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Evaluation of positional quality of point clouds obtained by Terrestrial Laser Scanner (TLS)

Avaliação da qualidade posicional da nuvem de pontos obtida a partir de Laser Scanner Terrestre (LST)

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Abstract: 3D TLS (Terrestrial Laser Scanner) surveys rapidly provide thousands of points of the mapped area and reduces the surveying operational costs. Several companies use TLS point clouds as a reference for other surveys, although the positional accuracy of this product has not been evaluated as fully reliable. This study aimed to evaluate the positional quality of point clouds generated by Terrestrial Laser Scanner (TLS) according to Decree No. 89.817 (Brasil, 1984), in addition to ET-CQDG (CONCAR, 2011; DCT/DSG, 2016). For this purpose, control points collected with GNSS receivers by RTK surveying were used for the evaluation. The number of control points was defined by the isolated lot method with sampling procedure, according to DCT/DSG (2016). To evaluate the spatial distribution of points, the Ripley K-Function was used. For trend analysis, the directional mean of the discrepancy vectors, together with circular variance was used. The results for this study show that TLS points cloud is compatible by considering the planimetric precision and planimetric accuracy to the scale of 1: 280 for flat areas, being classified as class A (CAS-DCS, Cartographic Accuracy Standard-Digital Cartographic Standard) for planimetry, according to Brazilian standards of positional accuracy, showing no trends in the coordinates.

Keywords: Quality Control; sampling; Positional Accuracy; Cartography; TLS; ET-CQDG.

Resumo: O levantamento 3D via LST (Laser scanner terrestre) fornece rapidamente milhares de pontos da área mapeada e reduz os custos operacionais em termos de levantamento. Várias empresas usam a nuvem de pontos LST como referência para outros levantamentos, embora a acurácia posicional deste produto não tenha sido avaliada como totalmente confiável. Assim, o objetivo deste estudo foi avaliar a qualidade posicional da nuvem de pontos gerada pelo LST de acordo com o Decreto nº 89.817 (Brasil, 1984), aliado ao ET-CQDG (CONCAR, 2011; DCT/DSG, 2016). Para tanto, foram utilizados pontos de controle coletados com receptores GNSS pelo método de levantamento RTK para a avaliação. O número de pontos de controle foi definido pelo método do lote isolado com procedimento de amostragem de acordo com o DCT/DSG (2016). Para avaliar a distribuição espacial dos pontos, utilizou-se a Função K de Ripley. Para análise de tendência, foi empregada a média direcional dos vetores de discrepância, juntamente com a variância circular. Os resultados mostram que a nuvem de pontos LST é compatível em termos de acurácia e precisão planimétricas à escala de 1:280 para áreas planas, sendo classificada como classe A (PEC-PCD, Padrão de Exatidão Cartográfica-Padrão Cartográfico Digital) para planimetria, de acordo com o padrão brasileiro de precisão posicional, não apresentando tendências nas coordenadas.

Palavras-chave: controle de qualidade; amostragem; acurácia posicional; Cartografia; LST; ET-CQDG.

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1. Introduction

Recently, the Terrestrial Laser Scanners (TLS), Mobile Laser Scanners (MLS) and Aerial Laser Scanners (ALS) systems, by considering a general acquisition data with laser sensors, have had constant improvement, with better resolution, both in terms of terrestrial sensors (WUTKE and CENTENO, 2007; MARTINS NETO *et al.*, 2013; TAN *et al.*, 2024), among others, and airborne sensors presented in Vosselman and Dijkman (2001), Rottensteiner and Briese (2002), Botelho and Centeno (2007), Fonseca Neto *et al.* (2017). This leads to a positive trend for applications requiring digital terrain models (DTM) and digital surface models (DSM) with high precision (PIROTTI *et al*., 2012).

In the geoscience area, the TLS , MLS and ALS have been used in several engineering applications (STAIGER, 2003) such as digital terrain modelling (DTM), due to the rapid data acquisition rate and reliability of the altimetric information provided by the equipment (PIROTTI *et al.*, 2012); topographical and cartographic mapping for cadastral purposes (VOSSELMAN and DIJKMAN, 2001; BOTELHO and CENTENO, 2011); pre-projects of highways and railroads; checking of interference (ROTTENSTEINER and BRIESE, 2002); object extraction (CENTENO and PEIXOTO, 2023); detection glaciologically relevant surface elevation change (VOORDENDAG *et al.*, 2023); historical monuments for preservation and reconstruction of cultural heritage; archaeological sites for archaeological study/research; large structures such as aircraft and watercraft for the evaluation of parts manufacturing quality before assembly; bridges; monitoring of structures for wear assessment (LENARTOVICZ, 2013); in the area of industrial expansion for monitoring interference in the assembly of new equipment and of how "As Built" survey (VOSSELMAN and DIJKMAN, 2001; STAIGER, 2003; NASCIMENTO JÚNIOR *et al.*, 2006; WUTKE and CENTENO, 2007; BOTELHO and CENTENO, 2011; PIROTTI *et al.*, 2012; LENARTOVICZ, 2013; MARTINS NETO *et al.*, 2013).

According to Santos *et al.* (2016a), to define the finality for which a product will be destined, it is necessary to evaluate the positional quality of spatial data, since cartographic mapping produces models of reality, which will later be used for decision-making. Thus, as high the control level of spatial data so will be the precision level for decision making.

The main aim of this study is to analyse the positional planialtimetric quality of point clouds generated by TLS, using the point and linear feature analysis method.

This work is justified by the fact that many users of TLS for spatial data generation do not have true knowledge of the positional quality obtained from such products (NASCIMENTO JÚNIOR *et al.*, 2006; WUTKE and CENTENO, 2007; PIROTTI *et al.*, 2012; LENARTOVICZ, 2013; MARTINS NETO *et al.*, 2013).

