A Comparative Study on Airborne LiDAR Data Processing Software for a Smarter Road Construction in Case of Space Science and Geospatial Institute

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Abstract

The application of IT in the Ethiopian Construction industry has been quite questionable in the past depriving the country from enjoying the benefits. IT practices such as using Light Detection and Ranging (LiDAR) in surveying for road design is relatively new to the country. The current geometric design manual being used by Ethiopian Road Administration (ERA) doesn't direct the use of LiDAR technology for surveying, yet that hasn't stopped ERA from buying its LiDAR surveyed data output from Space Science and Geospatial Institute (SSGI). In this paper, available LiDAR point cloud post processing software that could be used by SSGI are investigated. The software are compared with a thorough analysis of the technical, organizational and business aspects at hand in order to recommend the best for SSGI.

KEYWORDS: Light Detection And Ranging (LiDAR), Ground Control Point (GCP), Inertia Measurement Unit (IMU) & Global Positioning System (GPS)

1. Introduction

The construction industry is one of the major contributors to the Ethiopian Gross Domestic Product (GDP). According to [1], Construction was one of the sectors that accounted for most of the country's GDP growth despite the COVID-19 pandemic. Quick, sustainable and critical advancements such by highly involving IT to bring about technological progress to the industry is vital to Ethiopia's socio-economic growth.

The Ethiopian Construction industry is lacking from several fronts that are depriving its growth, one being in performance [2]. It's identified in [3] that lack of strong IT application is one of the factors hindering the capacity of acting bodies such as consultants and contractors, which has contributed as a factor to its poor performance. Thereby foreign construction firms are taking up the majority of big and complex contracts over domestic firms. For example, 55% of the road sectors big and complex project contracts were awarded to foreign firms as reported in [4].

The road construction in Ethiopia has gradually increased, reaching 144,024 km of all-weather roads at the end of 2019/20 fiscal year. This accomplished the countries 41% road development goal of that fiscal year. The country had spent 37.3 billion birr in the previous fiscal year on road development alone. By the end of 2023, it is envisioned by Ethiopian Road Administration to have 10,000km of road built in addition to existing using 41 billion birr. Ethiopian Road Sector Development Programs (RSDP) has been strongly pushing the development of new roads for the past 15 years. This demands the usage of latest technologies in civil engineering and IT to secure the intended goals for Ethiopian roads. [5]

The adoption of airborne LiDAR technology also known as Airborne Laser Scanning (ALS) in construction has revolutionized the industry. Latest ALS technologies boast of scanning at pulse repetition frequency of 2MHz, obtaining 5cm vertical accuracy by 13cm horizontal accuracy, flight heights ranging from 300m up to 5500m and thus acquiring 6 million points per second [6]. This accumulates vast amount of raw data especially for large road projects that is crunched by some LiDAR processing software in order to output usable data formats for instance orthomosaic or Digital Terrain Model (DTM). SSGI has been dealing with providing such remotely sensed survey data deliverables to its customers such as Ethiopian Road Administration (ERA), which is intended for constructing roads.

Road construction in Ethiopia according to ERA's manual in [7] recommends the use of Photogrammetry as one of its site surveying techniques, but not LiDAR for it is yet to be updated as disclosed by ERA's Road Design Director in the interview recorded in annex 2. Photogrammetry is another type of 3D scanning technology that uses photographic images to extract geometric information from an object [8]. Photogrammetry entails limited accuracy especially in cases of dense vegetation and edge detection affecting output quality [9]. Acquiring Photogrammetric data is also affected by insufficient day light; where by acquisition of data for instance is hindered on a cloudy day or limited to day time [9]. Thus the manual supplement's Photogrammetry with field survey (total station) seeking more reliable results, which concurrently diminishes performance due to reliance on traditional practices resulting in higher monetary and time costs as road project size increases. These limitations among many others pushed SSGI to using LiDAR technology over photogrammetry to provide site investigation data deliverables to ERA, bypassing the obsolete at hand ERA's 2013 manual. This change was welcomed by ERA as the LiDAR deliverables were also compatible to ERA's CADD system; contingent on the used LiDAR data processing software's compatibility to a CADD system.

