Photogrammetric solutions for rock mass characterization in underground openings

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NBG Vårsleppet 2020

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My introduction

- Post-doctoral researcher at Aalto University and Rock Mechanics Specialist at Fractuscan Ltd
- Academic background:
  - DSc in Geoengineering @ Aalto, 2019
  - Master's in Mining Engineering (EMC European Mining Course) @ Aalto, TU Delft & RWTH Aachen, 2014)
- Research topics: photogrammetry, virtual reality, underground thermal energy storage, fracturing geomechanics, risk assessment

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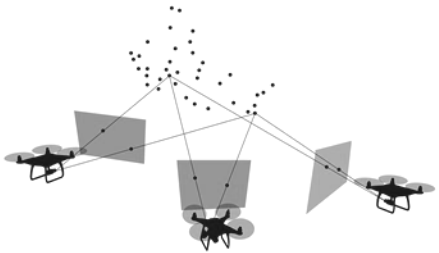
FRACTUSCAN

EMC
EUROPEAN
MINING COURSE

Source: http://fractuscan.com/

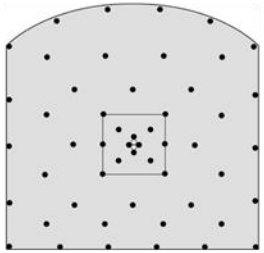
Content

1



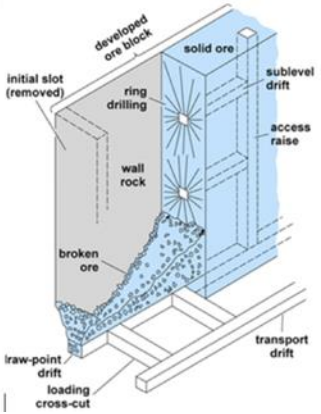
Background and motivation

2



Case study 1: tunnel

3



Case study 2: open stope

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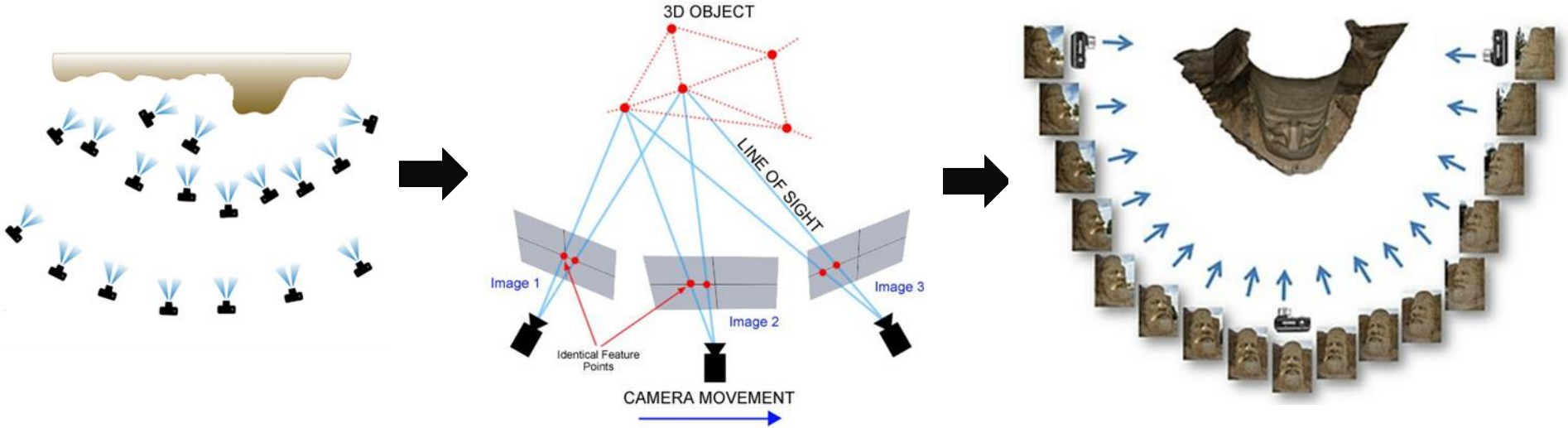
Structure from Motion (SfM) photogrammetry as an accurate, cheap and efficient method to create 3D models of rock surfaces

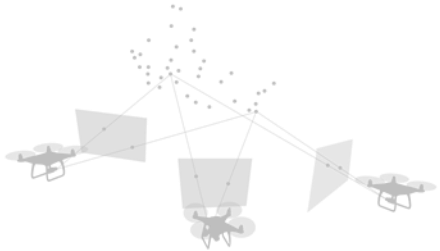


How can we use the photogrammeric 3D models?

- Rock mass characterization
- Remote visual inspection
- Exact tunnel profiles
- Accurate volume calculation
- Reconciliation and hazard identification
- Fragmentation analysis after blasting
- Training in virtual reality

