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VIRTUAL 3D MODELLING BY CLOSE RANGE PHOTOGRAMMETRY USING NON-METRIC CAMERA FOR AS-BUILT BUILDING INFORMATION MODEL

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Abstract

The report presents a new insight into the concept of virtual 3D modelling by close range photogrammetry using non-metric camera that could be applied in As-built Building Information Model (BIM). This study was achieved by carrying out Camera calibration on the non-metric Sony DSC HX7V camera used for the photographic digital image data acquisition. Basic data acquired are digital image captured with the non-metric camera and Ground Control Points (GCP) surveyed with a South Total Station instrument. Data processing entailed creation of a virtual 3D model of the study area with Agisoft Photoscan software. The 3D model was created based on close range photogrammetric principles and computer vision techniques. For the purpose of the virtual 3D model assessment, points, distances, area and volume measurements were made on the 3D model and corresponding measurements were also made using conventional direct ground surveying technique. Results of the 3D model accuracy assessment reveals a standard error of 0.249m, 0.361m and 0.030m in easting, northing and height coordinates respectively and a marginal improvement with scale bar optimization from 0.392m to 0.204m and 0.030m to 0.016m mean standard error in planimetric and height components respectively. With availability of suitably enough ground measured points and distances required to suitably control the 3D model, the non-metric compact camera by close-range photogrammetry would give an accurate virtual 3D representation of a scene, required for As-Built BIM application.

Keywords: As-Built BIM, Camera calibration, Close-Range Photogrammetry, Non-Metric Camera, Virtual 3D model.

Introduction

In close-range photogrammetric applications, cameras are the most important instrument required. For close-range photogrammetric applications, digital cameras used can be divided into two categories with respect to their metric properties, which are the non-metric and metric cameras. The non-metric (amateur) digital cameras are comparatively low-cost and low-resolution while the metric (professional) digital cameras are comparatively expensive, with high-resolution. The metric or Professional cameras have a range of features, such as good lens quality, a robust structure, a large sensor with high resolution and sensitivity, and the ability to switch lenses, while the non-metric or amateur cameras may contain any of these features. The main difference between the metric and non-metric cameras is the lower geometric stability of amateur cameras [5; 28]. To apply the non-metric cameras in close-range photogrammetry, there is a need for determination of the intrinsic camera parameters through a process known as camera calibration. The camera calibration is a process required to extract accurate and reliable 3D information from images. Various algorithms have been proposed for camera calibration in the area of photogrammetry

and computer vision. The developed algorithms are generally based on the perspective camera model [28]. The self-calibration approach was initially developed by [2] and has been routinely used as an efficient technique in photogrammetry [17]. The photogrammetric camera calibration has been the subject of many publications. Digital cameras applied for photogrammetric measurement, and in the particular parameter sets, the stability of parameters, camera configurations, and analysis techniques are proposed [8;16; 26]. Many efforts have been made to completely automate the process of taking images, calibrating and orienting them, recovering the 3D coordinates of the imaged scene and modelling them, but while promising, the methods are thus far not always successful or proven in practical applications. The fully automated procedure, widely reported in the computer vision community [8; 21; 22] starts with a sequence of closely separated images taken with an uncalibrated camera. The system automatically extracts points of interest (such as corners), sequentially matches them across views and then computes camera parameters and 3D coordinates of the matched points using robust techniques. Self-calibration (or auto-calibration) to compute the intrinsic camera parameters (usually only the focal length) is generally used in order to obtain metric reconstruction from the projective one. The 3D surface model is then automatically generated. In case of complex objects, further matching procedures are applied in order to obtain dense depth maps and a complete 3D model. [27] presented an overview of dense stereo-correspondence algorithms. Some approaches have also been presented for the automated extraction of image correspondences between wide baseline images [6; 15; 18; 23; 33] but their reliability and applicability for automated image-based modelling of complex objects is still not satisfactory as they yield mainly a sparse set of matched feature points. However, dense matching results under wide baseline conditions were reported in [29] and [19]. Automated image-based modelling methods rely on features that can be extracted from the scene and automatically matched, therefore occlusions, illumination changes, limited locations for the image acquisition and untextured surfaces are problematic [25]. The level of automation is also strictly related to the quality (precision) of the required 3D model. Automated reconstruction methods, even if able to recover the complete 3D geometry of an object, reported errors up to 5% (accuracy of c. 1:20) [22], limiting their use to applications that require only nice-looking partial 3D models. Furthermore, post-processing operations are often required, which means that user interaction is still needed. For the purpose of this research the process is not fully automated since GCPs are considered with a view for an improved accuracy that could be potentially useful in Building Information Modelling (BIM) applications.

