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Original paper

Performance evaluation of different selected UAV image processing software on building volume estimation

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Abstract: The aim of this research is to evaluate the performance of four UAV image processing software for the automatic estimation of volumes based on estimated volume accuracy, spatial accuracy, and execution time, with and without Ground Control Points (GCPs). A total of 52 images of a building were captured using a DJI Mavic Air UAV at 60m altitude and 80% forward and side overlap. The dataset was processed with and without GCPs using Pix4DMapper, Agisoft Metashape Pro, Reality Capture, and 3DF Zephyr. The UAV-based estimated volume generated from the software was compared with the true volume of the building generated from its as-built 3D building information modeled in Revit 2018 environment. The resulting percentage difference was computed. The average volumes estimated from the four software with the use of GCPs were 4757.448 m^3 (3.87%), 4728.1 m^3 (2.54%), 4291.561 m^3 (11.5%), and 4154.938 m^3 (14.35%), respectively. Similarly, when GCPs were not used for the image processing, average volumes of 4631.385 m^3 (4.52%), 4773.025 m^3 (1.6%), 4617.899 m^3 (4.89%), and 4420.403 m^3 (8.92%) were obtained in the same order. In addition to the volume estimation analysis, other parameters, including execution time, positional RMSE, and spatial resolution, were evaluated. Based on these parameters, Agisoft Metashape Pro proved to be more accurate, time-efficient, and reliable for volumetric estimations from UAV images compared to the other investigated software. The findings of this study can guide decision-making in selecting the appropriate software for UAV-based volume estimation in different applications.

Keywords: Building Information Modelling, Unmanned Aerial Vehicle (UAV), UAV mapping, 3D modelling, image processing software

1. Introduction

The building and construction industry gradually moves from traditional methods to technological innovations, offering robust alternatives to pen-and-paper and spreadsheet-based systems (Jones, 2019). Unmanned aerial systems (UAS), virtual design and construction, and building information modelling (BIM) are among the technological advancements that are rapidly changing the landscape of the construction sector. In recent years, the scientific community and software developers have shown increasing interest in using the photos captured by unmanned aerial vehicles (UAVs) to construct 3D models, especially with the incorporation of computer vision algorithms in commonly used software tools (Höhle, 2008; Szeliski, 2010).

Initially developed for military applications, UAVs have evolved into valuable data collection tools for environmental monitoring, modelling, and management, among other applications (Ajayi et al., 2018). The usage of small drones/UAVs for aerial imaging, topographic mapping, and monitoring have become increasingly popular and cost-effective compared to traditional data collection methods (Ajeeth, 2015; Ajayi and Palmer, 2020). Building Information Modelling (BIM) is another technological advancement that has gained popularity in construction. BIM involves creating a digital model of a building or infrastructure asset that contains information about its design, creation, and maintenance (Peterson et al., 2011; Volk, 2014; CIOB, 2018).

The conventional terrestrial or ground-based survey approach for volumetric estimation, which utilises Theodolites and Levels, Total Stations, and Global Navigation Satellite Systems (GNSS), among other technologies, is expensive, time-consuming, and dangerous, particularly in unstable landforms (Raeva et al., 2016; Ab-Rahman et al., 2017; Stalin and Gnanaprakasam, 2017). Moreover, conventional surveying methods limit surface modelling points, resulting in lower accuracy in volume computations. High-density point clouds captured by UAVs have improved volume estimation surface models (Akwaowo et al., 2019).

UAVs, due to their compact size, mobility, ease of use, low cost, speed, and ability to record high spatial quality photographs, are increasingly being used for photogrammetry, terrain mapping, exploration, 3D mapping, precision agriculture, seismic damage assessment, and earthwork estimates (Baiocchi et al., 2013; Raeva et al., 2016; Propeller, 2018). However, image processing software is required to convert UAV data into deliverables. Various software packages have been developed in response to the growing UAV industry, each with unique features.

Therefore, this research focuses on the performance evaluation of different selected UAV image processing software in automatic building volume estimation, with and without ground control points (GCPs). The primary aim of this study is to explore the efficacy of UAV technology compared to traditional terrestrial or ground-based survey approaches for volumetric estimation in the construction industry. The findings of this study are expected to contribute to the knowledge base for the use of UAVs and suitable image-processing software for building volume estimation and informing industry practices for future projects.

Application of UAV in building volumetric analysis – A review

The use of Unmanned Aerial Vehicles (UAVs) for building volumetric analysis has gained significant attention in recent years due to its advantages over traditional methods. UAVs can provide high-resolution images that can be processed to create accurate and detailed 3D models of buildings, which can be used for various purposes such as construction planning, site inspections, and building inspections.