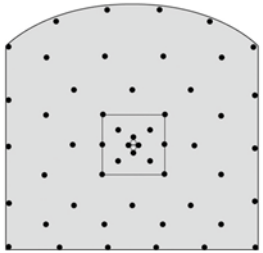
Content

1



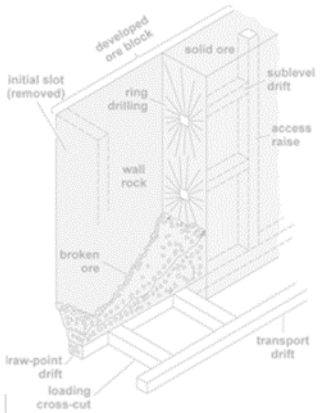
Background and motivation

2



Case study 1: tunnels

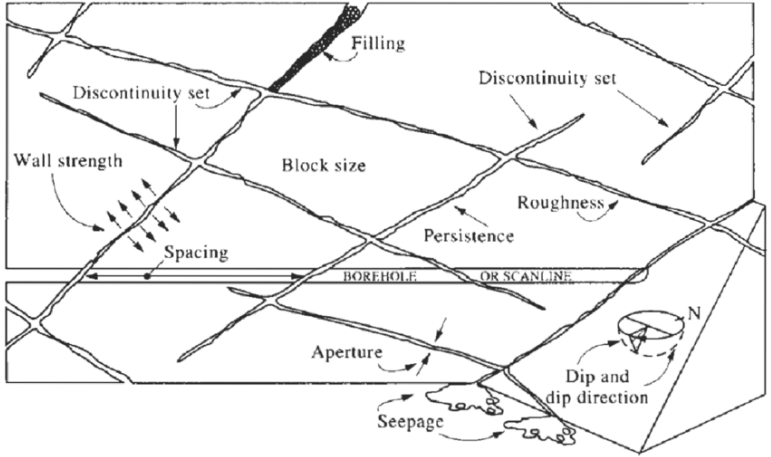
3



Case study 2: open stopes

Motivation 1/2

- Knowledge of discontinuities important in rock mass characterization
- Manual mapping biased and time consuming
- Photogrammetry as a viable method for digitizing rock surfaces for automatic fracture measurements



Hudson and Harrison, 1997

Palmström, 2000

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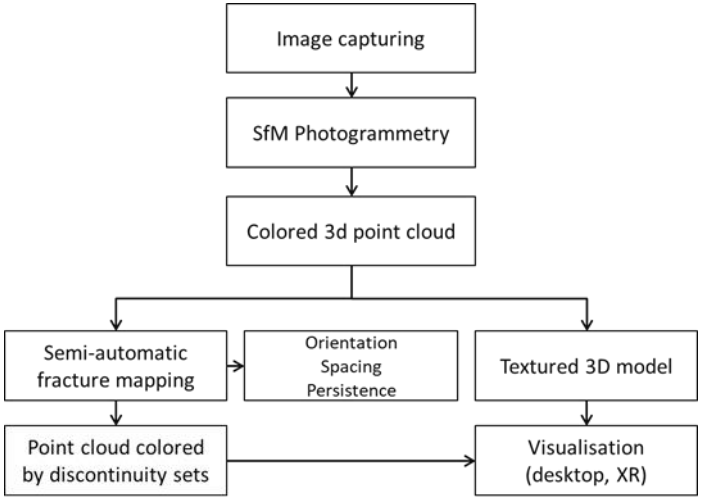
Photogrammetric scanning of URLA

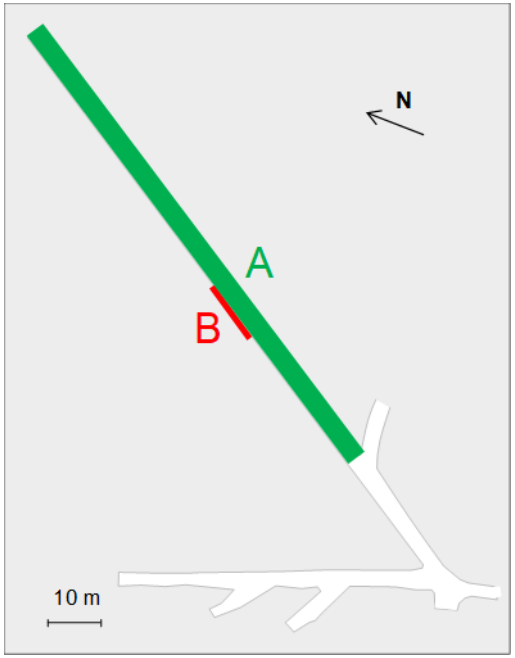
Goal: Digitize the Underground Research Laboratory of Aalto University (URLA)

Build 3D models of URLA

- Tunnel model (A)
- HQ rock wall section (B)

Extract the discontinuities from the point cloud



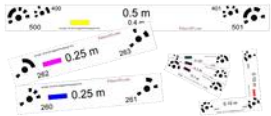


Janiszewski et al. 2020

Tunnel was digitized using photogrammetry

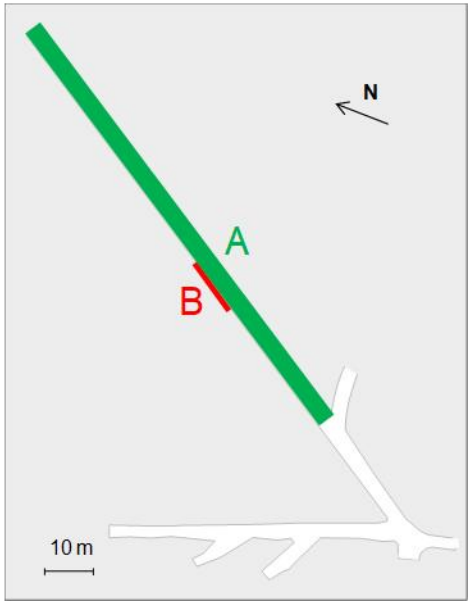
Camera: Canon EOS 5DS R + Canon 14 mm f/2.8

Lights: 3x Apurture HR672C + 3x 2x50W LED



- ✓ **1725 photos (A), 369 (B)**
- ✓ **> 70% overlap**
- ✓ **tripod**
- ✓ **f/8**
- ✓ **ISO 100**
- ✓ **RAW file format**
- ✓ **Post processing**

