

# 3D Photogrammetry for Quantitative Fracture Analysis

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## 1. Introduction

Damage to cultural heritage, intentional or inadvertent, has always been a consequence of armed conflict<sup>[1]</sup>. Contemporary conflicts have seen large scale, ideologically driven destruction by groups such as Islamic State (IS) and its affiliates<sup>[2]</sup>. However, the impact of ballistics on heritage is part of the wider spectrum of damage that needs to be considered for future preservation efforts. Characterising the extent and severity of damage using field based, non-destructive methods is limited to surface observations and measurements<sup>[3]</sup>, doing little to quantify internal damage networks. Using an experimental sample of Huesca sandstone shot with 7.62x39 ammunition, we aim to test the feasibility of using 3D photogrammetric methods to detect fracture orientations at impact sites. Here we compare data collection using two different plugins (Compass<sup>[4]</sup>/Facets<sup>[5]</sup>) within the CloudCompare<sup>[6]</sup> software, and propose photogrammetry as a way to link observable surface damage to internal fracture sets.

## 3. Image Acquisition

Photogrammetry utilises a series of overlapping and offset images to reconstruct 3D geometries through 'Structure from Motion' (SfM) algorithms<sup>[9]</sup>. In order to accurately reconstruct a sample in tcomplete 3D, sufficient overlap and offset is required between images, in addition to complete coverage of the sample. This can be achieved via a mobile camera rig and stationary subject, best for large/immovable or delicate subjects, or through a mobile subject and fixed camera. We opt for a rotating subject and fixed camera positions to keep consistent lighting conditions and a neutral background, optimising the quality of the final model. Images are taken every 10-20° through a full 360° revolution of sample at each of three fixed camera positions (see Fig. 1), the sample is then inverted and the process repeated in order to image all sides of the sample.

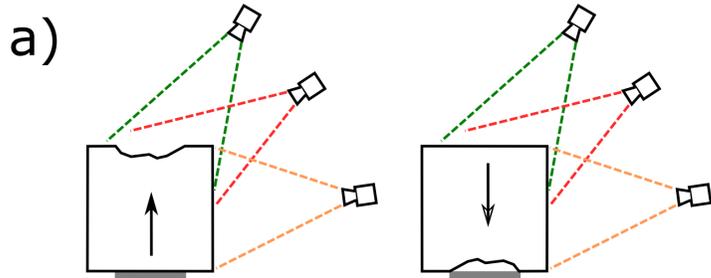
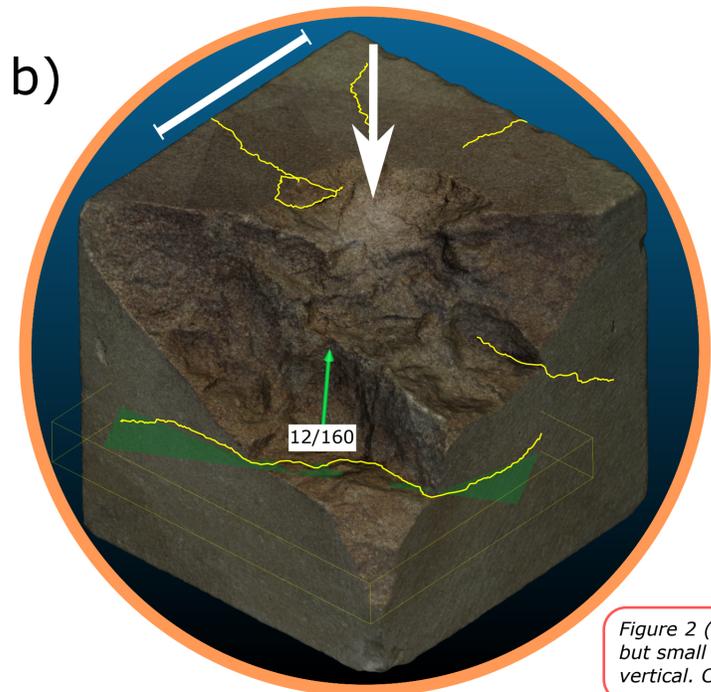


Figure 1 (left): (a) Schematic of image acquisition method for full 3D model generation. Images are gathered at 10-15° intervals from 3 static camera positions with the sample upright and repeated with the sample inverted. (b) Orthographic projection of completed 3D model of Huesca sandstone shot with 7.62x39 mm round at 200m. Surface fracture traces digitised in yellow. Arrow indicates impact direction. Scale bar is 75mm.