It is also important to point out other works and researches that comment and report on the state of the art and possibilities in terms of applications, as well as accuracy resulting from the use of TLS, such as in Staiger (2003), Nascimento Júnior *et al.* (2006), Wutke and Centeno (2007), Martins Neto *et al.* (2013), Cintra and Gonçales (2017), Alves *et al.* (2020), Elaksher *et al.* (2023), TAN *et al.*, 2024).

To evaluate TLS point clouds, the CAS (Cartographic Accuracy Standard) must be used and is defined in Decree No. 89.817 of 1984 (Brasil, 1984), which regulates the classification of cartographic products in Brazil, as well as the updates to the concepts established in (CONCAR, 2011; DCT/DSG, 2016), which defines the CAS-DCS (Cartographic Accuracy Standard-Digital Cartographic Standard).

2. Methodology

For practical conduction of this research, the following resources were used: VZ 400 model terrestrial laser scanner, RIEGL brand. The main characteristics of the scanner are: measurement rate of 42,000 pts/sec for a frequency of 100 KHz and 122,000 pts/sec for frequency of 300 KHz; maximum distance of 600 m for a natural target with 90% reflectivity and frequency of 100 kHz, and minimum distance of 1.5 m; precision of 3 mm and accuracy of 5mm; divergence of the laser 0.35 mrad, reading 360o horizontally and 100o (+ 60o/ - 40o) vertically; a pair of Javad Triumph-1 RTK GNSS receivers, used for precise surveying of laser scanner positions, with the following technical specifications: horizontal precision of 1.0 cm + 1.0 ppm, vertical precision of 1.5 cm + 1.0 ppm, for RTK (Real Time Kinematic) kinematic survey mode. For post-processed survey mode, the horizontal precision is 3 mm + 0.5 ppm and vertical precision is 5 mm + 0.5 ppm; computer software for processing collected data: to process data from the laser scanner, the RiscanPro program, version 2.6.1. was used, to carry out statistical analysis, the GeoPEC program, version 3.6 was used (SANTOS, 2023), to implement the linear feature method, ArcGIS Software Desktop version 10.5, was used, a vehicle to which the laser scanner was adapted by means of an anti-shock base (manufactured by Riegl), which has a shock absorber system, thus reducing impact on the equipment from the movement of the vehicle for scan the study area, a tablet was used to operate the laser scanner via WIFI, Dell Inspiron 15,computer with Intel® Core™ i7-6500U processor, CPU @2.50GHz, RAM memory of 16 GB, dedicated GeForce 930M 4 GB video card, 64-bit operating system.

The methodology (figure 2) can be divided into the following phases: (1) defining the study area; (2) field surveys with TLS and data processing; and (3) validating the point cloud generated by TLS.

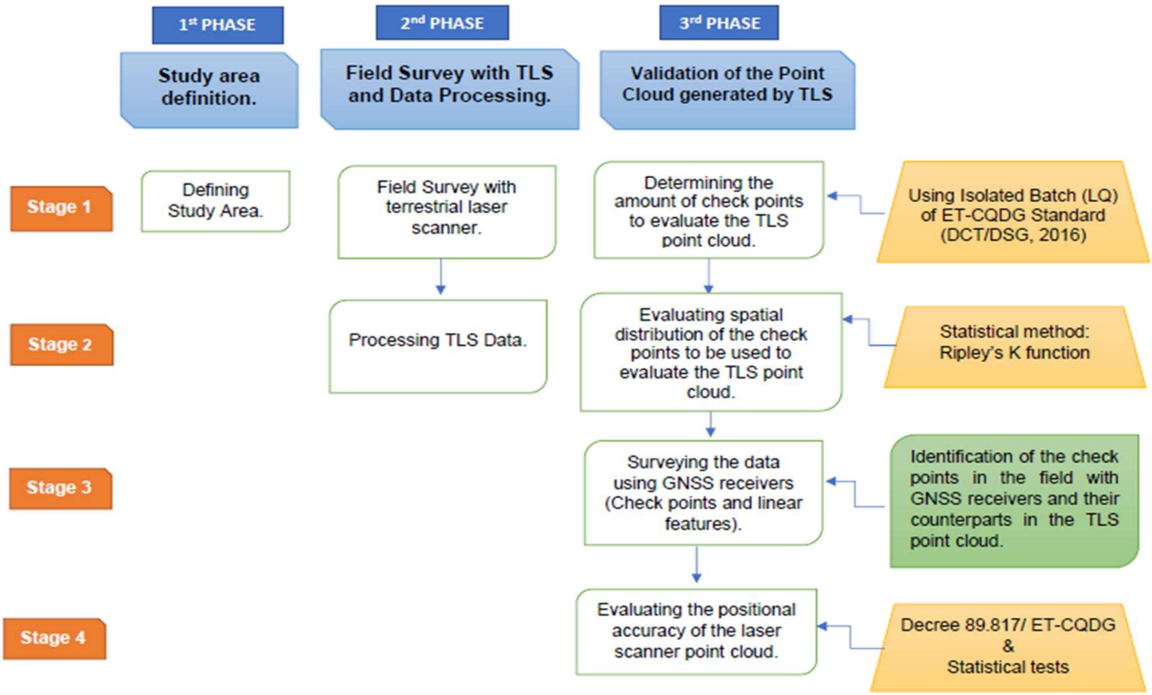

Figure 1 – Overview of all phases of the methodology.
Source: Authors (2024).

