Influence of SfM reconstruction techniques on the extraction of rock slope discontinuities

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ABSTRACT: Rock slope discontinuities can be analyzed using 3D point clouds (3DPC), which are typically acquired through 3D laser scanning (3DLS) instruments or Structure from Motion (SfM) photogrammetry. While 3DLS is often regarded as a precise dataset, the use of SfM is gaining popularity due to the advent of remotely piloted aircraft systems and its relative affordability. Traditionally, extracting discontinuities from 3DPC relies on dense cloud reconstruction. However, the exploration of tiled models as an alternative approach remains limited. In order to assess the viability of using tiled models, we conducted an experiment on a pyramid-shaped sculpture reconstructed using both 3DLS and SfM techniques. The results demonstrate that the orientation of discontinuities obtained from the tiled model aligns well with those derived from both the TLS and dense cloud results. Interestingly, the extraction of discontinuities from the tiled model proves to be more efficient than from the SfM dense cloud.

Keywords: Structure-from-Motion, 3D Point Clouds, discontinuities, rock slope, experiment, tiled-model.

1 INTRODUCTION

Discontinuities play a crucial role in determining the deformational and failure behavior of rock masses. Essentially, a rock mass comprises blocks of intact rock separated by these discontinuities (Bieniawski, 1989). These discontinuities are surfaces, which can be planes or irregular, and possess low or negligible tensile strength (ISRM, 1978). They exhibit a characteristic orientation when considered as planes, allowing them to be grouped into sets. For each set, additional parameters such as normal spacing, persistence, aperture, and roughness significantly contribute to the characterization of the rock mass (ISRM, 1978). These parameters are determined through geometric assessments. However, other factors, such as the type of filling or weathering, also hold importance. As discussed elsewhere (Hoek & Karakas, 2008), the intact rock may be further characterized by various physical, chemical, or geomechanical properties.

Discontinuity analysis has been traditionally performed using different data collection strategies in the field, such as compass, clinometer, tapes, and other tools (ISRM, 1978). However, field data collection might be limited by the site conditions, safety, and other constraints such as direct accessibility. Since 3D remote sensing techniques and instruments have become widely used in the last decade (Jaboyedoff et al., 2012), the analysis of 3D datasets enables the analysis of inaccessible areas of rock massifs, allowing instantaneous data sharing worldwide.

Remote sensing techniques provide 3D point clouds via Light Detection and Ranging instruments (LiDAR), in our case ground-based 3D laser scanners (3DLS) or Terrestrial Laser Scanners (TLS) or employing the Structure-from-Motion (SfM) techniques. TLS instruments can provide high-resolution datasets and an accuracy of 2 mm at 100 meters (Leica Geosystems AG, 2011). The 3D point clouds captured with TLS are usually accepted as a benchmark, regardless of registration errors and others.

The instrumental cost of 3D laser scanners is significant, making its use unaffordable for limited budgets. That is the reason why the SfM technique emerges as a cost-effective trend because its equipment is more accessible: digital cameras, if needed with Unmanned Aerial Vehicles (UAV), and a computer to process the photos along with the software. However, SfM-derived datasets employing conventional equipment are not usually as precise as LiDAR data.

Restitution of surface can be performed using open-source software packages or commercial software. Some popular examples are Agisoft Metashape, Pix4D or RealityCapture. In this work, we use Agisoft Metashape. SfM workflow comprises the following steps: (1) cameras alignment, (2) ground control points insertion and optimization of cameras, (3) dense cloud reconstruction, (4) mesh reconstruction and (5) texturing. The most time-consumption step is the dense reconstruction. However, a recent update enables the tiled-model reconstruction from depth maps, which are got after step (2).

This work aims to analyze whether extracting 3D point clouds via tiled models might be a viable alternative to extracting discontinuity sets from dense clouds, both in terms of data processing speed and quality of the reconstruction. To assess the reconstruction quality, we consider the TLS dataset as the benchmark. Since we focus on discontinuity sets, we assess the rock mass discontinuity sets that are identified and extracted.

2 MATERIALS AND METHODS

A simple case study was conducted to simulate the geometry of a regular rock mass using a pyramid constructed from granite stone cubes (Figure 1). The sides of the pyramid were arranged in a parallel manner to emulate block discontinuities. This virtual rock mass consisted of three orthogonal discontinuity sets: one sub-horizontal and two sub-vertical. Additionally, the normal spacing was defined to be half of the side length of the cubes.

