Comparison of TLS and Photogrammetric 3D Data Acquisition Techniques: Considerations for Developing Countries

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Abstract –
With the use of digital data, in conjunction with technologies such as BIM and digital twin, construction professionals have the ability to monitor the progress efficiently and perform detailed quality assessments. The rapid development of multiple data acquisition technologies, such as terrestrial laser scanning (TLS) and photogrammetry techniques, has allowed their broad integration in mostly middle to large-scale construction projects worldwide. However, this type of technology is often not accessible to small-scale contractors, especially in developing countries where high upfront costs and lack of skilled workers might be limiting factors. This study compares the economic, quality, feasibility, and value of TLS versus Photogrammetric data acquisition methods; i.e., the scope is not to discuss the benefits of using 3D digitization techniques but to consider if small-scale contractors can still take advantage of said benefits by using affordable technologies. Moreover, the impact of achieving complete automation by employing robotic platforms with TLS systems is also considered. A small case study is used to illustrate the quality and economic comparisons.

Keywords –
Construction 4.0; Terrestrial Laser Scanning; Photogrammetry; BIM; Construction Robots

1 Introduction

Lack of proper management and control in the construction is one reason for delay and cost overruns in developing countries [1]. In pursuit of improving construction project control and enhancing productivity, researchers have proposed progress monitoring approaches based on digitization. Cutting-edge technologies used in construction sites are associated with high infrastructural requirements and cost of equipment, heavy computational power requirements and skilled/trained manpower [2]. These elements are typically lacking in construction companies in developing countries [3].

Data acquisition technologies are widely applied in the construction environment. However, except for 2D imagery [4] and basic terrestrial laser scanning (TLS) [5] devices, the use of such technologies makes it privative for low-budget construction companies due to the special infrastructural requirements and limitations that may arise. Other technologies, such as depth cameras, do not add any significant value to be considered in this study. For those reasons, this study compares point clouds generated using photogrammetry (2D imagery) and TLS to identify how low-cost applications can lead to high-effective outcomes regarding the integration of technology in developing countries. Other technologies, such as depth/stereo cameras, fall between the ones chosen but are not widely used in the field.

2 Comparison criteria

The comparison between the applicability of reality capture technologies in this study is conducted based on the following dimensions.

Economical: The initial and operational costs incurred in collecting and processing the data are compared. This includes the procurement of the initial device as well as the cost associated with the sufficient computational power required for the deployment and successful application.

Quality: Quality of the point cloud data that is obtained. It is measured in terms of point cloud density, noise volume, and lack of points due to occlusions.

Feasibility: Feasibility is measured in terms of ease of application on the construction site. Considering the specific characteristics of a construction site, the level of hindrance to deployment is measured.

Value added: Any improvement in construction automation needs to add value compared to regular manual operation. The comparison considers the level of detail required for a construction operation and the level of information obtained through applying the alternative data collection and processing scheme. This parameter is subjective and is defined based on specific project characteristics.

3 Case Study

In order to test the two approaches, a small-scale construction site in the NYUAD campus (Saadiyat Island, United Arab Emirates) was chosen. Being on campus, the construction site was convenient to the authors, and it included many real conditions of a construction site (e.g., highly cluttered areas with temporary structures and storage of construction materials), making it a great space to illustrate this study.

3.1 Data acquisition and processing

The data acquisition was performed in four ways: (1) TLS mounted on a tripod: two different scan positions where the scanner was manually moved between them. (2) Autonomous Robotic System (ARS): autonomous robotic platform equipped with the TLS. Same scanning locations as the previous approach. (3) Static photogrammetry: a digital single-lens reflex (DSLR) camera mounted on a tripod, taking pictures in the same scanning locations as the two previous approaches. (4) Free-roam photogrammetry: handheld DSLR camera, data capturing as the camera moves around, with free tilt, rotation angle, height, and orientation

The scanning positions were the same for all (1 through 4). The only difference between 1 and 2 is how the scanner was moved between said scanning positions. In the case of the TLS mounted on a tripod (1), the scanner was moved manually by an operator. In the case of the TLS on board the ARS (2), the navigation was performed autonomously by the ARS, completely removing the human interaction in the process.

For the case of static photogrammetry (3), a DSLR camera mounted on a tripod was used to take two pictures every three seconds while rotating 360 degrees on the vertical angle. The same routine of image data collection is repeated five times at the same spot by varying the camera tilt angle approximately from -90º to 90º (measured from the horizontal plane) with 45º increments. This static photogrammetry is conducted at two different locations where the locations are selected manually to maximize the visibility of the whole area. For the given area, a total of 263 images were collected.

In the free-roam photogrammetry (4), data was collected roaming around the construction site, manually locating views and planes to reduce the clutter spots. The camera was set to take a picture every 2 seconds. The elevation of the camera was also manually adjusted based on the height of nearby objects. For the given experimental area, a total of 845 images were collected.