2.1 Phase 1: Defining the study area

The first stage of Phase 1 started with the choice of the surveyed area. For this study, we determined an area (see the Figure 3) within the Campus of the Universidade Federal de Viçosa, located in the Zona da Mata region of Minas Gerais State, with geographic coordinates 20°45'14" S and 42°52'54" W in the WGS-84 (World Geodetic System 84) Reference System. The size of the study area was approximately 11.8 ha (hectares).

2.2 Phase 2: Field surveys with TLS and data processing

On the first stage of Phase 2, a survey of the study area was done using a RIEGL TLS, model VZ 400, attached to a vehicle by means of an anti-shock base manufactured by RIEGL, where the average point cloud density was about 4,000/m² (four thousand by square meters). Fifty-five (55) positions were surveyed with the TLS.

The second stage of Phase 2 started with processing data from the terrestrial laser scanner unit. The RiscanPro software, version 2.6.1 was used. After processing, the result collected corresponded to a point cloud that will have its positional accuracy evaluated in the following stages.

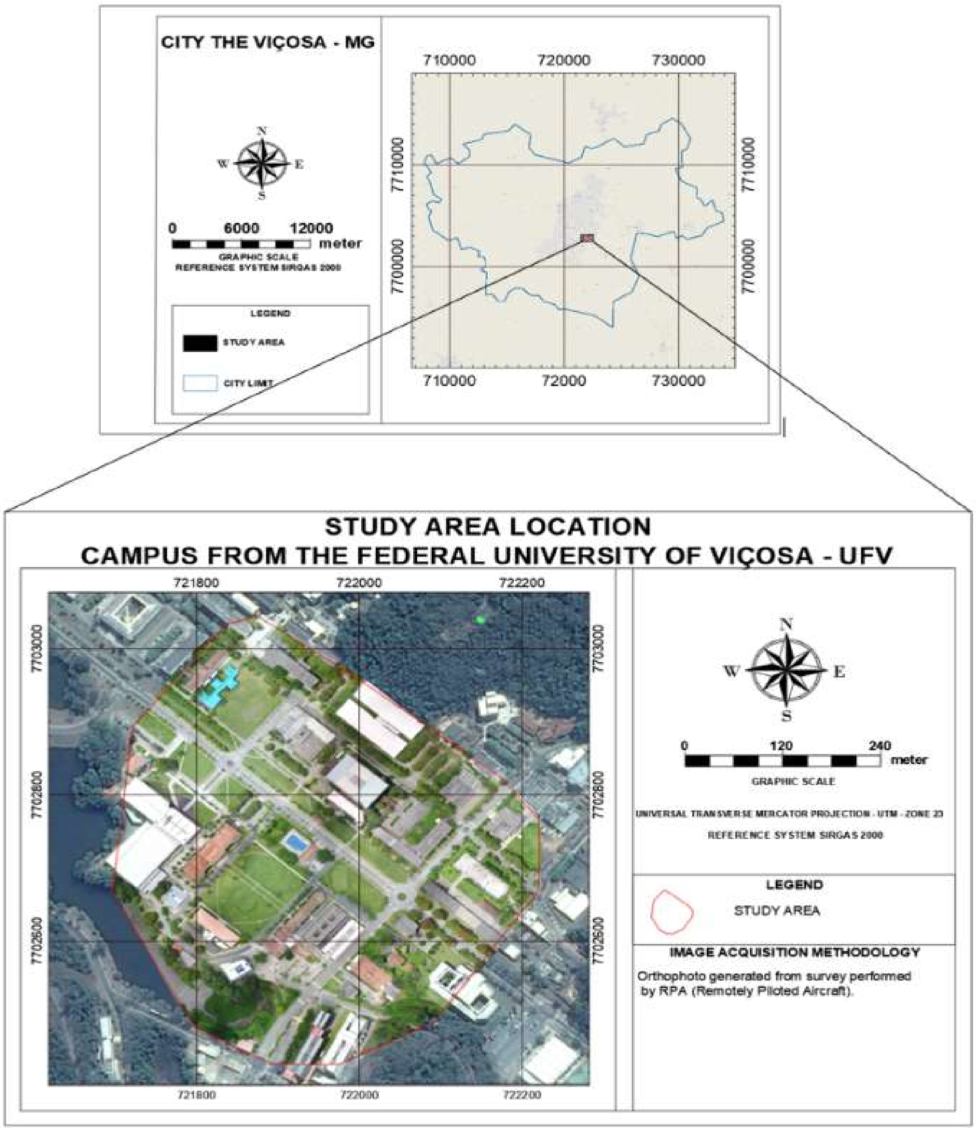

Figure 2 – Study area, UFV Campus - Federal University of Viçosa.
Source: Authors (2024).

2.3 Phase 3: Validation of point cloud generated with the Terrestrial Laser Scanner (TLS)

One of the techniques for evaluating the positional accuracy of a cartographic product is the use of the feature points method (ARIZA-LÓPEZ, 2002; NERO, 2005; CINTRA and NERO, 2005; ARIZA-LÓPEZ et al., 2007; ARIZA-LÓPEZ e ATKINSON-GORDO, 2008, NERO et al., 2017).

In this method, the evaluation of positional accuracy of feature points is done by comparing samples of check points, obtained on the field or in a more accurate spatial data, with a sample of homolog points in the spatial data to be evaluated. From the results generated from this comparison, many formulations and statistical tests are applied according to the positional accuracy regulation used.