ALS data has increased radically in magnitude and complexity. Modern ALS complemented with Full-Waveform (FWF) data contains an additional up to 256 samples for each return pulse compared to the traditional ALS survey which collected four or more returns per transmitted pulse. With the restrained ability of computational processing power and hardware the above mentioned large and complex ALS data is a burden to compute. Therefore, the processing of ALS data takes up long periods of time especially with traditional sequence algorithms. [10]

This comparative study addresses SSGI's problem of owning expensive post point cloud processing software with processing speed issues and disk storage issues due to vast output as recorded in annex 1. Therefore, this study aims to unveil the best possible ALS data processing software, for SSGI, currently on the market allowing for robust, capable and efficient processing abilities without breaking the bank. It will exhibit the application of IT in the road construction industry with 3D mapping tools that are capable of making construction practices smarter; all in all seeking advancement with enhanced performance to the industry.

2. Objective

The main objective is to compare and contrast among airborne LiDAR data processing tools in order to identify which tool is overall a better choice with regards to the technical, organizational and business perspectives, and the specific objective is to recommend the LiDAR point cloud post processing software for SSGI that would aid it deliver an efficiently achieved, accurately processed and feasibly acquired output, all done without compatibility issues whether to SSGI nor to its client ERA; all in all suitably satisfying SSGI's LiDAR processing needs.

3. Related Work

The application of IT in construction has become increasingly common deploying new technologies such as Internet of things, big data, cloud computing, virtual reality (VR), augmented reality (AR), unmanned aerial vehicles (UAV), three-dimensional (3D) scanning, geographic information systems (GIS) and digital construction [11]. 3D scanning aided by software is a non-contact measuring technology through digitizing 3 dimensional scans of physical objects allowing for design, analysis and development as mentioned in [12]; in addition to visualization capabilities. It cuts down time and effort in doing conventional contact measurements inevitably enhancing performance [12]. Photogrammetry and laser scanning are example types of such 3D scanning of which Laser scanning or LiDAR takes precedence in precession in times of dense vegetation, poor lighting and atmospheric conditions [13], [14].

Light Detection and Ranging (LiDAR) as defined by [15] is a remote sensing technology that sends out pulses of laser light and measures the time the reflection from the target object is detected back to the sensor. Each beam of light reflected back to the sensor creates a three dimensional point and a collection of those elevation points creates a point cloud forming a 3D representation of the earth's surface and its features. One way to collect large LiDAR data is by attaching the Laser scanning instrument to an aircraft, which is called Airborne Laser Scanning (ALS) [16]. As the LiDAR data is collected on a moving platform, it consists of devices such as global positioning system (GPS) navigation devices and inertia measurement units (IMU) are used to create a georeferenced point cloud; as illustrated in Figure 1 [17]. The LiDAR sensor collecting such data is usually mounted at the bottom of the aircraft. This technology allow surveying areas that are large, difficult to access, unsafe for people, tough terrain, etc. that would be time consuming and costly to do using the traditional methods such as total station. This rendering of 3D reconstruction and mapping the scene aids the engineers and management with more effective and efficient decision making and work.