- **Software: Reality Capture, Agisoft Metashape**



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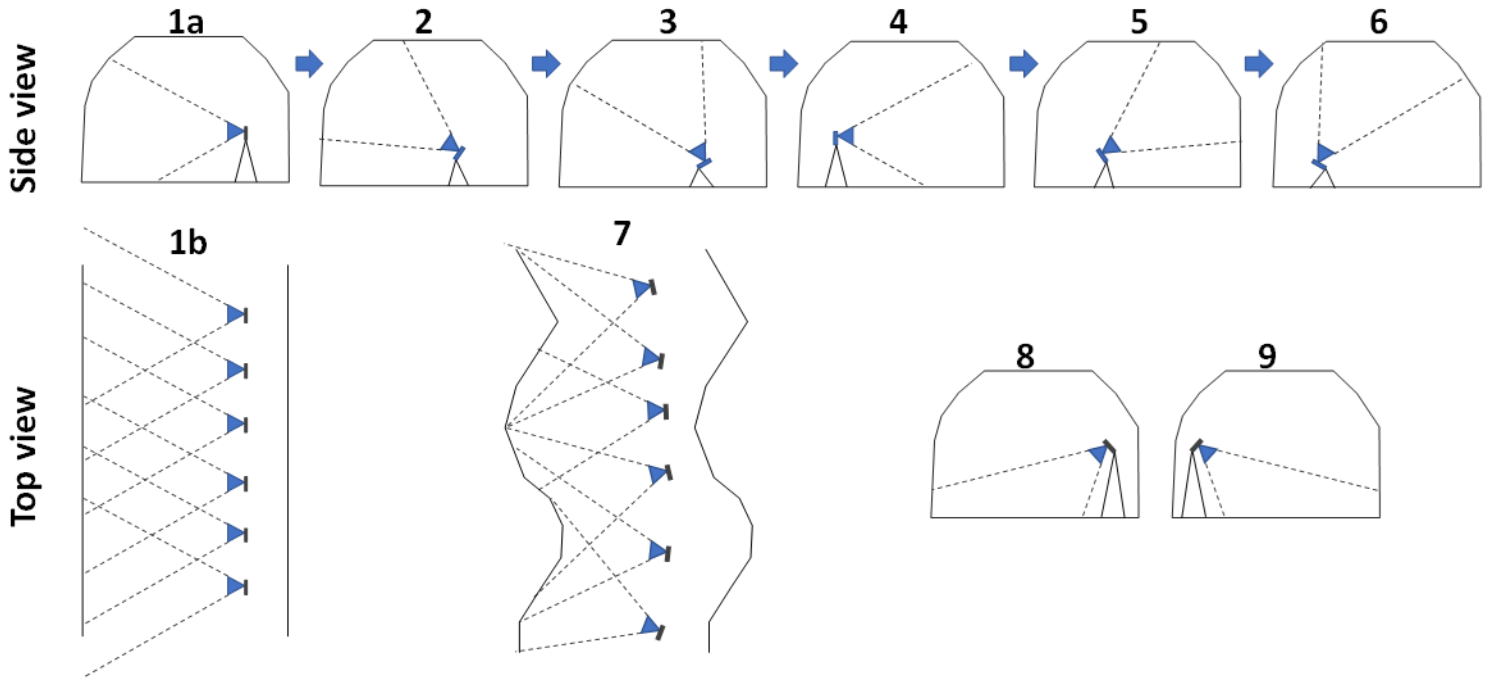
Workflow for image capturing in tunnels



Janiszewski et al. 2020

Images were processed in photogrammetric software

Point cloud

Textured mesh

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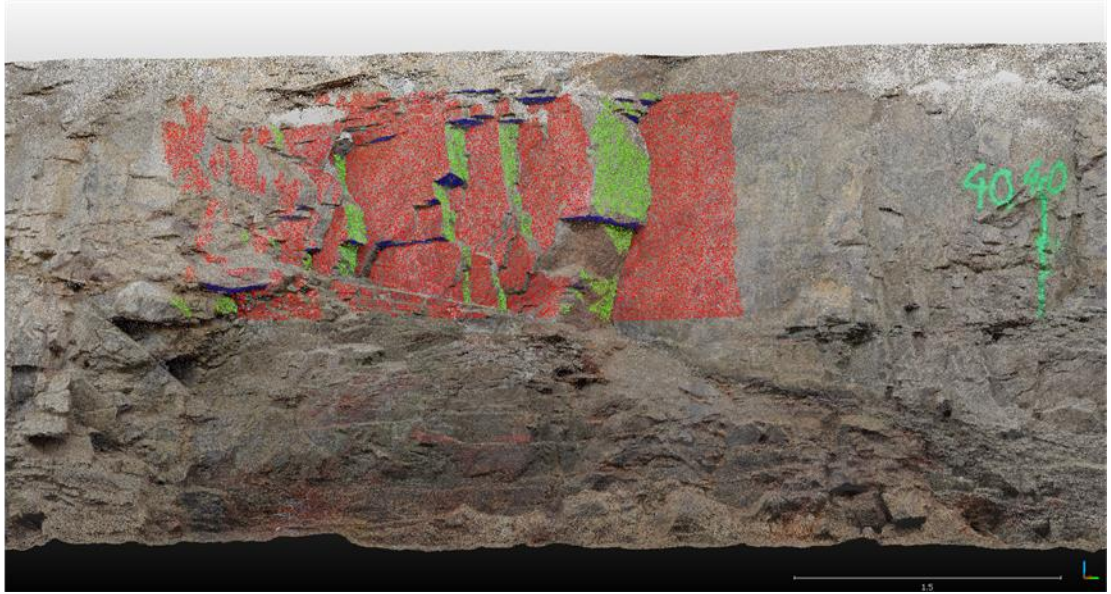
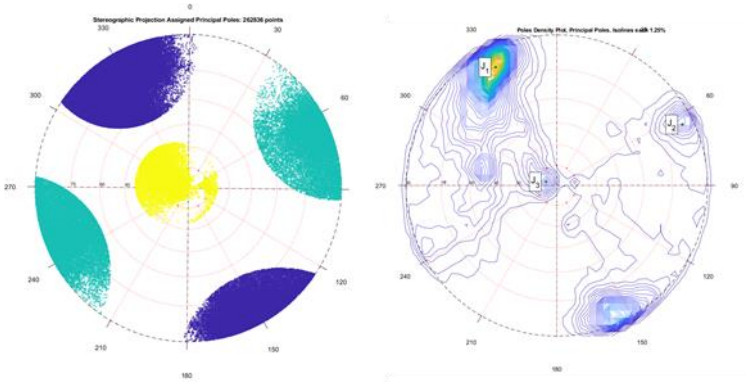
Janiszewski et al. 2020

