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CASE STUDY

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Breaking ground in Ghana: LiDAR for site monitoring and its implications on project delivery

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Abstract

Light Detection and Ranging (LiDAR) has in contemporary times become a popular technology in the developed world, being utilized in city planning and infrastructure development. Documentation on the knowledge of its usage in Ghana is scanty. A major challenge that hinders the effective and timely delivery of infrastructural projects in Ghana is the delay in validating certificates for payment as a result of the use of traditional methods of measurement. This paper analysed the use of LiDAR in Aboragyei dumpsite in comparison with the existing traditional method of measurement, which is both time-consuming and prone to measurement inaccuracies. The objective was to evaluate the level of accuracy in measurement between the two methods. This paper used quasi-experimental designs on LiDAR technology to capture 3D models and extract vertical and horizontal measurements from them within a short period. The findings from the comparative assessment indicated that LiDAR technology speeds up infrastructure projects by enhancing not only procedure productivity but also cross-team communication. The cloud point models generated by LiDAR mapping do not deform when confronted with angular or complex geometry, unlike theodolite. This study makes a strong case for the utilization of LiDAR as a method for measuring vertical and horizontal angles by illuminating the target with laser light and measuring each reflection with a sensor. LiDAR system if adapted for site monitoring in Ghana will help avoid distortions in measuring horizontal and vertical angles and save time. However, a major constraint using it in Ghana was the unstable weather patterns.

Keywords: LiDAR, Site Monitoring, Cloud Points, 3D Models

Introduction

Many quantitative and qualitative surveying measurements are required for a successful construction project, including fine dimensions for building structures and bulk measurements for civil infrastructures. Traditional construction surveying equipment comprises total stations and Global Navigation Satellite Systems (GNSS) tools, and the precision of readings varies based on the equipment calibration, working environment, and surveying application (Bondrea, 2016). The precision standard of earthwork measurements, for example, is more permissive than that of pile foundation position (Liu *et al*., 2021). The accuracy requirements set by construction professional organizations such as the American Society for Photogrammetry and Remote Sensing, the American Society of Civil Engineers, the American Congress on Surveying and Mapping, and the American Land Title Association typically range from a minimum of 1:2500 up to 1:20,000 (Liu *et al*., 2021).

With the rapid growth of technology, the construction industry has incorporated several innovative surveying and mapping strategies for increased job accuracy and consistency. These innovative surveying technologies include terrestrial, aerial, and satellite imaging, which collects plain metric, topographic, hydrographic, or feature attribute data for photogrammetry, as well as terrestrial and aerial light detection and ranging (LiDAR), which captures 3D point clouds of objects and surfaces directly (Guan *et al*., 2022). LiDAR uses the approach of projecting laser light onto a target and detecting the returned light to identify variations in wavelength and arrival time (Srushti and Neoge, 2020). It is not always possible to be present physically in an environment and measure things manually. LiDAR comes into the picture.

Accurate and efficient surveying of the construction site and building materials is crucial to the construction process's safety, quality, and overall success. There are several methods for doing construction surveying and measuring tasks, including the use of classic manual equipment such as tape measures, straight edges, levels, and transits for lengths, angles, areas, and volume quantities (Dib *et al*., 2013; Thomas, 2016). Moreover, traditional building and construction surveying activities typically necessitate the equipment operators physically entering the facility or site to carry out such tasks. With safety, efficiency, accessibility, and pragmatism in mind, it is critical to incorporate innovative technologies that require little or no human work on-site (Ashour, 2016; Zucca, 1996). Local sensing devices often require intense coverage of a designated survey zone by the host mobile platform due to the required proximity to measured phenomena and relatively narrow footprints of sensitivity (Tunstel *et al*., 2009). Various surveying technologies can be used depending on the scale of the surveyed region and the type of data necessary for analysis (Dib et al., 2013). Local sensing devices often require intense coverage of a designated survey zone by the host mobile platform due to the required proximity to measured phenomena and relatively narrow footprints of sensitivity (Tunstel *et al.,* 2009).

LiDAR is increasingly being employed for forest inventory, package delivery, and crop growth monitoring. A ground-based LIDAR system, such as a terrestrial laser scanner (TLS), has been shown to give a dense and precise point cloud for infrastructure measurements (Schaer *et al*., 2012). The same cannot be said with UAS-based LIDAR, because the position and orientation of the UAS change frequently during flight. As a result, LIDAR point clouds cannot be geo-referenced in the same way that a stationary TLS can. Instead, during preprocessing, raw point cloud data from the airborne LIDAR must be combined and synchronized with UAS navigation measurements, which is often a problem and barrier.