Several studies have been conducted to evaluate the performance of UAVs in building volumetric analysis. For instance, a study by Kuo and Chen (2019) compared the accuracy of different UAV image processing software in estimating the volume of a building. The authors found that photogrammetry-based software produced more accurate results than LiDAR-based software.

Also, Kim et al. (2019) examined the use of UAVs for building inspection and maintenance. The authors demonstrated the feasibility of using UAVs to capture high-resolution images of buildings, which can be used for various purposes, such as identifying structural defects and estimating the volume of a building.

In addition, Hirschmugl et al. (2020) evaluated the use of UAVs for construction planning and monitoring. The authors demonstrated the potential of UAVs in providing accurate and detailed 3D models of construction sites, which can be used for various purposes, such as estimating excavation volume and monitoring construction project progress.

Furthermore, Yan et al. (2021) proposed a new method for building volumetric analysis using UAVs and deep learning by demonstrating the feasibility of using deep learning algorithms to automatically extract building features from UAV images, which can be used to estimate the volume of a building with high accuracy.

Overall, the reviewed literature suggests that UAVs have great potential for building volumetric analysis and can provide accurate and detailed 3D models that can be used for various purposes. However, more research is needed to fully evaluate the volumetric computational accuracy of different UAS image processing software, and this is the gap this research seeks to fill

2. Materials and methods

2.1. Study area

The study area for this research (see Fig. 1) is the School of Entrepreneurship Management Technology (SEMT), Lecture Theatre located at the main campus of the Federal University of Technology Minna, Niger State, Nigeria, which is situated on Latitude 09°31′57″ of the equator and Longitude 06°26′50″ of the Greenwich Meridian. The SEMT Lecture Theatre was chosen for this study because it is free from obstruction that could prevent the drone from observing some or all the parts of the building.

