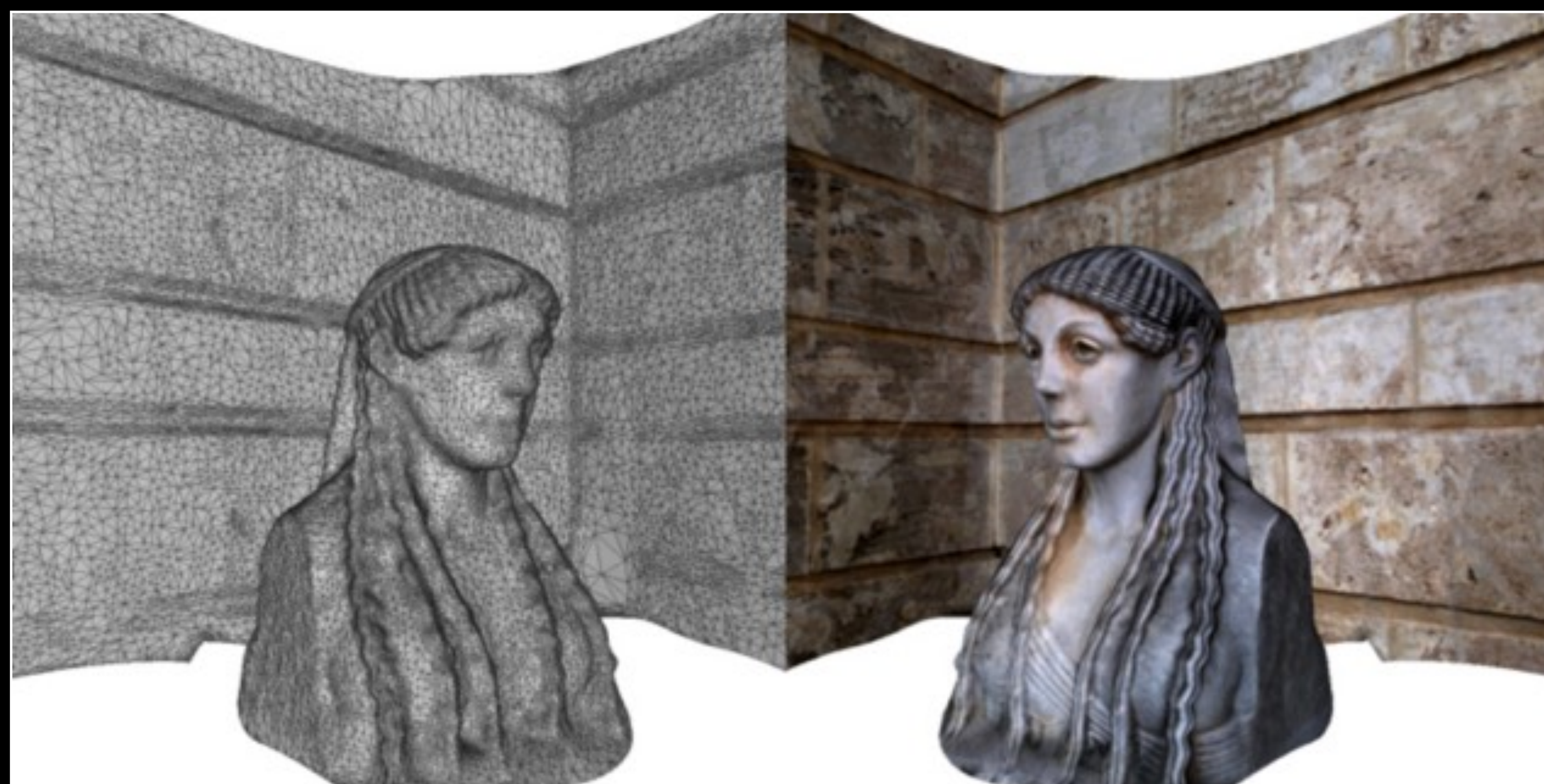
Automated 3D model reconstruction from photographs

Paul Bourke
iVEC@UWA

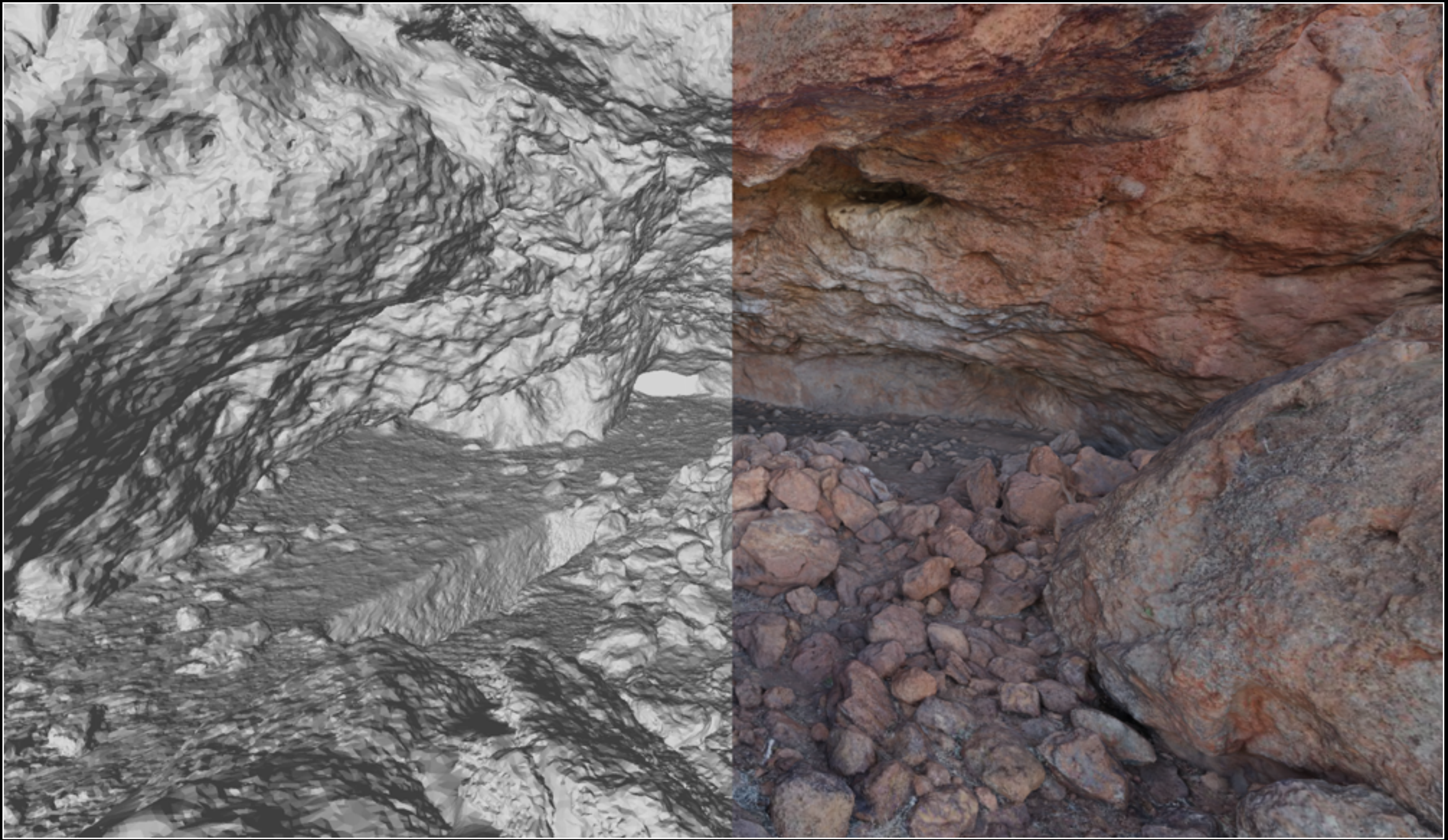


iVEC
@UWA

iVEC : One slide introduction

- Joint venture between the 5 main research institutions in Western Australia. UWA, Curtin, Murdoch, ECU, CSIRO.
- Provide researchers at the partners with supercomputing (just hit the top 500 list at number 41), data storage (multiple tens of petabytes), visualisation (three main visualisation nodes).
- I wear three hats
  - Researcher at The University of Western Australia
  - Head of the iVEC visualisation team
  - Director of the iVEC@UWA Centre at The University of Western Australia
- Reconstruction activities driven from mainly Archaeology/Heritage, Geoscience. Archaeology: indigenous rock art and marine archaeology.

Diotima (Mistress of Pericles)
Credited with the concept of
platonic love.
Statue at UWA



Rock shelter, Weld Range, Western Australia
Derived from 350 photographs

Outline

- Introduction, Outcomes, Motivation
- Software
- Photography
- Example 1: 2.5D
- Geometry processing
- Example 2: 3D
- Other topics (Accuracy)

Break

- Limitations and challenges
- Worked example 3: Grinding stone
- Additional / Advanced topics
- Questions and discussion

These slides will be made available online at http://paulbourke.net/vsmm2014/

Sample datasets available on request.

Outcomes

- Familiarity with the state of the technology.
- Knowing what questions to ask.
- Understand the terminology.
- Familiarity with the software and tools.
- Some expectations of the limitations.
- Knowledge of a range of applications/research the technology is being applied to.

- Will not be overly technical but happy to discuss further after the formal part.

3D reconstruction from (ad hoc) photographs

- Goal: Automatically construct 3D geometry and texture based solely upon a number of photographs.
- Similar to traditional photogrammetry but employs different algorithms.
- Creating richer objects (compared to photographs) for recordings in archaeology and heritage.
- Create geometric models suitable for analysis, eg: in geology or geoscience.
- Create digital assets for virtual environments.
- Wish to avoid any in-scene markers required by some solutions.
  Often impractical (access) or not allowed (heritage).
- Want to target automated approaches as much as possible.
  [Recent site survey recorded 100’s of objects].

- Al the examples shown will be applications from the presenters work.

Applications : Virtual worlds, Serious gaming

- Creating 3D assets for virtual environments, serious games.
- Removes the need for time consuming 3D modelling.
- Removes the interpretation that occurs when modelling organic / complicated shapes.

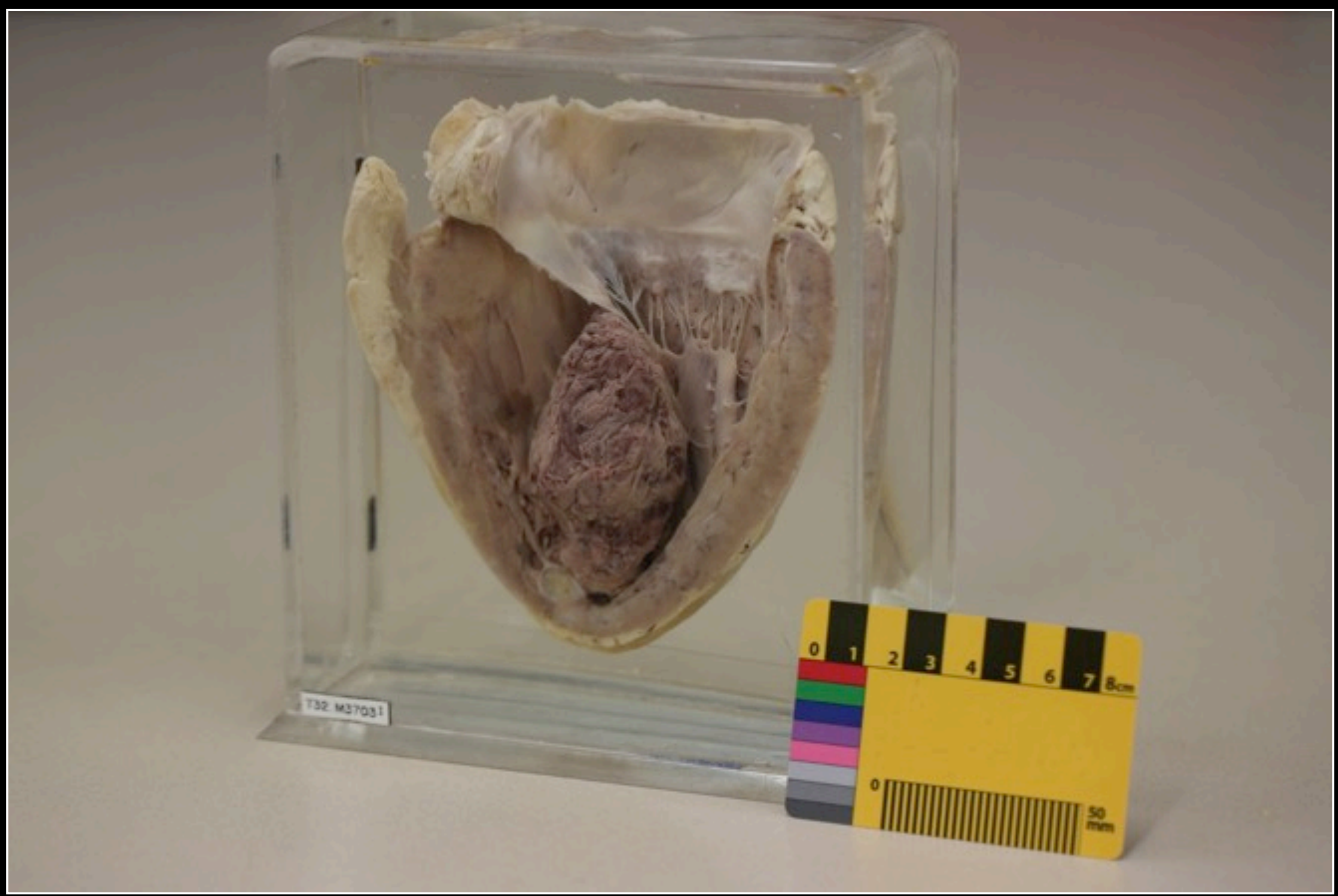
Beacon Island

Applications : Assets for virtual environments

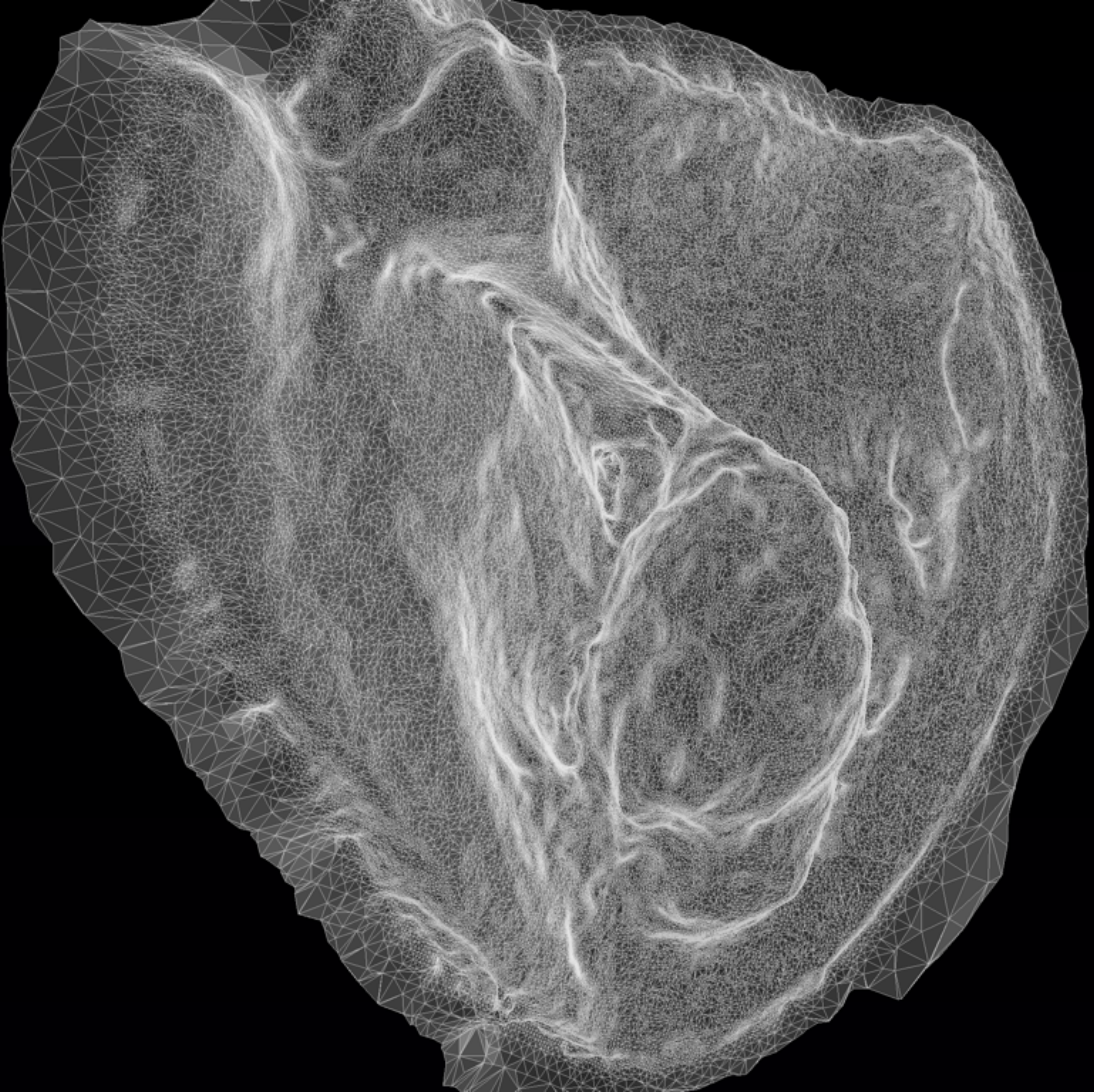
Beacon Island Virtual environment

Applications : Teaching in medicine

- Medical applications (eg: Feeding mothers breast volume)
- Non intrusive and non contact capture can have advantages.
- Capture of 3D objects for forensic analysis.
- Current project digitising teaching collection of diseased body parts.

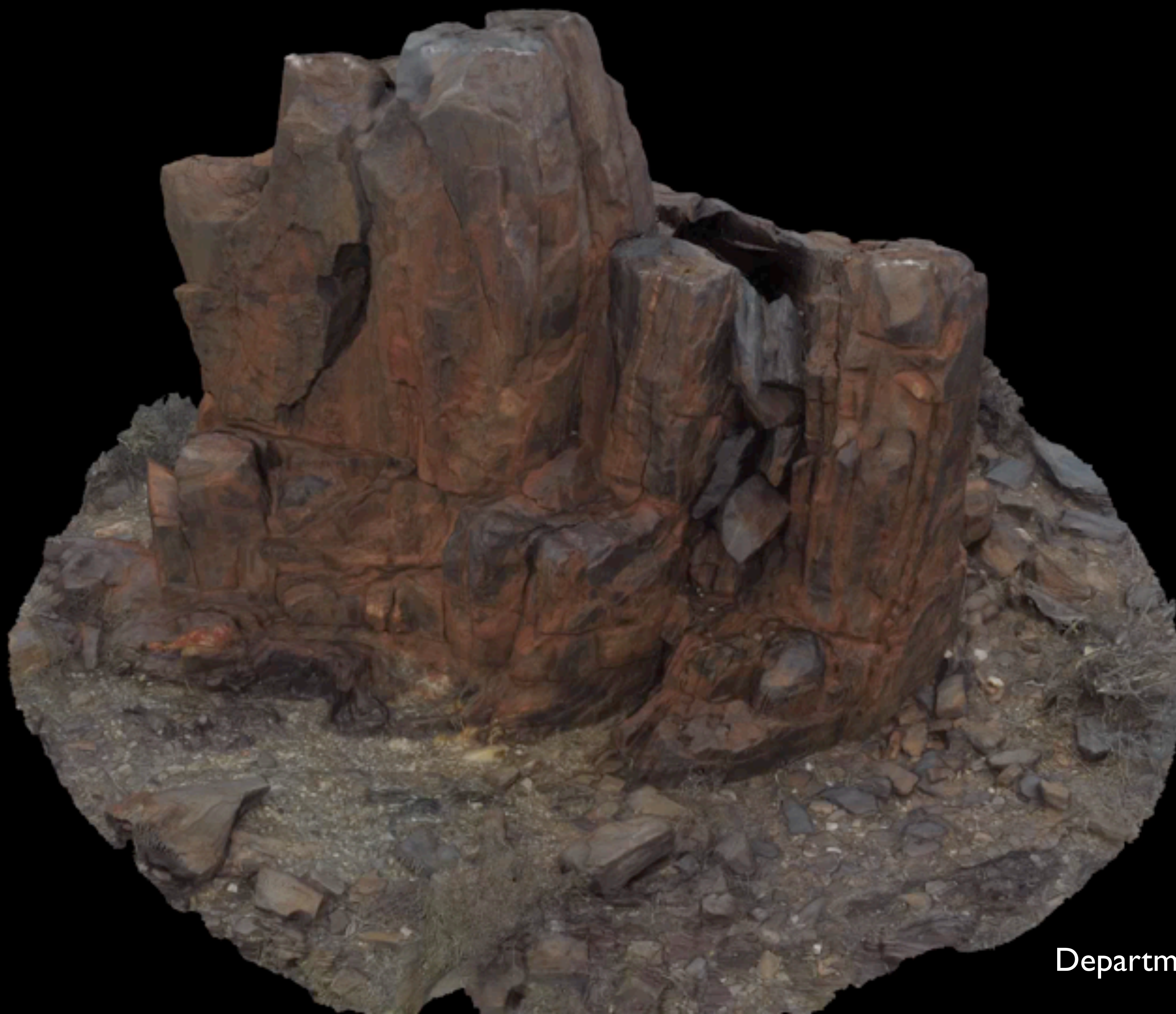


Pathology, QE II



Applications : Geoscience

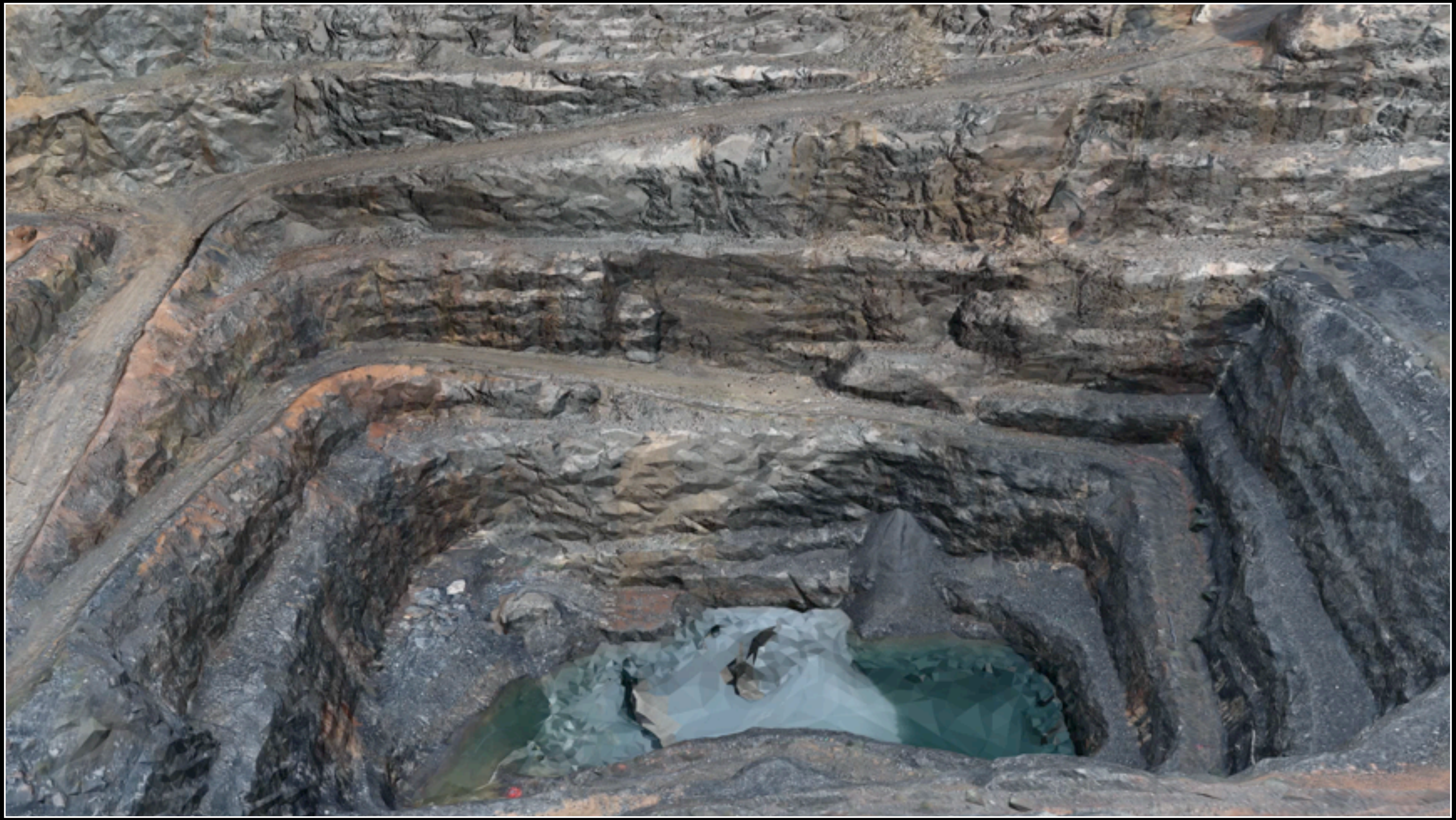
- Capturing geological structures for analysis.
- Often in difficult terrain and remote locations.



Department of Mines and Petroleum

Applications : Mining

- Capture rock volume removed in mining operations. Accuracy is critical.
- Advantages from a safety perspective, don't have to close down operations to allow surveyors on site.



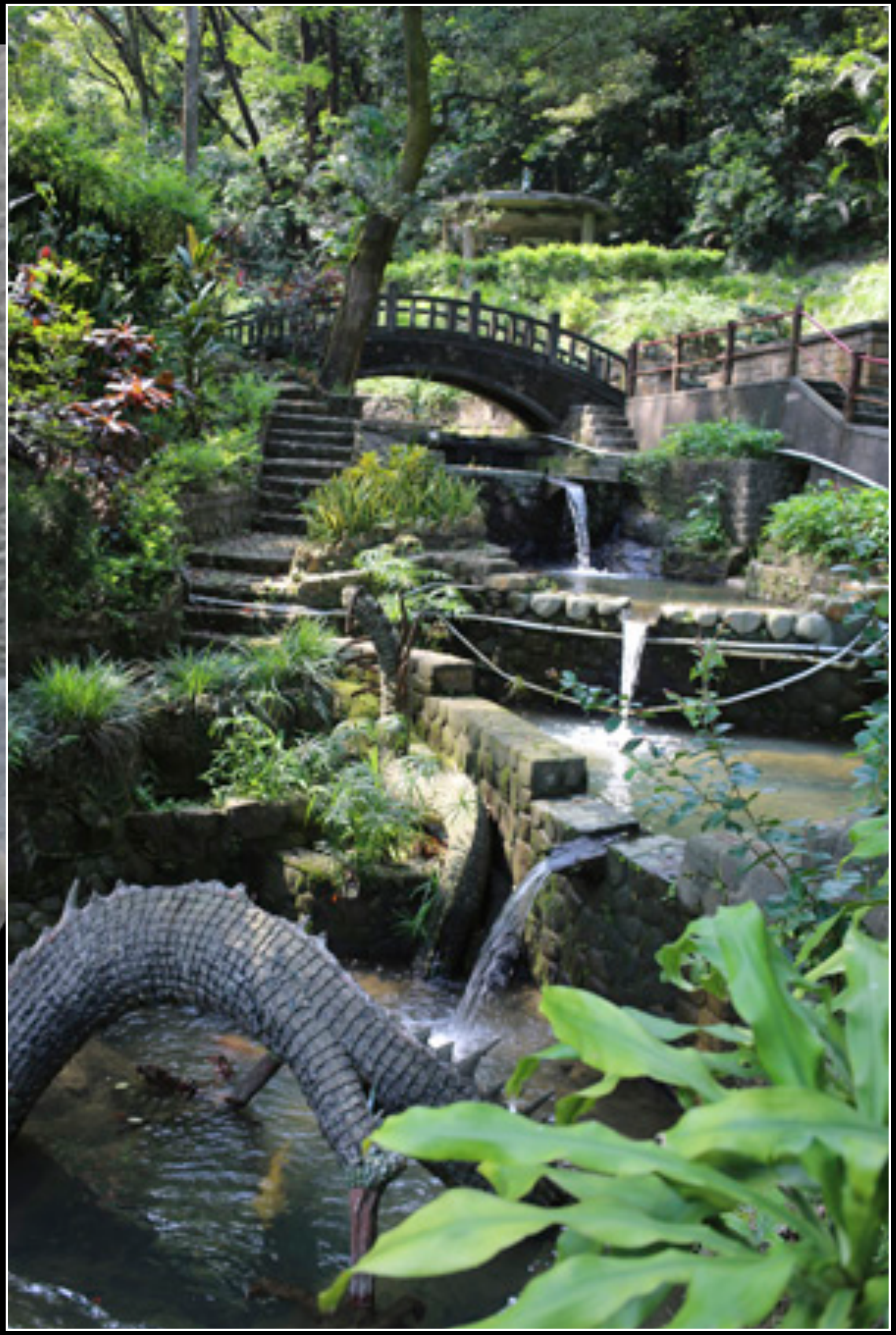
Centre for Exploration Targeting, UWA

Applications : Artefacts in cultural heritage

Remote in-the-field capture

Ngintaka headdress, South Australia Museum

Applications : Digital capture in heritage



Dragon Gardens, Hong Kong

History

- Photogrammetry is the general term given to deriving geometric information from a series of images.
- Initially largely used for aerial surveys, deriving landscape models.
Originally only used a stereoscopic pair, that is, just two photographs.
- More recently the domain of machine vision, for example: deriving a 3D model of a robots environment.
- Big step forward was the development of SfM algorithms: structure from motion.
This generally solves the camera parameters and generation of a 3D point cloud.
- Most common implementation is called Bundler: “bundle adjustment algorithm allows the reconstruction of the 3D geometry of the scene by optimizing the 3D location of key points, the location/orientation of the camera, and its intrinsic parameters”.

Other technologies

- In some areas it is starting to replace technologies such as laser scanning. LIDAR - light detection and ranging.
  - particularly so for capture in difficult locations
  - only requires modest investment
  Questions of accuracy to be discussed later.

- Another technology are so called depth cameras.
  - Primesense (eg: Kinect)
  - Structured light techniques (eg: Artec Scanner)
  Operate in limited range of lighting conditions, data tends to be quite noisy. Limited range.