The planimetric ($disc_{2D}$) and altimetric ($disc_Z$) discrepancy values, described in Equations 1 and 2 are obtained by the vectors of positional resultant between reference coordinates (X_{ref}, Y_{ref}) obtained on the field, with the test coordinates obtained from spatial data (X_{test}, Y_{test}). The mathematical model for the calculating the RMSE of the discrepancies can be observed in Equation 3, where *n* is the number of check points (sampling) and *pj* is the index number of the point that has being checked in the Equations 1 or 2.

$$disc_{2D} = \sqrt{(X_{test} - X_{ref})^2 + (Y_{test} - Y_{ref})^2} \quad (1)$$

$$disc_Z = Z_{test} - Z_{ref} \quad (2)$$

$$RMSE = \sqrt{\frac{\sum_{j=1}^{n} disc_{pj}^{\ 2}}{n}} \quad (3)$$

In Brazil, the positional quality of cartographic products is determined by the Cartographic Accuracy Standard (CAS) in Decree nº 89.817 of June 20, 1984, published in the Official Union Journal of June 22, 1984, that regulates the classification of cartographic products in terms of positional accuracy (BRASIL, 1984). In 2016, the Geographical Service Board of the Brazilian Army (DSG) designed the Technical Specification for Geospatial Data Quality Control (ET-CQDG) to obey Decree nº. 6.666/2008 (Brasil, 2008), that establishes the installation of the Spatial Data National Infrastructure (SDNI), and its main goal to provide a standardized form of quality evaluation of geospatial data group products integrating the Brazilian National Cartographic System (SCN).

Table 1 shows the tolerance values for evaluating planialtimetric positional accuracy in accordance with Decree No. 89.817 (Brasil, 1984) and ET-CQDG (DCT/DSG, 2016).

Table 1 – Tolerances used for evaluating the positional accuracy of the planaltimetric method.

Class		Planimetric		Altimetry (DTM 1:1,000)	
DECREE 89.817	ET-CQDG	CAS or CAS-DCS	SE or DSE	CAS or CAS-DCS	SE or DSE
-	A	0.28 mm x s	0.17 mm x s	0.27 m	0.17 m
A	B	0.50 mm x s	0.30 mm x s	0.50 m	0.33 m
B	C	0.80 mm x s	0.50 mm x s	0.60 m	0.40 m
C	D	1.00 mm x s	0.60 mm x s	0.75 m	0.50 m

Where: Class=class according in DECREE 89.817 (Brasil, 1984) (A, B and C) or ET-CQDG (DCT/DSG, 2016) (A, B, C and D); Planimetric=planimetric parameters evaluation; Altimetry (DTM 1:1,000)=altimetric parameters evaluation for Digital Terrain Model compatible with the 1;1.000 scale; CAS=Cartographic Accuracy Standard; SE=Standard Error; CAS-DCS=Cartographic Accuracy Standard- Digital Cartographic Standard; DSE=Digital Standard Error; s=reference scale of the mapping (for example: 1:1,000, 1:2,000, 1:10,000; mm=millimeters; m=meters
Source: Decree No. 89.817 (Brasil, 1984) and ET-CQDG (DCT/DSG, 2016).

Two conditions must be fulfilled for the classification of positional accuracy of a cartographic product:

(i) Ninety percent of the points collected in spatial data must present discrepancy values (*disc*) equal or inferior to the value of CAS-DCS, in relation to the scale and class tested when the coordinates are compared to coordinates surveyed on a field with a more accurate method, according to Equation 4. The SDCP (Standard Deviation of Control Points) is the difference between both the X or Y or Z coordinate observations and the X or Y or Z reference coordinates, respectively.

$$90\%\ disc \leq \text{CAS-DCS} \quad (4)$$

(ii) The RMSE (Root Mean Square Error) of discrepancy samples, based in ASPRS (2015) and Zanetti, Braga and Santos (2018), must be lower or equal to the DSE (Digital Standard Error) in relation to the scale and class tested, according to Equation 5.

$$\text{RMSE}\ (disc) \leq \text{DSE} \quad (5)$$

Before evaluating the positional accuracy of the laser scanner point cloud, the number of check points required was determined and their spatial distribution was evaluated. The first stage of Phase 3 started with determining the number of check points and their spatial distribution.

For this purpose, the isolated lot procedure from ET-CQDG Regulation (DCT/DSG, 2016) was used. According to ET-CQDG (DCT/DSG, 2016), lot size must be defined by determining the valid cells, where each valid cell corresponds to one element of the population. The regulation suggests that the product to be evaluated be partitioned into 4 x 4 cm cells on the project scale. Initially, the cloud was evaluated in the 1:1000 scale, resulting in division into 40 x 40 m cells on the ground. It can be seen from Figure 4 that the edges have cells smaller than 40 m, so that all cells are within the boundary of the mapped area.

This way, 68 lots with dimensions of 40 by 40 m and 5 smaller lots were determined. The sum of the smaller cell areas corresponds to 40x40 m cells, totaling 73 lots on the point cloud, as shown in Figure 4.

Once the lot size was defined, the sample size was determined referring to the ISO 2859-2 (ISO, 1985) table and adapted to the ET-CQDG (DCT/DSG, 2016). The sample was then evaluated by Isolated Lot, converting AQL (acceptable quality limit) into QL (quality limit).

Based on Table 2, in the lot size equals 73 and the AQL value of 4% for the interval comprising the lot size, the result obtained was a QL of 20%. Subsequently, Table 3 was used, entering the QL value of 20% for the same interval that comprised the lot size, obtaining a sample size of 10 (ten) check points, and none of them could be discarded.

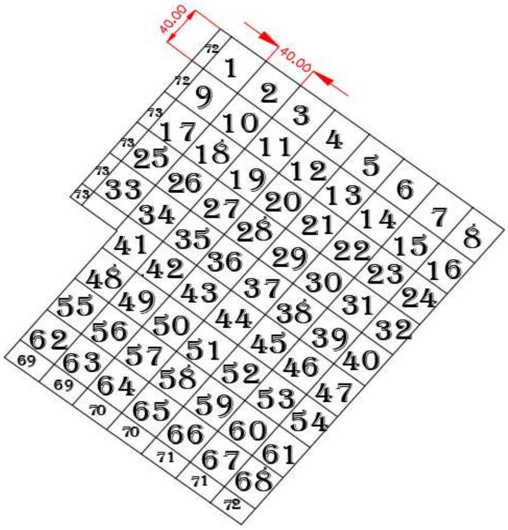

Figure 3 – Schematic image of the 73 lots, with dimensions of 40 x 40 m.
Source: Authors (2024).

