From Photos to Models

Strategies for using digital photogrammetry in your project

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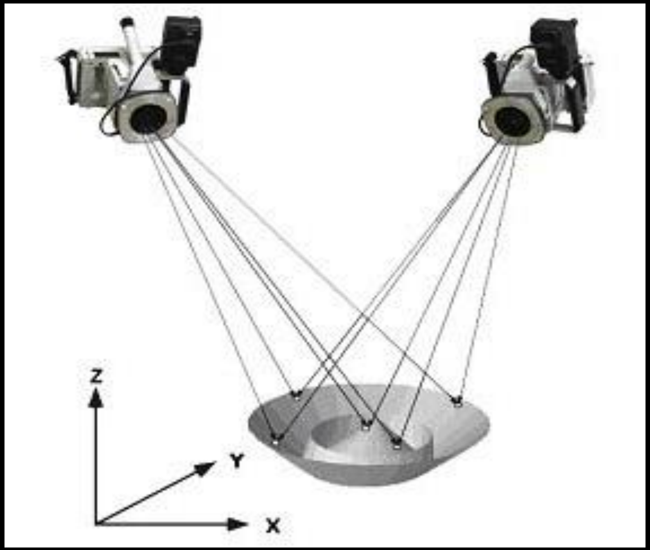
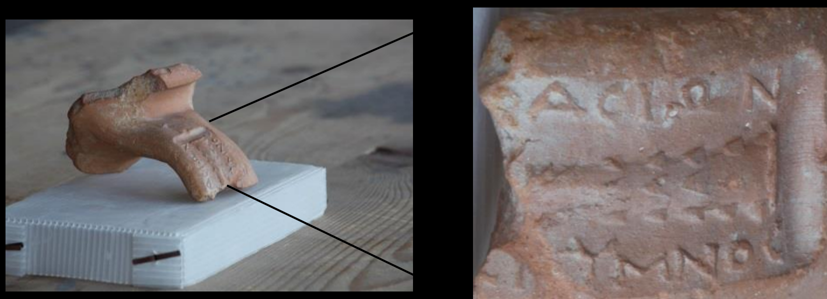
What is Photogrammetry?

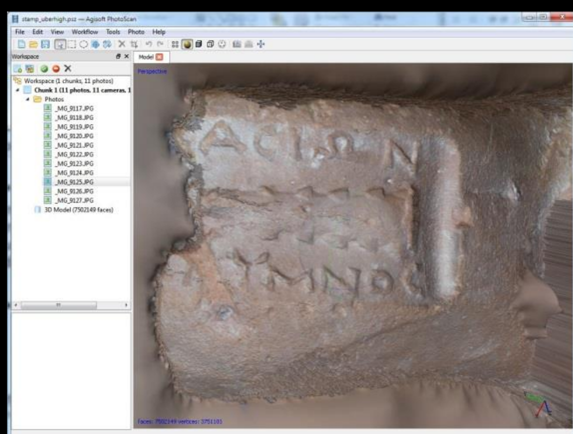
The “art, science and technology of obtaining reliable information about physical objects and the environment through the process of recording, measuring and interpreting photographic images and patterns of electromagnetic radiant imagery and other phenomena.” (American Society for Photogrammetry and Remote Sensing 1980)



What can Photogrammetry do for my project?

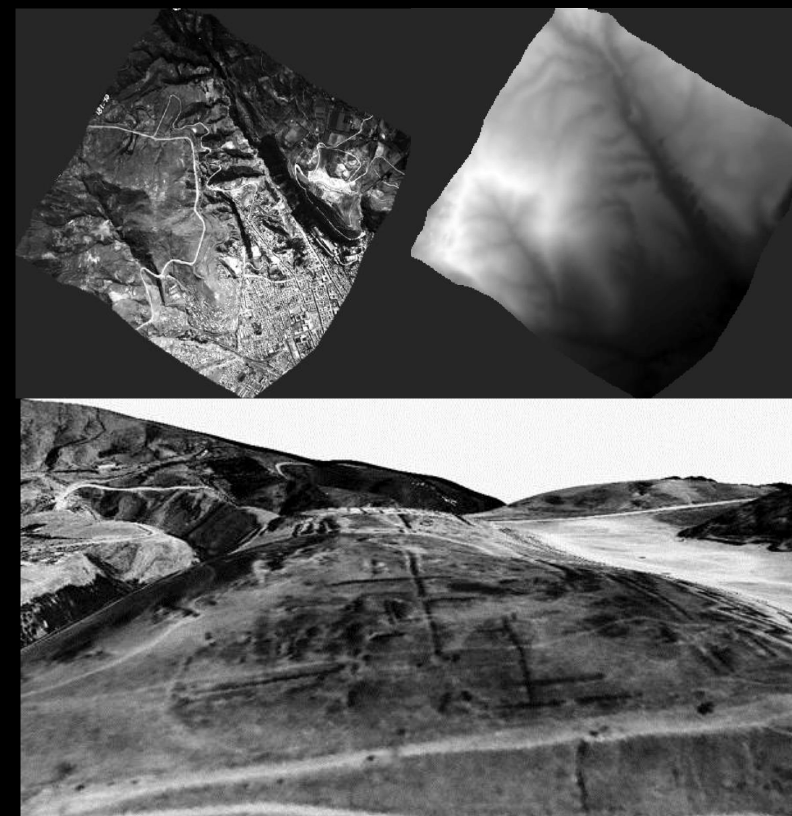
Close-range DSLR Scale





Amphora stamps from Ancient Athenian Agora
(with American School of Classical Studies at Athens

Aerial Photo Scale



DEM generated from historic images of Cusco, Peru Cotsen Institute/UCLA Geomatics Field school 2009)

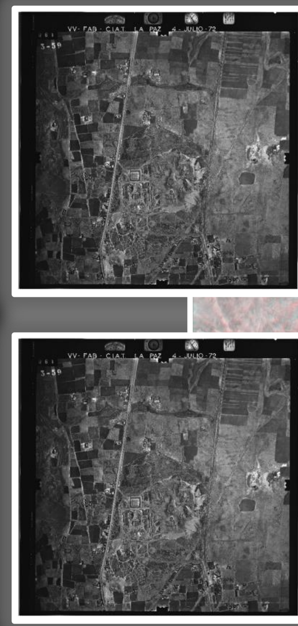
What can Photogrammetry do for my project?

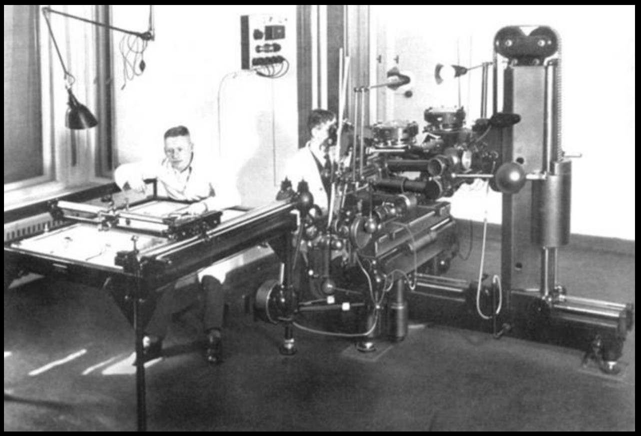
- Documentation
- Visualization
- Metric Analysis
- Geometric Comparison
- Reconstruction from Historic Photos
- Change Detection
- Prospection

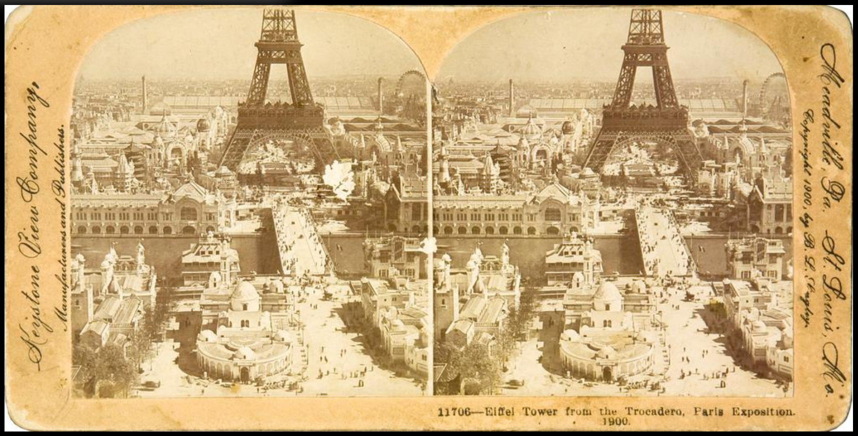
A LITTLE BACKGROUND

In the Beginning…

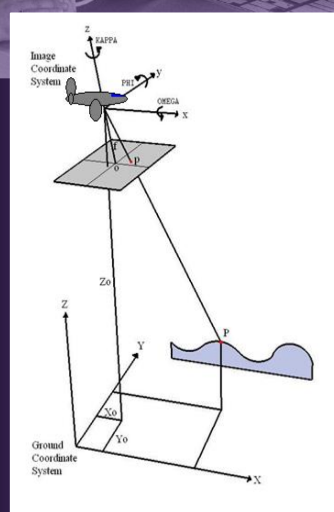
- From late 1800s and early 1900s, primarily aerial Photogrammetry
- Originally done via optical-mechanical systems







Digital Photogrammetry Beginnings

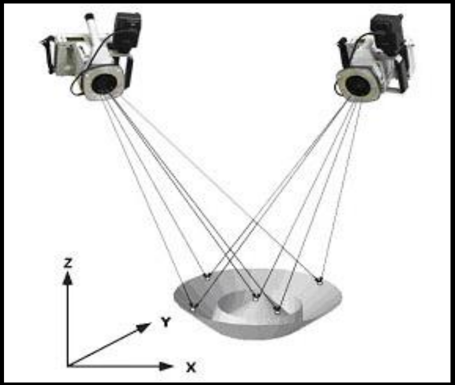


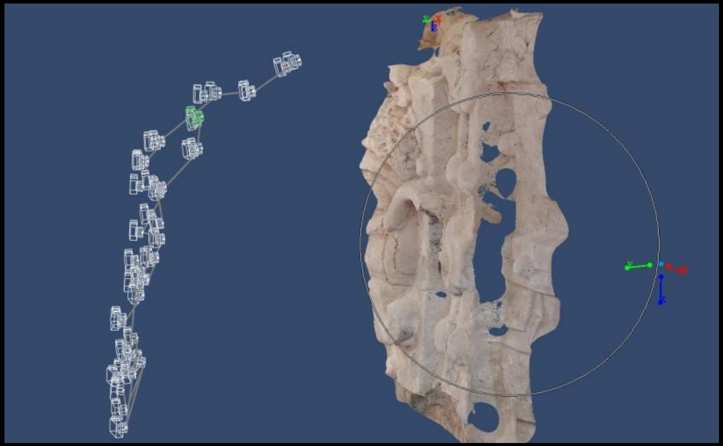
- In 1990s vendors developed computer based systems
  - In mid 1990s these cost north of $250,000!
- Use of very expensive metric cameras
  - $10K +
- Complex processes
- Required technical staff and equipment
- No room for human error

Automated Close-Range Photogrammetry (CRP)

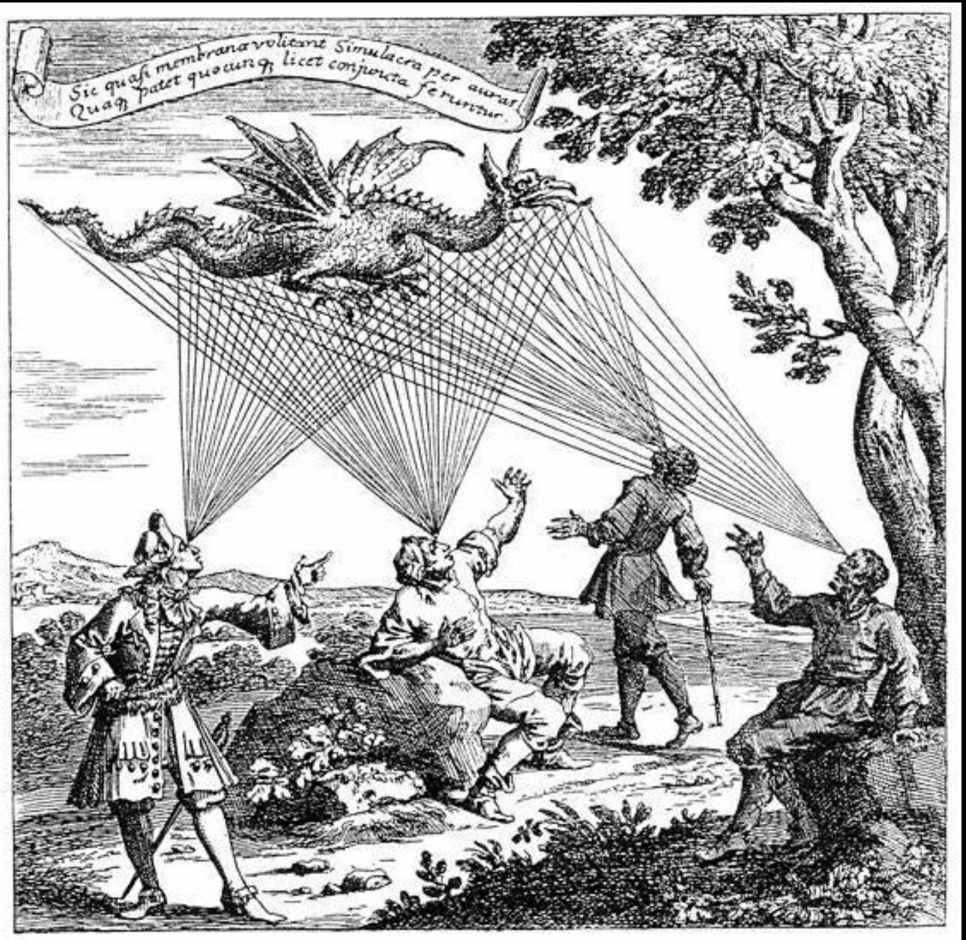
Photogrammetry for the masses

The generation of 3D models from 2D images using the SIFT (scale-invariant feature transform) algorithm to automate the workflow of feature matching between multiple photos that's required in photogrammetry.





How does automated CRP it work?

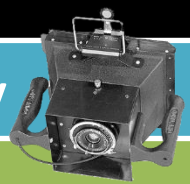


Драконъ, видимый подъ различными углами зрѣнія
По гравюрѣ на мѣди изъ „Oculus artificialis teledioptricus" Цана. 1702 года.

Evolution of Automated CRP

Late 1800s, Early 1900s

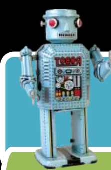
Photogrammetry



- Nonlinear
- Iterative
- Highly Accurate
- Historically manual

Bundle Adjustment

Mid 1900s



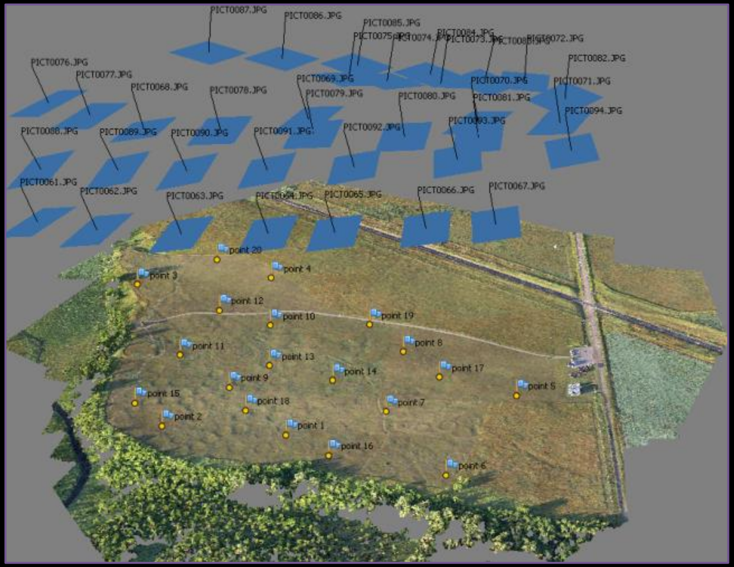
Computer Vision/SfM

- Fast
- Linear
- Approximate
- Generally Automated

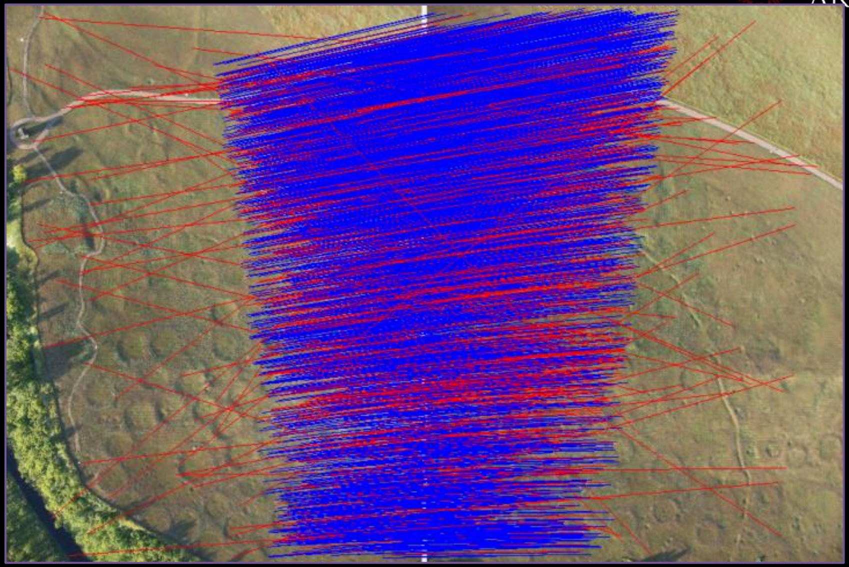
2004

SIFT algorithm

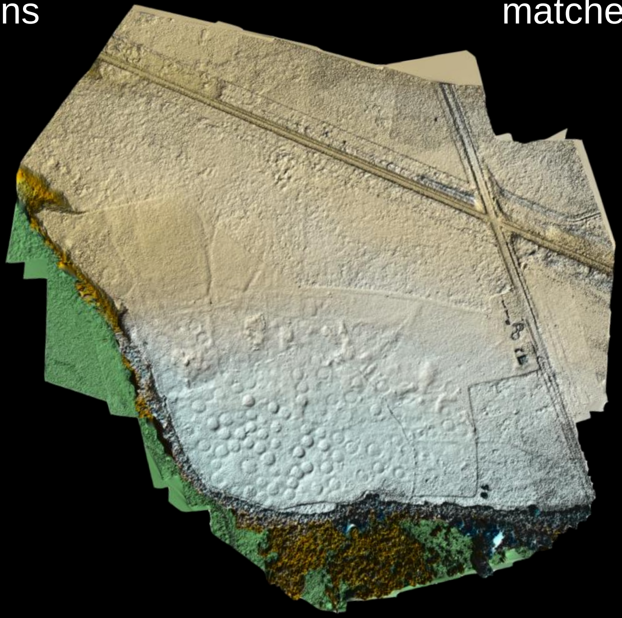
Automated Close-Range Photogrammetry



Data collection: Multiple overlapping photos from different locations



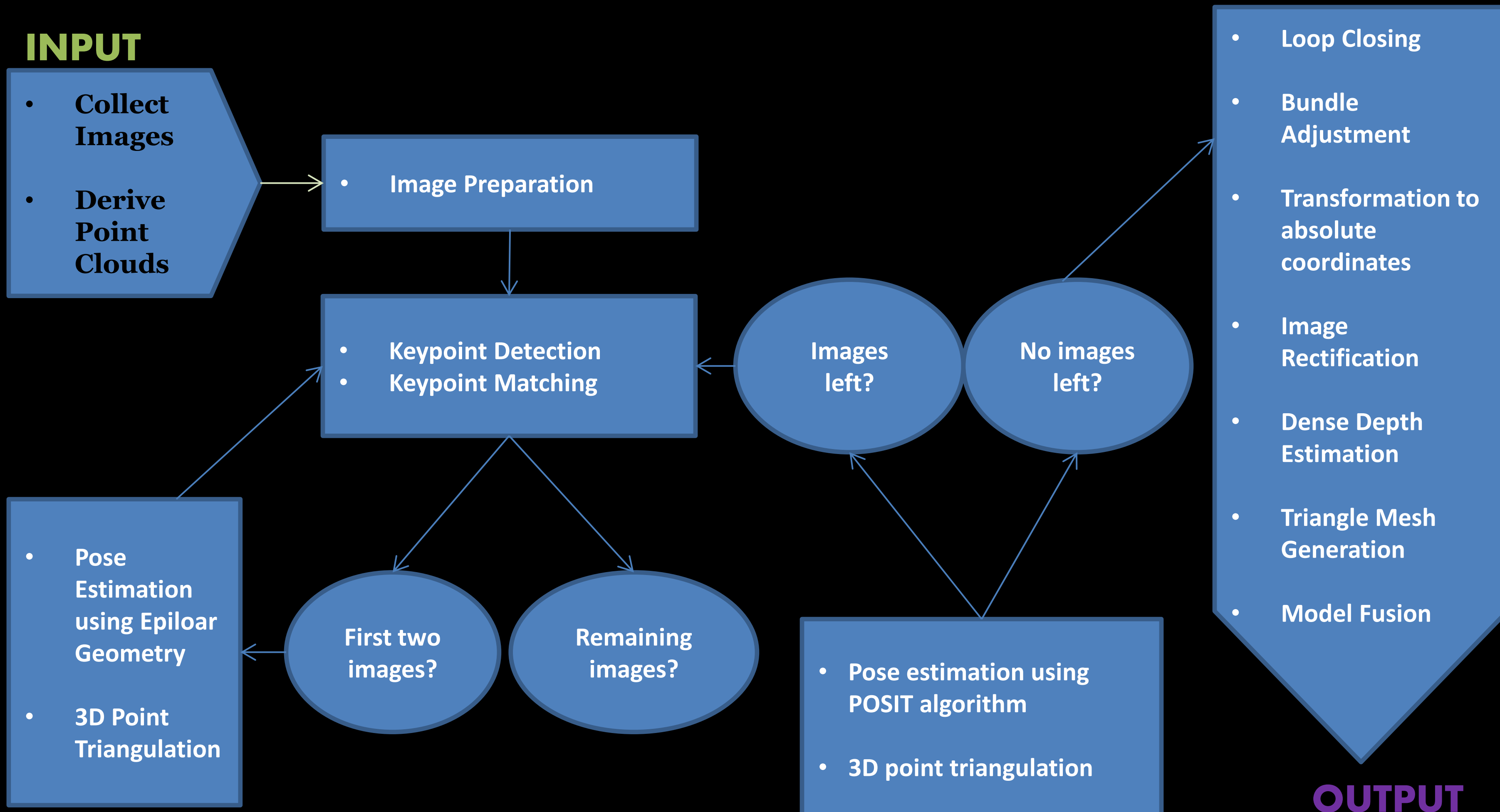
Automated feature matching: Over 2000 matches and nearly 1000 incorrect matches

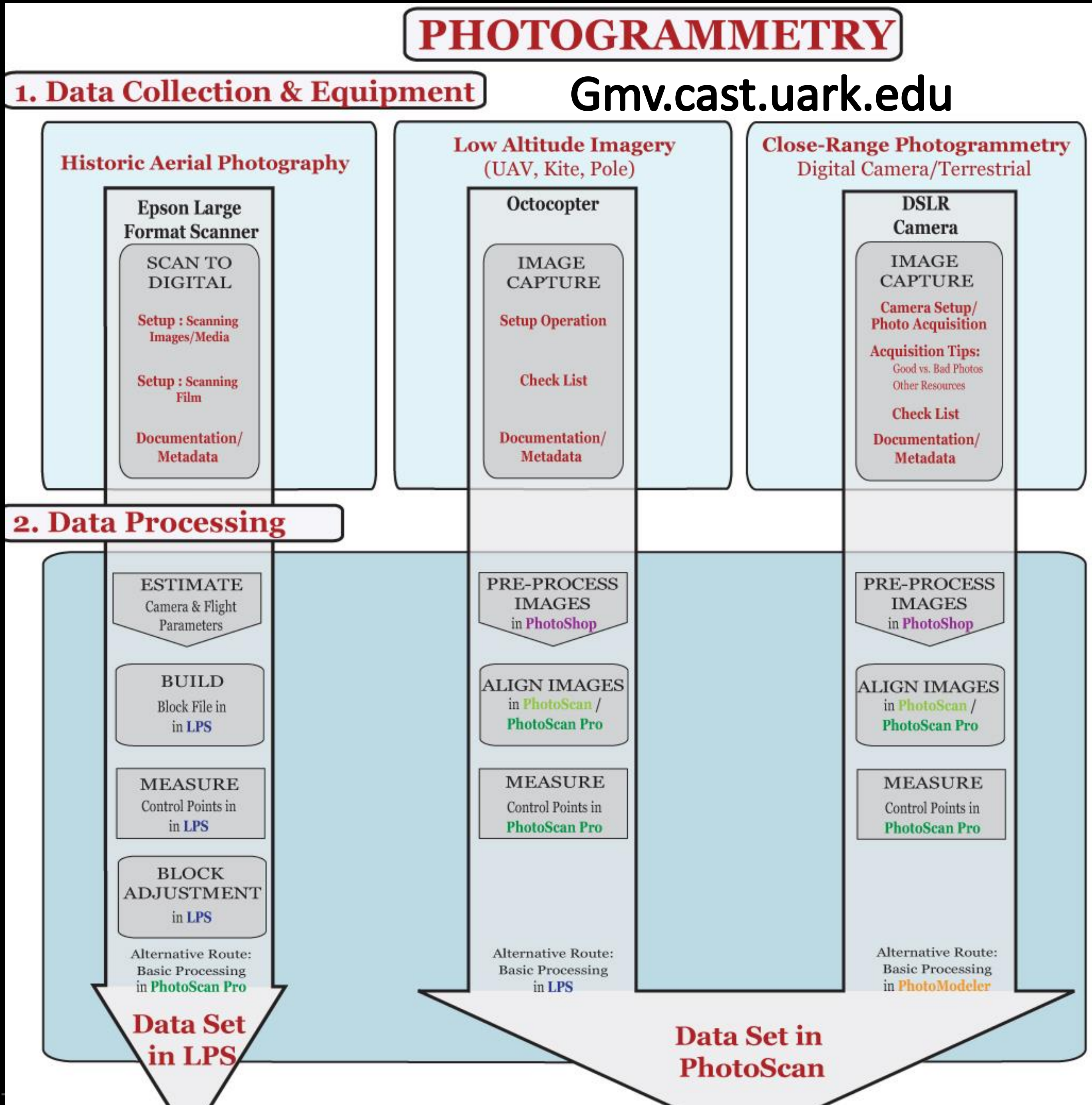


Derived interpolated surface geometry (mesh)

