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COMPARISON OF PHOTOGRAMMETRY TOOLS CONSIDERING REBAR PROGRESS RECOGNITION

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KEY WORDS: Photogrammetry Software, Point Cloud Model, Point Cloud Evaluation, Steel Reinforcement, Progress Detection.

ABSTRACT:

Construction progress monitoring is an important process throughout the project timeline towards its successful completion. Among imaging techniques, photogrammetry is considered as economical and effective method. However, few studies can be found on construction progress monitoring via photogrammetry; thus, not much guideline is available for this domain. This study evaluated the photogrammetry tools for the progress assessment of the rebar grid framework. Photogrammetry tools were evaluated and analysed following defined criteria, and Agisoft Metashape, and 3DF Zephyr were identified as better options. This study aims to provide a guideline to construction industry professionals and stakeholders towards the adoption of photogrammetric progress assessment for construction activities.

1. INTRODUCTION

Construction progress monitoring is an essential and continuous activity, declared as a key factor towards project success (Pazhoohesh and Zhang, 2015). The evolution of Industry 4.0 (I4.0) and digital technologies have changed the attitude of construction industry stakeholders towards the adoption of advanced practices (Manzoor et al., 2021). Researchers have been working in digitising the process of construction project progress monitoring via data-acquisition technologies, as it helps to enhance accuracy by reducing human errors and the required effort (Mahami et al., 2019). Laser scanning, photogrammetry, and videogrammetry are renowned imaging techniques adopted for point cloud reconstruction (Rahimian et al., 2020). In comparison to laser scanning, photogrammetry stands as a major competitor with advantages, such as photogrammetry process is economical compared to laser scanning, digital images can be taken from any device, point cloud contains colour information, point clouds can be densified, frames can be intercepted from video streams for point cloud generation, etc. (Zhu et al., 2016; García-Gago et al., 2014).

In the domain of construction management, various studies have been performed for progress assessment of building components, such as RC elements (slab, columns, beams and walls), steel structures, shoring, formwork, masonry brickwork, tiles, etc. (Omar et al., 2018; Turkan et al., 2010); however, few studies have been focused on rebar (Alaloul et al., 2021). Rebar is the main reinforced concrete element, and its inspection is considered a rigorous and timely process, as rebar inspection requires close observation and experienced inspectors are preferred (Wang et al., 2017). Researchers have mostly adopted laser scanning for rebar detection, and very few studies have performed photogrammetry-based 3D point cloud reconstruction of rebar for the purpose of progress monitoring (Alaloul et al., 2021). Based on internet sources and literature review, more than 37 photogrammetry-based software and tools are available. The aforementioned finding shows that there are plenty of options available for the application of photogrammetry, and there is a need to assess the better available tools considering the environment of the construction sector. The construction industry is enhancing towards digitisation, and to make this working theme successful, there is a need to provide less costly solutions (Qureshi et al., 2020). Likewise, in the domain of automated construction projects progress monitoring via digital data acquisition technologies, photogrammetry is a less costly solution with practical outcomes (Faltŷnová et al., 2016).

Various studies have been performed on the comparison of photogrammetry tools. However, each study compared the different combinations of tools considering varying target objects, i.e., most of the studies covered buildings, historical monuments (Luo et al., 2019; Verykokou and Ioannidis, 2018; Murtiyoso et al., 2018), and aerial views (Alidoost and Arefi, 2017; Eltner and Schneider, 2015), whereas some also considered human figures, busts, fabric, etc. (Zhang et al., 2019; Wang et al., 2020). However, very few such comparison studies have been performed considering construction project elements for progress assessment (Pena-Villasenin et al., 2020). In light of the above discussion, this study is aimed to achieve the most suitable options among available photogrammetry tools by evaluating the point clouds considering the construction project monitoring theme. Furthermore, the photogrammetric testing and simulations have been performed by considering the rebar as a test subject, as rebar are distinct construction elements. Therefore, this study aims to improve the confidence of industry professionals in the adoption of photogrammetry tools for various construction processes in place of expensive detection technologies.