Building Information Modelling (BIM) is a collection of data which digitally represent the relevant characteristics of a building [31]. It is created through a process of modelling which includes practices such as distribution and storage of these datasets. BIM is a rich data platform, but it is not practical if it only represents the design, and not the building as it is built. As-Built BIM includes all the changes made on the building during the construction phase; it can be an up-to-date representation model of the building. The widespread use of As-Built BIM is prevented by the lack of a time-efficient and accurate method of easily creating BIMs [11]. The capabilities of BIM as representation models and its requirements for As-Built BIMs have been extensively investigated [4; 9; 24; 31]. However, [11] claimed that the topic of

representing As-Built BIM is in its early stage. Furthermore, current procedures rely on manual processes which are labour-intensive, time-consuming and susceptible to errors. According to [30], existing work focuses on modelling the simplest objects of a building rather than modelling complex objects such as doors and windows. In addition, they showed that there are significant disconnections between surface-based modelling and volumetric modelling representations. Collecting and incorporating reliable As-Built data for BIM is still challenging, when considering accuracy, time and cost constraints [30]. Several technologies are available for creating As-Built models. [4] presented a semiautomatic approach for generating BIM facade models for existing buildings, and concluded that future work requires procedural development for generating entire building models, rather than parametric library objects such as column and pediments. In addition, they suggested that future work should be more comprehensive to serve end-users.

Therefore, so much work is needed to improve the accuracy of the current practices considering cost and time in construction [9]. [12] carried out a productive modelling for development of As-Built BIM of existing indoor structures. Their work employed a terrestrial laser scanner for data acquisition, and a 3-step approach for 3D geometric drawings that involved segmentation for plan extraction, refinement for removal of noisy points and boundary tracing for outline extraction. The 3D geometric drawing and point data was later used to conduct a manual As-Built BIM creation. The research work of [34], presented a parametric-assisted method for 3D generation of As-Built BIM models for the built heritage. Their work made use of open-source cloud computing and interoperability, that employed digital photogrammetry and open-source software (Grasshopper) to automatically rebuild complex and irregular geometry from mesh, which lead to creation of a Non-Uniform Rational Basis (NURBS) 3D model.

Realizing 3D model of irregular surfaced objects needs several points to represent the surface exactly. These points can be easily obtained from measurements made on photographs [3]. Multiple and overlapping images taken from different perspectives, produces measurements that can be used to create accurate 3D models of objects, with or without knowledge of the position of camera, because the geometry of the object is established directly from the images [20]. Considering the increase in demand for 3D modelling required for As-Built BIM there is need for the potentials of the non-metric amateur camera to be exploited which would provide the necessary datasets at a cheaper cost. This study is aimed at creating a virtual 3D model by close range photogrammetry using non-metric digital camera, with a view to serve as geometric input for As-Built BIM applications.

Study Area

The area of study as shown on Figure 1, is limited to the main library of the Federal University of Technology Akure, located at Akure south local government area of Ondo state, Nigeria. The building is located between approximately latitude 7° 18' 14.17"N to 7° 19' 11.12"N and longitude 5° 08' 04.00"E to 5° 06' 02.10"E. This building was selected for the study, considering some characteristics which are the ease of access for suitable exposure station required for image capture. The high textured surface for point extraction for accurate point correspondences (image matching). As at the time of image capture the study

area building was undergoing renovation and expansion project, which presented it best for as built representation.



Figure 1: Satellite Image showing Study Area

Materials and Method

The study involving the creation of a virtual 3D modelling by close range photogrammetry using non-metric digital camera with a view to serve as geometric input for As-Built BIM applications. The method adopted in this study is summarized on Figure 2. For the purpose of the integrated data acquisition, data collected include: Photo of camera calibration grid, terrestrial overlapping photo of the scene of the study area, Ground control points (GCP) and linear distance measurements collected on the surface of the building. Instruments used for this data collection include: Measuring Tape, Camera SONY DSC HX7 camera and a Total station and its accessories. The processing phase include camera calibration, image processing for creation 3D models, and extraction of X, Y, Z dense point cloud these were carried out with the aid of Photomodeler Scanner, and Agisoft PhotoScan software; these are image-based 3D modeling software that work on Close Range Photogrammetric principles.