Automated Close-Range Photogrammetry

Many Parameters and Processing Choices





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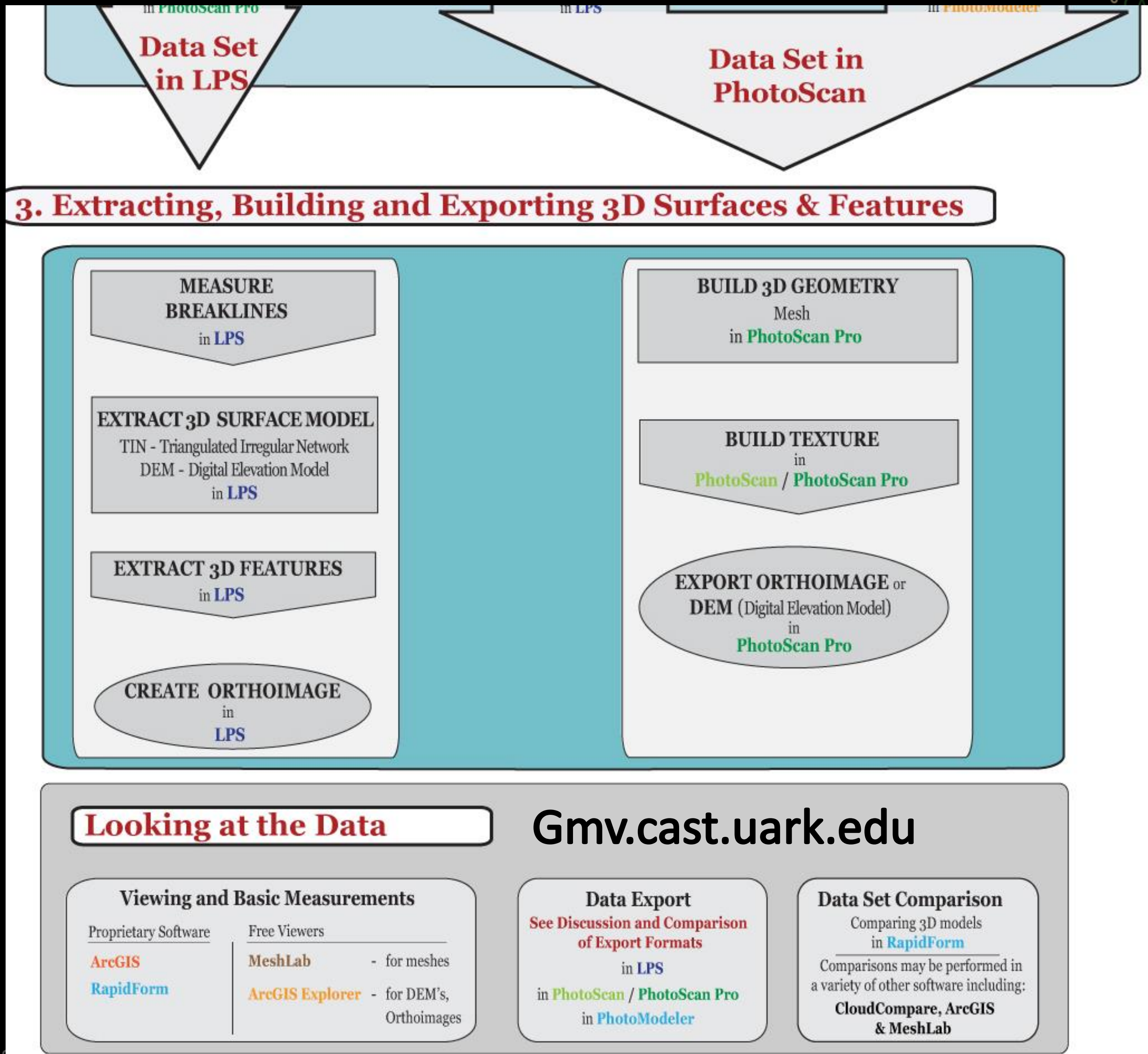

in PhotoScan Pro
Data Set in LPS
in LPS
in PhotoModeler
Data Set in PhotoScan
3. Extracting, Building and Exporting 3D Surfaces & Features
MEASURE BREAKLINES
in LPS
EXTRACT 3D SURFACE MODEL
TIN - Triangulated Irregular Network
DEM - Digital Elevation Model
in LPS
EXTRACT 3D FEATURES
in LPS
CREATE ORTHOIMAGE
in
LPS
BUILD 3D GEOMETRY
Mesh
in PhotoScan Pro
BUILD TEXTURE
in
PhotoScan / PhotoScan Pro
EXPORT ORTHOIMAGE or
DEM (Digital Elevation Model)
in
PhotoScan Pro
Looking at the Data
Gmv.cast.uark.edu
Viewing and Basic Measurements
Proprietary Software
ArcGIS
RapidForm
Free Viewers
MeshLab - for meshes
ArcGIS Explorer - for DEM's, Orthoimages
Data Export
See Discussion and Comparison of Export Formats
in LPS
in PhotoScan / PhotoScan Pro
in PhotoModeler
Data Set Comparison
Comparing 3D models
in RapidForm
Comparisons may be performed in a variety of other software including:
CloudCompare, ArcGIS & MeshLab

Typical Project Workflow

- Project Planning
  - Define project goals
  - Choose suitable equipment
    - Computer, camera, lens, tripod?
  - Complete project metadata
    - (our suggested metadata forms available at gmv.cast.uark.edu)
  - Camera calibration (automated in some software)
- Acquire Images
  - Be systematic
  - Record metadata
- Acquire External Control (optional)
  - GPS, LiDAR, Total Station, existing GIS data
  - Record metadata
- Process/Enhance Digital Images
  - Convert raw to tiff (uncompressed jpeg)
  - White balance
  - Color matching
- Photogrammetric software processing
- Create and Export Deliverables

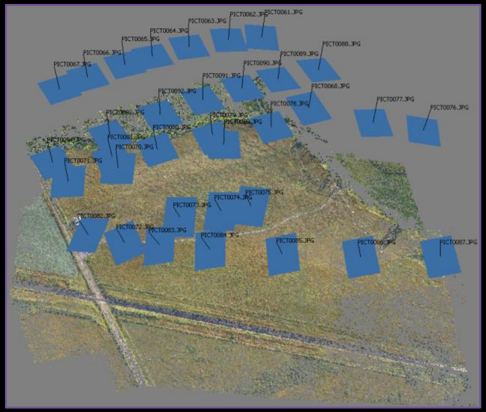
IMAGE ACQUISITION

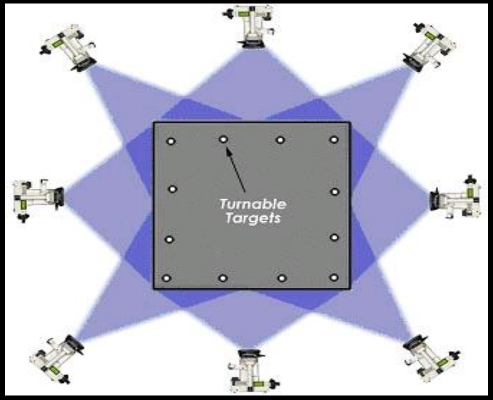
Things to avoid

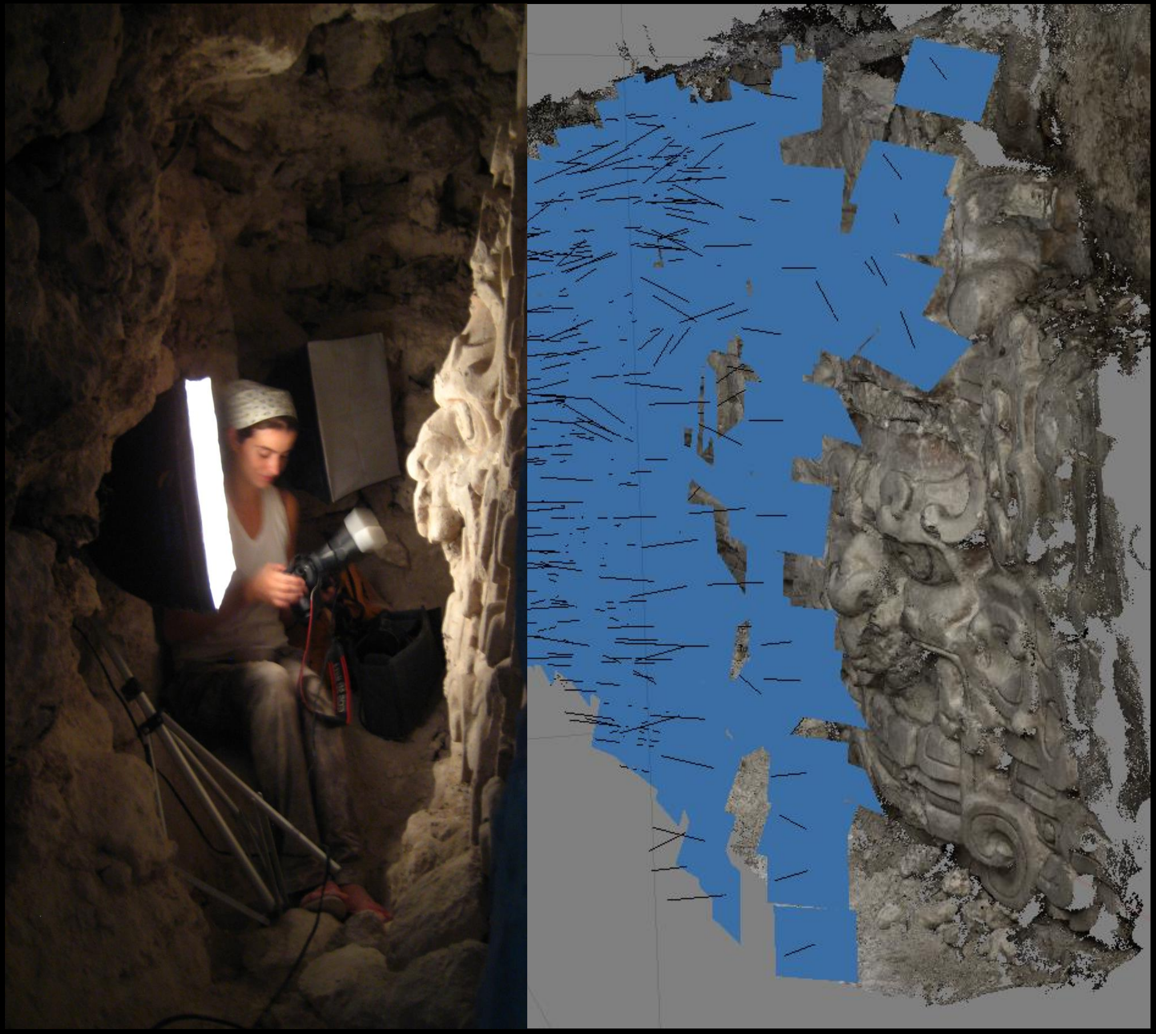
- Very dark surfaces
- Reflective surfaces
- Transparent surfaces (including water)
- Uniform textures and solid color surfaces
- Moving light sources/shadows
- Capturing your own shadow

What's necessary

- Contiguous photos with 80% overlap







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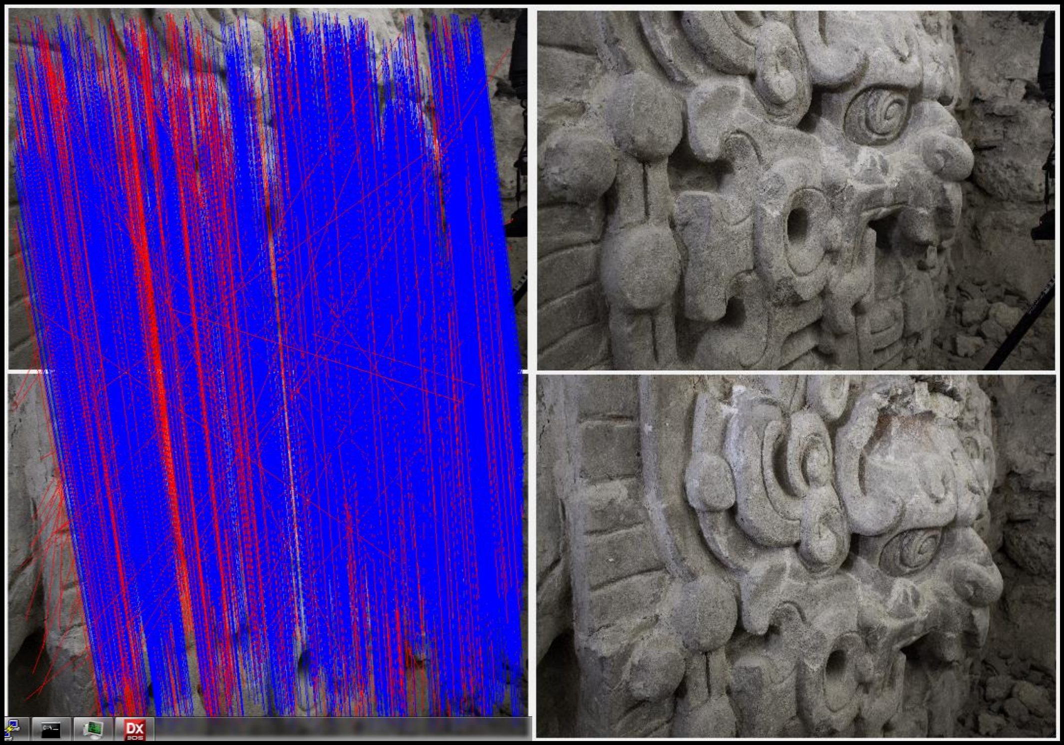
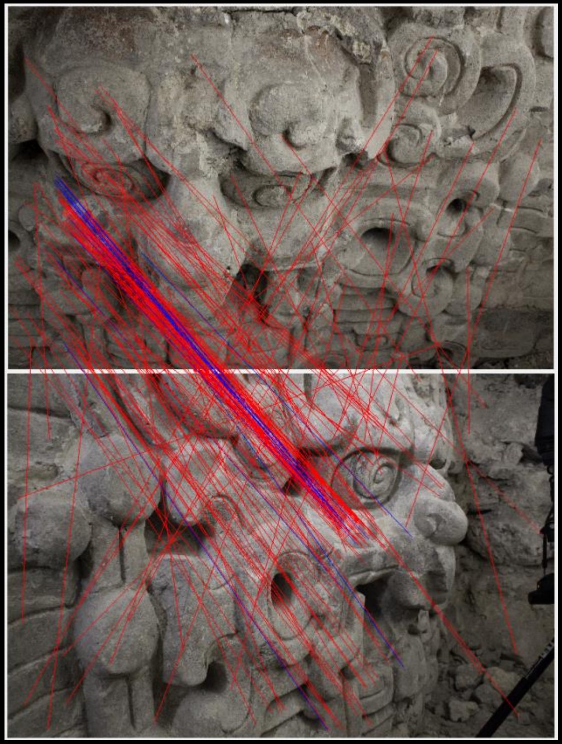


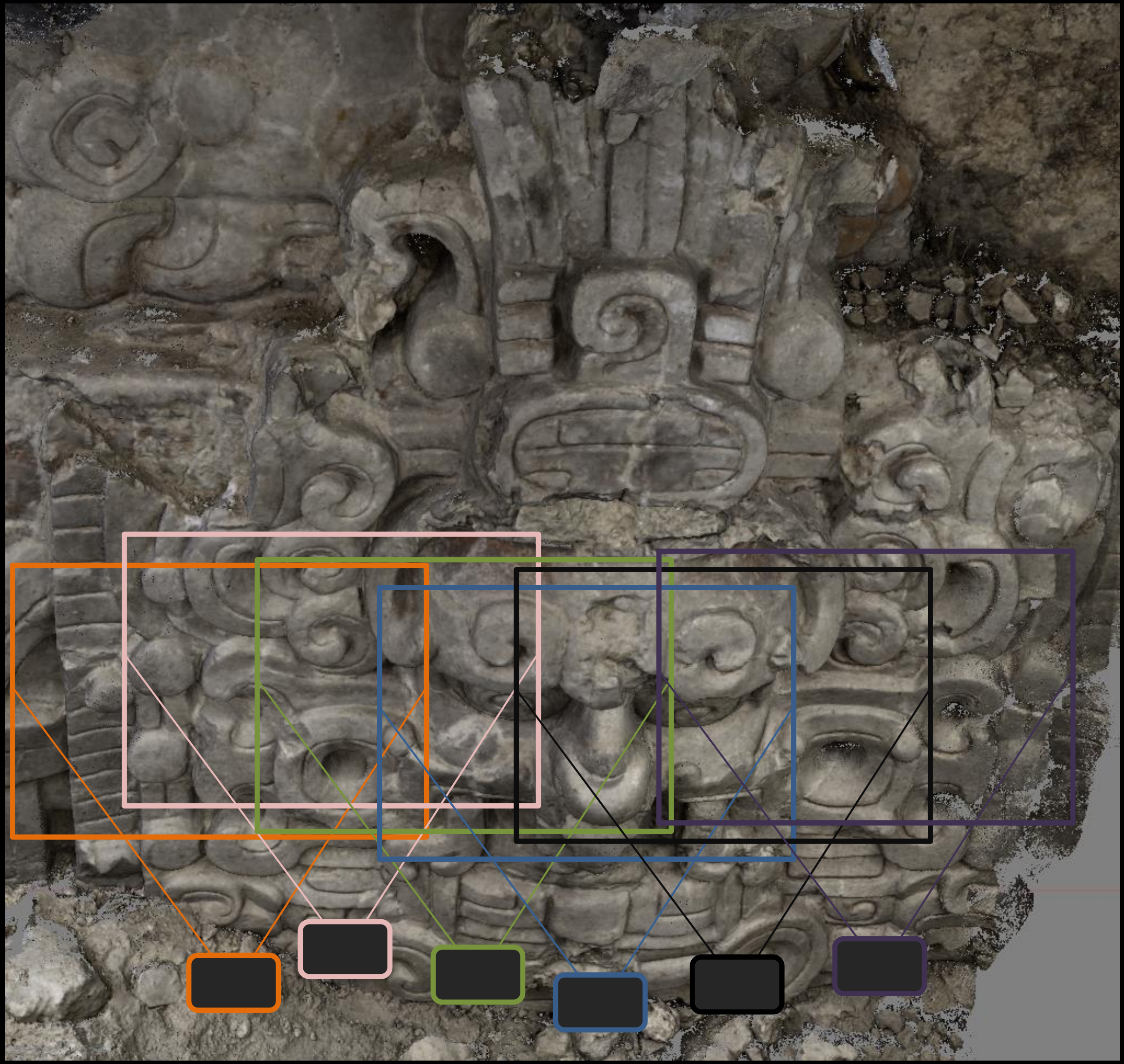
Good overlap:
3967 good matches (blue), 1525 bad (red)



Bad overlap:
16 good matches, 142 bad

What’s necessary

- Contiguous photos with 80% overlap
- Move camera between shots



What’s necessary

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- Contiguous photos with 80% overlap
- Move camera between shots
- Minimize/eliminate moving shadows
  - Static light source
  - Diffuse light

What’s necessary

- Contiguous photos with 80% overlap
- Move camera between shots
- Minimize/eliminate moving shadows
  - Static light source
  - Diffuse light

- 5+ megapixel camera
- Wider lenses (50 mm or less)
- Maximize depth of field
  - Aperture between F8 and F16
    - This varies with lens
  - Tip: use aperture priority mode
- Include scale in a few extra photos or precisely measure and record a few features
- Color checker

Will my camera work?

Metric vs Non-Metric

"A metric camera is a general term applicable to a camera which has been designed as a survey camera and possessing a well defined inner orientation. That is a camera possessing a good lens with a wide field of view and small distortion, a calibrated principal distance and in which the position of the principal point can be located in the image plane by reference to fiducial marks. The picture format is normally fairly large and the film is flattened in the focal plane at the instant of photography. Cameras not possessing these characteristics can be defined as simple or non metric Cameras."

- Adams, L.P., 1980. *The Use of Non Metric Cameras in Short Range Photogrammetry*. 14th Congress of the International Society for Photogrammetry, Commission V, Hamburg, Germany.

It is around this time (1980) that non-metric cameras were established as a suitable tool for close-range photogrammetry, and that the accuracy of projects using non-metric cameras could equal those using metric cameras.

- Karara, H.M., and W. Faig, 1980. An Expose on Photographic Data Aquisition Systems in Close-Range Photogrammetry. 14th Congress of the International Society for Photogrammetry, Commission V, Hamburg, Germany.

Will my camera work?

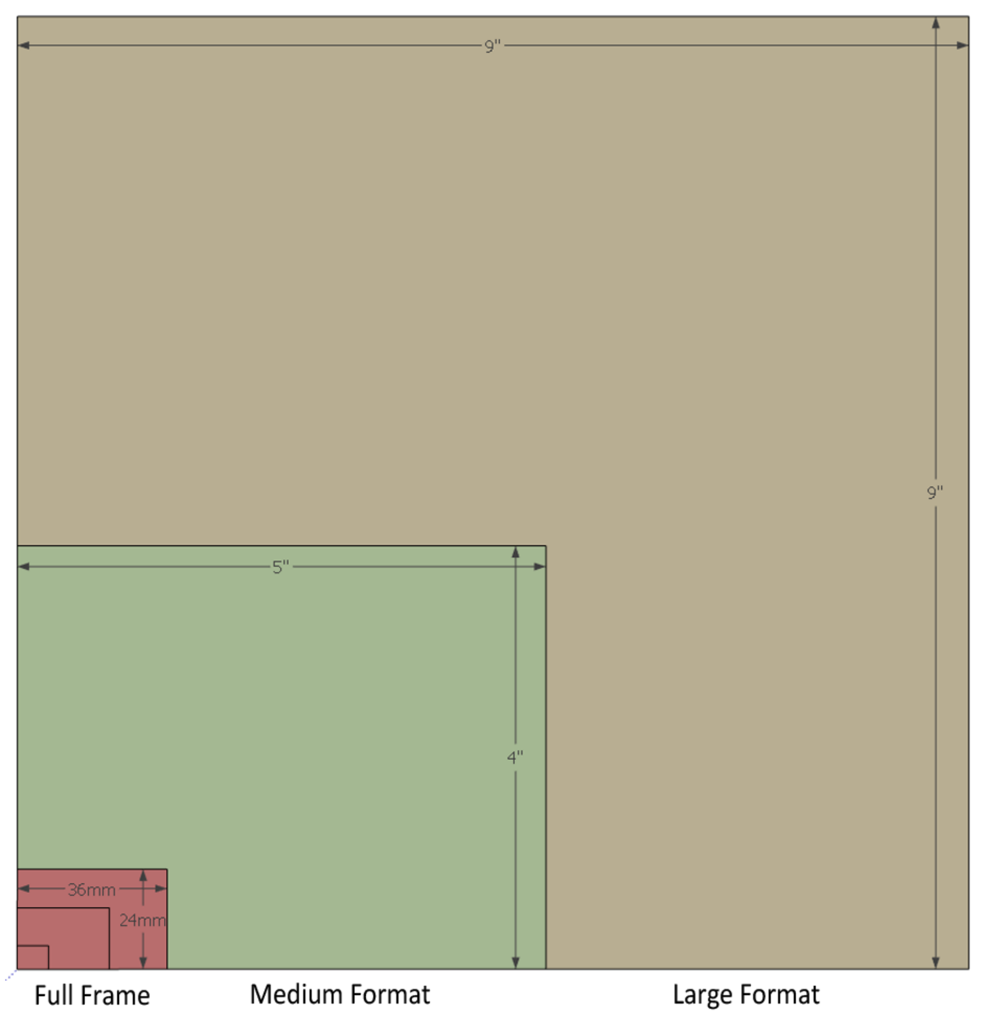
- Things to consider:
    - Image resolution (pixel count) – More is typically better, but only if the sensor size is reasonable.
    - Sensor size – Larger is typically better, but with good conditions a small sensor can do well. **Ideally, your camera sensor will be APS-C (crop factor of 1.6) or bigger, and be 8 MP or higher.**
    - Access to camera parameters – Manually setting the aperture size, shutter speed, and ISO will allow you to control the depth of field and exposure of each image. By maximizing the depth of field, objects both near and far will be "sharp" and can be more accurately measured.
    - Focus of lens – Ideally you can set the focus to manual, so the camera does not autofocus for each image.
    - Image format – can you save images to TIFF or uncompressed JPEG format?
    - Use with accessories – can the camera be mounted to a tripod? Remote shutter release? Flash/strobe compatible?
    - Lens distortion – wide angle lenses are best. For full frame DSLR cameras, a 20-28mm fixed focal length lens is ideal. For cropped sensors you'll need to calculate the equivalent (e.g. a crop factor of 1.6 would need an 18mm lens (1.6 * 18 = 28)). Fish eye lenses (e.g. GoPro) have too much distortion.
    - Rolling shutters – inexpensive cameras (e.g. iPhone camera) can have an electronic rolling shutter, meaning the sensor is not globally exposed. Rather, each line is exposed consecutively from one side to the other. This type of exposure is not modeled by most photogrammetric software and will normally fail.
    - EXIF information – Though not 100% necessary if you already know the specs of your camera (or have your camera calibrated), EXIF data should be preserved. This is used by most photogrammetric software to extract initial camera parameters (i.e. focal length, sensor width/height) and GPS coordinates if available.
    - Digital and/or optical zoom – Do not use digital zoom. If your camera has an optical zoom, set this at the beginning of the project and do not adjust. Literally tapping the zoom ring of the lens is a good idea.
    - Image stabilization – Turn off any image stabilization. If your camera has this feature and you cannot turn it off, you can likely expect poor results.