Fractures extracted from the point cloud using Discontinuity Set Extractor (DSE)





Discontinuity set	Dip direction [°]	Dip [°]	Density [%]
1	332.7	82.9	56.0
2	64.1	85.6	13.0
3	288.7	8.6	4.7

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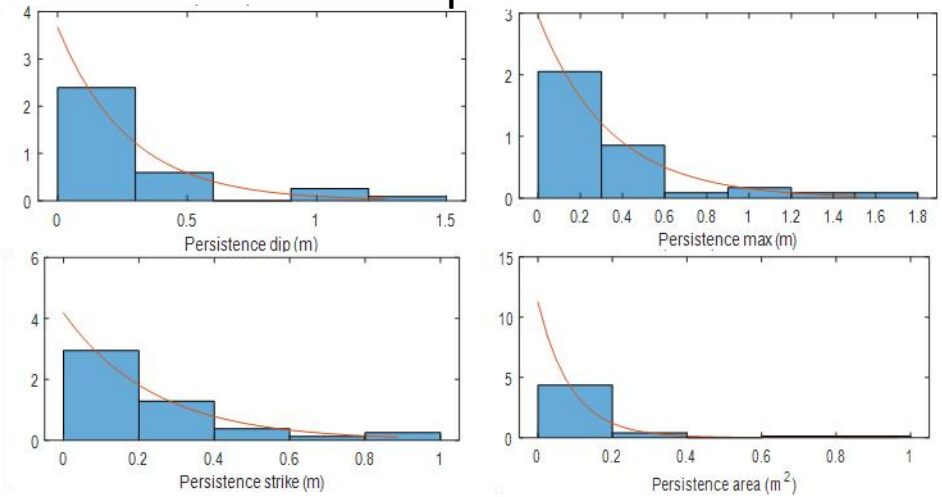
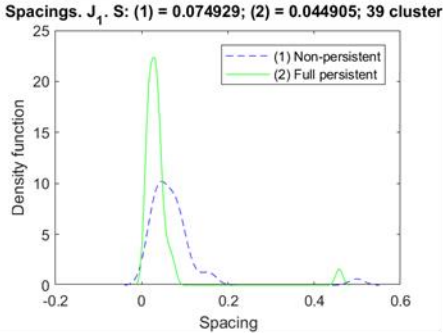
Riquelme et al. (2014). A new approach for semi-automatic rock mass joints recognition from 3D point clouds. Computers & Geosciences, 68, 38-52.

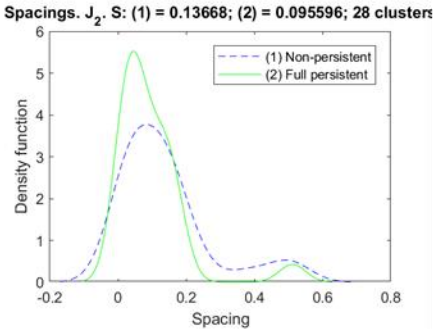
Fractures properties were analysed in DSE

