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112
ISSN eletrônico 2177-2738
RA'EGA, Curitiba, PR, V.61, n.1, p. 112 – 133, 12/2024
http://dx.doi.org/10.5380/raega.v61i1.95457

Reviving Brasília Through Analyzing Historical Aerial Photographs

Revivendo Brasília Através da Análise de Fotografias Aéreas Históricas

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http://dx.doi.org/10.5380/raega.v61i1.95457

Abstract

This study presents an optimized method for processing and retrieving digital data from 1950s aerial photographs of the Plano Piloto area in Brasília. In analogous contexts, internal orientation parameters are often unavailable, and external orientation parameters must be obtained through non-standard approaches, as the identification and geolocation of control points in the field becomes impractical in substantially altered landscapes. Nevertheless, advancements in computer vision techniques, integrated into modern photogrammetry software such as Agisoft Metashape, provide a viable solution for mapping historical analog aerial photographs. The software successfully processed 156 aerial photographs, using 17 control points, yielding a historical orthoimage and a digital surface model with medium-scale accuracy. The generated model enabled precise identification of key features, including vegetation cover, land use, and terrain characteristics, providing valuable insights for the analysis of land occupation dynamics in the study area. The proposed methodology exhibits substantial potential for replication in similar cases, establishing a robust framework for the processing of historical aerial imagery.

Keywords:
Historical aero photogrammetry, Computer Vision, Structures From Motion, Brazil's Federal District, Occupation dynamics.

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Resumo

Este estudo propõe um método otimizado para o processamento e a recuperação de dados digitais a partir de fotografias aéreas da década de 1950, referentes à área do Plano Piloto de Brasília. Em contextos similares, os parâmetros de orientação interna podem não estar disponíveis, e os de orientação externa precisam ser obtidos por métodos não convencionais, visto que a identificação e localização de pontos de controle no campo tornam-se inviáveis em paisagens substancialmente modificadas. Contudo, os avanços em técnicas de visão computacional, incorporados em softwares fotogramétricos modernos, como o Agisoft Metashape, proporcionam uma alternativa eficaz para o mapeamento de fotografias aéreas analógicas antigas. O software processou com sucesso 156 fotografias aéreas, utilizando 17 pontos de controle, que resultou na obtenção de uma ortoimagem e de um modelo digital de superfície históricos, com precisão de média escala. O modelo gerado permitiu a identificação acurada de elementos como cobertura vegetal, uso do solo e características do terreno, contribuindo com informações valiosas para a análise da dinâmica de ocupação da área em estudo. O método proposto demonstra elevado potencial para replicação em casos similares, constituindo uma abordagem robusta para o processamento de imagens aéreas históricas.
Palavras-chave:
Fotogrametria aérea histórica, Visão Computacional, Estruturas de Movimento, Distrito Federal do Brasil, Dinâmica de ocupação.

I. INTRODUCTION

Aerial photograph data, collected worldwide by civil or military entities, provides a valuable historical record of territorial evolution, assisting in environmental maintenance and urban planning (DA SILVA, 2015). Improving the ability to recognize past land use and monitor changes over time is especially vital in countries like Brazil and other developing nations, providing valuable insights into comprehending the current landscape and directing future planning efforts. However, historical aerial photography often experiences degradation, insufficient digitization quality, and lacks essential flight information (MAIWALD et al., 2023). Despite ongoing efforts to digitize data, one of the foremost challenges persists in the loss of original parameters, specifically those related to camera (interior orientation parameters – IOP) and images positioning and orientation (external orientation parameters – EOP). Nevertheless, advancements in semi-automatic image processing methods and the expanded use of Unmanned Aerial Vehicles (UAVs) started to offer robust algorithmic alternatives for data reconstruction (COGLIATI et al., 2017) among them we can mention computer vision techniques such as Structures from Motion (SfM) and dense image matching techniques that were incorporated into photogrammetric processing software.

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Efforts to recover aerial photographs for Orthomosaic and Digital Elevation Models to support studies on land use land cover changes, aiming to investigate environmental crimes, illegal vegetation suppression, and urban expansion rely on flight and camera parameters, alongside preprocessing techniques, which makes historical image processing costly without adequate information (GOMEZ et al., 2015). A key challenge in computer vision is reconstructing three-dimensional models from two-dimensional images, highlighting the wealth of information in aerial image files (WESTOBY et al., 2012), (NEBIKER et al., 2014). The Structure from Motion (SFM) method offers a cost-effective approach with significant potential for processing historical photogrammetric data (MAIWALD et al., 2023; COGLIATI et al., 2017; GONÇALVES et al., 2016; ISHIGURO et al., 2016; LOWE, 1999; BROADBENT, 2012; VARGO, 2017).

The idea of moving Brazil's capital to the central region dates to colonial times for strategic and territorial reasons. In 1883, a dream by Dom Bosco suggested a location between parallels of latitude 15° and 20°, later interpreted as the site for the new capital. President Kubitschek initiated Brasília's construction in 1956, following Dom Bosco's coordinates. To obtain valuable information on the formation of relief and land use and occupation of the region chosen for the new capital, in 1953 an aerial survey of the entire area and its surroundings was carried out, forming an extensive photogrammetric collection. Notwithstanding this extensive collection of aerial photography, preceding the establishment of the Brazilian Federal District and Brasília, essential information for photographs from the 1950s is notably absent. Flight and camera specifics, as well as calibration data, have been misplaced or are difficult to retrieve. The original photographic negatives or photolith film are untraceable, with the sole analog collection stored in the Public Archives of the Federal District. Furthermore, some analog photos suffer from inconsistent brightness, resulting in the loss of fiducial landmark details, while physical damage is apparent in certain instances. Moreover, variations in size and orientation among scanned images make effective use of this valuable collection even more difficult.

Facing the challenge, this study analyzes the application of computer vision techniques to historical aerial photographs, where interior and exterior orientation parameters are unknown, to generate digital orthomosaic models. The construction site of Brasília within the Federal District serves as a case study.

II. MATERIALS AND METHODS

Study area

The study area covers the northwestern section of the Federal District, Brazil, known for its varied land use patterns (Figure 1). The area's wide geographical scope provides a valuable opportunity to explore the

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applications of its historical aerial photographs. By studying these images, we can gain valuable insights into evolving land use patterns, such as changes in vegetation, shifts in regional water dynamics, urban densification, the transformation of rural areas into urban landscapes, and interventions in wetlands. Additionally, the photos offer context for the implementation of Brasilia's Pilot Plan project. These aspects help us understand the complex socio-environmental dynamics and relationships in Brazil's Federal District.