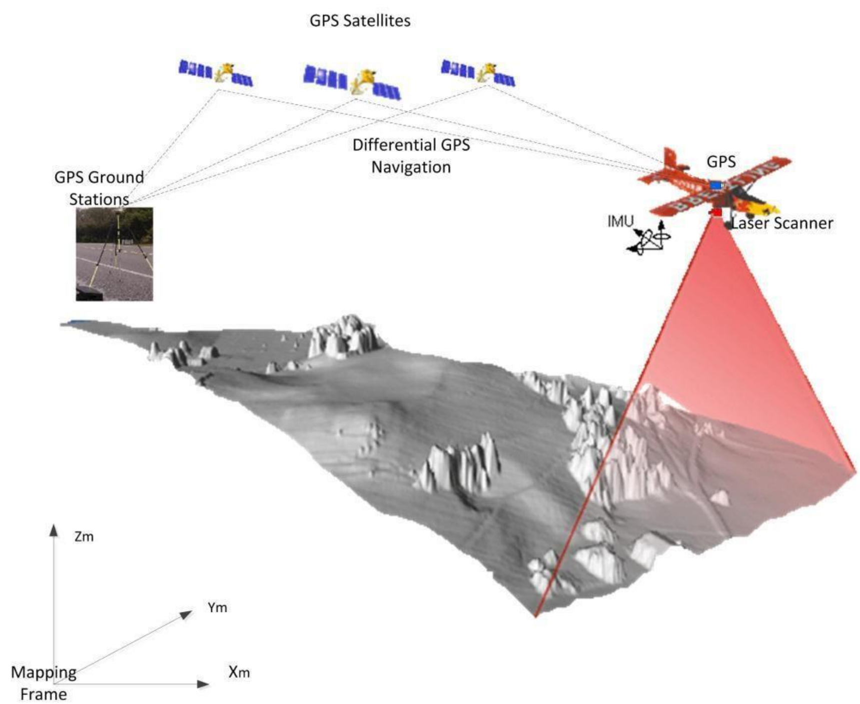

Figure 1 Airborne LiDAR data collection [25]

Field surveying and passive sensing approaches was the way to go for road geometry prior to the arrival of Laser scanning with all its bells and whistles. The traditional 2-dimensional terrain mapping was insufficient for road design, construction and management, which required site data to be in 3 dimensional formats. The conventional approach to acquiring 3D models done by surveyors were through manually digitizing aerial images with the use of few sparsely located ground control points, which took up a lot of time, was expensive and compromised the 3D model's accuracy. These limitations were overcome by ALS. [18]

Initial applications of airborne LiDAR were started by NASA in the 1970's working on aerial prototypes for "space borne sensor deployment". The remote sensing focused on environmental and terrain mapping studies. LiDAR has continually evolved into various applications rendering high accuracy as demonstrated by the German Stuttgart University in geometrical profiling. Airborne LiDAR required a GPS system with full working area coverage and an accurate IMU system, which was made possible after mid-1980. The capacity of LiDAR to provide terrain mapping data had increased by mid-1990's providing from 2000 up to 25,000 pulses per second. Having gone through several steps of evolution LiDAR's high speed, great accuracy and active data extraction, while having market price stability, has made it an optimal solution for mapping. [19]

Advantages of ALS for road site surveying include but not limited to for instance, giving a wide range exposure on surveyed site sufficient for any geometric road analysis [18]. Second, ALS is not hindered by any obstacles on the site ground preventing it from have a clear view for scanning [18]. Third, the safety of both surveyors and drivers is not compromised as there is no interference with vehicles on the road nor is there any physical presence of surveyors on sloppy, tough and inaccessible terrains that might be a safety hazard [18]. In addition, it has the ability to map the ground beneath dense vegetation by penetrating laser pulses through minute gaps in the foliage [20]. Moreover, LiDAR is not affected by any external lighting outside of the sensor while collecting the data, for it's an "active sensing technology" [21]. This property ensures that scanning can take place at any time during day or night and under any "bright light or geometric distortions"; that would have commonly halted a Photogrammetric approach [21]. Hence, ALS is the optimal site investigation technology.

The main product found after processing airborne LiDAR data is a 3D model of earth elevations. This modeling of elevation allows for "site planning, site grading, earthwork, quantity estimates, and more", which means having a visual of the project site and ability to take action remotely without being physically present on the site [22]. The 3D earth models are classified as Digital Elevation Model (DEM), Digital Surface Model (DSM) or Digital Terrain Model (DTM). These models serve various purposes such as soil mapping, land slide studying, hydrological studying, vegetation management, aviation purposes, road development and management among others. A DSM captures all surfaces whether it's ground, vegetation or manmade surfaces above ground such as buildings or power lines [23]. DEM, on the other hand, models the pure ground points negating all other above- ground surfaces [23]. However, DEMs are further divided into more types dedicated to specific operations. For instance in the transportation community, the DEMs would include the bridge decks, though it is above-ground level, in order to have a complete view of the roadway system [24]. Lastly, DTM refers to 3 dimensional topographic model of the bare- earth consisting of a collection of points with reference to a geodetic datum, thus equivalent to adding vector features to a DEM like "ridges and breaklines" [24]. This model holds the vital bare-earth topographic representation used by the highway engineering sector [25].