## 4. Manual Plane Selection

The Compass plugin in CloudCompare measures planes based on the selected vertices of a point cloud. The vertices selector can be scaled to sample a desired plane size. The plugin generates best fit planes with and outputs associated dip and dip direction measurements<sup>[4]</sup>. The fewer vertices selected, the lower measurement reliability. Compass is also able to digitise, and fit a plane, to surface fracture traces (see Fig.1a) for inclusion in subsequent stereonet projections (see Fig.2).

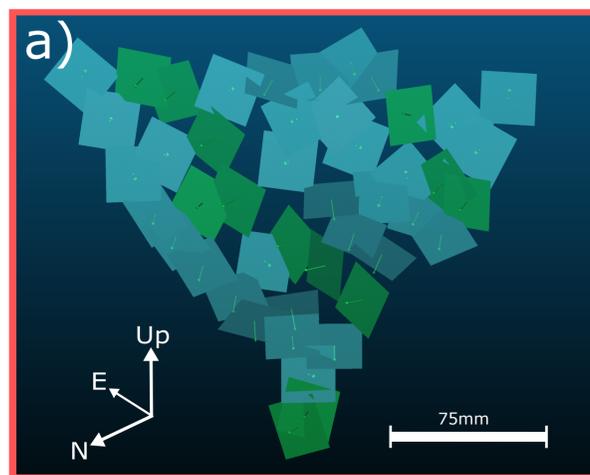


Figure 2 (above): (a) Best-fit planes of manually selected using the vertices selector. The general morphology of the shattered surface is present, but small scale variations lost. (b) Lower hemisphere, equal area stereonet projection of poles to planes from manual selection. Impact direction is vertical. Contoured poles show two clustered orientations, however the low number of data points mean this may be unreliable.

## 5. Automatic Plane Detection

The Facets plugin in CloudCompare automates the collection of orientation data. It progressively breaks down the point cloud into cells, through either a Kd-tree or Fast March algorithm, until all points within the cell fit the best fit plane (facet)<sup>[5]</sup>. It then works backwards, merging adjacent facets which share dip and dip directions. Settings can be adjusted to focus on smaller, or larger changes in plane orientations. The merged facets (see Fig. 3) are coloured based on dip direction and saturated based on dip (steep = vibrant colour), allowing for first pass observations of fracture orientations.

## 6. Discussion

Photogrammetric methods of 3D model generation have enabled the collection of plane orientations with relative ease. The initial process of model generation is the most time consuming part of the process (~4-5 hours including photography and SfM). Once completed however, large amounts of data (e.g. nearly 500 data points using automatic detection) can be extracted in minutes. The Compass plugin is useful for its freedom and functions to digitise fracture traces and match planes to them. However, the manual nature and inherent bias in vertex selection is a substantial disadvantage compared with Facets' automated pipeline. Facets represents the surface morphology better, and detracts any bias in plane selection. Within similar time frames, Facets produces 12x the number of data points as manual selection, avoids duplicate measurements, and allows for more reliable contouring of stereonet plots. With adaptations to image acquisition, this workflow could be conducted in a field based manner. In situ impacts on heritage could be imaged in the field, then models and data generated at a later stage. The open source nature of all the software used means researchers only real requirement is a camera and computer.

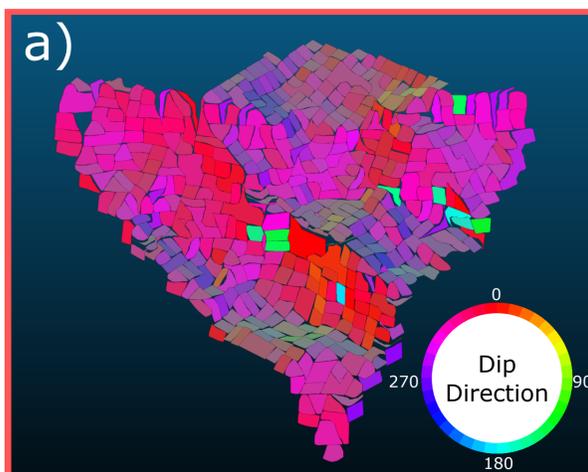


Figure 3 (above): (a) Planes automatically selected using the Kd-tree algorithm with 5° angular step in Facets plugin. Planes coloured based on dip direction. (b) Lower hemisphere, equal area stereonet projection of poles to planes from automatic selection. Impact direction is vertical. Contoured poles show two orientations much more reliably than the manual selection method.

## 2. Work Flow

