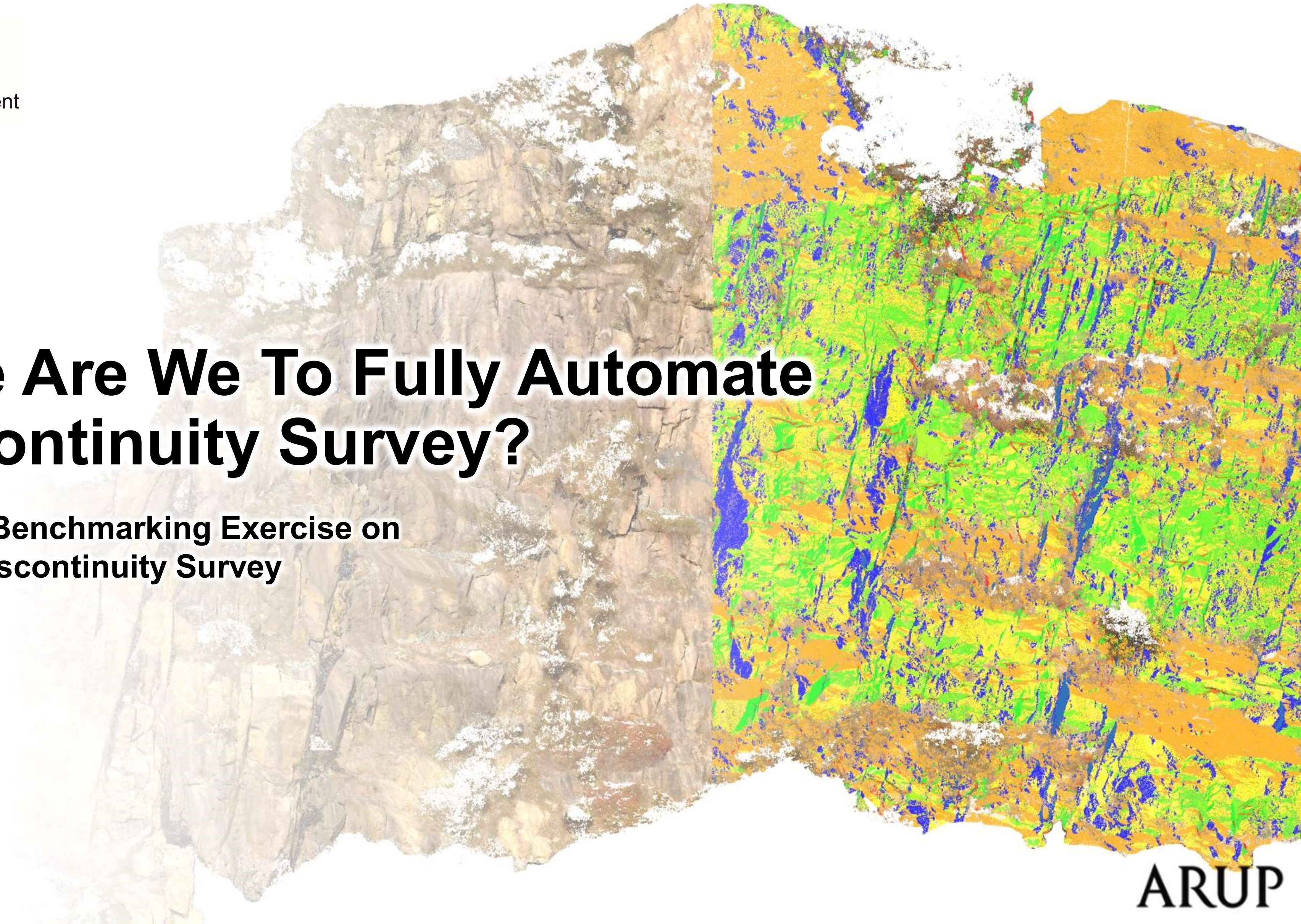
土木工程拓展署
Civil Engineering and
Development Department

How Close Are We To Fully Automate Rock Discontinuity Survey?

Lesson Learnt from Benchmarking Exercise on Digital Rock Mass Discontinuity Survey