Though ALS technology has shown significant growth in 3D data collection and quality, it is yet to relieve its users working on point cloud processing from time intensive manual correction of classification errors and lack of full automatic feature extractions [18]. Classification of surface features fall into ground and above ground categories, whereby the ground surface is "the continuous and smooth surface that has nothing visible below it" whereas above ground objects are further classified as attached or detached objects. Attached objects elevate above bare-earth on certain sides but not all like bridges and viaducts, while detached objects are elevated above the bare-earth surface on all sides like buildings and trees. [25]

Filtering ground point from non-ground points is a necessary preprocess step required before applying interpolation on extracted ground points to generate 3D models such as DTMs [26], [27]. There are various filtering approaches or algorithms that yield different levels of efficiency depending on types of terrain. Hence a user must be versed with the various assumptions taken in the various ground filters in order to properly choose and apply them [26]. These algorithms are the engines running the numerous commercial software used to process our LiDAR data such as Axelsson's algorithm that is implemented in TerraScan as reported in [27], which is the core module of the Terrasolid software suit that is currently being used by SSGI.

In the process of algorithms filtering ground points from non-ground points they consider preregistered suppositions of ground features. However, these assumptions are commonly mistaken by the actual ground characteristic in cases of shrubs, short walls along walkways, bridges, buildings with different size and shape, hill cut-off edges, complex mixed covering, areas combining low and high-relief terrains, and lack of reliable accuracy assessment. Small hedges that dot the ground surface when seen from above are called shrubs. They are usually less than a meter in height, but they are one of the most common ground features wrongly identified as ground. Short walls are another reason to mislead filters into assuming its ground especially when the LiDAR scanning is taken in urban places at high resolution. Likewise bridges also are reason for confusion to some filters such as single dimensional scanning filters, as bridges have certain sides directly elevated above ground while remaining sides linked to the ground surface in a continuously even manner. [26]

Buildings with different sizes and shapes may be wrongly labeled as ground in sections where it's still part of the building. In addition to buildings other mixed coverings to terrains that happen mainly in urban areas persist to confuse filtering algorithms [26]. Hills with sharp cut-off edges also end up getting mislabeled as above ground in areas the slop exceeds the highest ground slop limit [26]. Moreover, filters run into the tough dilemma of choosing among slop or elevation limits in areas of varying relief between high and low [26]. Hence choosing commercial software to accurately process LiDAR data with filters that don't fail to recognize the pitfalls of mislabeling terrain is a tricky task.

Road construction and maintenance is done all over Ethiopia in both rural and urban areas. As mentioned above urban areas are quite challenging to ground and non-ground filtering algorithms as they have highly mixed coverings over the terrain, which can be confusing to the filters. In addition to mixed land cover features over urban terrains, rivers that cross such urban areas also play a factor in filters miscalculating ground points during interpolation; creating inaccurate DTMs [27]. In the Ethiopian context, this will certainly pose a problem as rivers flow in all areas of the country, whether urban or rural.

Various landscapes require different filtering approaches suited to the respective landscape. Applying similar slop configuration for both areas that consist of hilly and flat landscapes may conclude in an inaccurate ground point classification [27]. This highlights the importance of filters to be adjustable allowing for parameters to be tuned to the terrains context for more accurate results [27]. Iterative filtering approaches are considered to yield tunable filters such as Axelsson's algorithm [27]. Filters with adaptive ability such as to slope thresholds is another approach proposed by [27].

Different types of filters that generate varying qualities of DTM for either specific or general terrains have been developed. "Block-minimum, slope operator, triangulated irregular network (TIN) modeling and raster calculation" are some approaches [28]. While another comprehensive review of filters compiled by [26] identifies 6 types or categories namely segmentation and cluster-based, morphological, directional scanning, contour-based, TIN- based and interpolation-based filters. The paper in [26] demonstrated and analyzed typical algorithms for each category with their respective advantage and disadvantages. It continued to examine the capabilities of 10 commercial ground filters in 3 various terrains of firstly a site with rough slope and dense vegetation, second with relatively flat urban areas containing objects of various sizes and shapes, and lastly a site with rough terrain and discontinuous surfaces. The conclusion of [26]'s study suggested that the ground filters were most challenged by surfaces with rough terrain or discontinuous slope, dense forest canopies and regions with low vegetation.

Another most recent review on ground filtering algorithms in Z. Chen et al. [28], which having considered existing filter algorithm approaches, managed to categorize them into 6 types consisting of surface-based adjustment, morphology-based filtering, TIN-based refinement, segmentation and classification, statistical analysis and multi-scale comparison. The paper was able to compile the best terrain suitable and not so suitable for each filter type along with the memory storage demand and computational efficiency of each of the 6 categories.