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2. METHODOLOGY

The methodology was devised to evaluate the best options among available photogrammetry tools. Therefore, the criteria were defined for selecting the right tools based on three considerations, i.e., the tool should be offering close-range photogrammetry, most adopted by the research community (via literature review), and ease of availability of the tool via the internet. Figure 1 illustrates the strategy adopted to meet the study objective, where the overall methodology for selection and testing has been divided into three stages as follows:

1. Literature review and expert opinion
2. Photogrammetric model generation
3. Metadata and numerical analyses

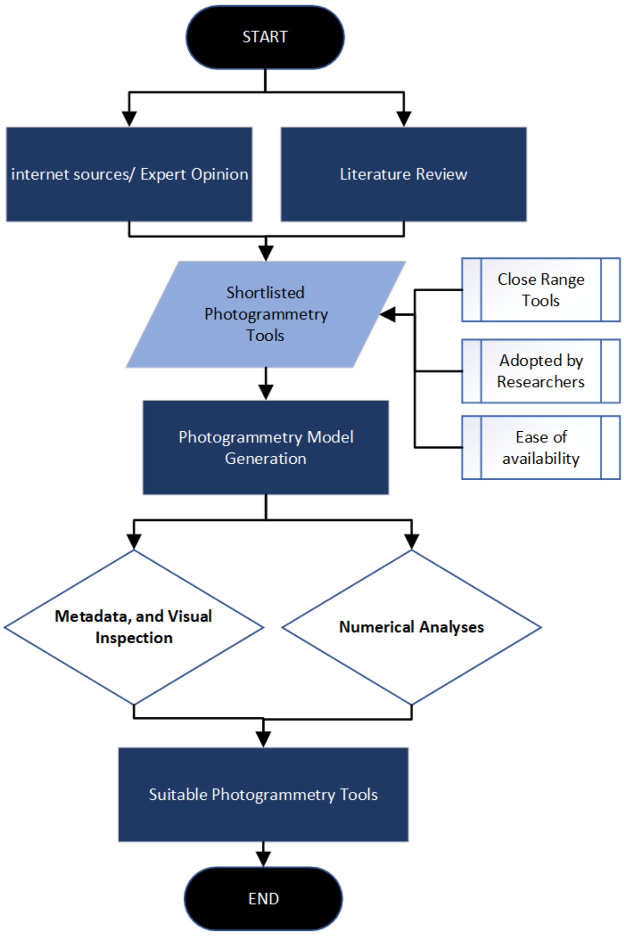

Figure 1. Study flowchart

2.1 Literature review and expert opinion

A literature review was performed to identify the most adopted photogrammetry tools by the research community. Articles were explored on Web of Science (WoS), and Scopus, for the last five years, considering specific keywords combinations, i.e., (photogrammetry OR point cloud) AND (image OR photo) AND (software OR tool OR technique). Following this, the most relevant articles were collected for review. Moreover, professional advice was also collected, and the expert opinions were taken from the website "ResearchGate" (https://researchgate.net/). The past literature and internet sources identified 37 photogrammetric open-sourced and paid software. Table 1 shows the list for 37 aforementioned photogrammetry tools.