ARUP

Dennis Wong

Geologist

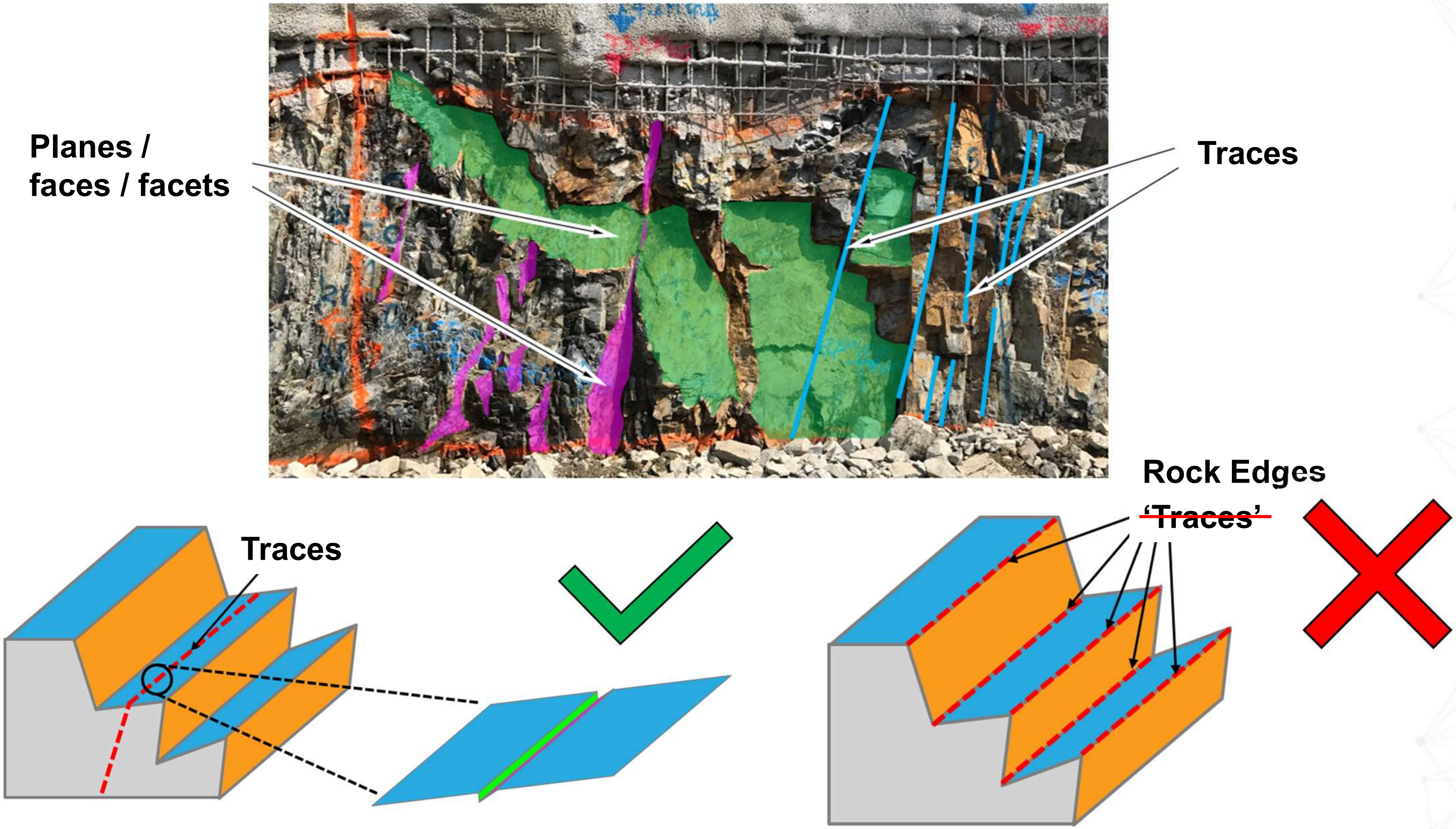
Sigma Mascot (HK) Limited

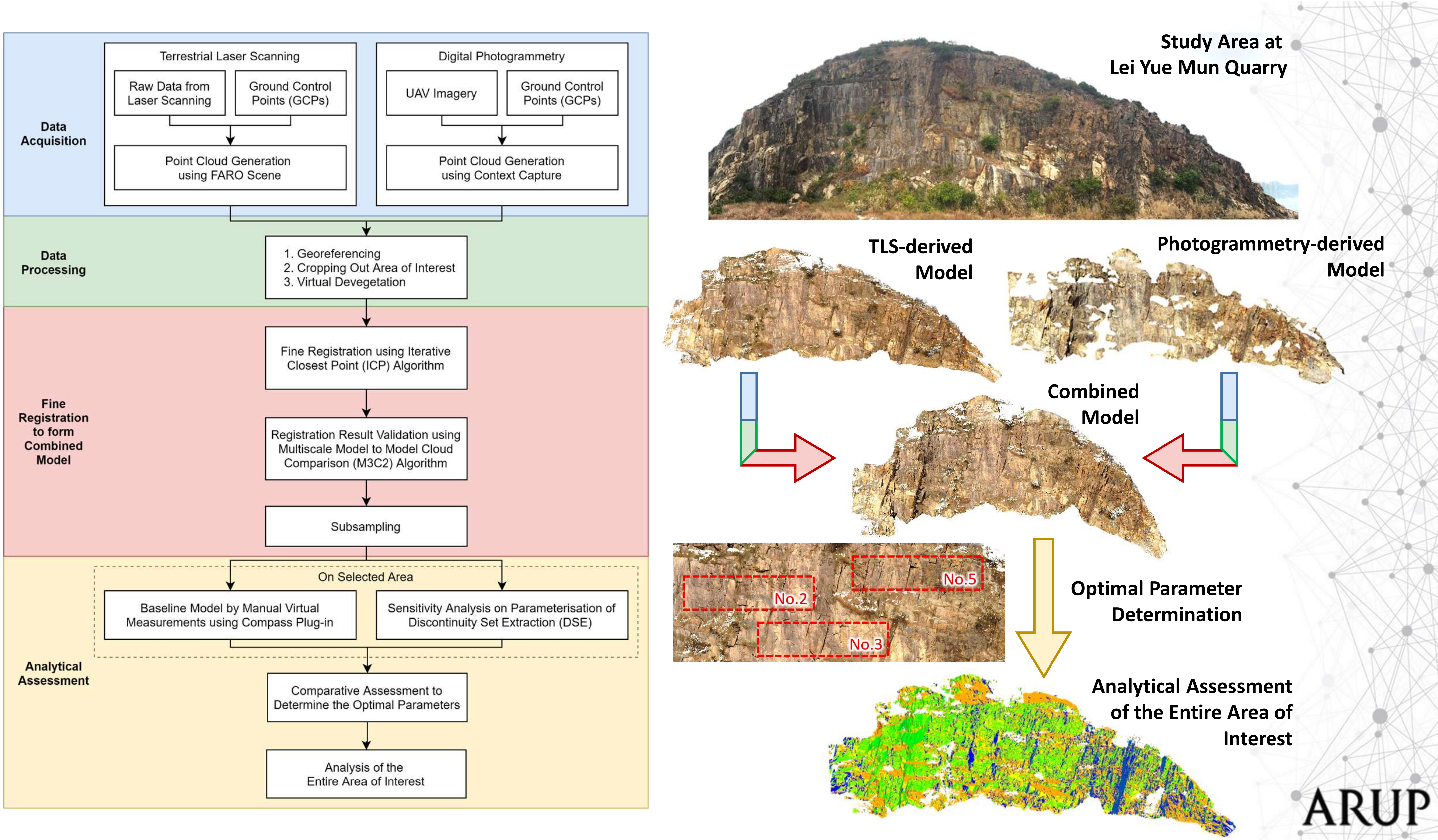
Remote Sensing Specialist

Dr. Antonio Abellan

Director at Centre for Research on the Alpine Environment

Terminology



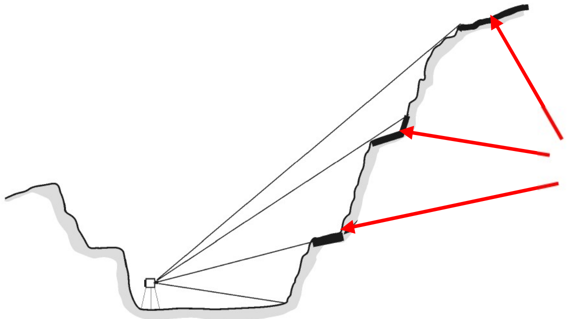

Data Acquisition
Terrestrial Laser Scanning
Raw Data from Laser Scanning
Ground Control Points (GCPs)
Point Cloud Generation using FARO Scene
Digital Photogrammetry
UAV Imagery
Ground Control Points (GCPs)
Point Cloud Generation using Context Capture
Data Processing
1. Georeferencing
2. Cropping Out Area of Interest
3. Virtual Devegetation
Fine Registration to form Combined Model
Fine Registration using Iterative Closest Point (ICP) Algorithm
Registration Result Validation using Multiscale Model to Model Cloud Comparison (M3C2) Algorithm
Subsampling