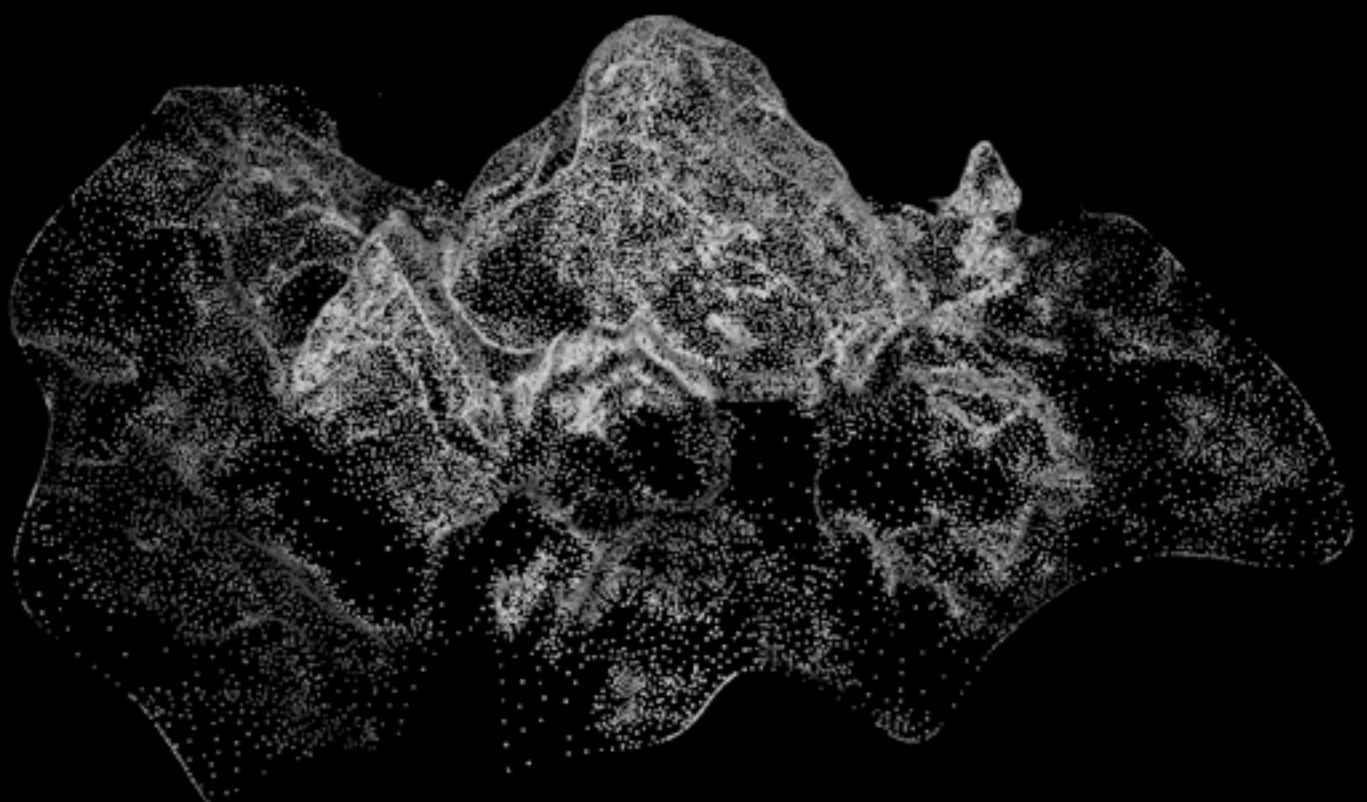
- Light field cameras (plenoptic camera).
  - Captures an array of images from a grid of positions
  - Currently resolution is too low.

LIDAR

Structured light

Software (A selection only)

- Processing pipeline from a number of opensource projects **[HPC]**
- SiroVision
- PhotoScan **[Desktop]**
- PhotoSynth
- PhotoModeller Scanner
- 123D Catch
- Visual SfM (Structure from Motion)
- Apero
- AdamTech solution
- iWitness Pro
- .... lots of others.
  Major aspect of the work we are doing is to evaluate the various tools.



Software : Pipeline components

- Perform lens calibration (only done once, increasingly optional optional).
- Read images, correct for lens, and compute feature points between them.
(eg: SIFT - scale invariant feature transform)
- Compute camera positions and other intrinsic camera parameters.
(eg: Bundler, SfM - Structure from Motion, http://phototour.cs.washington.edu/bundler/)
- Create sparse 3D point cloud, called “bundle adjustment”.
(eg: PMVS - Patch-based Multi-view Stereo, http://www.di.ens.fr/pmvs/)
- Create dense point cloud.
(eg: CMVS - Clustering Views for Multi-view Stereo, http://www.di.ens.fr/cmvs/)
- Form mesh from dense point cloud.
(eg: ball pivoting, Poisson Surface Reconstruction, Marching Cubes)
- Reproject images from camera positions to derive texture segments.
- Optionally simplify mesh (eg: quadratic edge collapse decimation) and fill holes.
- Export in some suitable format (eg: OBJ files with textures).

Software : Typical HPC pipeline

SIFT for key point extraction between images

↓

SfM software package Bundler to generate a sparse 3D point cloud

↓

PMVS2 (Patch-based Multiview Stereo software) to reconstruct the model of the imaged scene as dense point cloud

↓

Convert point cloud to mesh

↓

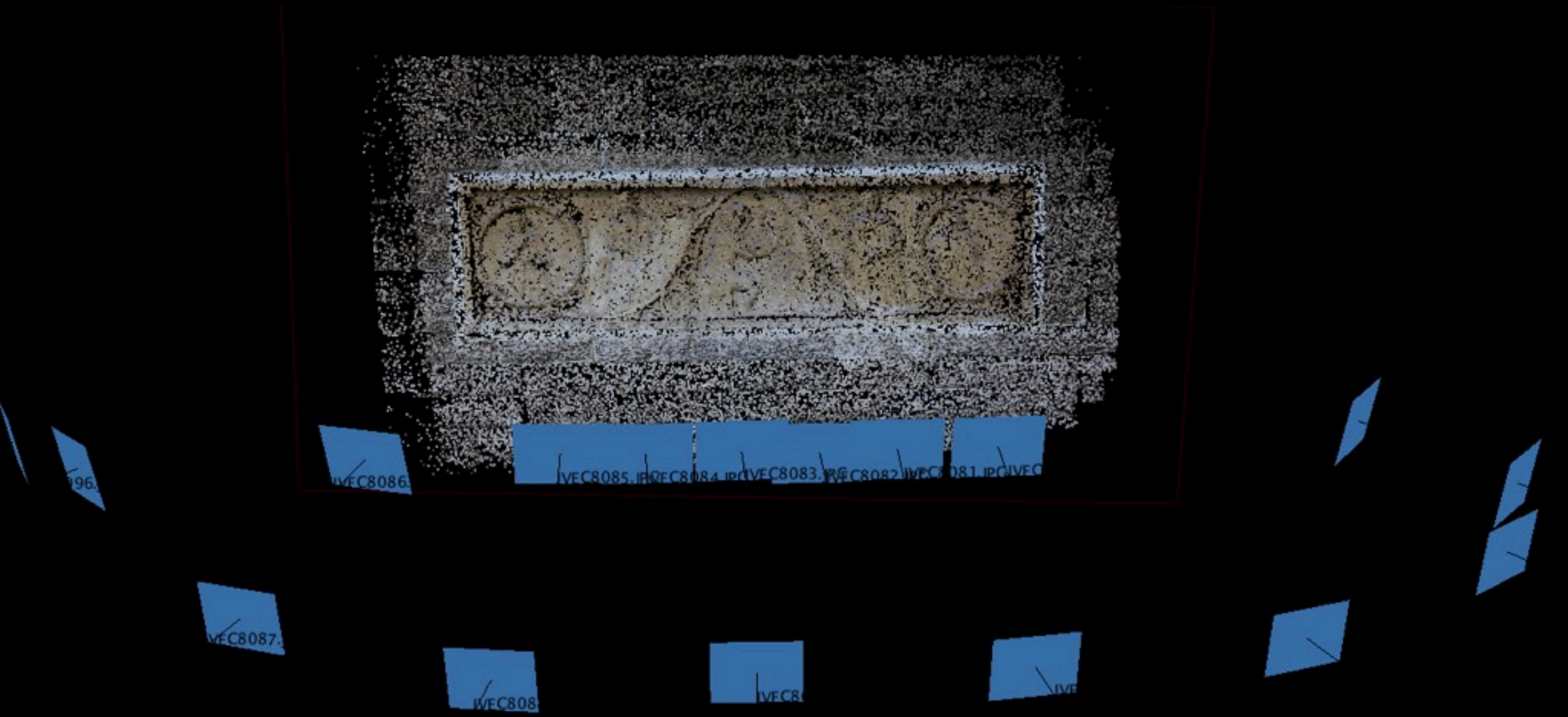
Re-project textures

Software : Pipeline - Photographs

- Don’t take two photos from the same position.
- Obviously can’t reconstruct what is not photographed.
- In general, more is better. Can always process just a subset of the images.

Software : Pipeline - Sparse point cloud

- Find matching points between photographs, feature point detection.
  SIFT - scale invariant feature transform
- Compute camera positions and other intrinsic camera parameters.
  Bundler, SfM - Structure from Motion

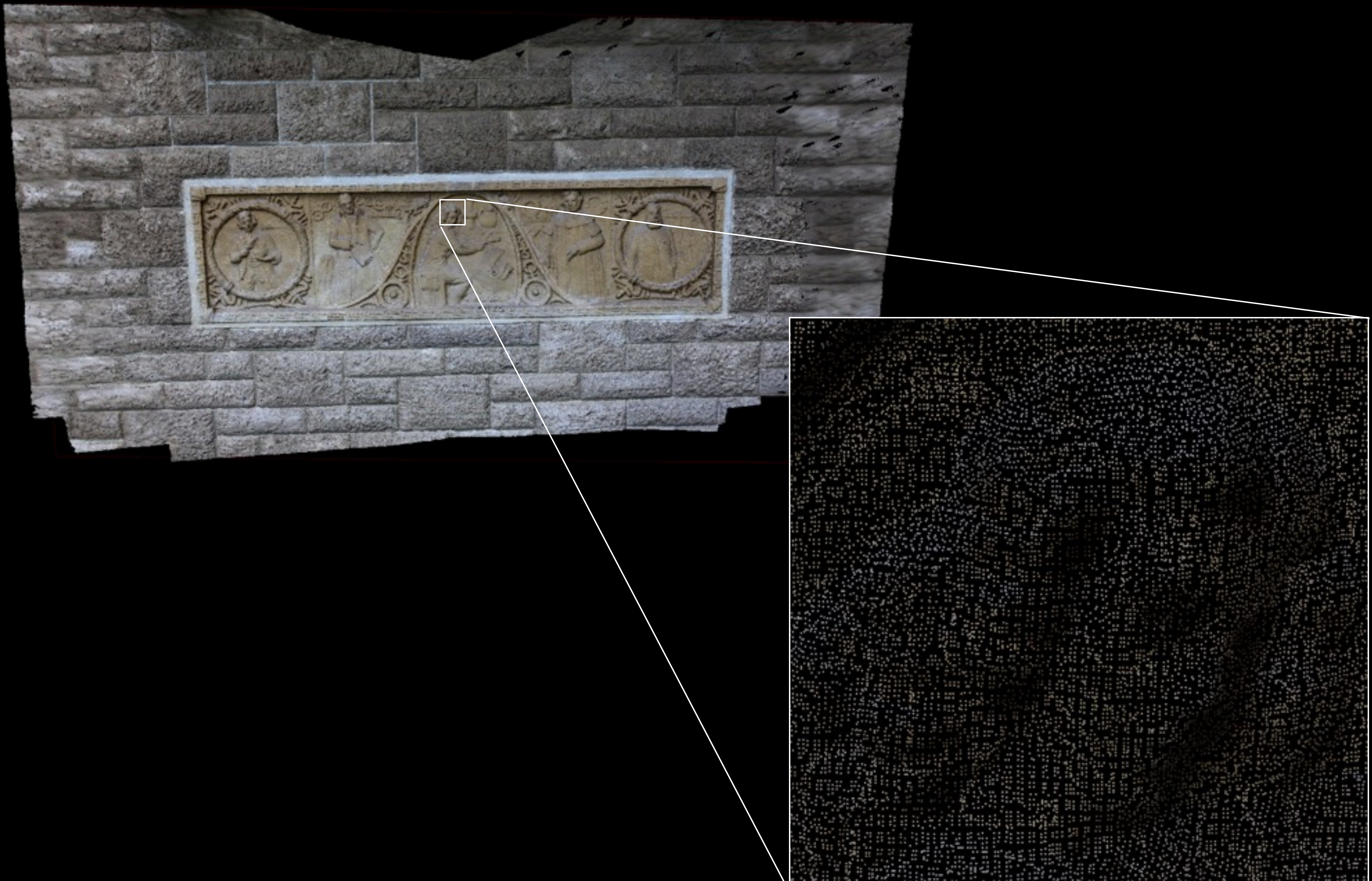


Software : Pipeline - Dense point cloud

- CMVS - Clustering Views for Multi-view Stereo.

UWA Geography Building

Software : Pipeline - Dense point cloud



Software : Pipeline - Mesh generation

- Various algorithms: Ball pivoting, Poisson Surface Reconstruction, Marching Cubes.
- Optionally simplify mesh (eg: quadratic edge collapse decimation) and fill holes.

Software : Pipeline - Texture mesh

- Re-project photographs from derived camera positions onto mesh.

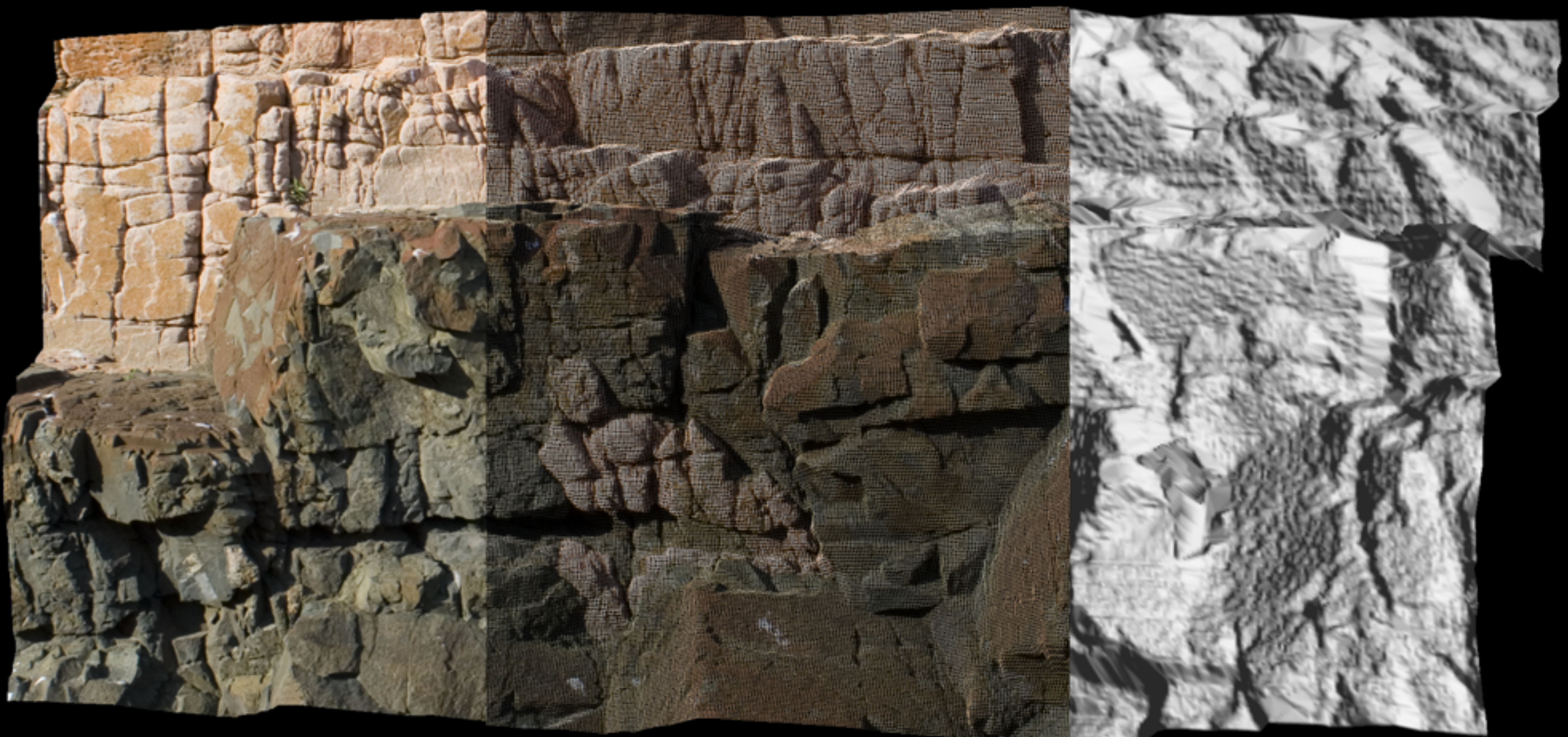
UWA Geography Building

Software : Pipeline - Export

UWA Geography Building

Software : Sirovision (http://sirovision.com)

- Captured from 2 images only, stereo pairs but with wide base line separation.
- With in-scene markers and calibrated lens claims 3 to 5cm accuracy at 100m distance.
- Targeted mining industry, developed by CSIRO.



Textured Mesh Surface

Software : PhotoSynth

- Microsoft, MSWindows only (obviously)
  http://photosynth.net

- Based upon Bundler. GUI front end, computed remotely.

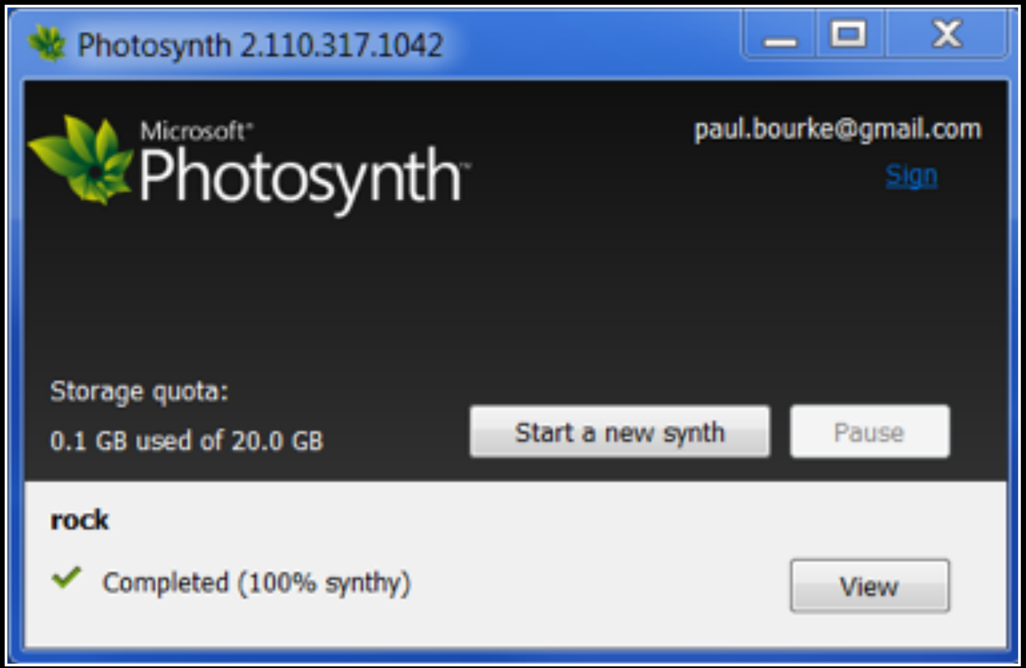
- Provides a “image effect” based upon reconstructed surface.

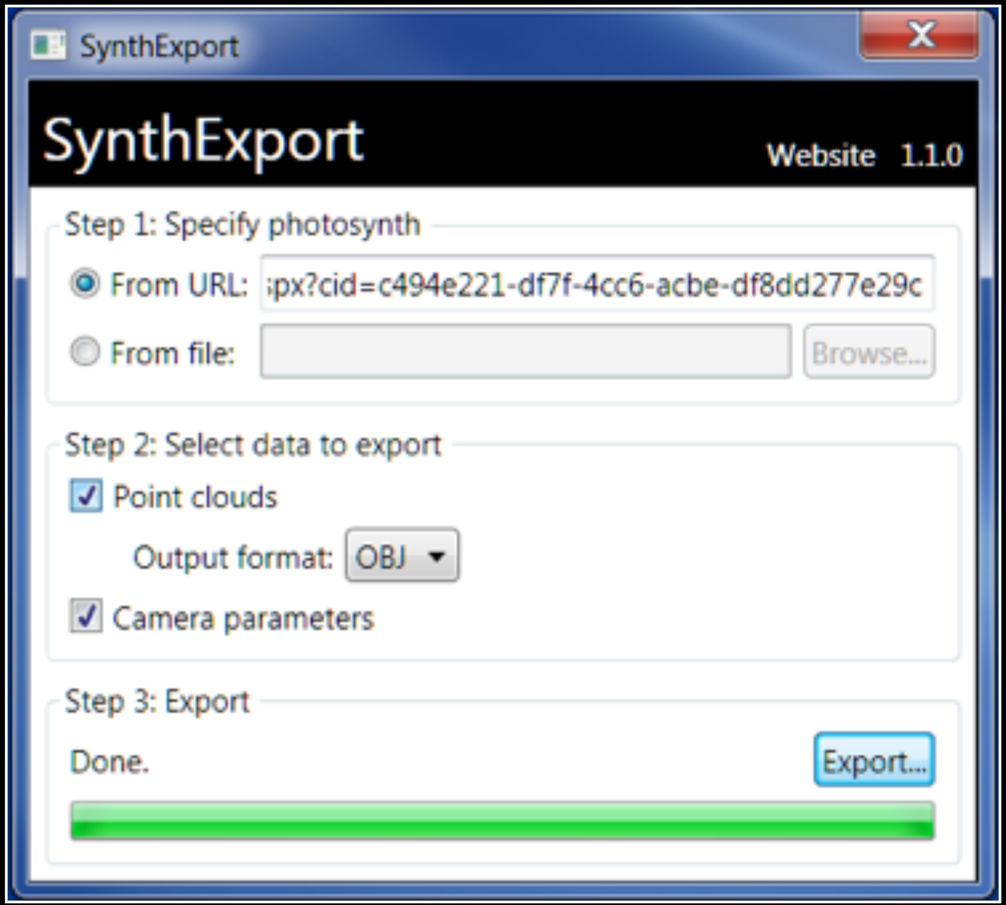
- Can be useful for identifying image sets for other pipelines.

- Not possible to extract the mesh/texture data from within the online software.

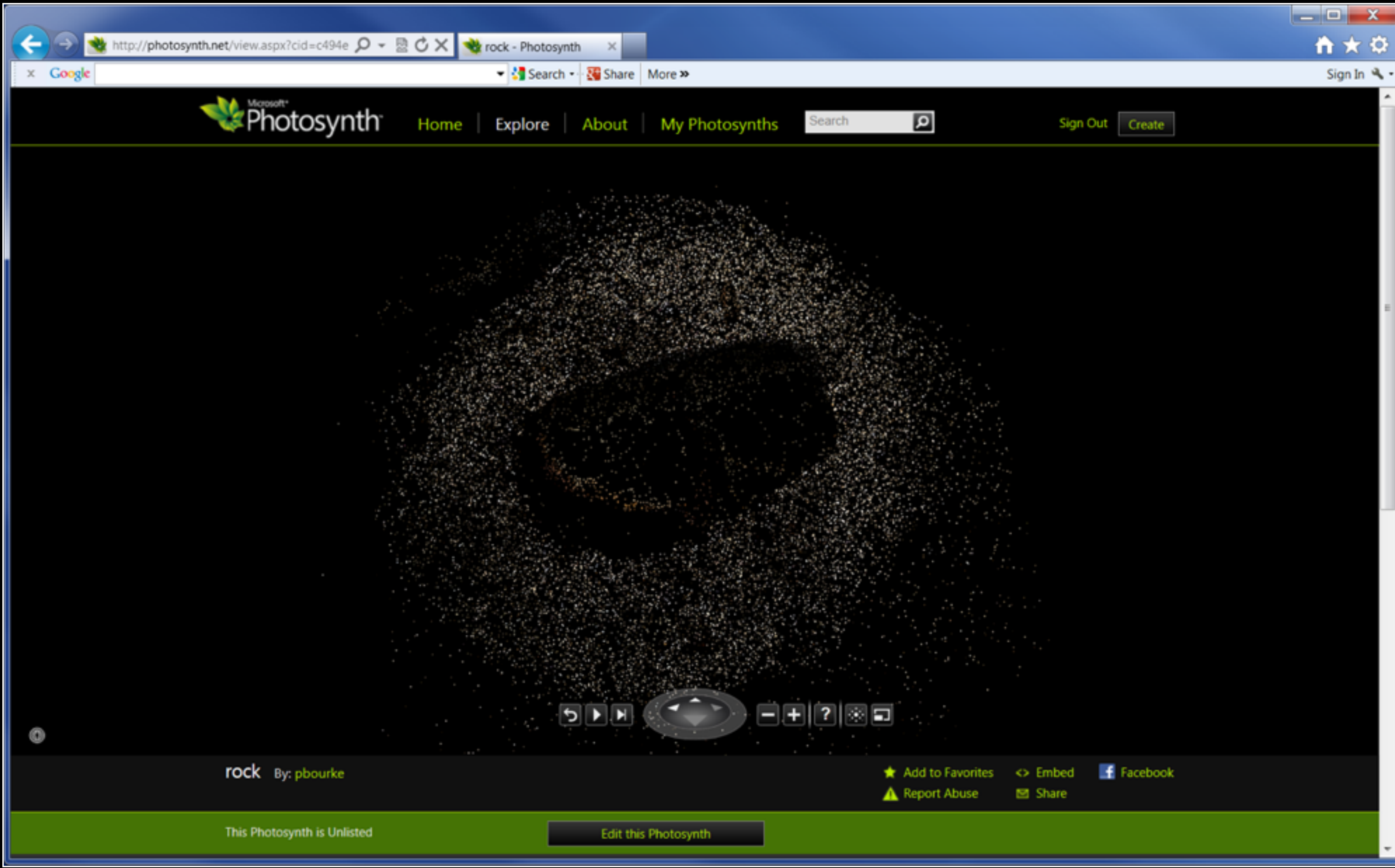
- Synth Export
  http://synthexport.codeplex.com/
  Provides point cloud and camera parameter export. Would need to reconstruct mesh by other means.

- Not a leading edge tool any more.