Thus, the summary of the 6 categories made in [28] is as follows starting with the first, surface-based filtering method is suitable in forested areas while should be avoided in areas of rough and steep terrains. It has a high demand on memory storage but a middle level computational efficiency. Secondly, the morphological based type can be arguably used in steep terrains and terrains with very little mixture of object coverings while not being suitable in complex mixed covering terrain. It requires very little memory storage while yet having a high computational efficiency. Thirdly, TIN based is said to be suitable for steep terrains, yet unsuitable for urban areas and discontinuous terrains, while having a middle level demand on memory storage and also middle level computational efficiency. The fourth segmentation-based filter type is meant to be used in urban areas and terrains with various objects, but not in areas of rough and steep terrains or dense forests. However, the paper [28] didn't have data on memory storage demand nor computational efficiency for segmentation-based filters. Fifth, statistical analysis is recommended to be used in generally flat terrain but not in terrains with various objects, and it's a low-level demander in memory storage with also a low-level computational efficiency. Lastly, multi-scale comparison is best suited in urban areas while not recommended in rough and steep terrains, with a memory storage demand of middle level and a low computational efficiency.

The above study shows that each filtering method specializes in certain type of areas but not in others. The filters best suited in urban areas might not work for rural forested areas [28]. In [28], the paper suggests combining the filters to get the benefits of multiple filters. It also suggests combining the generated DTMs from various filters after the filtering process has taken place, also to extract the benefits of various DTM generators post the filtering; thereby increasing accuracy [28].

The entire filtering algorithms mentioned above fall into the rule-based filtering method category. Rule based algorithms put into consideration the physical elements of point clouds in order to distinguish non-ground from ground features; normally done with a workflow of procedures [29], [30]. Despite not having a one-size-fits-all rule-based algorithm there has been progress in development of machine learning algorithms that are generally applicable to all terrains. There are two classes of machine learning algorithms, supervised and unsupervised machine learning algorithms [30]. Supervised machine learning is further divided into two, whereby the labeling data classes are done manually or automatically with the use of automatically generated training data [30]. On the other hand, training data is not needed for unsupervised machine learning, which is further subdivided into 4 [30]. They are classification tree method, grouping and separability methods, and rule application methods [30].

Whether the underlying development to filtering approach of the commercial software is rule based or machine learning one thing is clear, the LiDAR processing software performance remains to be a point of research. [31]

4. Comparative Analysis and Detailed Recommendation

4.1 Comparative Analysis

This comparative study has taken the technical, organizational and business aspects into consideration in determining the better software. This research has applied dynamic software testing mechanisms for the technical comparison aspect to choose the best Airborne LiDAR data processing software for SSGI. Dynamic software testing entails running the program under scrutiny unlike static testing techniques which don't [32]. As we expand Dynamic testing category we find Functional and Non-functional testing techniques, whereby Functional testing types are further subdivided into Black-box, White-box, Grey- box, Unit testing, Integration testing and more [32], [33]. On the other hand Non-functional testing techniques refer to Performance, Security, Usability and more testing methods [33]. This study has considered one of each, meaning Black-box testing from Functional and Performance testing from Non-functional software testing techniques.

As for Black-box testing, this study has chosen to apply a subtype technique identified in [34] as Use Case testing technique to determine the functionality in the short-listed software. In addition, the level of accuracy particularly vertical accuracy sustained by the GIS software while generating digital terrain models by interpolating the input point cloud has been measured by Root Mean Square Error (RMSE). RMSE is one of the statistical considerations under taken to determine vertical accuracy of LiDAR data [35]. RMSE can be defined as follows:

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}\left(Z_{data(i)} - Z_{check(i)}\right)^2}{n}} \qquad [35]$$

where $Z_{data(i)}$ refers to the actual elevation data at check point (i), $Z_{check(i)}$ refers to the elevation data determined by the GIS software after inputting the LiDAR point cloud at check point (i), and lastly n refers to the entire collection of check points or also known as ground control points (GCP) [35]. This study has taken the max limit of 12.5 cm RMSE as the standard limit for acceptable accuracy according to [36], which refers to the Idaho LiDAR Consortium's (ILC) standards. Therefore, the software with the lowest RMSE that is also under the 12.5cm limit would be distinguished as the most accurate.