Analytical Assessment
On Selected Area
Baseline Model by Manual Virtual Measurements using Compass Plug-in
Sensitivity Analysis on Parameterisation of Discontinuity Set Extraction (DSE)
Comparative Assessment to Determine the Optimal Parameters
Analysis of the Entire Area of Interest
Study Area at Lei Yue Mun Quarry
TLS-derived Model
Photogrammetry-derived Model
Combined Model
No.2
No.5
No.3
Optimal Parameter Determination
Analytical Assessment of the Entire Area of Interest
ARUP

Model Comparison

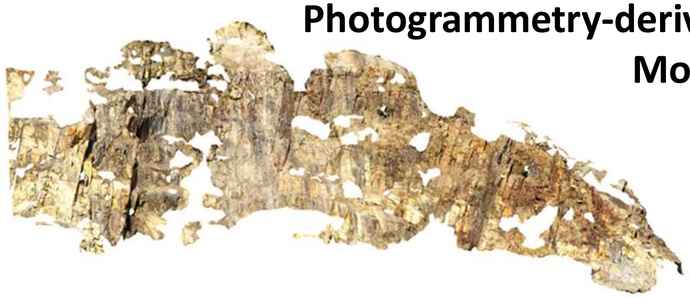
- Both terrestrial laser scanning (TLS) and photogrammetry are not perfect in terms of data quality

TLS-derived Model

- ➢ More serious point density heterogeneity observed on discontinuities with different orientation
- ➢ Occlusion issue can be substantial especially when scans could only be possible from ground level