Lot size	AQL (%)		
	1,0	4,0	10
16 to 25	12,5	32	32
26 to 50	12,5	20	32
51 to 150	8,0	20	32
151 to 1200	5,0	20	32
1201 to 10 000	3,15	12,5	20
10 001 to 150 000	3,15	8,0	20
150 001 and larger	2,0	8,0	20

Figure 4 – Determination of Quality Limit and (QL) in %.
Source: DCT/DSG (2016) and ISO 2859-2 (ISO, 1985).

Lot size		Quality limit (QL) in %								
		0,8	1,25	2,0	3,15	5,0	8,0	12,5	20	32
16 to 25	n	↓	↓	↓	↓	↓	17	13	9	6
	Ac						0	0	0	0
26 to 50	n	↓	↓	↓	50	28	22	15	10	6
	Ac				0	0	0	0	0	0
51 to 90	n	↓	↓	50	44	34	24	16	10	8
	Ac			0	0	0	0	0	0	0
91 to 150	n	↓	90	80	55	38	26	18	13	13
	Ac		0	0	0	0	0	0	0	1
151 to 280	n	170	130	95	65	42	28	20	20	13
	Ac	0	0	0	0	0	0	0	1	1
281 to 500	n	220	155	105	80	50	32	32	20	20
	Ac	0	0	0	0	0	0	1	1	3
501 to 1200	n	255	170	125	125	80	50	32	32	32
	Ac	0	0	0	1	1	1	1	3	5
1201 to 3200	n	280	200	200	125	125	80	50	50	50
	Ac	0	0	1	1	3	3	3	5	10
3201 to 10 000	n	315	315	200	200	200	125	80	80	80
	Ac	0	1	1	3	5	5	5	10	18
10 001 to 35 000	n	500	315	315	315	315	200	125	125	↑
	Ac	1	1	3	5	10	10	10	18	
35 001 to 150 000	n	500	500	500	500	500	315	200	↑	↑
	Ac	1	3	5	10	18	18	18		
150 001 to 500 000	n	800	800	800	800	↑	↑	↑	↑	↑
	Ac	3	5	10	18					
500 001 and larger	n	1250	1250	1250	↑	↑	↑	↑	↑	↑
	Ac	5	10	18						

Figure 5 – Defining sample size, according to Quality Limit (QL) in%.
Source: DCT/DSG (2016) and ISO 2859-1 (ISO, 1999).

Therefore, using the isolated lot procedure from ET-CQDG regulations (DCT/DSG, 2016), ten (10) check points were selected to validate the TLS point cloud. However, in this study, we chose to use a larger number of check points in order to obtain a larger sample than suggested by ET-CQDG isolated lot principle (DCT/DSG, 2016).

For a more rigorous analysis, it was decided that 29 (twenty-nine) check points would be used to evaluate the positional accuracy of the laser scanner point cloud.

In the second stage of Phase 3, Ripley K Function statistic method was used to determine the behavior of check point distribution, as suggested, and presented in the study by Santos *et al.* (2016b).

ArcGIS Desktop software was used to generate the Ripley K Function Graph, and entry data were two files in the shapefile format: one referring to the planimetric coordinates of check points and another referring to the limit of the surveyed area. A graph was used to analyze K function, as shown in Figure 5. The blue line in the graph shows the expected pattern (random), the red line represents the observed pattern, and the grey dotted line represents the confidence level. It can be seen that for the set of check points used, spatial distribution showed a random pattern, since the observed is within the confidence interval of the expected pattern.

In view of the results obtained, it was evidenced that the check points were well distributed to validate the TLS point cloud.

This way, the third stage of Phase 3 started, where check point survey done using GNSS receptors.

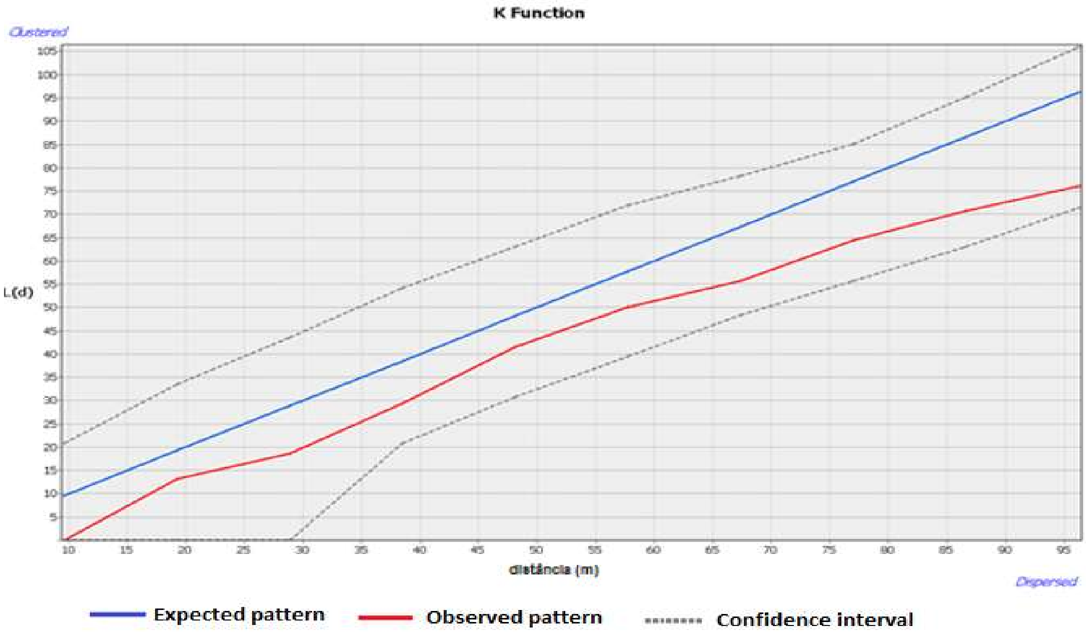

Figure 6 – Result of Ripley's K Function analysis for check points surveyed via GNSS to validate the TLS point cloud. Source: Authors (2024).