Regarding Performance testing, measuring points of response time (processing time taken), resource utilization such as Central Processing Unit (CPU), as well as exerted strain on Random-Access Memory (RAM) and disk was measured and compared among the software, which are identified by [37] as key performance indicators (KPI) under efficiency-oriented indicators and service oriented indicators respectively of a performance test. The performance test consists of testing for achieving basic GIS processing tasks on

LiDAR data such as loading point cloud data, making classification particularly ground classification, which also includes filtering the point cloud data accordingly, applied in all candidate software. This test will be carried out with the use of Windows Performance Recorder (WPR) and Windows Performance Analyzer (WPA) along with the respective candidate software.

The second main aspect of this comparative research is the organizational aspect. It took into consideration SSGI's computing capacity and looked into its ability to handle the short listed software. It also compared the softwares' ability to interoperate with CAD systems and import LAS formatted point cloud. Lastly, the business aspect of this comparison was further investigated to acquire the most feasible or cheapest software, yet one with the best value for money invested without breaking the bank.

Initially the list of software to compare was 11, with software namely Terrasolid, Global Mapper, TopoDot, Trimble, VRMesh, LiDAR360, Phoenix, Mapteks PointStudio, Arc Gis Pro, Vision LiDAR, and MATLAB. Firstly, Terrasolid was chosen as part of this study for the obvious reason of its current use by SSGI. Secondly, Global Mapper was selected for the reason of it being a familiar tool to the SSGI staff, though it's only being used for visualization purposes with its unregistered post free trial version, with all advanced features turned off, there could be technical capabilities not explored in its full paid version. Trimble Realworks and TopoDot were also selected for they are the most popular softwares comparable to Terrasolid as seen in [38]. The remaining softwares were selected for reasons of being high tier LiDAR post processing softwares. However, the trial version for demonstration purposes was acquired for only 4 of the listed softwares. The demo software was acquired for namely Terrasolid, LiDAR360, Mapteks PointStudio and ArcGis Pro. The comparison is thus focused on comparing the 4 LiDAR point cloud post processing software.

4.1.1 Detailed Technical Aspect Comparison

The technical comparison comprised of applying a Black box Use Case testing approach for Functional testing method and Performance testing approach for Non-functional testing technique as mentioned above. The software tests and comparisons were accomplished by using the point cloud and GCP data provided by SSGI on all short listed GIS software. The point cloud data was scanned from the Entoto to Kotebe area in Addis Ababa and consisted of 51,753,630 points covering a mixed type of terrain. A single laptop was used, having an Intel(R) Core(TM) i7-8550U CPU at 1.80GHz & 2.00 GHz processor, 24GB RAM and a 64bit system platform that is running a Microsoft Windows 10 Pro operating system.

Starting with the Black Box Use Case testing, there are 2 Use Case models used to make the comparison. There are 7 set of basic necessary steps performed as mentioned by

SSGI's GIS technician interview shown in annex 1. The difference between the 2 Use Case models as seen in table 1 below happens at the 4th step, where GCP's that are out of the perimeter of the input point cloud or scanned area are included in use case 2 to possibly mislead the software.

Step	Use Case 1 Tasks	Use Case 2 Tasks
1	Import LAS format raw point cloud data acquired form SSGI	Import LAS format raw point cloud data acquired form SSGI
2	Perform Ground classification with filtering of the point cloud	Perform Ground classification with filtering of the point cloud
3	Generate a Digital Terrain Model (DTM)	Generate a Digital Terrain Model (DTM)
4	Import actual Ground Control Points (GCP) within scanned area	Import Ground Control Points (GCP) with additional off-grid check points
5	Calculate RMSE	Calculate RMSE
6	Make elevation adjustment	Make elevation adjustment
7	Recalculate RMSE	Recalculate RMSE

Table 1 Testing Use Case Modules

The resulting Black Box test shows Arc Gis Pro failed the test after the 4th step in both use cases, whereas the remaining softwares passed all steps in both use cases which could be seen in table 2 below.

Software	Pass/ Fail						
	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7
Terrasolid	Pass	Pass	Pass	Pass	Pass	Pass	Pass
LiDAR360	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Mapteks PointStudio	Pass	Pass	Pass	Pass	Pass	Pass	Pass
ARC Gis Pro	Pass	Pass	Pass	Pass	Fail	Fail	Fail

Table 2 Black Box Test Result for both Use Cases

Having done the Black Box testing, where by checking if the software can perform required tasks step by step, this study also measured the degree of accuracy at which it produced the output. Thus the resulting accuracy assessment of the software DTM output is shown in table 3. It depicts a large margin of difference between Mapteks PointStudio and remaining Terrasolid and LiDAR360 software. The result also shows ARC Gis Pro could not generate an RMSE value for both use cases as it had failed to carry out steps 5 through 7 from both use cases. Additionally, Maptek PointStudio also failed the RMSE test as its value was above the maximum 12.5 cm.