In the first step, the pyramid and six black-and-white targets were scanned using a 3D laser scanner model Leica C10 ScanStation, employing four leveled scan-stations. The Cyclone software (Leica Geosystems AG, 2021) was utilized for registration, which initially used the targets and was subsequently optimized through cloud-to-cloud registration (Figure 1 a). Finally, the 3D point clouds (3DPC) and the coordinates of the targets were exported.

The second step involved capturing 97 photos of the pyramid using a Nikon D5300 24.2 Mpx camera with a 50 mm fixed lens. The photos were loaded into Agisoft Metashape (Agisoft LLC, 2019) and aligned. The coordinates of the six targets were inserted into all photos to optimize the camera locations and orientations. The 3DPC was reconstructed in two ways: (1) dense cloud reconstruction from the sparse point cloud, and (2) tiled model reconstruction from depth maps and sample points.

In the third step, discontinuities were extracted from both 3DPC using the open-source software Discontinuity Set Extractor, as described by Riquelme et al. (2014).

The TLS scans were registered using Cyclone software, with an overall error of 2 mm. The pyramid was then cropped and cleaned using CloudCompare software (Girardeau-Montaut, 2020) with the SOR filter, employing 15 neighbors and 5 sigmas twice. The average point distance was 3.3 mm, and the size of the 3DPC was 80,382 points (Figure 3a).

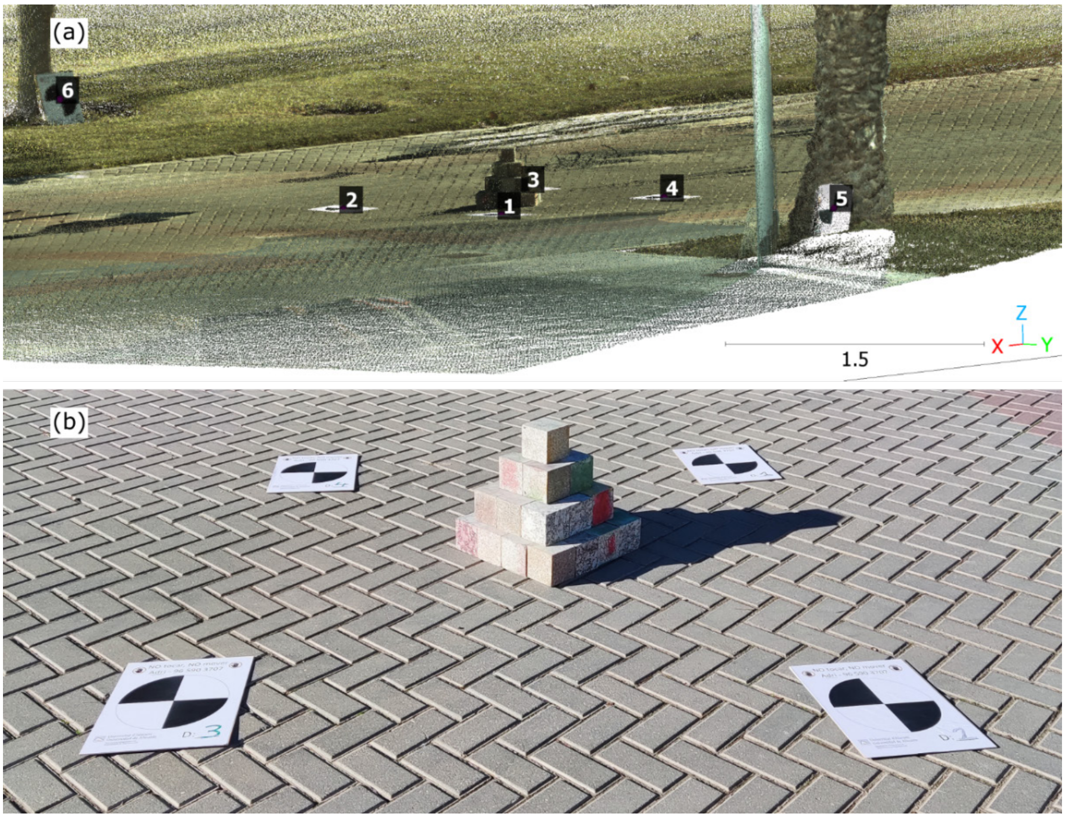

Figure 1. (a) 3DPC of the pyramid and the 6 black and white targets; (b) Pyramid made of cubic stones arranged in four levels: 1 block on the top, 4 blocks in level 2, 9 blocks in level 3, and 16 blocks in level 4.