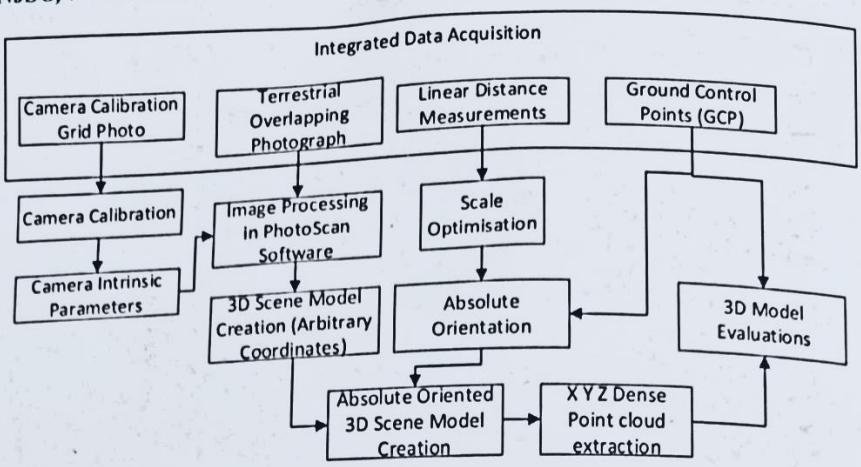


Figure 2: Workflow of methodology

Data acquisition

The Sony DSC HX7V amateur camera was used to acquire digital images of the building façade at close range. Properties of the camera used are outlined on Table 1.

Table1: Properties of camera used

Camera type	Sony DSC HX7V
focal length	42.5
Resolution (mega pixels)	16.2
Pixel array (width x height	1920 x 1080
image sensor type	CMOS

Camera Calibration

Prior to digital image acquisitions, camera calibration was performed. Measurement with cameras necessitates knowing the characteristics of the camera before applying it into a project. Calibration of the internal parameters of a camera is critical for accurate measurements [26] . Camera calibration is usually performed to determine interior orientation of the camera. Interior orientation is the relationship between camera-centric coordinates and image coordinates [10]. Usually, calibrated cameras produce five approximated parameters that can be used as a measurement device and also reduce error in measurements to achieve high accuracy results. These are the basic optical parameters, geometric and digital characteristics of the camera, which include; the perspective projection (focal length, f), the transformation between image planes coordinates and pixel coordinates (x, y) and the geometric distortion introduced by the optics (k1, k2, k3).

The calibration was done by using Photo Modeller calibration grid shown in Figure 3 that is provided in PhotoModeller Scanner program files folder. The grid was printed out at suitable size and placed on the floor to take the photographs with the camera and at same focal length to be used for on-site image acquisition proper. Self-calibration was used for this project because of its simplicity and ease of

processing. Twenty-one grid calibration photos were taken before the camera calibration processing, but require at least two photos must be rolled in rotation 90^0 clock-wise or counter clock-wise. For this study, Sony DSC HX7V digital camera was used. The photographed calibration grids were processed with Photo Modeler Scanner to obtain the camera parameters.

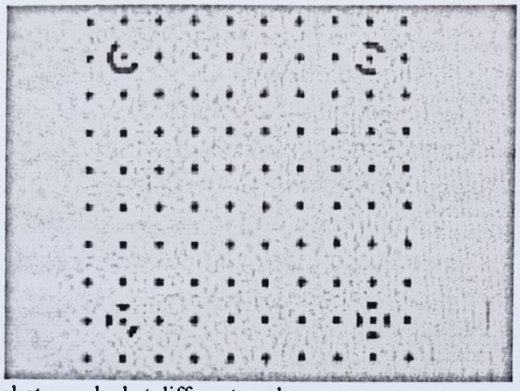


Figure 3: Calibration grid photographed at different angles

The field work stated with controls extension within study area. Measurement of the check points on the building façade was carried out using a total station in a reflectorless mode. The reflectorless mode of operation was adopted due to the fact that the established wall controls and check points were not reflective targets. A total of 13 points were established, which consisted of six controls for image processing and seven check points for accuracy evaluation. This was followed with collection of multiple overlapping images of the building façade at close range, using Sony DSC HX7V amateur camera. Image acquisition was carefully made such that a convergent pair have an overlap of 75 – 80%. This is necessary to ensure that each successive photograph duplicates part of the area coverage of the previous photo, and to ensure multiple photographic coverage all around the building façade [32]. Also, the inner geometry of the camera was kept constant, while homogeneous illumination was maintained throughout the image acquisition process.