On the fourth stage of Phase 3, evaluation of positional accuracy of the TLS point cloud started. Before this evaluation, TLS data was georeferenced in the same projection system coordinates of the GNSS data. To define the checkpoints, well identifiable locations were chosen (e.g., curb and crosswalk corners), which contained a point in the TLS cloud. After having this checkpoint in the TLS, its homologous point was collected in the field with GNSS receivers.

The process of positional accuracy was applied to the data to analyze the sample of positional discrepancies obtained from point features. First, the 3σ method was used to detect outliers, as recommended by Nero (2005). Afterward, trend analysis was performed using Student's t-test and Directional Mean and Circular Variance spatial statistics (Santos *et al.*, 2016b). As the Student's t-test is applied only to data following a normal distribution, the Jarque-Bera normality test was used at a 95% confidence level, as presented by Nero (2005). Finally, positional accuracy was evaluated by applying the positional accuracy pattern defined by Decree 89.817 (Brasil, 1984) together with ET-CQDG (CONCAR, 2011; DCT/DSG, 2016) for the study scale. Initially, a scale of 1/1000 was used. If the product is classified in Class A, the scale would be changed until reaching the maximum scale level, at which the result would return to Class A. In addition to the point feature evaluation, TLS point cloud was validated using linear features using Double Buffer, based on Santos *et al.* (2015, 2016a). Six linear features were collected, varying between straight features and curved features, according to Figure 6.

The linear reference features were collected through points with equidistance of every 1 m for curved segments and equidistance of every 3 m and every 10 m for straight segments. Subsequently, the drawing connected these points thus forming the linear reference features. In the TLS point cloud, homologous linear features (test features) were vectored on the screen mode with ArcGIS drawing tools. The maximum length of linear features was 240 m and the minimum length was 8 m.

3. Results analysis

3.1 Feature Points Method

With check points coordinates collected in the field and their counterparts extracted from the TLS point cloud, discrepancies were calculated using GeoPEC software, version 3.6 (SANTOS, 2023).

The graph in Figure 7 shows discrepancy values of components E, N and h (Geometric Altitude). Figure 8 shows the result of positional discrepancy with altimetric discrepancy.

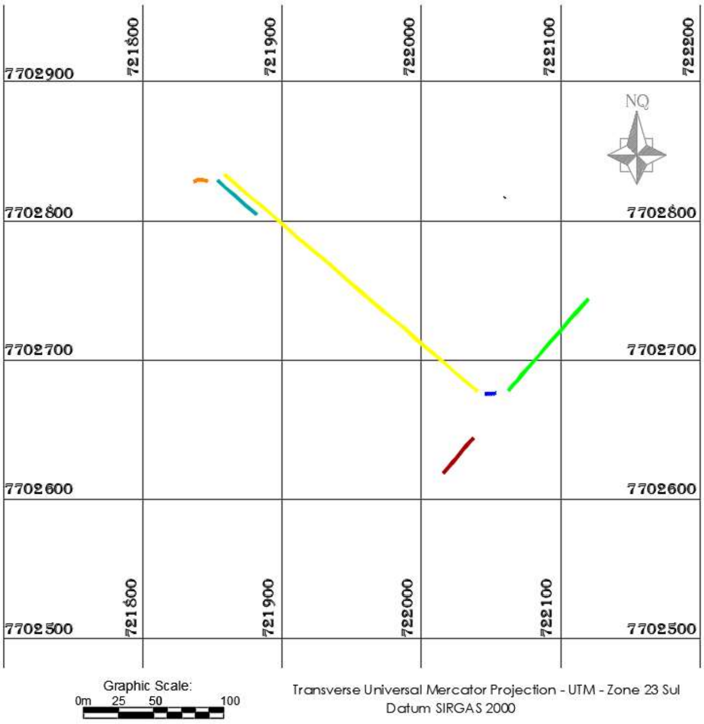

Figure 7 – Distribution of linear features determined by GNSS.
Source: Authors (2024).

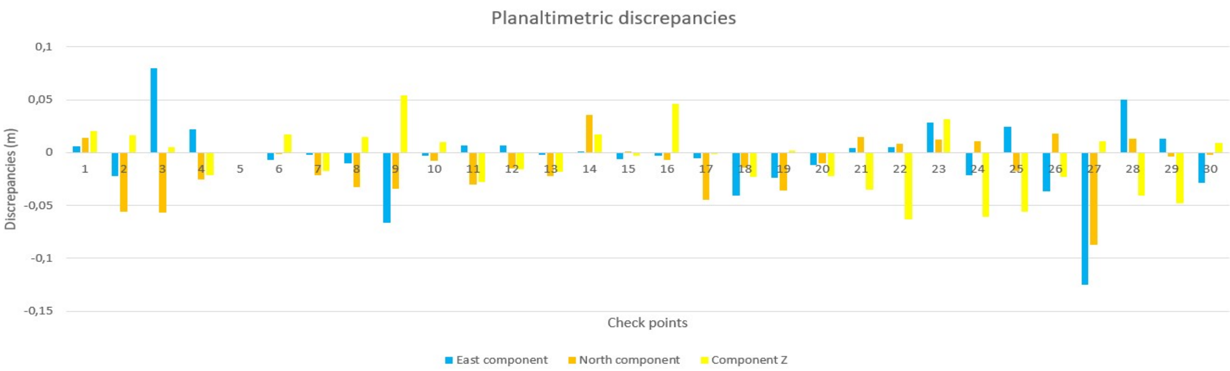

Figure 8 – Graph of planialtimetric discrepancies (m) of the point features obtained by GNSS survey and their counterpart features in the laser scanner cloud.
Source: Authors (2024).