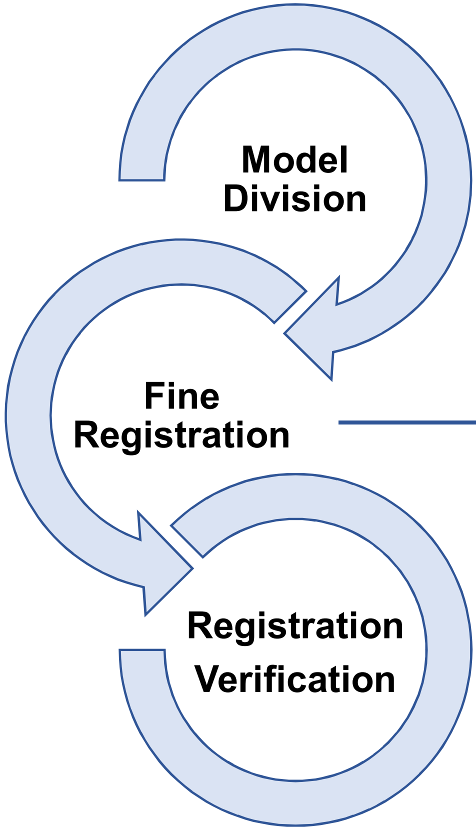
Photogrammetry-derived Model



- ➢ Image distortion may lead to inaccurate point cloud model construction
- ➢ Quality is sensitive to environmental factors (e.g. lighting and weather condition) and camera setting
- ➢ True ground data behind vegetations are usually completely absent

Data Preparation Methodology

- Combining the TLS- and photogrammetry-derived point cloud datasets

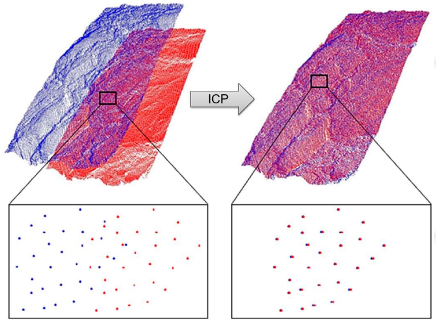


Model Division

- ➢ Segmenting the deformed photogrammetry-derived model into 15 divisions
- ➢ Applying the registration algorithm individually to ensure perfect fitting

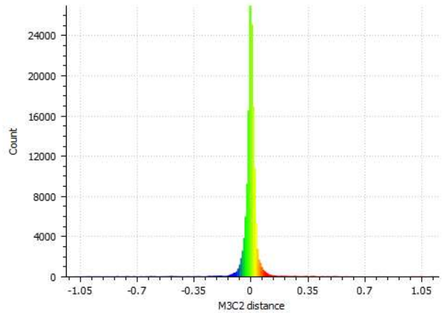
Fine Registration

- ➢ Using Iterative Closest Point (ICP) algorithm
- ➢ Progressively reducing the distance between datasets by translation, rotation and adjustment on scale



Registration Verification

- ➢ Using Multiscale Model to Model Cloud Comparison (M3C2) algorithm
- ➢ Computing the distance between registered datasets



Data Preparation | Baseline Data for Comparison | Analytical Tool | Sensitivity Analysis | Analytical Assessment | Major Observations | Concluding Remarks

ARUP

Combining the Models

- The combined model overcomes the impact of survey and data limitations

TLS-derived Model

Photogrammetry-derived Model

Combined Model

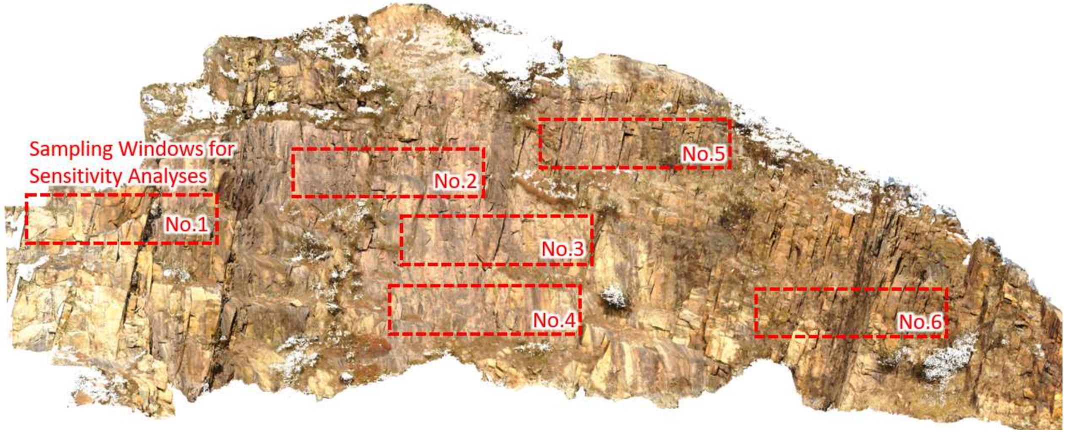
- ➢ Reducing area of empty data as obscured by vegetations
- ➢ Minimsing the occluded areas on sub-horizontal discontinuities
- ➢ Generating an exceptionally high-resolution point cloud