A total of 158 images of the building facade were captured with the calibrated camera, set at the focal length used for camera calibration. Figure 4 shows a sample pair of acquired overlapping photographs.

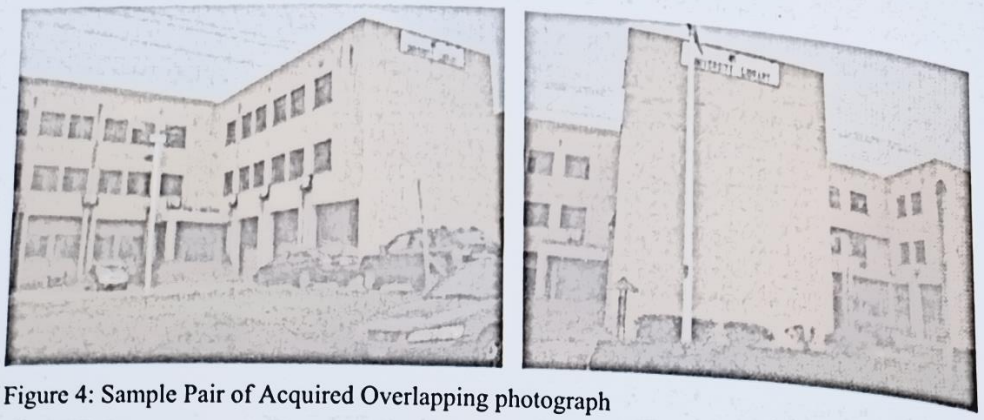


Figure 4: Sample Pair of Acquired Overlapping photograph

The coordinates of the wall control points and check points are shown in the Table 1. Two distances were measured on the building with a tape for scale bar optimization shown on Table 2.

Table 2: coordinate of points used to control and assess the model

Point ID	Type	Northing (m)	Easting (m)	Height (m)
1	Control	807821.003	735768.309	390.110
2	Control	807834.487	735733.076	389.202
3	Control	807795.014	735772.067	388.224
4	Control	807758.730	735739.950	385.733
5	Control	807764.688	735712.354	388.121
6	Control	807821.189	735702.473	388.157
1	Check Point	807770.016	735754.115	386.687
2	Check Point	807828.156	735747.306	389.376
3	Check Point	807761.300	735731.718	386.660
4	Check Point	807838.551	735710.414	390.080
5	Check Point	807774.605	735689.158	387.859
Window level	Check point	807 840.123	735710.589	388.564
Window2	Check point	807769.012	735754.962	390.835

Table 3: distance measured for scale bar optimization

Line id	Remarks	Length(m)
Point6_point7	For optimization	16.330
Point8_point9	For optimization	12.630

Data processing: 3D model Constructing

After successful calibration of the camera, suitable photos for 3D model construction were selected among the acquired images and loaded into photo scan without editing since photoScan operates with unmodified photos. Camera calibration parameters were imported, while photo quality estimation was done by switching to the detailed view in the Photos Pane, and selecting all Photos to be analysed. The essence of photo quality estimation is to assess the quality of the inputted images, so that those with poor quality can be removed. At this stage, the PhotoScan finds the camera position and orientation for each photo and builds a sparse point cloud model. Relative Orientation having been completed, computed camera positions and a sparse point cloud were displayed (Figure 5).

3D texture model was generated using the Build Texture command selected from the Workflow menu. It is worthy of note here that the 3D model generated is referenced to computer coordinate system. This is proved by incorrect orientation of the model and the coordinates of dense points created. The next step is the absolute orientation, which is to orient the model to the ground coordinate system by setting the coordinate system either by placing markers using ground control points or camera coordinates. Since non-metric camera was employed, the former was used with sufficient precaution based on the GCPs collected. The effect of this step was instantly observed in the correct orientation of the 3D model. The dense points generated were also oriented. Scale bar optimization was carried out based on linear measurements made to further optimize the scale component. More than 19 million dense points were extracted for the scene.