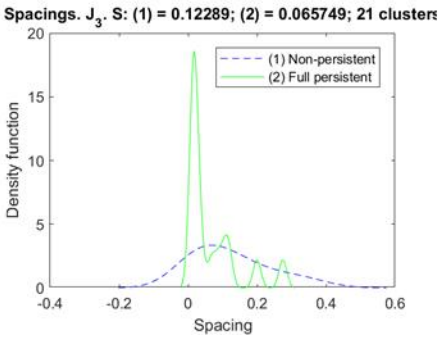
Fracture persistence



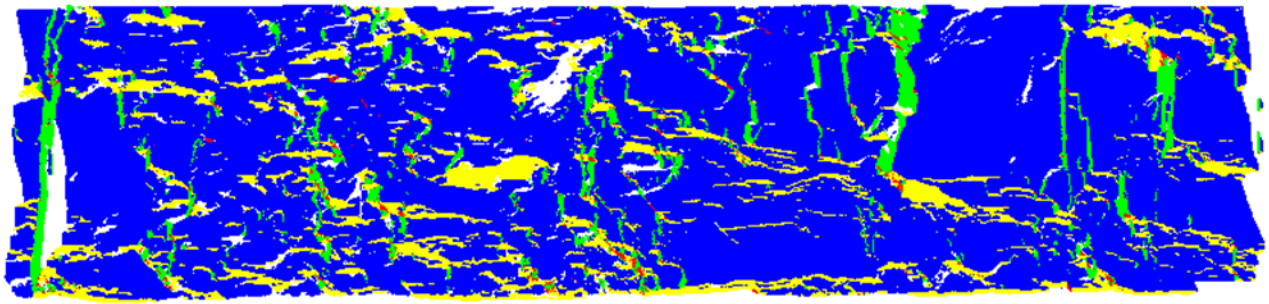
Fracture spacing

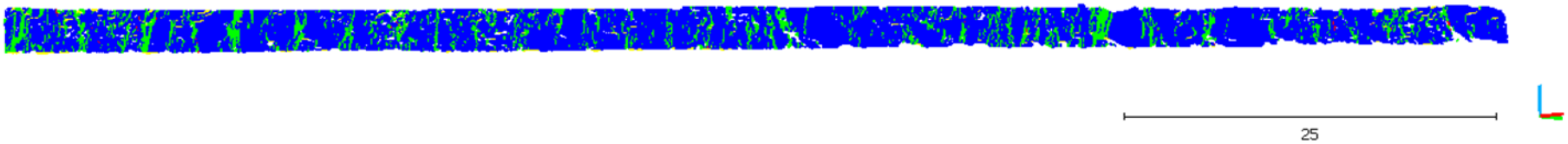




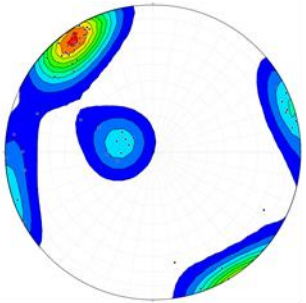


Rapid mapping of large surfaces is possible

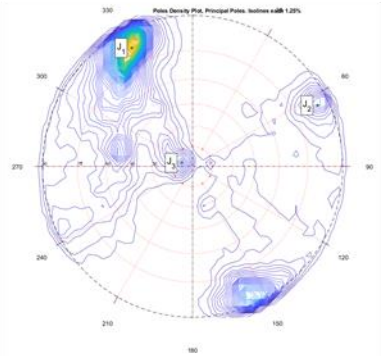


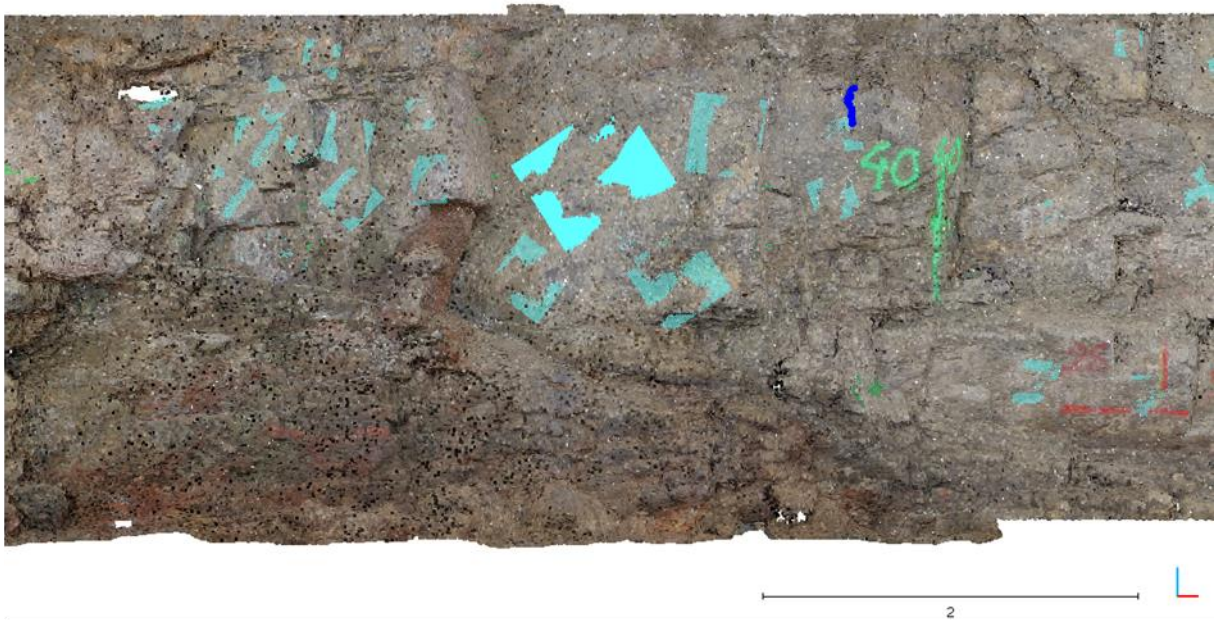


Fractures can also be mapped using the Compass plugin in CloudCompare software



DSE





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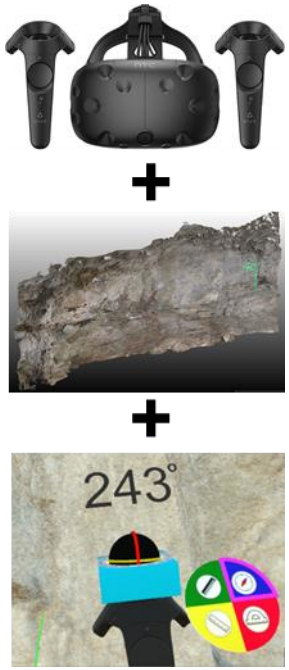
Textured 3D tunnel model