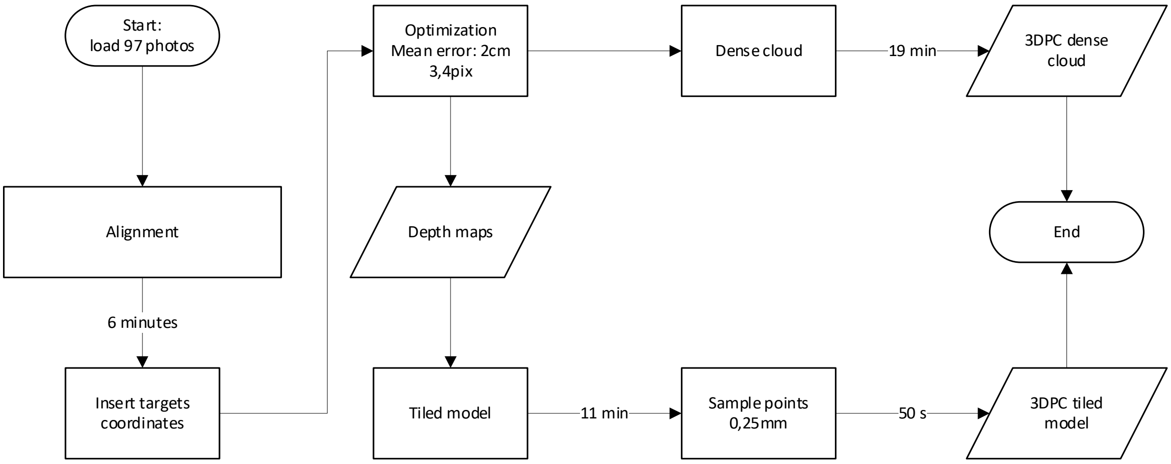

Figure 2. Workflow and timing of key steps.

SfM processing was performed using Agisoft Cloud on a system with AMD Radeon Pro V520 MxGPU (gfx1011), 18 compute units, free memory: 7984/8048 MB, OpenCL 2.0 driver version: 3110.6 (PAL,LC), platform version: OpenCL 2.1 AMD-APP (3110.6). The processing times of key steps are shown in Figure 2. The resulting 3DPC generated from the tiled model and dense cloud processing are displayed in Figure 3(b) and (c), respectively. It is also worth noting that the tiled model was obtained approximately 8 minutes faster than the dense cloud. The density of the dense and tiled model 3DPC was 19.761.565 and 12.554.945 points, respectively. To analyze the discontinuity sets, a sub-sample was applied, ensuring a fixed distance of 1 mm between points. The resulting sizes were 571.905 and 707.332 points, respectively.

Figure 3. Orthographic view of the 3DPC captured via: (a) TLS, (b) tiled model, and (c) dense cloud.

3 RESULTS AND DISCUSSION

In all three cases, the DSE software utilized its method, which involved calculating normal vectors by fitting the 30 nearest neighbors to a local plane. Figure 4 displays the resulting stereonets, along with their corresponding poles. Notably, the poles generated by the 3DLS process appear to have a lighter load due to the lower number of scanned points compared to those generated by the SfM process. The density of poles was computed using Kernel Density Estimation (Botev et al., 2010). This figure demonstrates that the three density plots are nearly identical. Moreover, the orientations of the principal poles vary by 2 degrees.

The duration of each step of running the DSE process is presented in Table 1.