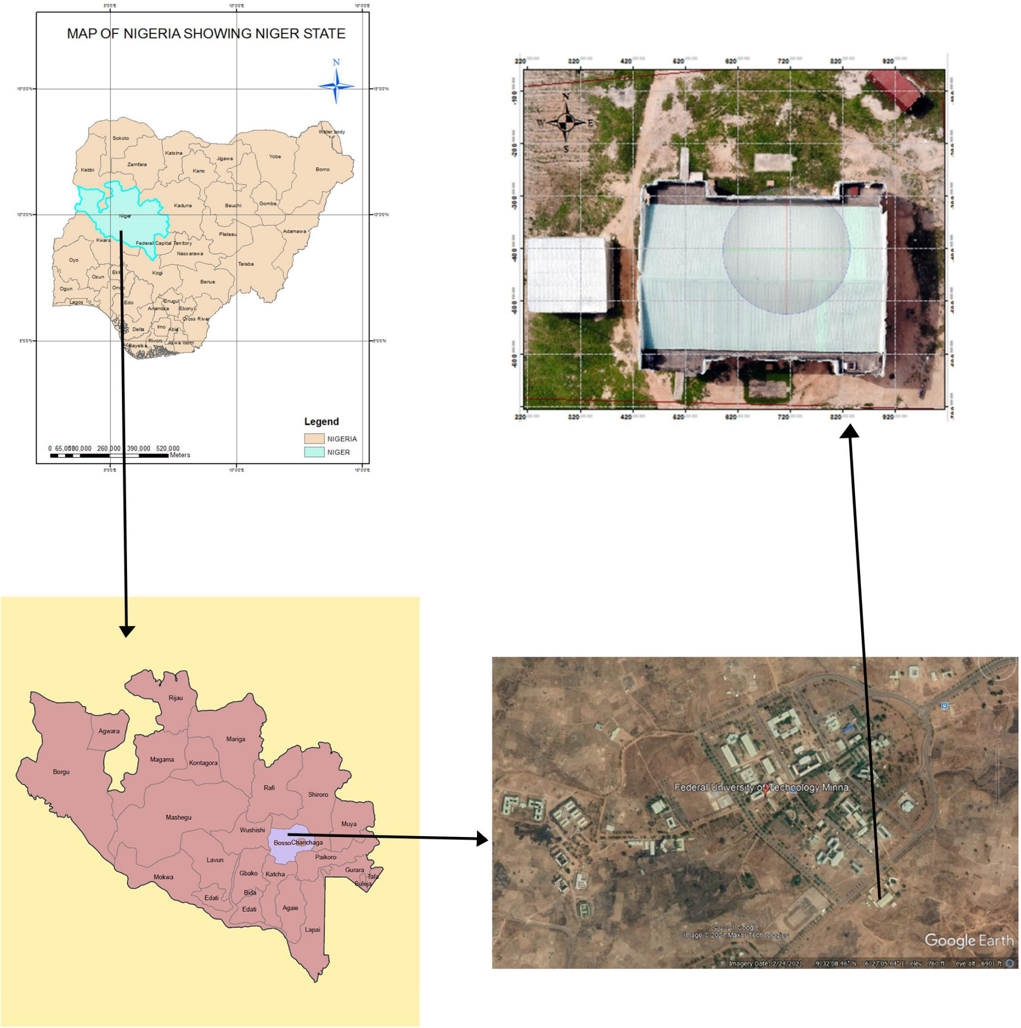

Fig. 1. Diagrammatic representation of the study area

2.2. Hardware and software

The spatial positions of the pre-marked GCPs were coordinated using a Hi-Target v30 GNSS RTK Differential Global Positioning System (DGPS) receivers. The DGPS effectively corrects GPS signals by adjusting real-time GPS signals based on a known position to reduce pseudo-range inaccuracies. The technical and performance specifications of the Hi-Target DGPS used are presented on the Hi-target's webpage (https://en.hi-target.com.cn/).

The deployed UAV weighs about 430 grams. It has an embedded GNSS sensor, allowing real-time image location and geotagging. The UAV was deployed 60 meters above the target at 4 meters per second speed. The UAV photos covered the entire study site. The performance parameters of the deployed drone are presented on the DJI's official website (https://www.dji.com/mavic).

The computer specification used for the entire study is a Dell G3 gaming laptop, Intel(R) Core(TM), i5-9300H CPU @ 2.40 GHz, 12 GB RAM, 500 GB SSD memory space, and Geforce GTX 1050. AutoCAD 2015 and Revit 2018 (v3) were used to estimate building volume from the as-built design. In contrast, Agisoft Metashape Pro (v1.6.1), Pix4DMapper Pro (v2.0.1), RealityCapture (v1.0.3.4987), and 3D Zephyr (4.530) were used to estimate building volume from UAV photos. Summarised details and usage of these software packages are described as follows:

AutoCAD 2015

AutoCAD 2015 was used to process and save the 2D plans of the building in each perspective before linking them to Revit 2018 (v3) for further processing.

Revit 2018 (v3)

Revit 2018 (v3) was used to develop the 3D model of the as-built design specifications of the SEMT Lecture theatre. It was from this 3D model that the reference volume of the building was derived. The volume computation for a structure is based on its room-bounding components and is calculated as the area of its base multiplied by the structure's height (RevitSupport, 2021).

Pix4DMapper pro (v2.0.1)

According to Pix4D (2021), Pix4DMapper is the leading photogrammetry software for professional drone mapping applications. Images captured by drone, hand, or plane are automatically converted, and their accurately georeferenced 2D and 3D maps and models are produced. They are adaptable, timely, and may be used with various applications and software. Pix4DMapper support stated that volume computation in Pix4DMapper is computed using the Digital Surface Model (DSM). To draw a new volume, the point cloud and the DSM must be generated (Pix4DSupport, 2020).

Agisoft Metashape Pro (v1.6.4)

Agisoft Metashape (formerly Agisoft PhotoScan) is a photogrammetry processing tool developed by Agisoft LLC, based in St. Petersburg, Russia. The software is offered in two editions: Standard and Pro. The Standard edition is appropriate for interactive media jobs, while the Pro is optimised for GIS content development. Agisoft metashape allows volume measurement above best fit/mean level/custom level planes. The drawn polygon vertices calculate the best fit and mean level planes (Agisoft, 2021).

3DF Zephyr (4.530)

3DF Zephyr is a complete photogrammetry processing software suite with post-processing, measurement, 3D modelling, and content production capabilities. It can recreate 3D from images or movies by automatically extracting and selecting relevant frames. 3DF Zephyr uses "Hollow objects volume" for volume computation. This tool allows the calculation of the volume of a cloud/mesh when the photographic survey has been carried out from the inside of the acquired object itself, as in the case of a room or a tank. Unlike the standard volume computation, this algorithm entails that the normal of the objects point towards the inside. This also means that any other objects cluttering the inner space will not be considered during this specific computation (3DF Zephyr, 2021).