Format Size

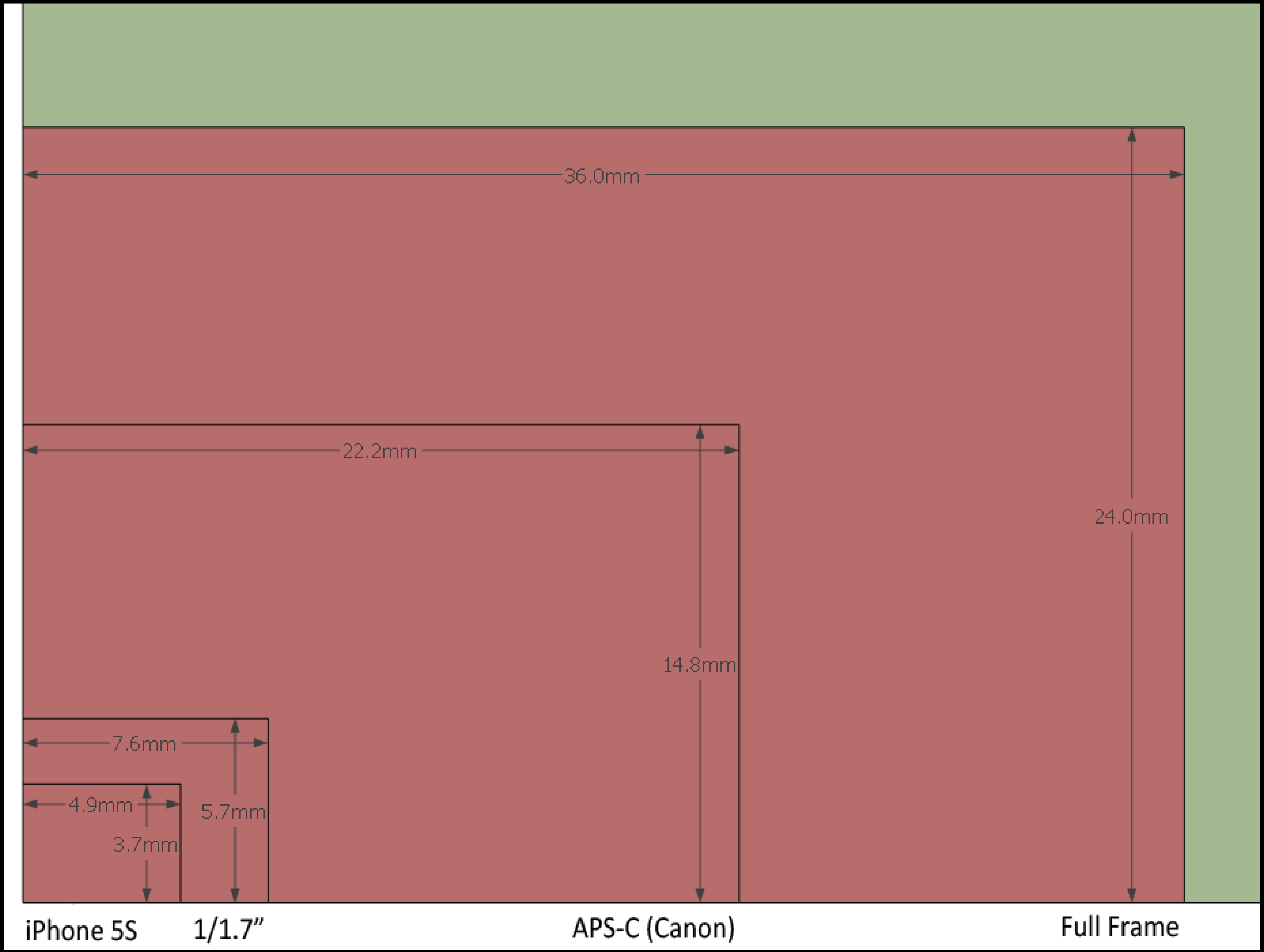
- Large format
  - Digital e.g.: Intergraph DMC II250, 17216 x 14656 pixels (250 MP), 112mm focal length
    - 2.5cm GSD@500m (392x366m)
  - Analogue camera parameters:
    - Square sensor, 9 x 9 inch, 150mm or 300mm focal length
    - Typically 100 line pairs/mm optical resolution (2540 line pairs/inch)
    - Scanned at 12.5 microns (2100 dpi), will produce a 330 MP image. At 20 microns, will produce a 130 MP image.
  - Leica ADS40, Vexcel UltraCam

- Medium format
  - Intergraph RMK D, 5760 x 6400 pixels (37 MP), 45mm focal length
    - 8cm GSD@500m (460x512m)

- Small format
  - All "full frame", 35mm equivalent DSLRs (Canon 5D 22MP, Nikon D800 36MP)
    - 6.5cm GSD@500m (365x243m)
  - All "cropped frame" DSLRs (Canon APS-C, Nikon DX)
  - Also all point-and-shoot or compact cameras



Format Size



36.0mm
24.0mm
22.2mm
14.8mm
7.6mm
5.7mm
4.9mm
3.7mm
iPhone 5S
1/1.7”
APS-C (Canon)
Full Frame

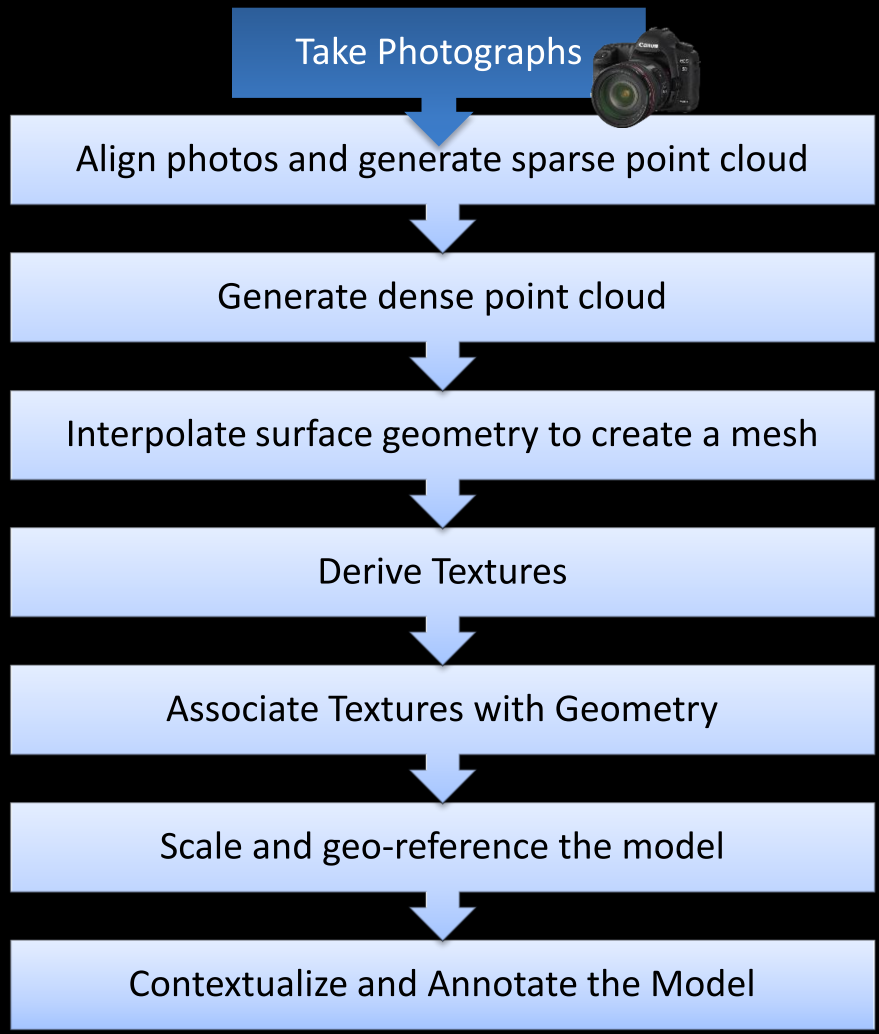
Final model resolution

A function of pixel size, lens focal length, working distance

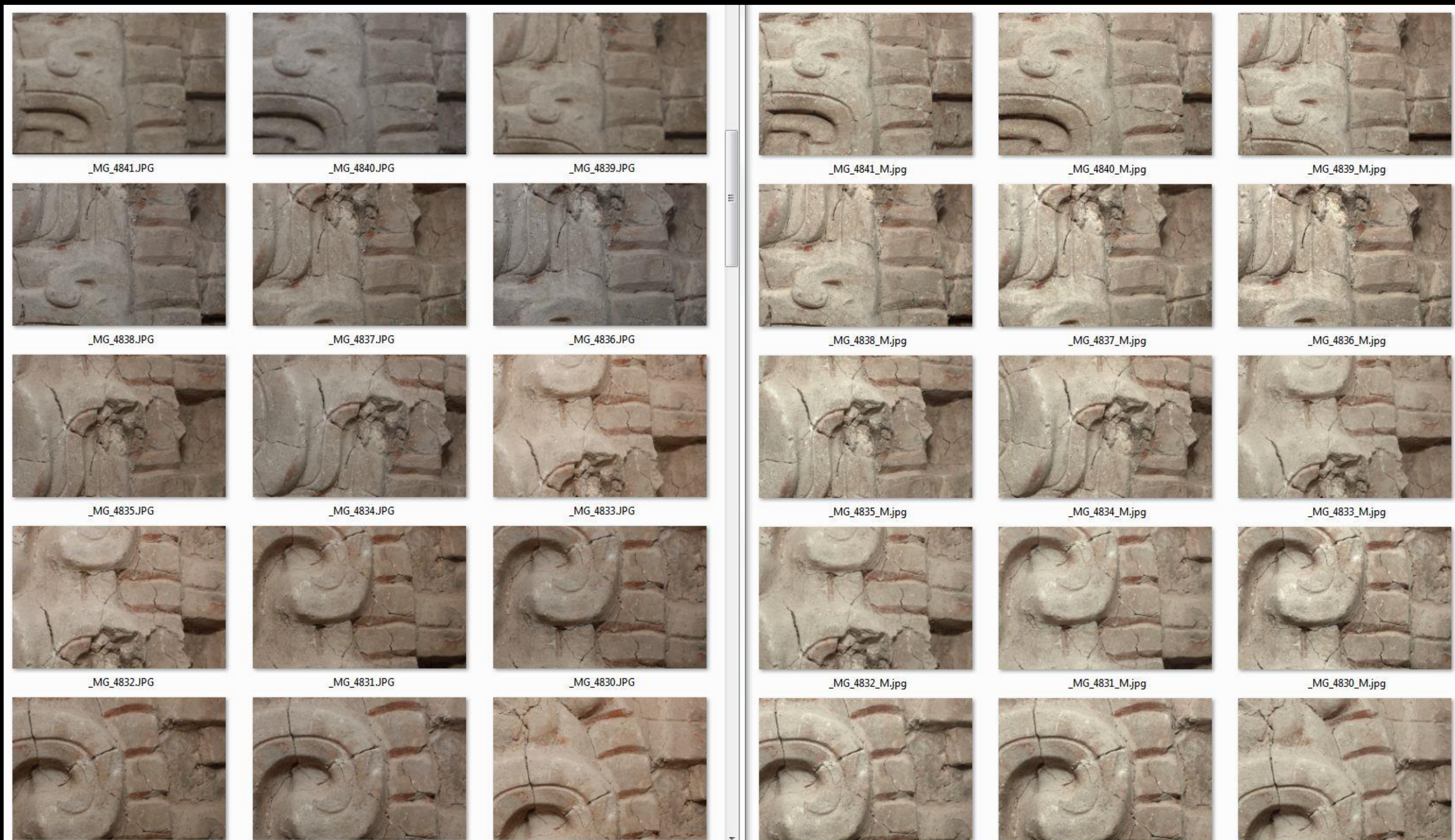
	Canon 5D Mk II Full Fram, 22MP, 6.5um		Canon 70D 1.6x crop, 21MP, 4.1um		Nikon Coolpix P330 4.55x crop, 12MP, 1.9um	
	28mm	50mm	18mm	30mm	6mm	11mm
Distance (m)	Pixel size (cm)					
1	0.02	0.01	0.02	0.01	0.03	0.02
5	0.12	0.07	0.11	0.07	0.16	0.08
10	0.23	0.13	0.22	0.14	0.31	0.17
20	0.46	0.26	0.46	0.27	0.62	0.34
50	1.16	0.65	1.14	0.69	1.55	0.85
100	2.32	1.30	2.28	1.37	3.10	1.69
200	4.64	2.60	4.57	2.74	6.20	3.38

DATA PROCESSING

Basic processing pipeline

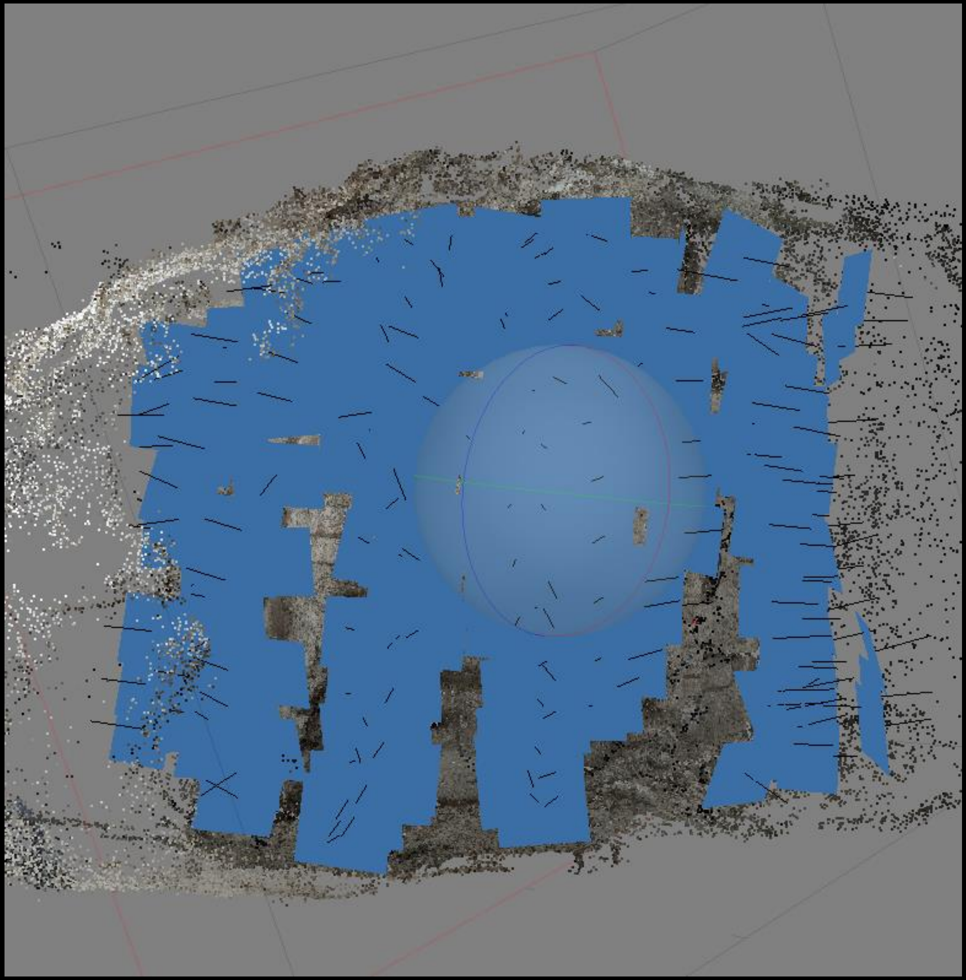


Pre-processing color match and white balance



Initial photo alignment

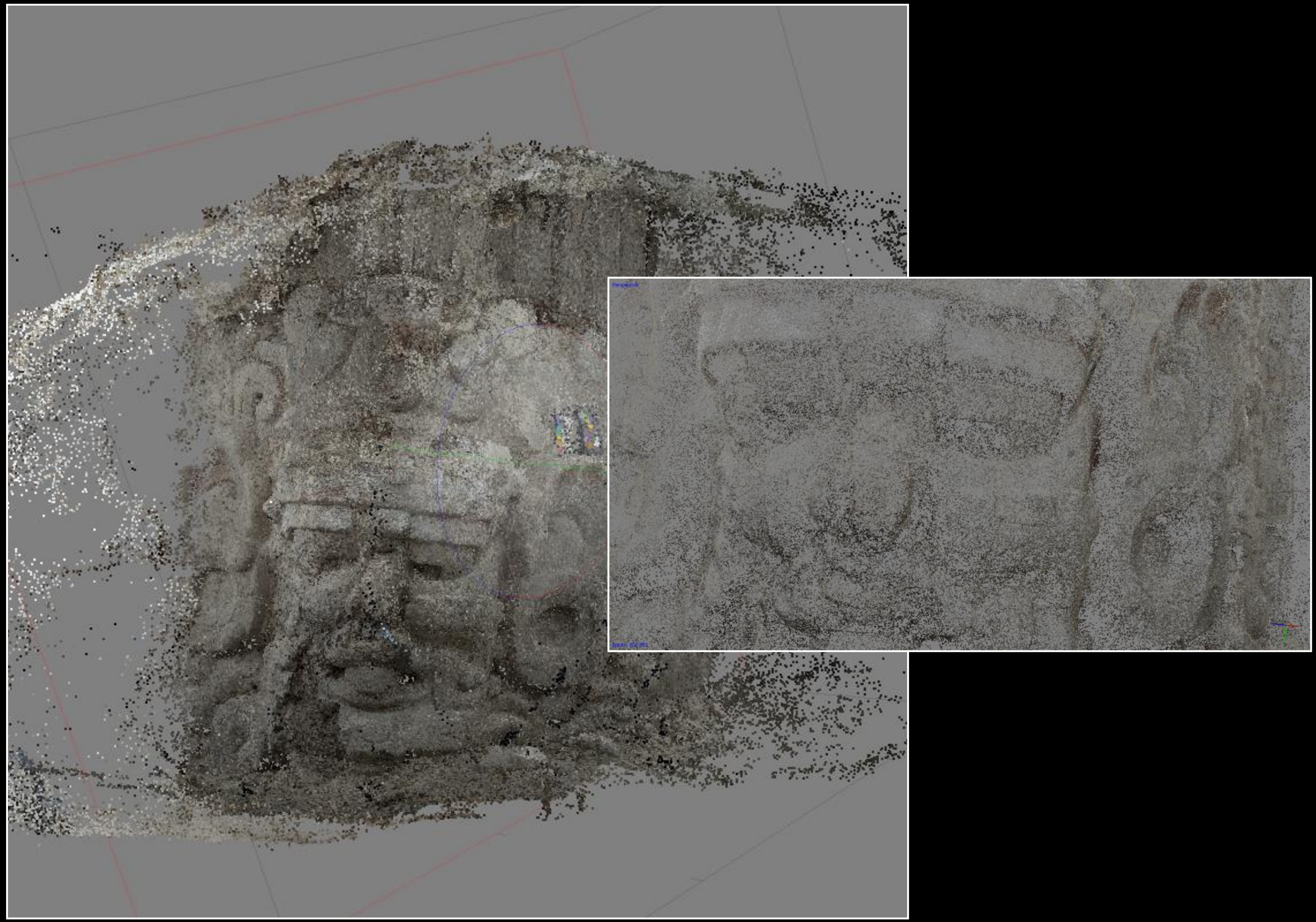
Match points (SIFT features) between photos



186 photos from Canon 5D MarkII

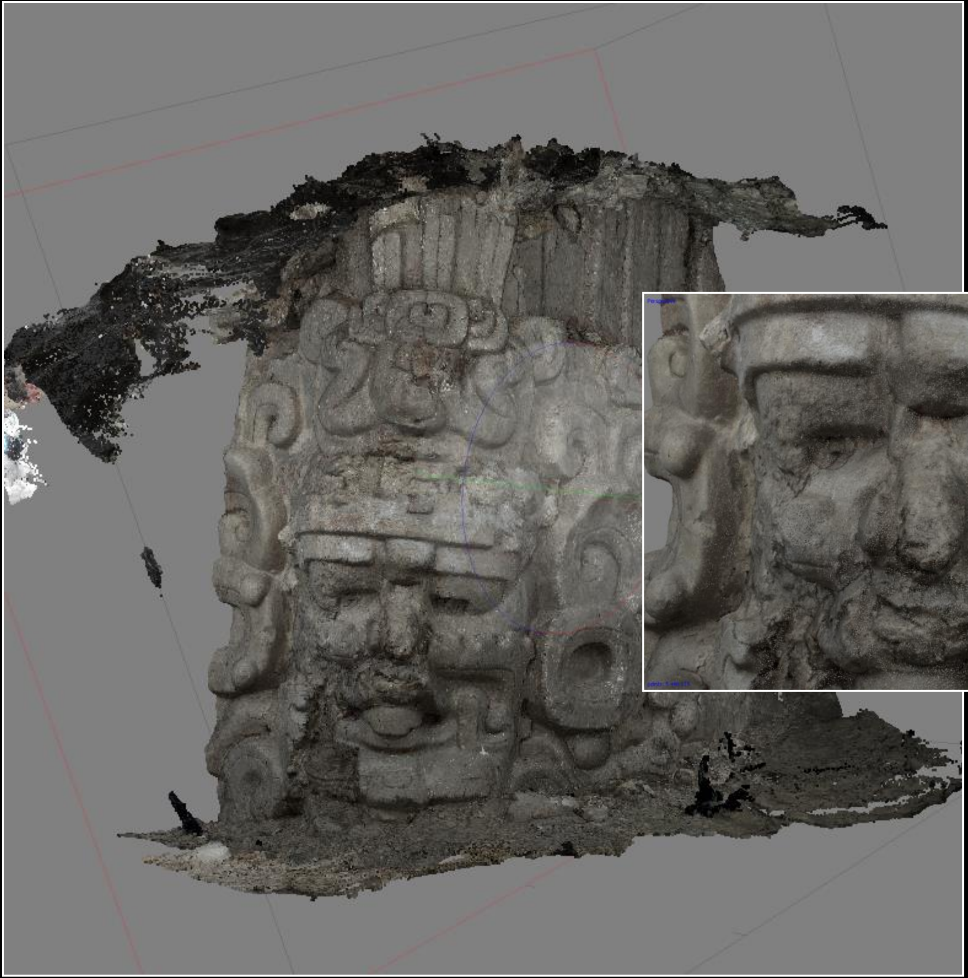
Sparse point cloud

3D reconstruction from match points



Dense point cloud

Reconstruction from sparse point cloud

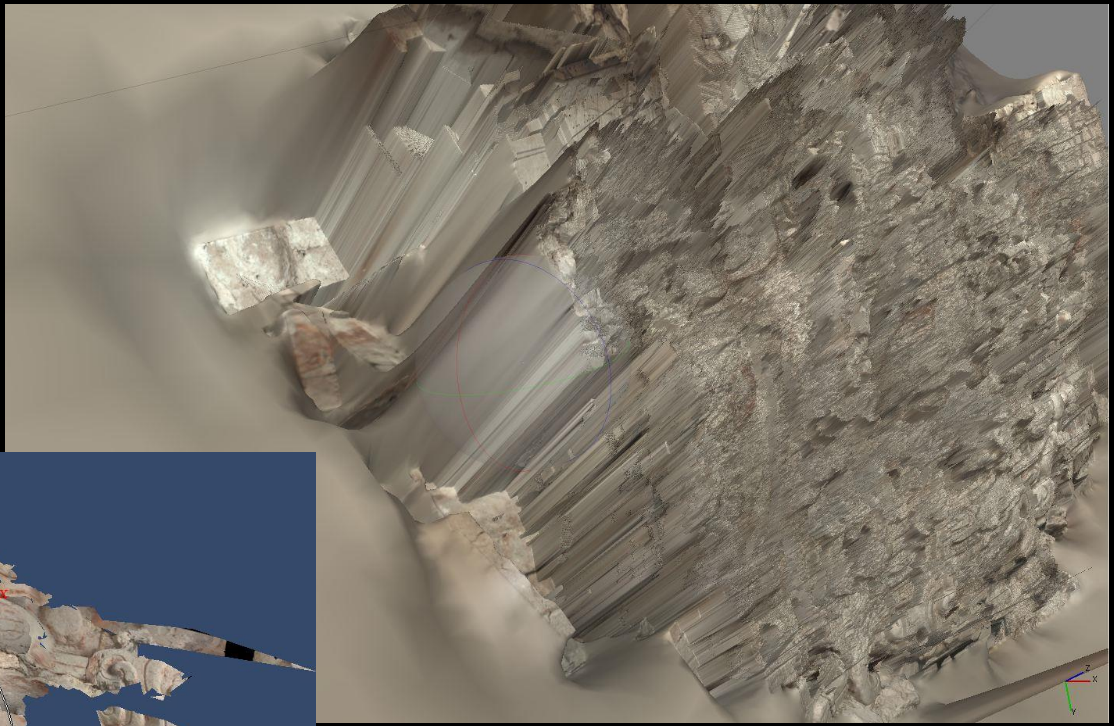


801,883 points

Meshed Polygonal Model
(interpolated surface geometry)

12,059,870 faces, 6,036,297 vertices

Bad photos and unfortunate processing



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Some examples of the increasing number of software solutions to process close range data

- Agisoft's PhotoScan and PhotoScan Pro
- Photomodeler and Photomodeler Scanner
- Visual SFM
- Mic-Mac and Apero
- 3DF Zephyr
- 123D Catch
- Python Photogrammetry Toolbox

  (and PPT GUI)
- SFM Toolkit
- Arc3D
- 3DM Analyst
- My3D Scanner
- Cubify Capture
- Insight 3D
- Pix4D
- Trimble's Inpho
- LPS
- BINGO for SOCET SET

Data Processing Considerations

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Naïve Processing

- Default/Blackbox processing
- Easier results for visualization
- Quick results

123D Catch

Visual SFM

PhotoModeler

Scanner

Photoscan

Rigorous parameter selection

- Goal and project specific pipeline
- More metrically reliable
- Time and computation intensive