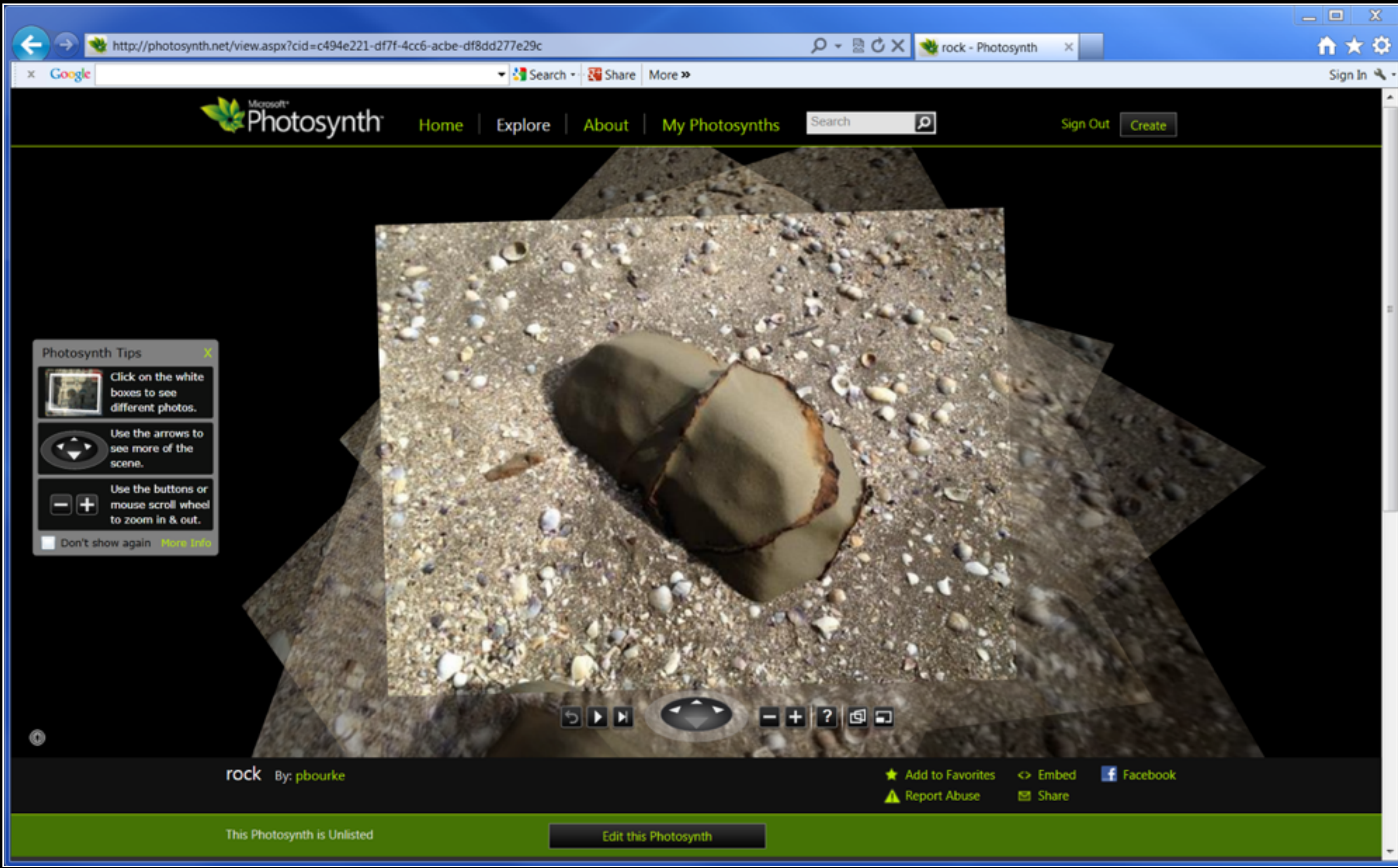




Software : PhotoSynth



Software : PhotoSynth

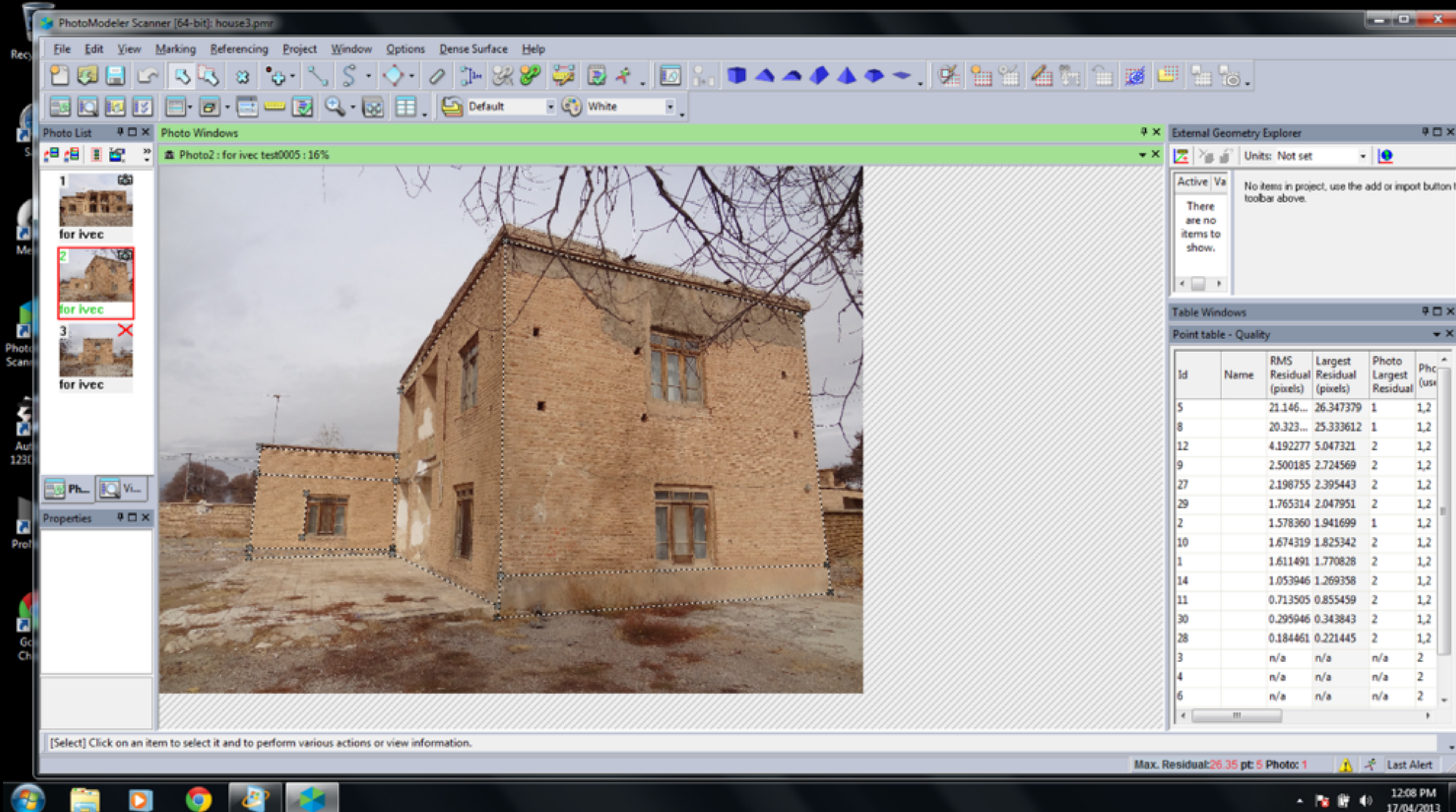


Software : PhotoModeller Scanner

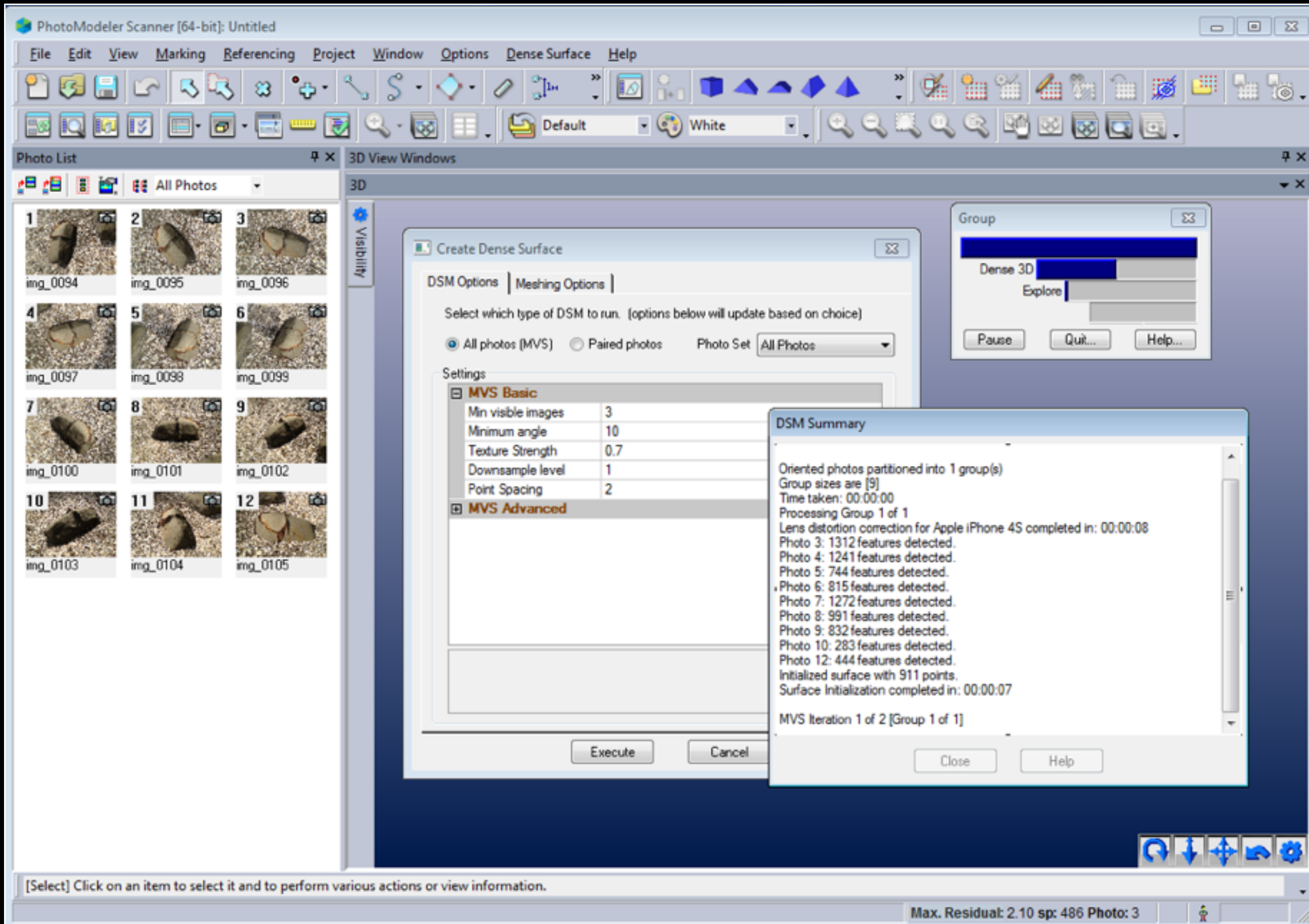
- From EOS systems.
- http://www.photomodeler.com/
- Comes in two flavours, the standard package is for human driven extraction of rectangular objects such as building facades.
- PhotoModeller Scanner is for more organic shapes.
- Claims to be capable of very accurate results, generally has a more rigorous procedure.
- Requires manual interaction.
- MSWindows only.

- A contender to PhotoScan but to date have not had better results.
- VERY slow compared to almost everything else.

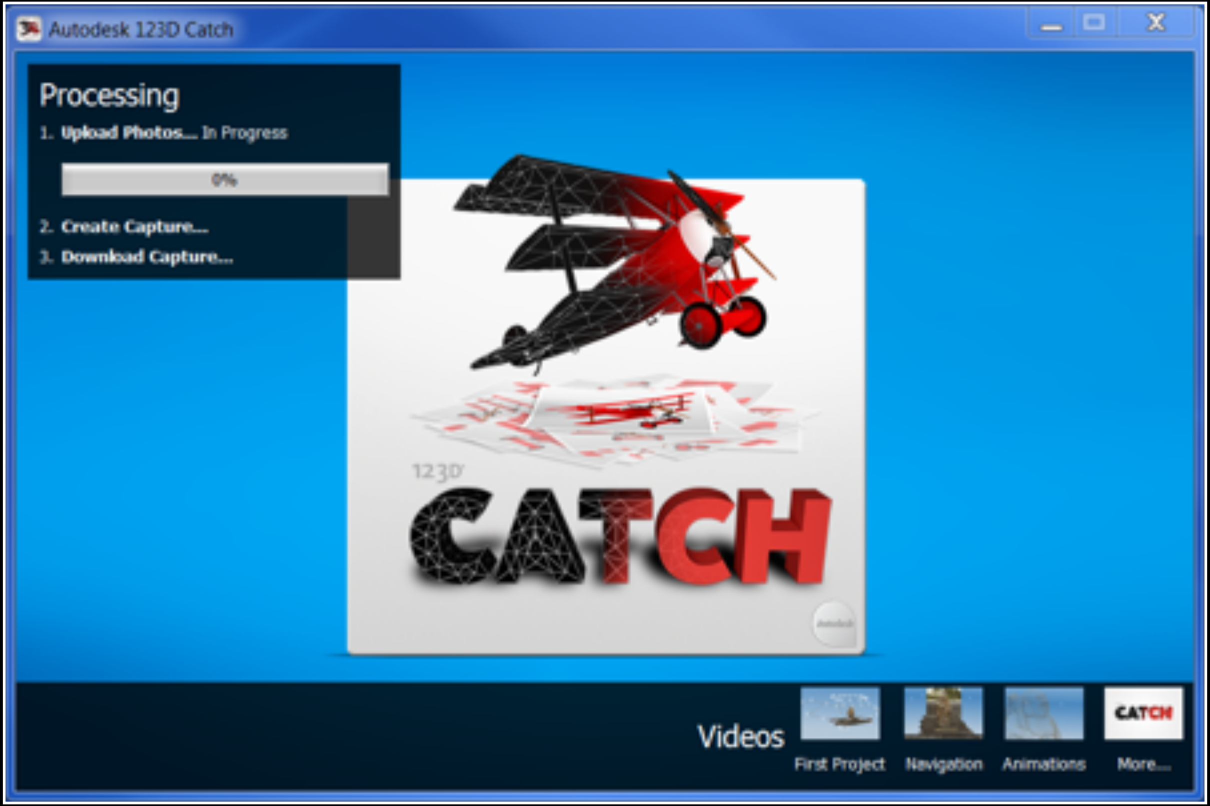
Software : PhotoModeller



Software : PhotoModeller Scanner

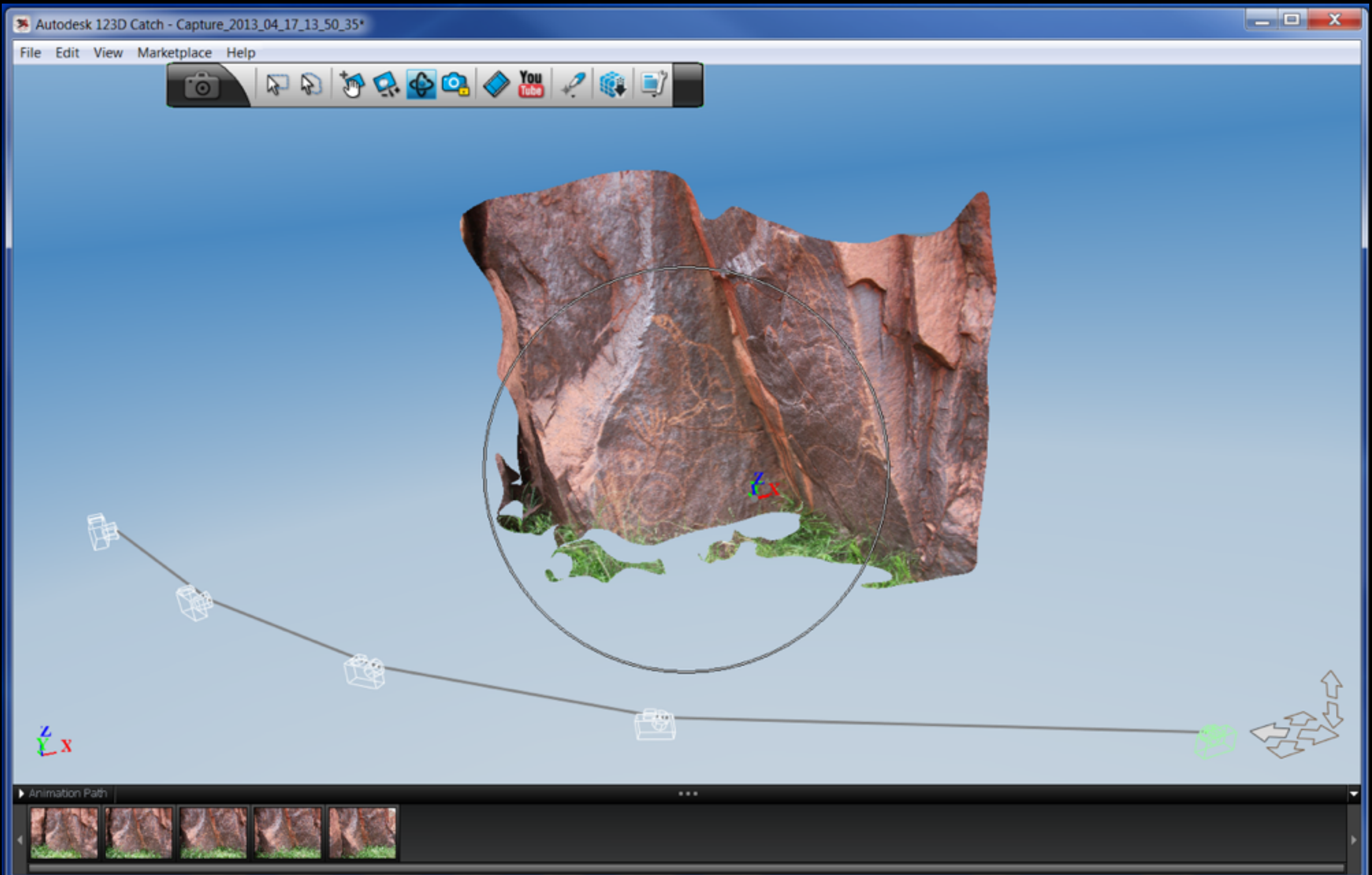


Software : 123D Catch

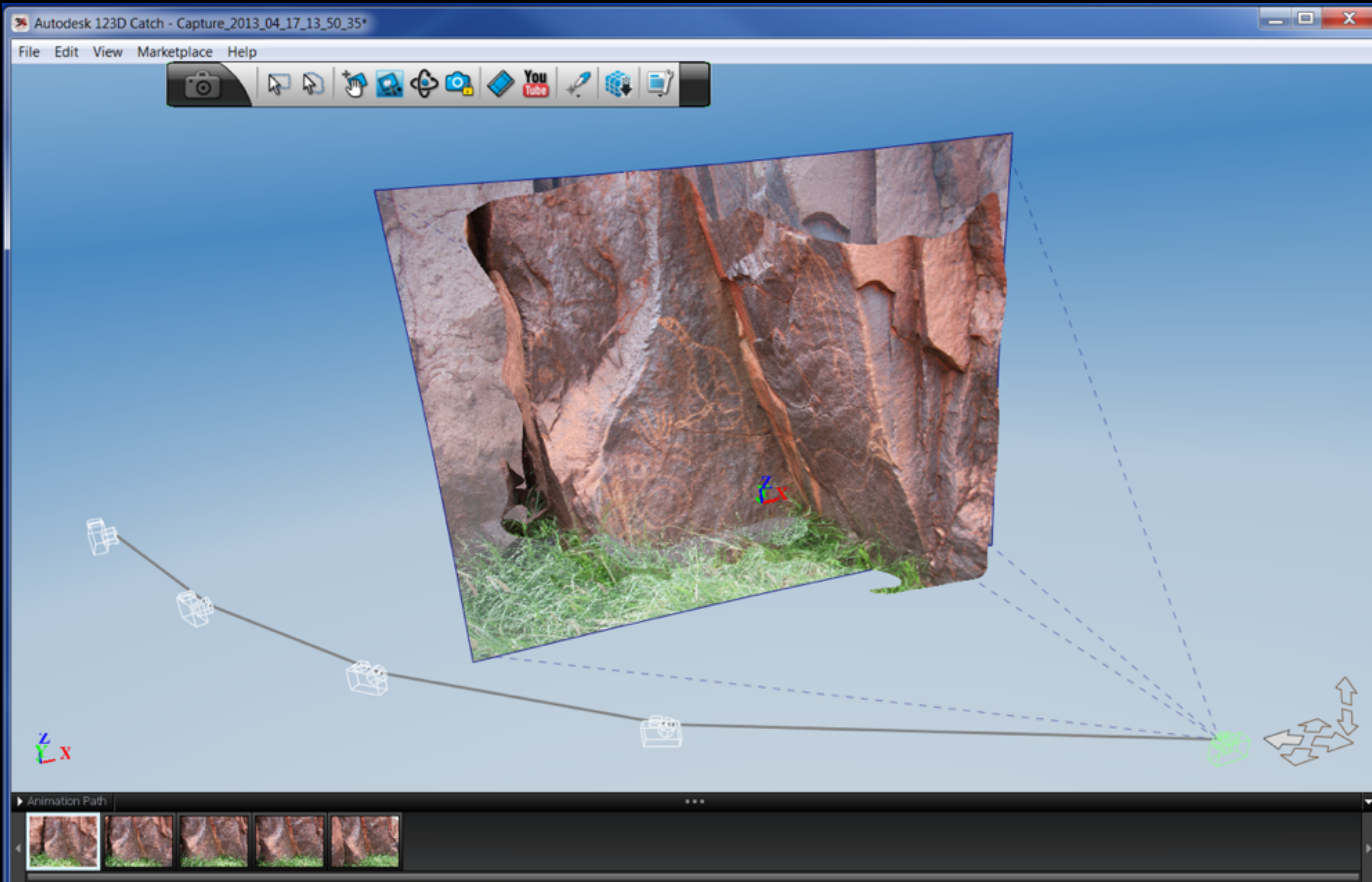


- From AutoDesk.
- Free.
- Cloud based so requires an internet connection.
- Reasonable rate of success but no option to change algorithm parameters if things don't work.
- Does not provide access to intermediate data, such as the point cloud.
- No option for (standard) camera calibration.
- MSWindows only GUI.
- No longer a leading edge solution.

Software : 123D Catch



Software : 123D Catch

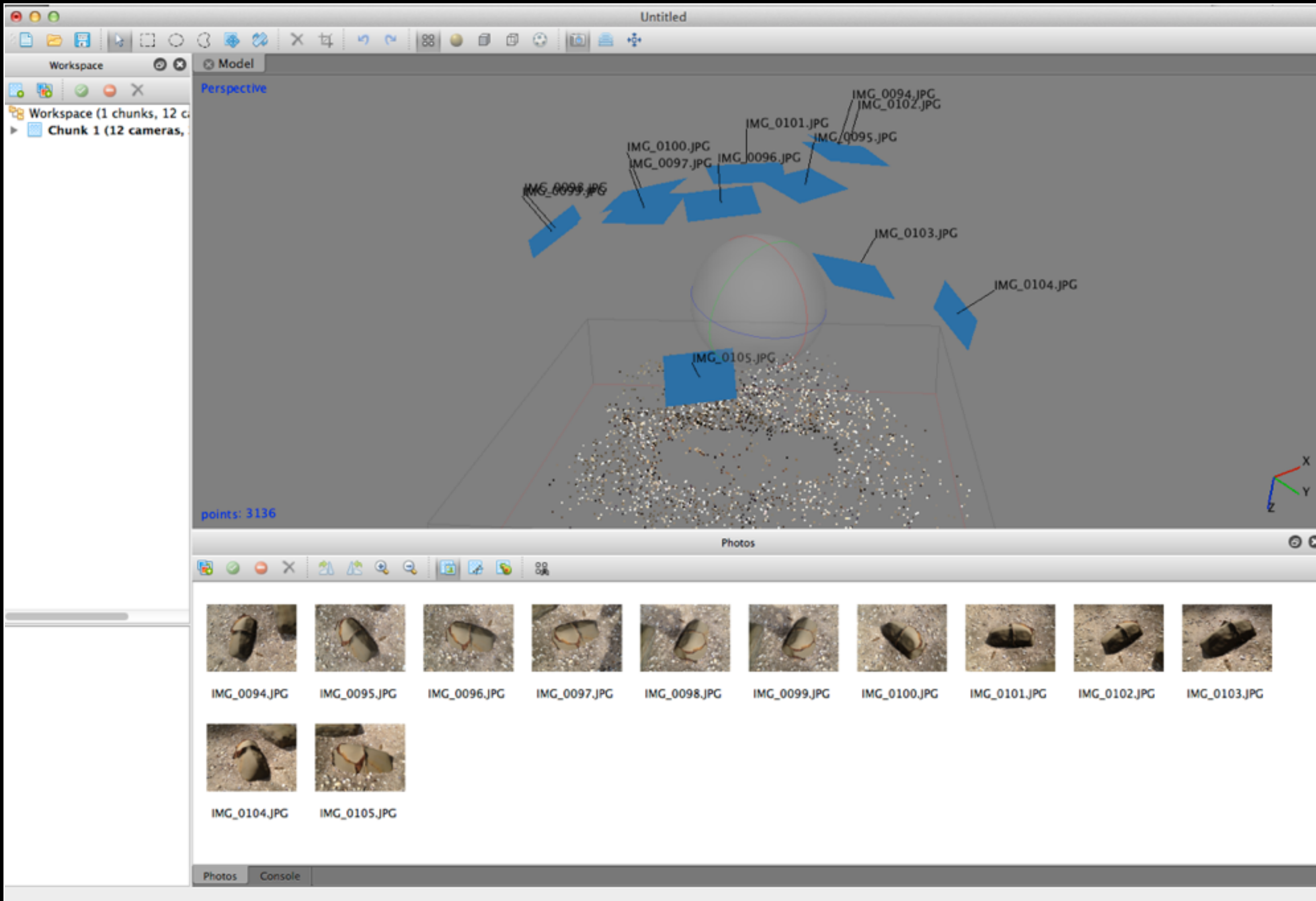


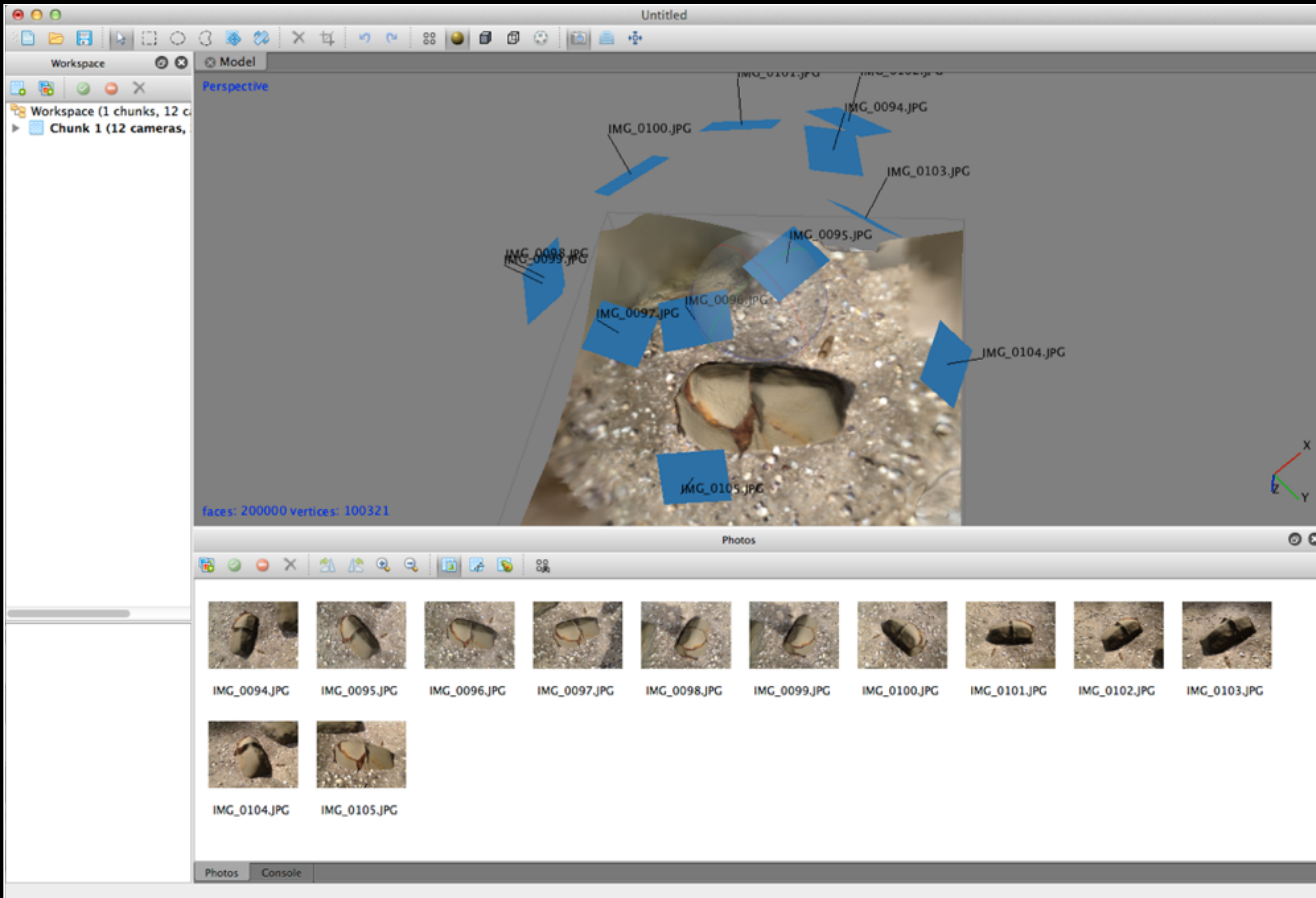
Software : Visual SfM - Bundler

- From the University of Washington.
- An open source distribution of Bundler (MSWindows, Mac, Linux).
- Includes a GPU accelerated implementation.
- Matches images, derives camera attributes, and computes a point cloud.
- Dense point cloud and mesh generation needs to be performed elsewhere.
- http://www.cs.washington.edu/homes/ccwu/vsfm/
- Bundler on Mac OS X called easyBundler.
- http://openendedgroup.com/field/ReconstructionDistribution
- Variations of this are what we run on our HPC machines, scales well.
  Most stages run in parallel except the texture projection.
- A good place to start if interested in OpenSource pipelines.