RealityCapture (v1.0.3.4987)

RealityCapture is a photogrammetry software that creates 3D models from unequally spaced pictures (or laser scans). It is currently used in cultural heritage (art and architecture), gaming, surveying, mapping, visual effects (VFX), and virtual reality (VR) in general. It includes picture registration (alignment), automated calibration, polygon mesh calculation, colouring, and texturing. RealityCapture can blend camera and laser scan images. It is designed to be low-resource. It works linearly, so doubling the input doubles the processing time. RealtyCapture computes volume using the VBUILT algorithm (RealityCapture, 2020).

2.3. GCP placement and survey

As shown in Figure 2, the identified points for establishing GCPs were marked using pegs and white markers. Ten (10) GCPs were established evenly around the study area and coordinated (see Table 1 for the coordinates) with Hi-Target v30 DGPS in RTK mode.

Table 1. Coordinates of established GCPs and checkpoints

Control ID	Easting (mN)	Northing (mE)	Height (m)	Remark
Point 1	1055377.6338	220634.6997	232.4789	GCP
Point 2	1055370.5761	220635.7598	232.5970	GCP
Point 3	1055351.8860	220634.9449	232.6150	GCP
Point 4	1055344.1970	220632.8362	232.6200	GCP
Point 5	1055344.3583	220615.3681	232.2558	GCP
Point 6	1055344.1888	220598.7994	232.0296	GCP
Point 7	1055352.0830	220597.7647	231.9066	CP
Point 8	1055371.0050	220598.715	231.8375	CP
Point 9	1055379.3299	220600.8397	231.8485	CP
Point 10	1055379.8035	220617.1853	232.2007	CP

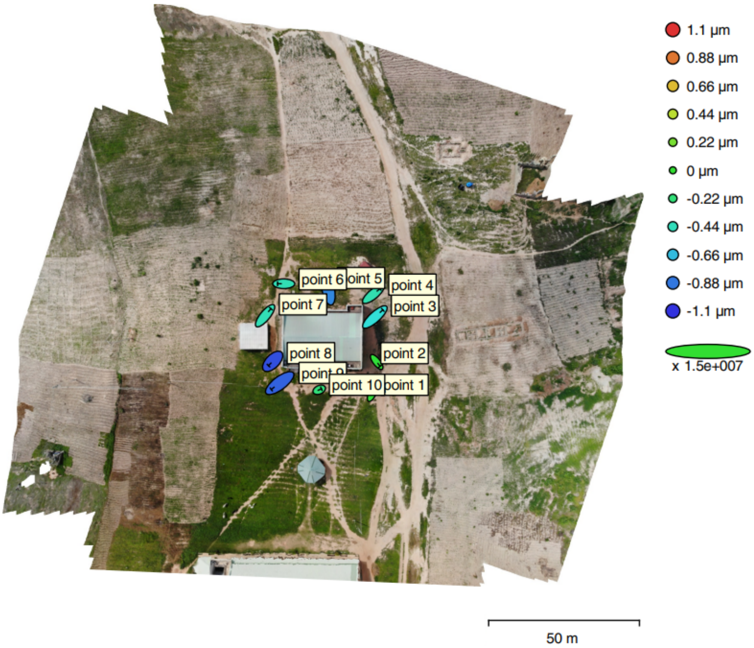

Fig. 2. Orthomosaic showing the GCPs and checkpoints around the building

2.4. Data collection

Figure 3 shows the study's data collection, processing, and analysis methods. The Works Department (Federal University of Technology Minna) provided the lecture theatre's as-built design containing the 2D and 3D models of the building. Revit 2018 (v3) was used to construct the 3D model and building details. The Revit volume was utilized as a reference to estimate the preferred processing software.