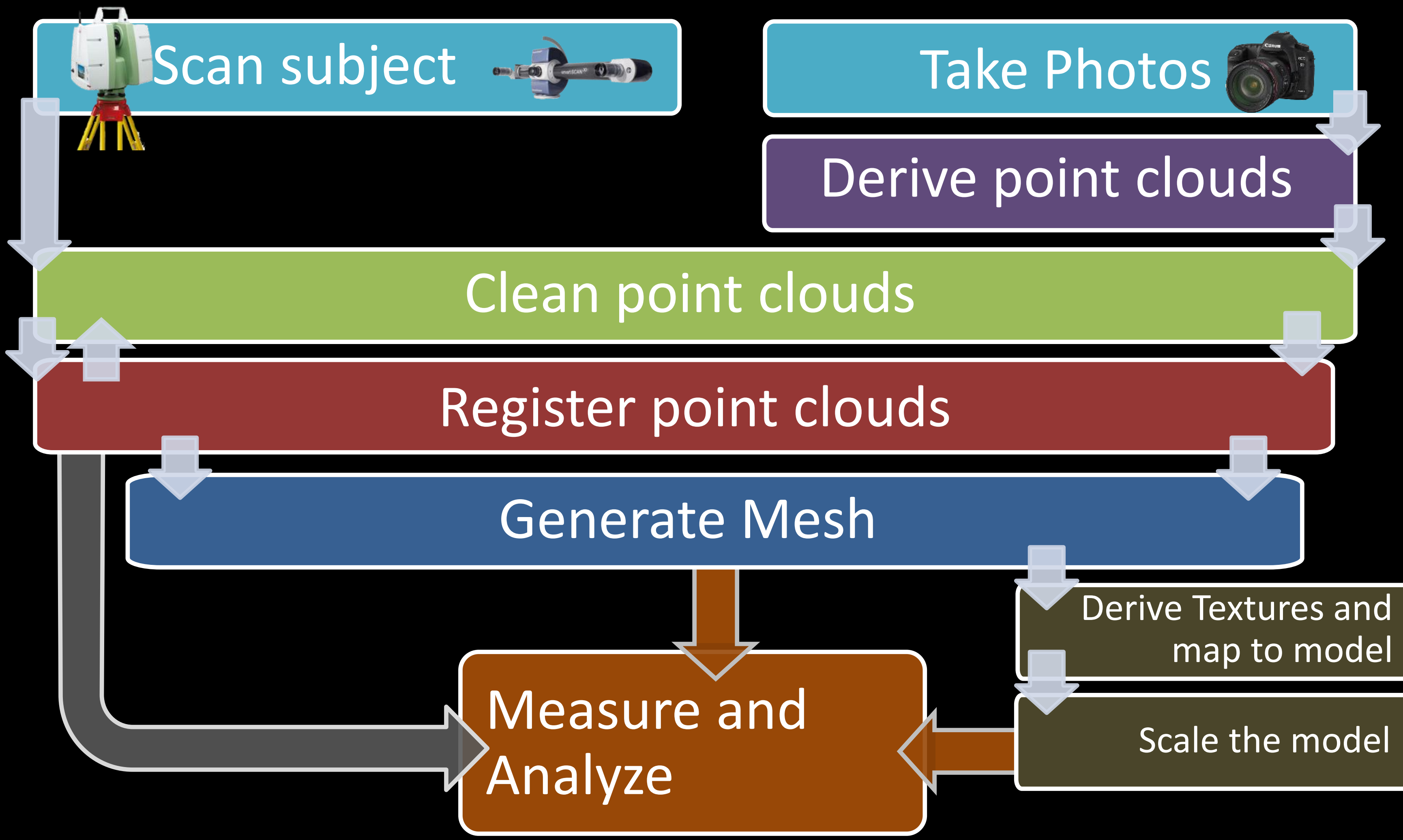
Most Common Software Comparison

	Pros	Cons
Visual SFM	• Good point matching algorithm • No *a priori* camera calibration • Focus can be adjusted • Allows multiple focal lengths • Free • Allows for ground control points	• Significant distortion possible • Processing intensive • No friendly option for measuring scale only • GCPs = 3D transformation only (no self calibration) • Must export to another software for mesh generation (e.g. Meshlab)
PhotoScan (Agisoft)	• Good point matching algorithm • No *a priori* camera calibration • Focus can be adjusted • Allows multiple focal lengths • Extremely detailed models • Local processing (more control) • Good parameter control relative to 123D Catch • Detailed reporting/logs	• Processing intensive • Memory intensive 12+ gb • Less parameter control relative to *PhotoModeler Scanner*
PhotoModeler Scanner	• Detailed reporting and logs • Best parameter control • Customizable processing • Local Processing	• Fixed focus required • A priori camera calibration required • Matching algorithm is dated • Time consuming with more manual intervention

HOW ACCURATE IS IT?
SOFTWARE COMPARISONS

With high precision 3D scanner model comparisons

General 3D Data Pipeline



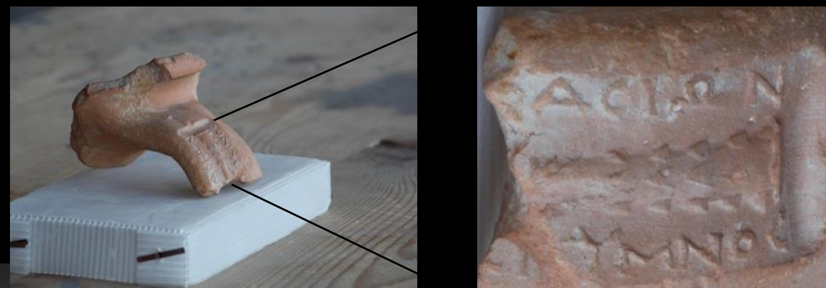
		Breuckmann Scanning 	Close-Range Photogrammetry 
Data Capture	Environmental Conditions	Requires low light and external power source (such as generator) **Must scan at night when outdoors.**	Works best with diffuse light. A sheet to minimize strong shadows may be necessary
	Field Time	8 hrs = 1 x 2 m area at 0.06 mm resolution 2 x 2 m area at 0.15 mm resolution	MUCH faster than the Breuckmann (Actual time depends on resolution)
	Data Depth	Up to 6 cm at 0.06 mm resolution 23 cm at 0.15 mm resolution	Infinity
	Problematic Surfaces	Dark and/or shiny surfaces. Glass is impossible.	Flat surfaces that are monochrome or have repetitive patterns
	Basic Processing Time	1/8 to 1/4 of the field time if no noise: e.g. 1-2 processing hours for 8 field hours	5 - 20 x's longer than field time
	Project Goals	Metric precision and analysis of fine features not measurable with calipers	Limited field time

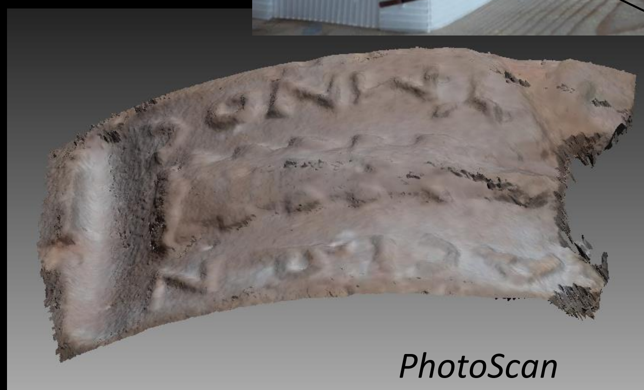
Case Example:

AMPHORA STAMP
ANCIENT ATHENIAN AGORA

In collaboration with the American School of Classical Studies, Athens

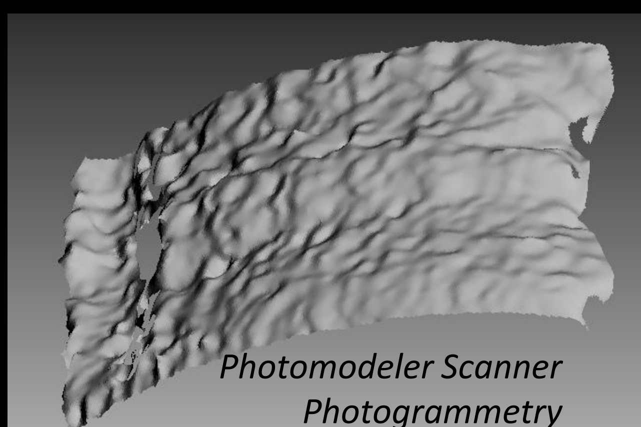
Amphora stamp





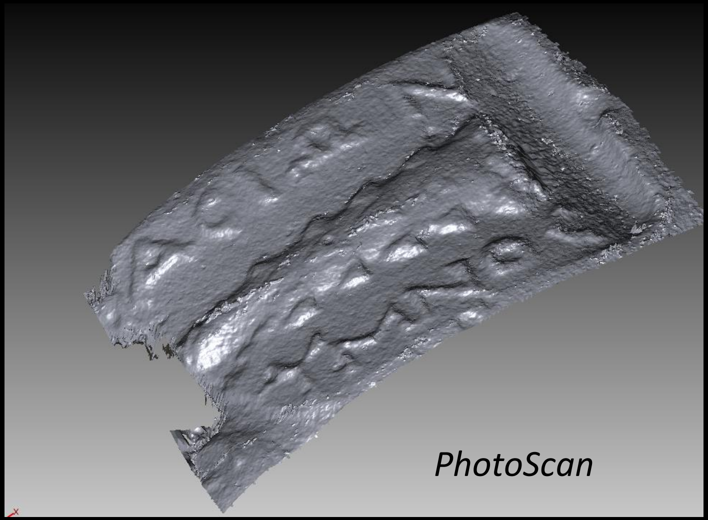
PhotoScan

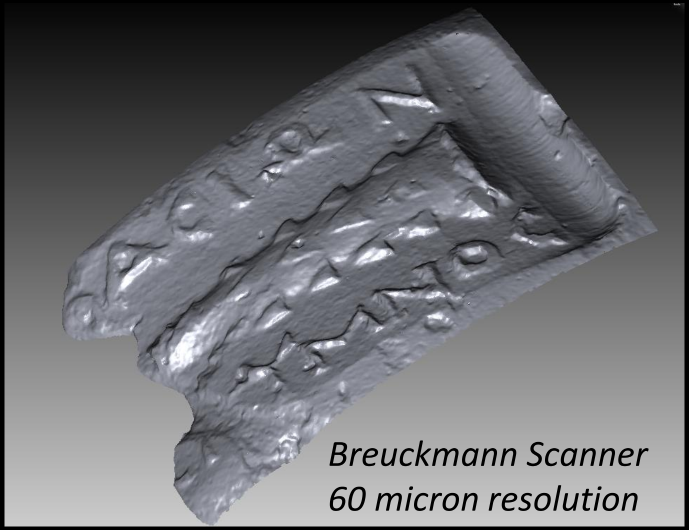
Breuckmann Scanner
60 micron resolution

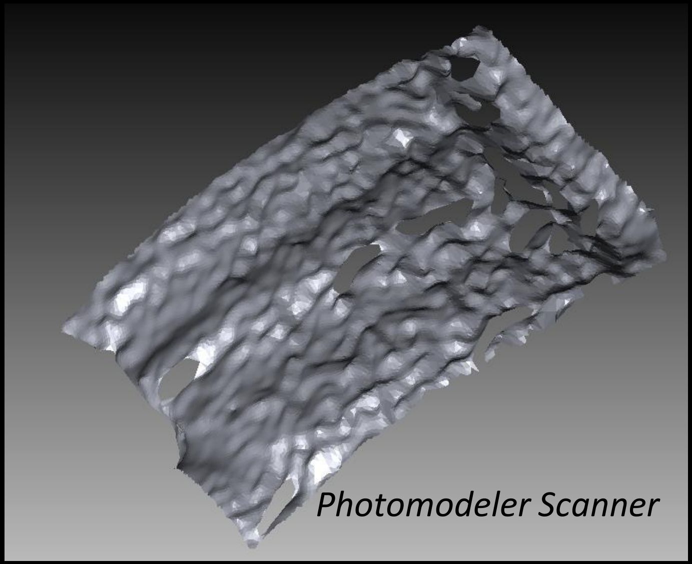


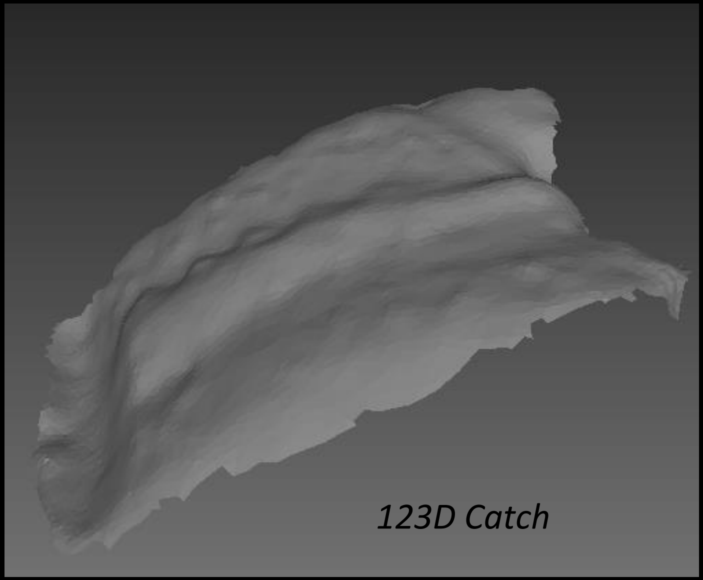
Photomodeler Scanner
Photogrammetry

123D Catch

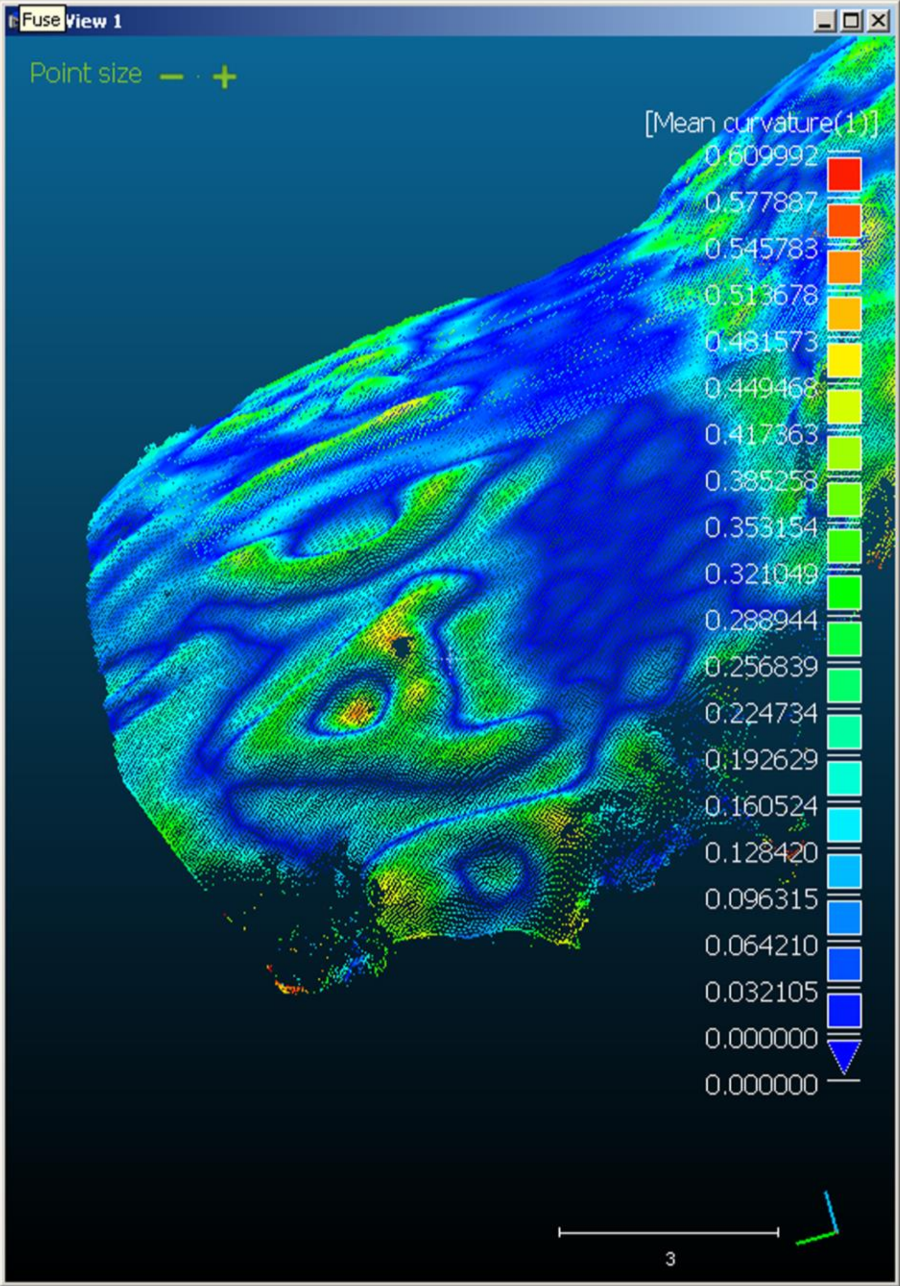

PhotoScan

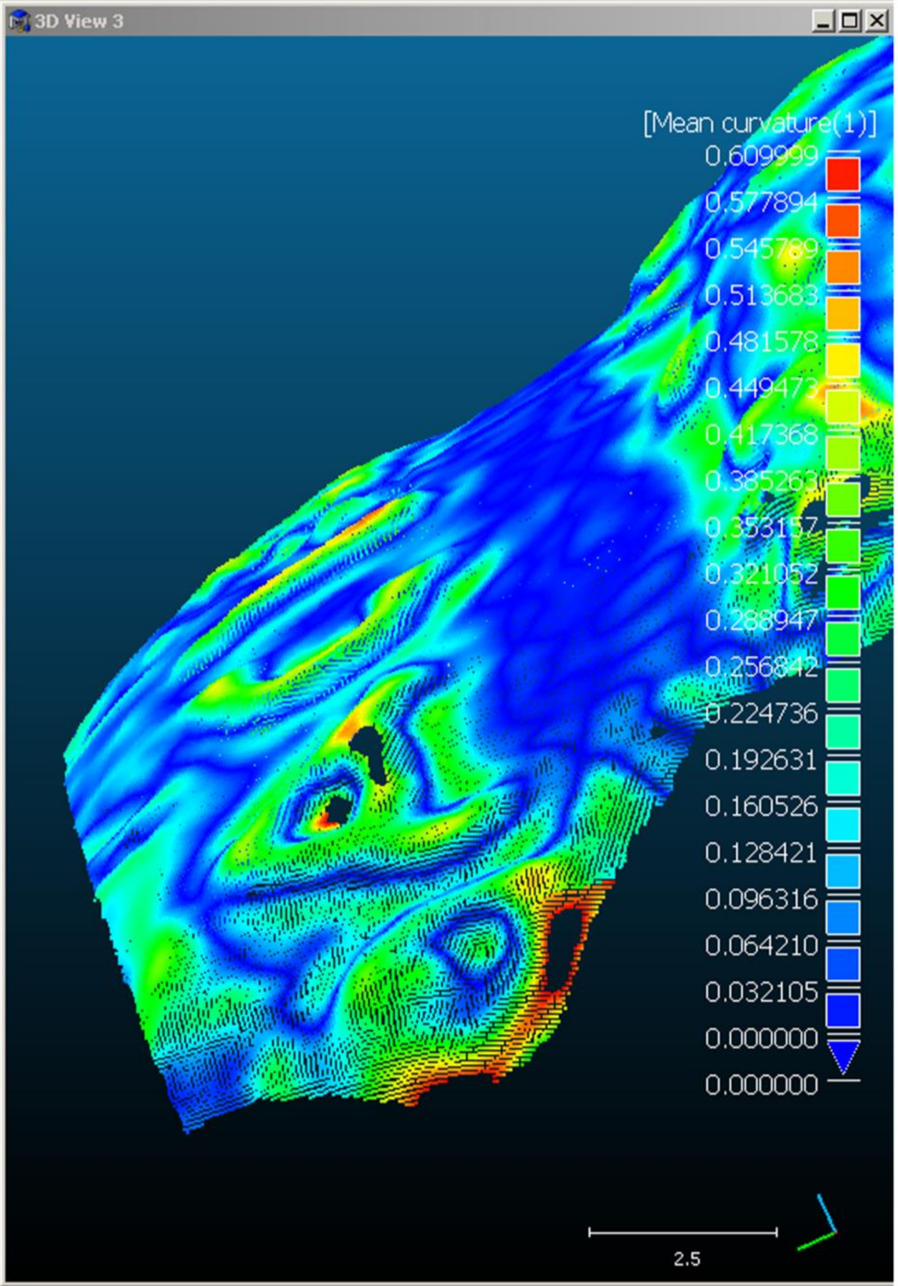

Breuckmann Scanner
60 micron resolution


Photomodeler Scanner

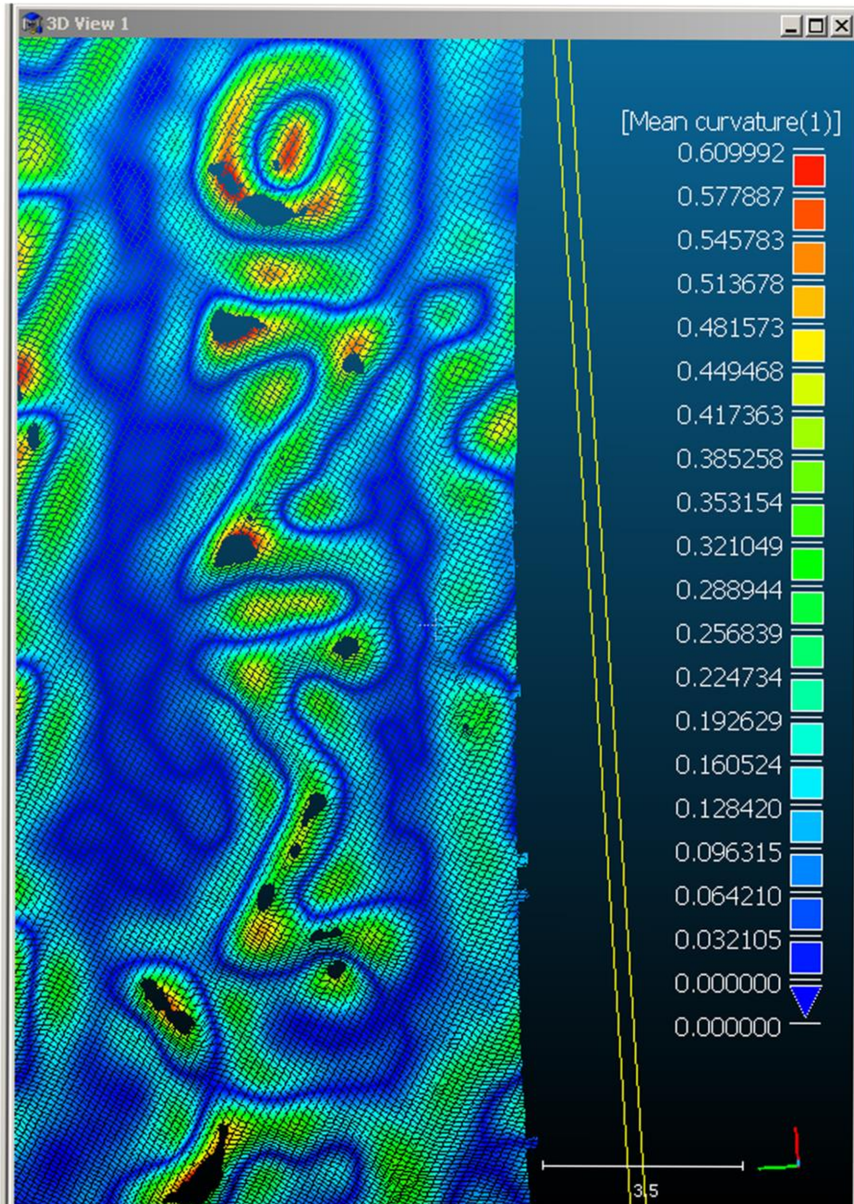

123D Catch

Photoscan *Breuckmann*

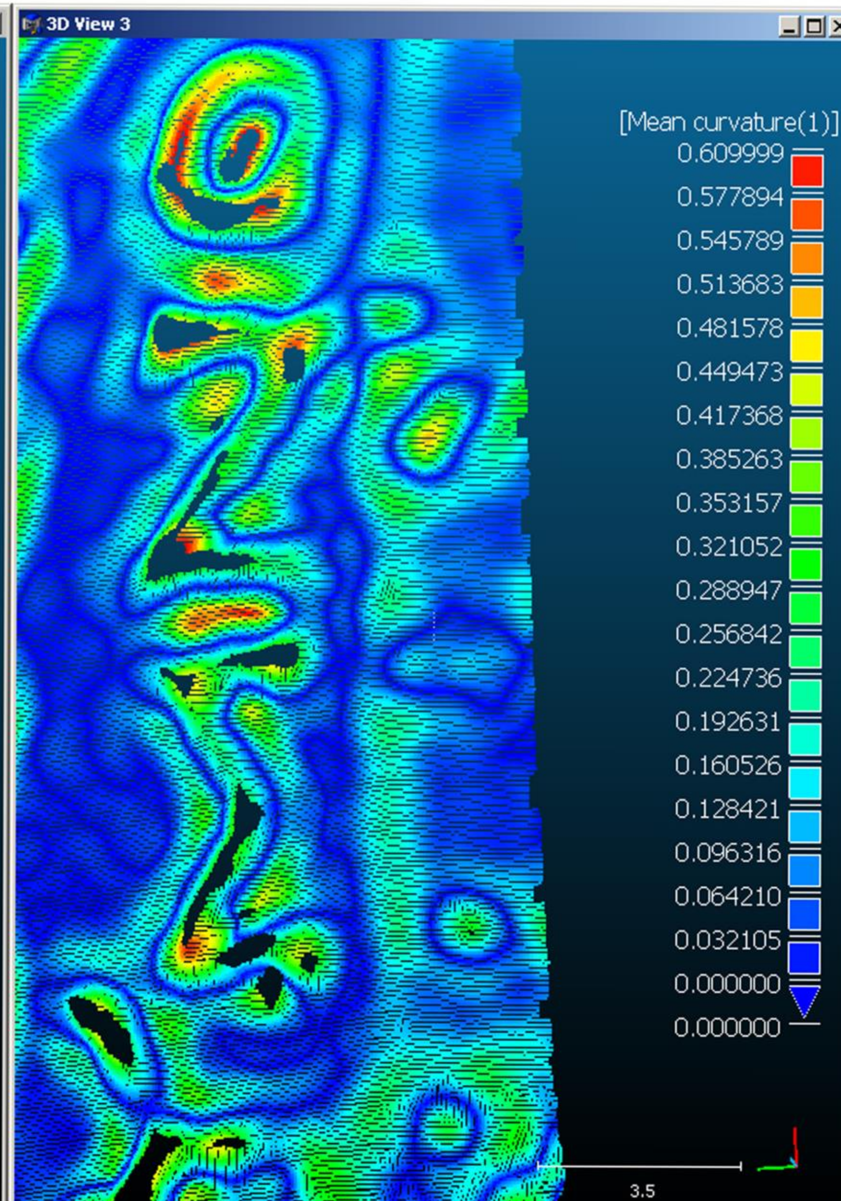




Photoscan



Breuckmann

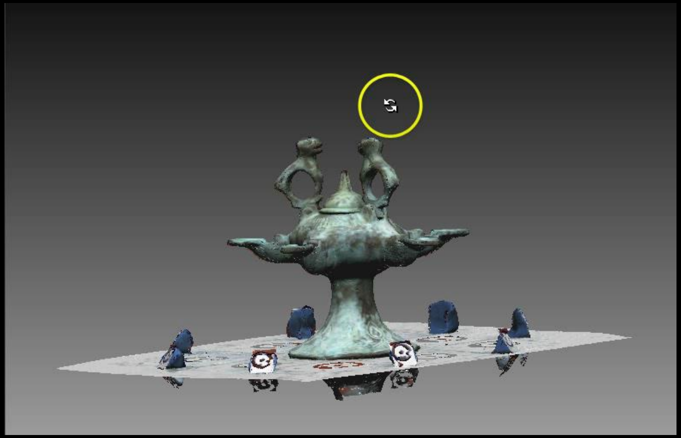


Object Models

Breuckmann vs. Photogrammetry

Photo

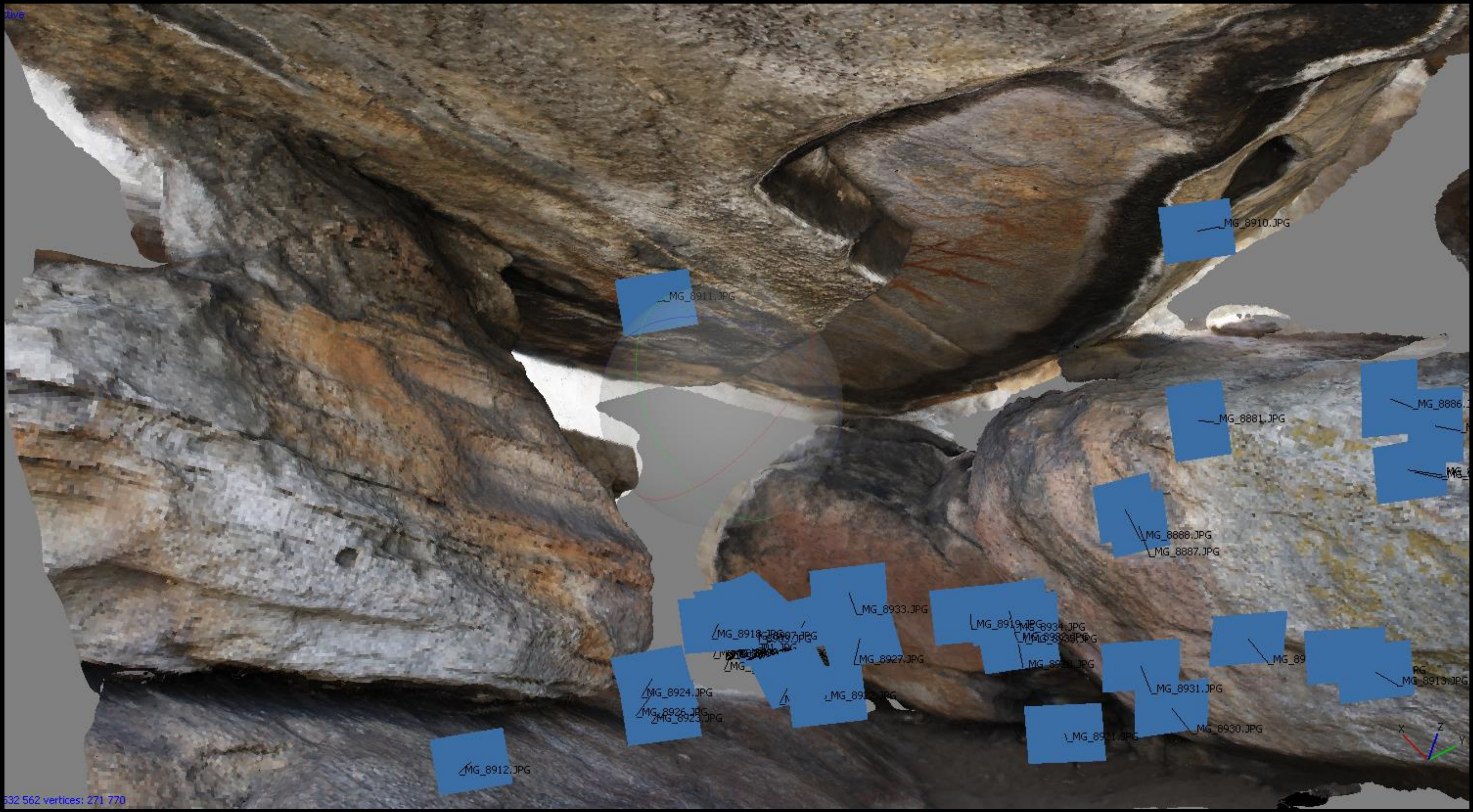
123D Catch



Breuckmann Smartscan HE: 60 micron res

Photoscan

Rock Art



123D Catch

Rock Art

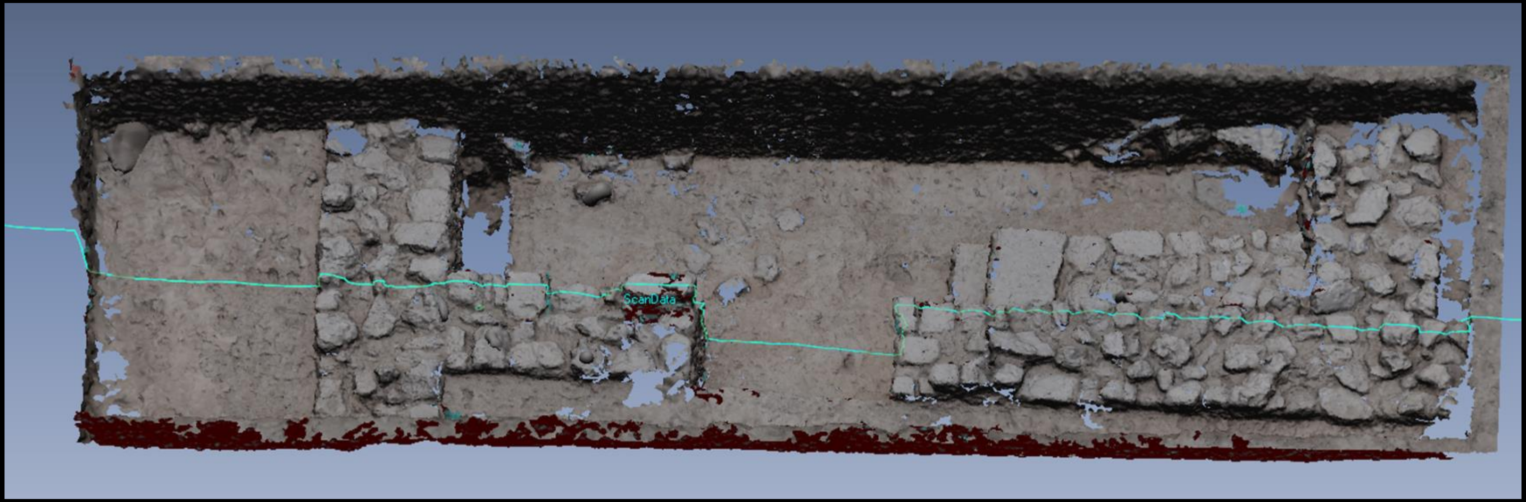
Photoscan

Case Example:

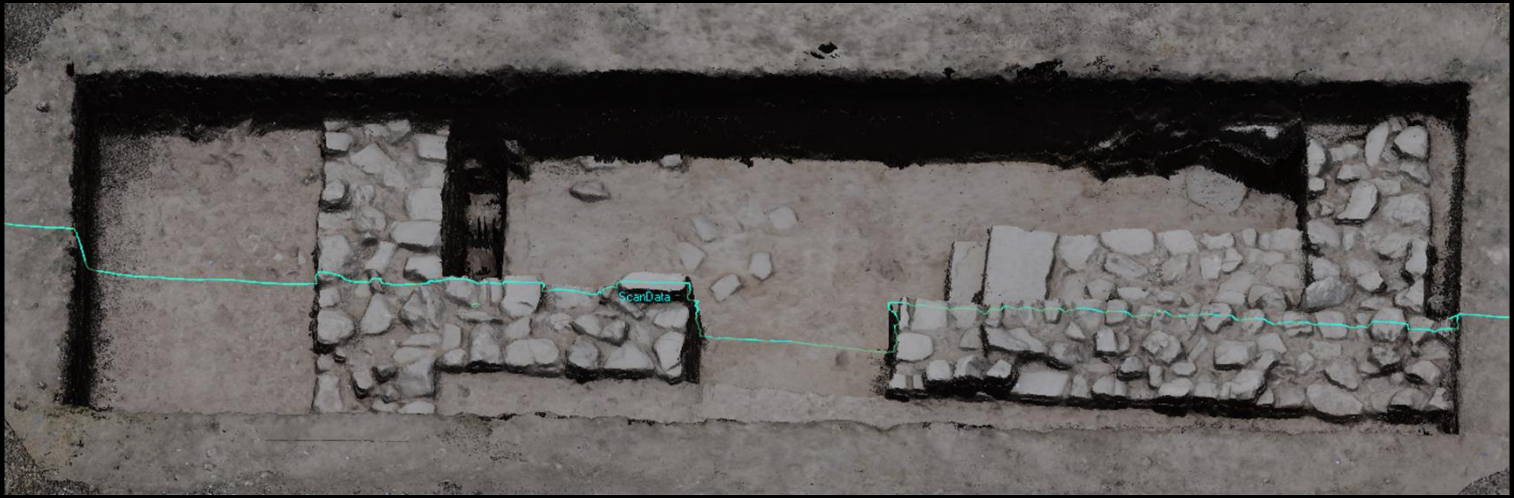
KALAVASOS, CYPRUS

In collaboration with the Kalavasos and Maroni Built Environments Project

Photogrammetric Trench Profiles

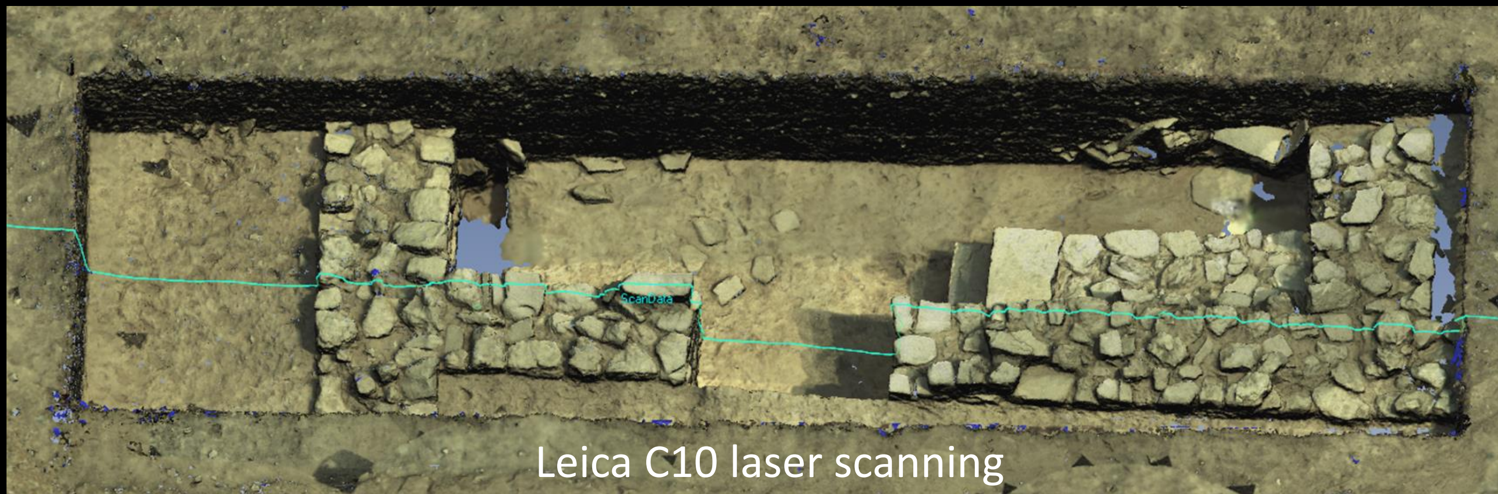


Visual SfM model

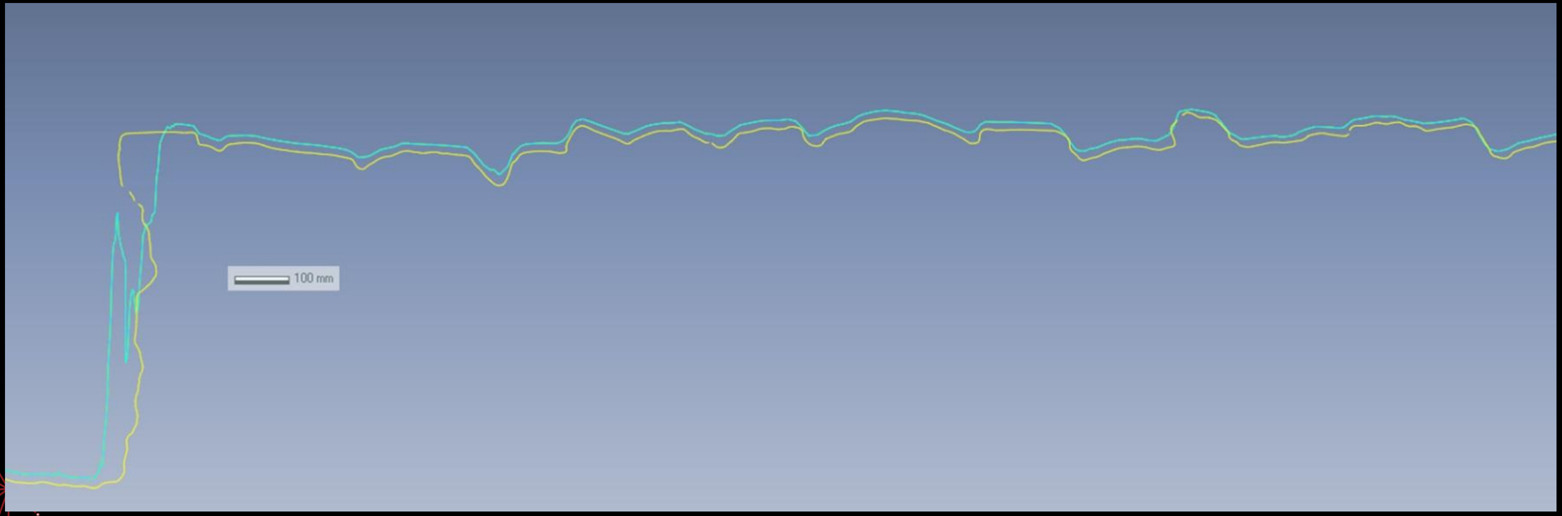


Photoscan model

Trench Profiles



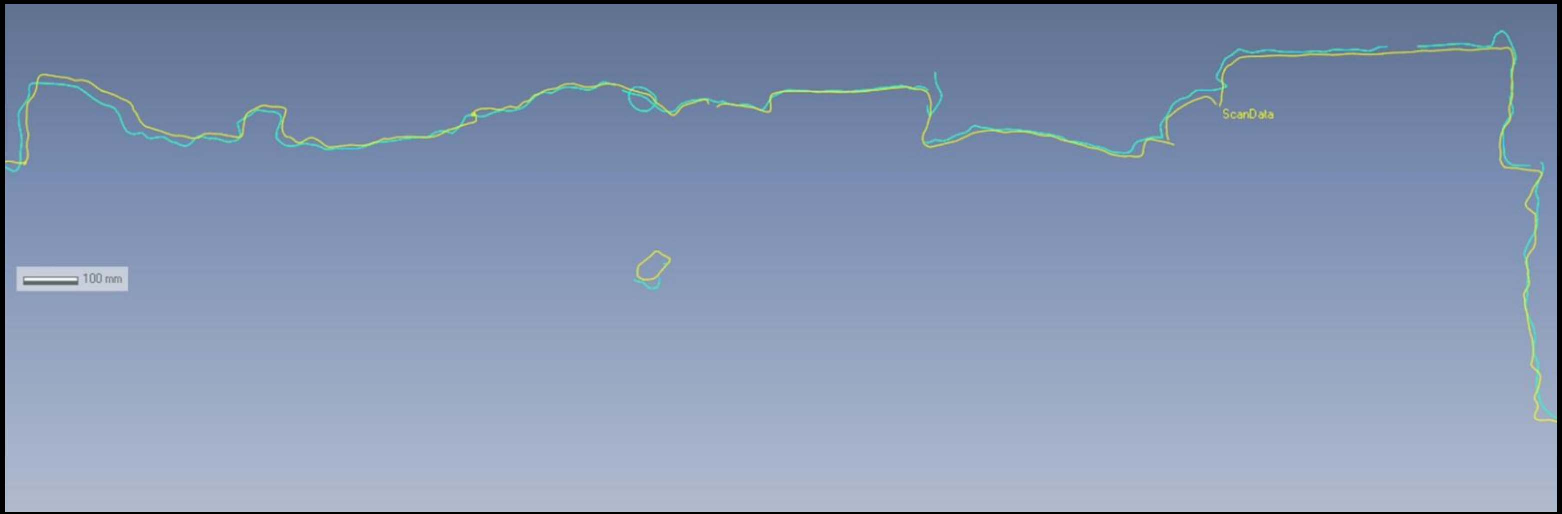
PhotoScan VS Scan Data

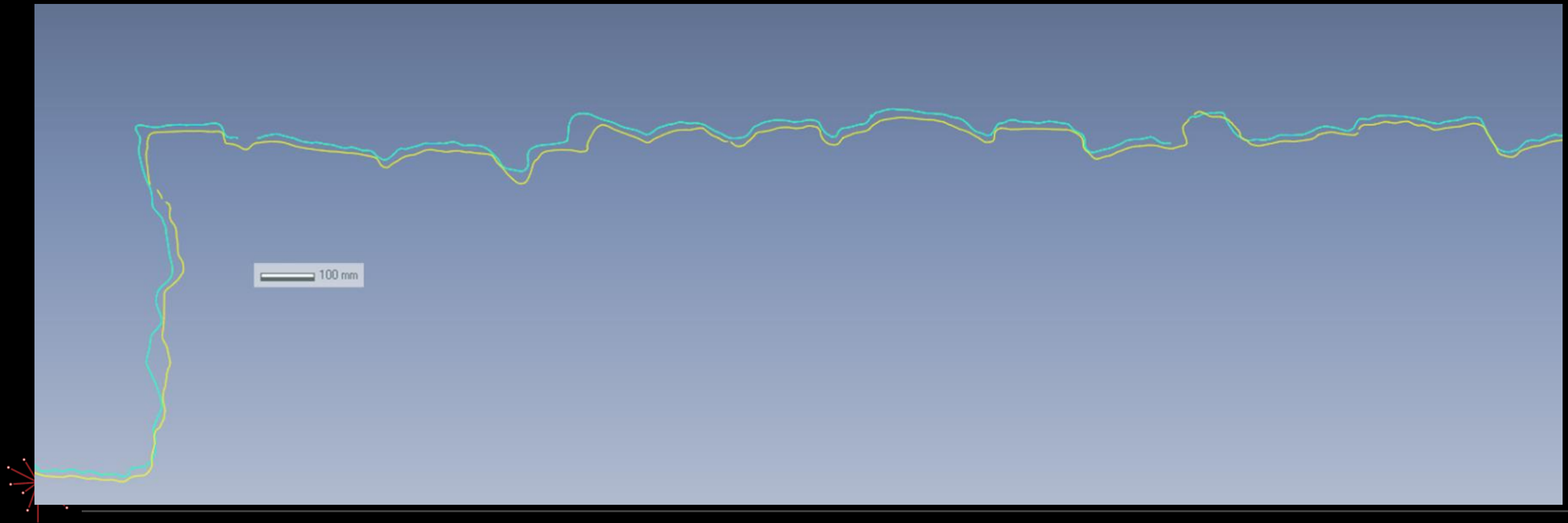


Photoscan model

Scan data

VSFM VS Scan Data



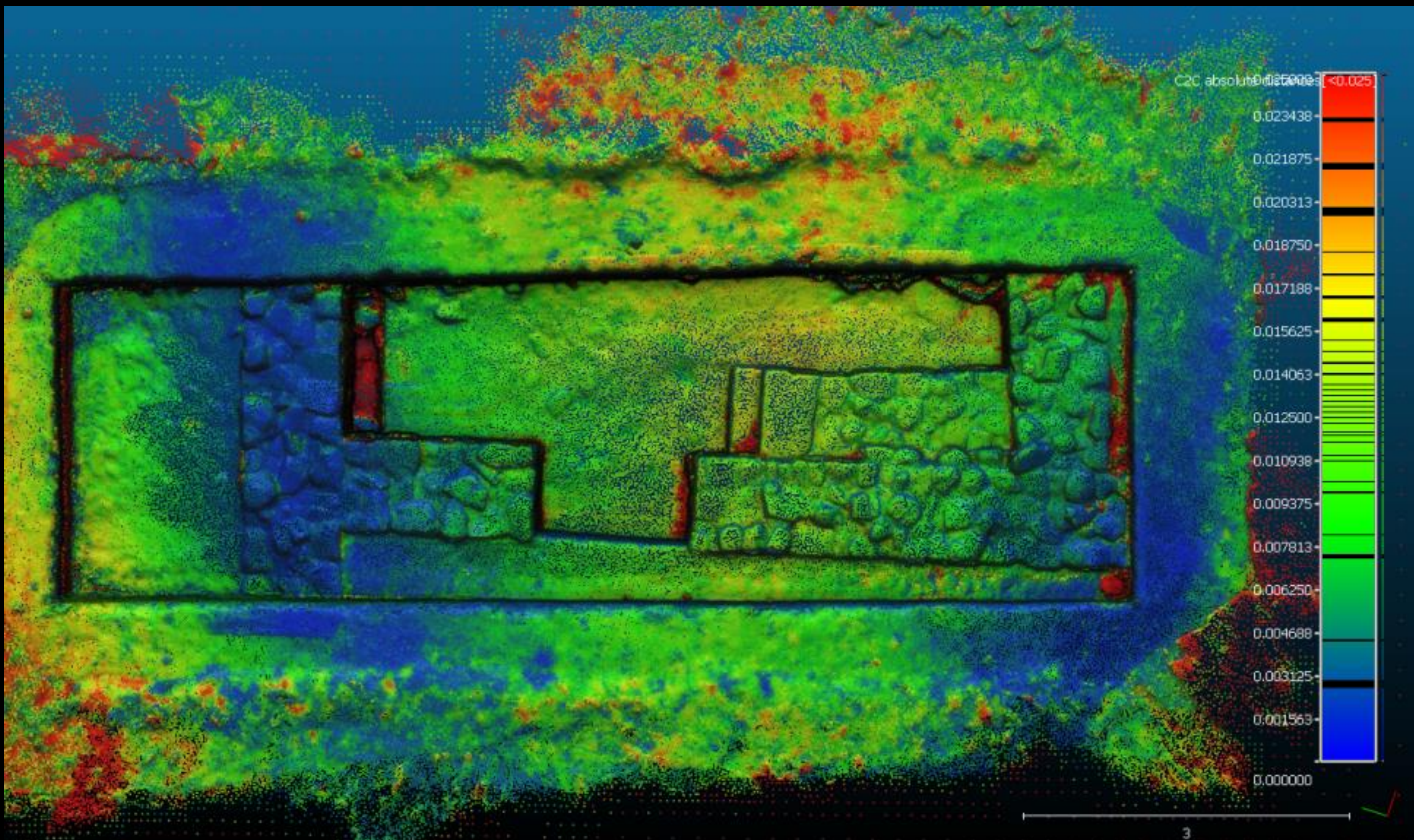


VSFM model

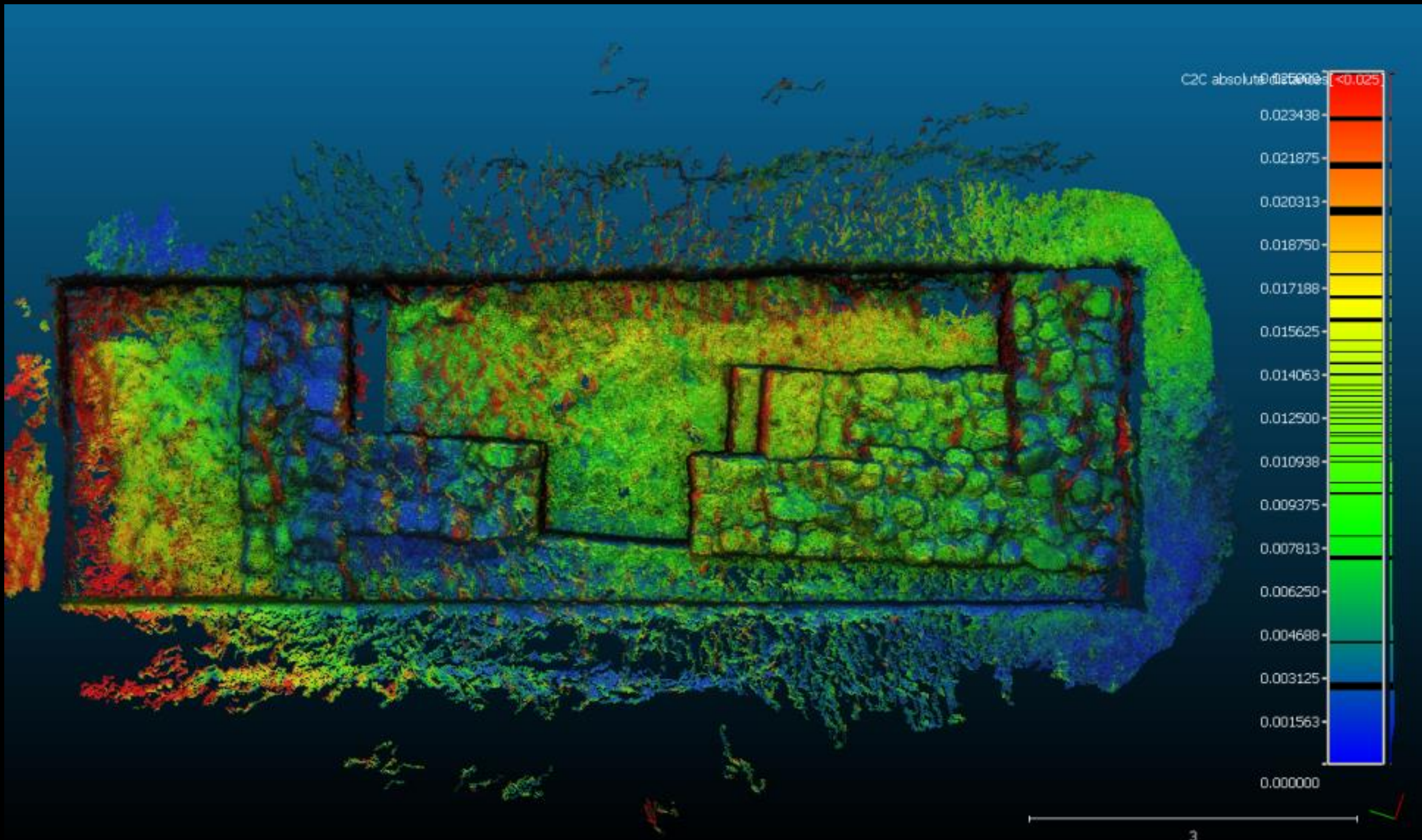
Scan data

UNIVERSITY OF ARKANSAS

PhotoScan VS Scan Data



VSFM VS Scan Data

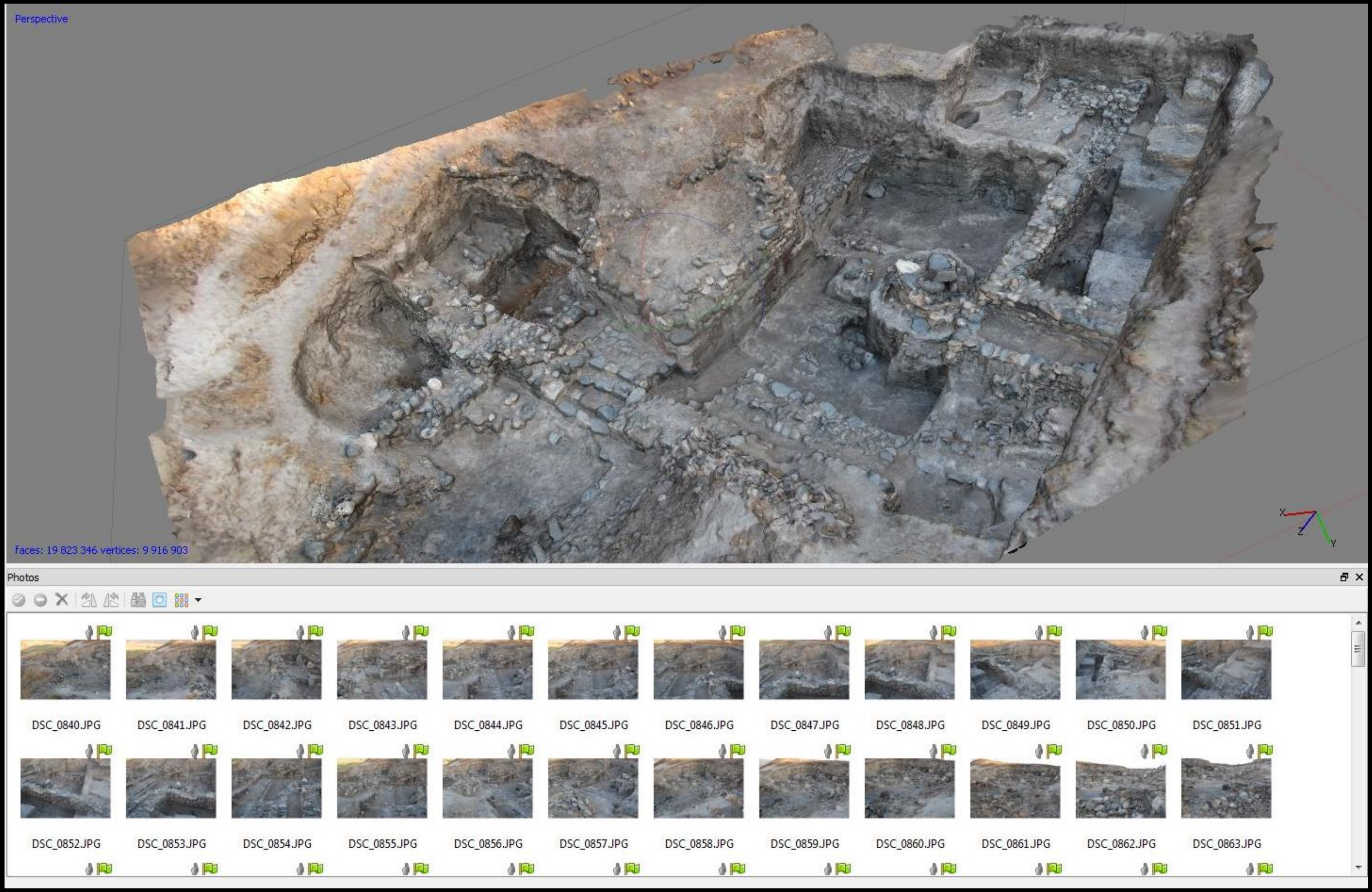


Collection and processing times

	Terrestrial CRP		TLS	
Data Collection		78 photos in 4 min		8 scans 1.5 hrs
Data Processing		Medium quality Photoscan model in 5 hours		8 scans in 0.5 hr

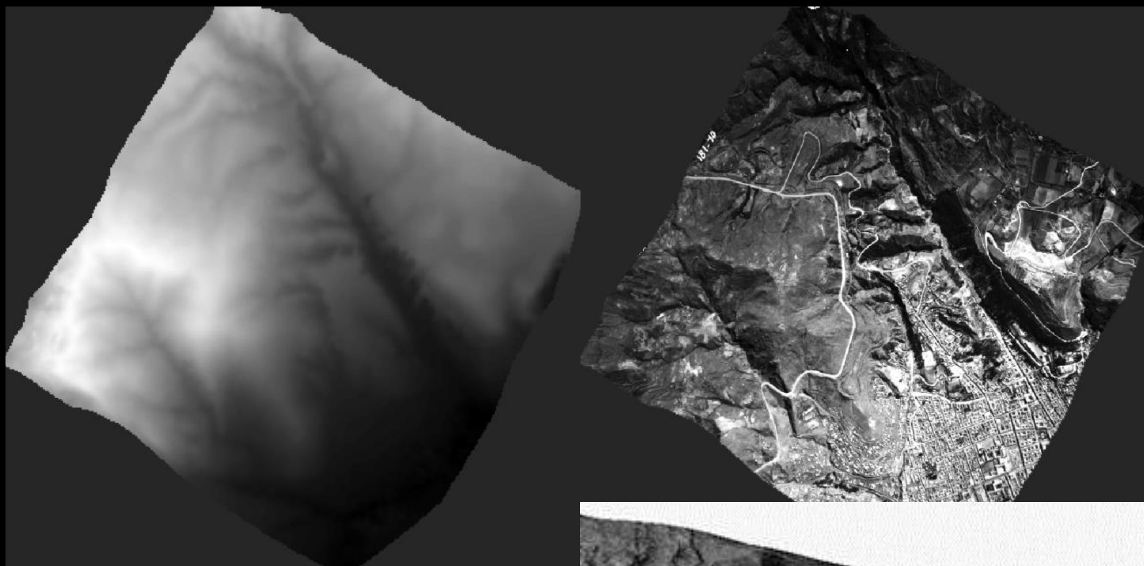
HISTORIC PHOTO CASE EXAMPLES

Photogrammetry from historic photos

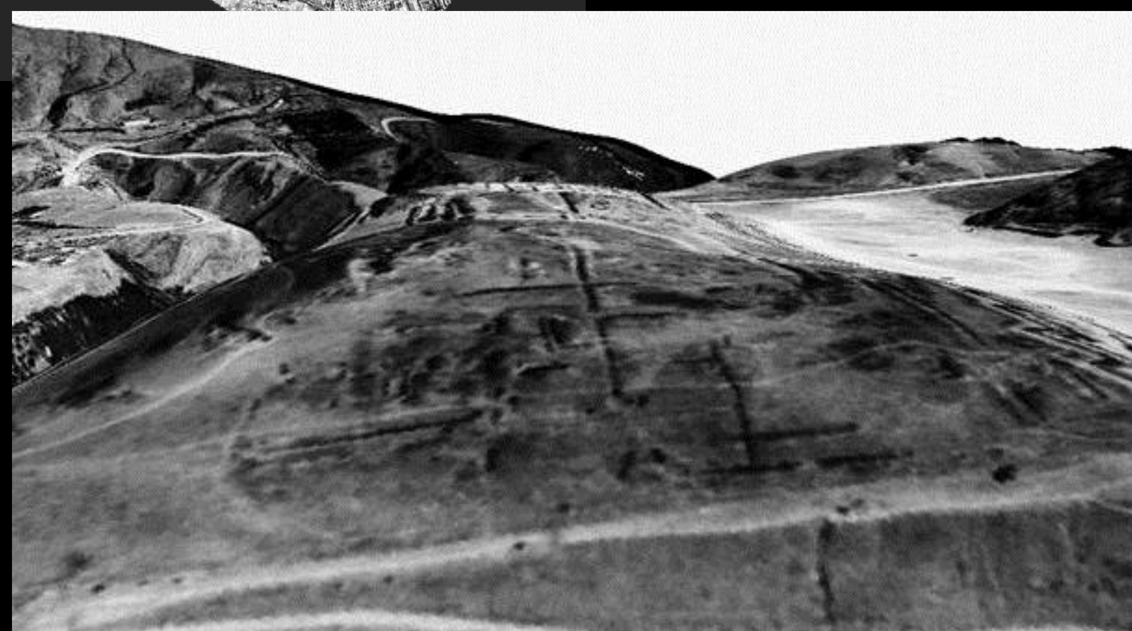


Photoscan model from 2008 photos at Qarqur, Syria. Eric Jenson, University of Arkansas

Photogrammetry from historic photos



DEM generated from historic images
of Cusco, Peru
Cotsen Institute/UCLA
Geomatics Field school 2009



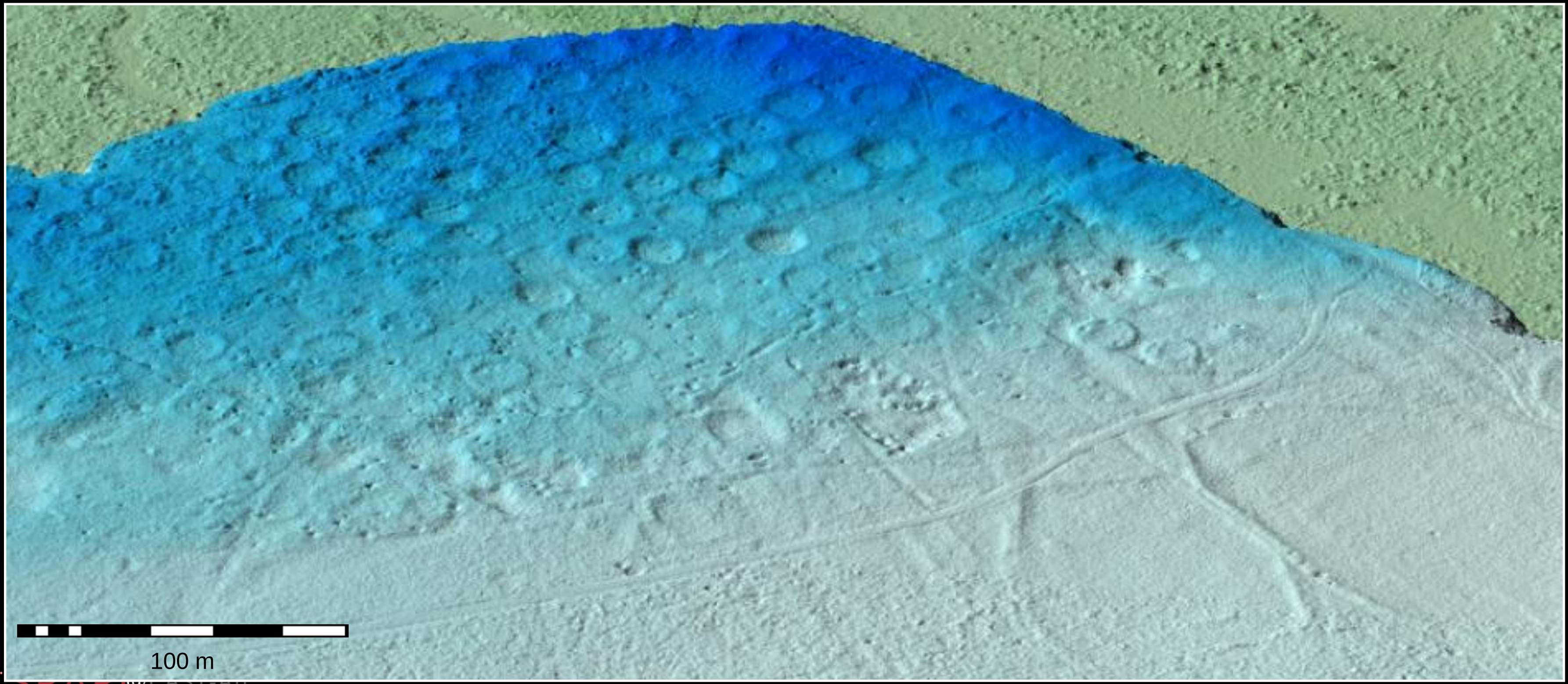
Archaeological Prospecting Case Example:

FORT CLARK STATE HISTORIC SITE, NORTH DAKOTA

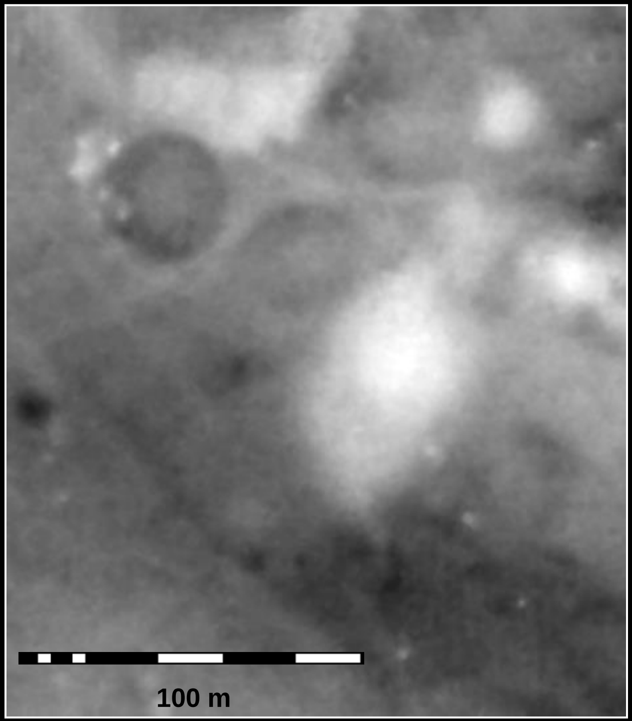
In collaboration with …

Elevation Model Data Sets

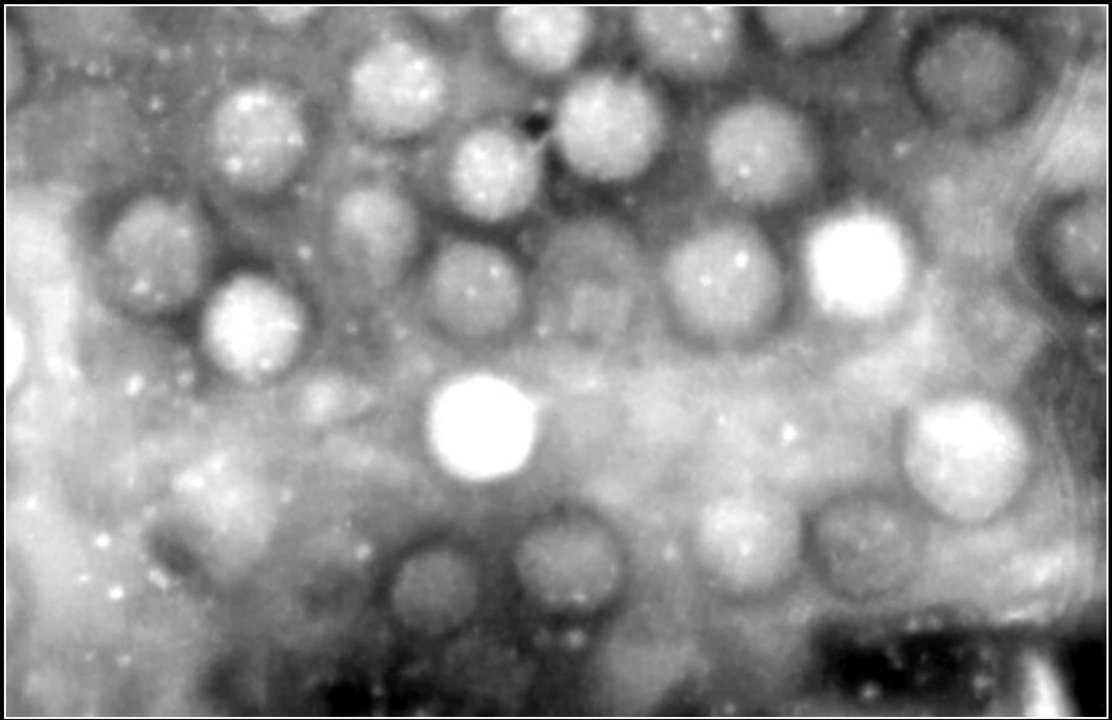
1) Lidar: Leica ALS60 system mounted in a Cessna Caravan 208B
   - 900 x 1200 m survey area, average point density (first return) = 16.0 points/m^2, ground point density = 4.0 points/m^2, vertical accuracy (RMSE) = 2.4 cm



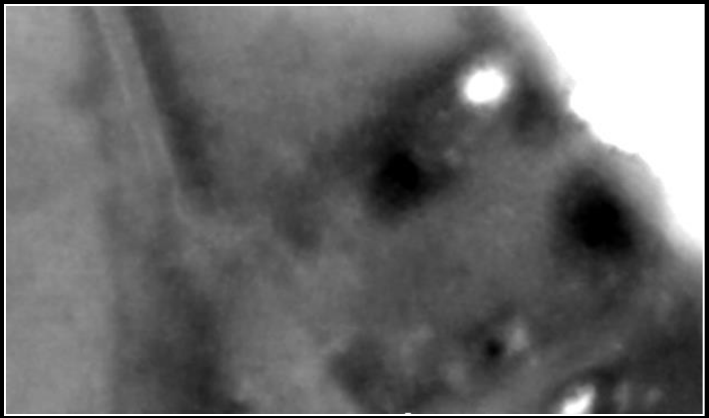
Lidar (Local Relief Model)



Borrow pit with pathways



Entryways, trails, and cabins

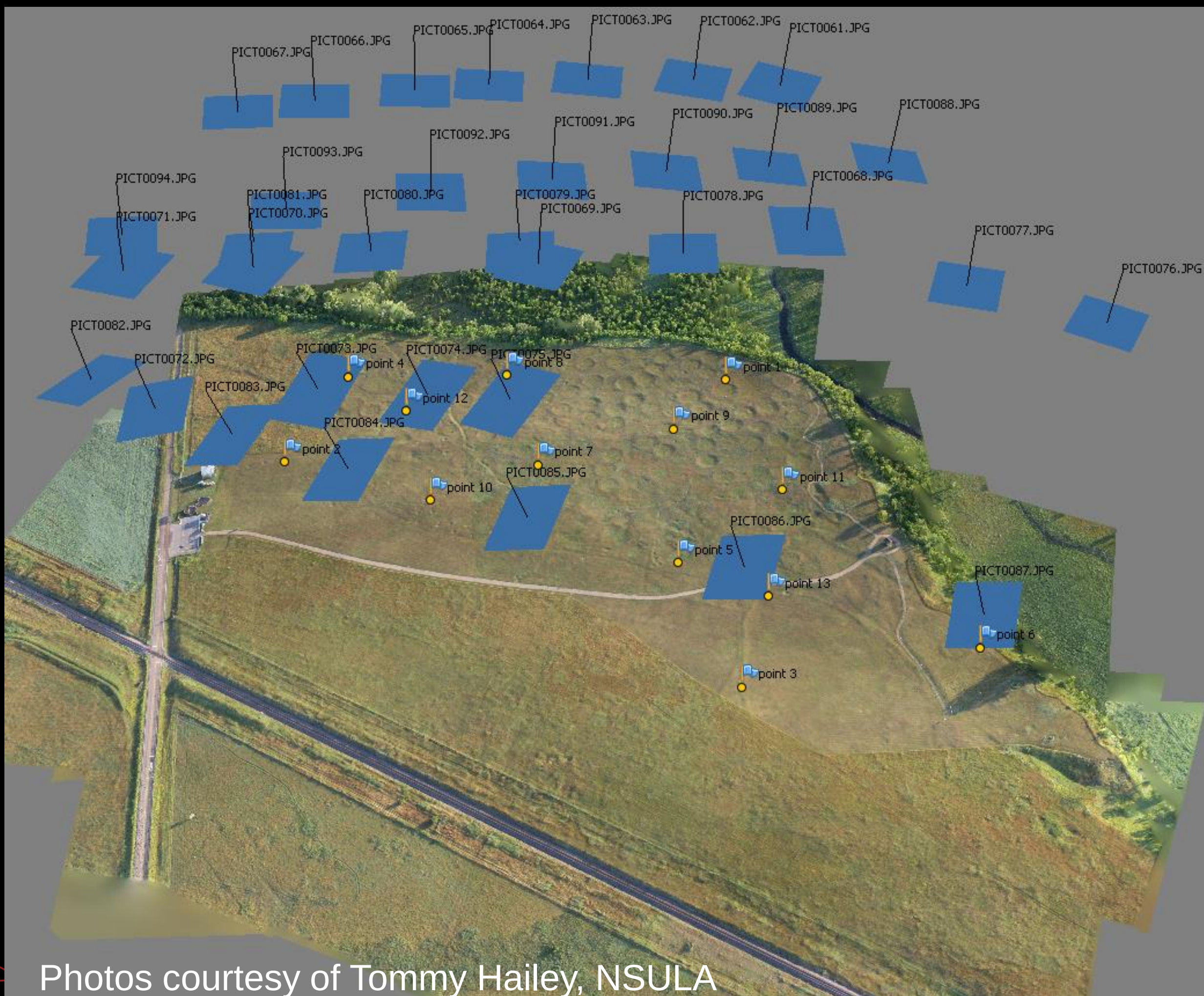


Individual structures within Fort Clark

SPARC @CAST-AIL

Fort Clark State Historic Site, North Dakota
Elevation Model Data Sets

2) Digital photogrammetry: 34 digital color photographs (Konica Minolta DiMAGE A2) collected from a powered parachute

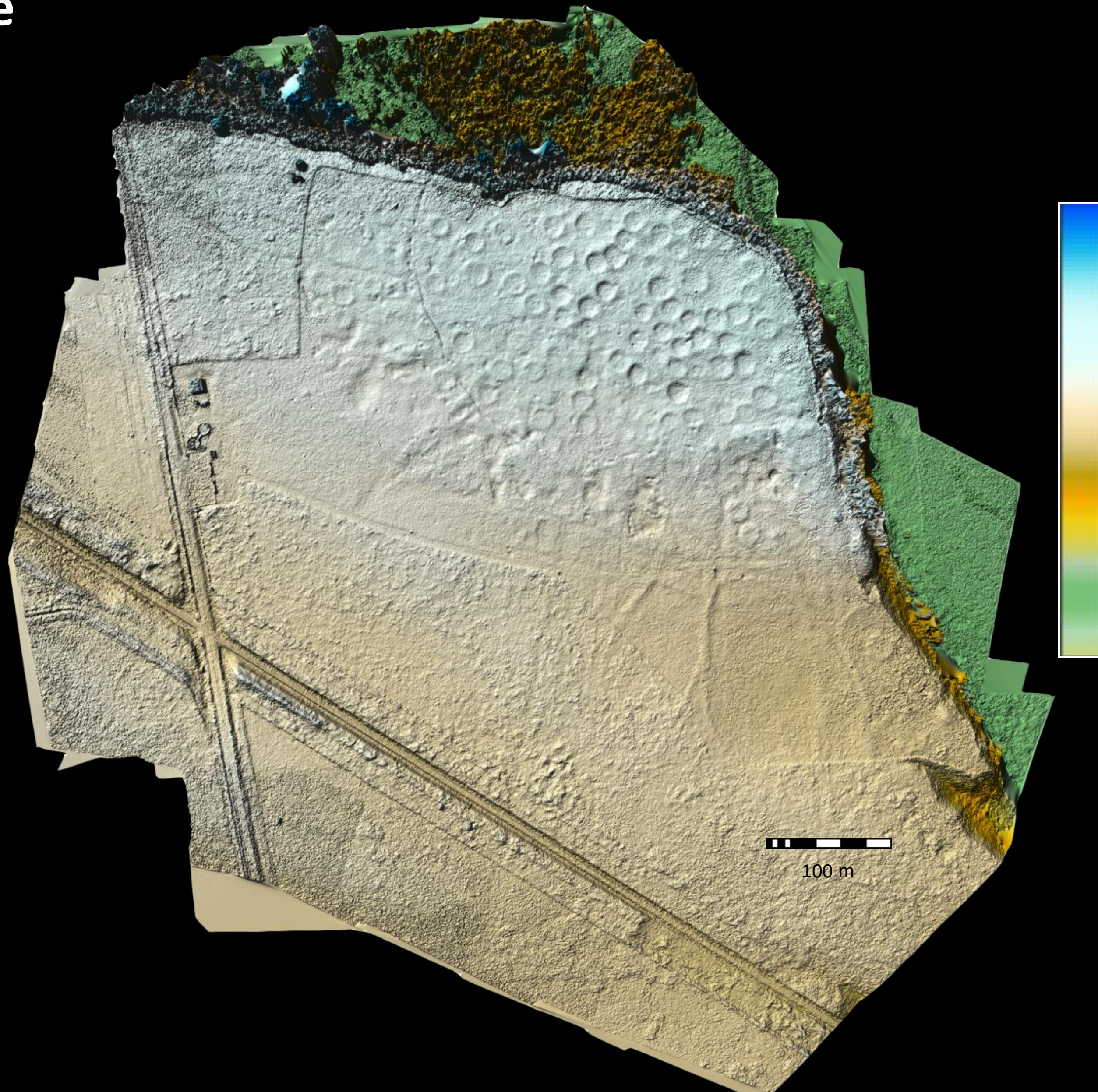


Photos courtesy of Tommy Hailey, NSULA

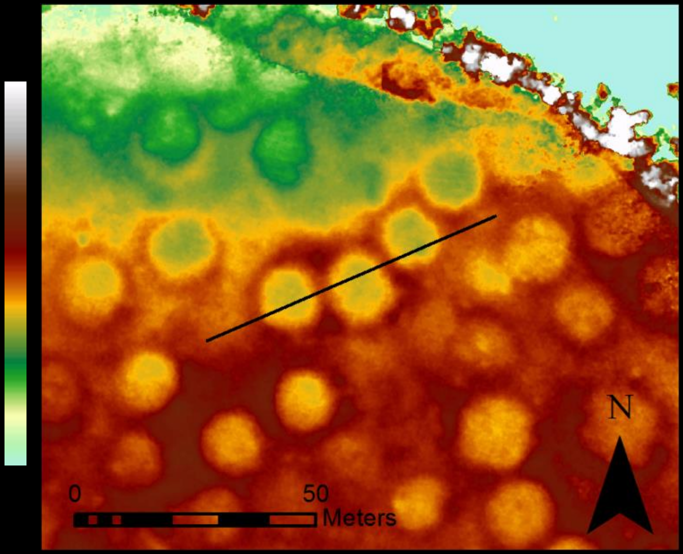
- Sensor size: 8.8 x 6.6 mm
- 7 mm focal length
- Flying height: ~285 m
- Pixel resolution: ~10 cm
- Check point error (RMSE) = ~14 cm horizontal and ~18 cm vertical