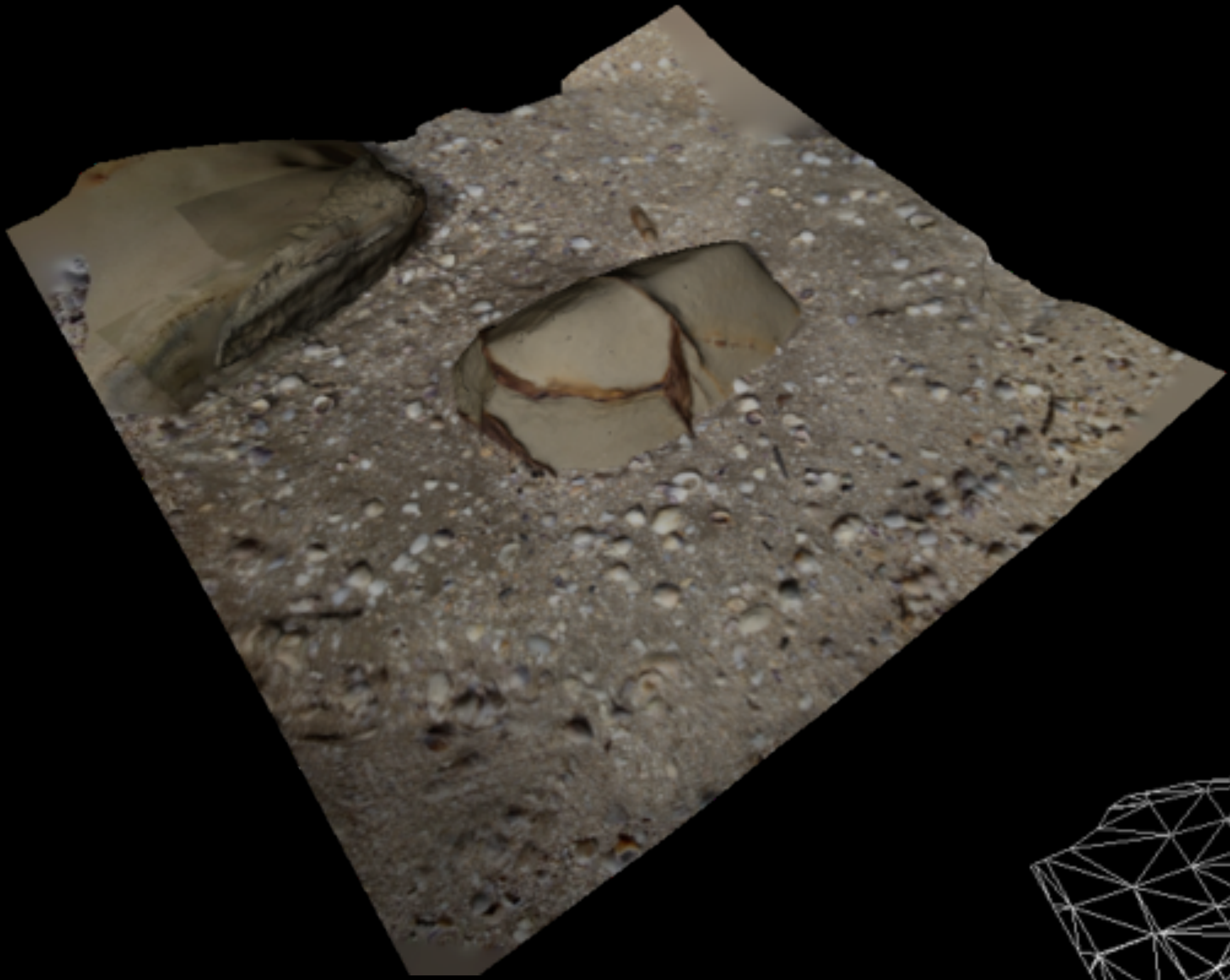
Software : PhotoScan

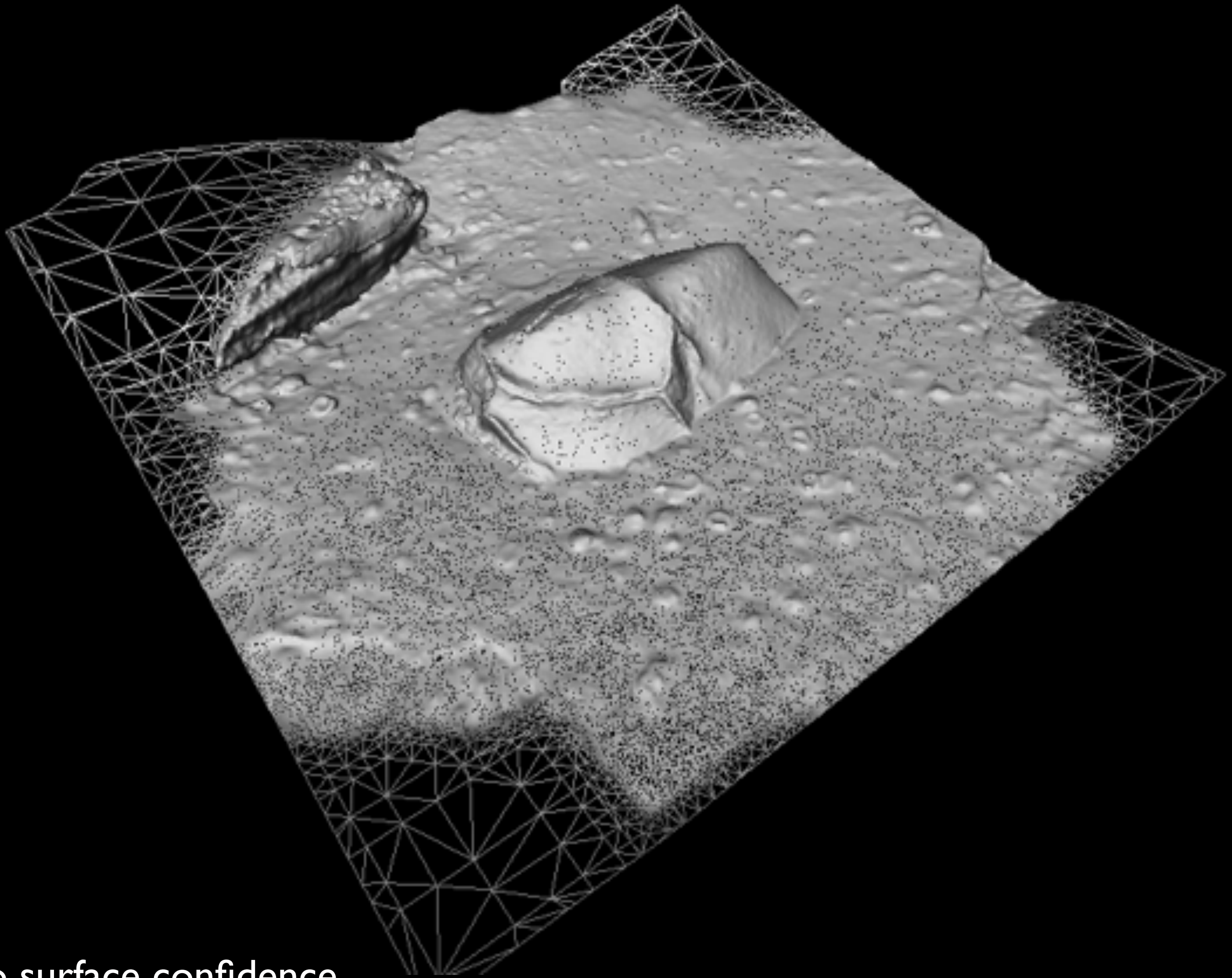
- From AgiSoft. http://www.agisoft.ru/products/photoscan.
- A series of individual steps (pipeline) one follows.
  Offers a batch mode for processing large collections.
- Good mixture between low level control and automation.
  Generally “just works” but can tuned for problematic cases.
- Available for Mac and MSWindows.
- Two versions
  - Standard is quite affordable
  - Pro version largely for georeferencing and other features important for the surveying community.
- Under rapid development ... regularly improving.
- Very stable.
- Fast, all parts of the pipeline seem to load balance well over cores.


Untitled
Workspace
Model
Perspective
Workspace (1 chunks, 12 c
Chunk 1 (12 cameras,
IMG_0094.JPG
IMG_0102.JPG
IMG_0101.JPG
IMG_0095.JPG
IMG_0100.JPG
IMG_0097.JPG
IMG_0096.JPG
IMG_0103.JPG
IMG_0104.JPG
IMG_0105.JPG
points: 3136
X
Y
Z
Photos
IMG_0094.JPG
IMG_0095.JPG
IMG_0096.JPG
IMG_0097.JPG
IMG_0098.JPG
IMG_0099.JPG
IMG_0100.JPG
IMG_0101.JPG
IMG_0102.JPG
IMG_0103.JPG
IMG_0104.JPG
IMG_0105.JPG
Photos
Console



Untitled
Workspace
Model
Perspective
Workspace (1 chunks, 12 c
Chunk 1 (12 cameras,
IMG_0094.JPG
IMG_0100.JPG
IMG_0103.JPG
IMG_0095.JPG
IMG_0098.JPG
IMG_0096.JPG
IMG_0097.JPG
IMG_0104.JPG
IMG_0105.JPG
faces: 200000 vertices: 100321
X
Y
Z
Photos
IMG_0094.JPG
IMG_0095.JPG
IMG_0096.JPG
IMG_0097.JPG
IMG_0098.JPG
IMG_0099.JPG
IMG_0100.JPG
IMG_0101.JPG
IMG_0102.JPG
IMG_0103.JPG
IMG_0104.JPG
IMG_0105.JPG
Photos
Console





Mesh density related to surface confidence.

Software : Distinguishing features

- Degree of human guidedness and interaction required.
- Degree of control over the process, options that support fixing errors.
- Big difference between the need to reconstruct one object vs hundreds.
  My bias is towards largely automated processes.
- Requirement or opportunity for camera calibration. Becoming less necessary.
  Should result in higher accuracy, questionable for a single fixed focal lens.
- Sensitivity to the order the photographs are presented.
- The number of photographs and resolution that can be handled.
- Degree to which one needs to become an “expert”, learning the tricks to get good results.
  - There are a potentially a large number of variables.
  - Trade off between simplicity and control.
  - 123D Catch is at one end of the scale, PhotoModeller Scanner at the other end.
- Ability to create high resolution textures, larger than 4Kx4K, or multiple textures.

Photography : Lenses

- Preferred: fixed focal length lens, also referred to as a “prime lens”.
  - Depends on the software, but generally recommended as it removes one variable to be solved in the Bundler stage.
- EXIF: generally software reads EXIF data from images to determine focal length, sensor size, and in some cases lens make/model for calibration curves.
- Most “point and click” cameras have a fixed focal lenses because they require no moving parts, don’t require electronics (not drawing extra power).
- I use Canon 5D MkIII with prime lenses: 28mm, 50mm, 100mm macro.

Sigma 28mm, f1.8

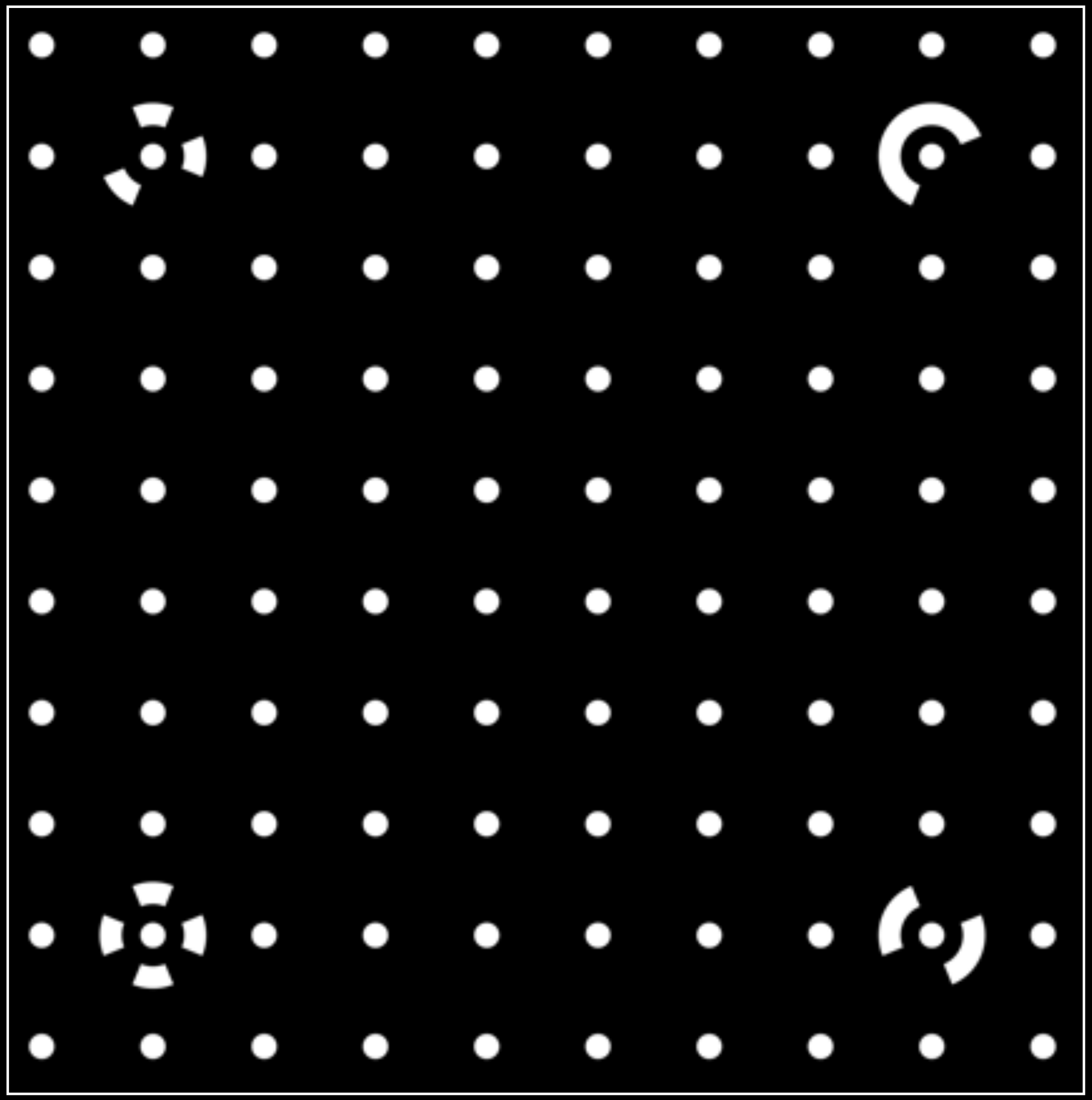
Sigma 50mm, f1.4

Photography : shooting guide

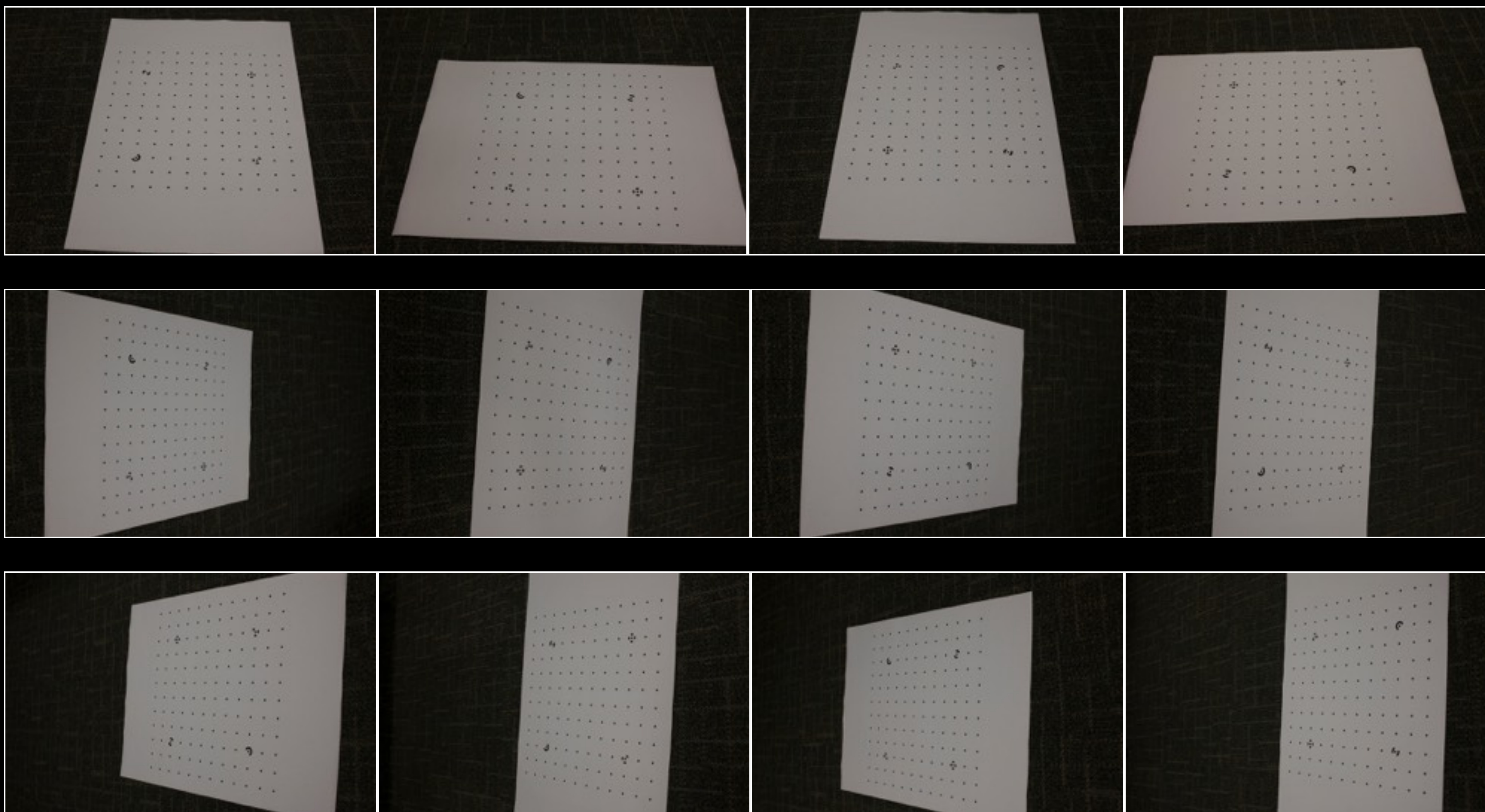
- Obviously one cannot reconstruct what one does not capture.
- Aim for plenty of overlap between photographs (Can always remove images).
- For 2.5D surfaces as few as 2 shots are required, more generally 6 - 20.
- For 3D objects typically 20 or more. ~ 10 degree steps.
  Repeat at one or more levels if the object is concave vertically.
- For extended objects and overlapping photographs perhaps hundreds.
  1/3 to1/2 image overlap ideal.
- Historically worked better for the images to be captured in order moving around the object, this is being relaxed in the latest algorithms.
- Generally no point capturing multiple images from the same position!
  The opposite of panoramic photography for example.
- Camera orientation typically doesn’t matter, this is solved for when computing camera parameters in the Bundle processing.
- Lens calibration is becoming less important as standard lens have online published curves. Still necessary for accurate results from unusual lenses.

Photography : Camera calibration

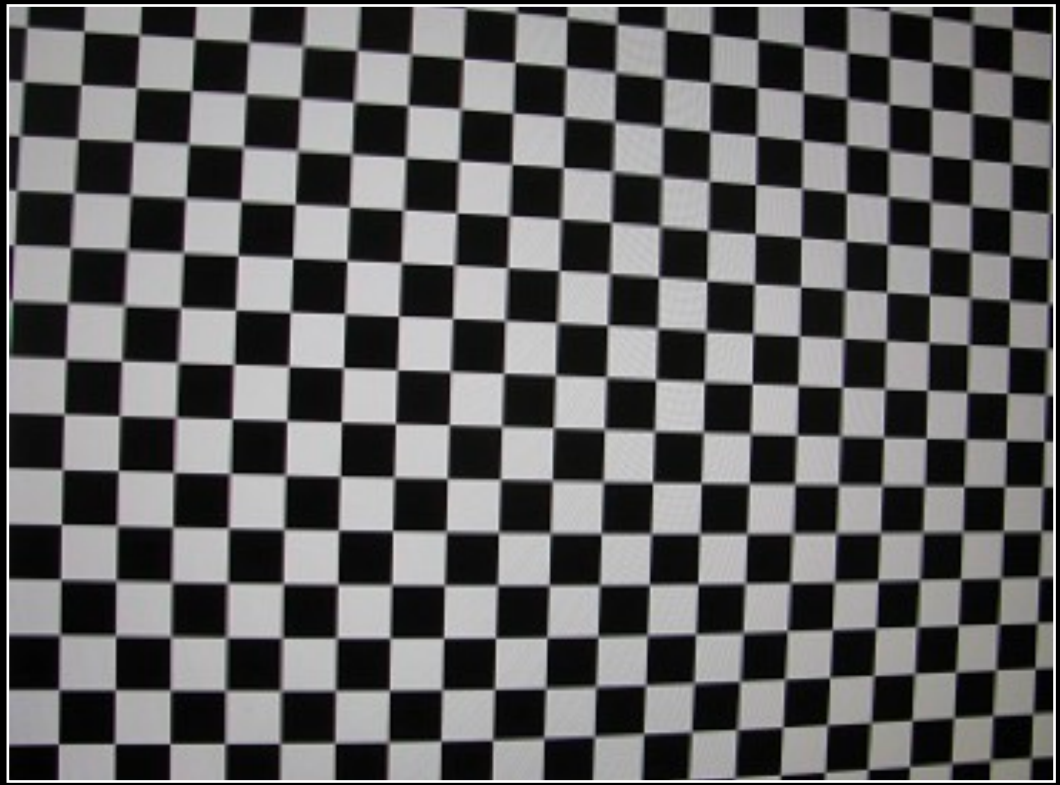
- Camera/lens characteristics derived photographs of a known pattern.
- Different procedures depending on the software.
- Calibration pattern used by PhotoModeller shown here: printed A1 sheet.



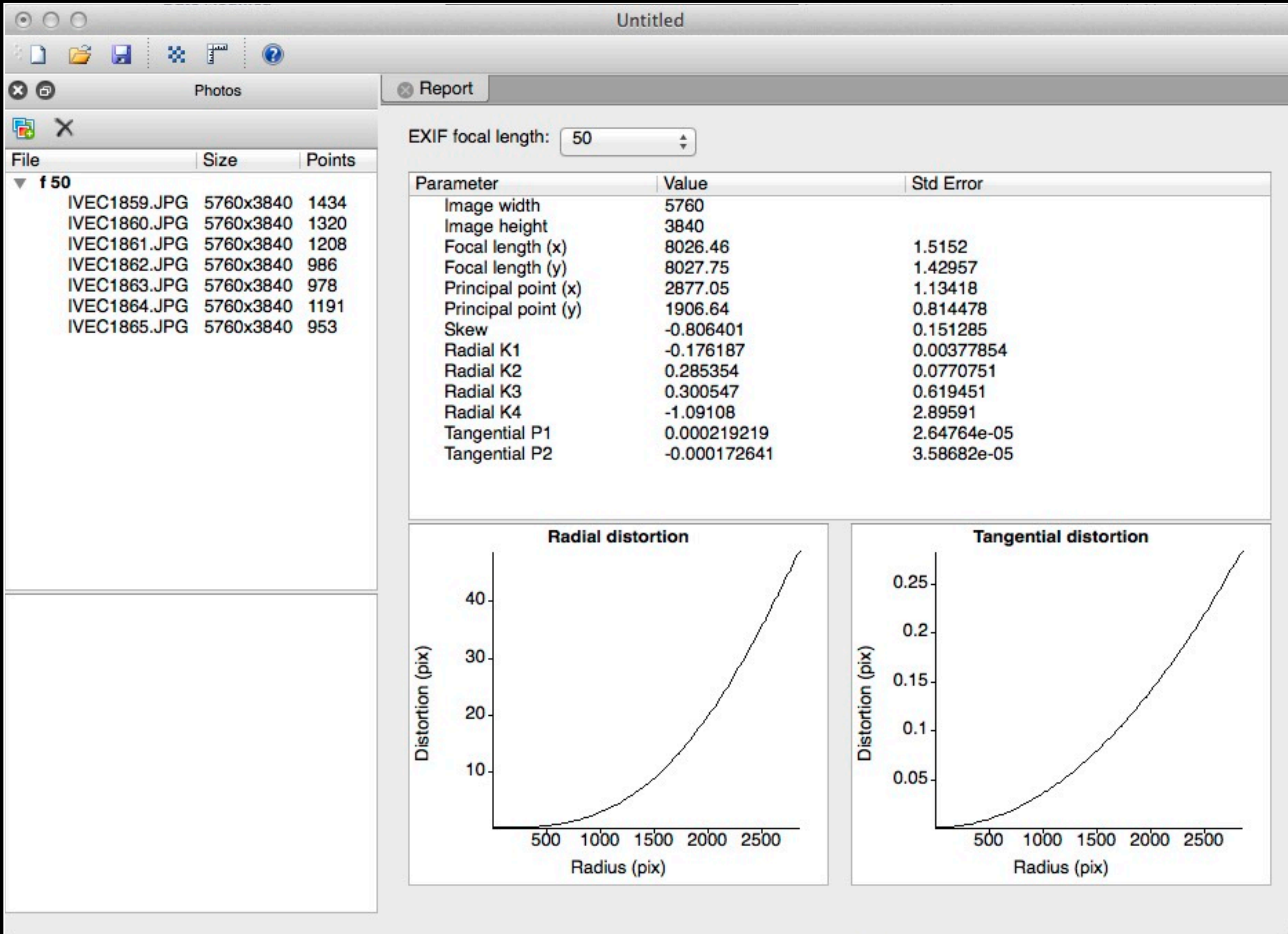
- 4 photographs captured (one from each direction).
- Repeated with the camera in three orientations (rotated 90, 0, -90).



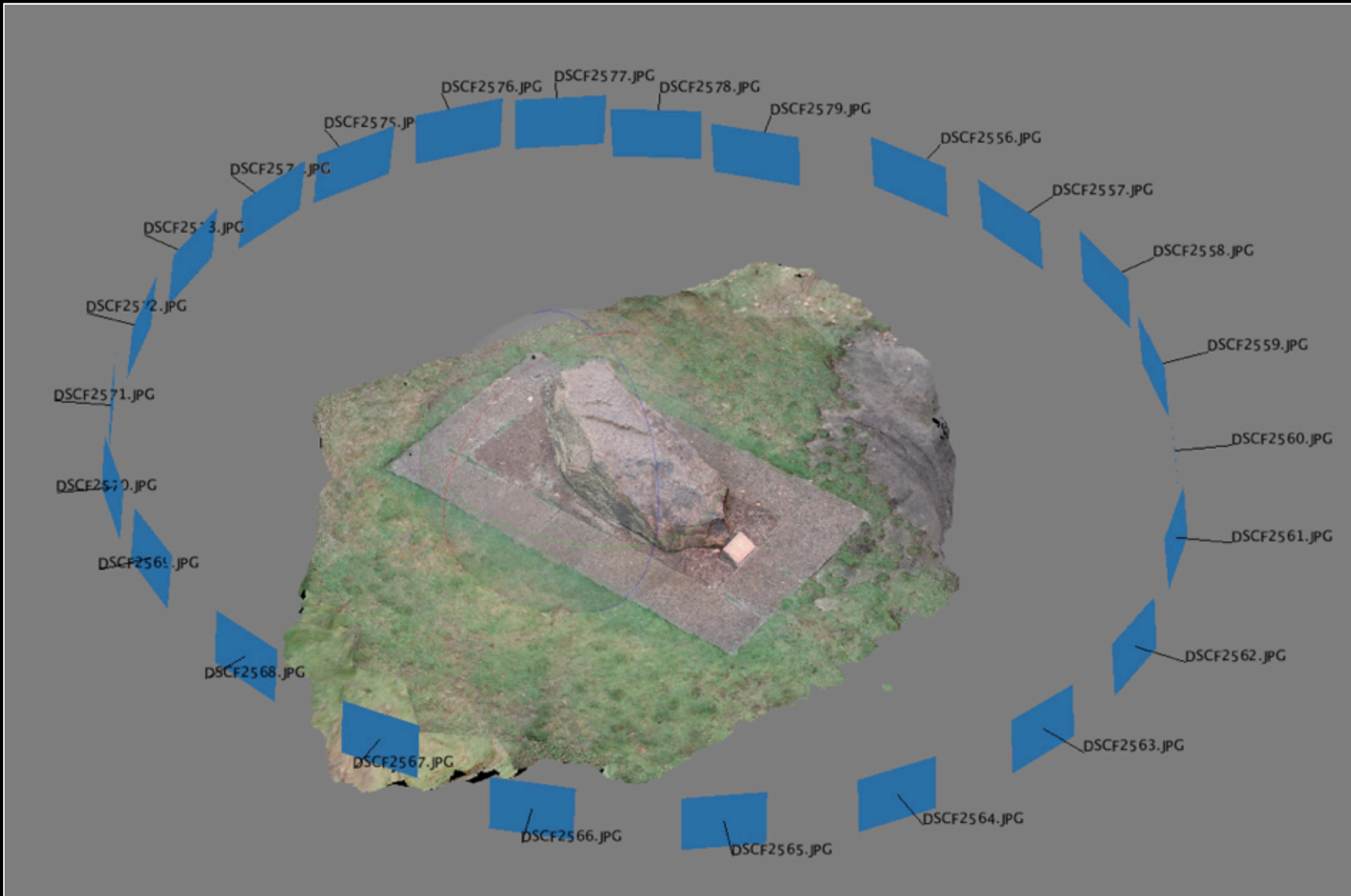
- PhotoScan provides a separate utility called "lens".
- Estimates
  - focal length in both directions
  - principle point components in both directions
  - radial and tangential distortion coefficients
- fx, fy,   cx, cy,   K1,K2,K3,   P1,P2
- Produces a display on screen to photograph from different directions.
- Generally doesn't solve for focal length, reads from EXIF.