Tools	Developer
COLMAP	J. L. Schoenberger
Meshroom	Alice Vision
MicMac	IGN
Regard3D	Roman Hiestand
VisualSFM	Changchang Wu
OpenMVG	P. Moulon, P. Monasse, & R. Marlet
OpenMVS	Pierre Moulon
Multi-View Environment	T U Darmstadt
Photogrammetry Toolbox	P. Moulon,and A. Bezz
3DF Zephyr	3DFlow
WebODM	OpenDroneMap
Agisoft Metashape	Agisoft LLC
RealityCapture	Capturing Reality
ReCap Pro	Autodesk
PhotoModeler	Eos Systems Inc.
SOCET GXP	BAE Systems
DroneDeploy	DroneDeploy
Pix4D	Pix4D
iWitnessPRO	Photometrix Photogrammetry
Bentley Context Capture	Bentley Systems
IMAGINE Photogrammetry	Geosystems/ Hexagone
Trimble Edgewise	Trimble Inc.
SimActive Correlator3D	SimActive Inc.
Maps made easy	Drones made easy
PrecisionHawk 3D map	PrecisionHawk
Open Drone Map	OpenDroneMap
Drone2Map	ArcGIS
DatuSurvey	Datumate
Elcovision 10	PMS AG
LiMapper	GreenValley International
AutoMeasure64	Cognitech
PointCab4BIMm	BIMm GmbH/ Archicad
PreVu3d	PreVu3D Inc.
Undet	Undet Software
Summit Evolution	DAT/EM International
WinATLAS	KLT Associates
Geomatica	PCI Geomatics

Table 1. List of available photogrammetry tools.

Based on the defined criteria, nine tools were shortlisted for this study, which include VisualSFM, Meshroom, COLMAP, 3DF Zephyr, Regard 3D, RealityCapture, Autodesk ReCap Pro, Agisoft Metashape, PhotoModeler.

2.2 Photogrammetric model generation

In the second stage, 3D point cloud models were generated from the selected photogrammetry tools for testing purposes. A sample images dataset was developed for the rebar grid framework consisting of 50 images, as shown in Figure 2. The rebar grid was assembled, covering an area of 2.74m$\times$2.74m (7.5 sq.m), with 16 rebars and each steel bar of 2.74m in length. The point cloud models were generated from the selected photogrammetry tools by following the developer guidelines and keeping high/ extreme software/ tool settings. The specifications of the camera and workstation used for data collection, simulation and cloud computation have been shown in Table 2.

Items	Specification & Details
Camera	Samsung SM-A225F
Work Station	Dell Precision 3630 Tower Intel Xeon CPU 64 GB RAM NVIDIA GeForce RTX 2060

Table 2. Camera and workstation specifications.

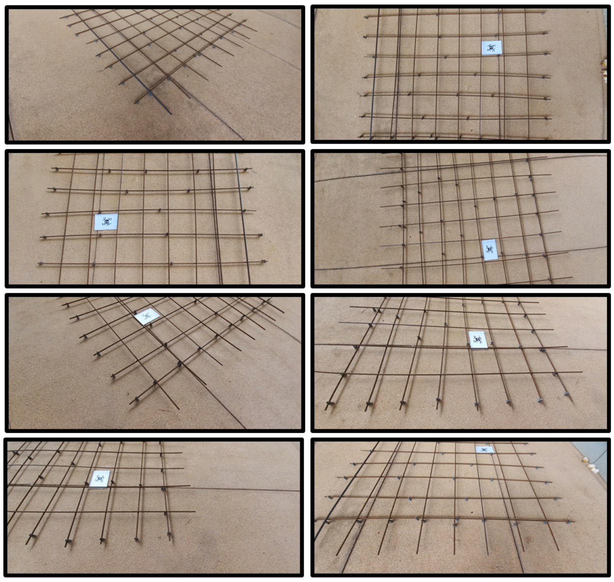

Figure 2. Rebar grid framework dataset

2.3 Metadata and numerical analyses

In the third stage, the attained point cloud models were evaluated and compared for information against five parameters, i.e., computational time, the number of dense points, mesh formation, percentage (%) completion of model elements (rebar), and % noise.

2.3.1 Time, dense points, and mesh The first three parameters were inspected via visual inspection and CloudCompare (https://danielgm.net/cc/). The computational time was noted for each tool separately until the complete photogrammetry process was achieved. However, the models were imported in CloudCompare and analysed to calculate the number of dense points cloud and mesh formation.