https://youtu.be/VTZaR5HGzOw

3D models were imported into Unity 3D game engine and VR system was built



https://youtu.be/8Zxtotw_vyg

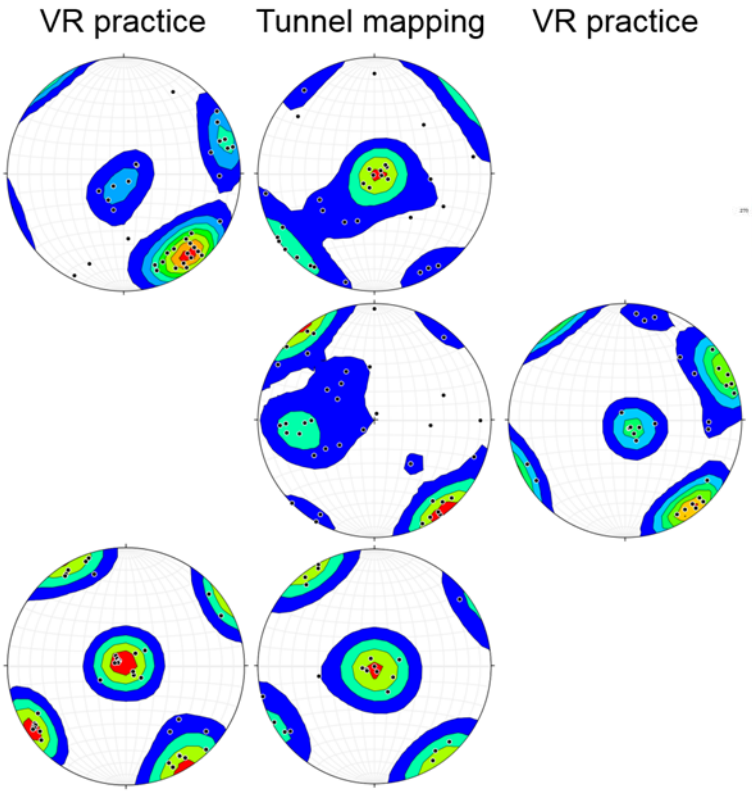
Training in VR improves learning outcomes

Student Group A
First Virtual Reality Training
Then Tunnel Mapping Exercise

Less scatter

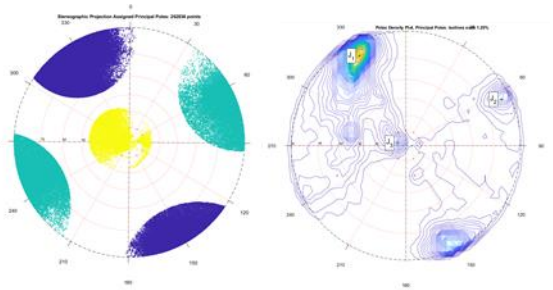
Student Group B
First Tunnel Mapping Exercise
Then Virtual Reality Training

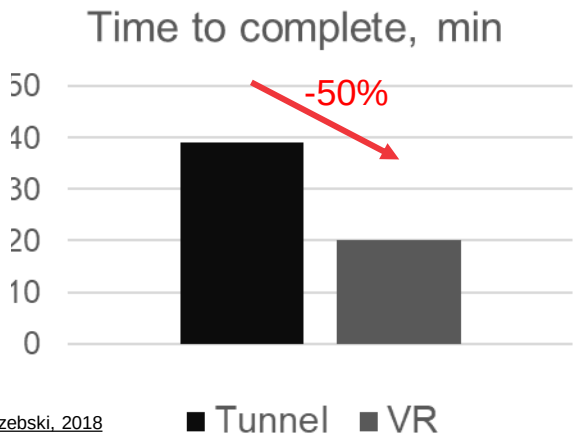
Aalto Staff (for comparison)
First Virtual Reality Training
Then Tunnel Mapping Exercise



Uotinen et al. 2019

DSE





Jastrzebski, 2018

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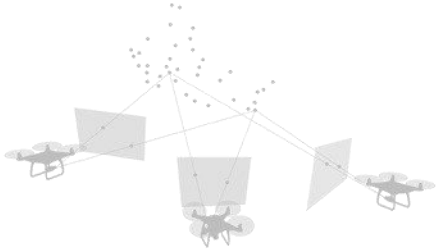
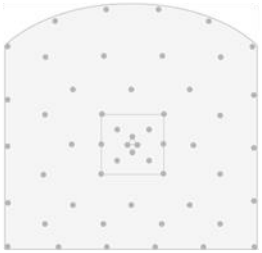
Content

1



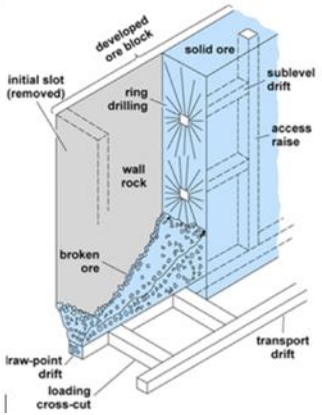
Background and motivation

2



Case study 1: tunnels

3



Case study 2: open stopes

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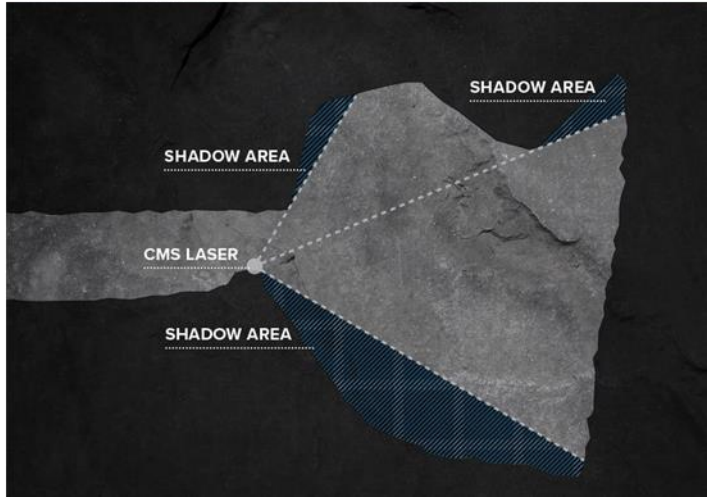
Motivation 2/2