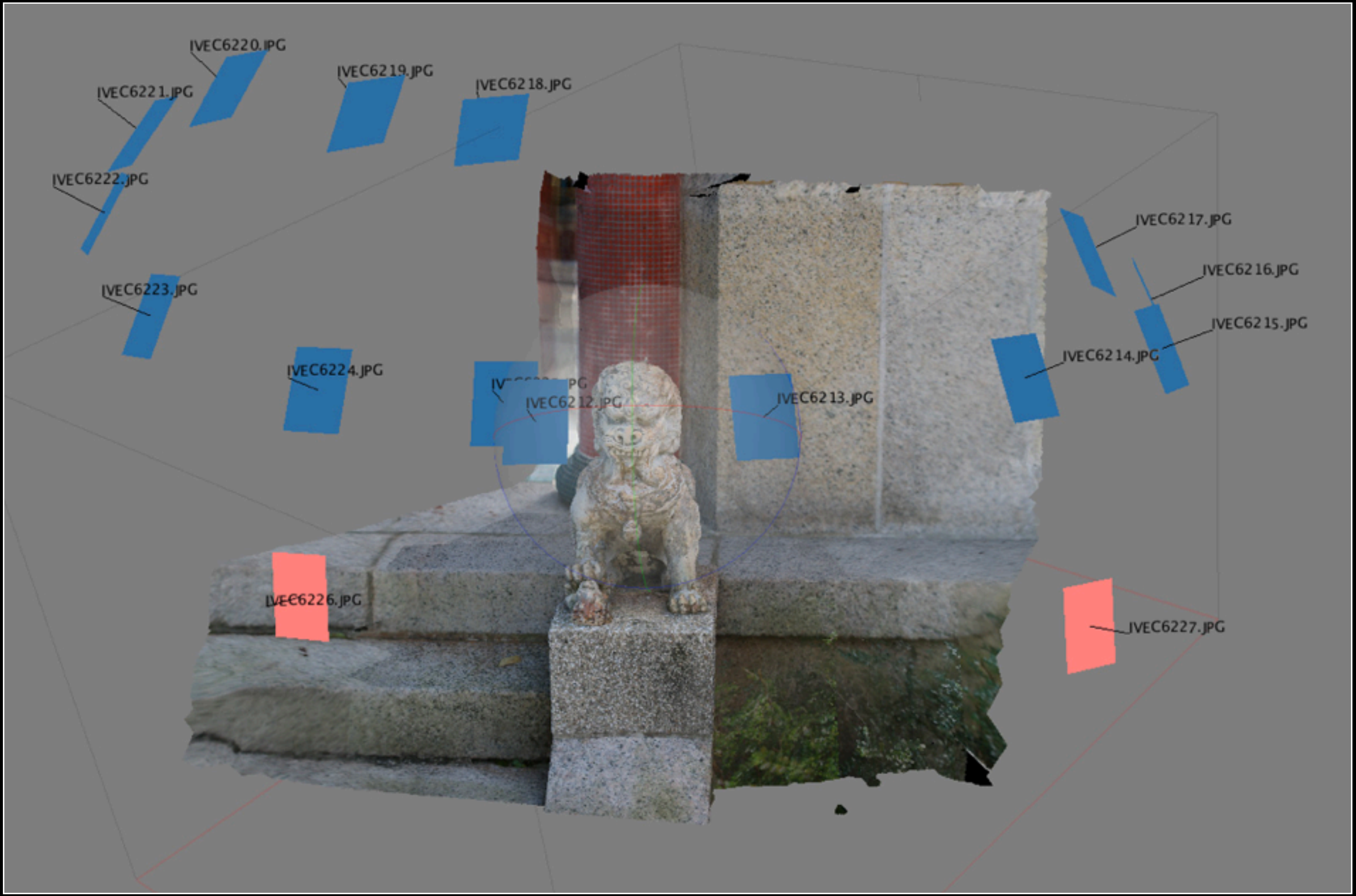


EXIF focal length: 50
fx = 8026.46 +- 1.5152
fy = 8027.75 +- 1.42957
cx = 2877.05 +- 1.13418
cy = 1906.64 +- 0.814478
skew = -0.806401 +- 0.151285
k1 = -0.176187 +- 0.00377854
k2 = 0.285354 +- 0.0770751
k3 = 0.300547 +- 0.619451
p1 = 0.000219219 +- 2.64764e-05
p2 = -0.000172641 +- 3.58682e-05

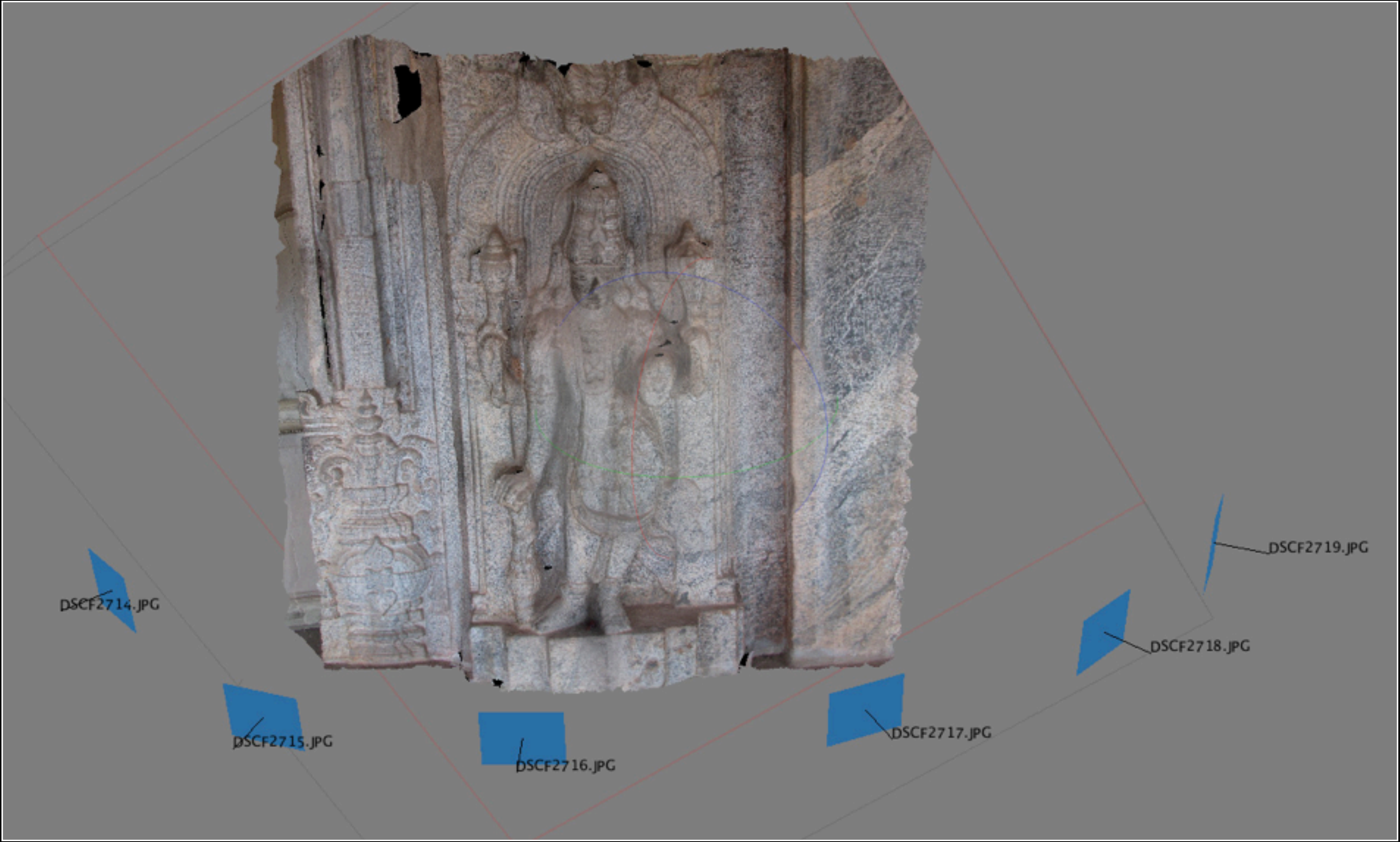

Untitled
Photos
File
Size
Points
f 50
IVEC1859.JPG 5760x3840 1434
IVEC1860.JPG 5760x3840 1320
IVEC1861.JPG 5760x3840 1208
IVEC1862.JPG 5760x3840 986
IVEC1863.JPG 5760x3840 978
IVEC1864.JPG 5760x3840 1191
IVEC1865.JPG 5760x3840 953
Report
EXIF focal length: 50
Parameter
Value
Std Error
Image width 5760
Image height 3840
Focal length (x) 8026.46 1.5152
Focal length (y) 8027.75 1.42957
Principal point (x) 2877.05 1.13418
Principal point (y) 1906.64 0.814478
Skew -0.806401 0.151285
Radial K1 -0.176187 0.00377854
Radial K2 0.285354 0.0770751
Radial K3 0.300547 0.619451
Radial K4 -1.09108 2.89591
Tangential P1 0.000219219 2.64764e-05
Tangential P2 -0.000172641 3.58682e-05
Radial distortion
Distortion (pix)
10
20
30
40
500 1000 1500 2000 2500
Radius (pix)
Tangential distortion
Distortion (pix)
0.05
0.1
0.15
0.2
0.25
500 1000 1500 2000 2500
Radius (pix)

Photography : shooting guide

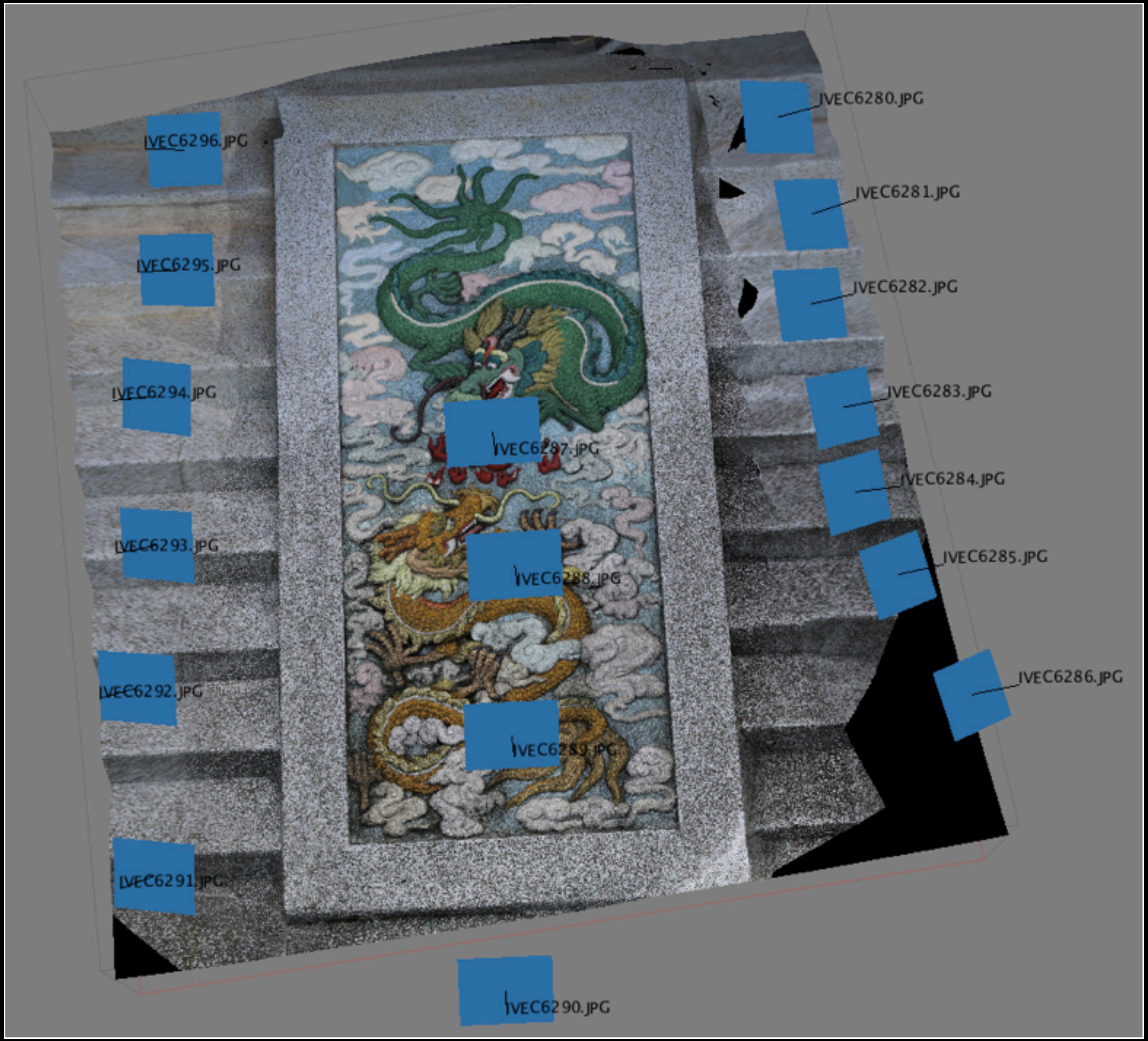




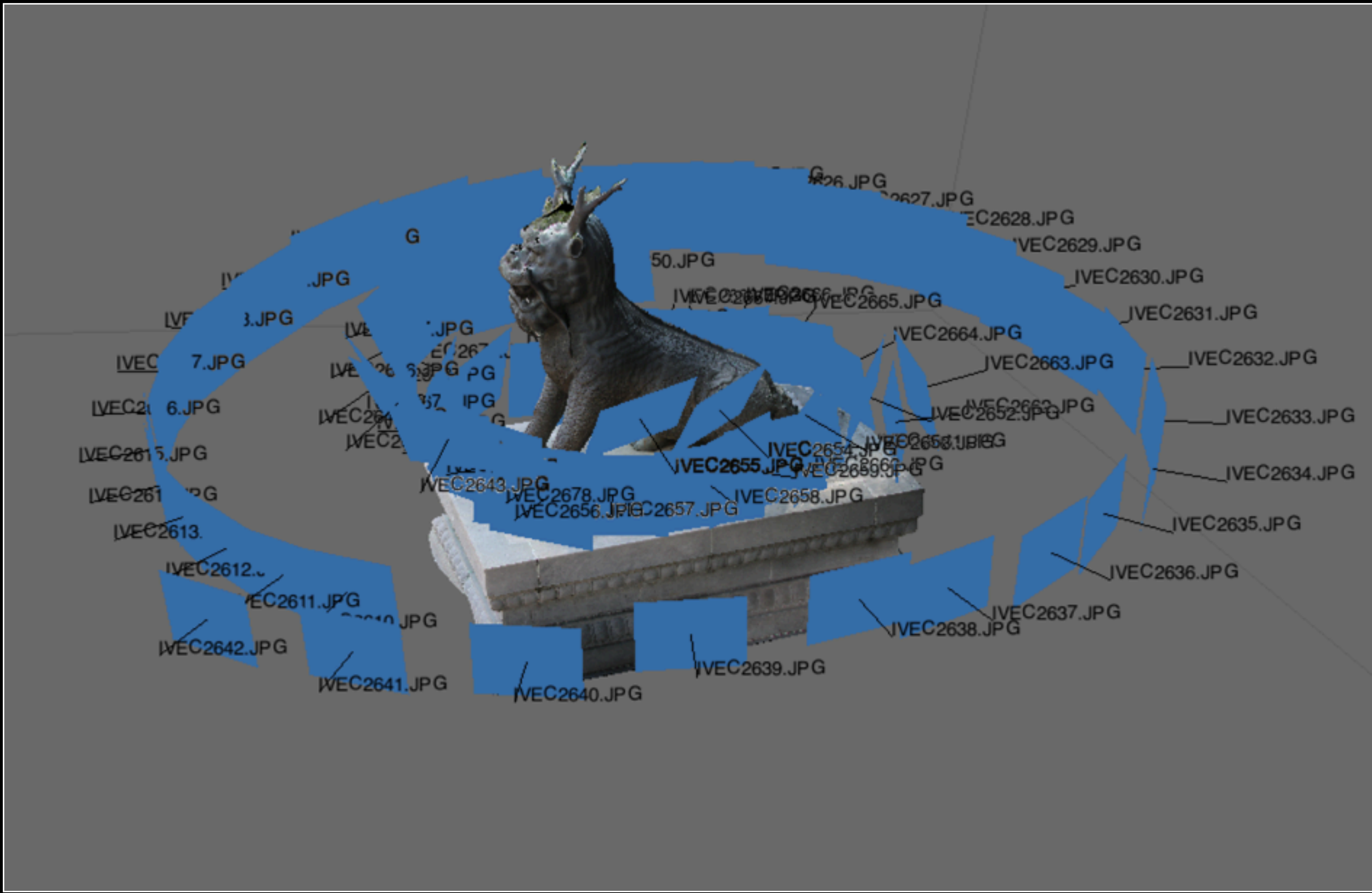
Dragon Gardens, Hong Kong



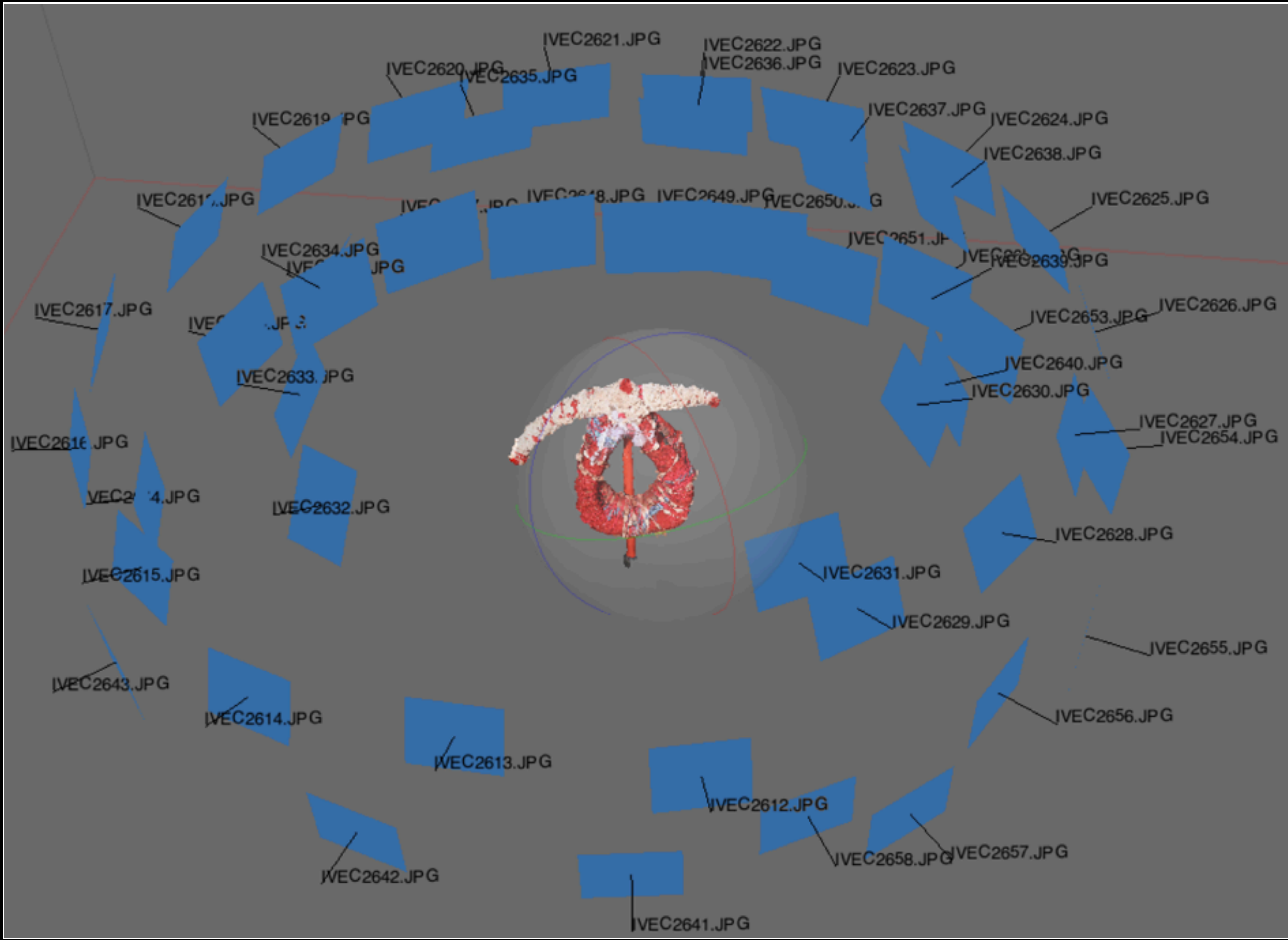
Manipal, India



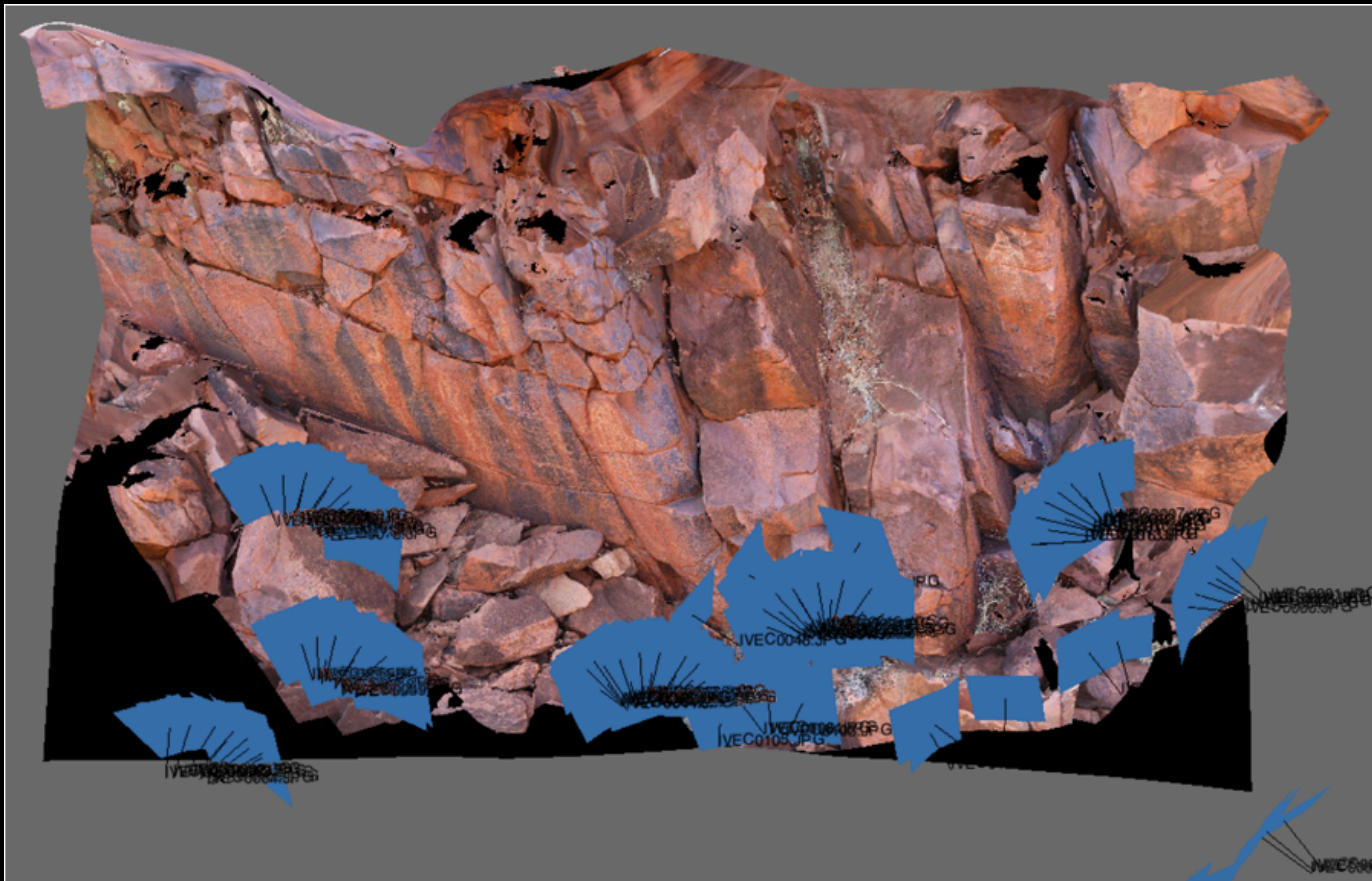
Dragon Gardens, Hong Kong



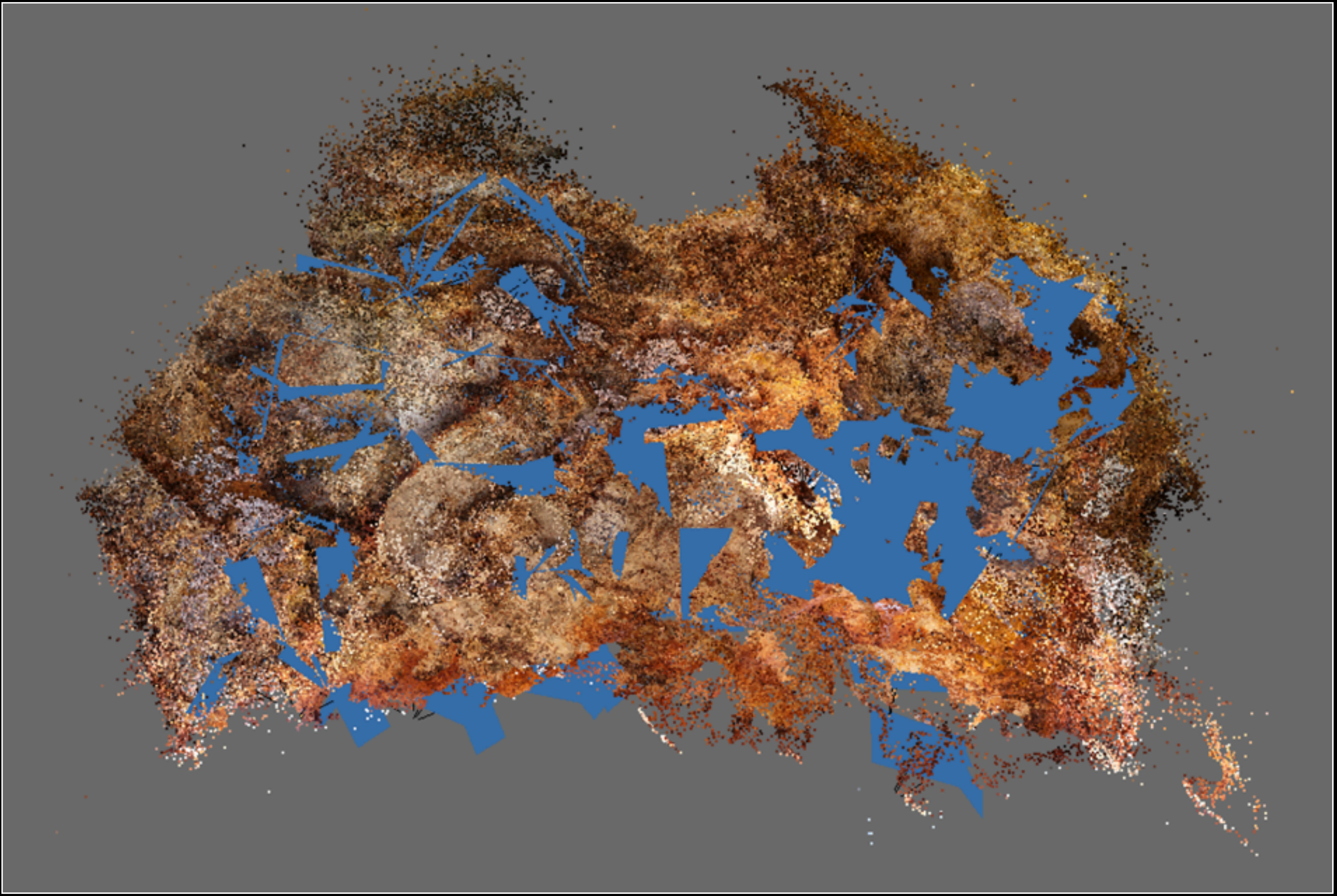
City University, Hong Kong



Ngintaka headress



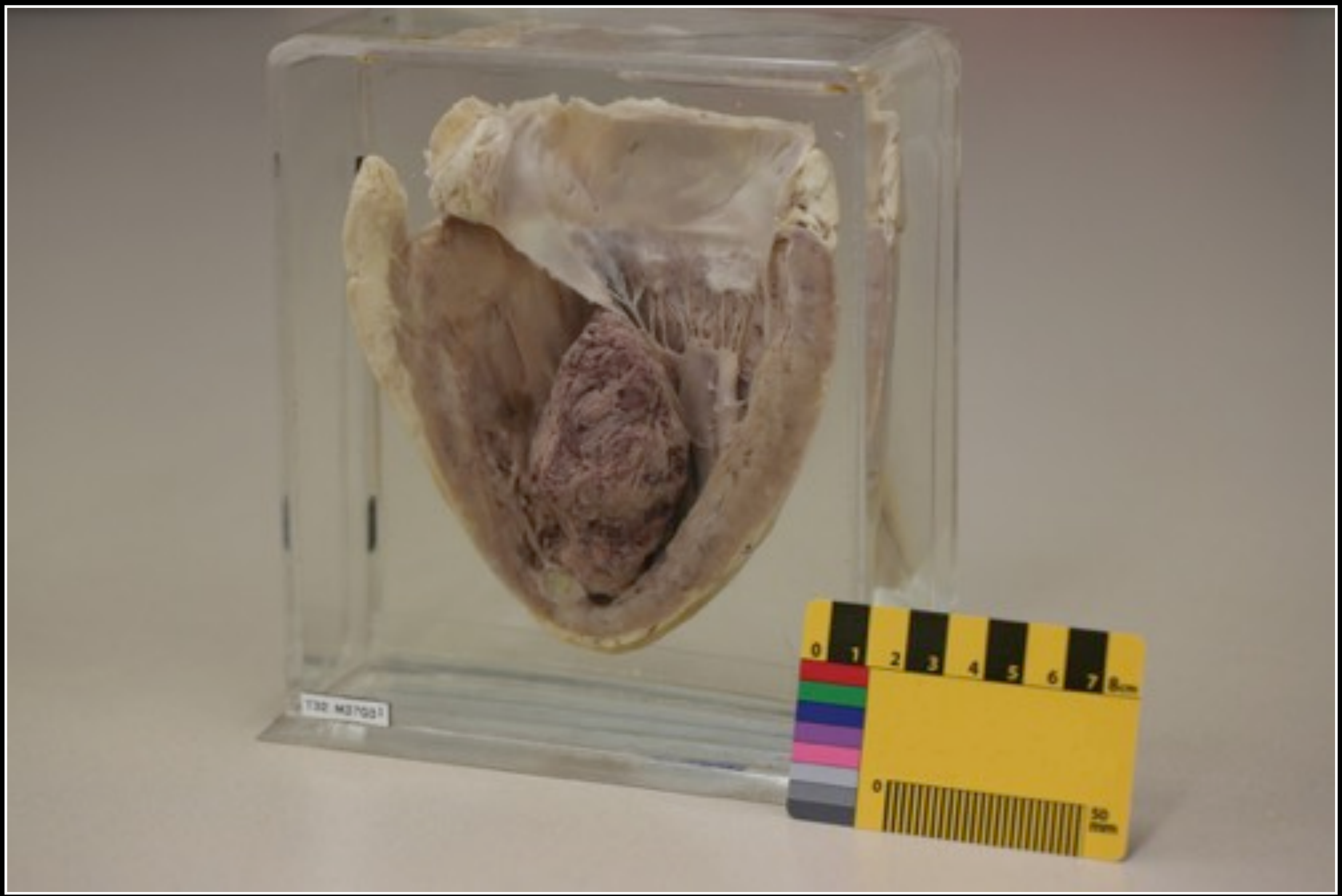
Manmanna



West Angeles rock shelter

Photogaphy : Linear reference objects

- Improved results if there is a linear reference object in the scene.
- They need not be part of the final reconstruction if slightly outside the object of interest.
- Reference colour bars also useful if colour correction is important.



QE II Pathology

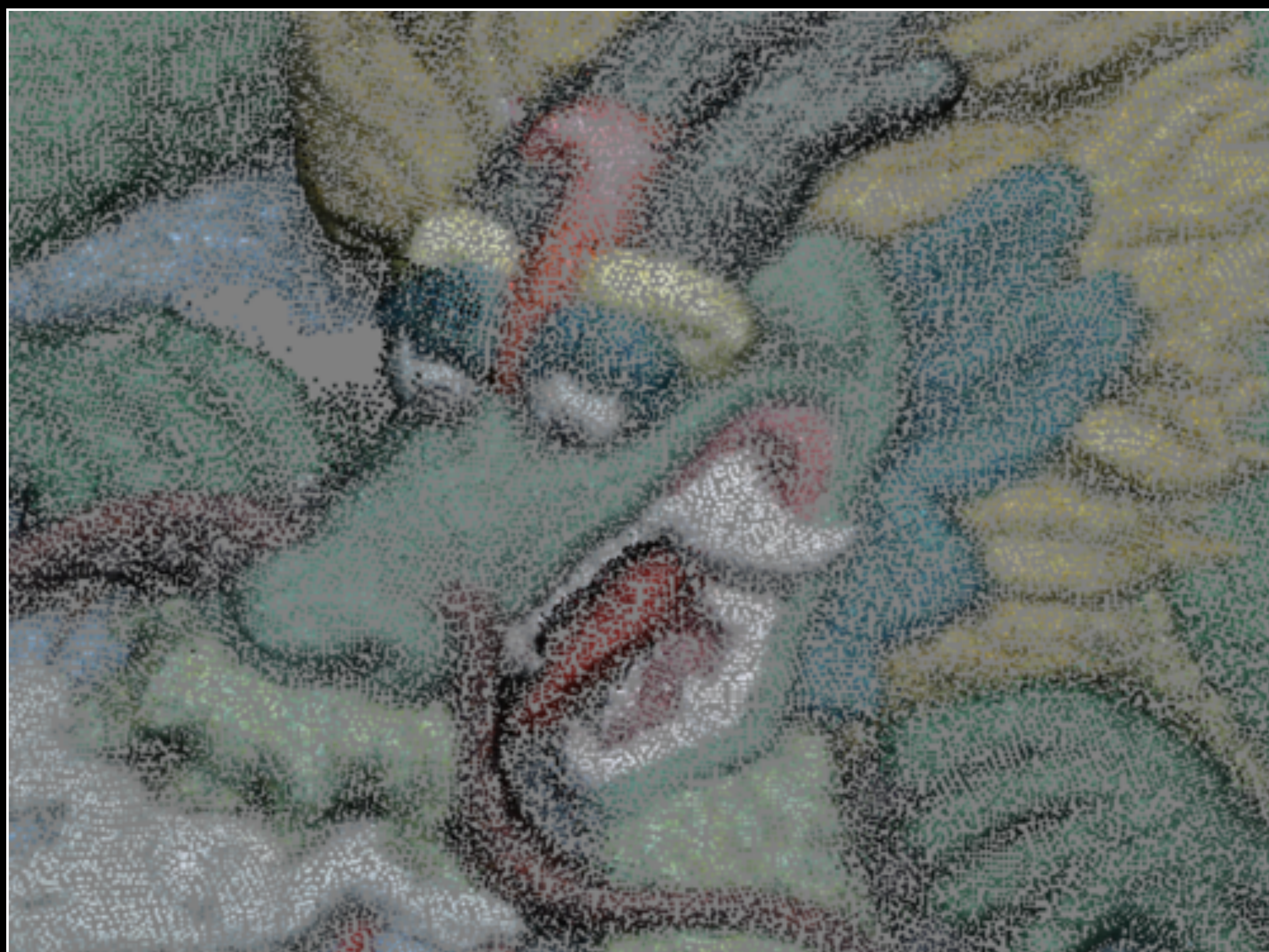
Long Island

Photography : Photograph quality

- Clearly improved results with crisp, high resolution images.
- Improvement with increased photograph count, see later in accuracy discussion.
- Easy area to explore, capture a photograph set and progressively subsample or blur images.

