. Therefore, criteria such as proximity and location will be adopted.

AUTHOR´S CONTRIBUTION

A.L.I. conceived of the presented idea and supervised the project. G.P.F. and A.L.I. researched and selected theoretical references. G.P.F. collected and modeled the geospatial data and performed spatial analysis. All authors discussed the results. G.P.F. wrote the manuscript and all co-authors performed paper revision, refinement and helped shape the manuscript.

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