<u>Specifications of the combined model:</u>

- Subsampled to 1 cm
- File size : 4 GB
- No. of points: about 35.6 million

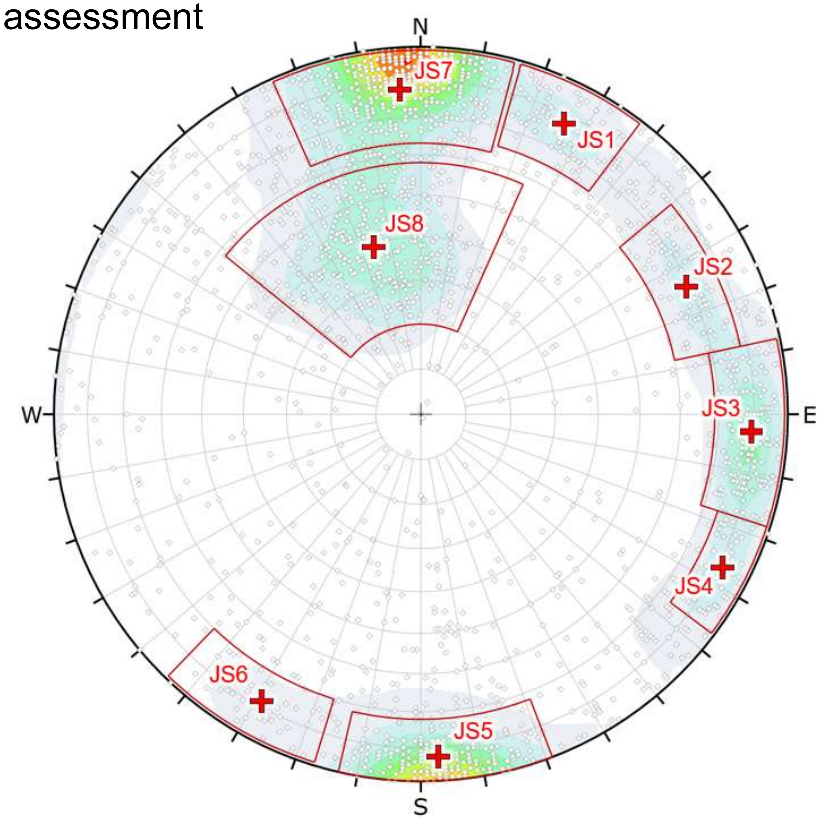
Baseline Data for Comparison

- Produced by taking measurements on 6 sampling windows of the combined model
- Using the Compass plug-in in CloudCompare to construct best-fit planes on manually picked discontinuities
- To determine the optimal parameters adopted in analytical assessment



No.1 Sampling Window

No.4 Sampling Window

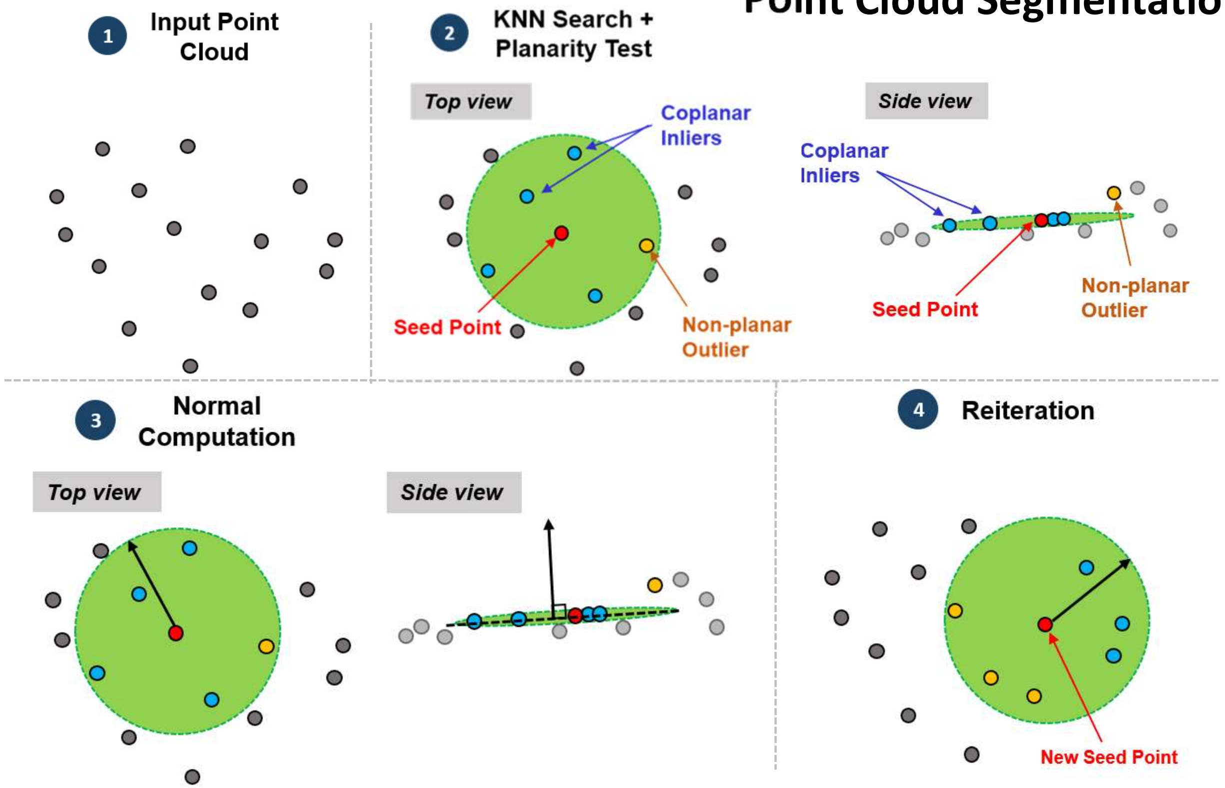


ARUP

Analytical Tool – Discontinuity Set Extractor (DSE)