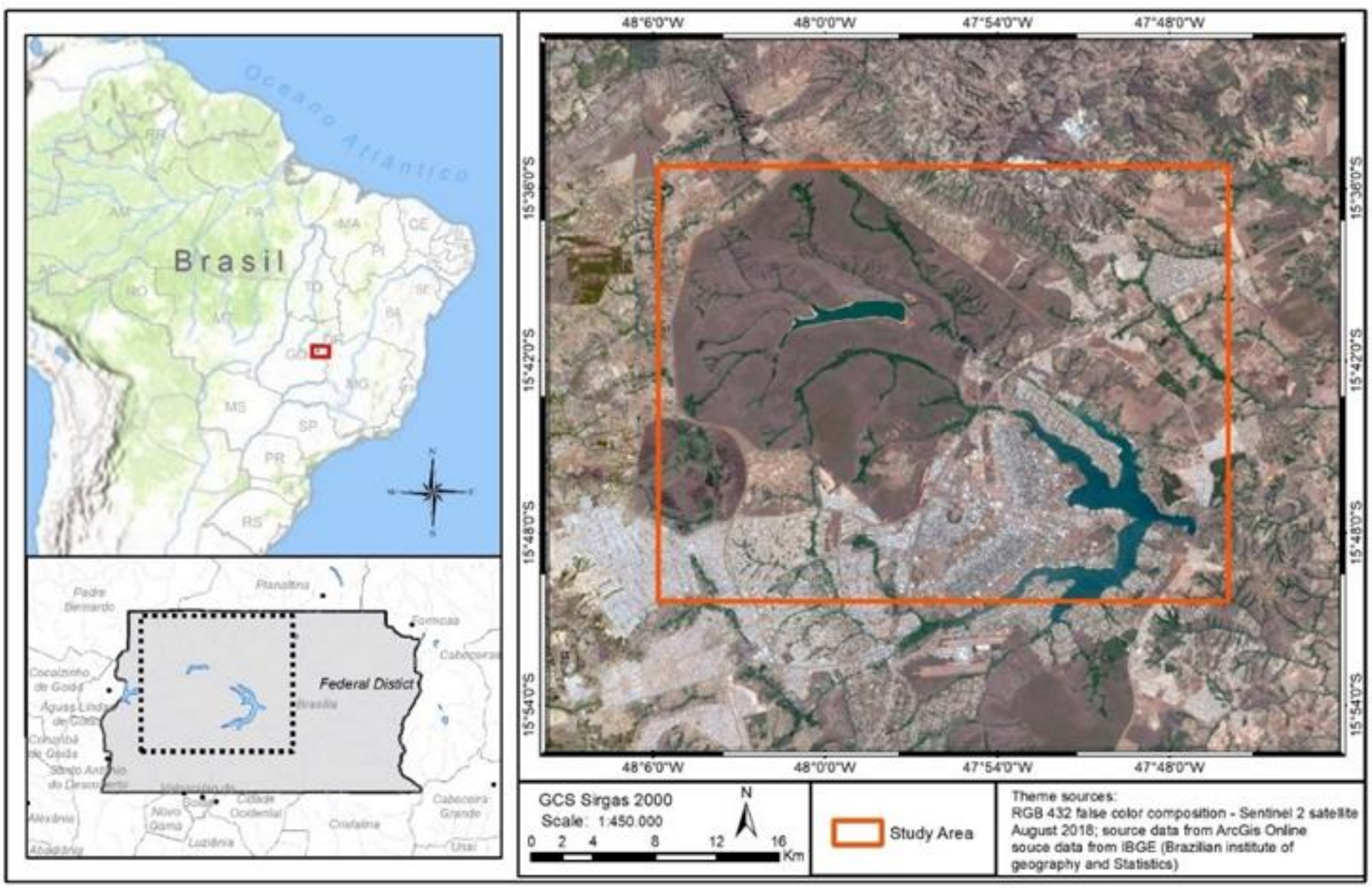

Figure 1 - Study area delimited by the orange rectangle.

Aerial photographs dataset

For our research we considered 262 historical aerial photographs acquired on a flight carried out in 1958. These photographs were obtained from the Geosciences Institute of Brasilia University. These images entirely cover the study area and are believed to have been captured around 1958. Notwithstanding, pertinent details such as the digitization process, overflight parameters, and camera specifications remain elusive in many photographs.

The dataset used in this study consists of historical aerial photographs acquired over 60 years ago, which were only digitized half a century later. This significant delay led to the deterioration of the images, rendering

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the fiducial marks unusable in many of them. Despite this, it was still possible to recover the focal length information from some photographs. Figure 2 shows an aerial photograph in good condition from which the focal length data was retrieved.

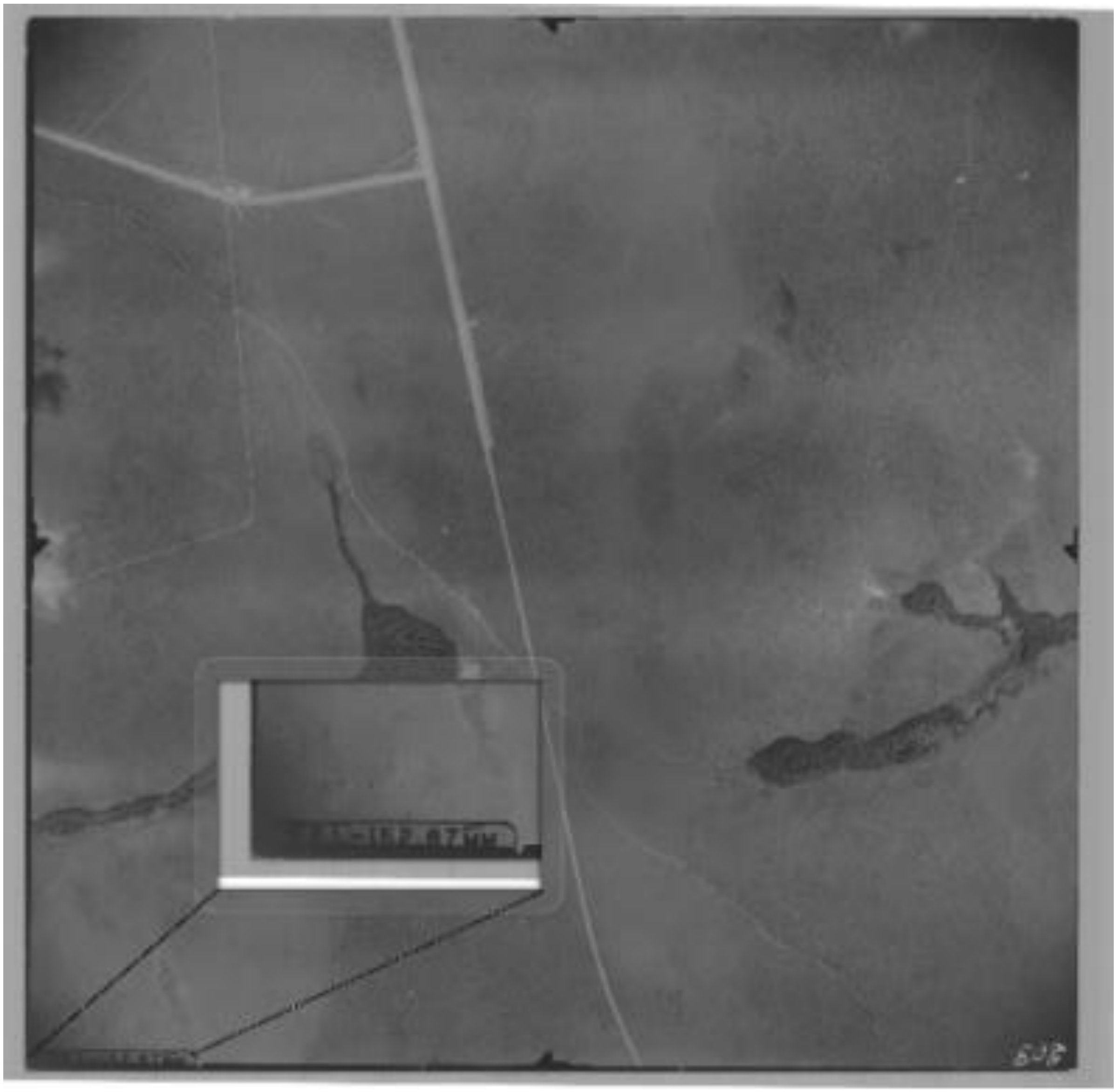

Figure 2 - Detail of the original photograph with fiducial marks and focal distance marked in the analogical data.