Dragon Gardens, Hong Kong

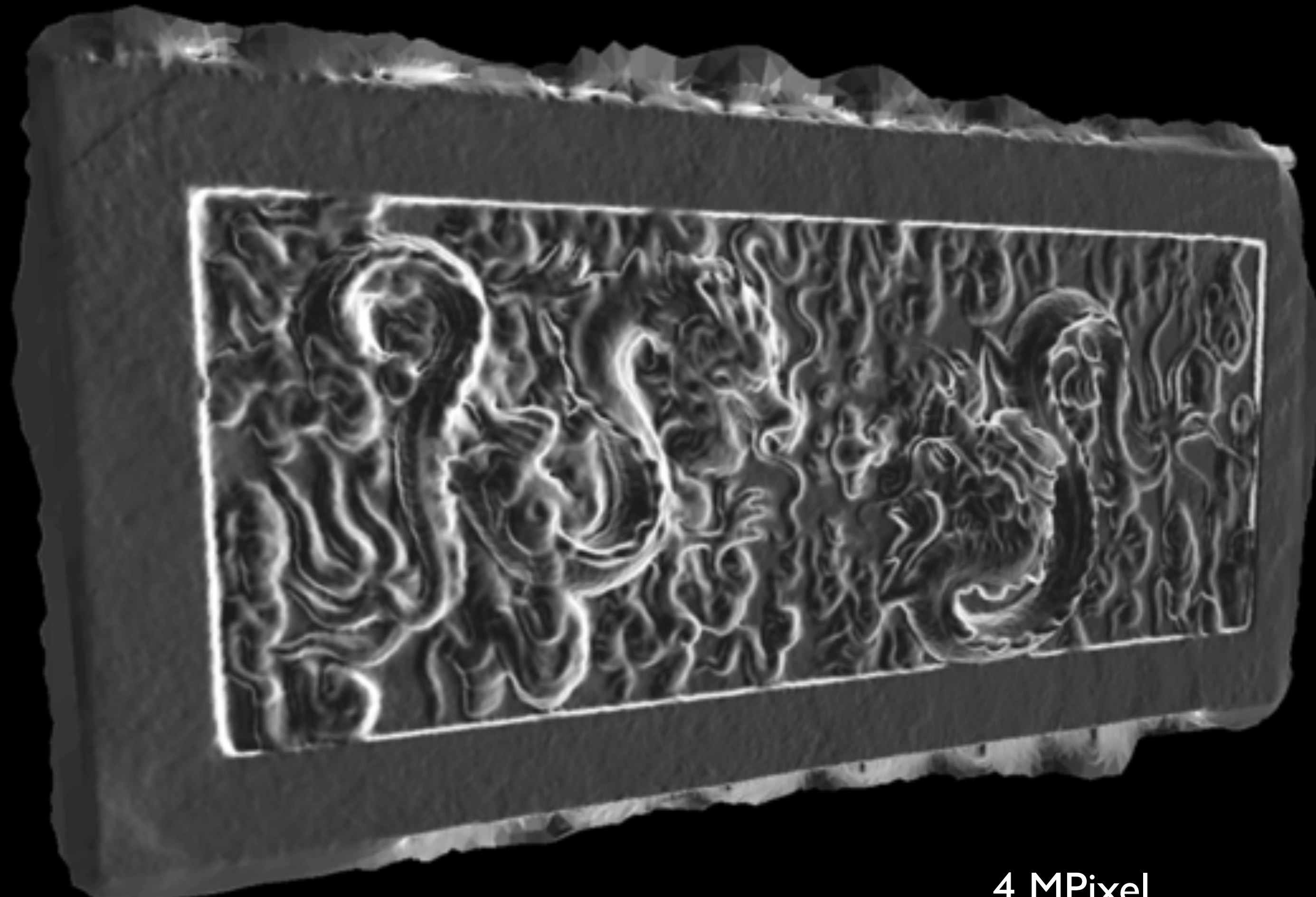
Comparing dense point clouds



4 MPixel

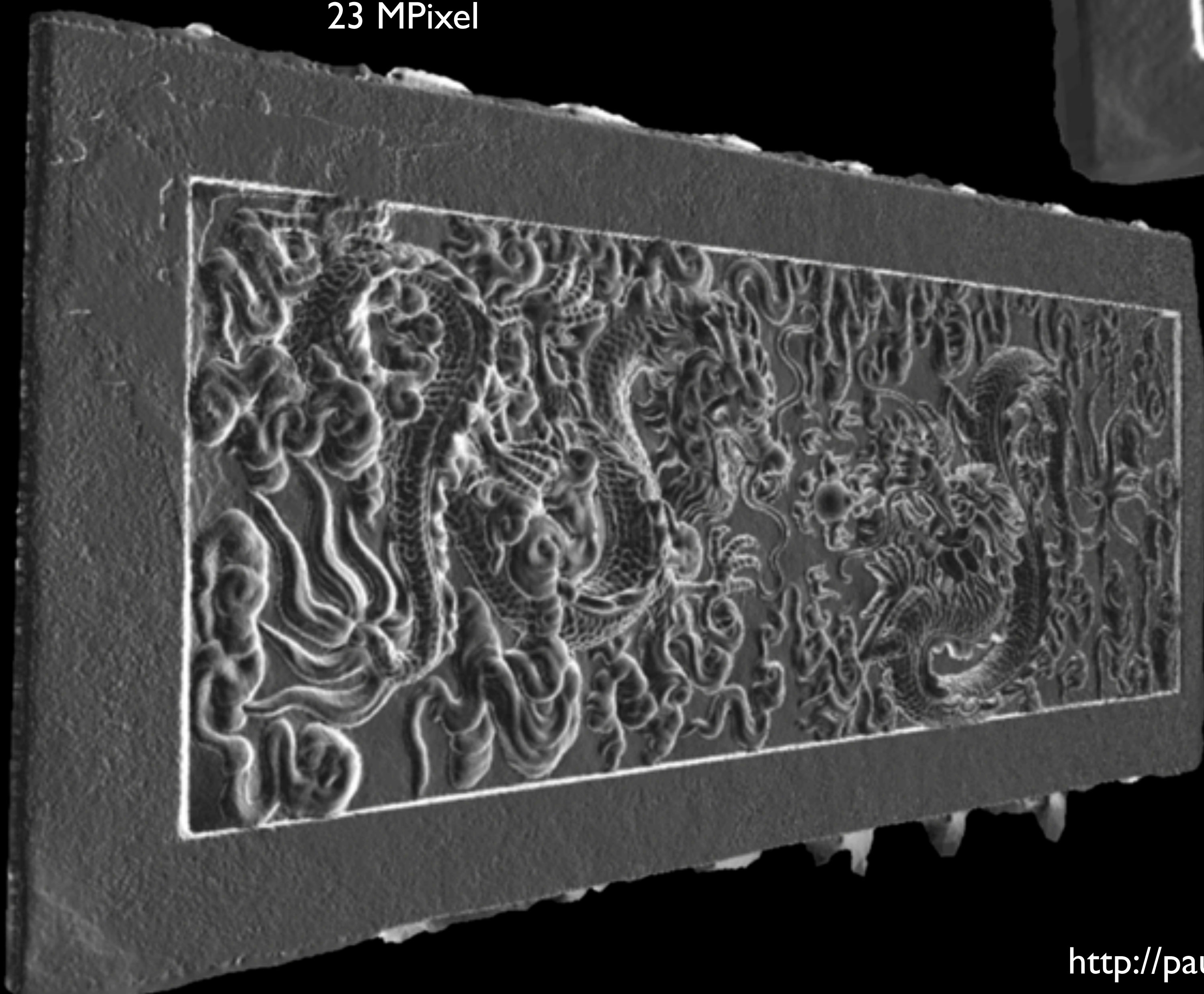
23 MPixel

Dense point cloud for greyscale photographs



4 MPixel

23 MPixel



http://paulbourke.net/miscellaneous/reconstruction_image_quality/

Example 1 : Motifs, Indian Temple

- A relatively low number of photographs are required for 2.5D surfaces.
- Degree of concavity determines the number of photographs required.
- Facades and engravings (low concavity) can require as few as 3 to 6 images.
- 20cm high engraving on doors, 200+ engravings to capture.
- Photographs can be orientated at any angle.
- Each object takes perhaps 15 sec to capture, 10 minutes (on average) to process.
- Able to process in the field and redo any that failed.
- This example uses a simple point and shoot camera.

Chaturmukha, India

Chaturmukha, India

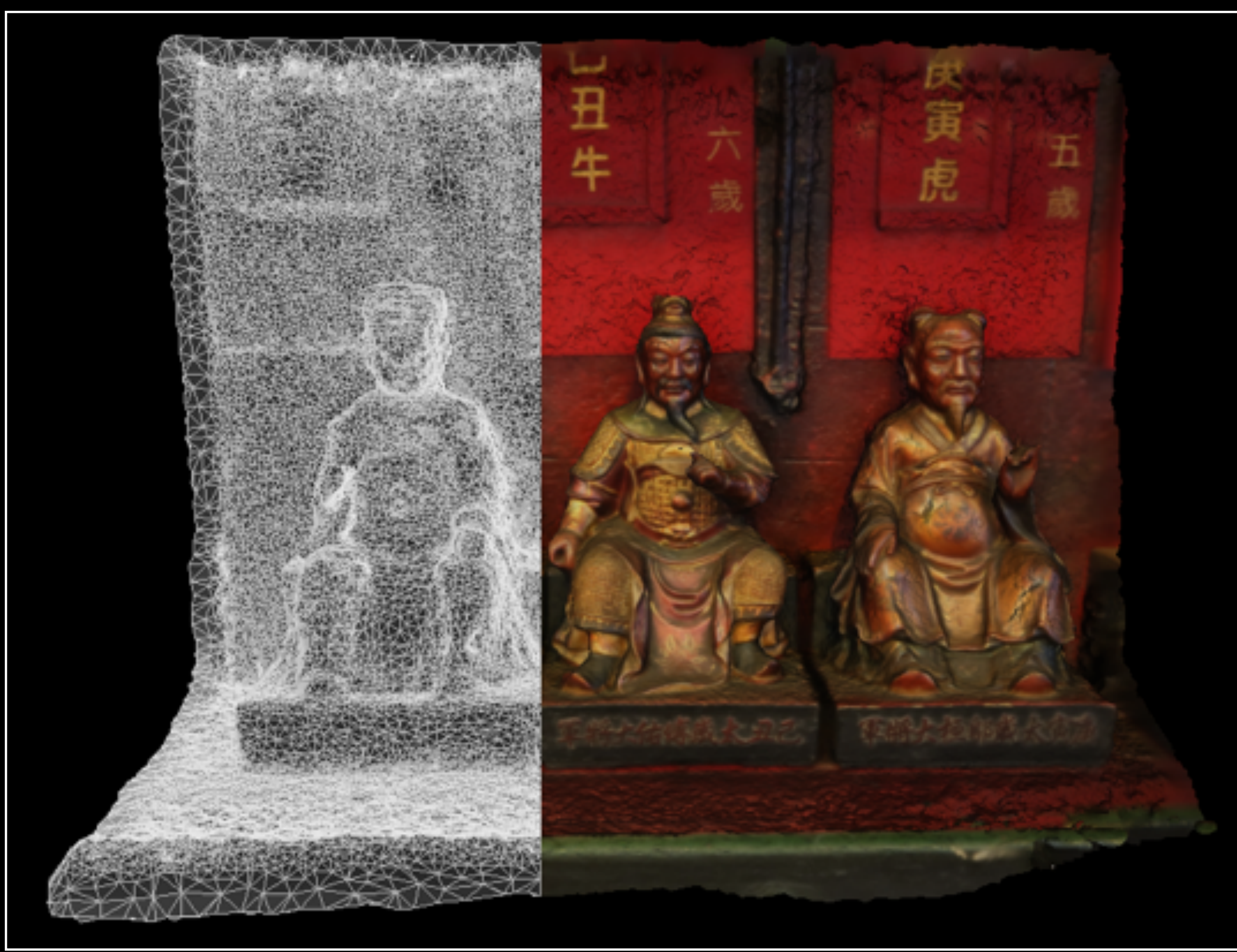
Photography : Coverage

- Pretty obvious, one is never going to reconstruct what isn't captured.

~30 photographs

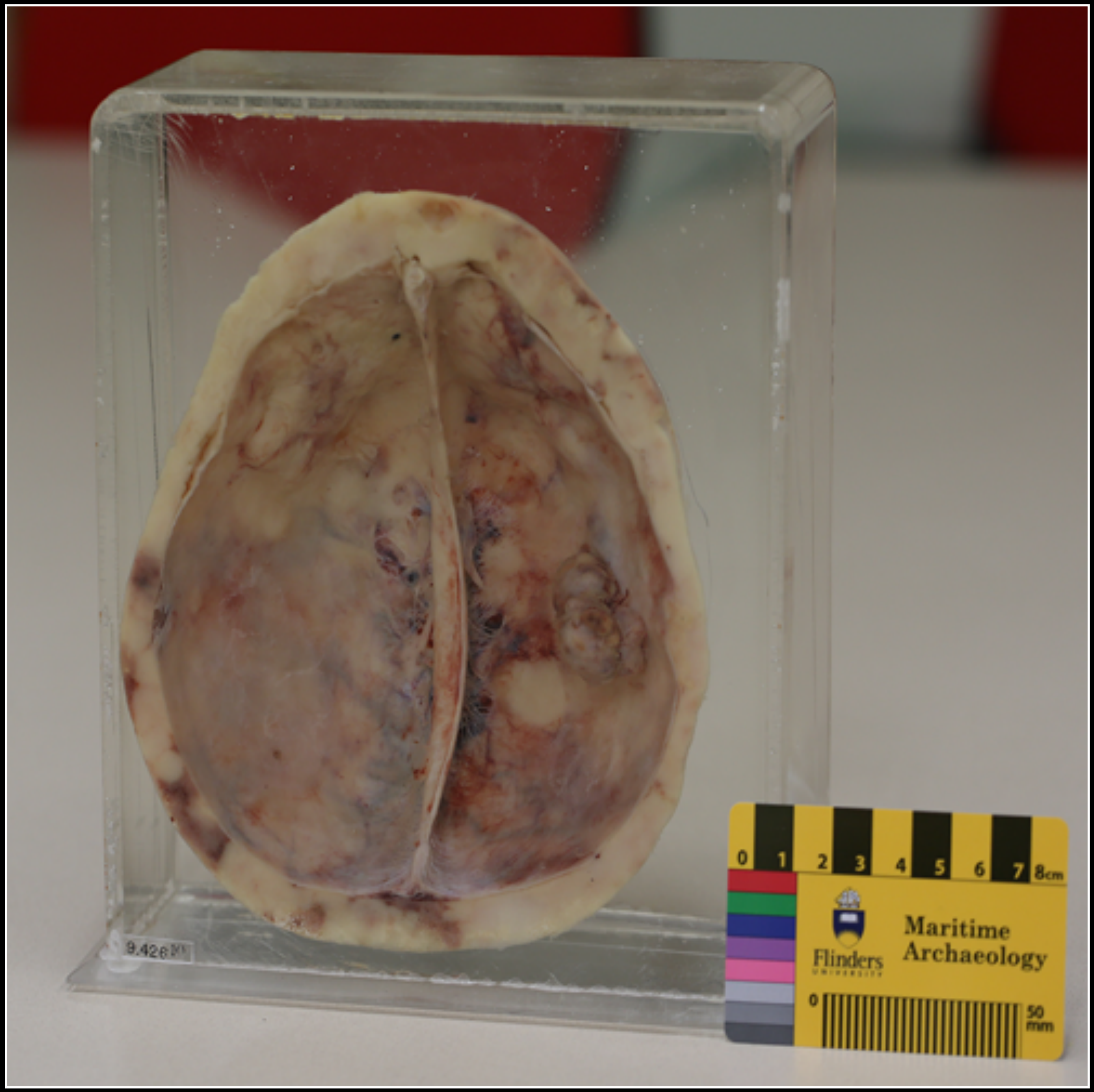
Limited by left most photograph

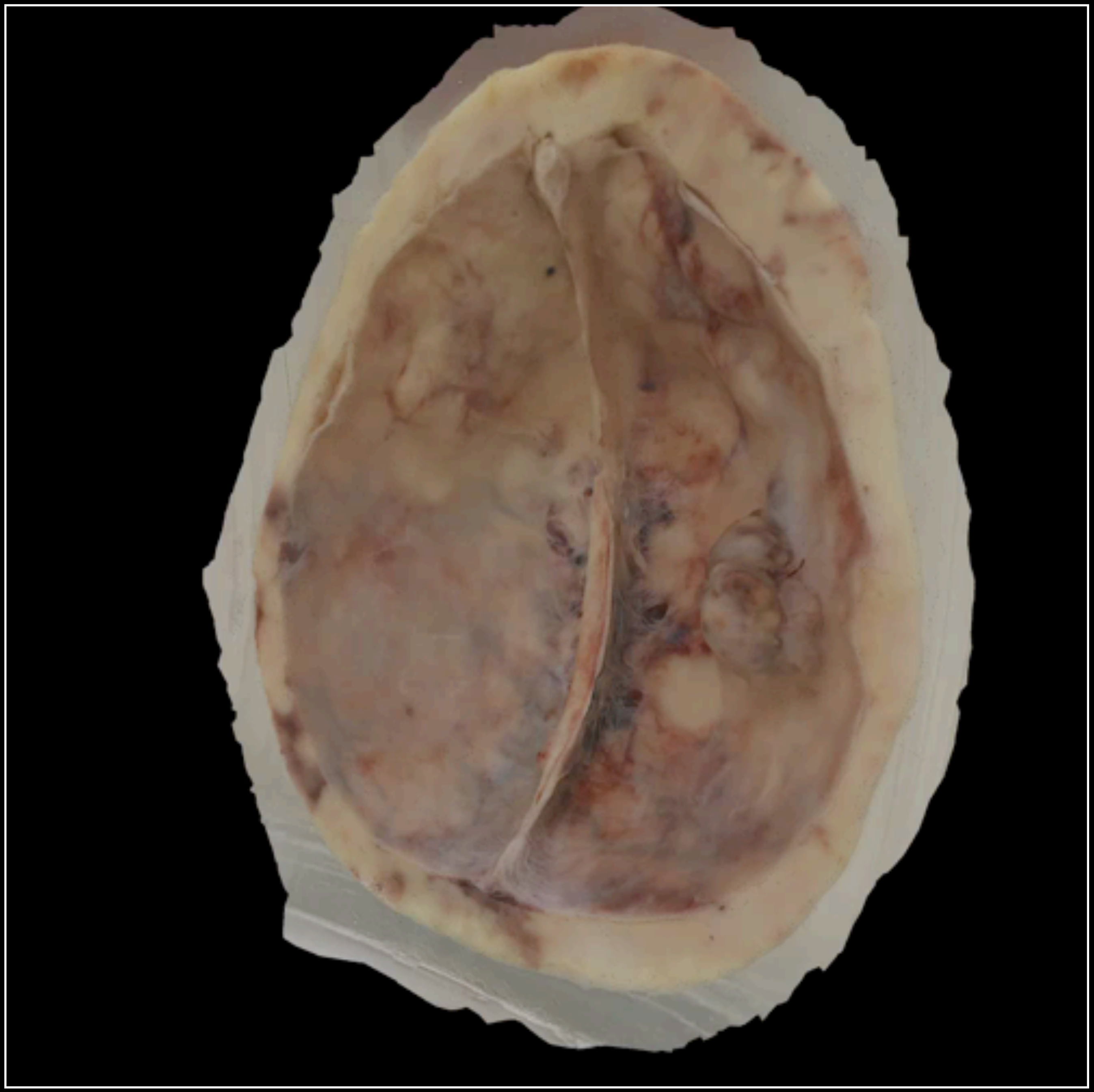
Tung Wah hospital temple, Hong Kong



Photograph : depth of focus

- Feature point detection benefits from sharp / crisp photographs.
- Shallow depth of focus can be used to ensure feature points are only found at the depth of interest.





Geometry post processing

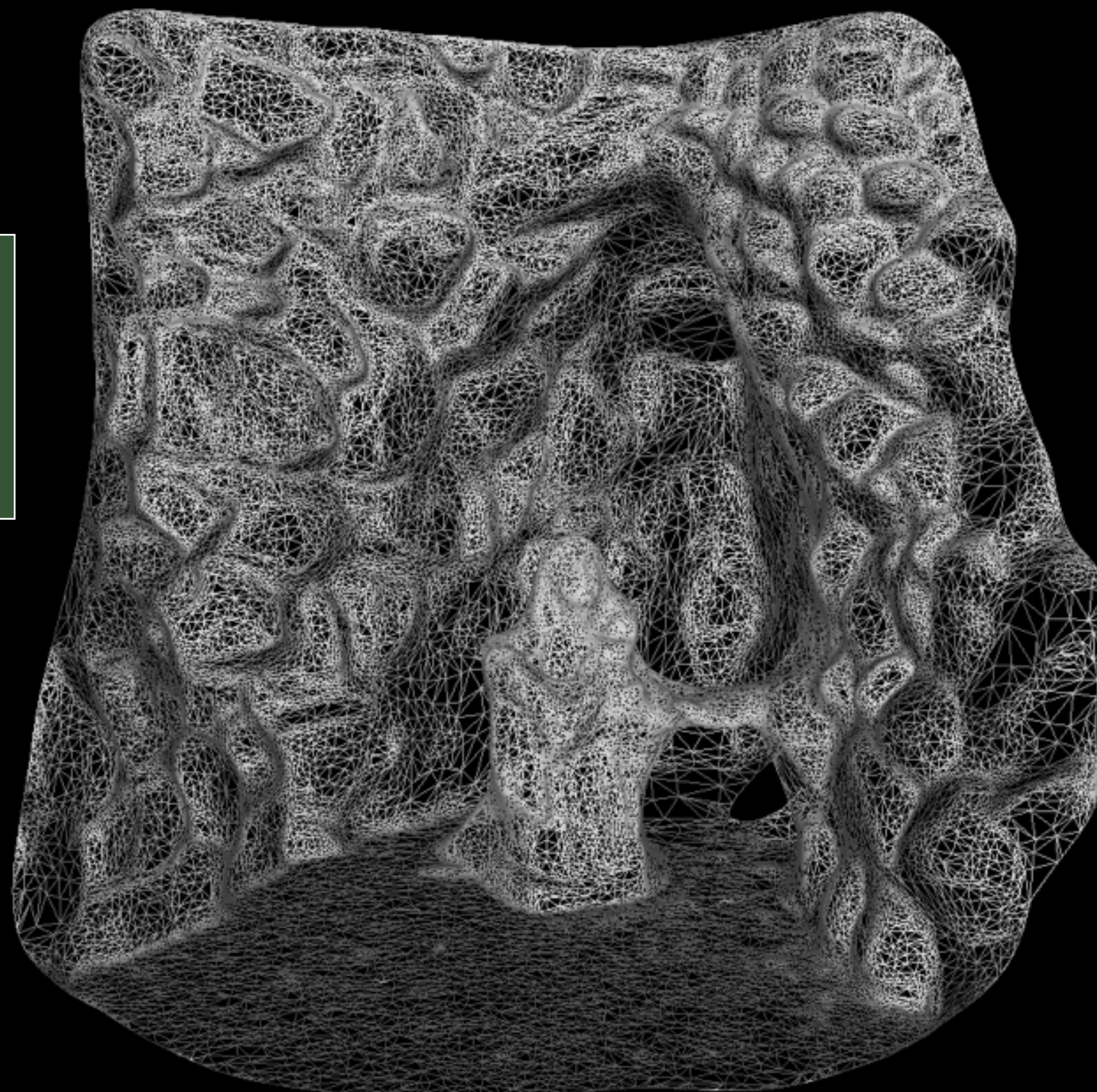
- Generally dealing with unstructured meshes

- Mesh simplification
- Hole closing
- Removing shrapnel

- Per vertex editing
- Mesh thickening

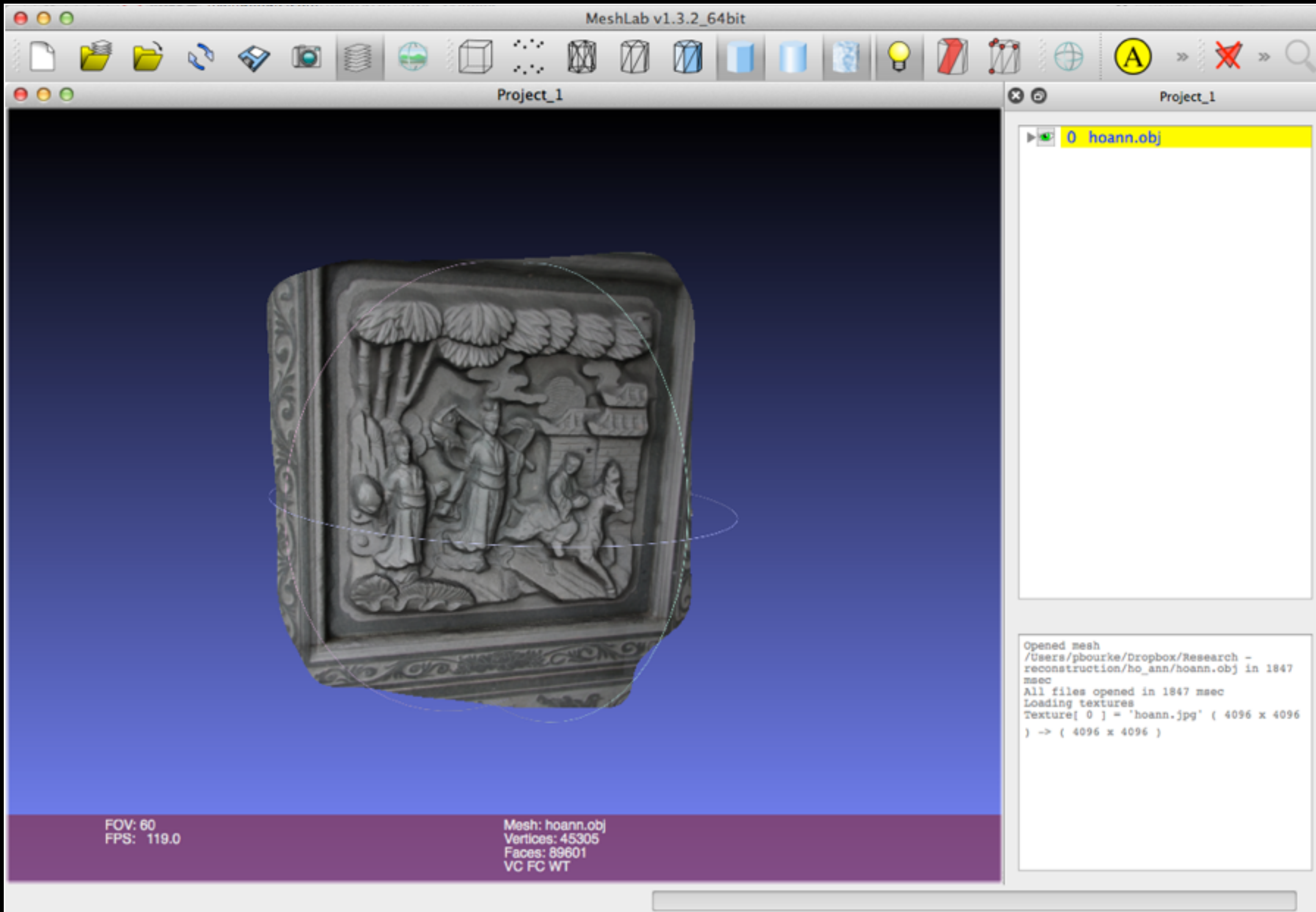
- Meshlab
- Blender

- File formats



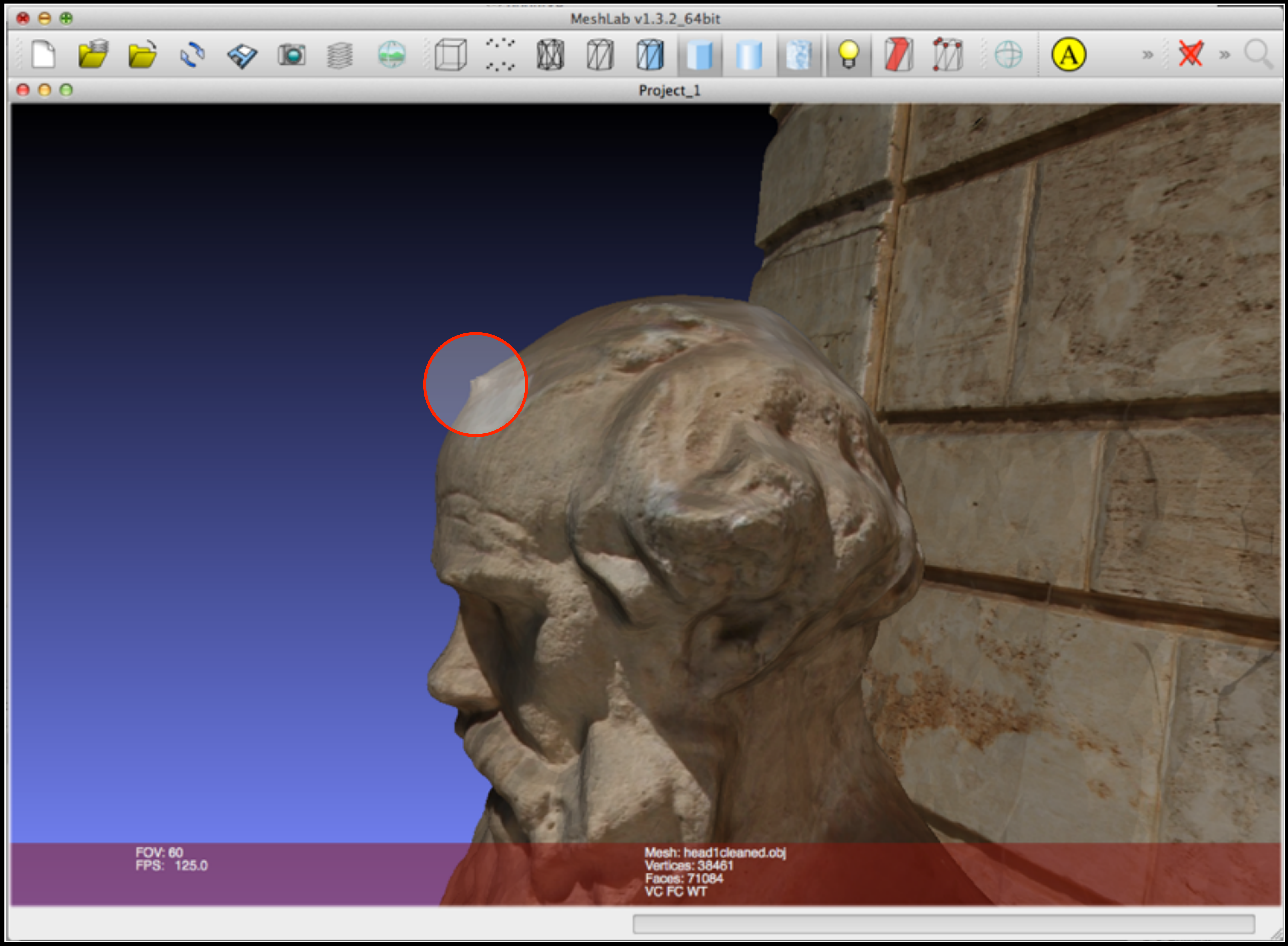
Geometry processing : MeshLab

- There are a number of packages that can be used to manipulate the resulting textured mesh files.
- Meshlab is the free package of choice.
- It is cross platform with a high degree of compatibility.
- Very general tool for dealing with textured meshes.
- Has a large collection of algorithms and is extensible.
- Unfortunately not all algorithms are “reliable”.
- In cases where raw Bundler is used to create a point cloud, Meshlab can be used to construct the mesh using one of a number of algorithms.
  - Ball pivot (my general choice)
  - Marching Cubes
  - Poisson surface reconstruction