- Utilising the plane-based approach in Discontinuity Set Extractor (DSE) originated from Riquelme et al. (2014)
- Generating plane equations (Ax+By+Cz+D=0) for each planar point clusters

Point Cloud Segmentation



- ➢ Preserve data integrity
- ➢ Prior clean-up is not required
- ➢ Less sensitive to noises

Sensitivity Analysis on knn value

Unclassified

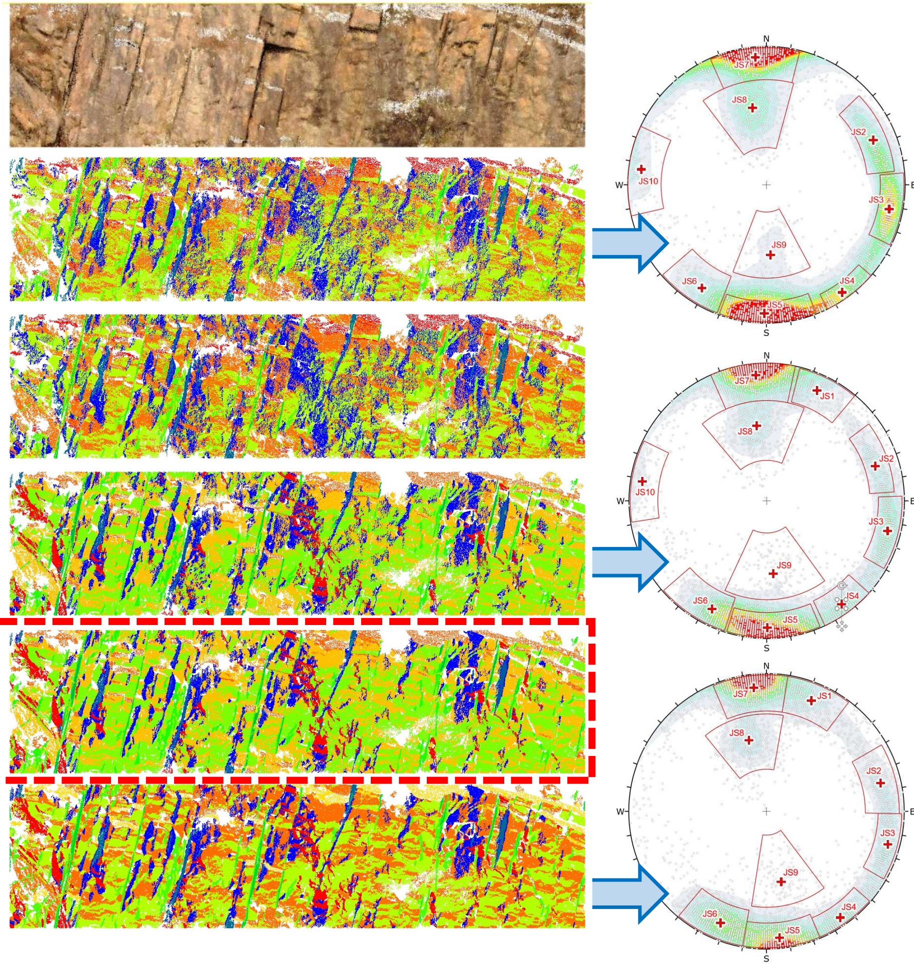
knn = 15

knn = 20

knn = 30

knn = 40

knn = 50



<u>As knn increases:</u>

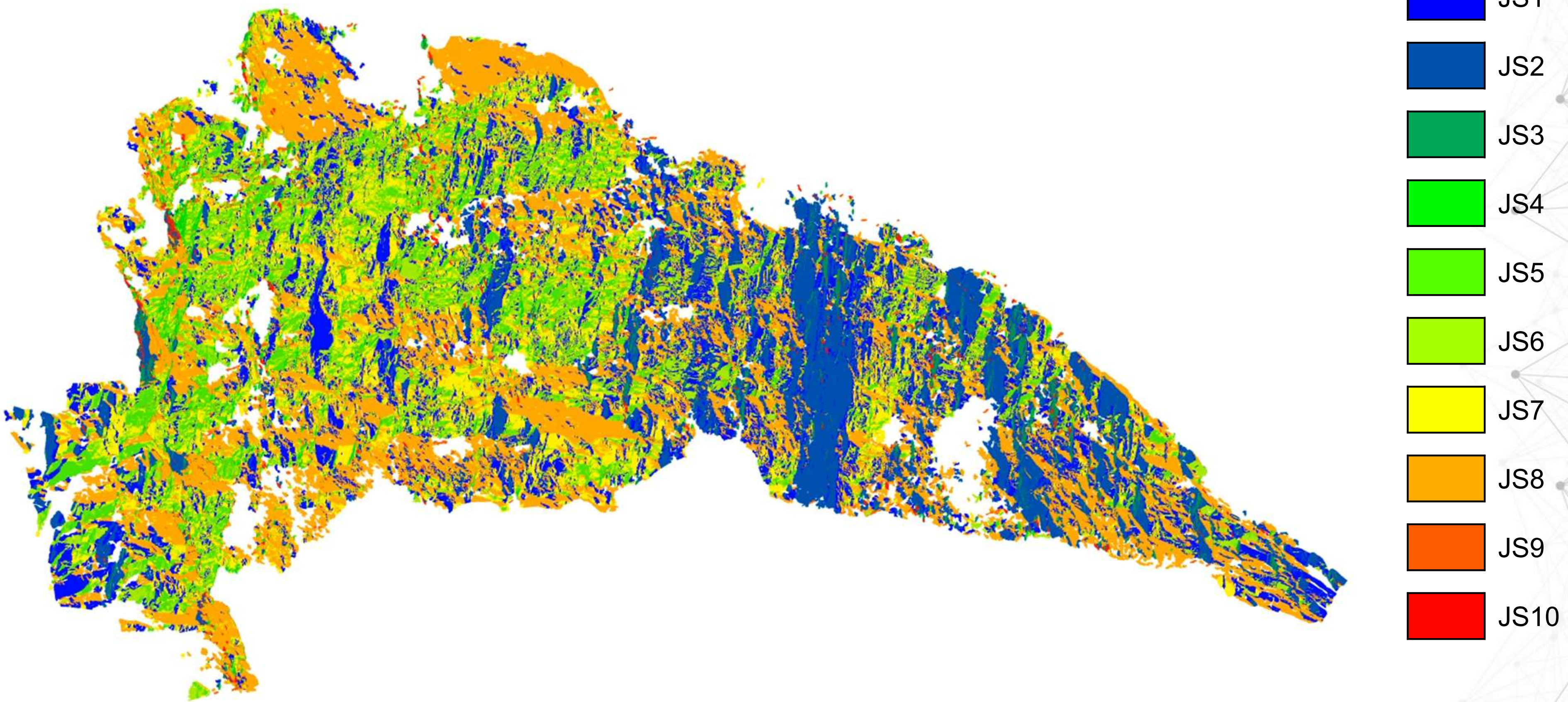
- ➢ Less susceptible to noises and local point cloud roughness
- ➢ Capability of detecting subtle discontinuities decreases due to excessive smoothing of local curvature
- ➢ Physical boundaries among individual discontinuities get more distinct
- ➢ The poles among discontinuity sets become less fuzzy in the stereoplots