Software	Use Case 1 Results		Use Case 2 Results	
	RMSE Before Adjustment (cm)	RMSE After Adjustment (cm)	RMSE Before Adjustment (cm)	RMSE After Adjustment (cm)
Terrasolid	6.7794	0.0460	6.7794	0.0460
LiDAR360	6.6970	0.0720	6.6970	0.0720
Maptek PointStudio	970.713	943.6370	3,678.5570	1,746.7110
ARC Gis Pro	Unknown	Unknown	Unknown	Unknown

Table 3 Result of Black Box Test

Secondly, the Performance test was carried out simultaneously with the Black Box test during steps 1 and 2, meaning when loading the point cloud data and performing Ground classification with filtering of the point cloud. The two tasks were selected as they are the most prominent moments when performance is lowest according to the interview in annex 1. It was carried out in the background to see how the software performed with regards to speed and resource consumption. The result of the performance is seen in table 4 and 5 below.

Software	**Trial No.**	**Point Cloud Loading Time (min)**	**Program CPU Usage (%)**	**Total RAM Usage (MB)**	**Total Disk Usage (MB)**
Terrasolid	1	0.550	9.090	13,687.441	906.640
	2	0.167	6.620	14,141.074	30.726
	3	0.183	9.690	14,177.508	35.468
Mean		0.3000	8.4667	14,002.0077	324.2780
LiDAR360	1	0.883	6.540	20,232.242	4,543.963
	2	0.867	6.550	14,256.430	4,398.158
	3	0.517	3.800	14,465.059	3,172.219
Mean		0.7557	5.6300	16,317.9103	4,038.1133
Maptek PointStudio	1	1.200	0.880	16,991.629	1,977.735
	2	1.867	0.350	21,810.176	3,737.484
	3	1.017	1.210	23,953.176	2,064.638
Mean		1.3613	0.8133	20,918.3270	2,593.2857
	1	0.983	5.910	12,795.285	139.475

ARC Gis Pro	2	0.383	8.230	12,612.602	52.830
	3	0.717	6.300	12,437.477	62.418
Mean		0.6943	6.8133	12,615.1213	84.9077

Table 4 Performance Test during Loading Point Cloud Data (Step 1)

Software	Trial No.	Ground Classification & Filtering Time (min)	Program CPU Usage (%)	Total RAM Usage (MB)	Total Disk Usage (MB)
Terrasolid	1	6.117	34.350	19,645.445	68.271
	2	5.900	31.350	19,547.488	80.216
	3	5.983	32.430	19,696.844	111.395
Mean		6.0000	32.7100	19,629.9257	86.6273
LiDAR360	1	14.333	12.540	10,326.125	1,063.355
	2	23.267	13.180	10,178.578	170.699
	3	20.233	12.930	10,626.957	129.366
Mean		19.2777	12.8833	10,377.2200	454.4733
Maptek PointStudio	1	1.533	0.280	28,826.145	1,367.915
	2	2.550	0.540	30,834.355	100.291
	3	1.150	0.230	32,060.273	1,875.724
Mean		1.7443	0.3500	30,573.5910	1,114.6433
ARC Gis Pro	1	1.150	9.740	13,774.965	2,544.226
	2	0.817	9.820	11,988.793	1,841.791
	3	0.817	12.48	11,403.016	1,623.589
Mean		0.9280	10.6800	12,388.9247	2,003.2020

Table 5 Performance Test during Ground Classification & Filtering (Step 2)

When considering both ARC Gis Pro and Maptek PointStudio have failed in prior tests, disqualifying them from further comparison, the research could focus on Terrasolid and LiDAR360. Therefore, the performance test shows Terrasolid was the fastest and least disk consuming software compared to LiDAR360 in both step 1 and 2. LiDAR360 had clearly a better CPU usage in both step's 1 and 2, but RAM usage was a close call among the two.