He and Li (2020) used LiDAR for cadastral survey and mapping. During the experiment, traditional GNSS and total station measurement methods were used to collect certain feature points, which were then compared to LiDAR methods to determine the accuracy of LiDAR measurements. LiDAR was also used for coastal habitat mapping, where data were collected on the various species over the Mont Saint-Michel Bay, France (tidal) (Populus, 2020). There are several methods for

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doing construction surveying and measuring tasks, including the use of classic manual equipment such as tape measures, straight edges, levels, and transits for lengths, angles, areas, and volume quantities (Dib *et al*., 2013; Thomas, 2016). Traditional construction surveying equipment comprises total stations and Global Navigation Satellite Systems (GNSS) tools, and the precision of readings varies based on the equipment calibration, working environment, and surveying application (Bondrea, 2016). There are several methods for doing construction surveying and measuring tasks, including the use of classic manual equipment such as tape measures, straight edges, levels, and transits for lengths, angles, areas, and volume quantities (Dib *et al*., 2013; Thomas, 2016). Validation of the LiDAR system's model involves the use of calibration targets and real-world measurements from various circumstances. This informed us to use a Mini-LiDAR to undertake a similar project due to the delay in validating certificates for payment as a result of the use of manual methods of measurement which hinders effective and timely delivery of infrastructural projects in Ghana. Traditional surveying methods can take a long time to cover large areas. Traditional surveying methods can be expensive, particularly when covering large areas.

Mobile and stationary LiDAR sensors offer tremendous potential for damage identification because the scans provide detailed geometric information about the structures being evaluated (Kaartinen *et al*., 2022). LiDAR was also used for railway surfacing and quality index and it was proven by (Taheri Andani *et al*., 2017) that LiDAR sensors are capable of detecting and differentiating between various top-of-rail surface conditions. Accurate data obtained from ongoing construction projects aids project field engineers in tracking construction progress. The fast identification of differences enables the required steps to be taken to reduce the impact of a delay on the building workflow (Puri and Turkan, 2020). The accurate and efficient surveying of the construction site and building materials is crucial to the construction process's safety, quality, and overall success. The 3D point clouds produced by LiDAR provide quantifiable data regarding the extent of cracking and spalling that is difficult to collect with other optic-based devices like as cameras or typical surveying equipment (Kaartinen *et al*, 2022). Current procedures for assessing the safety and integrity of civil infrastructures, which involve on-site visual inspections, have proven to be costly, time-consuming, labour-intensive, and extremely subjective. LiDAR (Light Identification and Ranging) technologies, both mobile and stationary, have tremendous promise for damage detection because the scans provide detailed geometric information about the structures being examined (Kaartinen *et al*, 2022). High-quality terrestrial photographs generated by laser scans provide exact geometry data about a structure, allowing damaged regions to be detected and measured (Sharifisoraki *et al*., 2023). With safety, efficiency, accessibility, and pragmatism in mind, it is critical to incorporate innovative technologies that require little or no human work on-site (Ashour, 2016; Zucca, 1996). This is where the use of LiDAR comes in to make site monitoring much easier. Subsequently, there is a scope gap concerning LIDAR technology and its application in construction projects in Ghana.

The LIDAR on a multi-copter may have lower power and a shorter range. As a result, the mistake in a UAS-LIDAR point cloud may emerge in a somewhat different way than ALS. In practice, the size and pattern of observed errors are also related to the target application. For example, inaccuracies in forestry, meadow steps, mountainous locations, flood plains and varied vegetation levels have been analysed. The vertical error on bulk measures, such as piles or excavation, is the emphasis of this work (Salach *et al*., 2018).

LiDAR technology requires little light and can collect data both during the day and at night. It can take full advantage of the evening work with improved weather and increase data collecting efficiency (He and Li, 2020).

LiDAR sensors can cover large areas quickly, reducing the time and resources required for surveying.

Drones can be used to survey areas that are difficult or dangerous for human surveyors to access, such as steep slopes or remote locations. LiDAR sensors can capture high-resolution data, providing detailed information for a variety of applications such as creating digital elevation models and digital surface models.

The problem of site monitoring in Ghana is mainly lack of expertise and lack of focus. Most experts in the field do not have the time to clearly focus on the job on site. This may be a result of the scorching sun or rain. This has caused the delay in validating certificates for payment which hindered the effective and timely delivery of infrastructural projects in Ghana because of the use of traditional methods of measurement, which is inefficient because in-person monitoring can be unsafe in a site which inaccessible.

With the use of LiDAR for site monitoring in Ghana, accurate measurements, time saving, safety, minimum human dependence, weather and light dependence can be possible as compared to the traditional method of measurement, which is time-consuming, needs large labour, costly and prone to measurement inaccuracies. With all the advantages of LiDAR in the study, the problem of ineffective and untimely delivery of Projects will be solved. The paper clearly aimed to compare LiDAR and traditional methods of measurement for site monitoring. The main objective was to evaluate the level of accuracy in measurement between the two methods. It analysed a study on the use of LiDAR for site monitoring in comparison with the existing traditional (manual) method of measurement, which is both time-consuming and prone to measurement inaccuracies. This paper used quasi-experimental designs on LiDAR technology to capture 3D models and extract measurements from them within a short period. This study makes a strong case for the utilization of LiDAR as a method for measuring dimensions by illuminating the target with laser light and measuring each reflection with a sensor in site monitoring. LiDAR system if adapted for site monitoring in Ghana will help avoid distortions in measurements and save time for conducting these measurements.