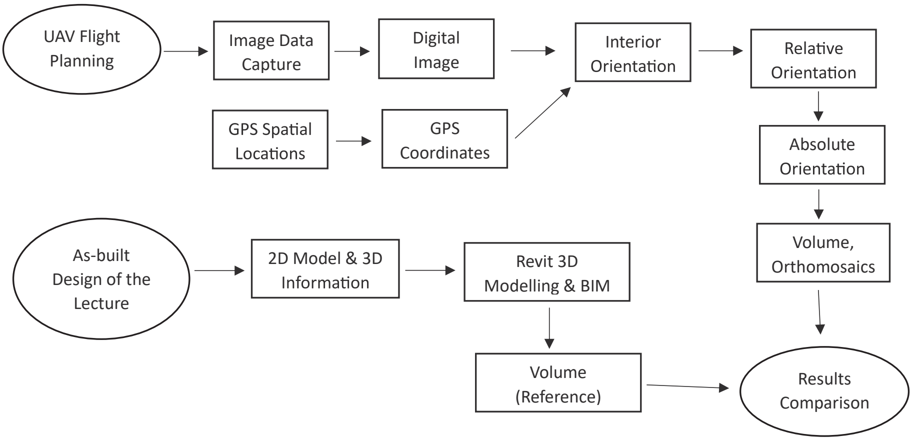

Fig. 3. Methodology of the study

All necessary settings were configured for the UAV's image-capture flight plan. The camera angle was 90 degrees to achieve vertical imaging with a 60-m flying height, 80% side overlap, and 80% forward overlap. All UAV components, including the camera, propellers, and non-imaging sensors, were checked for proper operation. For take-off and landing, a suitable UAV base station was chosen. The UAV data was obtained during a clear, sunny afternoon with no precipitation, assuring a safe flight mission. The drone took 52 photos over 3.31 hectares.

2.5. Data processing

The data processing workflow adopted in each software varies and depends on how each software was developed. However, a general overview of the procedure is presented in Figure 4 and discussed as follows; after the images were collected from the study area, they were imported into each UAV image processing software. Each software merges the images to produce just a single model of the study area.

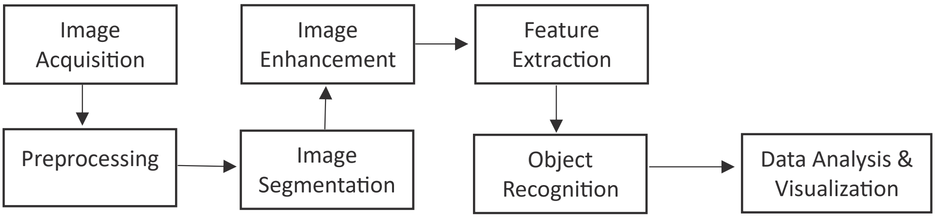

Fig. 4. Typical data processing steps

Furthermore, the model was georeferenced by the GCPs. The same procedure was also carried out without GCPs, and the volume of the structure under consideration was estimated. Each software produced a report that consisted of the time it took each software to process the images before it produced the final model; the Ground Sampling Distance (GSD) and positional RSME were obtained. After the deliverables mentioned above had been obtained, the deliverables were compared.

3D modelling and volume estimation

2D drawings serve as the foundation for BIM projects, and it is thus critical to transfer 2D plans from one software to another correctly. The 2D drawings and perspectives were exported from the AutoCAD environment into Revit. The drawing perspectives (in 3D) were then developed, and the volume was finally estimated.

Volume estimation from image data

The steps for volume estimation in each of the four image processing software are similar; overlapping images taken with the drone were aligned shortly after importing them into the software, and the aligned images were georeferenced by importing the coordinates of the ten GCPs, and CPs were established around the building before the UAV data capture. A dense points cloud was constructed using the camera positions obtained during image alignment. The built dense point cloud's construction parameter includes construction quality, which was left as the default in all four-image processing software. The Digital Elevation Model (DEM) was generated using each software's default settings. This process was repeated four times, and the volume predicted by each software was recorded and analysed.

In addition, to estimate the level of uncertainty in the computed volumes in each image processing software, the percentage difference was calculated using the volume of the BIM as the actual volume and the volume estimated by each image processing software as the computed volume, as shown below:

$$P_{\text{difference}} = \frac{(\text{computed} - \text{actual})}{\text{initial}} \times 100. \tag{1}$$

A second set of four independent volume estimation processing campaigns was run without importing GCP reference coordinates. For image processing, onboard GPS data was employed during UAV data capture. This was done to distinguish between georeferencing inaccuracy and final software volume estimates. Since these processing campaigns lacked GCPs, RMSE wasn't calculated. Volume estimates and project execution time were recorded and analysed.

3. Results

3.1. The 3D as-built model

Figure 5 depicts the 3D as-built model of the building. The volume generated from the as-built model in the Revit environment was 4850.774 m^3. This served as the reference volume with which the estimated volumes from the processing software were evaluated.

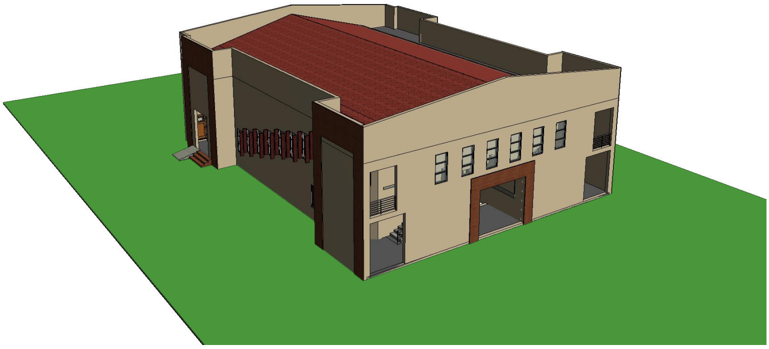

Fig. 5. The 3D as-built model of the building

3.2. Comparative analysis of volume estimation (with GCPs)

Table 2 shows the estimated building volume for the four processing campaigns utilizing GCPs' reference coordinates to georeference the image. It also presents the as-built 3D model's volume, which was used as the benchmark. The variations between estimated and as-built volumes are expressed in percentages.