PhotoScan enables measurements of direct distances, coordinates, areas and volumes on the reconstructed 3D scene. Distance and coordinate measurement were done on the model and were applied in evaluating the 3D model based on the previously measured GCPs reserved as check points. This was carried out with and without scale optimization and the standard error of model measurement were thus computed based on the differences between the ground measured and model estimated X Y and Z coordinate values. Table 4 shows measured ground and model coordinates of controls and check points.

Table 4: Measured Ground coordinates and Measured model coordinates of control and check points

	Ground coordinates			**Measured Model coordinates**		
S/N	X (m)	Y (m)	Z (m)	X(m)	Y(m)	Z(m)
1	735768.309	807821.003	390.11	735768.428	807820.859	390.161
2	735733.076	807834.487	389.202	735733.231	807834.649	389.162
3	735772.067	807795.014	388.224	735771.825	807795.102	388.174
4	735739.95	807758.73	385.733	735740.023	807758.588	385.793
5	735712.354	807764.688	388.121	735712.458	807764.801	388.102
6	735702.473	807821.189	388.157	735702.288	807821.078	388.146
7	735754.115	807770.016	386.687	735754.166	807770.098	386.692
8	735747.306	807828.156	389.376	735747.314	807827.705	389.382
9	735731.718	807761.3	386.66	735731.502	807760.053	386.656
10	735710.414	807838.551	390.08	735710.53	807838.093	390.075
11	735689.158	807774.605	387.859	735688.726	807773.955	387.862
12	735710.589	807 840.123	388.564	735710.138	807 840.536	388.572
13	735754.962	807769.012	390.835	735754.567	807770.003	390.841

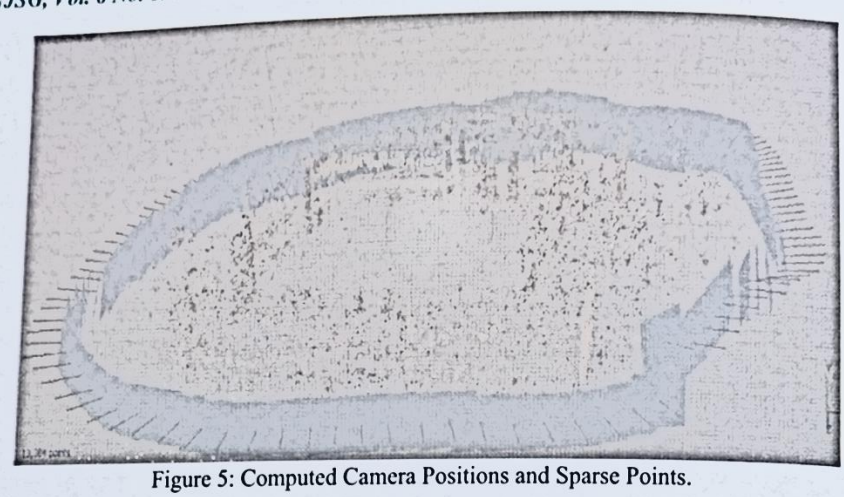


Figure 5: Computed Camera Positions and Sparse Points.

Results

The results of this study are estimated camera parameters (Table 5), oriented 3-D model (Figure 6) evaluation of model based on different control modes vis a vis four controls and six controls each with and without scale optimization (Table 7) and measurement of perimeter, area and volumes (Table 8).

Table 5: Estimated Camera Parameters

Camera parameters	Sony DSC HX7V
Focal length (f) (mm)	7.708065
Format width (fw) (mm) (F-width, F-hight)	6.860481
Format height (fh) (mm)	5.145275
Principal point(Xp) (mm)	3.383302
Principal point(Yp) (mm)	2.596786
Lens distortions k1	9.026e-004
Lens distortions k2	5.500e-004
Lens distortions k3	0.000e+000
decentering distortions p1	7.112e-005
decentering distortions p2	1.284e-005