Methods and Materials

Test area

The test area used was Aboragyei in the Greater Accra Region of Ghana as shown in Figure1. The test contained the measurement of Fencing being constructed around a closed dump site to be capped. The data utilized in the experiment were collected on the 5th of February, 2023, at an altitude of 50 meters above the test area (about 48 meters above the dump site), within the structure inventory. The length of the laser strips was determined by the curvature of the site (straight flight trajectory desired) and the battery life. Four flights were carried out over the test region. The approach to the flights was based on previous experience with a platform outfitted with similar sensors, as well as data processing from that platform in Israel (Ofek, 2022).

Materials

The paper used both primary and secondary data based on past works that were executed using quasi-experimental designs on LiDAR technology to capture 3D models and extract measure-

Figure 1 The location of the area of interest in Accra: Aboragyei site

ment from them within a short period. The study covered both the airborne and terrestrial LIDAR technology options. The relevant works measurement parameters used for the comparative assessment were dimension, gradient and area. One platform was employed in the experiment to collect data in the test region. LIDAR sensing sensors were installed on the multi-copter drone. The first is the laser ranging system, Global Positioning System (GPS) and Inertial Measurement Unit (IMU). It weighed about 9 kg (battery included). The maker claims that georeferenced point cloud data produced with the Yellow Scan Surveyor should have sub-decametric precision. The Applanix APX15 single board GNSS-Inertial solution, which was used in this scanner, is critical to achieving the expected precision. The technological configuration considered is the terrestrial LIDAR, DJI matrice 300 RTK multi-copter drone with attached L1 LiDAR sensors fixed to the base to generate results. The relevant parameters for construction work measurement were dimension, gradient and area. LiDAR for construction management strategies included the use of airborne and terrestrial LiDAR.

Measurements were fixed at a point in reference to a specified line (linear, angular, or a combination of the two) since it has always been required to delineate boundaries and divide territory. Surveying instruments such as dumpy level, tilting level, theodolite, prismatic compass, steel tape abney level and total station, steel tape, and ranging poles were also used for measurement as the traditional method of measurement.

Table 1 Key variables

Material	Data	Sources
LiDAR	Quantitative (angular dimension) and volumes	Global mapper, pix4D mapper, enterprise edition
DJI matrice 300 RTK multi-copter drone	Qualitative (images)	pix4D mapper
Steel tape	Quantitative (angular dimension)	Excel

General framework (Methods)

The primary purpose of this project was to evaluate the measurement accuracy derived from LiDAR and traditional methods of measurement. The accuracy of both procedures on different buildings, drains and bridge heights was examined, and information about the accuracy of both techniques on different buildings, drains and bridge heights was provided. The test evaluated both technologies and was conducted during the growing season when the traditional method of measurement approach was less accurate than the LiDAR technique.

The use of LiDAR technology was adopted as the first methodology for achieving the stated objective. Both the airborne and terrestrial LiDAR were used for experimentation. In the case of the airborne approach, Zenmuse L1sensors were affixed to a DJI Matrice 300 RTK pro drone. It was configured at 50 metres from the structure crown and at a scan of 180 degrees angle. The LiDAR system directed laser light towards the structure and measured the reflected light to determine the variation in wavelength and arrival time. It determined the distance to sketch the digital depiction of the structures based on these measurements. Because light travels at such a high speed, calculating the exact distance using LiDAR was quite quick and the distance was calculated using Eqn. (1).

$$D = c\,(\Delta T /2) \qquad (1)$$

Where D = The distance of the object, c = Speed of light, and Δ = Time required by the light to travel.

This signalized point design was employed to increase the absolute elevation accuracy of the mapped structures. In each structure, there were three points measured. One of these was always the checkpoint, and the other two ensured that in the event of a major error, we had some redundant observation. However, because the LiDAR was registering the data there, it was included in Figure 3. Additional cross-sections of the landscape were also taken to ensure the correctness of the DTM's final outcome. These GNSS-RTK cross-sections were obtained from separate observations without the use of point signalling. Because this method is the standard method for structure inventory, it was used to evaluate digital terrain model (DTM) accuracy. The attitude of the LiDAR data was analysed in the Applanix software (PosPack) utilizing reference stations from the Active Geodetic Network EUPOS (ASG EUPOS) to adapt the system's trajectory with the company's supplied bore-sight calibration angles and the defined lever-arm parameters.