Methodology

Considering the challenges inherent to standardizing photographs and identifying consistent features across historical and contemporary images—especially in the context of substantial land use and land cover changes—a methodology was developed to perform photogrammetric processing over historical photographs, considering the identification of control points stable over time. This method utilized the Agisoft Metashape

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and ARCGIS softwares to process photographs with unknown parameters to enhance the accuracy of image analysis, as illustrated in Figure 3.

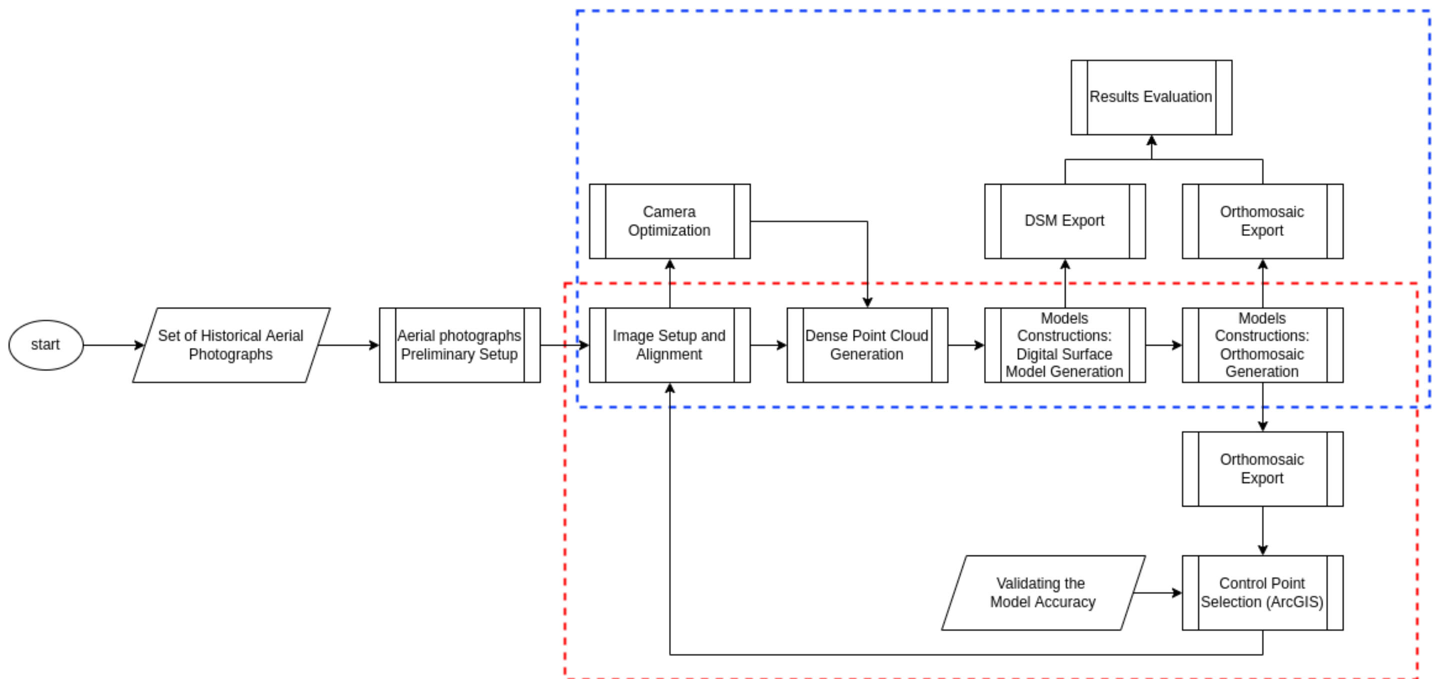

Figure 3 - Method workflow.

The proposed methodology employs an iterative framework for the application of established procedures. In the initial iteration, the photogrammetric processing workflow is executed without the inclusion of Internal Orientation Parameters (IOP), External Orientation Parameters (EOP), or control points, as these parameters are not predetermined. This phase encompasses the steps detailed in "Aerial Photographs Preliminary Setup," "Image Setup and Alignment," "Dense Point Cloud Generation," and "Model Construction." Subsequently, the resulting orthomosaic and Digital Surface Model (DSM) are evaluated together with reference data to facilitate the identification of control points, as outlined in the "Control Point Selection" step.

In the subsequent iteration, the control points identified in the previous phase are incorporated into the photogrammetric processing workflow as reference markers. The workflow then proceeds with the steps "Image Setup and Alignment," "Camera Optimization," "Dense Point Cloud Generation," and "Model Construction." This iteration culminates in the generation of georeferenced orthomosaic and DSM products. Finally, the "Validating the Model Accuracy" step is undertaken, which involves a comprehensive assessment of the generated products against the reference data.

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a) Aerial Photographs Preliminary Setup

This topic covers the initial steps to standardize the aerial photographs dataset to ensure consistency across the images. The digitalized images suffer from variation in pixel size, rotation, deformations due to the curvature of the photographic paper, insertion of non-existent edges and deterioration of fiducial marks. These pose a challenge, due to each photograph experiencing unique distortions, making fiducial marks essential for accurate analysis. Unfortunately, the dataset did not provide fiducial marks for all images, which impacted the ability to address these distortions.

Aiming to standardize the photographs an Image processing was applied to remove non-existent edges and fiducial marks, since their unavailability for all images makes their use unfeasible. The aim of removing the edges was to avoid the occurrence of false correspondences and the inclusion of incorrect tie points during the processing of the photogrammetric block.

b) Image Alignment Setup

Image alignment was an automated step performed in Metashape software, where the software identifies key points in each image and determines the overlaps between them. This process is necessary for creating a cohesive mosaic from multiple aerial photographs.

Initially, the photographs were processed without any correction or injunction in the photogrammetric block. The initial process allows the alignment of images forming an uncontrolled mosaic, which made it possible to identify and select points with good temporal stability that can be used to determine control points for adjusting the photogrammetric block. This method helps maximize overlap detection, even when images are slightly misaligned or distorted.

During alignment, a key point limit of 40 000 was set, additionally an overlap point limit of 4 000. These values define the number of matches the software attempts to identify between images. A higher number of key points can result in more accurate alignment, while overlapping points ensure that images are properly connected.

Choosing the adaptive camera model adjustment option allows the software to dynamically adjust camera parameters to improve alignment accuracy as more matches are found between images.

After initial alignment, image overlaps were verified to ensure correct alignment and model accuracy. In cases where the search for tie points was unsuccessful, the alignment was refined by manually adjusting tie points or adjusting camera parameters, aiming to align at least 60% of the images. Start with medium accuracy

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for processing speed and increase to "high" for precision as more overlaps are detected. Finally, integrate overlap points into the model to ensure proper image positioning.

c) Camera Optimization

The process of configuring and aligning images is necessary for ensuring that aerial photographs are correctly combined to produce an accurate digital model. This involves entering camera parameters, performing automated alignment, and verifying image overlaps. To accomplish this, the focal length, F = 152.67 mm, was entered into the processing software (Metashape) to ensure accurate perspective adjustments and to create a precise digital model. Since the IOP and EOP are unknown, the optimization of EOPs is only possible through indirect georeferencing of the block through the use of control points, a procedure carried out in the second iteration of the workflow.

d) Dense Point Cloud Generation

The generation of the point cloud and model construction are crucial for converting aligned aerial photographs into a detailed 3D model. This process involves creating a dense point cloud from the aligned images, followed by constructing a 3D mesh, which represents the terrain surface. The 3D mesh is then used for generating models like DSM and orthomosaics, enabling detailed visualization and advanced spatial analysis of the area.

e) Models Constructions

Throughout the development of the experiments, 2 models of the DSM and orthomosaic types were produced, in the first iteration the products were generated without any information of IOP, EOP, nor control points, leading to products with arbitrary coordinate system. In the second iteration, the inclusion of control points leads to block georeferencing, producing models in a known coordinate system.