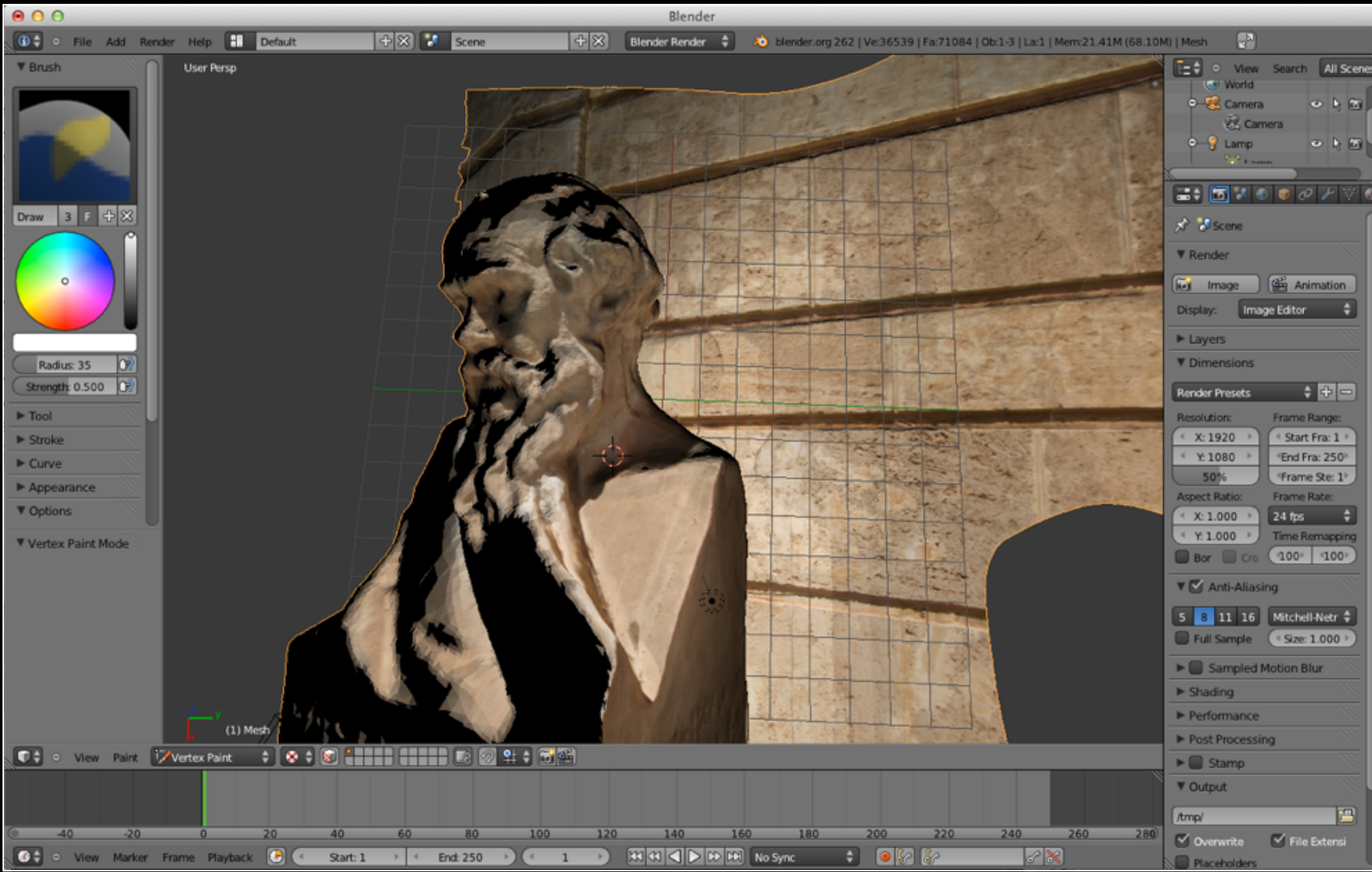

MeshLab v1.3.2_64bit
Project_1
Project_1
0 hoann.obj
Opened mesh
/Users/pbourke/Dropbox/Research -
reconstruction/ho_ann/hoann.obj in 1847
msec
All files opened in 1847 msec
Loading textures
Texture[0] = 'hoann.jpg' (4096 x 4096
) -> (4096 x 4096)
FOV: 60
FPS: 119.0
Mesh: hoann.obj
Vertices: 45305
Faces: 89601
VC FC WT

Geometry processing : Blender

- Largely used for per vertex editing.
- “Big hammer to crack a small nut”, takes some time to learn the interface.
- For example, not uncommon to get single vertex “spikes” especially of highly specular grains.
- Contains it’s own mesh simplification and thickening algorithms.
- Also used to export in a myriad of additional formats.
  For example fbx for Unity3D, not available in MeshLab.



Socrates, UWA


Blender
File
Add
Render
Help
Default
Scene
Blender Render
blender.org 262 | Ve:36539 | Fa:71084 | Ob:1-3 | La:1 | Mem:21.41M (68.10M) | Mesh
Brush
Draw
Radius: 35
Strength: 0.500
Tool
Stroke
Curve
Appearance
Options
Vertex Paint Mode
User Persp
(1) Mesh
View
Paint
Vertex Paint
Search
All Scenes
World
Camera
Camera
Lamp
Scene
Render
Image
Animation
Display:
Image Editor
Layers
Dimensions
Render Presets
Resolution:
X: 1920
Y: 1080
50%
Frame Range:
Start Fra: 1
End Fra: 250
Frame Ste: 1
Aspect Ratio:
X: 1.000
Y: 1.000
Frame Rate:
24 fps
Time Remapping
Bor
Cro
100
100
Anti-Aliasing
5
8
11
16
Mitchell-Netr
Full Sample
Size: 1.000
Sampled Motion Blur
Shading
Performance
Post Processing
Stamp
Output
/tmp/
Overwrite
File Extensi
Placeholders
-40
-20
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
View
Marker
Frame
Playback
Start: 1
End: 250
1
No Sync

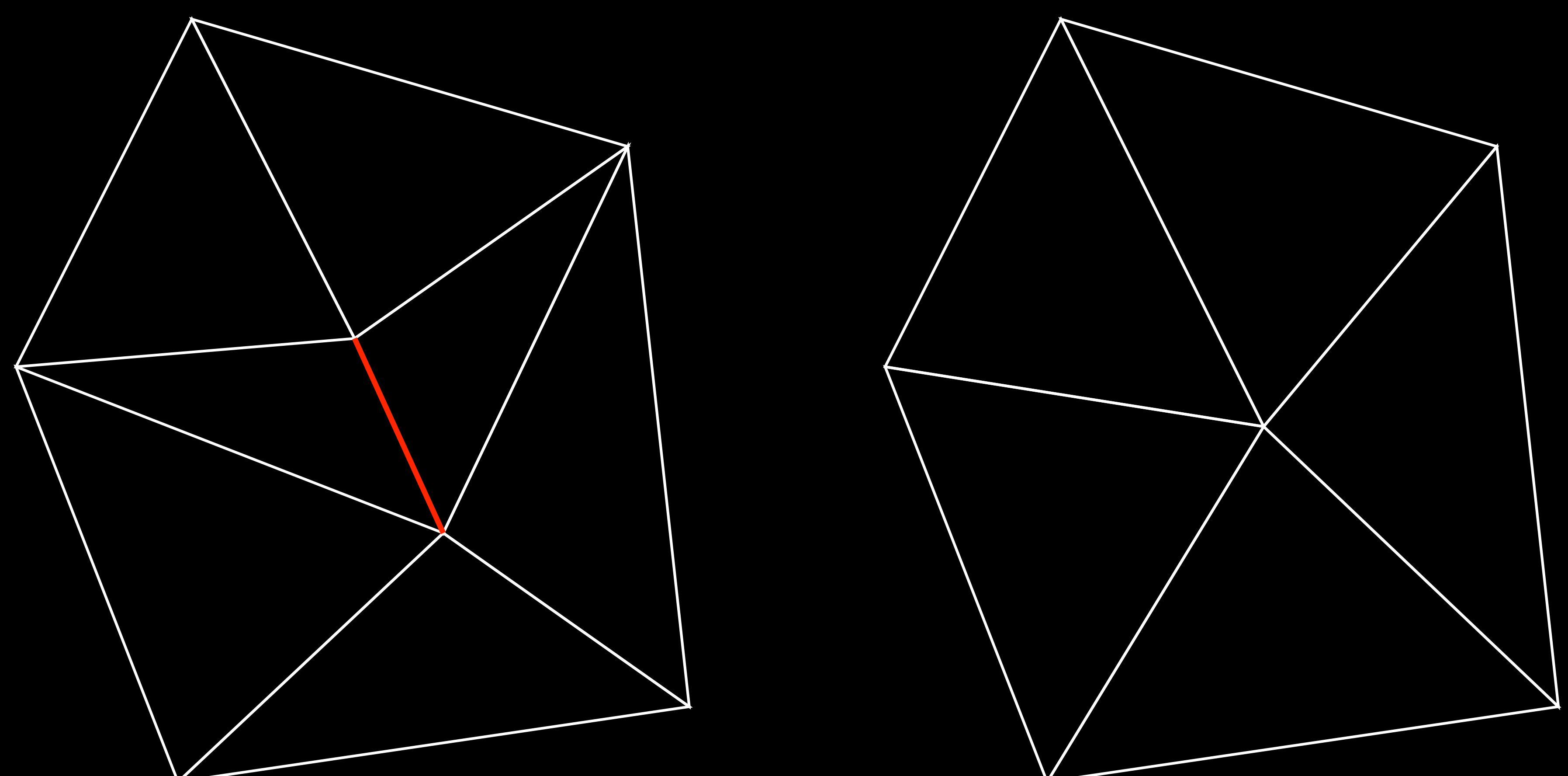
Geometry processing : Mesh simplification

- Meshes directly from the reconstruction (generated from the dense point cloud) are generally inefficient. Often need to reduce them for realtime applications and/or web based delivery.
- Also used to create multiple levels of details (LOD) for gaming and other realtime applications.
- The goal is easy to understand: remove mesh density where it will make minimal impact on the mesh appearance. For example, don't need high mesh density in regions of low curvature.
- Most common class of algorithm is referred to as "edge collapse", replace an edge with a vertex.
- A texture and geometry approximation ... need to estimate new texture coordinate at new vertices.
- Need to preserve the boundary.
- This has been a common topic in computer graphics research and is still an active topic in computer graphics.

- Most edge collapse algorithms involve replacing an edge with a vertex
  - How to choose the edges to remove is the “trick”.
  - Where to locate the new vertex so as to minimise the effect on the surface.
  - How to estimate the new texture coordinate.

- Number of triangles reduced by 2 on each iteration.

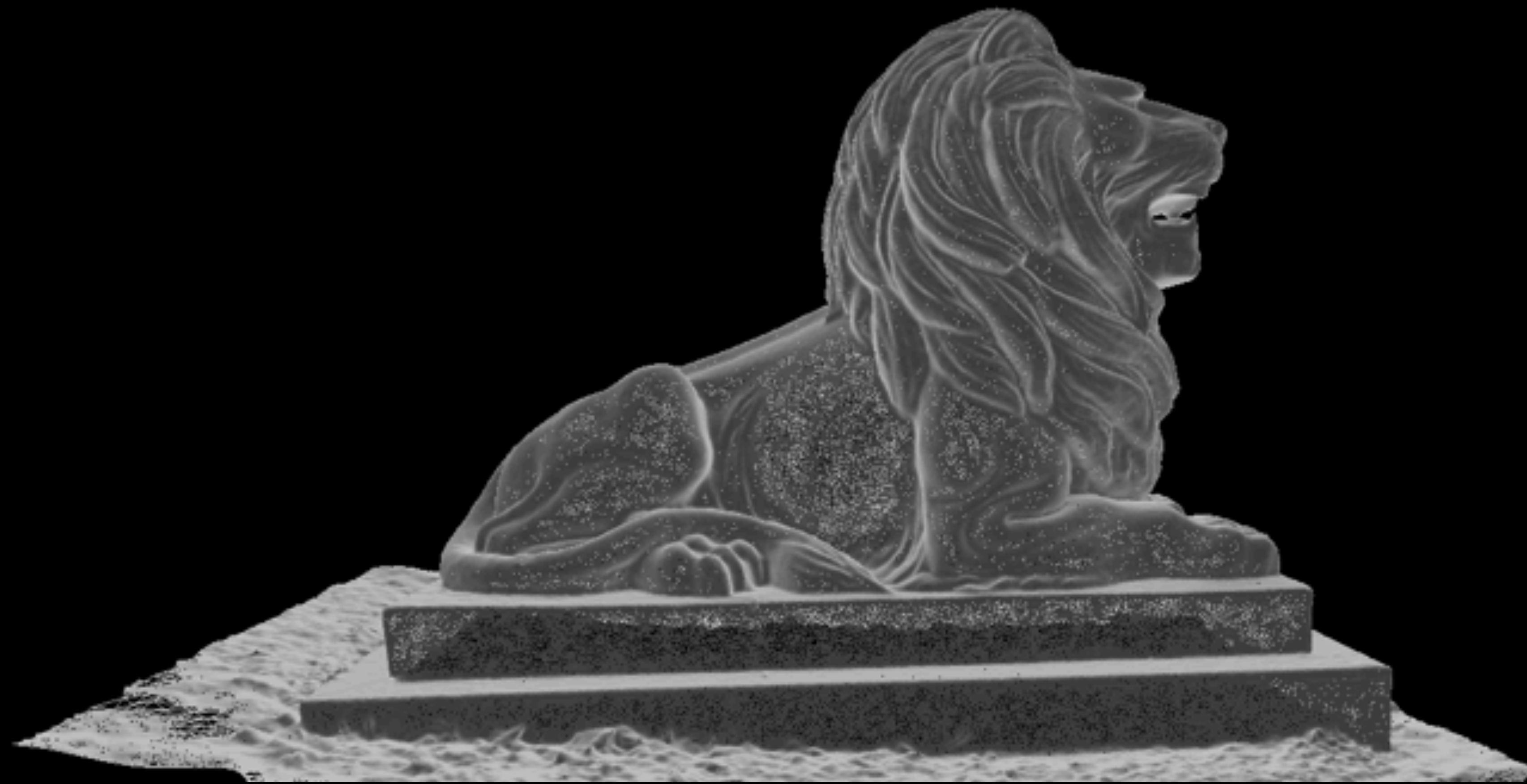
- Can calculate the deviation of the surface for any particular edge collapse.
  Choose edges that result in the smallest deviation.
  Remove edges on flat regions, retain edges in regions of high curvature.



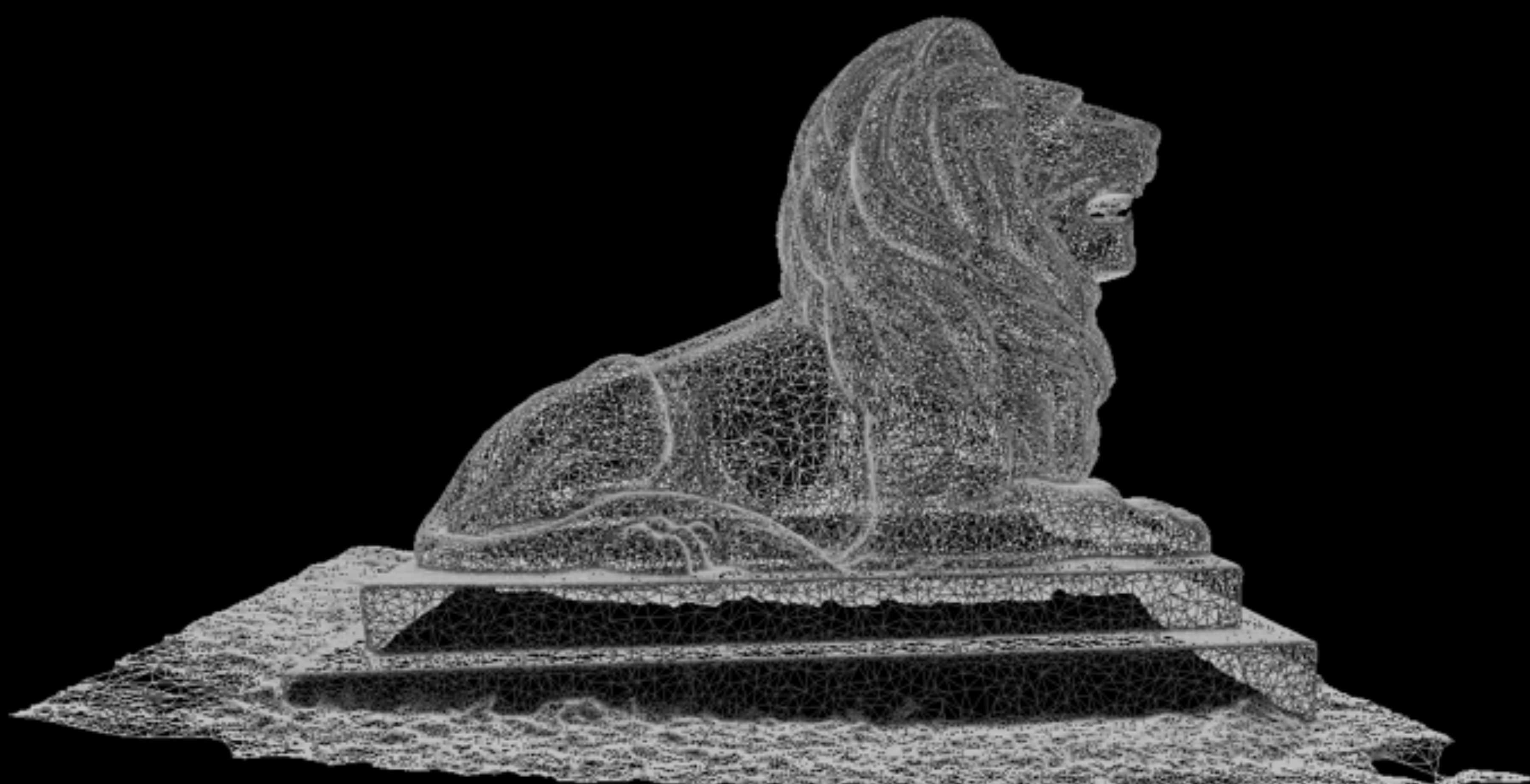
Red edge removed, results in two fewer triangles

1,000,000 triangles

100,00 triangles



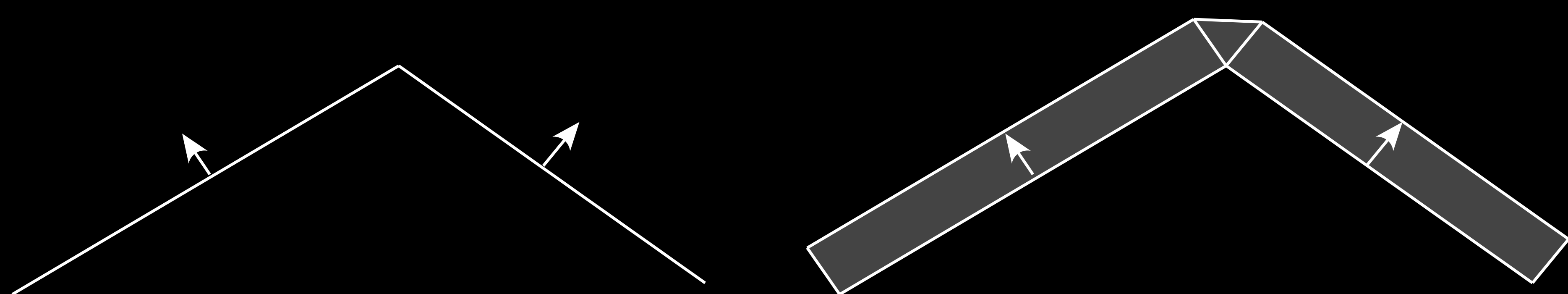
1,000,000 triangles



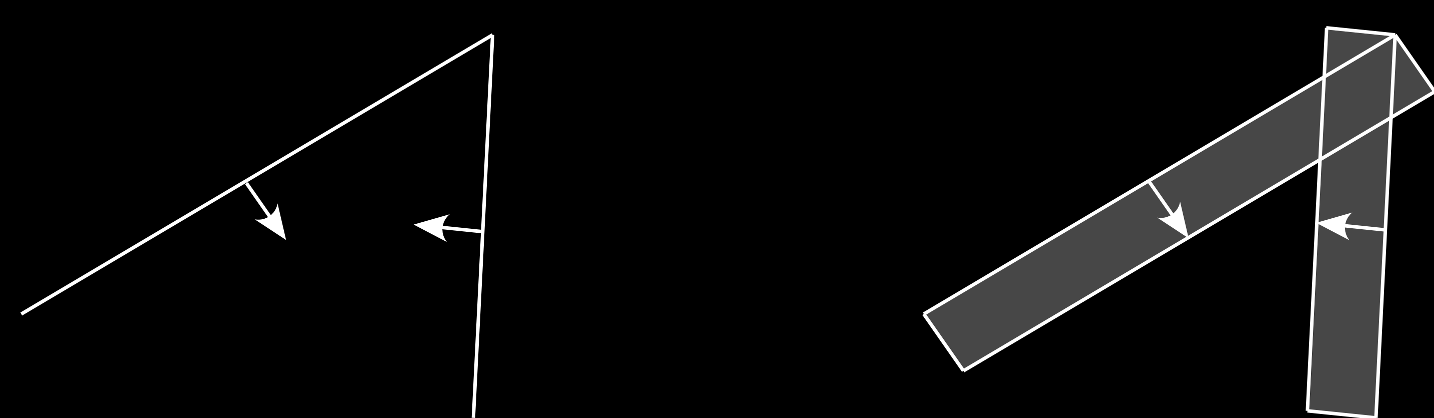
100,00 triangles

Geometry processing : Mesh thickening

- Cases exist where one does not want idealised “infinitely thin” surfaces.
- Double sided rendering in realtime APIs is not quite the same visual effect as physical thickness.
- Required to create physical models, see rapid prototyping later.
- Perhaps the most common algorithm is known as “rolling ball”.

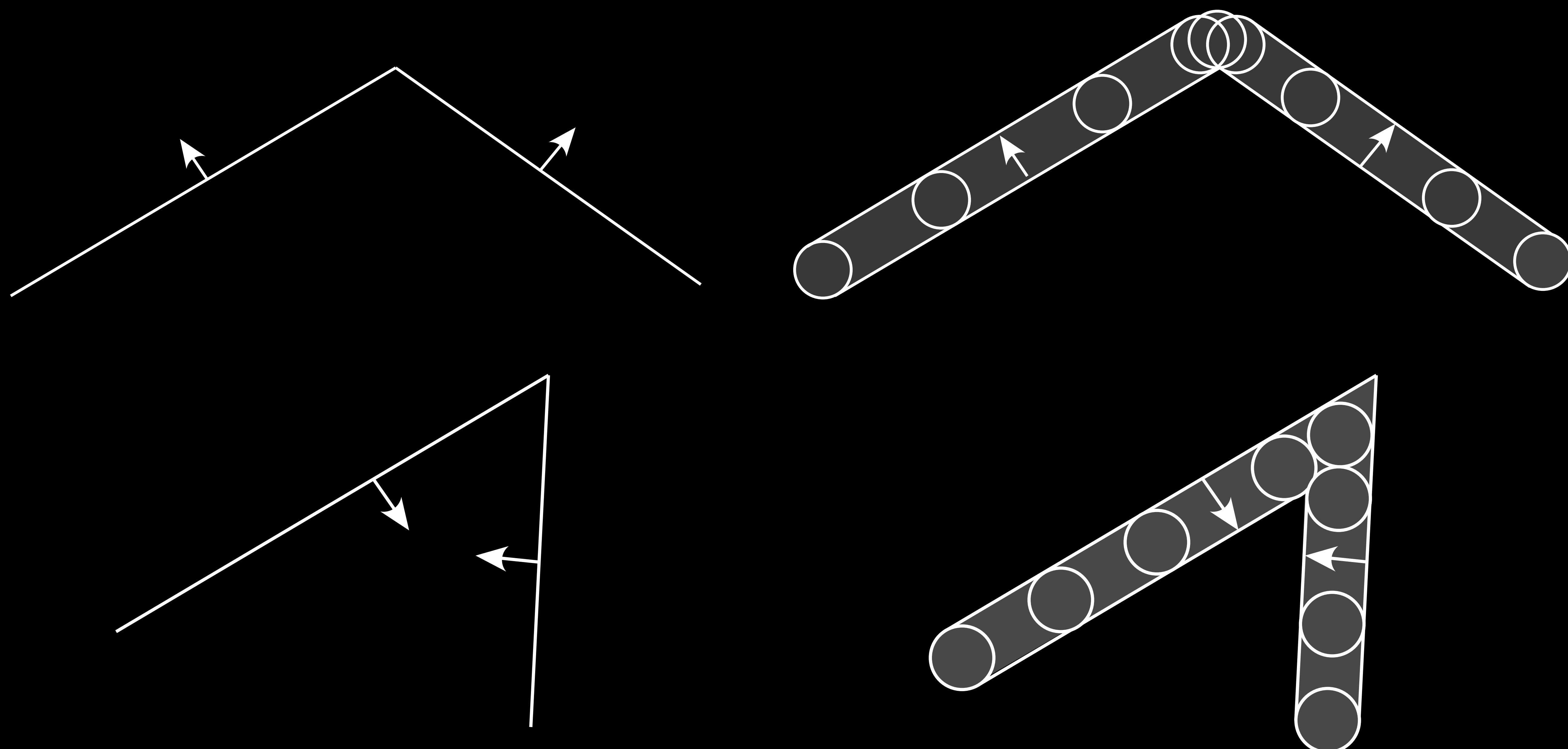


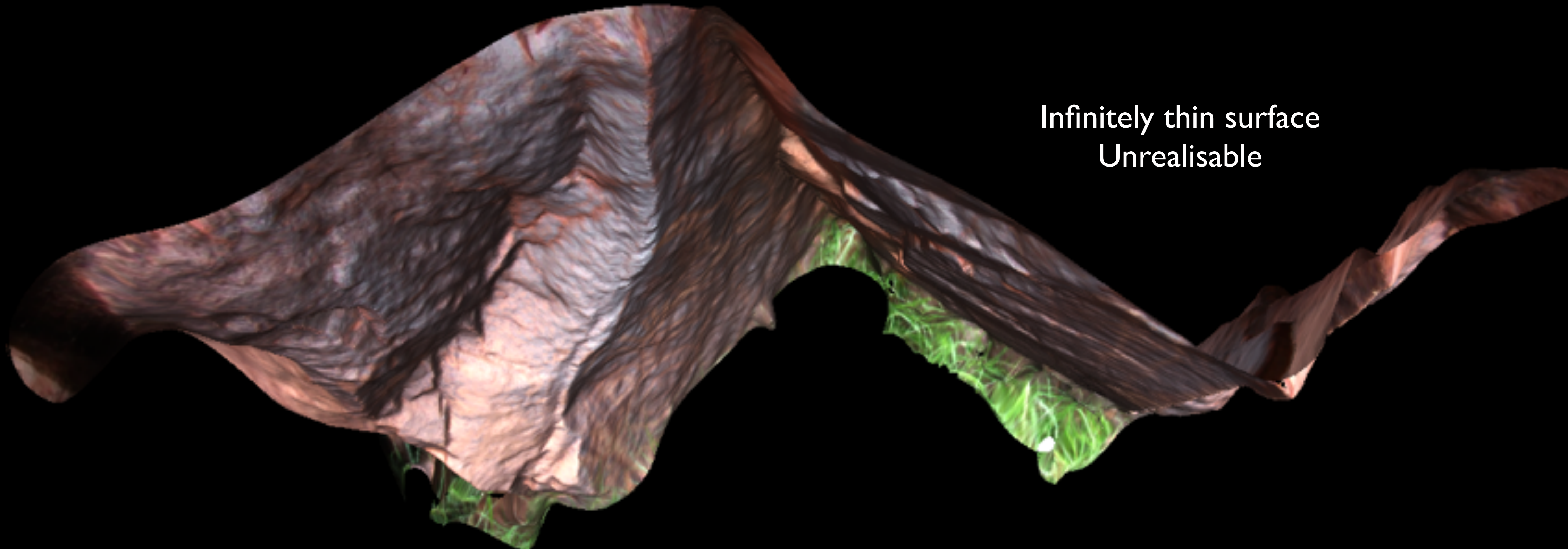
Thin joints arise at regions of high curvature

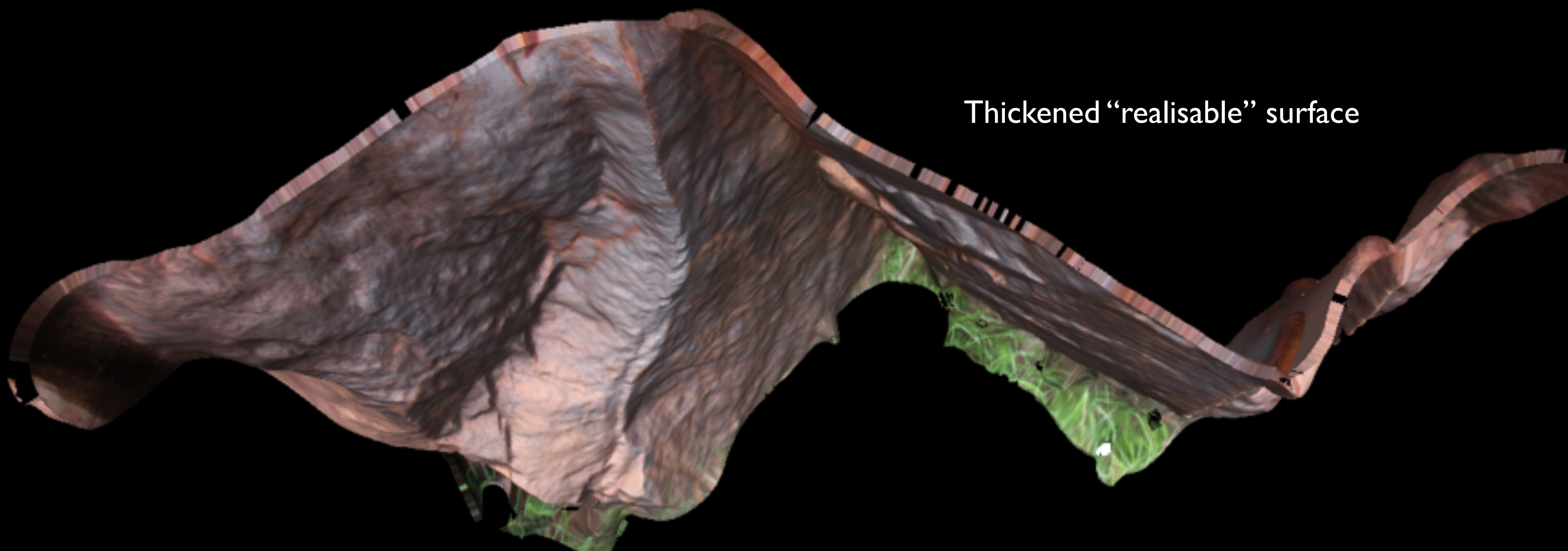


Get “poke-through” with sharp concave interiors

- Solution is called “rolling ball” thickening.
- Imagine a ball rolling across the surface, form an external mesh along the ball path.
- Implemented in Blender as a modifier called “solidify”.