2.3.2 Percentage (%) completion of rebar model The completion % of generated rebar model was evaluated via performing numerical analysis. The generated models were imported to CloudCompare and scaled up to the ground truth dimensions (GTD). In each model, generated rebars were measured for lengths considering all the 16 rebars individually. The GTD length of each rebar in the dataset was 2.74m±0.01m, and collectively 43.48m±0.16m running length for the all 16 rebars in the grid framework. To attain the percentage completion of generated point cloud model, the overall attained measured rebars length of each generated point cloud model was compared to GTD of the rebar dataset. Equation 1 was implemented to achieve the % completion of each model.

$$\%\mathrm{C} = \frac{L_c}{L_{GTD}} \times 100, \quad (1)$$

where $\%C$ = % completion of rebar
L_c = calculated length of rebars
L_{GTD} = GTD of rebars

2.3.3 Percentage (%) noise To evaluate % noise, each scaled-up model was cropped for 3.04m×3.04m (±0.01m), i.e., approximately 9.2 sq.m area around the rebar grid framework using CloudCompare. The overall number of point clouds were noted, and regions with noise were identified. Using CloudCompare, the noise was removed for each model separately, and the number of points cloud was noted again. Thus, % noise for each model was calculated by evaluating the difference between two readings by using Equation 2.

$$\%\mathrm{N} = \frac{N_i - N_c}{N_i} \times 100, \quad (2)$$

where $\%N$ = % noise
N_i = Number of point cloud in initial model
N_c = Number point cloud in cleaned model

3. RESULTS AND DISCUSSION

The 3D point cloud models have been generated for the same images dataset, following the guidelines given by the developers and considering high/ extreme software settings for the best as well as detailed outcomes. The evaluation of selected photogrammetry tools was performed based on metadata, % model completion, and % noise. Table 3 illustrates the generated point cloud models from the selected photogrammetry tools.

It can be seen that 3D point cloud generation performance varies between selected tools. VisualSFM, Meshroom, COLMAP, and Regard 3D generated partial point cloud models. However, 3DF Zephyr, PhotoModeler, Agisoft Metashape, and RealityCapture gave better outcomes. The model attained via Autodesk Recap Pro was average, as incomplete element generation was observed for rebars. Table 4 shows the metadata analysis of the generated point clouds.

Metadata on generated point cloud models were collected on computational time, generated number of the point cloud, and mesh development. The computation time represents the time taken by each photogrammetry tool for the generation of the 3D point cloud model by following all the available processes by that tool. The number of point cloud generated in each model were calculated for the cropped area, i.e., 9.2 sq.m, in which 16×2.74m±0.01m rebars were placed. Likewise, the mesh generation was observed and noted for each model to assess the extend of photogrammetry pipeline provided by the each developer of the selected nine photogrammetry tools.

It can be observed that all the tested photogrammetry tools offered mesh formation except VisualSFM, which only performed dense point cloud generation. Moreover, the maximum number of point cloud was attained by Agisoft Metashape (10,138,227), followed by RealityCapture (4,894,717). Likewise, the computational time of the COLMAP was the highest (35 minutes), followed by Autodesk Recap Pro (27 minutes). However, minimum computational time was taken by VisualSFM (3 minutes), but it doesn't offer mesh generation. Whereas, RealityCapture (7 minutes), Meshroom (9 minutes), and Photomodeler (9 minutes) offered the lowest computational time with mesh generation.

Table 5 reveals the % completion of rebar element in the point cloud model. There were 16 rebars in the dataset, with each of 2.74 m±0.01m in length. Each model was scaled up to GTD and evaluated separately for the running length of generated rebars using CloudCompare. It can be observed that Agisoft Metashape has been the most successful tool with a 99% of

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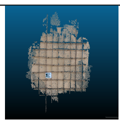
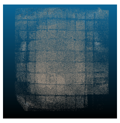
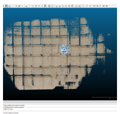
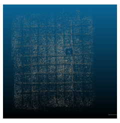
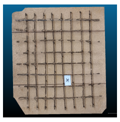
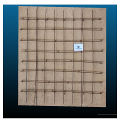
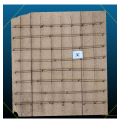
Tools	Point Cloud Model
VisualSFM	
Meshroom	
COLMAP	
3DF Zephyr	
Regard 3D	
Autodesk ReCap Pro	
PhotoModeler	
Agisoft Metashape	
RealityCapture	

Table 3. Generated 3D point cloud models.