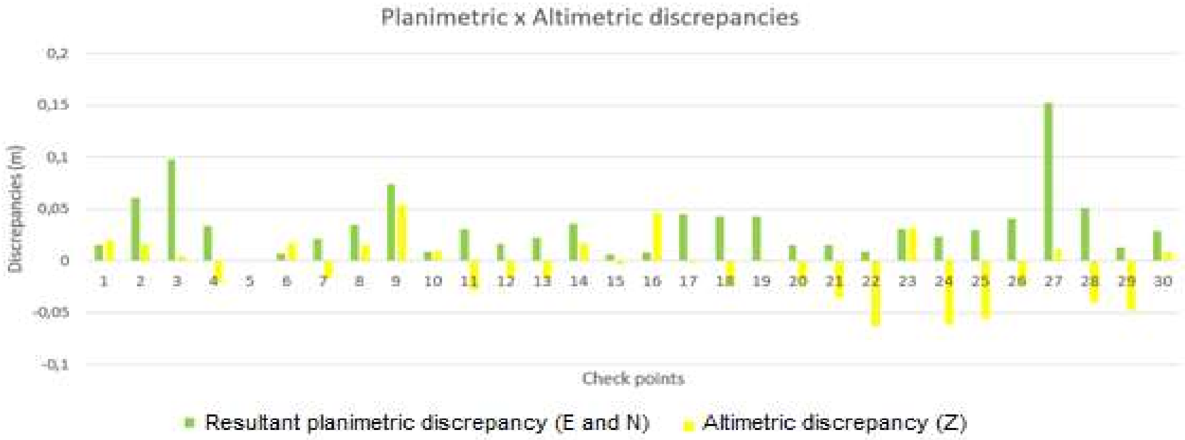

Figure 9 – Graph of resultant planimetric and altimetric discrepancies (m) of the point features obtained through GNSS survey and their counterpart features in the laser scanner cloud.
Source: Authors (2024).

Using the 3σ method for the 1/280 scale, it was found that there were no outliers in the discrepancies sample between the coordinates extracted from the point cloud and those collected in the field.

Subsequently, the Jarque-Bera normality test (Bowman-Shelton) was applied to verify whether the sample had normal distribution or not. The statistical result indicated that for both planimetry and altimetry the samples showed non-normal distribution. To verify the existence of trend in the point cloud the Student's t, Directional Mean and, Circular Variance statistical tests were used. As the data sample did not show normal distribution, it used the Directional Mean, and Circular Variance results (both presented for GeoPEC software) to analyze the existence of trend. The value of the Directional Mean was 202.2717° and Circular Variance of 0.6757 (no dimension), evidencing that for planimetry, as well as altimetry, the sample did not show trend (more detail to see Santos et al., 2016b).

After analyzing the positional accuracy of the laser point cloud, following ET-CQDG CAS-DCS evaluation guidelines (Brasil, 1984; CONCAR, 2011; DCT/DSG, 2016), it was classified as Class A, associated with the mapping scale of 1/280 for planimetry. Planimetric mean ($disc_{2D}$) of the sample was 0.035m, deviation of 0.031m, RMSE of 0.046m, the maximum discrepancy value of 0.152m, and minimum discrepancy of 0.006m. It is important to say that 1/280 scale was the maximum scale that satisfied class A of CAS-DCS.

With the values above, it can be concluded that we should not observe merely the value of TLS accuracy, which is 5 mm (the nominal TLS accuracy according to the manufacturer), as every TLS point cloud was referenced in the survey with the RTK. Thus, there is a propagation of the uncertainty variance of the laser scanner, the uncertainty of the RTK, and the baseline. Thus, the RMSE value obtained from TLS positional accuracy assessment becomes compatible with all the uncertainties generated in the process.

In evaluating altimetric positional accuracy of the TLS cloud, curves with 0.30 m equidistance were defined, thus the limits of CAS/ET-CQDG "Class A" were set at 0.081 m and the standard error was 0.050 m. Thus, it was found that 100% of the discrepancies were within CAS limits, and the RMSE of 0.031m was smaller than the scale SE for this class. Therefore, MDTs can be classified as "Class A" for use on a scale of 1/280 or less. Table 4 shows statistical data of the planimetric evaluation and Table 5 shows data regarding the altimetric evaluation of the said sample.

Table 2 – Statistical data evaluating the planimetric positional accuracy of the TLS point cloud.

Items Analyzed	Results
Sample size (*n*)	29
Grouped spatial data? (K Function)	No
Number of outliers	0
Is sample biased?	No
Does the sample show normal distribution?	No
Mean ($disc_{2D}$)	0.035 m

Standard deviation ($disc_{2D}$)		0.031 m
RMSE ($disc_{2D}$)		0.046 m
Resulting from Planimetric Discrepancies	Maximum value	0.152 m
	Minimum value	0.006 m
CAS-DCS (1:280 – Class A)		0.078 m
SE (1:280 – Class A)		0.048 m
% of Discrepancy ≤ CAS		93.1 %
RMSE ≤ SE		Yes
Is spatial data precise? (In compliance with Decree 89.817/ET-CQDG)		Yes

Source: Authors (2024).