Table 2. Estimated volumes generated from the processing software with GCPs. In parentheses are shown the values of differences of the volume estimations

	Pix4DMapper	Agisoft metashape Pro	3DF Zephyr	RealityCapture
First campaign (m^3)	4650.63 (4.12%)	4728.8 (–2.51%)	4358.42 (–10.15%)	3565.49 (–26.50%)
Second campaign (m^3)	4676.75 (–3.59%)	4732.5 (–2.49%)	4347.52 (–10.27%)	4347.26 (–10.38%)
Third campaign (m^3)	5039.85 (3.89%)	4733.4 (–2.42%)	4397.52 (–9.34%)	3895.85 (–19.69%)
Fourth campaign (m^3)	4662.56 (–3.88%)	4717.7 (–2.74%)	4062.78 (–16.25%)	4811.15 (–0.82%)
Average (m^3)	4757.448 (3.87%)	4728.1 (2.54%)	4291.561 (11.50%)	4154.938 (14.35%)
Rank	second	first	third	fourth
Revit (m^3)	4850.774			

Pix4DMapper generated 4757.448 m^3, which shows a 3.87% variance from the reference volume. Agisoft Metashape Pro generated 4728.1 m^3 with a 2.54% difference. 3D Zephyr yielded 4291.561 m^3 showing 11.5% difference, while RealityCapture yielded 4154.938 m^3, a 14.3% difference from the reference.

3.3. Comparative analysis of spatial resolution (with GCPs)

Ground Sampling Distance (GSD) refers to the physical size of each pixel in an image, which is determined by the camera's spatial resolution and the altitude of the platform capturing the image. A higher GSD means larger pixel sizes, which can result in lower spatial resolution and less image detail. Higher flight altitude implies high GSD. It was discovered that different software algorithms produced varying GSD readings despite maintaining constant flying height throughout UAV data acquisition. The software's orthophotos had different spatial resolutions due to varying GSD values. 3DF Zephyr came first with an average GSD value of 1.352 cm/pix, while Agisoft Metashape came second with a steady GSD value of 2.40 cm/pix. Pix4DMapper came third with an average

GSD value of 2.475cm/pix, while RealityCapture came fourth with an average GSD value of 7.235 cm/pix. It was observed that Agisoft Metashape's GSD remained constant throughout the four repeated processing campaigns, while the other three software packages generated slightly varied GSDs.

3.4. Comparative analysis of processed image RMSE (with GCPs)

To evaluate the accuracy and precision of the GCPs, the Root Mean Square Error (RMSE) of the data by each software was computed after each processing campaign. RMSE was calculated using the Eq. (2):

$$\mathrm{RMSE}_{(l)} = \sqrt{\sum_{i=1}^{n} \frac{(\bar{l} - l_i)^2}{n}}\,. \tag{2}$$

3DF Zephyr generated no RMSE error, while Pix4DMapper generated an average RMSE of 0.17 m, 0.20 m, and 0.28 m for x, y, and z, respectively. Agisoft Metashape Pro, on the other hand, generated an average RMSE of 0.03 m, 0.03 m, and 0.04m for x, y, and z, respectively. In contrast, RealityCapture generated an average RMSE of 11.29 m, 13.03 m, and 786.84 m for x, y, and z, respectively.

3.5. Comparative analysis of project execution time (with GCPs)

The time taken by each processing software during each campaign was recorded to evaluate the processing speed of the software. 3DF Zephyr came first with an average execution time of 32 minutes 6 seconds, RealityCapture came second with an average execution time of 32 minutes 47 seconds, Agisoft Metashape came third with an average execution time of 33 minutes 35 seconds, while Pix4dMapper came fourth with an average execution time of 1 hour 9 minutes 2 seconds.