Tools	Computational Time Minutes(M)	No. of Dense Points	Mesh
VisualSFM	3 M	370,149	No
Meshroom	9 M	211,551	Yes
COLMAP	35 M	880116	Yes
3DF Zephyr	26 M	1,201,034	Yes
Regard 3D	26 M	72,098	Yes
ReCap Pro	27 M	271,516	Yes
PhotoModeler	9 M	145,491	Yes
Agisoft	14 M	10,138,227	Yes
RealityCapture	7 M	4,894,717	Yes

Table 4. Metadata of generated point clouds.

Tools	% Model Completion
VisualSFM	72%
Meshroom	63%
COLMAP	33%
3DF Zephyr	97%
Regard 3D	51%
ReCap Pro	84%
PhotoModeler	88%
Agisoft	99%
RealityCapture	81%

Table 5. Percentage rebar model completion.

completion rate. 3DF Zephyr also attained a good outcome with a 97% completion rate. However, most of the photogrammetry tools have accomplished % completion between 89% to 60%. Where lowest model completion was achieved by COLMAP (33%), and Regards3D (52%).

Table 6 illustrates the % noise formation in generated point cloud models. Point clouds obtained with imaging reconstruction techniques are often corrupted with a significant amount of outliers and noise (Rakotosaona et al., 2020). In this study, the scaled-up point cloud models for each tool were analysed for noise using CloudCompare, and noisy areas were removed. As already discussed, models were overviewed for the area of 9.2 sq.m, which was cropped from the originally generated point cloud model covering 16×2.74m±0.01m region. For each tool, noise-cleaned model was compared with uncleaned model for % noise assessment by following Equation 2. It can be noted that most of the photogrammetry tools offered less noise generated models. Minimum noise were observed in Agisoft Metashape (0.003%), RealityCapture (0.005%), and 3DF Zephyr (0.042%). However, high noise were reported for COLMAP (20.465%), and Autodesk Recap Pro (7.366%).

4. DISCUSSION

This study has been performed to evaluate better performing photogrammetry tools considering construction environment and materials for purpose of progress monitoring. From the literature review and expert opinion, nine photogrammetry tools were selected for testing, i.e., VisualSFM, Meshroom, COLMAP, 3DF Zephyr, Regard 3D, RealityCapture, Autodesk ReCap Pro, Agisoft Metashape, and PhotoModeler. Rebar was selected as a testing material, and the rebar grid framework was assembled on a 9.2 sq.m area with 16 rebars and 2.74m ±0.01m in length. The image-based dataset was prepared using a Samsung SM-A225F camera, and 50 images were captured. Photogrammetric models were generated by each selected tool for the same dataset. To gain the best and most detailed outcome models, high/ extreme model generation settings were adopted depending on each tool.

Attained models were analysed and evaluated against computation time, number of the point cloud, mesh formation, % model completion, and % noise. It was observed that for computational time VisualSFM (3 minutes), RealityCapture(7 minutes), Photomodeler (9minutes) and Mushroom (9minutes) took less time than others. However, VisualSFM doesn't offer Mesh generation. Whereas, Agisoft Metashape (10,138,227), RealityCapture (4,894,717), and 3DF Zephyr (1,201,034) generated high number point clouds compared to other models. Among all point cloud models, Agisoft Metashape (99%), 3DF Zephyr (97%), and Photomodeler (88%) generated the most completed point cloud rebar elements. Likewise, less noise was observed for Agisoft Metashape(0.003%), RealityCapture (0.005%), and 3DF Zephyr (0.042%).