- Restricted access to open stopes
- CMS unable to provide accurate measurement of all surfaces
- Drone photogrammetry as a viable and safe method for scanning stopes



Recent development of drones enables their use in underground mines

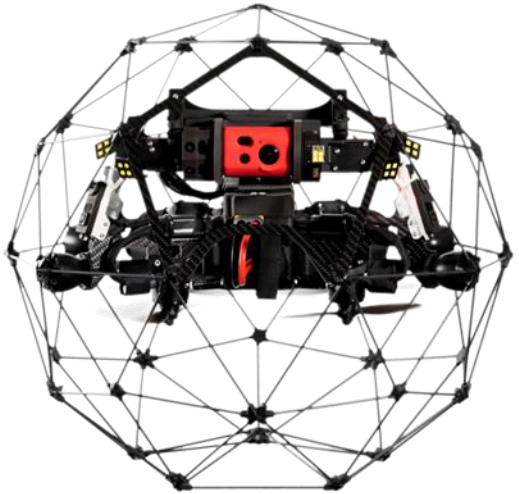
AUTONOMOUS REMOTE MAPPING

Source: www.emesent.io

SAFETY FLEXIBILITY

Source: www.lnkonova.se

CONFINED SPACE ACCESSIBILITY



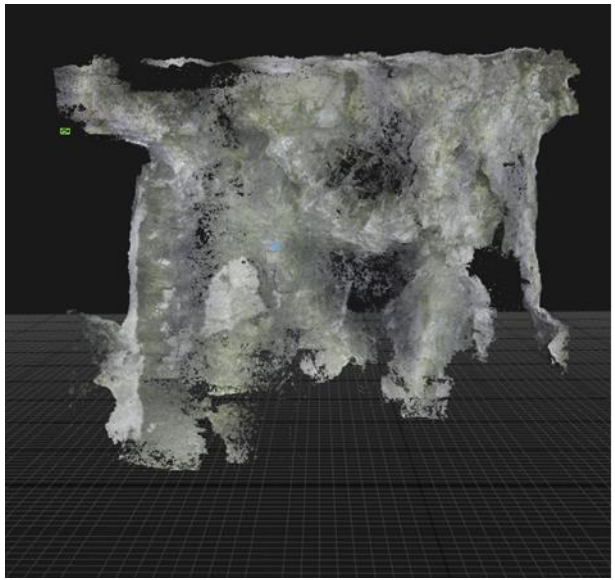
Source: www.flyability.com

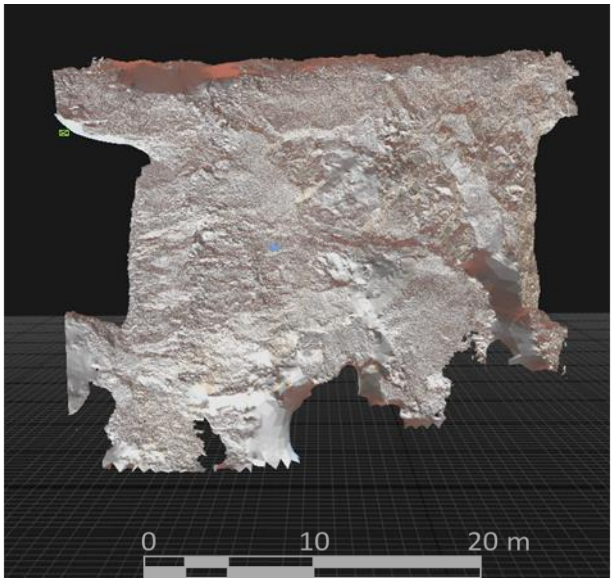
Drone images were captured in UG stope

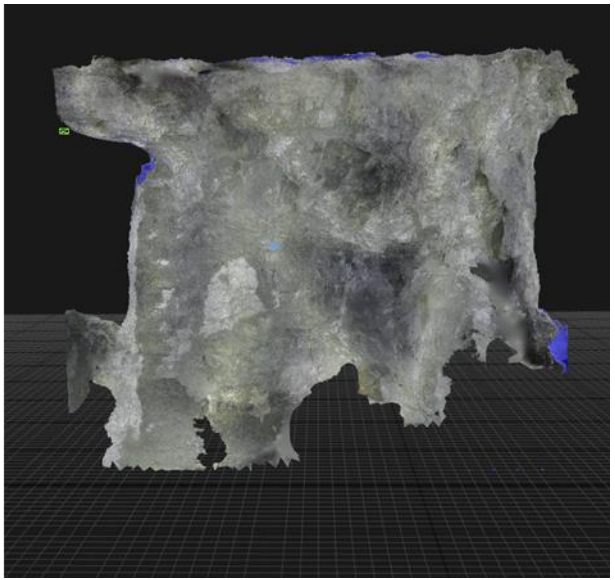
- Golden Sunlight Mine in Montana, USA (Barrick Gold Corp.)
- Stope dim. 10 x 30 x 100 m
- 4 flights
- 2105 photos