DSM Construction:

The Digital Surface Model (DSM) provides a detailed representation of the Earth's surface, including all objects like buildings and vegetation. To create a DSM, first align the photos and generate a dense point cloud. Then, "Build DSM" function was used in the "Workflow" menu, set parameters such as resolution and interpolation method. Once generated, the DSM was reviewed for accuracy and executed necessary edits. Finally, export the DSM in a suitable format for further analysis or GIS integration. This process allows for precise surface modeling and analysis.

Ortho-Mosaic Construction:

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The orthomosaic is a composite image that combines aligned and orthorectified aerial photographs to create a representation of the studied area. The orthorectification process was performed considering the images positioning and orientation determined at the alignment phase, as well as the DSM product. At the first iteration both DSM and Orthomosaic were generated in an arbitrary coordinate system given the lack of knowledge of IOP and EOP and the non-use of control points in the first phase of processing.

f) Control Point Selection

The orthomosaic produced by the photogrammetric processing without any injunctions was imported to the ArcGIS software. From a visual analysis of the mosaic and considering the similar features between the historical mosaic and the reference mosaic, a set of 4 points were selected to roughly georeference the data. To perform the gereferencing of the orthomosaic, translation, rotation and scale parameters were considered.

From the initial georeferencing, a visual search was carried out for details that remained stable over time. Seventeen (17) points were identified in both historical photographs and recent imagery obtained from reference dataset from 2009 aerial photogrammetric survey of the Federal District. These points were selected for their consistent visibility across both temporal datasets. The most reliable points for accurate identification were the confluences of watercourses and intersections of road networks in their early stages of development (Figure 4). The three-dimensional coordinates were assigned to these identified points to enhance model accuracy. Precise localization of these points was important to minimize errors that could degrade the quality of the 3D model.

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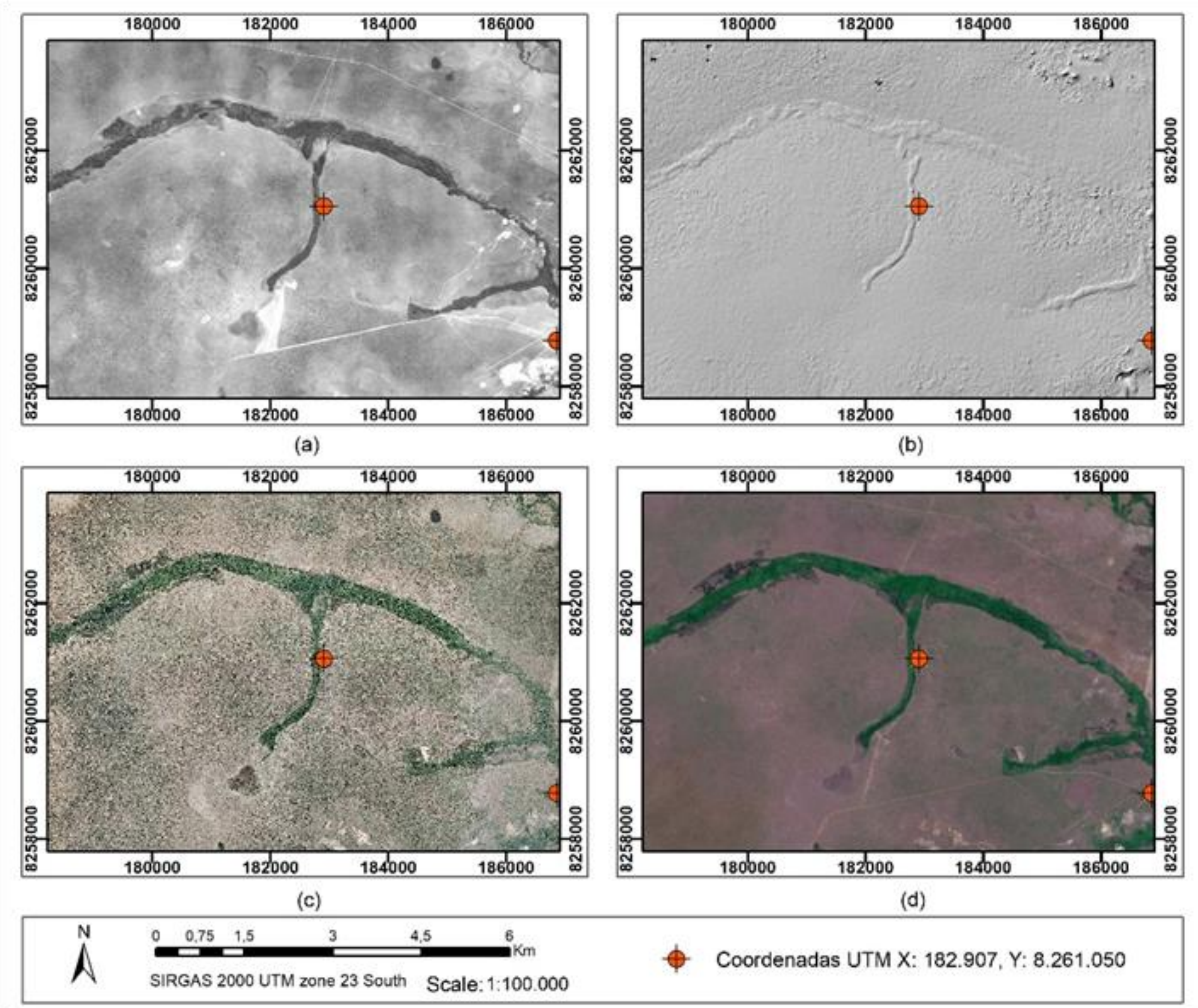

Figure 4 - Representation from diverse sources: a) 1959 Orthomosaic. b) 1959 Digital Historic Shaded Relief. c) 2009 orthophoto. d) RGB Composition Sentinel 2.

g) Validating the model accuracy

To validate the Historical DSM accuracy, we selected a reference area at the National Park of Brasilia to analyze and used a set of 36 orthophotos from 2009 aerial photogrammetric survey of the Federal District, sourced from an open-access government web mapping application repository (SEDUH, 2023). These images were used to identify unchanging reference points over time, essential for accurate comparison and measurement of positional errors. Subsequently, basic statistical analyses were conducted on the models for further evaluation. To test the model, we analyzed differences in elevation profiles from a target area with consistent historical data quality spanning both 1959 and 2009.