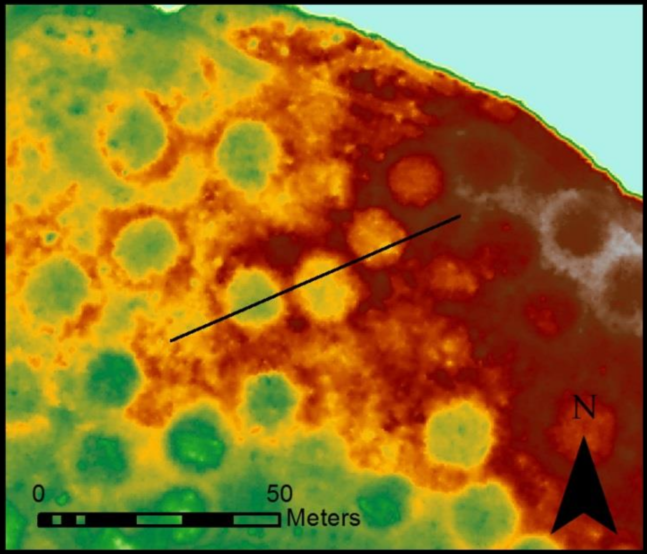
Low Altitude Aerial Photogrammetry from Powered Parachute

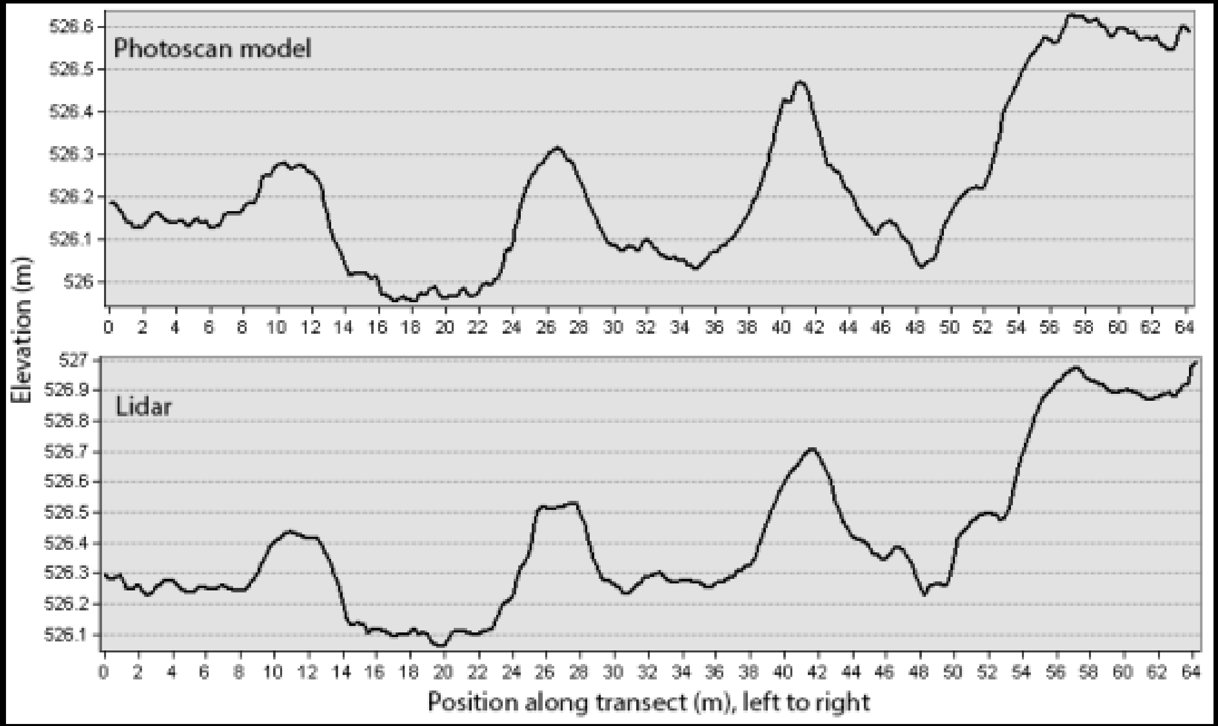
- 750 x 850 m area
- 10 cm resolution DSM
- Point density: ~29 points/m^2



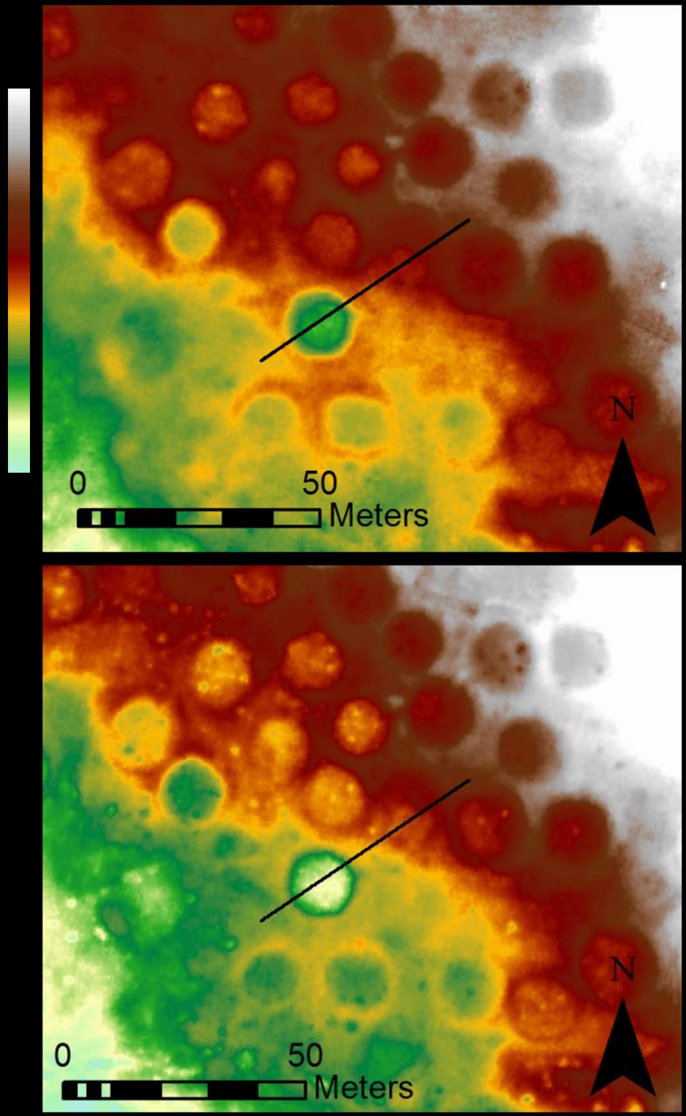
Profile comparison

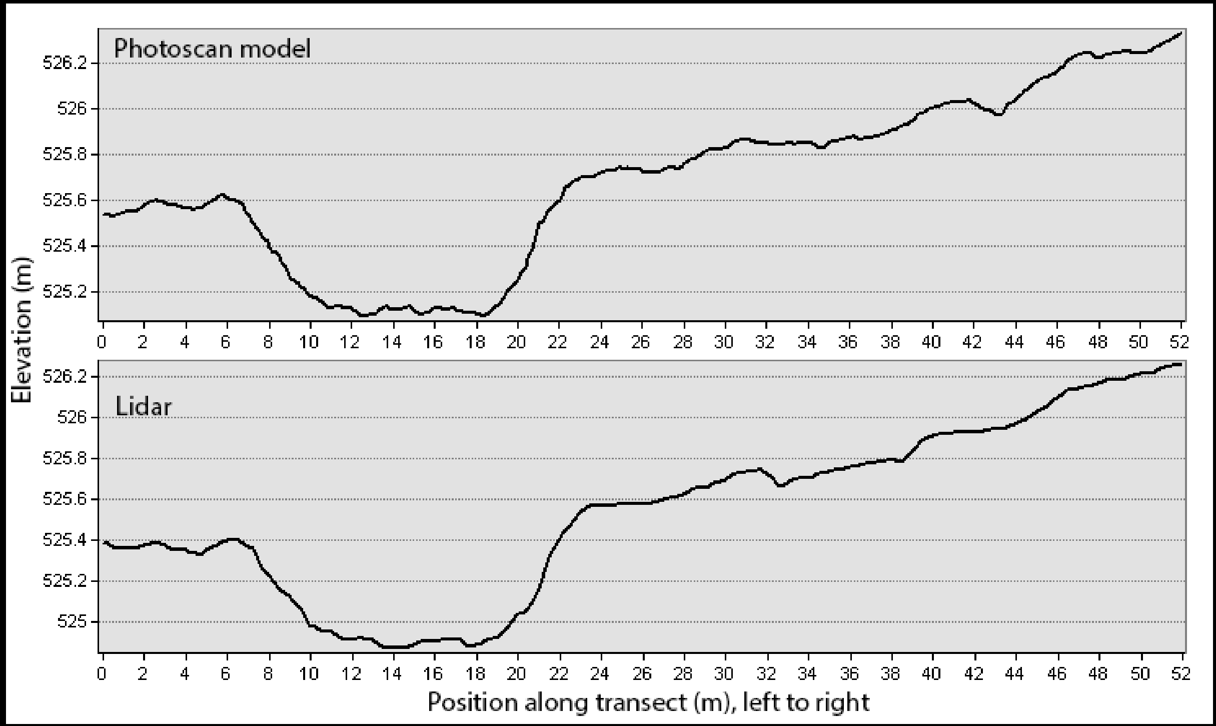






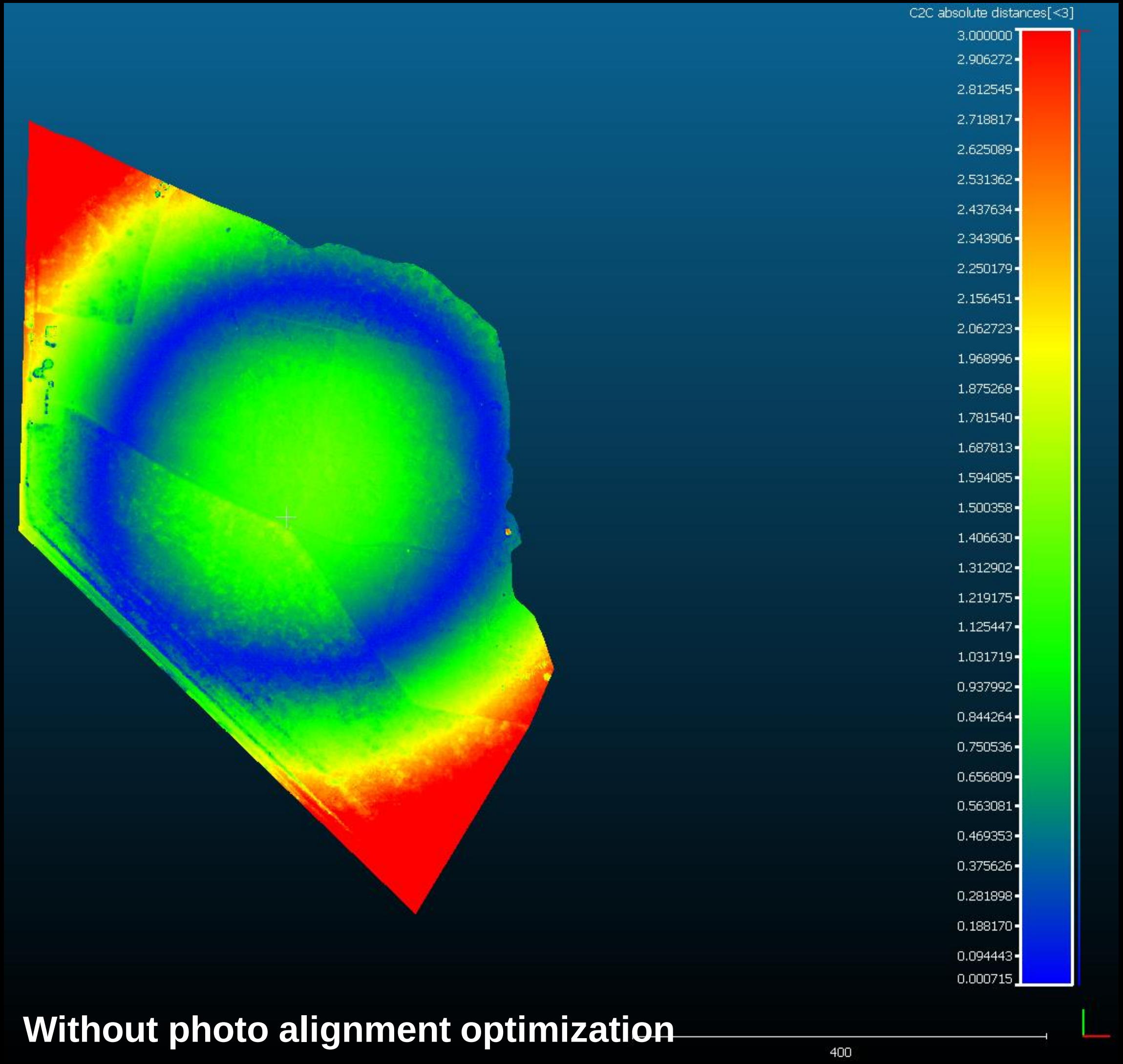
Profile comparison





Cloud Compare

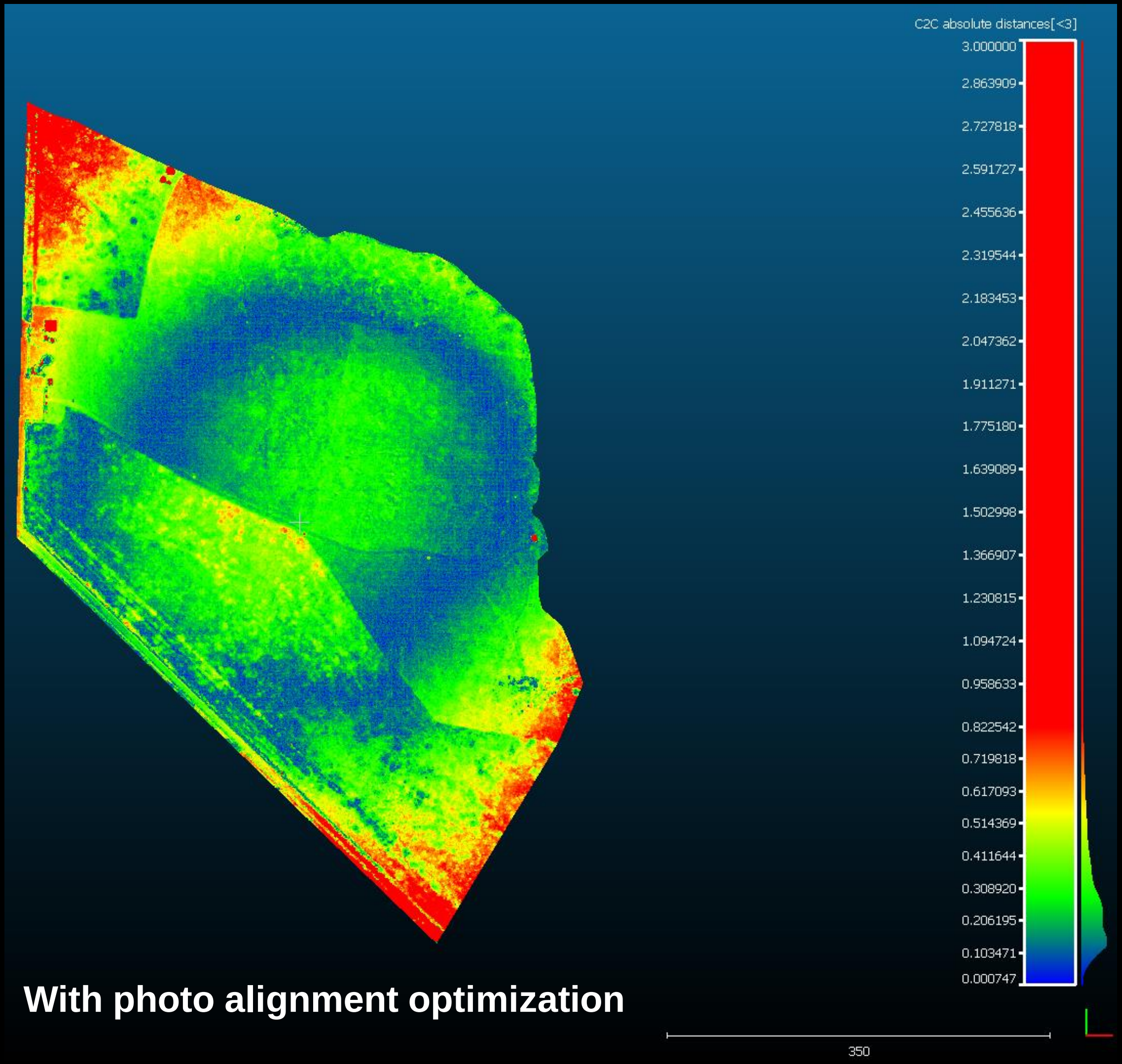
Lidar DEM – Photoscan DSM

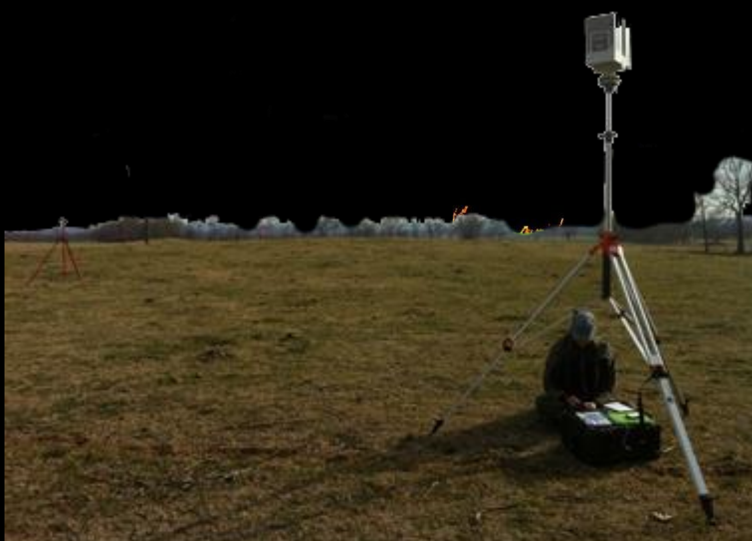


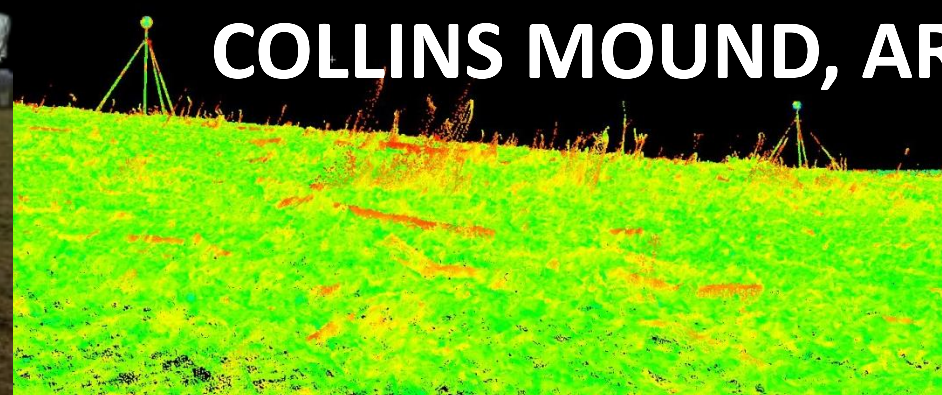
Without photo alignment optimization

Cloud Compare

Lidar DEM – Photoscan DSM





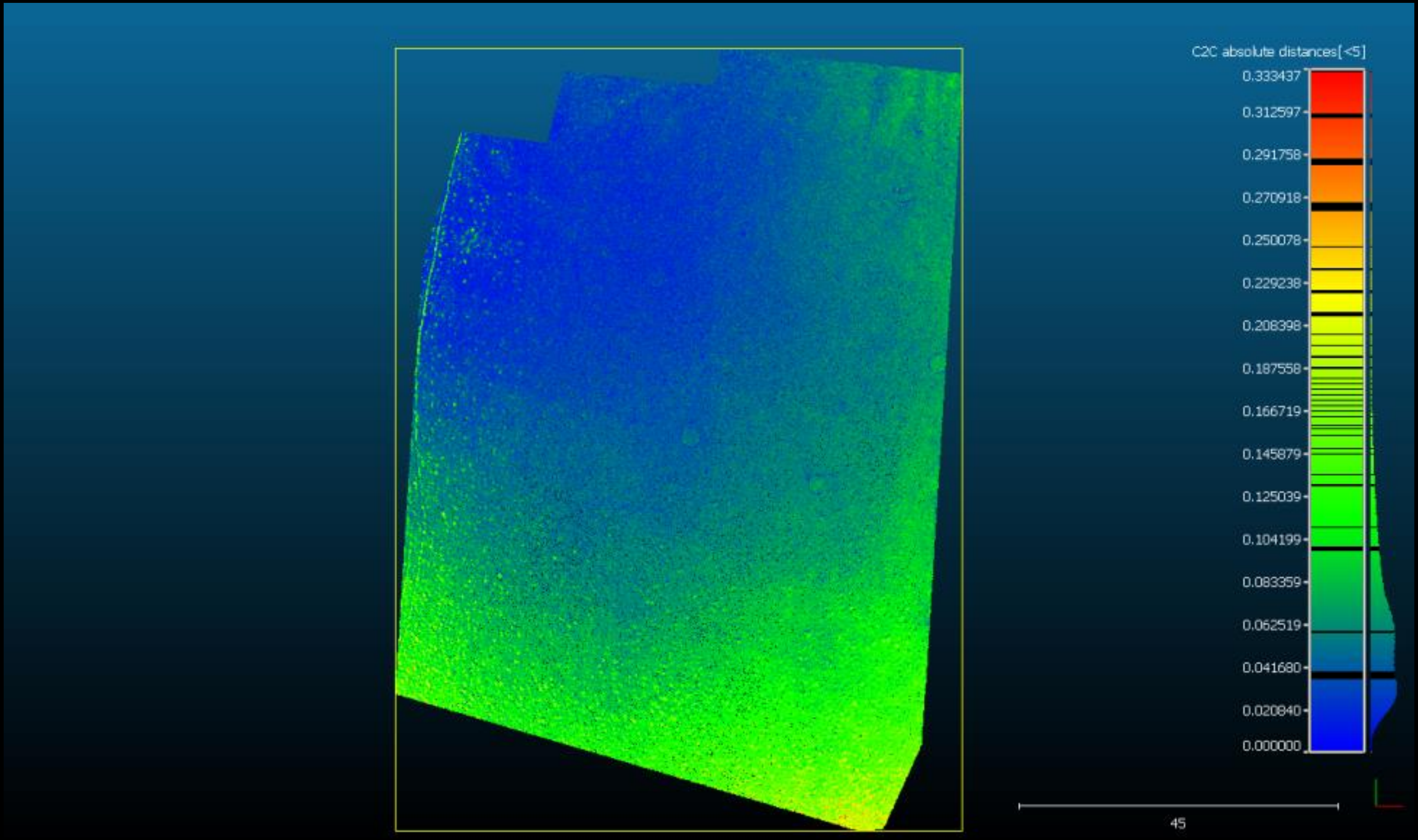


Case Example:

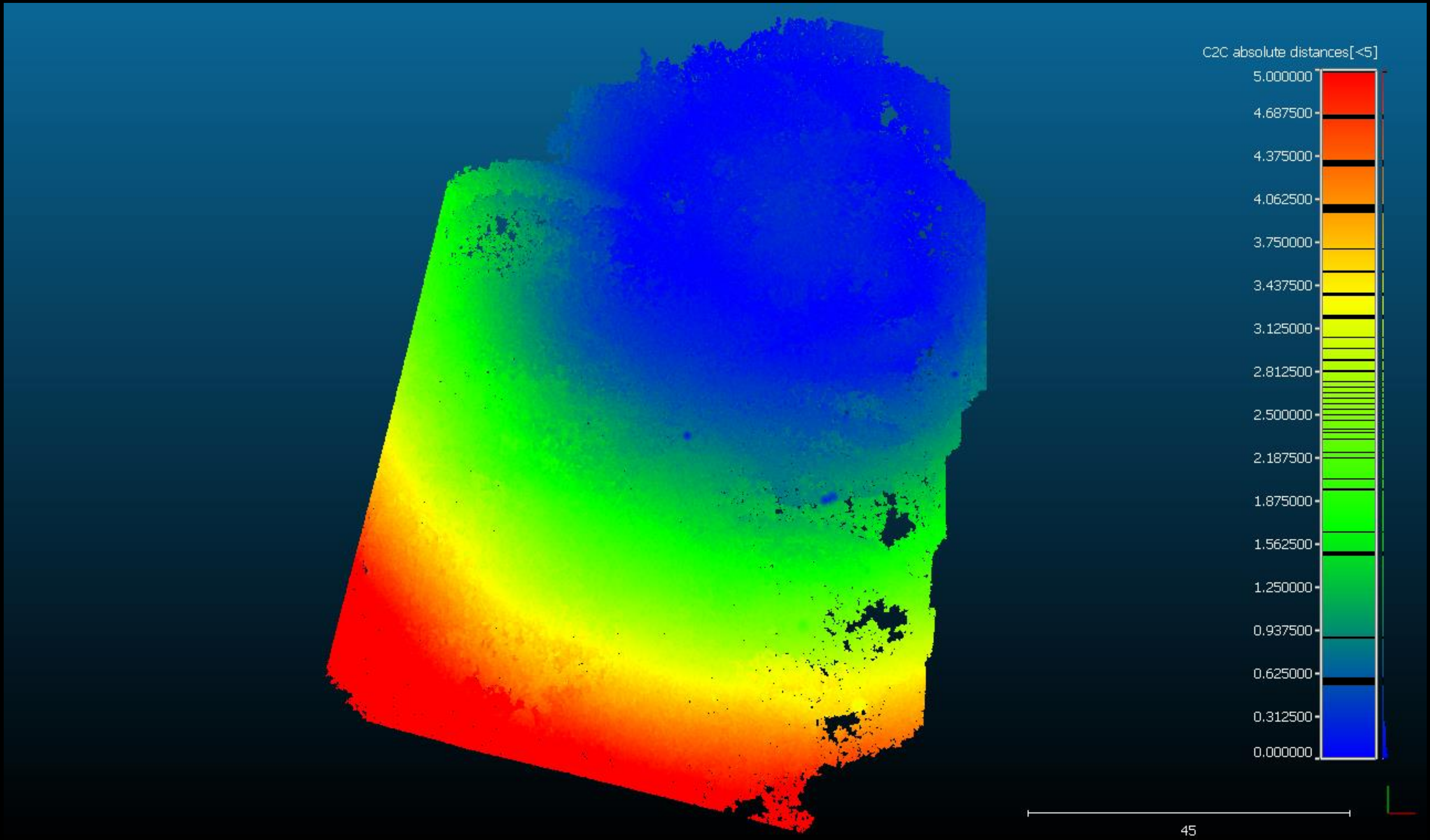
COLLINS MOUND, AR

In collaboration with the Stephanie Sullivan, PhD candidate, University of Arkansas

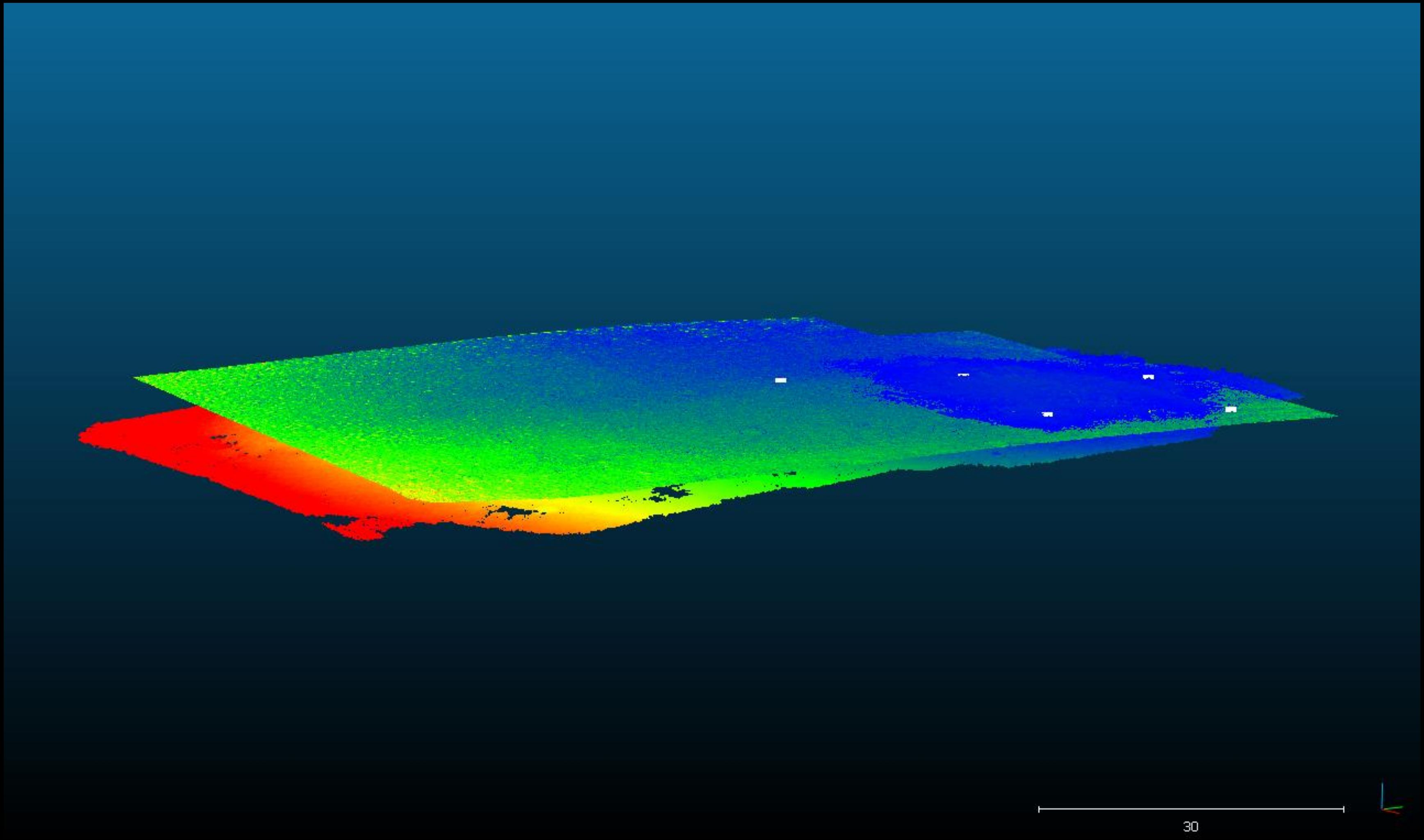
PhotoScan VS Scan Data



VSFM VS Scan Data

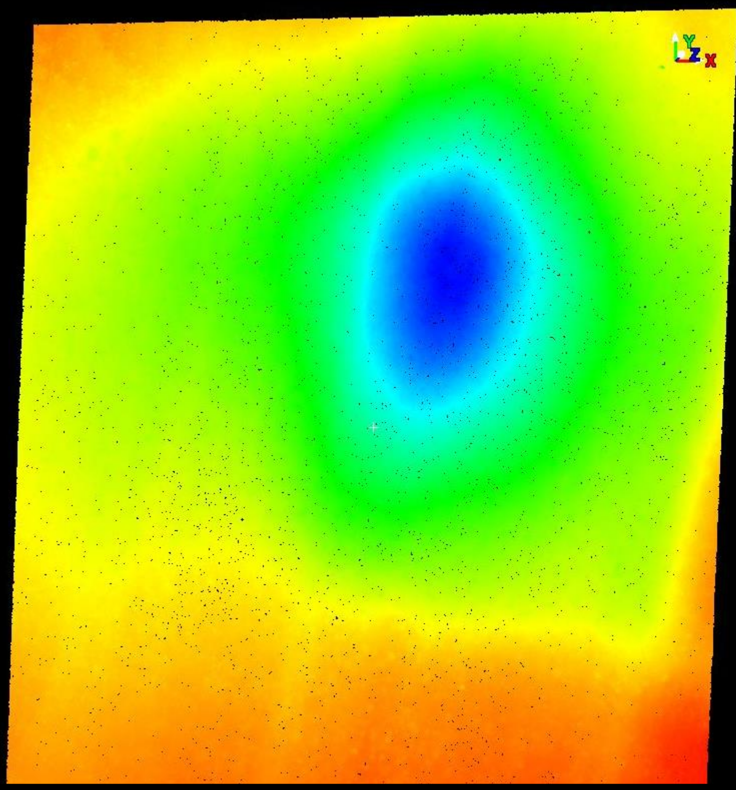


Side view of Collins

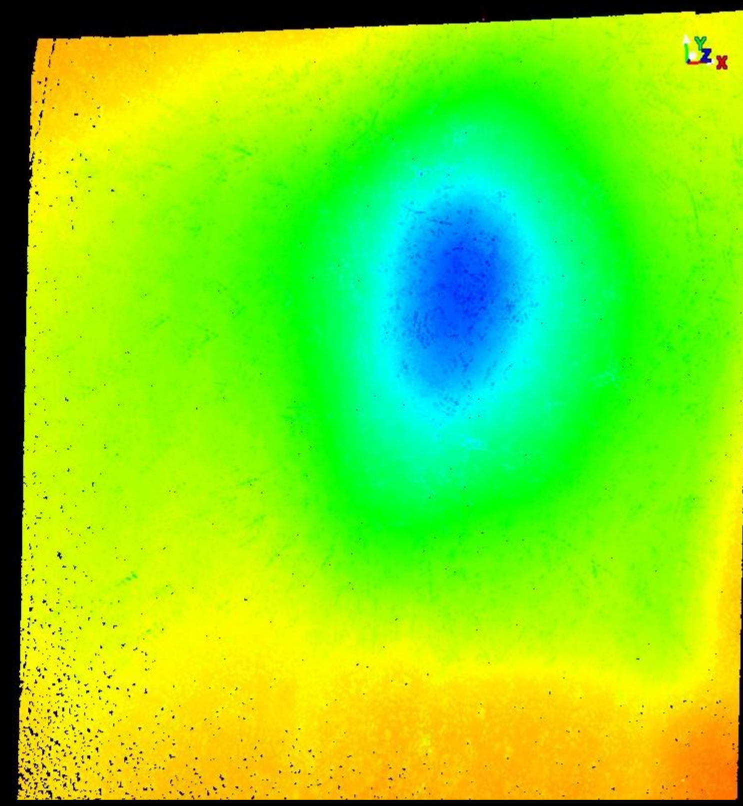


Qualitative Analysis

Z-value (elevations) visualization



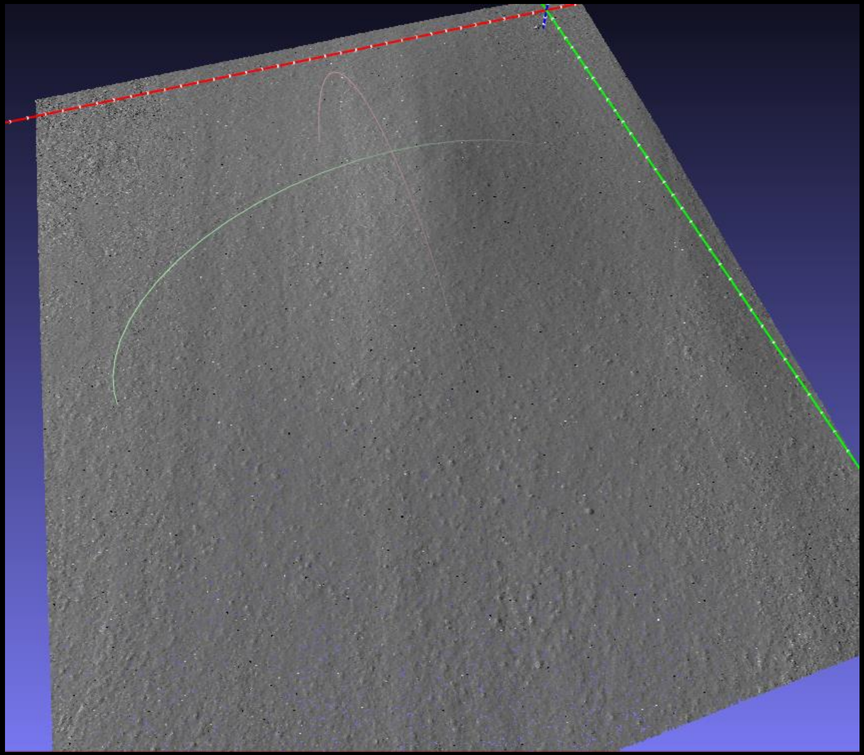
Photoscan



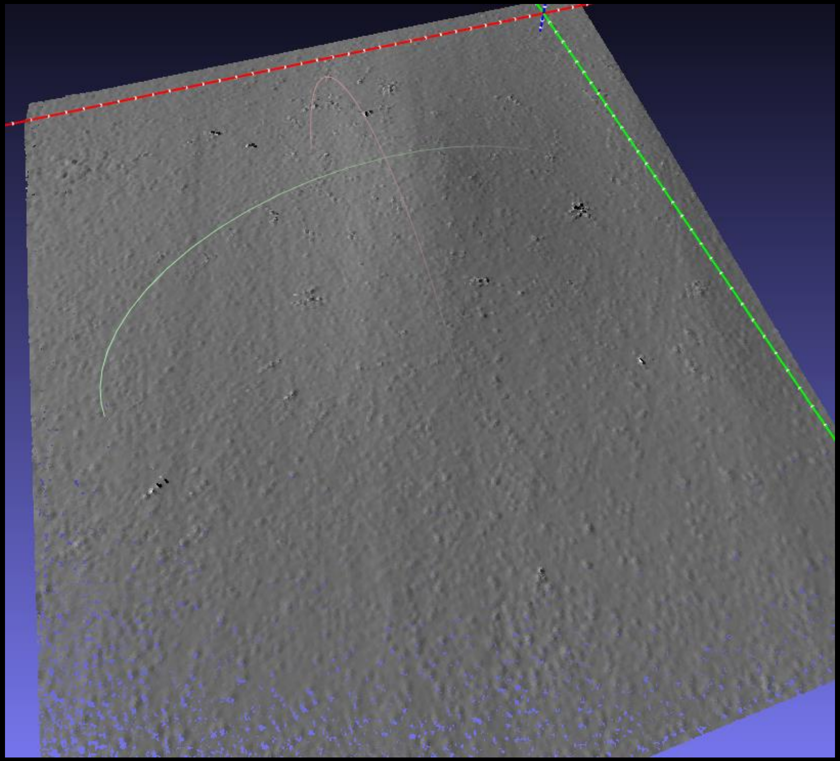
Z+F laser scanning

Qualitative Analysis

- Which datasets reveal which types of features

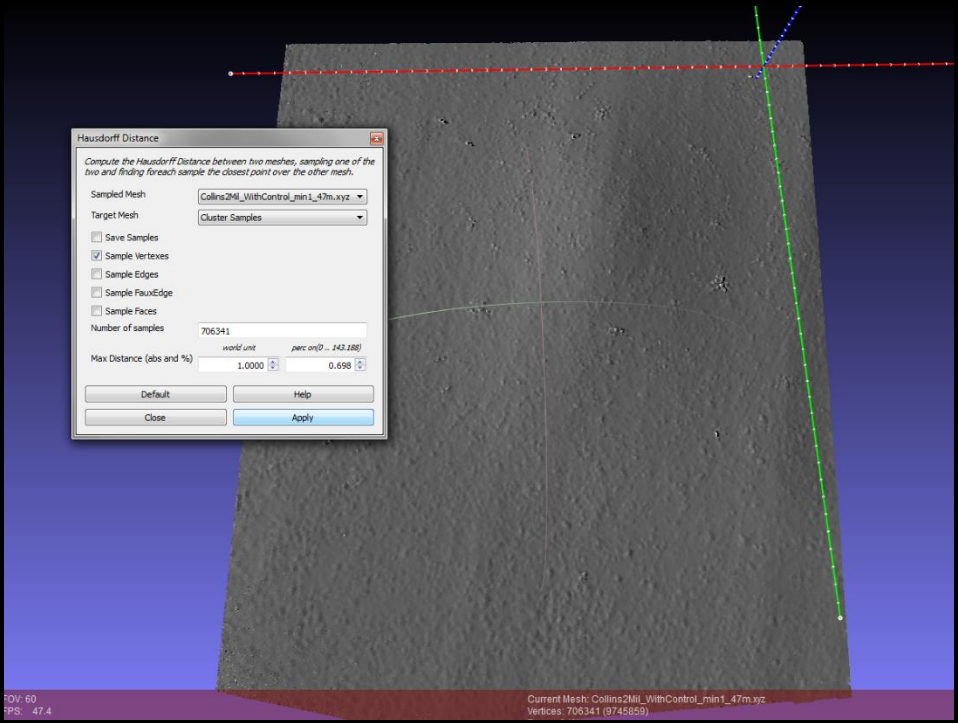


Kite aerial photogrammetry



Z+F laser scanning

Quantitative Analysis

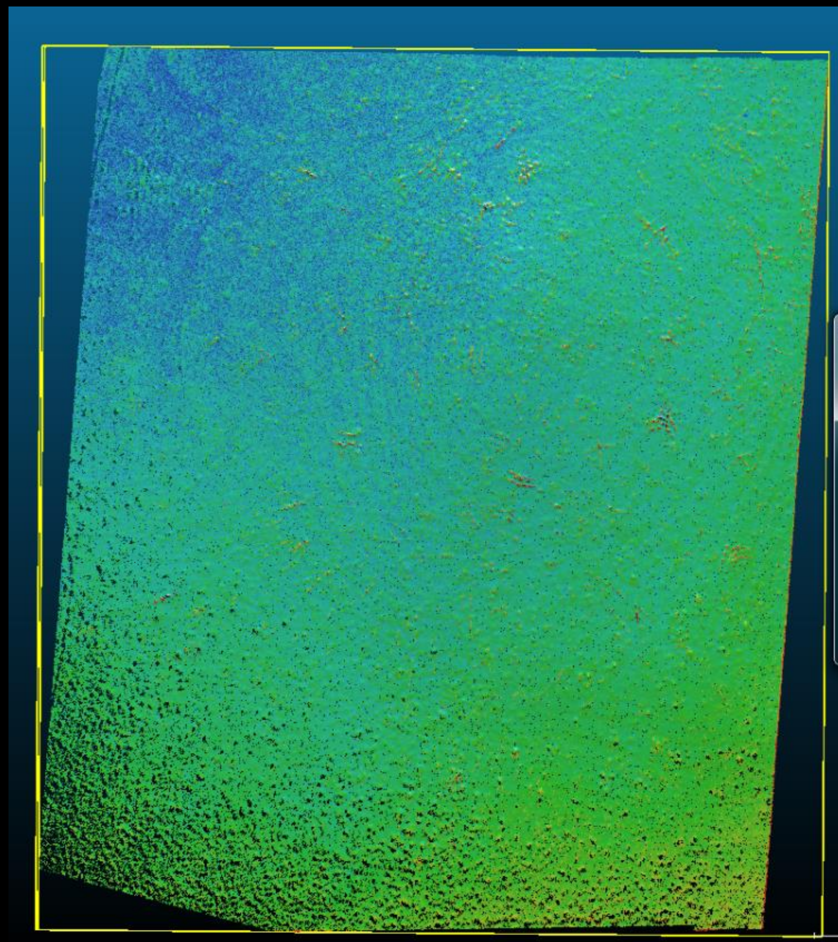


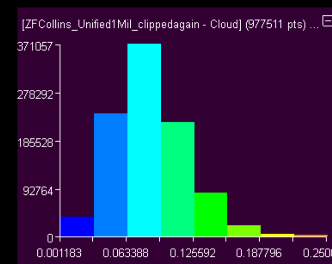
Hausdorff Distance in Meshlab

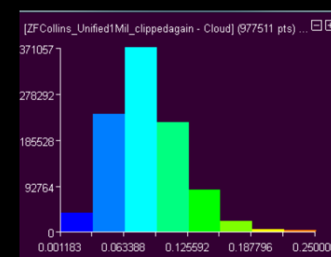
Avg max distance = 0.868 m

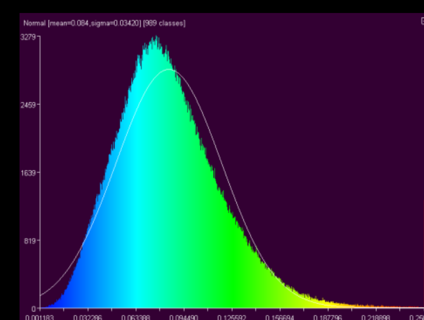
mean distance = 0.082 m

Quantitative Analysis







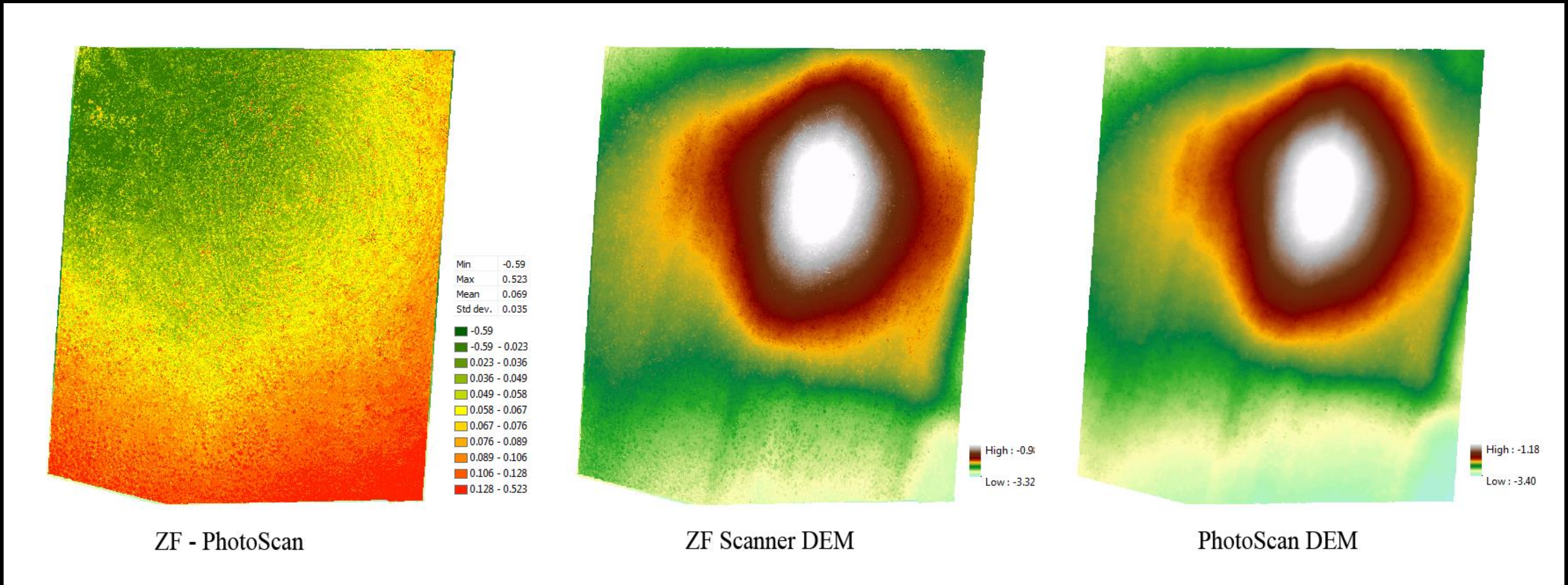


Hausdorff Distance in Meshlab

Avg max distance = 0.929 m

mean distance = 0.036 m

Quantitative Analysis



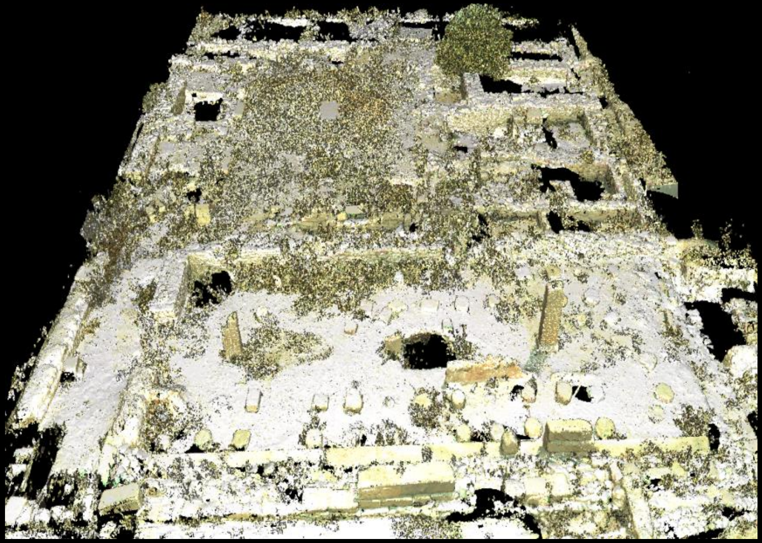
ArcMap
max difference = 0.523m
mean difference = 0.69m

Collection and processing times

	Aerial CRP		TLS	
Data Collection		28 photos in 3 min		7 scans in 2.5 hrs
		55 in 6 min		7 scans 3.5 hrs
Data Processing		Medium quality Photoscan model in 3 hours		7 scans in 1 hr
		Medium quality Photoscan model in 4 hours		7 scans in 1 hr

Kite aerial/UAV photography will yield good geometry of low architectural remains. Period.

Kite aerial photogrammetry



Leica C10 laser scanning

KAMBE Project, Kalavasos, Cyprus

Conclusions

- Keep your project goals in focus at all times
- Know your camera and lenses
- Know the basics of photogrammetry and how that relates to your software settings
  - You can get by with leaving default settings and pressing just a few buttons—will that meet your project goals?
- Photogrammetry can be good solution
  - Great for visualization
  - Must be executed with great care for metric analysis