4 Results and discussion

4.1 Economical comparison

The economic representation of each technology examined in this case study is presented in Table 1. Table 1 presents the economic factors in terms of initial investment to buy the equipment and the operating expenses required to process the data and convert it to a complete representation of the construction site. In general, photogrammetric methods have relatively affordable initial expenses. Although the experiment is conducted using a high-end DSLR camera, photogrammetry can be achieved with affordable devices such as smartphone cameras. On the other hand, TLS requires relatively expensive tools. To achieve complete automation by mounting the TLS device on an autonomous robot, the initial cost can be doubled.

The initial investment is not the only factor that should be considered, but also the computational capacity required to process the raw data and the skilled/unskilled labor needed to provide a tangible result in any of the approaches. In this regard, the conducted case study revealed that although photogrammetric methods only require a basic camera and operation skills for a relatively shorter period, the data processing could be a lengthy task and requires a specific set of photogrammetric skills. This generally causes a relatively higher amount of man-hours and computational equipment utilization cost.

Photogrammetric methods could appear viable options for short-living and low-budget construction projects. However, the decision must consider multiple factors that could be influenced by applying this particular technology.

4.2 Quality comparison

Quality is defined based on multiple parameters, including noise ratio, point cloud density, and point cloud coverage of a given space. The results of the quality measure are presented in Table 2. Attribute-wise, all methods provide semantic information in terms of geometry (X, Y, Z), point normal (Nx, Ny, Nz) and color (RGB). However, the 3D laser scanner comes with an additional reflectance feature (R), which expands the applicability of a specific method to a wider domain.

The percentage of noise from the point cloud data is computed as a ratio of the removed data during multiple layers of filtering to the total pre-filtered point clouds. As a result, photogrammetry-based methods had less noise with 14.6% and 13.76% for the static and free-roaming camera-based photogrammetry, respectively. The percentage of noise values for the TLS-based methods were 30.6% and 20.91% for static and ARS mounted TLS, respectively. Although the noise volume appears smaller in photogrammetric methods, this can be attributed to the low density and short span reaching abilities these specific methods have. Both filtering layers applied are statistics-based, which depends on the dispersity and semantic inputs of the neighboring points. As the samples are less dense, outliers could fit in the model and mislead the filtering process.

Table 1: Economic comparison

Approach /Technology	Investment		Operation requirements			
	Data collection equipment	Processing	Data collection		data processing	
			Skills	Man-hours	Skills	Man-hours
(1) Static TLS	\$19,000	\$8,000	Use of TLS	12.52 min	CAD, 3D data processing	5 min
(2) TLS in ARS	\$39,000	\$8,000	Use of TLS / Robotic skills	17.70 min	CAD, 3D data processing	5 min
(3) Static photogrammetry	\$1,000	\$8,000	None	5.25 min	Photogrammet ry engineer	22 min
(4) Free-roaming photogrammetry	\$1,000	\$8,000	None	6.17 min	Photogrammet ry engineer	67min

Moreover, the static TLS resulted in 10% more noise when compared with the ARS mounted TLS. This can be attributed to the ability of the mobile system to take a closer scan of objects that are reflective and cluttered.

A point cloud's volume is measured based on the volumetric space enclosed within the set of neighboring points. The search of points enclosed around a given point is conducted using a 0.077 m search radius consistently among all data sets. The results obtained are summarized as the mean and standard deviation of a density histogram (Table 2). Comparatively, among the four methods, the TLS mounted on the ARS provided the densest results but were very close to the results obtained from the static TLS. However, density can only represent the compactness of points around a given scan. For instance, through a visual inspection, static photogrammetry has clear openings where limited objects are reconstructed. It is challenging to measure the magnitude of occlusion through the point cloud density. Therefore, the point cloud population in rasterized cells is computed to observe the relative completeness of points in a given space.

Table 2. Quality comparison

Data source	Attributes	Point count		Point Cloud Density		Per-cell population ratio
		Pre- filtering ($1x10^6$)	Post - filtering (SOR and MLS) ($1x10^6$)	Mean ($1x10^9$)	STDEV ($1x10^9$)	
TLS	*	59.23	41.09	2.21	1.35	260.03
ARS	*	54.27	42.92	2.23	1.54	264.57
Static camera	**	2.10	1.79	0.24	0.23	42.44
Free-roaming camera	**	27.06	23.34	0.67	0.83	131.82

** Geometry (X, Y, Z), Point Normal (Nx, Ny, Nz), Color (RGB), and Reflectance (R) ** Geometry, Point Normal, and Color*

The per-cell population ratio represents the average distribution of points in equal-sized cells with a magnitude of 0.05. Table 2 presents ARS mounted TLS as the most complete while the static camera-based photogrammetry is the least complete. The mobile aspect of the robotic system has helped improve the completeness of the TLS-based system. Similarly, the free-roaming photogrammetry improved the static camera photogrammetry by more than 3-fold.