<u>Comparing knn = 40 with Baseline:</u>

- ➢ Min. deviation : 1.14°
- ➢ Avg. deviation: 2.97°
- ➢ Max. deviation: 7.34°

ARUP

Analytical Assessment - Classified Point Cloud

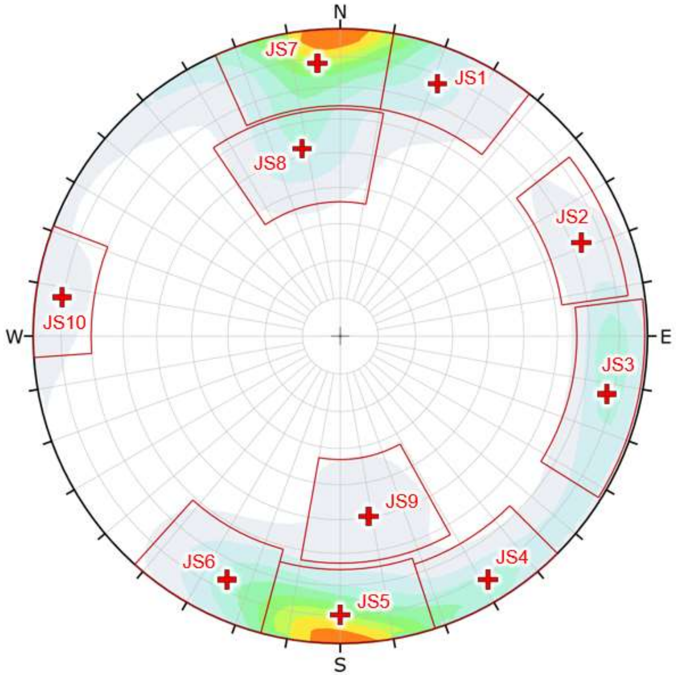


ARUP

Analytical Assessment – Extracted Rock Mass Parameters

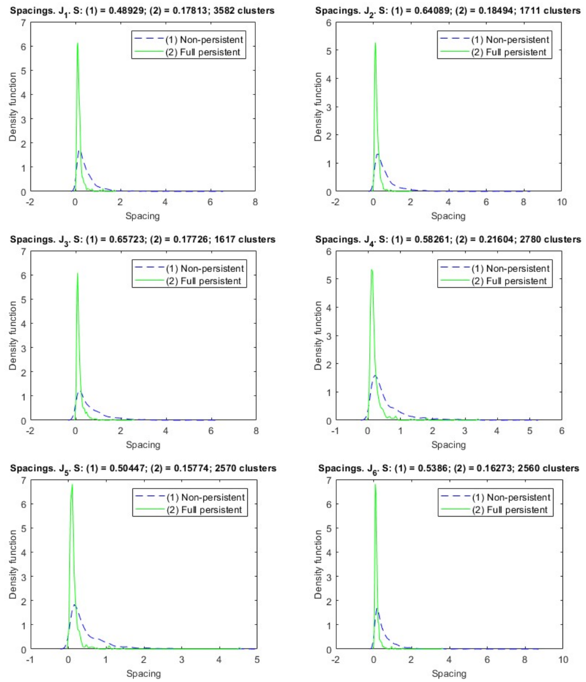
1 Orientation

- Computed from parameters A, B and C of plane equations



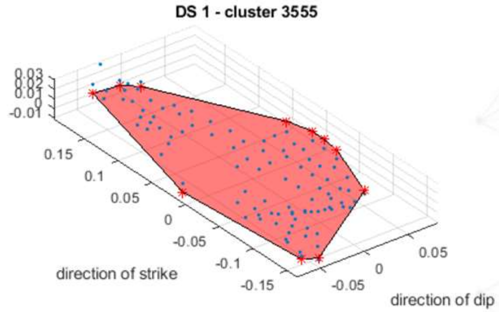
2 Spacing

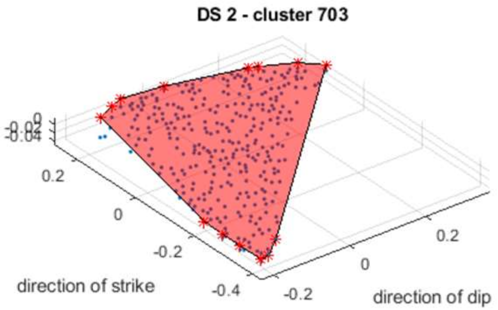
- By subtracting consecutive sorted parameter D of plane equations of same discontinuity sets



3 Persistence

- By using convex hull algorithm





ARUP

Major Observations

Fusion of Point Cloud Models

- Overcomes the problem of occlusion of TLS
- Complements the low point density of digital photogrammetry

Compass Plug-in

- Serves as an ideal tool to manually map discontinuities within point clouds to resolve the safety and accessibility issues of traditional approaches
- The manual picking process induces human biases and selective sampling

Discontinuity Set Extractor (DSE)

- Provides a robust, reproducible and accurate solution to identify discontinuity planes
- The derived information and quality of the classification is highly dependent on parameterisation

Semi-automatic Trace Mapping

- Requires totally different methods and is currently technologically immature
- Optical approach (image edge detection) is seriously affected by the varying environmental factors
- Geometric approach (curvature mapping) demands ultra high-resolution point clouds

Concluding Remarks

- Whitman and Bailey (1967)

  the use of the computerised approach does not free the engineer from making a judgement concerning the reasonableness of a solution

- Analytical tools / softwares / algorithms do not intend to offer one-click solutions
- We should always appreciate the professional judgement exercised during the assessment of the solution and the determination of the optimal parameters