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III. Results and Discussion

The results of the proposed methodology will be discussed considering the steps developed, being organized into the following topics: uncontrolled photogrammetric processing; control points selection; controlled photogrammetric processing; and validating the model. The first topic presents the results and discussions about the initial processing, in which IOP, EOP and control points parameters were not informed. The second topic presents the results of the search process for time-stable points, which enable the georeferencing of the block through the addition of control points in the photogrammetric process. The third topic presents the results of the photogrammetric processing that considered the injunction of control points. The last topic presents the precision analysis of DSM generated from the historical aerial photographs processing.

a) Uncontrolled photogrammetric processing

The initial photogrammetric processing consists of the images without any correction or adjustment and no IOP nor EOP were applied. From this processing it was noted that the software was able to successfully identify the overlapping regions. However, the lack of geographic reference data within the model presents a challenge in establishing a uniform pixel size for the photographs used. This constraint is inherent in the software capability, which is influenced by the quantity of photographs encompassed within these contiguous areas. This characteristic becomes even more evident when it comes to photographs without IOP known a priori.

The initial photogrammetric processing resulted in a Orthomosaic and a DSM. From the Orthomosaic it is possible to identify features in regions where the land use and land cover remains unchanged. The same can be observed from the DSM, however from the DSM it is possible to identify areas in which its morphology remains preserved, maintaining altitude values. Although it is possible to generate products from initial processing, it is in an arbitrary coordinate system, given the lack of knowledge of the parameters and the non-use of control points at this stage of the process.

Figura 5 presents a temporal stable region of the DSM and the Orthomosaic, both in the historical data and in the reference data. It is worth mentioning that prior to georeferencing, the products can be compared only visually since there is no known coordinate system associated with the generated products.

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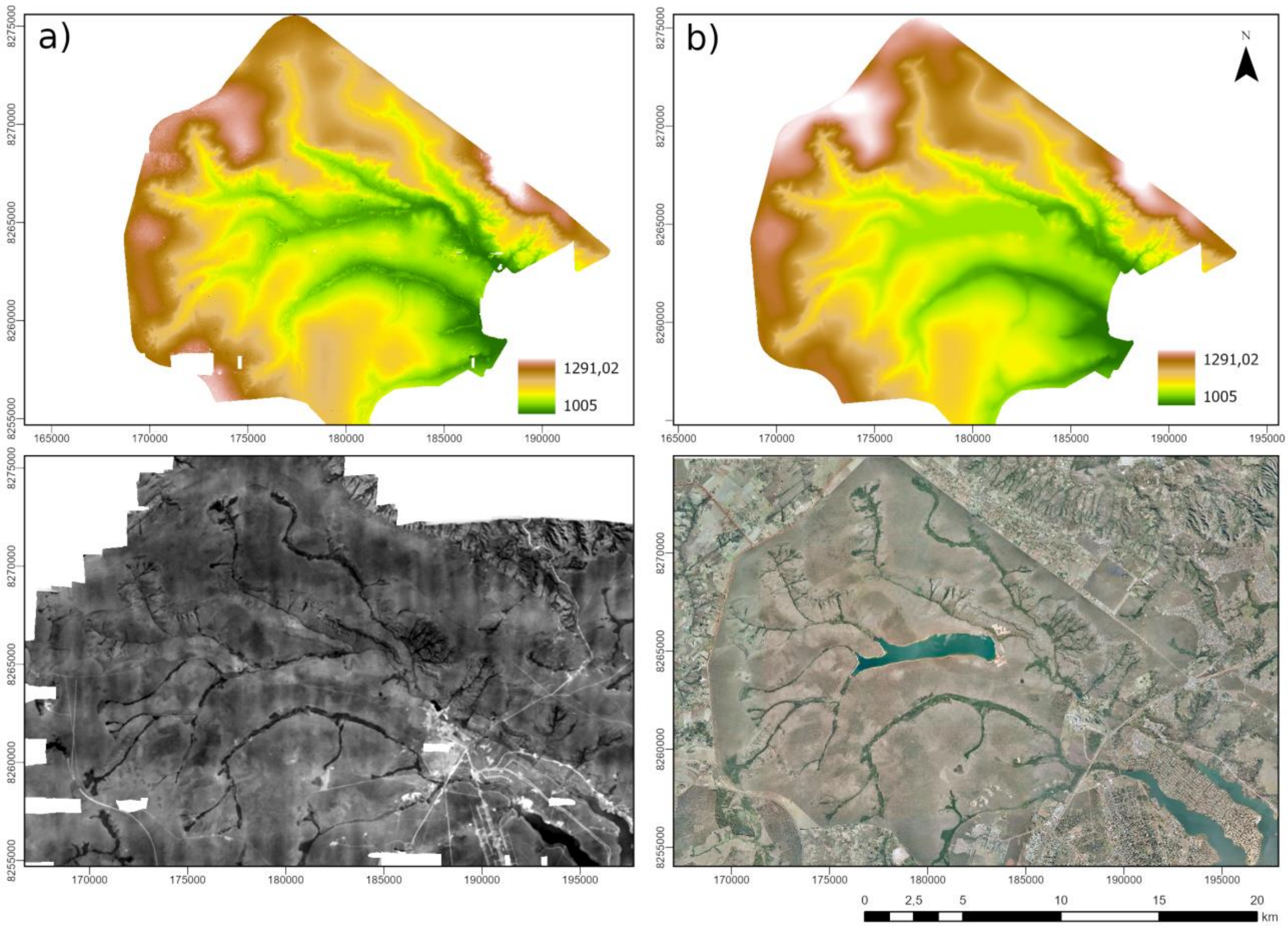

Figure 5 - Temporal Stability Analysis of DSM and Orthomosaic: a) The Historical DSM (1959) in the superior image, and the Historical Orthomosaic (1959) in the lower image; b) The Reference DTM (2009) in the superior image, and Reference Orthomosaic (2009) in the and lower image.

b) Control point selection

The accuracy of the three-dimensional model was contingent on the quality of the input data, which did not receive the same level of meticulous processing as the two-dimensional data. Errors related to surface roughness were acknowledged, particularly in riparian areas where the digital surface model indicated elevated terrain, impacting the results.

The Orthomosaic and DSM georeferencing was performed using ArcGIS tools, which allow the user to select the transformation to be considered. In this phase an affine transform was applied considering the minimum number of points. The points were first identified and pointed on the Orthomaic and then applied to estimate the affine transformation parameters.

The transformation applied in ArcGIS allow the overlap between the products generated and the reference date, making it possible the visualization of regions with a noteworthy level of detail, proving sufficient

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for discerning specific patterns within the anthropic dynamics of the study area. Based on the combined visual analysis of the relief (DSM) and the texture (Orthomosaic) a set of control points was selected, which were used as control points in the final photogrammetric processing.

c) Controlled phtogrammetric processing

After the control point selection, the selected point and its coordinates were added as an injunction to the photogrammetric processing, allowing the software to adjust the photogrammetric block and all the unknow parameters (IOP, EOP and points coordenates). As results, at the end of the photogrammetric process the Orthomosaic and DSM were generated. Figure 6 illustrates the Orthomosaic generated from historical aerial photographs, meanwhile, Figure 8 highlights the Historical DSM.