4.1.2 Detailed Organizational Aspect Comparison

The main intention in looking at the organizational perspective is to see if the software integrates well with the designated company's working environment. In order for a LiDAR post processing software to be acceptable for SSGI it should first be able to operate under SSGI's computing capacity and secondly generate an outcome that can be compatible with its clients processing application. Therefore, firstly the software requirements of each prospective software as registered in annex 4 was compared with SSGI's computing specification which is also registered in annex's 1 and 3. The resulting deduction after the comparison is seen in table 6.

Secondly, the ability of each prospective softwares output to be compatible with CADD systems was compared also as seen in table 6. This entailed looking into each software capability to exporting in DWG, DXF or XYZ formats as determined from annex 1. This research also has taken the liberty on making sure they are compatible with LAS point cloud data as it was the type of data received from SSGI as input for processing within this comparative research.

Software	**Compatible to SSGI'S Computing Spec.**	**LAS Compatible (Input Data)**	**CAD Compatible (Output Data)**
Terrasolid	✓	✓	✓
LiDAR360	✓	✓	✓
Maptek PointStudio	✓	✓	✓
ARC Gis Pro	✓	✓	✓

Table 6 Prospective Software Input and Output Compatibility

Therefore, all the short listed software are compatible to SSGI's computing environment, are able to import LAS data types and interoperate with SSGI's client CADD system. Thus all satisfying the organizational needs of SSGI.

4.1.3 Detailed Business Aspect Comparison

Having looked at the technical and organizations aspects for comparison this study also took care of looking into the prospective software's through the financial lens. Each of the 4 prospective software companies was requested to provide an annual subscription quote for 2023. The acquired price quotes for annual subscription by each prospective software company is listed in table 7 as seen below. The comparison showed LiDAR360 to be the cheapest of them all.

Software	Annual Subscription
Terrasolid	$1,767.70
LiDAR360	$1,500
Maptek PointStudio	$12,420
ARC Gis Pro	$6,250

Table 7 Price Quotation as of 2023

4.2 Recommendation

Having considered various determinants to compare the short listed softwares for SSGI, this paper has selected the most important of them all for SSGI. They are time, CPU, RAM and disk utilization, accuracy, software to system compatibility, software output to SSGI's client CADD system compatibility and annual subscription price point. ARC Gis Pro and Maptek PointStudio were eliminated from the comparison early in the technical assessment. This study has shown Terrasolid remains to be the better software on the market over the remaining LiDAR360 software. This was so because Terrasolid was able to provide more accuracy on its DTM output in addition to also saving processing time on average by 60% in point cloud loading and 69% during ground classification with filtering, which is critical to SSGI, also overall better in performance when compared to LiDAR360. Terrasolid had no compatibility issues, but as did all. LiDAR360 may be the cheapest software, but when compared to Terrasolid there is only a $267 markup on annual subscription price, which is insignificant to SSGI as it's a government institution. Therefore, seeking better post point cloud processing software is not the best strategy going forward for SSGI at this current point in time. I hence recommend seeking other solutions that are inexpensive to solve the remaining issues of processing time and storage issues. These are resource management and hardware upgrading problems. Therefore, I recommend resource management, especially with regards to CPU, memory and the disk drives in order to get better performance. The current software's processes should be given priority when running over other non-system processes. Minor steps such as discarding obsolete files or moving them to external storage could free up space on disk helping the storage issues. Another simple disk management could be to extend the hard drive partition into unallocated spaces resulting in enlarging disk space. Moreover, upgrading SSGI's 32GB RAM to 64GB, also upgrading processing capacity is an inexpensive way of gaining more performance, solving SSGI's computing issues.

5. Conclusion

There is potential for the Ethiopian construction industry to grow into the desired high performing industry. This is being made visible as government institutions such as SSGI and ERA allowing the use of high end softwares, such as Terrasolid, to digitize the surveying side of road construction; applying IT. This study has made a thorough comparison with regards to the technical, organizational and business aspects in determining Terrasolid remains to be the better software from the short listed 4 softwares. Recommendations that are cheap and inexpensive are made to enhance the current software abilities, thus completely answering all remaining issues. However, there were limitations in this study of not freely being capable to acquire popular softwares like Trimble Realworks and TopoDot and also using a single sample input point cloud though having a sufficiently mixed terrain type it lacked the presence of a river, which could have further shown the softwares' ground filtering capability.

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