3.6. Comparative analysis of volume estimation (without GCPs)

Table 3 displays the estimated building volume for the four processing campaigns without GCP reference coordinates. The estimated volumes are compared to the as-built model volume, and differences are represented as percentages. Pix4DMapper generated 4631.385 m^3, which shows a 4.52% variance from the reference volume, while Agisoft Metashape Pro yielded 4773.025 m^3 showing a 1.6% difference. 3D Zephyr generated 4617.899 m^3, which show a 4.89% difference, while RealityCapture yielded 4420.403 m^3, an 8.92% difference from the actual volume.

Table 3. Estimated volumes generated from the processing software with GCPs. In parentheses are shown the values of differences of the volume estimations

	Pix4DMapper	Agisoft metashape Pro	3DF Zephyr	RealityCapture
First campaign (m^3)	4661.51 (–3.90%)	4842.6 (–0.17%)	4609.56 (–4.97%)	4837.46 (–0.27%)
Second campaign (m^3)	4584.23 (–5.49%)	4744.4 (–2.19%)	4813.25 (–0.77%)	4269.51 (–12.18%)
Third campaign (m^3)	4612.90 (–4.90%)	4741.8 (–2.24%)	4506.795 (–7.09%)	4067.76 (–16.14%)
Fourth campaign (m^3)	4666.90 (–3.79%)	4763.3 (–1.80%)	4541.992 (–6.74%)	4506.88 (–7.09%)
Average	4631.385 (4.52%)	4773.025 (1.60%)	4617.899 (4.89%)	4420.403 (8.92%)
Rank	Second	First	Third	Fourth
Revit (m^3)	4850.774			

3.7. Comparative analysis of project execution time (without GCPs)

The time each processing software spent during each campaign without GCP coordinates was recorded to evaluate the software's processing speed without GCPs. Agisoft Metashape came first with an average execution time of 16 minutes 36 seconds, RealityCapture came second with an average execution time of 27 minutes 22.6 seconds, 3DF Zephyr came third with an average execution time of 34 minutes 34 seconds, while Pix4DMapper came fourth with average execution time of 1 hour 8 minutes 17 seconds.

3.8. Comparative analysis of spatial resolution (without GCPs)

The average GSD for each software in the four processing campaigns without GCPs was recorded and evaluated. 3DFZephyr came first with an average GSD value of 1.45 cm/pix, while Agisoft Metashape pro came second with an average GSD value of 2.40cm/pix. Pix4DMapper came third with an average GSD value of 2.483 cm/pix, while 3DF Zephyr came fourth with an average GSD value of 1.45 cm/pix.

3.9. Comparative analysis of the average percentage difference of the estimated volumes

Figure 6 presents the average percentage differences of the volume estimations obtained from all processing campaigns.

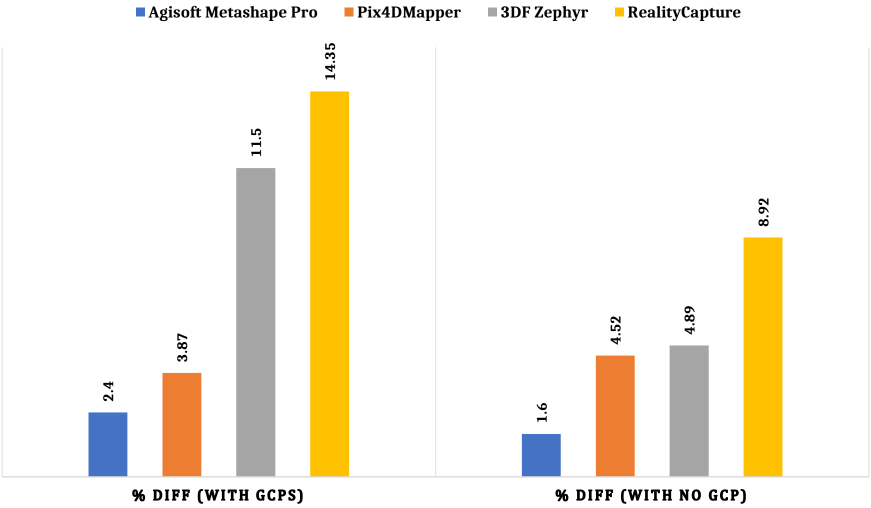

Fig. 6. Average percentage difference of the estimated volumes

4. Discussion

The volume estimation accuracy of RealityCapture and 3DF Zephyr was less accurate than that of Pix4DMapper and Agisoft Metashape Pro, possibly due to the software's deliverables. Pix4DMapper and Agisoft used Digital Elevation Models (DEMs) to estimate building volume, while RealityCapture and 3DF Zephyr used meshes. The lack of DEM creation in RealityCapture and 3DF Zephyr may have contributed to less accurate volume estimations. Agisoft Metashape Pro was the only software that provided camera calibration coefficients, correlation matrix, and position error, suggesting its algorithmic resilience and stability.