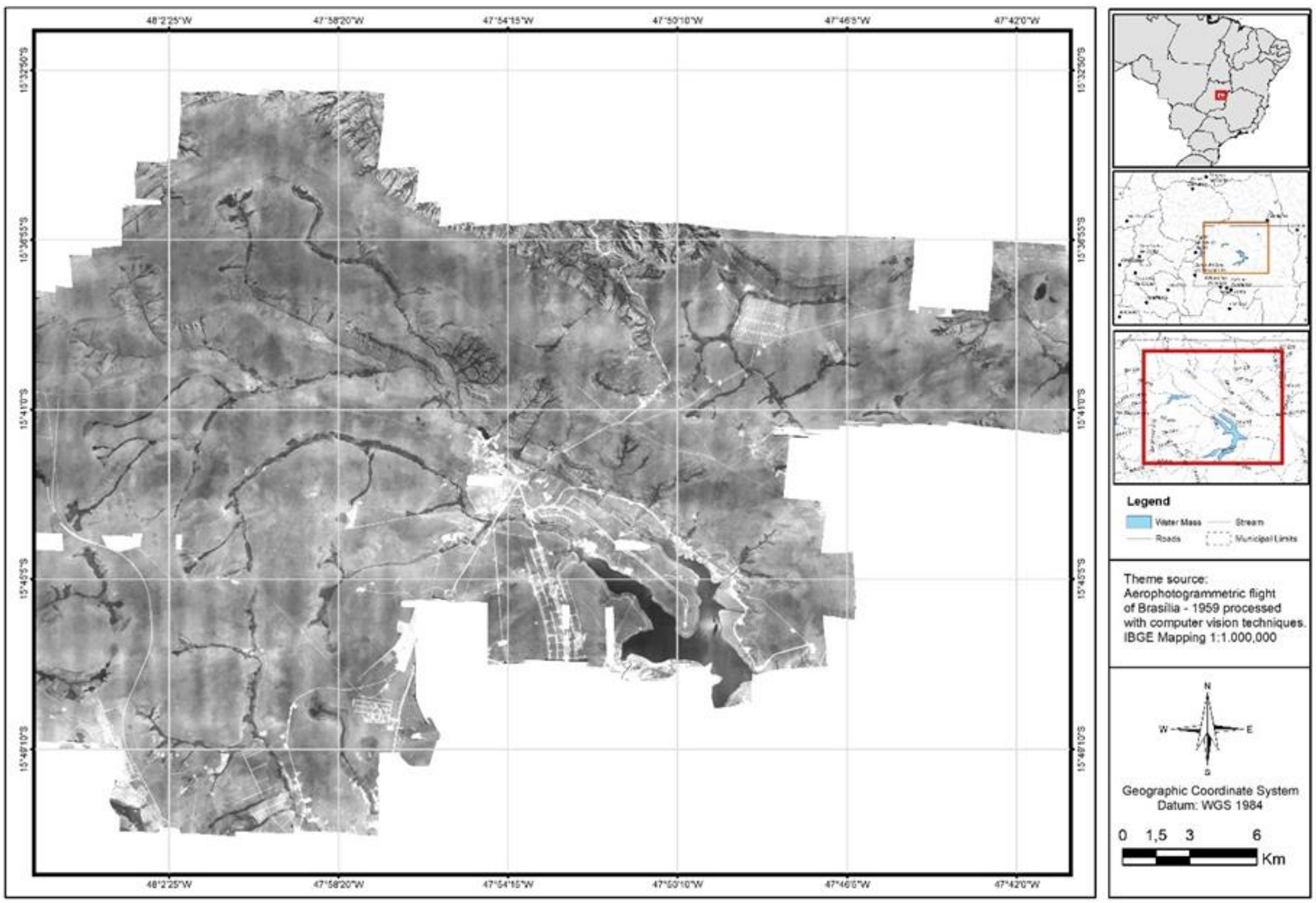

Figure 6 - Historical Orthomosaic generated from IOP and EOP unknown.

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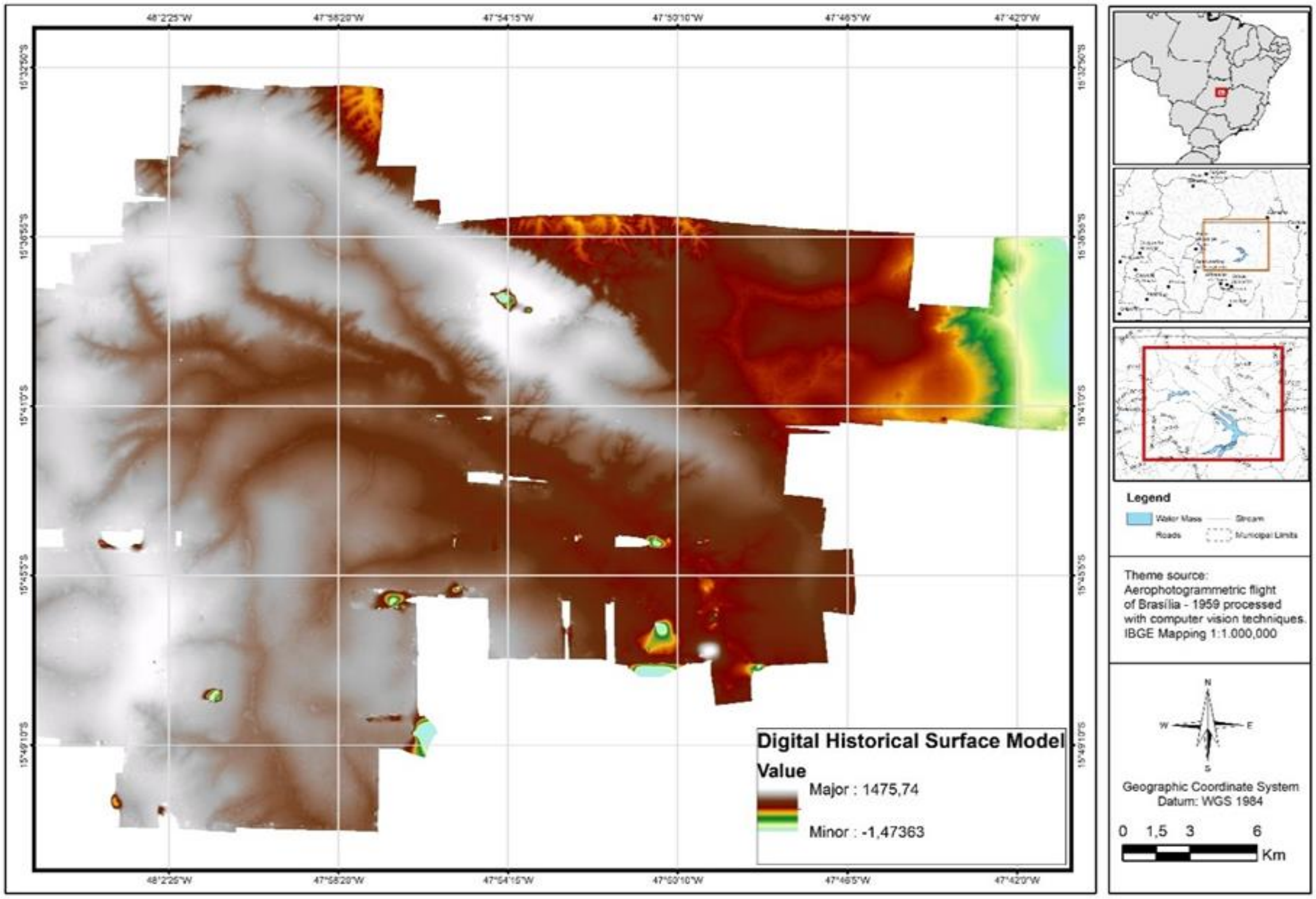

Figure 7 - Historical DSM generated generated from IOP and EOP unknown.