4.3 Feasibility comparison

The experimental site consists of flat planes, clutter, narrow paths, and hidden areas (e.g., underneath scaffoldings and equipment). Tripod-mounted methods (static camera photogrammetry and static TLS) share blind spot occurrences around the hidden areas or behind solid objects. On the other hand, the free-roaming camera and ARS mounted TLS have the advantage of mobility to address hidden zones to reduce occlusion.

Although the ARS can navigate through the room with a clear understanding of obstacles and obstructions, narrow paths and clutter could hinder the system from accessing certain areas. In a similar observation, unlike the TLS methods, photogrammetric methods heavily depend on natural illumination. Inter-reflection between shiny objects and less illuminated areas within the experimental area were some of the primary causes of noise.

4.4 Value added to the project

The technologies in this case study show that complete automation can only be achieved through the TLS mounted ARS approach. This approach has proved efficient in construction sites in various instances [5]. However, this method commonly requires trained workers to collect and process raw information. It has proved to be fast and provides relatively complete point clouds with the highest density value. The method comparatively results in the highest standard data, but for a higher cost. This method can be proposed for large projects with higher contract amounts. In most cases, large construction sites produce a relatively large amount of waste and are easy victims of mismanagement. Manual operations could result in delayed data with little to no room to produce decisions before resources are wasted. On the other hand, small-scale and low-budget construction projects need to perform a cost-benefit analysis before choosing automated data acquisition methods. One of the important aspects of the examined technologies in this case study is the ability to create a simplified way of visualizing the construction site in 3D. This helps contractors, owners, and consultants devise construction decisions, safety measures and many more, which are usually time-taking activities.

The applicability (i.e., benefits) of the four comparison criterion for the methods evaluated in this case study is summarized in Figure 1. Applicability in the y-axis is a comprehensive measure composed of the four comparison criterion used in this study. Given the availability of digital cameras (economy and feasibility), photogrammetry is the most applicable method for small constructions. However, the quality of the data and the value that the processed data adds to the project varies between static and free-roaming photogrammetry. As the complexity of the project increases, the size of image data and the requirement of processing capacity (economy) increases. Based on the quality of data, the ease of obtaining the results (feasibility) and the value it adds to the project, TLS-based methods appear to be relatively applicable. Given the complexity of the construction, blind spots could be avoided, and data registration could be error-free if it is conducted with the help of an ARS.

5 Conclusions and future work

TLS and photogrammetry are used indistinctly of the applicability or suitability of the situation in which they are implemented but based on the availability of the required hardware/technology to the user. However, small-scale and low-budget contractors, especially in developing countries, often have to be specific regarding hardware requirements due to cost, availability or lack of qualified personnel. This study looks at the development of point clouds acquired with TLS and photogrammetry and serves as a base to objectively compare the feasibility and usability of each technology.

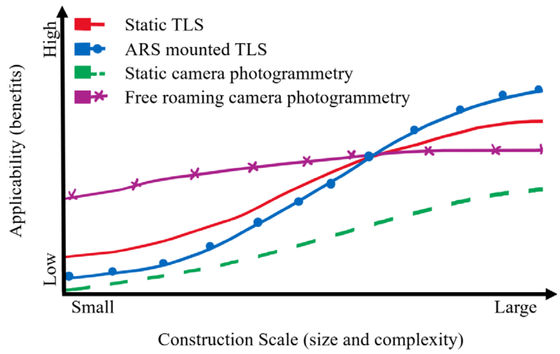

Figure 1: Comparative benefit of technologies investigated vs. the scale of construction project

The results are based on a small case study, which is not the best scenario to accurately represent the benefits of some of the technologies used. The study concludes that automated data acquisition provides reliable control with relatively low budgets for large and complicated construction projects. However, image-based methods could be more applicable for smaller construction projects, given their mild initial cost and skill requirement. Nevertheless, the value added to the process must be evaluated relative to the conventional methods.

References

[1] Frimpong Y, Oluwoye J, Crawford L. Causes of delay and cost overruns in construction of groundwater projects in a developing countries; Ghana as a case study. *International Journal of Project Management*. 2003 Jul 1;21(5):321-6.

[2] Kochovski P, Stankovski V. Supporting smart construction with dependable edge computing infrastructures and applications. *Automation in Construction*. 2018 Jan 1; 85:182-92.

[3] Adepoju OO, Aigbavboa CO. Assessing knowledge and skills gap for construction 4.0 in a developing economy. *Journal of Public Affairs*. 2021 Aug; 21(3):e2264.

[4] Mostafa K, Hegazy T. Review of image-based analysis and applications in construction. *Automation in Construction*. 2021 Feb 1; 122:103516.

[5] Wu C, Yuan Y, Tang Y, Tian B. Application of Terrestrial Laser Scanning (TLS) in the Architecture, Engineering and Construction (AEC) Industry. *Sensors*. 2021 Dec 30;22(1):265.