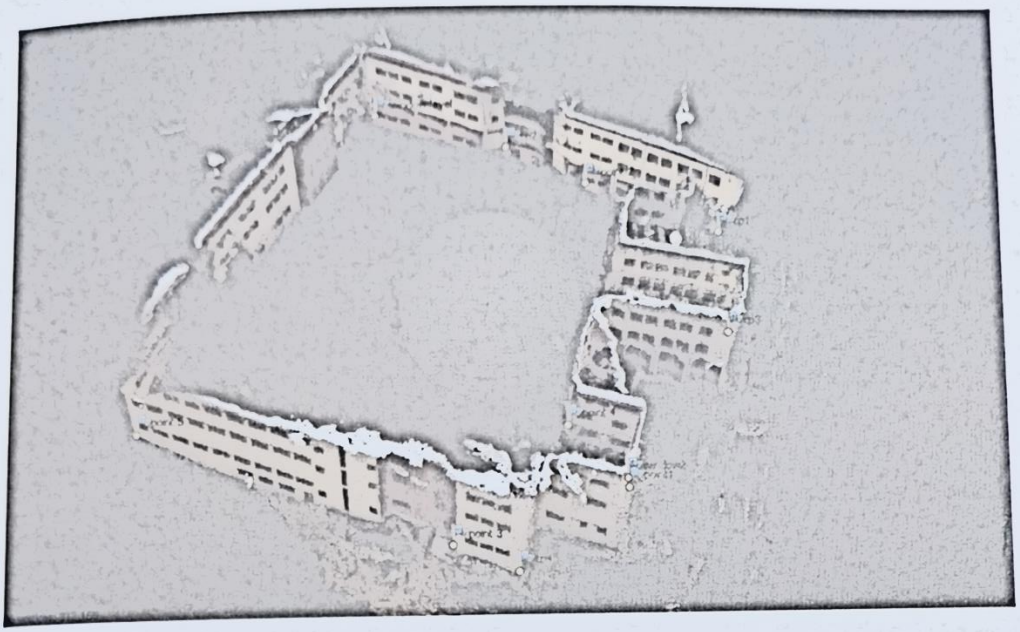


Figure 6: Orthogonal view of oriented 3-D model of FUTA Library

Table 6: Standard error of model measurement without scale bar optimization

S/N	Conventional Survey			Measured Model coordinates			Square of difference		
	X (m)	Y (m)	Z (m)	X(m)	Y(m)	Z(m)	(x-xi)2	(y-yi)2	(z-zi)2
1	735768.309	807821.003	390.11	735768.428	807820.859	390.161	0.014	0.021	0.003
2	735733.076	807834.487	389.202	735733.231	807834.649	389.162	0.024	0.026	0.002
3	735772.067	807795.014	388.224	735771.825	807795.102	388.174	0.059	0.008	0.003
4	735739.95	807758.73	385.733	735740.023	807758.588	385.793	0.005	0.02	0.004
5	735712.354	807764.688	388.121	735712.458	807764.801	388.102	0.011	0.013	0
6	735702.473	807821.189	388.157	735702.288	807821.078	388.146	0.034	0.012	0
7	735754.115	807770.016	386.687	735754.166	807770.098	386.692	0.003	0.007	0
8	735747.306	807828.156	389.376	735747.314	807827.705	389.382	0	0.203	0
9	735731.718	807761.3	386.66	735731.502	807760.053	386.656	0.047	1.555	0
10	735710.414	807838.551	390.08	735710.53	807838.093	390.075	0.013	0.209	0
11	735689.158	807774.605	387.859	735688.726	807773.955	387.862	0.187	0.423	0
12	735710.589	807 840.123	388.564	735710.138	807 840.536	388.572	0.203	0.171	0
13	735754.962	807769.012	390.835	735754.567	807770.003	390.841	0.156	0.982	0
SUM							0.755	3.649	0.011
Standard error $sd = \sqrt{\frac{\sum(x-xi)^2}{n}}$							0.241	0.53	0.03

Other results of model accuracy evaluation based on 4 and 6 controls with and without scale bar optimization is shown in the summary presented on Table 7.

Table 7: Summary standard error of model measurement

s/n	Model	σ_x (m)	σ_y (m)	σ_z (m)
1	4 GCPs	1.641	2.364	0.691
2	4 GCPs with scale optimization	1.079	2.566	0.643
3	6 GCPs	0.249	0.535	0.030
4	6 GCPs with scale optimization	0.046	0.361	0.016

Results shown on Table 8 are perimeter, cross-sectional area and volume measurement derived by computing from point coordinate measurement observed at the building external vertices using conventional surveying technique (Total stations survey) and corresponding measurements made on the virtual 3D building model.