Based on the Orthomosaic and DSM presented in Figures 6 and 7, it is possible to notice that some areas may exhibit noise and imperfections, such as negative values and regions lacking data. In general, these effects are caused by false correspondences in the alignment of the images, which in turn can be due to several causes. Among the possible causes of false correspondence, we highlight the loss of information in some photographs due to the advanced deterioration process. This event occurred in a few images, but it was enough to cause covering failures, generating regions without information, both in the orthomosaic and in the DSM.

Despite the Orthomosaic and DSM distortions become apparent in areas where photographs are distorted or where data collection is limited, discernible features such as vegetation areas, terrain alterations, road networks, sections affected by the ongoing filling of Paranoá Lake, and the presence of wetlands remain visible. It is important to mention that the process was able to generate a DSM that offers a coherent representation of elevation data.

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d) Validating the model

Evaluating the planimetric positioning imposes difficulties, the accuracy of points positioning was compromised by substantial changes in land use and land cover from 1959 to 2009. This contextual challenge prevented the identification of reliable points necessary for the analysis, thereby undermining the potential validity of subsequent statistical examination. Furthermore, the accuracy estimation would be significantly affected by points positioning in the historical photographs, invalidating the obtained results.

By analyzing the generated Orthomosaic some regions that were apparently distinguishable on small scales ended up losing definition as we zoomed in, the features in that regions become unfeasible for checking the Orthomosaic accuracy, making it impossible to compare the generated Orthomosaic with the reference data. Nonetheless, the positional variance remains tolerable at the semi-detailed scale (1:25 000), with no apparent errors. Expectedly, at the model's periphery, positional inaccuracies become more pronounced, leading to noticeable displacements that undermine its usability.

The DSM was evaluated considering a global assessment of the discrepancies and by local altimetric profile. The results and discussion of each analyses performed are presented in the sequence of this section.

The global evaluation considered the raster subtraction being the results the vertical error in each pixel. The Historical DSM (refer to Figure 8) demonstrates a fine alignment with reality. Notably, it effectively captures patches of vegetation, indicating its reliability. The dataset shows robust spatial resolution, evidenced by consistent color representation and precise positioning across most of the study area. Noteworthy features such as riparian vegetation, wetlands, water bodies, early road systems, and isolated trees are distinctly delineated, highlighting the dataset's ability to accurately depict the landscape.

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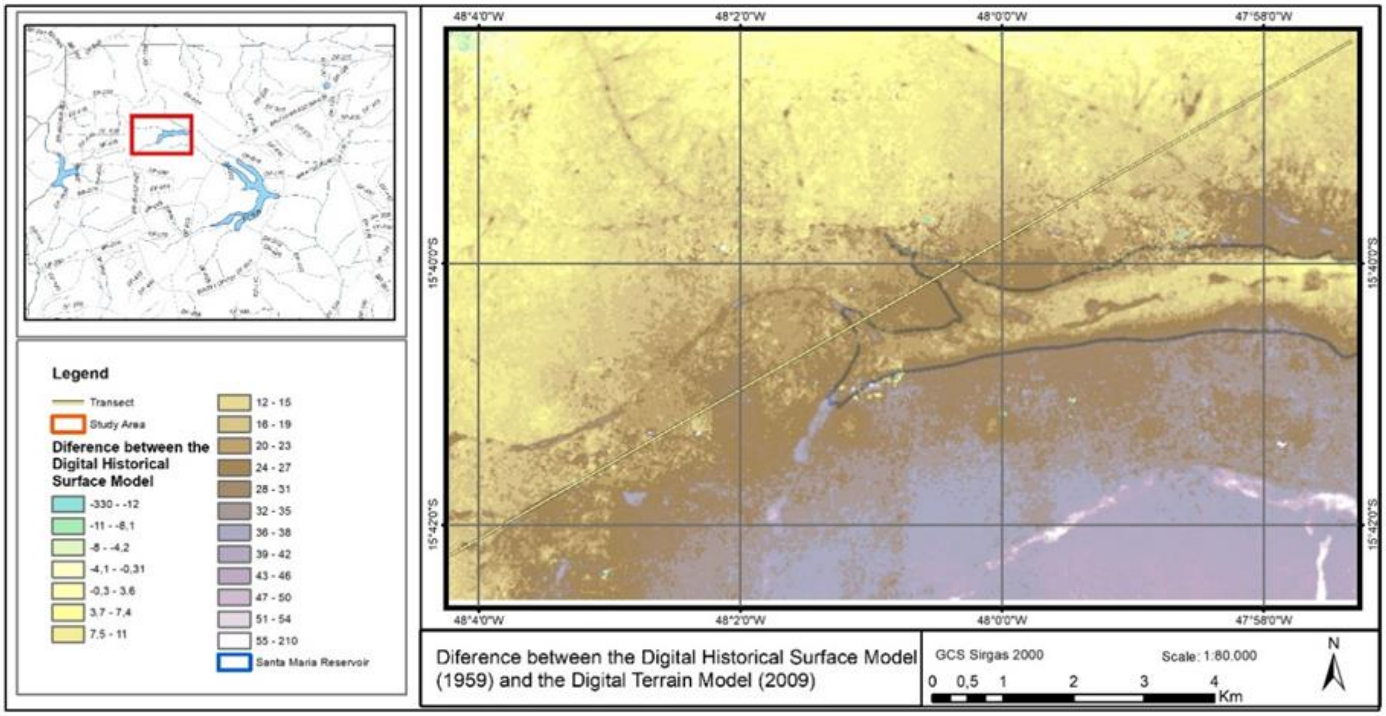

Figure 8 - Difference between the Historical DSM (1958) and the Digital Terrain Model (2009).

According to the standards outlined in the Brazilian technical specification for aquisition and quality control of Geospatial Data (CE/DCT/DSG, 2016; DCT/DSG, 2016), which delineates quality control protocols for gathering vector spatial data, it can be inferred that the dataset meets the necessary criteria for generating cartographic products based on the historical digital surface model. Based on the 2009 digital terrain model, the standard deviation of the difference is 11 meters. This places our historical model in the category of cartographic products falling under class A on a scale of 1:250 000 or class B on a scale of 1:100 000 (see Table 1). Nevertheless, validating vertical positioning accuracy presents challenges due to temporal disparities and the limited precision of horizontal positioning verification. The scarcity of reliable control points identified in old photographs imposes limitations on robust comparisons with currently identifiable points.

Evaluating the accuracy of this model proves challenging due to the dynamic evolving nature of land use over time, resulting in limited unchanged control points for precise three-dimensional geographic positioning.

Table 1 - Precision and Accuracy Standards in MDT for Digital Cartographic Production.

	1:25 000		1:50 000		1:100 000		1:250 000	
PEC-PCD (m)	PEC	EP	PEC	EP	PEC	EP	PEC	EP
A	2,70	1,67	5,50	3,33	13,70	8,33	27,00	16,67

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http://dx.doi.org/10.5380/raega.v61i1.95457

B	5,00	3,33	10,00	6,66	25,00	16,66	50,00	33,33
C	6,00	4,00	12,00	8,00	30,00	20,00	60,00	40,00
D	7,50	5,00	15,00	10,00	37,50	25,00	75,00	50,00

Source: DCT/DSG, 2016.

To conduct our comparative elevation profile analysis, the selected target area was centered on the Santa Maria dam within the Brasília National Park mainly because it appears to be unalterable over time. Subsequently, a diagonal cross-sectional representation was delineated across this chosen area, enabling the extraction of elevation profiles from both the 1959 and 2009 datasets.