It has been established from the above analyses that Agisoft Metashape, and 3DF Zephyr are the most suitable photogrammetry tools for close-range construction elements. Moreover, it has also been determined that a high number of generated point cloud doesn't reflect the best model, although a high number of point cloud improves the model's geometric features. Based on this study and past literature, one important aspect has been concluded that behaviour and performance of photogrammetry

Tools	% Noise
VisualSFM	1.081%
Meshroom	0.567%
COLMAP	20.465%
3DF Zephyr	0.042%
Regard 3D	0.694%
ReCap Pro	7.366%
PhotoModeler	0.069%
Agisoft	0.003%
RealityCapture	0.005%

Table 6. Percentage noise of generated models.

tools vary depending upon the type, nature of job/ activity, and surrounding environment of the targeted object. As for this job, the dataset was created in an outdoor environment, for a close-range rebar grid framework, and better outcomes have been observed for Agisoft Metashape, and 3DF Zephyr.

Different studies have given varying outcomes in respect to the comparison of photogrammetry tools. Alidoost and Arefi (2017) compared SURE, Agisoft Photoscan, Pix4Dmapper Pro and 3DSurvey for their capabilities by generating high-density point clouds and digital surface models of the historical site using an aerial view approach. Whereas, results with Agisoft, Pix4D, and SURE were found almost similar. However, 3DSurvey was found less effective. Delgado-Vera et al. (2017) compared and analysed Pix4d, Agisoft, Ensoamic, OpenDrone Map, Insight3d, VisualSFM, MicMac, and Qgis, considering the aerial view images for agricultural land. Whereas, OpenDroneMap software was found to be most suitable. Bianco et al. (2018) reported a comparison between COLMAP, OpenMVG, Theia, and VisualSFM, by reconstructed 3D point cloud models of Statue, Empire Vase, Bicycle Hydrant, Jeep, and Ignatius. However, COLMAP showed the best average results. Rahaman and Champion (2019) studied Agisoft, COLMAP, Python Photogrammetry Toolbox, VisualSfM, and Regard3D for workflow, features, accuracy, and processing time. This study adopted building, and frog images datasets and found Regard3D, COLMAP, and VisualSfM with reasonable outcomes. Reljić et al. (2019) evaluated 3DF Zephyr, Meshroom, Agisoft, and RealityCapture. The study examined major parameters and visual qualitative inspections on reconstructed busts and found Agisoft and 3DF Zephyr as better performance tools. Pena-Villasenin et al. (2020) performed a study by employing SfM to analyse historical building façade (San Martín Pinario). The comparison was examined between Pix4D, Agisoft PhotoScan and Autodesk Remake for geometric quality, visual quality, accuracy, and performance; however, Autodesk Remake (replaced by Autodesk Recap Pro) yielded good results.

Therefore, in light of this performed study and past literature, it can be determined that every photogrammetry software has some benefits over others, depending on the type of the targeted object, nature of the job, and site conditions. Hence, it cannot be declared that some particular software is the best; software should be selected or chosen depending upon the job description, and guidance may be taken from the available literature.

5. CONCLUSION

This study was devised to evaluate the best available photogrammetry tools for close-range progress assessment of the rebar grid. Nine photogrammetry tools were selected for testing, and 3D point cloud models were generated. Attained point cloud models were analysed and evaluated against computation time, number of point cloud, mesh generation, % model completion, % noise, via performing visual inspection and numerical analyses. The comparison revealed that Agisoft Metashape, and 3DF Zephyr are better options for close-range outdoor testing adopted for construction activity progress monitoring/ assessment. Moreover, there is no hard and fast rule that a higher number of point cloud assures excellent models. This study aims to motivate the construction sector towards the adoption of photogrammetry as data-acquisition technology as a part of progress monitoring process.

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