The differences in volume values obtained from Table 1 and Table 2 were attributed to variations in the campaigns' base points, algorithmic robustness, repetitive process (iteration), and volume estimating approach. Pixel-based volume calculation in photogrammetric software requires marking the base of interest points. Despite the constant size of the building, the volume value varied anytime the base of locations of interest was marked for re-estimation. Pix4D support explained that a Pix4D survey's volume measurement is triangulated between the volume's base polygon and a local TIN model in the image data's GSD (2020). In contrast, Agisoft (2016) disclosed that the importance of an object in Agisoft Metashape Pro is computed by breaking the model into pyramids and summing their volumes, with the model's faces counting as pyramid bases. RealityCapture and 3DF Zephyr lacked a volume estimation method, estimating volumes from the mesh surface.

When GCPs were utilised during data processing, Agisoft Metashape Pro estimated the most accurate volume, with a 2.54% average difference, less than the 3% maximum allowable difference specified by Raeva et al. (2016). Agisoft Metashape was found to be constant and precise during the four processing campaigns due to its reduced RMSE after the campaign, contributing to its improved volume estimation accuracy.

The study found that the average percentage differences of the volume estimated by 3DF Zephyr and RealityCapture were significantly high and very poor compared to Pix4DMapper and Agisoft metashape. This could be due to the high RMSE value generated by these two software packages. Additionally, 3DF Zephyr had the lowest GSD and highest spatial resolution, followed by Agisoft metashape and Pix4DMapper. RealityCapture's resolution was the lowest, which explains its low spatial precision.

From Figure 6, the volume estimation accuracy almost doubled in all the processing software when the image was not georeferenced using GCPs, except for Pix4DMapper, whose accuracy slightly decreased. This indicates that Pix4DMapper uses GCPs to generate superior volumetric estimates. Georeferencing errors affected Agisoft, 3DF Zephyr, and RealityCapture's volume estimates, as they work better without georeferenced image data. Agisoft Metashape Pro's predicted volume accuracy without GCPs was lower than Datumate's (2017) estimate of 4.5%. The findings of this research which affirmed that more accurate volumes were estimated by most of the software packages when GCPs were not used is in agreement with the findings of Yuan et al. (2018) which affirmed that accurate and reliable results can be obtained without using GCPs. Wu et al. (2019) also affirmed that accurate building volumes can be estimated from UAV images without GCPs, while Zhang et al. (2019) also conducted a comprehensive study of building volume estimation from UAV images without GCPs and found that the results were comparable to those obtained using GCPs. These studies and the present study suggest that precise volume estimation is possible in UAV image processing software without GCPs and it suggests that this strategy can be reliably used when the terrain of a site is dangerous or inaccessible.

Figure 6 also showed that Agisoft metashape processed faster than the remaining software when no GCP was used, almost half the processing time it used when GCPs were used. Pix4DMapper's project execution time when no GCP was used is virtually identical to the processing time when GCPs were used. This emphasises that volumetric estimation from UAV image data without GCPs is more time efficient. The study affirmed that Agisoft Metashape Pro has a robust, reliable, and time-efficient processing algorithm for volumetric estimations compared to the other software packages investigated in this study.

5. Conclusions

This study aimed to evaluate the performance of image processing software in building volume estimation, with a focus on the impact of each software's volume estimation algorithm on estimated volume, spatial accuracy, and project execution time. The results show that the choice of base point selection for volume estimation, unique to each software, resulted in variations in the volume values obtained for each processing campaign. However, among the software tested, Agisoft Metashape Pro demonstrated excellent spatial precision, accurate volume prediction, and efficient project execution time. Additionally, the study found that all tested software, except Pix4DMapper, produced more precise volume estimates without the use of ground control points (GCPs). This suggests that UAV image processing may not require GCPs for volumetric measurements. In summary, this research provides valuable insights into the performance of image processing software for building volume estimation. Agisoft Metashape Pro is recommended for its superior performance, and the potential of not needing GCPs for volumetric measurements could save time and resources in UAV image processing.

Author contributions

Conceptualization: O.G.A.; data collection and curation: B.S.O.; methodology: O.G.A., G.A.A.; formal analysis: O.G.A., B.S.O.; visualization: O.G.A.; resources: O.G.A.; G.A.A.; writing – original draft: O.G.A.; supervision: O.G.A.; writing – review and editing: O.G.A., B.S.O., G.A.A.

Data availability statement

The data will be available on request.

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