Table 3 – Statistical data evaluating altimetric positional accuracy of the TLS point cloud.

Items Analyzed		**Results**
Sample size (n)		29
Grouped spatial data? (K Function)		No
Number of outliers		0
Is sample biased?		No
Does the sample show normal distribution?		No
Mean ($disc_Z$)		-0.008 m
Standard deviation ($disc_Z$)		0.030 m
RMSE ($disc_Z$)		0.031 m
Discrepancy	Maximum value	0.054 m
	Minimum value	- 0.063 m
CAS-DCS (eq 0.30m – Class A)		0.081 m
SE (eq. of 0.30m – Class A)		0.050 m
% of Discrepancy ≤ CAS		100 %
RMSE ≤ SE		Yes

Source: Authors (2024).

3.2 Linear Feature Method

After evaluating the points, the linear features method was used, through the Double Buffer method uncertainty approach (SANTOS *et al.*, 2015). In this article, the feature point method (see item 3.1) was used for a more detailed assessment, with outlier detection, normality analysis, trend, and spatial distribution, as well as the classification of quality by the Brazilian standard. The linear feature method was used only for quality analysis with the application of the Brazilian standard. However, the descriptive statistics of the sample of positional discrepancies obtained by the Double Buffer method were added to the text. The planimetric mean ($disc_{2D}$) was 0.046m, deviation of 0.012m, RMSE of 0.047m, the maximum value of the 0.061m discrepancy, and minimum discrepancy of 0.026m. The laser scanner point cloud showed the same classification as the point evaluation method (Class A for scale 1/280). Figure 9 shows discrepancies in meters obtained by the Double Buffer method.

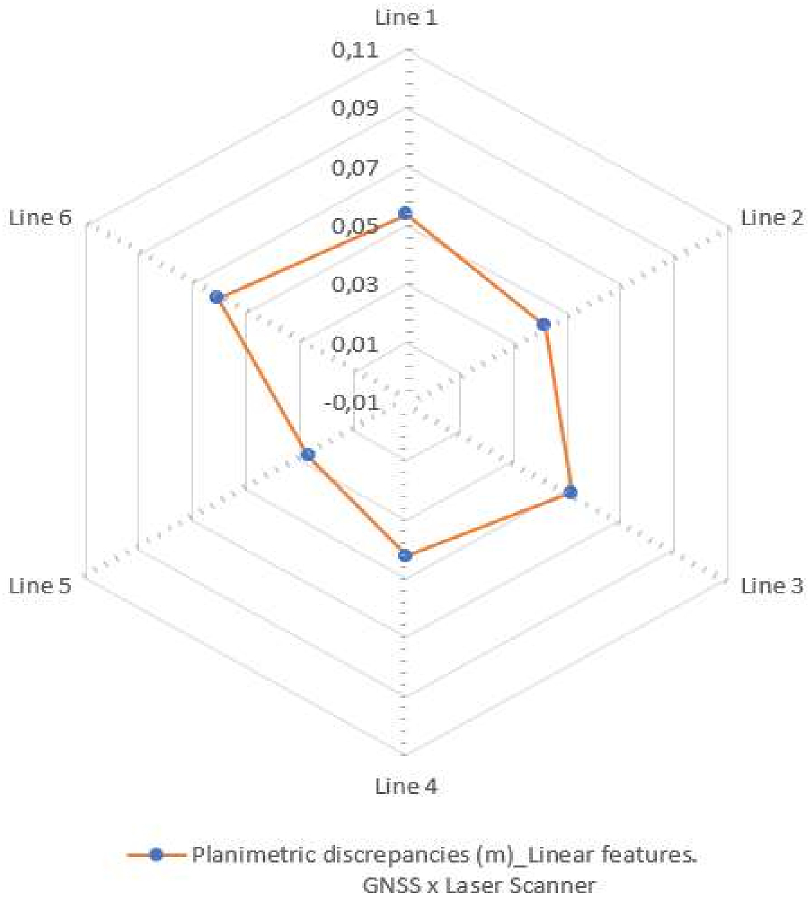

Figure 10 – Discrepancies graph (m), of linear features obtained by GNSS survey and its counterpart features in the laser scanner cloud, using the Double Buffer method.
Source: Authors (2024).

4. Conclusion

Because TLS is used as a reference for several surveys, the aim of this research was to evaluate the positional quality of the product generated by TLS, where is known of the positional accuracy of the point cloud generated by the equipment.

An important aspect is the density of point cloud which was about four points per square meter in this study. The result obtained in evaluating the positional accuracy of the TLS point cloud, using the point method, achieved Class A for a scale of 1/280 in planimetry. In altimetry, the cloud was classified as Class A for contour lines with vertical equidistance of 0.30 m. Both cases followed the evaluation guidelines of Decree No. 89819 (Brasil, 1984) and ET-CQDG (CONCAR, 2011; DCT/DSG, 2016). The results show that once the point cloud has been classified, it can serve as a reference product for further evaluation and in the trend analysis, it was found that data from TLS point clouds are free of systematic effects, that is, there is no displacement in the E (East) or N (North) direction. The Double Buffer method was applied through linear features to evaluate the precision of the laser scanner point cloud, and the results obtained were the same as when using feature points.

In addition, further research suggests the verification of these preliminary findings, replicating them to a broader area with irregular topography and dense vegetation and the positioning tests with more PPP (Precise Point Positioning) techniques with different conditions, for example.

Finally, a further suggestion would be the application of the simulation processes of this data with the functions presented here (Ripley's K, among others), together with those applied for several authors, in addition to considering sample distribution by weights and variables.

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