  - Survey purpose
  - Limitations of remote sensing techniques
  - Occlusion issues
  - Dimension of discontinuities
  - Point cloud resolution
  - Point density heterogeneity
  - Presence of geological domains
  - Orientation bias
- Essential to check against field mapping records
- Technological advancement is much needed to make digital trace mapping possible
- **Significant progress has been made on plane-based analysis**
- **Still a long journey to fully automate rock discontinuity survey**

ARUP

References

- Besl, P. J., & McKay, N. D. (1992, April). Method for registration of 3-D shapes. In Sensor fusion IV: control paradigms and data structures (Vol. 1611, pp. 586-606). International Society for Optics and Photonics.
- Riquelme, A. J., Abellán, A., Tomás, R., & Jaboyedoff, M. (2014). A new approach for semi-automatic rock mass joints recognition from 3D point clouds. Computers & Geosciences, 68, 38-52.
- Riquelme, A. J., Abellán, A., & Tomás, R. (2015). Discontinuity spacing analysis in rock masses using 3D point clouds. Engineering geology, 195, 185-195.
- Riquelme, A., Tomás, R., Cano, M., Pastor, J. L., & Abellán, A. (2018). Automatic mapping of discontinuity persistence on rock masses using 3D point clouds. Rock Mechanics and Rock Engineering, 51(10), 3005-3028.
- Thiele, S. T., Grose, L., Samsu, A., Micklethwaite, S., Vollgger, S. A., & Cruden, A. R. (2017). Rapid, semi-automatic fracture and contact mapping for point clouds, images and geophysical data. Solid Earth, 8(6), 1241.
- Whitman, R. V., & Bailey, W. A. (1967). Use of computers for slope stability analysis. Journal of the Soil Mechanics and Foundations Division, 93(4), 475-498.
- Wong, D., Millis, S., Chan, K. (2019). Digital Mapping of Discontinuities, Proceedings of the 39th HKIE Geotechnical Division Annual Seminar, Hong Kong, April 2019.

ARUP

We shape a better world

Thank you