Table 8: Perimeter Area and Volume measurement with scale optimization

	Conventional Survey	Model measured	Differences
Perimeter (m)	340.360	340.2459	0.1141
Cross-sectional Area(m^2)	4,395.5200	4394.0780	1.4419
Volume (m^3)	47,712.0511	47687.44	24.6091

Discussions

Generation of point clouds and surface models for BIM applications, have been carried out automatically in the past from terrestrial digital imagery, using the open-source software Bundler/PMVS2, free software Visual SFM, Autodesk Web Service 123D Catch beta and low-cost software Agisoft PhotoScan which were compared with the results from terrestrial laser scanning, which led to the conclusion that the models derived from imagery could not achieve the same quality of geometrical accuracy as laser scanning [14].

Again, imaged collected using the Unmanned Aerial Systems (UAS) taken with camera's optical axis in vertical and oblique position provided results being good in terms of accuracy (average error <2cm) and reliability [1]. These cameras are metric cameras designed for professional application. Not much has been done in the aspect of applying the amateur non- metric compact camera in the area of 3D reconstruction. This study presents the application of armature non-metric compact camera (SONY DSC HX7) in generating point clouds to represent As-Built 3D model using 158 overlapping terrestrial photos captured all around the FUTA main Library building (study area). The calibration was done with PhotoModeller scanner in a single sheet module using a calibrated grid printed from the software. This was carried out to determine the intrinsic camera parameters to make the amateur camera come closer to what seems like a metric camera.

In order to enable measurement on the model, successful calibration, alignment and orientation procedures lead to reconstruction of a textured virtual 3D model of FUTA main library. Accuracy of the reconstructed textured model using four and six control points with and without scale optimization is compared. The results reveal that model using six controls gave better accuracy (standard error in X, Y and Z direction) than what was achieved using only four controls. Furthermore, with scale bar optimization, the accuracy using both four and six control points improved. This shows that scale optimization enhances the planimetric accuracy of the model and show little effect on the vertical accuracy. Scale optimization enhances the planimetric accuracy of the model and show little effect on the vertical accuracy. Generally, model under six controls gives better planimetric and vertical accuracy than model under four control points. Model on four controls has standard errors of 1.641, 2.364, and 0.691 in easting, northing and height coordinates respectively while model on six controls has 0.249, 0.361 and 0.030 standard errors in its easting, northing and height coordinates respectively.

With scale bar optimization, the mean planimetric standard error of the model on six control points decreases from 0.392 to 0.204 while the heights standard errors decrease from 0.030 to 0.016. Considering the evaluations based on model measured perimeter, area and volume with respect to corresponding conventional surveying measurement with total station, the differences are 0.1141m of 340.360m in perimeter, 1.4419m^2 of 4,395.5200m^2 in area and 24.6091m^3 of 47,712.0511m^3 in volume. The accuracies in perimeter, area and volume conforms to the minimum standard for engineering surveying specified as 1:3000 [13].

Conclusion and Recommendations

A realistic good texture virtual 3D model of the study area was created using 158 overlapping photos of the building, collected by close-range photographs using non-metric camera. The virtual 3D model is measurable with satisfactory accuracy that conform to the minimum accuracy specification standard for engineering surveying. The calibration performed with PhotoModeller scanner software, enabled reliable measurement on the 3D model. Six and four GCPs and two sets of direct distance measurements, used to control the model, reveals that increase in the number of controls, from four to six provided improved accuracy in all 3D coordinate components. Scale optimization enhances the planimetric accuracy of the model, with little effect on the vertical accuracy. Perimeter, area and volume measurement from model, gave of reasonably satisfactory accuracy for engineering application. This study has provided a new insight a procedure that could be adopted in creation a virtual 3D model using of the low-cost non-metric camera and Agisoft PhotoScan software for As-Built BIM.

The model created can be exported as dense point cloud into 3D DXF (.dxf), 3D studio (.3ds), Wavefront (.obj), Rhino (.3dm), MayaScript (.ma), Maxscript (.ms), FilmBox (.fbx) file formats which makes the 3D

model portable thereby being more relevant by providing inputs applicable in As-Built BIM creation as well as other small construction projects. One of such relevance is the application of close-range photogrammetry in determining the volume of stockpile materials.

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