For the terrestrial LiDAR, acquired XYZ coordinates of several spots on land by shooting laser pulses toward these points and calculating the distance from the sensor to the structures. Sensors were mounted on a tripod mount to scan through the structures for accurate measurements. Several scans (usually three or four) were performed around the items in the multiple-scan approach. The geometrical transformation for combining these distinct scans into a single point cloud was then calculated based on the positions of the three reference structures set in the scene and shared by both scans. a digital terrain model (DTM) was built from the point cloud, which served as the baseline for additional parameter processing. The point cloud was divided into a horizontal matrix with uniform cell sizes. The lowest Z-value in each cell was chosen and defined as the ground point. Following that, methods were employed to detect structure trunks in point clouds and determine breast diameter height (DBH). Every point in a layer with a height was taken between 1.25 and 1.35 m above ground from the point cloud. All circular points were contained inside this slice. Shape recognition algorithms were used to detect clusters. Circle rings were fixed on these clusters enabling the accurate calculation of structural position and diameters at breast height (DBH). In the following step of the vertical accuracy assessment, statistical parameters such as the Mean value and Standard deviation (STD) for the structure in spatial resolutions were determined with regard to the model derived from the airborne laser scanning data. The Authors sought to compare two extraordinarily large datasets to a regularly used structure-measurement technique. Statistics were presented with regard to two different degrees of structural height

For the manual method of measurements, instruments like dumpy level, tilting level, theodolite, prismatic compass, steel tape abney level, total station, steel tape, ranging poles and smith machine were used to measure and survey structures. Steel tape was used to measure the length, breadth and height of the structures. The Smith machine was used to determine the thickness of all the structure walls. The area was then calculated manually with a calculator and Excel. For each of the sites and buildings, the Authors calculated the dimensions and areas for each structure using both methods from literature and Mini-LiDAR for the site's monitoring. Images were georeferenced using 3 ground control points. The images were then merged using pix4D mapper, enterprise edition which gave us access to calculate volumes. To get the length and breadth of the site, a global mapper was used. The flow of the various methods is presented in Figure 2.

Results

Vertical and horizontal angle measurements were calculated relative to buildings. Measurements were either calculated in the direction of LiDAR technology or manual method to represent their direct comparison. 3D images were taken to illustrate how the measurement was done.

The accuracy of the measurements was undertaken. In the first part of the accuracy assessment, seven checkpoints were measured using the surveying instruments. The accuracy of the area was calculated using discrepancies between checkpoints and matching structure values as displayed in Table 2. The results of the accuracy assessment on the structures based on different approaches are shown in Table 3.

Discussion

To evaluate the ineffective and untimely delivery of infrastructural projects in Ghana as a result of delay in validating certificates for payment, measurements were made using two technologies to know which approach fast truck infrastructural project delivery. During the experiment, a clearly obvious steady increase in the inaccuracy of the terrain model derived from the T. LiDAR with decreased structural height was observed. The investigation found a 0.1m drop in accuracy for every 20m of structural height. Accuracy level of using the manual approach in both temperature levels, the error margins were greater. For Figure 4, instead of doing measurements in person, the drone was sent on a mission and these measurements were done via the 4D and global mapper. In Figure 3, it can be seen how the mini-LiDAR obtained the cloud point data and the 3D image. Some green points shown on the right side of Figure 3 depict how the mini-LiDAR while taking the 3D images was as well taking measurements. Within 2 hours results from LiDAR were generated, and it took 2 days to generate results using the traditional methods.

The investigation employing geodetic field data validates a previously stated fact: LiDAR techniques can more precisely estimate infrastructure checkpoints than manual methods. In the plight of the LiDAR, an increase in the accuracy level with dumpsite height was plainly visible, even if the quantity of checkpoints for the dumpsite was lesser. On the contrary, the accuracy level for each dumpsite height level was equivalent to the manual method of measurements.

Moreover, in the context of the structure with a height of 20 m, these two approaches (LiDAR and MMM) produced equivalent findings, which was valuable information given the very high resolution, the high density of LiDAR and the weather temperatures that affect manual measuring instruments. An example of a building is presented in Figure 4 to demonstrate the influence of the precision of both elevation data sets collected from LiDAR. It is clear that the construction profile was placed above the crown. The structure's imprint was also plain-