Source: https://youtu.be/e8UVLwRfRdg

Images were processed to reconstruct the stope model







Point cloud **Mesh** **Textured mesh**

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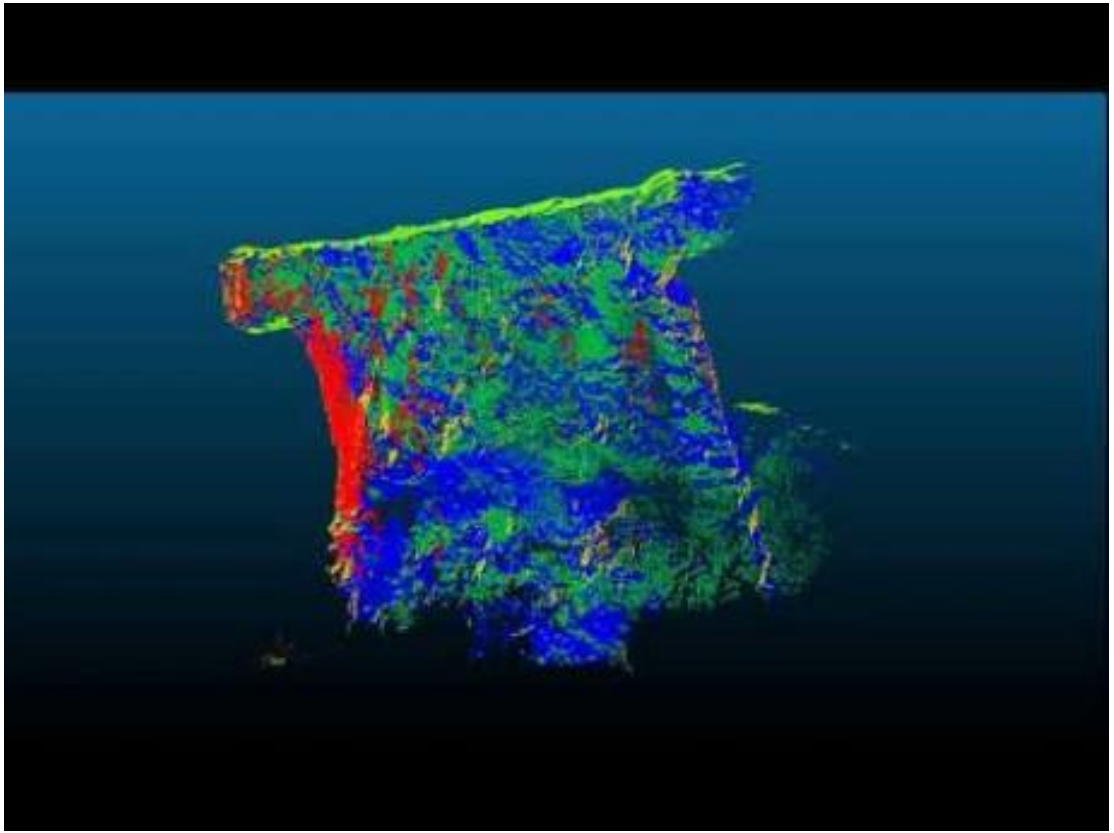
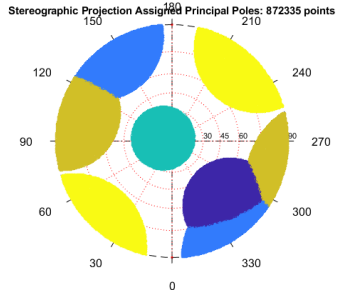
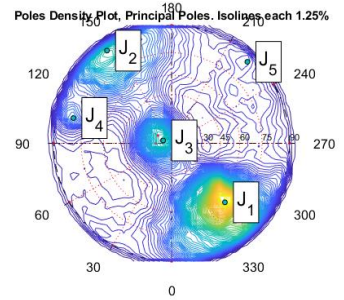
Textured stope model enables revisitng for remote inspection and visualisation

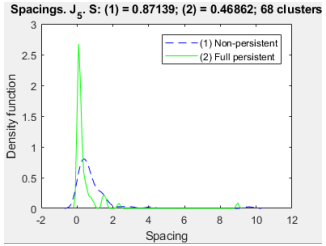
https://youtu.be/3GO6WDUrQ2g

Discontinuities extracted using DSE









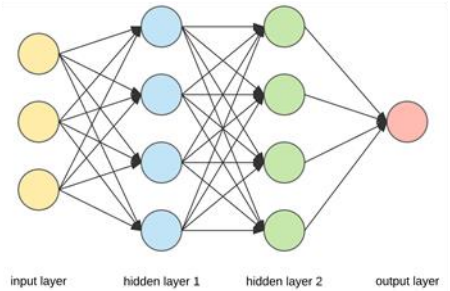
https://youtu.be/3GO6WDUrQ2g

Conclusions

- **SfM photogrammetry is a viable tool to produce hiqh-quality 3D models of underground openings**
  - Coloured 3D point clouds
  - Photorealistic textured 3D mesh
- **Photogrammetric models enable semi-automatic fracture mapping for rock mass characterization**
  - tunnels (DSLR cameras)
  - stopes (drones)

Future outlook

- Autonomous drone missions
  - Combined laser scanning and photogrammetry
- Real-time remote inspection and communication via XR
- Fully automatic fracture mapping using Artificial Intelligence



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References

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Uotinen L., Janiszewski M., Baghbanan A., Caballero J., Oraskari J., Munukka H., Szydlowska M., Rinne M. (2019) Photogrammetry for recording rock surface geometry and fracture characterization, Rock Mechanics for Natural Resources and Infrastructure Development contains the proceedings of the 14th ISRM International Congress (ISRM 2019, Foz do Iguaçu, Brazil, 13-19 September 2019), pp. 461–468. https://research.aalto.fi/files/37106734/14698_Uotinen_et_al_2019_Photogrammetry_for_recording_rock_surface_geometry_and_fracture_characterization.pdf

Uotinen L., Janiszewski M., Baghbanan A., Jastrzębski J., Rinne M. (2020) Virtual reality system for improved geo-structural mapping training of underground tunnels, *International Journal of Rock Mechanics and Mining Sciences* (Journal article in preparation).