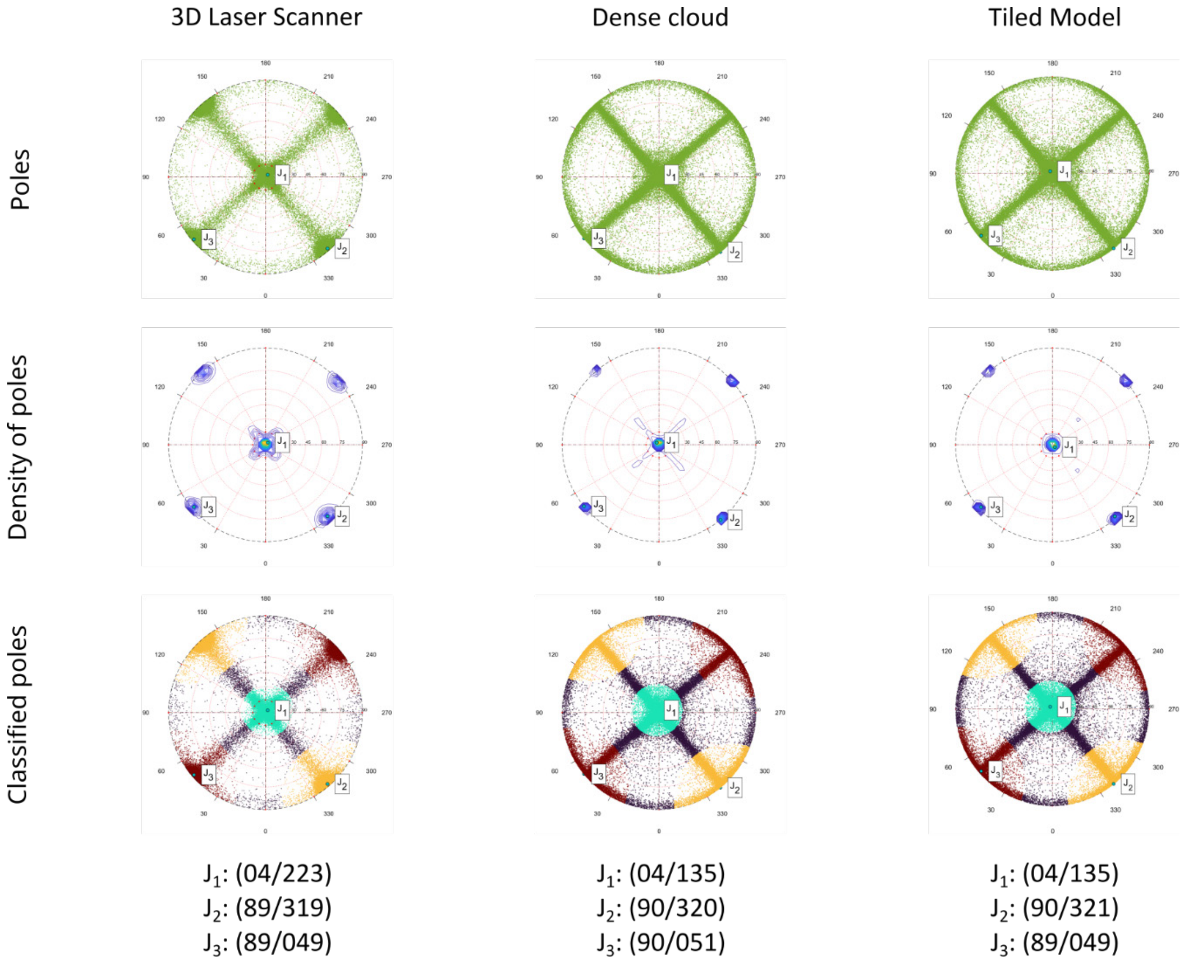

Figure 4. Results of the discontinuity sets extraction by DSE software of the 1 mm sub-sampled TLS and SfM via dense cloud and tiled model.

Table 1. Duration of the sub-sampling process and DSE running.

	Size [points]	Sub-sample 1 mm [s]	Size [points]	Normals	Poles' density	Poles assignment	Cluster analysis
TLS	80.382		80.382	6	0	0	5
SfM Dense	19.761.565	11	571.905	23	0	0	260
SfM Tiled model	12.554.945	10,5	707.332	28	0	0	415

4 CONCLUSION

This experiment demonstrated that the Structure-from-Motion workflow can generate a reasonably accurate surface for extracting discontinuity sets when compared to the 3DPC derived from TLS under controlled conditions. The SfM workflow offers two methods for generating the 3DPC: dense cloud and tiled model. As shown in Figure 2, the tiled model outperforms the 3DPC processing in terms of speed. Furthermore, Figure 3 reveals that both datasets are nearly identical. Additionally, three discontinuity sets were easily identified and extracted, as illustrated in Figure 4. These sets exhibited orientations that differed by less than two degrees, indicating the reliability of the tiled model as a faster means of surface reconstruction.

Table 1 presents the duration of running Discontinuity Set Extraction (DSE) on the three datasets. It is worth noting that the tiled model takes more time than the dense cloud and TLS datasets. This disparity can be attributed to the larger size of the sub-sampled dataset. It is observed that as the number of points to compute increases, the processing duration also increases.

In future studies, potential limitations that may arise when applying the analysis to real cases involving irregular surfaces, as opposed to a specifically prepared regular surface, will be considered.

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