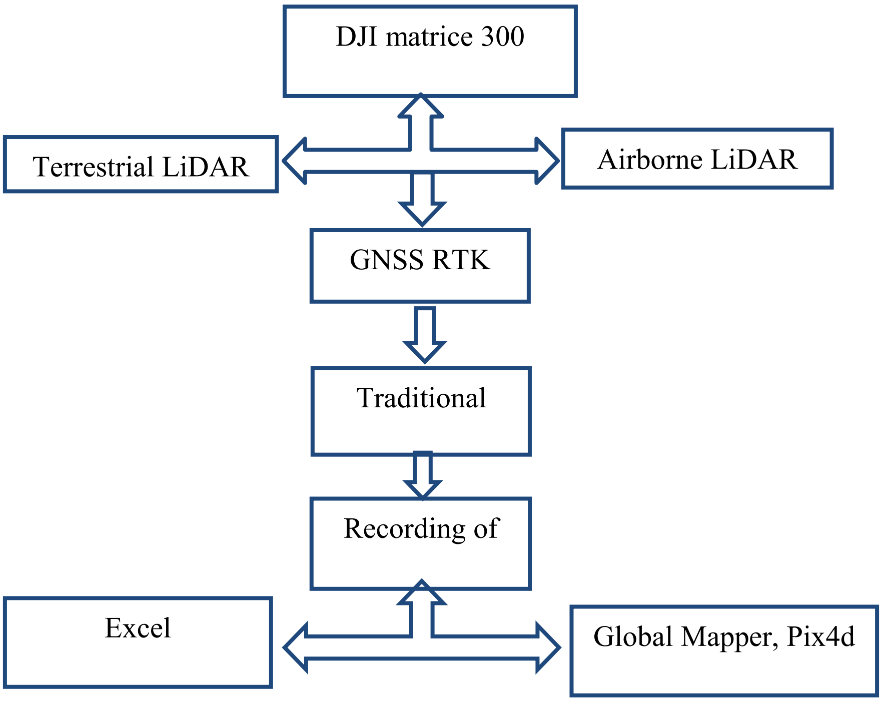

Figure 2 Flow chart of the methods

ly visible here. This discovery was equivalent to 50 m changes in structure height. Furthermore, if the structure was lower than 20 m, the profile of a road could be observed in the structure crown. The structure profile matched the structure from LiDAR in this case (both: TLS and ALS). Profiles coincided with each other along the entire length, indicating the visible ability of the laser scanner on the drone to penetrate through the Structure.

It was once again observed that for the LiDAR, the effects of the structure on measurement accuracy were observed by raising the mean value of the elevation difference (as shown in Table 3). For the manual method of measurement, the differences were positive for low and medium structures (>20 cm), demonstrating the obvious lack of penetration through the structure for the manual approach and possibly implying that the LiDAR data had a density of several dozens per square meter, implying that more detailed data could be obtained by airborne LiDAR than by manual measurement instrument. As shown in Figure 4.

In literature, when the results of T. LiDAR and A. LiDAR were compared, there was no massive distinction in the structural areas with heights of 20m and 50m, where the accuracy of both models and both resolutions compared to the manual ap-

Table 2 Accuracy assessment of the dump site based on the geodetic field measurements

Technology type	Number of check points	Height	Length	Area	Breadth	Thickness
LiDAR	1	3.63	50	2040	40	40
Manual	1	2	30	620	20	28

Table 3 Accuracy assessment for comparison

Points	T. LIDAR at 20m		A. LIDAR at 50m		Surveyors tape at low temperature	Surveyors tape at high temperature	
	Value	Error	Value	Error	Value	Value	Error
Length	32	-0.1	32.1	0	25	36	-11
Breadth	23	-0.1	24	0	18	30	-12
Height	100	-2.3	130	0	89	103	-14
Area	690	-0.01	770.4	0	450	1080	-132