Considering Figure 9 was observed a notable difference between the two temporal models, particularly accentuated in densely vegetated regions. The range of variation observed along this transect extends from -14 to 12 meters. On average, a difference of -3,89 meters is noted, with a standard deviation of 3,10 meters. It is important to acknowledge that part of this variation may result from differences in coverage patterns between the two temporal models. This divergence is particularly pronounced in valley regions, due to riparian vegetation. This distinct pattern observed, particularly in valley bottoms, demonstrates the potential for enhanced precision in quantification and deeper analysis, as illustrated by the profiles shown in Figures 10.

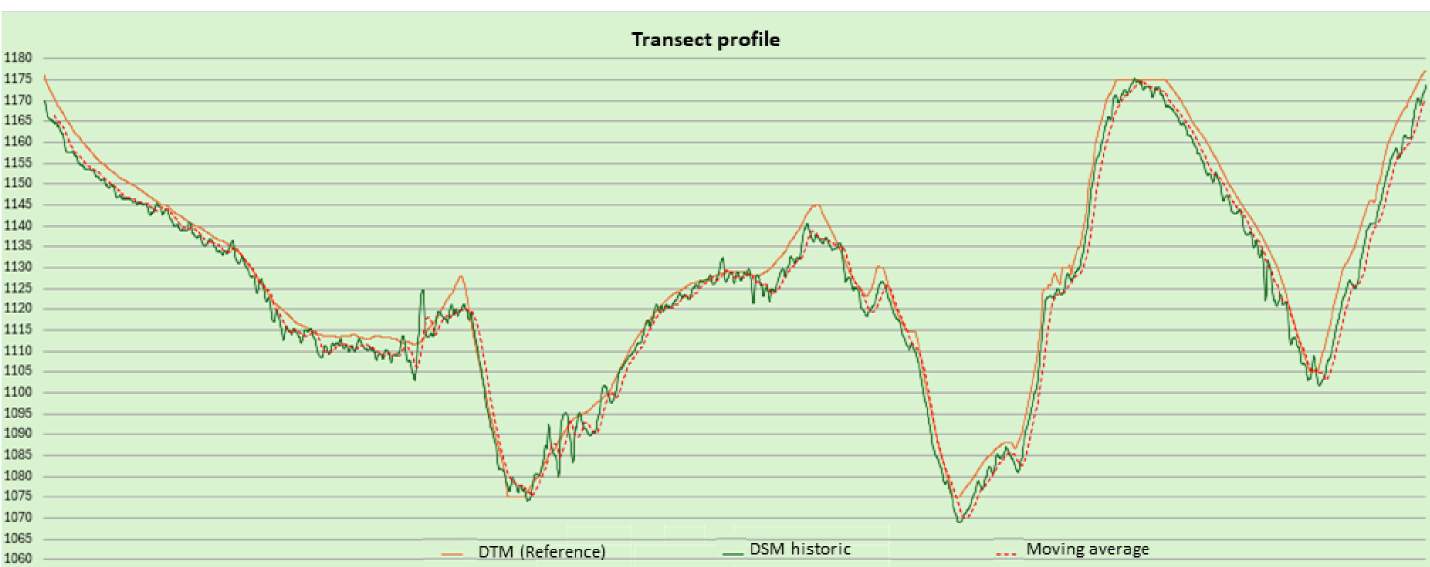

Figure 9 - Transect elevation profile of digital models compared.

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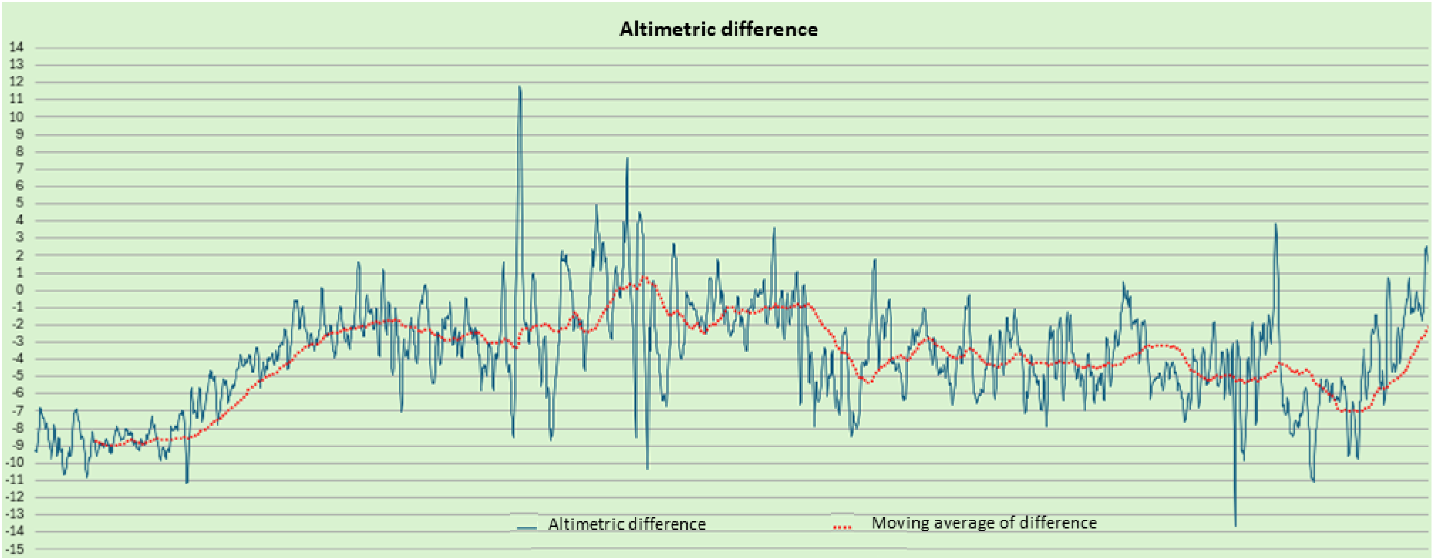

Figure 10 - Transect Elevation profile generated by 1959 and 2009 Digital Models subtraction.

IV. CONCLUSIONS

The present study demonstrates the effectiveness of implementing processing techniques where interior and exterior orientation parameters are unknown, utilizing Structure from Motion (SFM) algorithms for reconstructing digital information from historical aerial photographs lacking camera and flight parameters. This methodology successfully generated Historical DSM and a Historical Orthomosaic model with accuracy. The derived data proved to be valuable and sufficiently precise for investigating the region's socio-environmental dynamics.

Based on the methodologies delineated, the attempt to use inferences to extract artificial parameters proved ineffectual in generating data of satisfactory quality. Conversely, our approach prioritized optimization and the refinement of data processing, thereby facilitating the systematic alignment of 156 out of 262 photographs.

This innovative method unleashes the untapped potential within historical image archives, which have been neglected due to the absence of dependable processing techniques. This represents a significant advancement, particularly in countries like Brazil and other developing nations, by enhancing their ability to identify past land use and changes over time, provided they have a collection of historical analog photographs. By shedding light on historical land use patterns, this research provides valuable insights for comprehending the present landscape and guiding future planning efforts.

ISSN eletrônico 2177-2738
RA'EGA, Curitiba, PR, V.61, n.1, p. 112 – 133, 12/2024
http://dx.doi.org/10.5380/raega.v61i1.95457

Acknowledgements

This work was supported by the University of Brasília, Institute of Geosciences, Graduate Program in Applied Geosciences and Geodynamics, and by CAPES Foundation that granted the graduate fellowship.

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