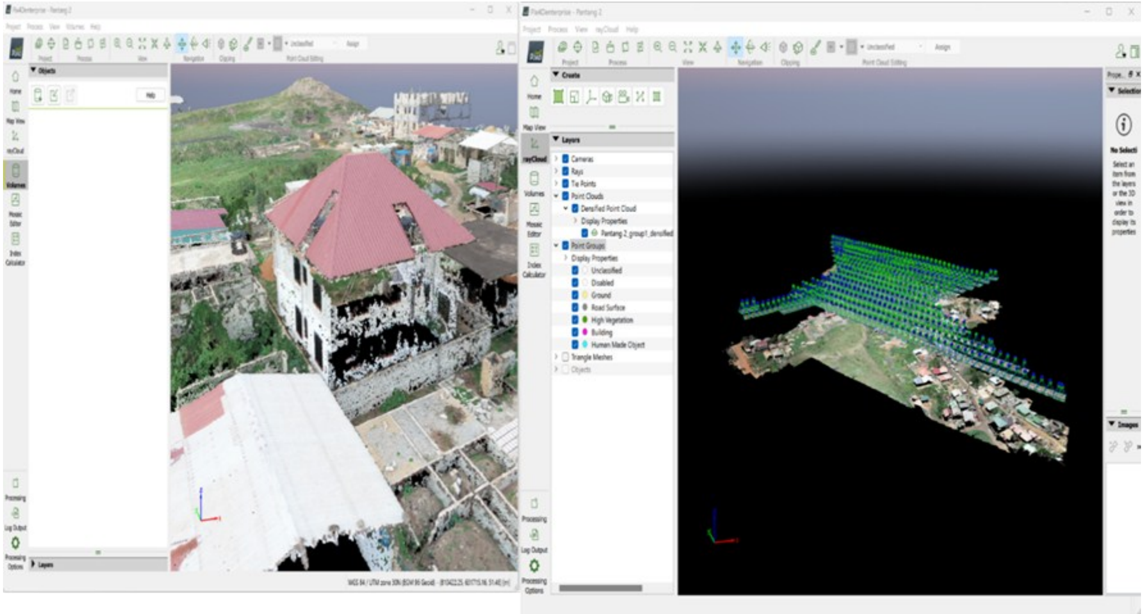

Figure 3 Point Clouds Data Using Mini LiDAR

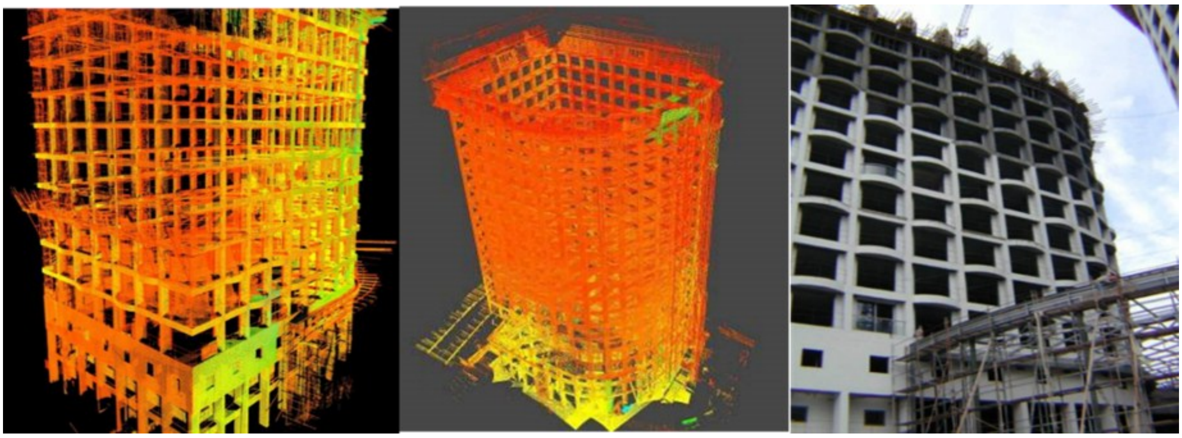

Figure 4 Structure frames measurement taken based on LiDAR Survey at 20 – 50 m

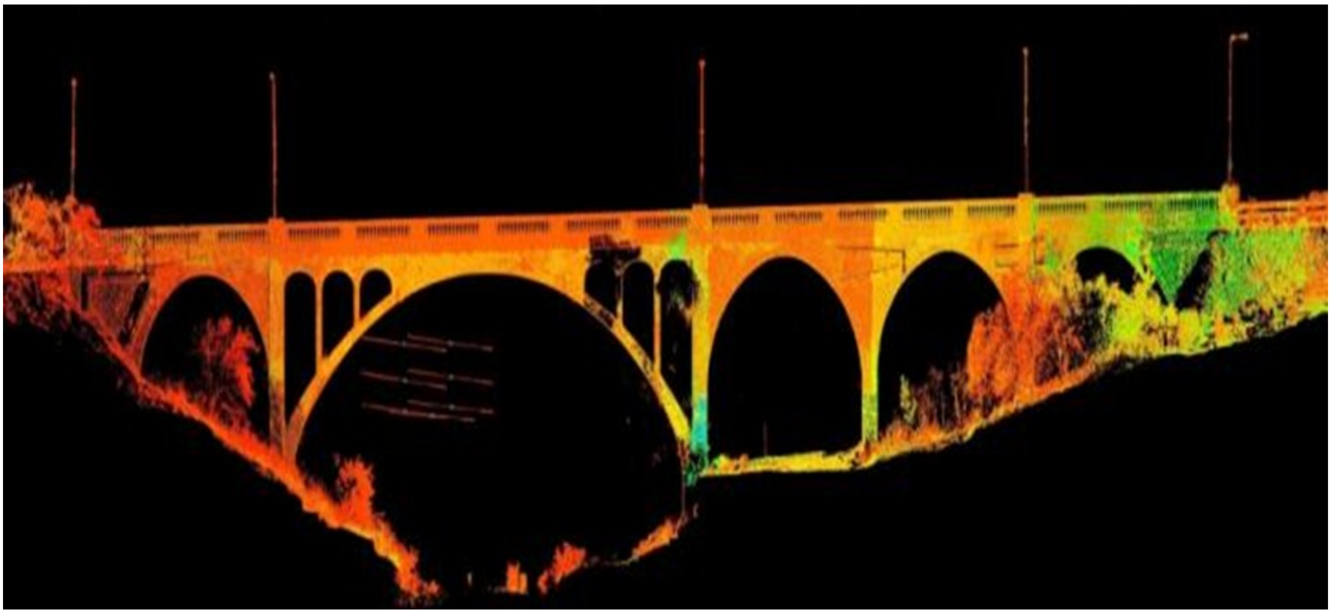

Figure 5 Point clouds data using T.LiDAR

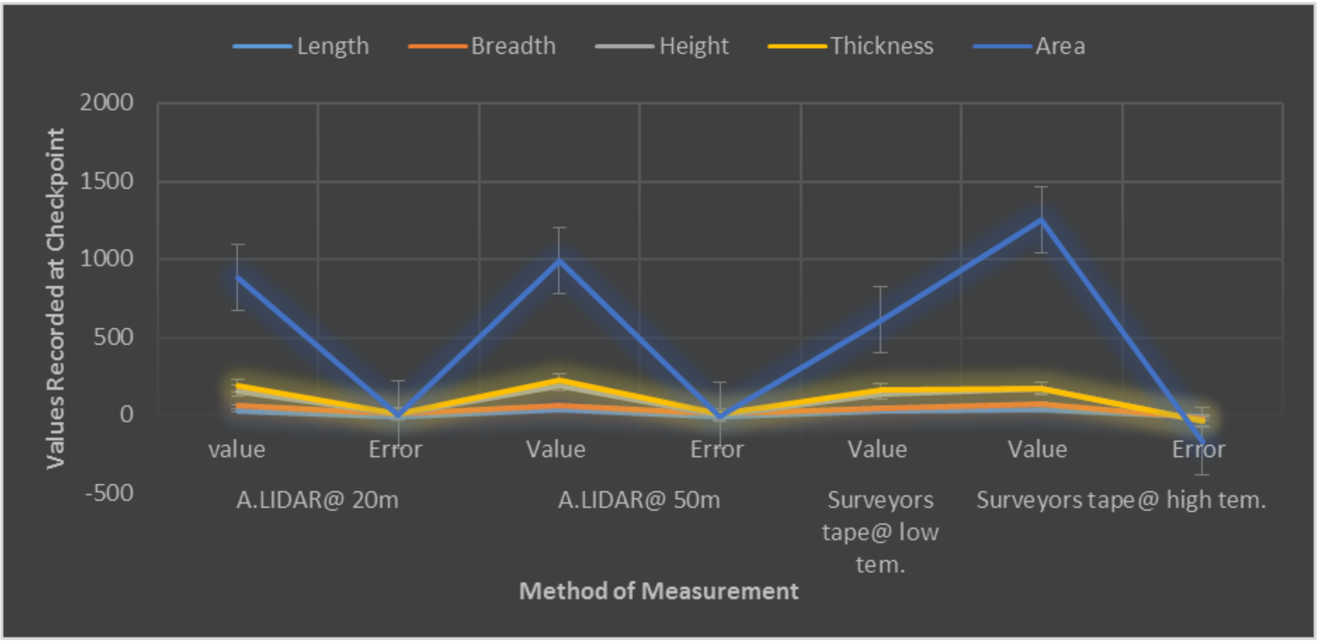

Figure 6 Comparison of LiDAR and surveyors tape accuracy

proach was between -11 m and -14 m. As a result, when using T. LiDAR gathered with the A. LiDAR, it is permissible to limit the region of study to places with this type of coverage, as shown in the experiments in Figures 4 and 5. A comparison to the surveyor's tape was also performed for data quality assessment, and due to its accuracy, it cannot be used as a reference dataset, as the LiDAR measurements in the first portion of the research were as shown in Figure 6. Overall, the accuracy of the structure models was higher with Airborne LiDAR than with the manual approach. Given the superiority of LiDAR data, UAV measurements are frequently contrasted with ALS as a low-cost alternative. In the experiments given in this study, a progressive increase in the Mean value of the structure height discrepancy between the manual and airborne LiDAR scanners was noticed, and it rose in tandem with the height of the building. This relationship could be simply explained by the passive nature of the optical sensor in the case of photos that cannot penetrate the structure, and thus the impact of the building on the produced model could not be erased even with filtering algorithms.

It is demonstrated that A. LiDAR could deliver accurate measurement results in the case of low and high structure height, as shown in Table 3. The T. LiDAR data analysis revealed no such association. The results were comparable to surveying measurements and ALS data for all the structural classes (every 20 m and 50 m of its height). Considering the resolution of the manual, the difference in the vertical accuracy was very small. It was caused by temperatures, improper levelling, and misalignment as a result of pressure. Over 600 openings of the structure could be obtained using the airborne LiDAR.

However, with two datasets of extreme density, the results demonstrated that the resolution of the structure had a greater impact on the LiDAR data. When compared to ALS data, it was also clear that irrespective of structure height, the TLS model was many meters (0.01m to 0.1m) lower. This observation was supported by the mean area of the difference in height between manual and LiDAR measurements. The mean area value for the ALS data with respect to geodetic measurements was 7.78 m, and for the manual technique, it was always in the range of 4.50 m, regardless of the resolution of the digital terrain model and structure height. The discovery revealed that the great density of LiDAR data was equally important when a very accurate digital terrain model was required. To assume the results, it was concluded that it is more accurate to use LiDAR for site monitoring. The findings from the comparative assessment indicated that LiDAR technology speeds up infrastructure projects by enhancing not only procedure productivity but also cross-team communication. It also provides construction teams with the capacity to produce 3D models of existing space and establish digital plans for those real areas. The cloud point models generated by LiDAR mapping do not deform when confronted with angular or complex geometry, unlike other types of surveying. This will speed up the process of certificates for payment and hence, will ensure the effective and timely delivery of infrastructural projects in Ghana.

Conclusion

The paper analysed the use of LiDAR for Site Monitoring in comparison with the existing traditional (manual) method of measurement, which is both time-consuming and prone to measurement inaccuracies. The study revealed that there is a significant increase in the density of point clouds, irrespective of whether they are generated by LiDAR or image-matching, because of the volume of such data required to revisit the derived structure accuracy, even if this product can be generated from an incredibly dense point cloud. The presented analysis of such datasets indicated that LiDAR technology is more accurate than the manual approach, according to the vertical accuracy analysis in areas covered by the structures. In the experiment, two structure classes were separated based on height values. Following that, the accuracies and error margins based on manual measurement were examined and compared to airborne laser scanning. In both structure classes, the LiDAR measurements were more accurate than the manual approach measurements, according to both studies. Furthermore, the TLS accuracy was compared to the ALS results, and this technique had a higher penetration into the structure, which was produced by a considerably higher density of the point cloud that could be given by a multi-copter platform. The Greater Accra Resilience and Integrated Development (GARID) Project intends to use LiDAR to execute its projects that require measurement.

Despite the fact that LiDAR technology has advanced quickly in recent years, the high cost of sensors makes this technology prohibitively expensive. The primary disadvantage of employing LiDAR in Ghana is the inconsistent availability of good weather. High humidity causes the LiDAR beams to intersect the droplets at short distances, hence reflecting enough beams back to the receiver. This causes the beams to detect the droplets as objects as mentioned in the introduction. Ghana most times record high humidity, thus in order to effectively deploy this, one will need to investigate the best periods where the drone can be deployed. The other approach that can be deployed in overcoming this challenge, is using a hybrid approach, where the manual methods of measurement will help aid validate the measurement recorded with the LiDAR in high humidity.

Point cloud filtering is becoming more commonly used in commercial systems. Only in the situation of bare land topography, favourable temperatures, and modest constructions do this manual technique make sense. The best time to collect this information is in the dry season. In terms of ALS data, it is possible to gather data at any time of year, but only this technique is advised during the dry season, as LiDAR can produce more accurate measurements and 3D results than the manual approach.

Table 4 Outcome of mini-LiDAR generated data

Gm_layer	Elevation (m)	Id	Area (m^2)	Real height (m)	Height (m)	Shape Length (m)	Shape Area (m^2)
Unknown Area Type	3.631	0	3.38+02	3.63+00	3.63+00	1.11+02	3.38+02
Unknown Area Type	3.541	0	7.78+01	3.54+00	3.54+00	3.58+01	7.78+01
Unknown Area Type	3.13	0	4.15+01	3.13+00	3.13+00	3.61+01	4.15+01
Unknown Area Type	2.515	0	1.21+01	2.52+00	2.52+00	1.63+01	1.21+01
Unknown Area Type	3.345	0	9.56+01	3.34+00	3.34+00	5.20+01	9.56+01
Unknown Area Type	3.867	0	2.28+02	3.87+00	3.87+00	6.28+01	2.28+02
Unknown Area Type	4.82	0	3.94+02	4.82+00	4.82+00	8.14+01	3.94+02
Unknown Area Type	3.131	0	1.82+01	3.13+00	3.13+00	2.08+01	1.82+01
Unknown Area Type	4.497	0	2.61+02	4.50+00	4.50+00	7.99+01	2.61+02
Unknown Area Type	3.545	0	4.79+01	3.55+00	3.55+00	3.20+01	4.79+01
Unknown Area Type	3.45	0	1.22+01	3.45+00	3.45+00	1.59+01	1.22+01
Unknown Area Type	3.651	0	2.16+01	3.65+00	3.65+00	1.89+01	2.16+01
Unknown Area Type	3.47	0	1.72+01	3.47+00	3.47+00	1.67+01	1.72+01
Unknown Area Type	3.43	0	1.65+01	3.43+00	3.43+00	1.65+01	1.65+01
Unknown Area Type	3.436	0	3.38+02	3.44+00	3.44+00	7.65+01	3.38+02
Unknown Area Type	9.79	0	5.07+02	9.79+00	9.79+00	9.33+01	5.07+02
Unknown Area Type	10.58	0	1.38+02	1.06+01	1.06+01	4.83+01	1.38+02
Unknown Area Type	4.259	0	1.38+02	4.26+00	4.26+00	4.99+01	1.38+02
Unknown Area Type	4.39	0	3.24+02	4.39+00	4.39+00	8.20+01	3.24+02
Unknown Area Type	6.879	0	3.57+02	6.88+00	6.88+00	9.73+01	3.57+02

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Conflict of Interest Declaration

The authors declare no conflict of interest.

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