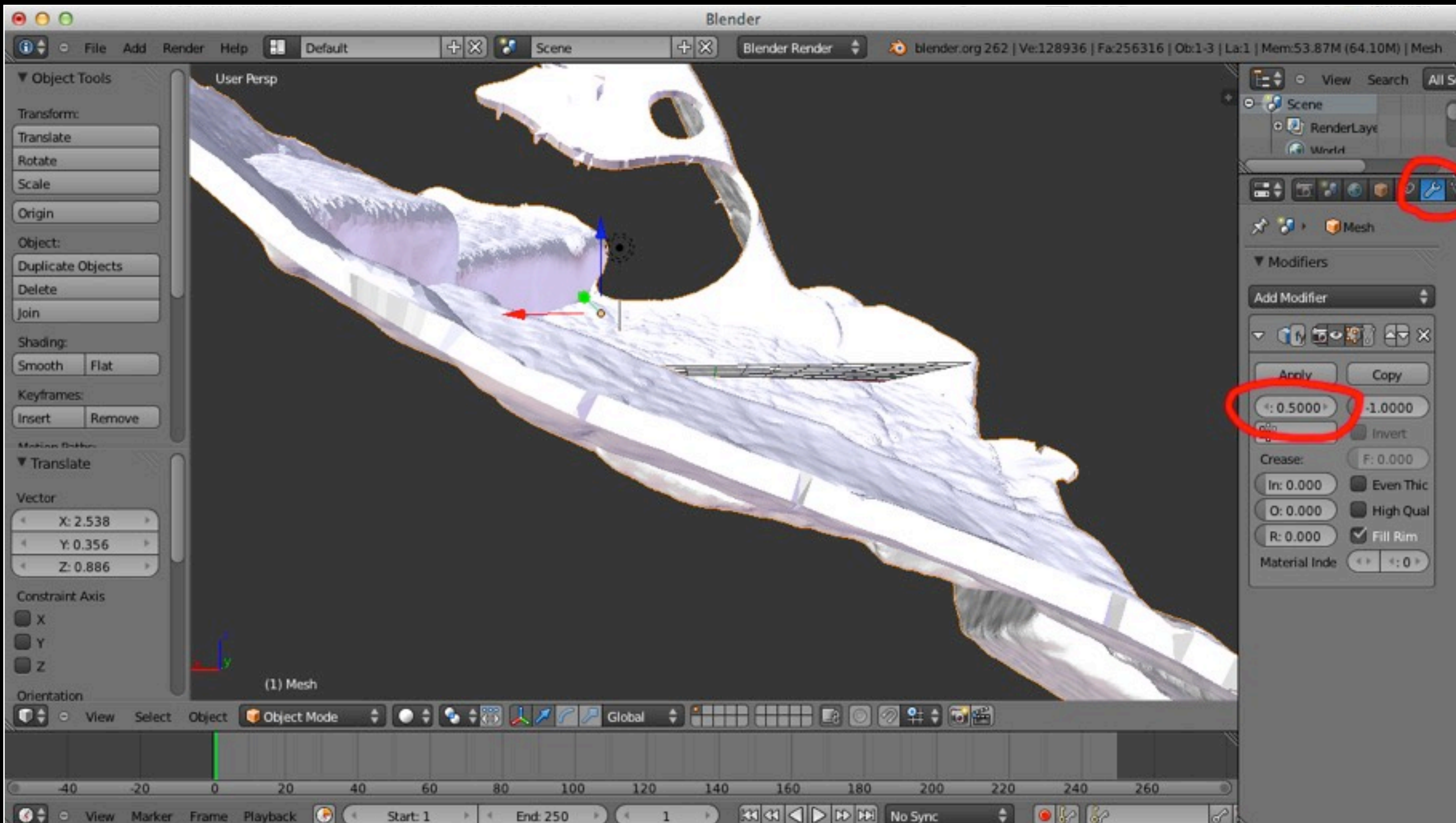



Infinitely thin surface
Unrealisable


Thickened “realisable” surface

- “Solidify” modifier in Blender.

- Modifiers are elegant since they don’t permanently affect the geometry, can change later.



Geometry processing : Removing shrapnel and hole closing

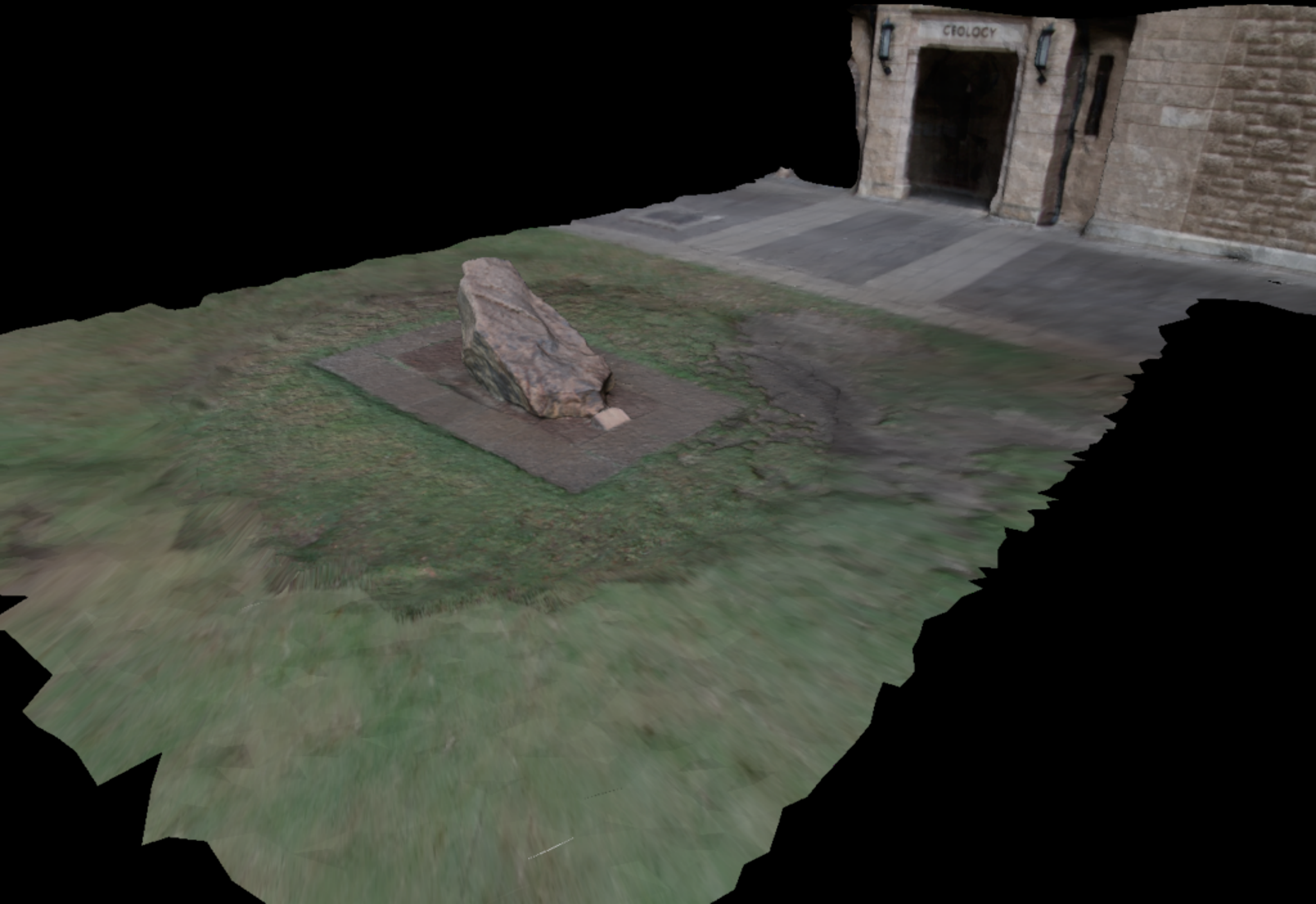
- Very common for there to be extraneous geometry.
- Remove reconstructed parts of the scene that are not of interest.
- Not uncommon for meshes to contain small holes, may be closed automatically by some reconstruction packages.

- Typically use MeshLab for hole closing.
- Also supported in some reconstruction packages, for example: PhotoScan.
- Don’t usually contain texture information, holes usually due to regions not visible in any photograph.

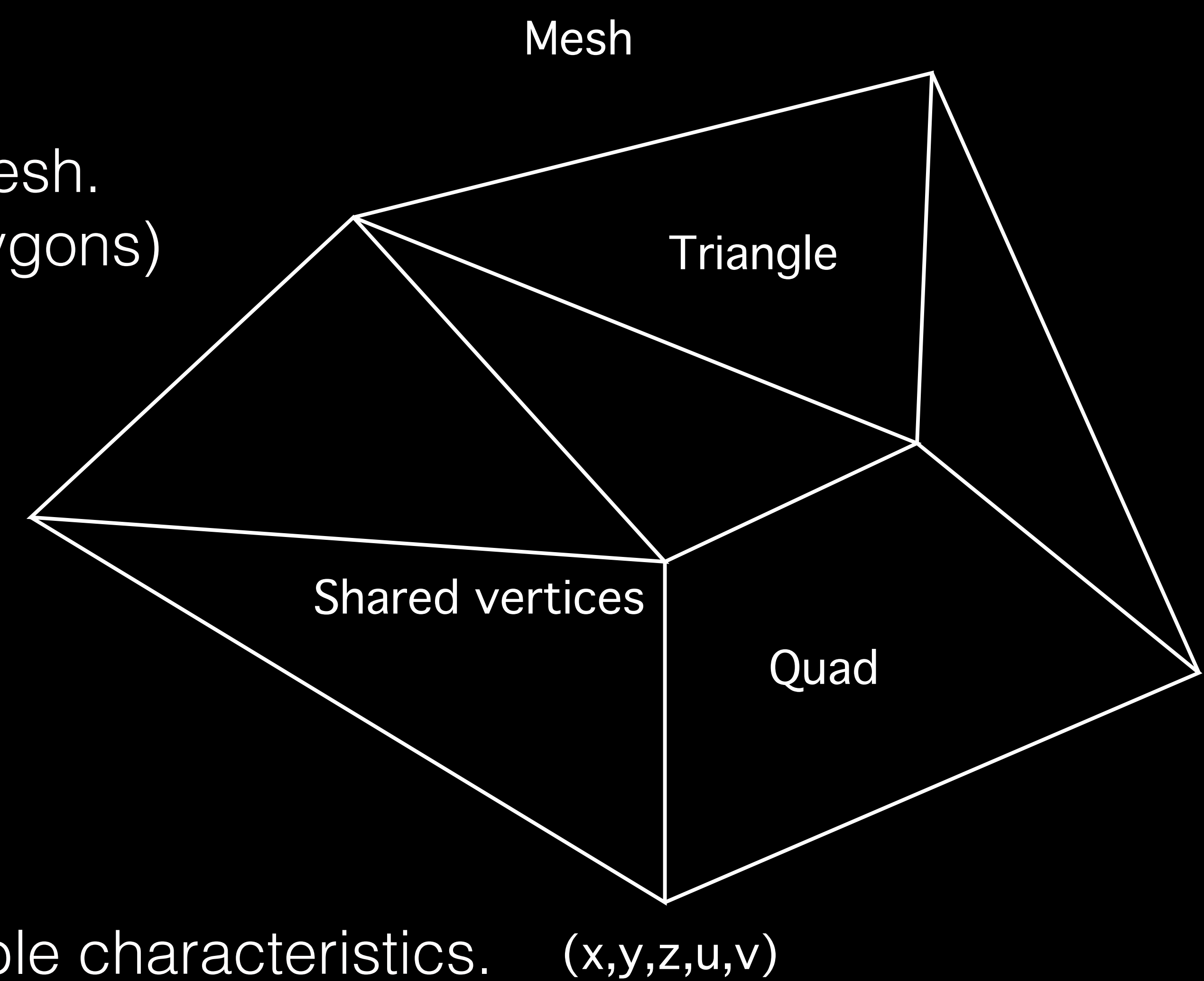
Indigenous marking stones


File
Edit
View
Marketplace
Help
Animation Path


File Edit View Marketplace Help
GEOLOGY
Animation Path


GEOLOGY

Geometry processing : File formats



- Requirements: unstructured triangular mesh.
  - mesh (vertices - edges - triangles - polygons)
  - texture coordinates
  - image based textures
- Common options
  - 3ds (3DStudioMax)
  - vrml, x3d
  - obj (Wavefront)
  - dae (collada)
- Pretty much standardised on obj, desirable characteristics.
  - text only so human readable
  - relatively easy to parse by software for post processing or custom utilities
  - well supported by commercial 3D applications (import/export)
  - shared vertices so no chance of numerical holes
  - supports multiple texture materials and images
- [Poorly formed obj files by 123D Catch]

- Anatomy of an OBJ file. Consists of 3 parts
  - vertex, face, normals, texture coordinates
  - materials file
  - texture image files

```
mtllib ./stone.obj.mtl

v 7.980470 5.627900 3.764240
v 8.476580 2.132000 3.392570
v 8.514860 2.182000 3.396990
  :
  :
vn -0.502475 -1.595313 -2.429116
vn 1.770880 -2.076491 -5.336680
vn -0.718451 -4.758880 -3.222428
  :
  :
vt 0.214445 0.283779
vt 0.213670 0.287044
vt 0.211291 0.287318
  :
  :
usemtl material_0
f 5439/4403/5439 5416/4380/5416 7144/6002/7144
f 5048/4013/5048 6581/5437/6581 5436/4400/5436
f 5435/4399/5435 5049/4014/5049 5436/4400/5436
  :
  :
```

vertices

normals

texture coordinates

triangles

vertex index

normal index

texture coordinate index

filename

material name

```
newmtl material_0
Ka 0.2 0.2 0.2
Kd 0.752941 0.752941 0.752941
Ks 1.000000 1.000000 1.000000
Tr 1.000000
illum 2
Ns 0.000000
map_Kd stone_tex_0.jpg
```

Example 2 : Diotima (UWA)

- Require significantly more images ... a full 3D object.
- 16 images in this case, a relatively low number for a full 3D object.
- Some algorithms perform better if the images are captured in sequence with the best matches at the start of the bundle adjustment.
- Depends on whether the software does a compare between all images.
- Diffuse lighting conditions so no strong shadows, see later on limitations.
- “Bald” spot because no photographs from above, see later on limitations on access.
- My test subject for comparing algorithms and capture.

Diotima (Mistress of Pericles)
16 images

Other topics

- Accuracy
- Resolution: Real vs apparent, Geometric vs texture
- Relighting
- Rendering
- Annotation
- Texture editing

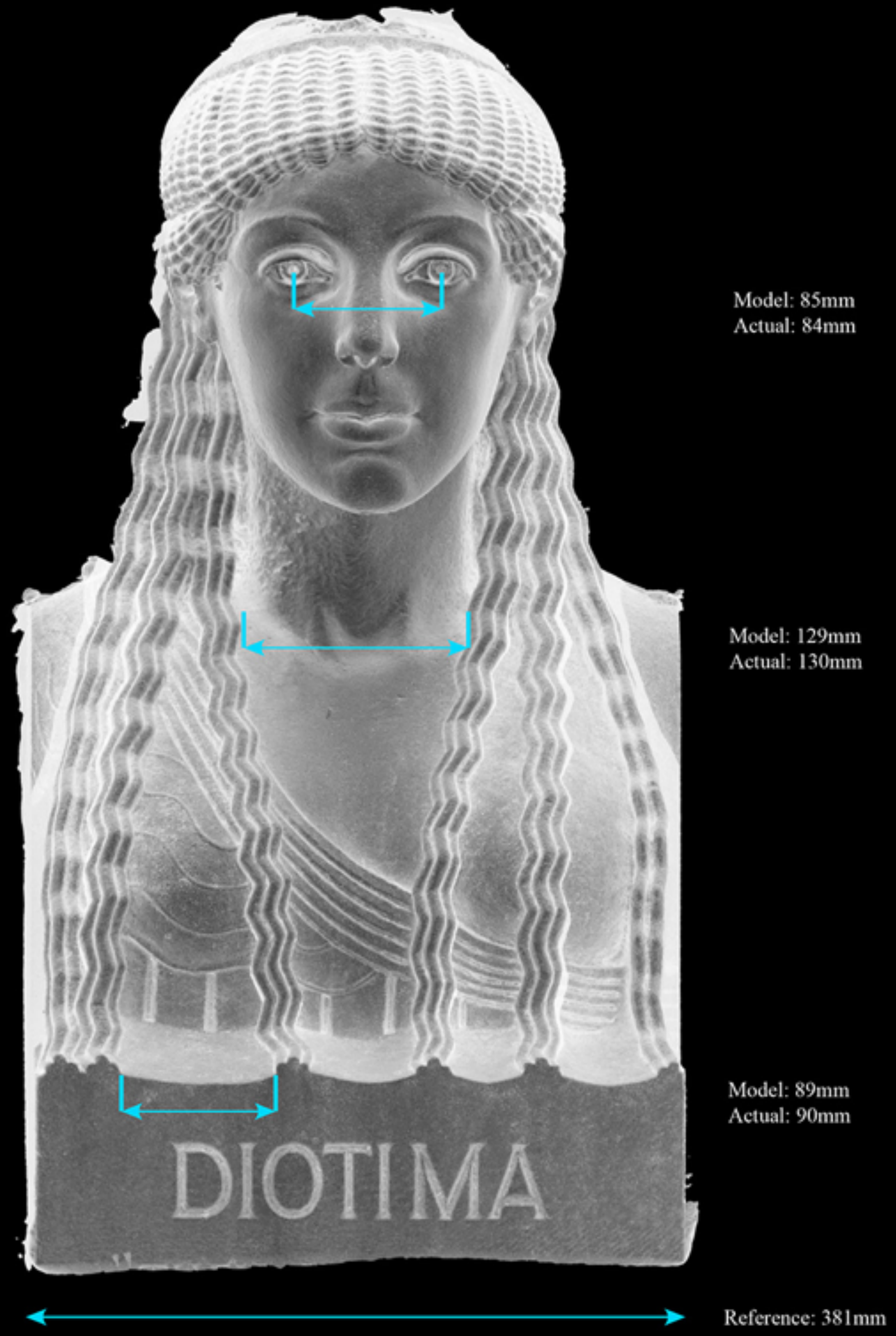
Other topics: Accuracy

- The first question many people ask is how accurate is it?
  Especially surveyors.

- Not easy to quantify
  1. Not all parts of a model are equally accurate.
  2. How does one get a ground truth to compare to?
  3. Accuracy can depend on characteristics of the model itself.
  4. How can you be sure best practice and best technology have been used?

- We have tested three methods to determine accuracy
  1. Reconstruct and compare key measures with known object.
  2. Perform ensemble reconstructions from large image sets, compare variation.
  3. Compare with other scanning techniques: laser scanning, CT, structured light.
  4. Visual comparison of zoomed in photographs of real and reconstructed.

- No absolute scale but use one length as reference.
- Model from 60 images.
- Subsequent measurements accurate to 2mm, most 1mm.



http://paulbourke.net/miscellaneous/reconaccuracy/

Original photograph

Reconstructed model

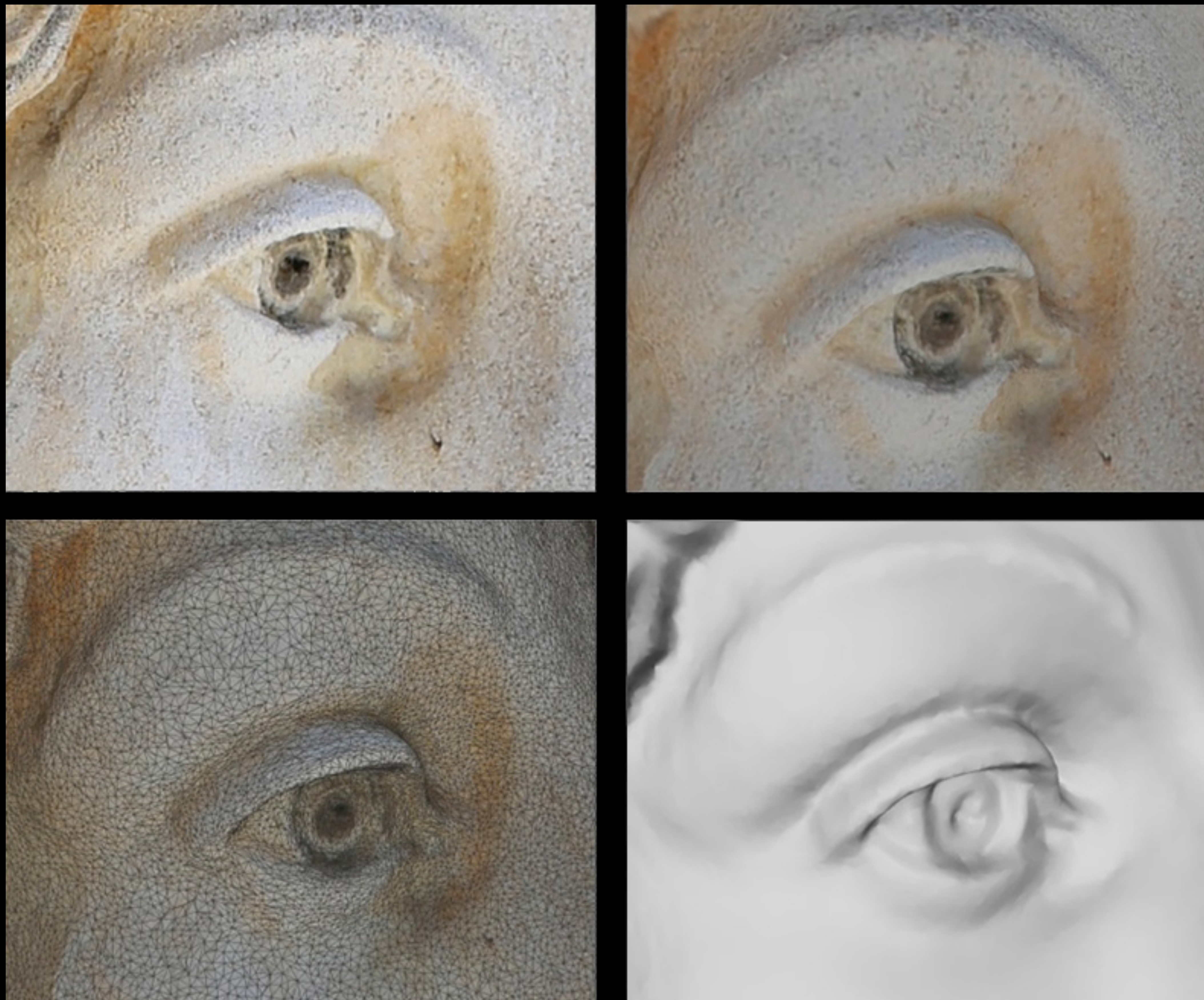
Shaded to emphasise surface variation

Original photograph

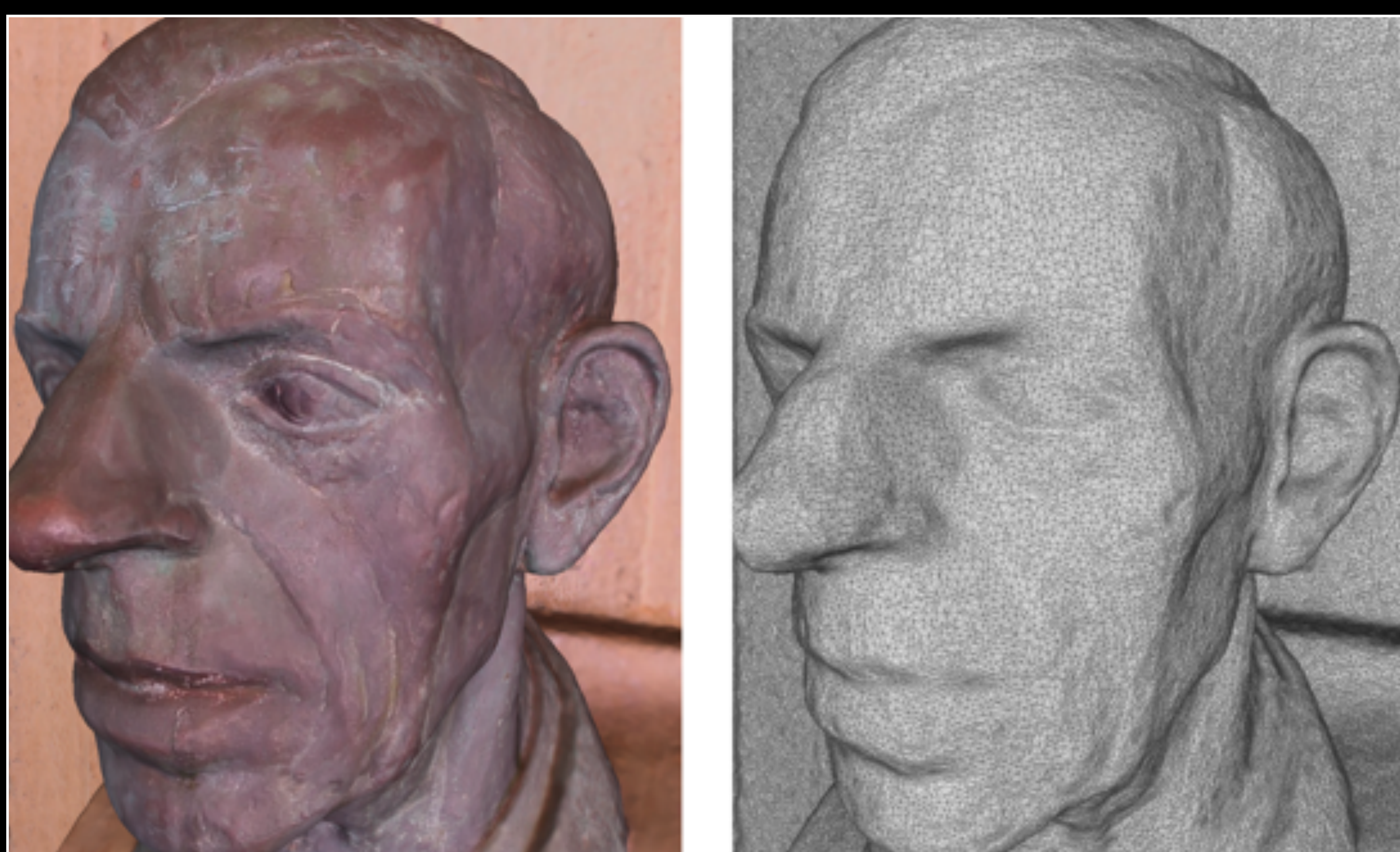
Reconstructed model

Shaded to emphasise surface variation

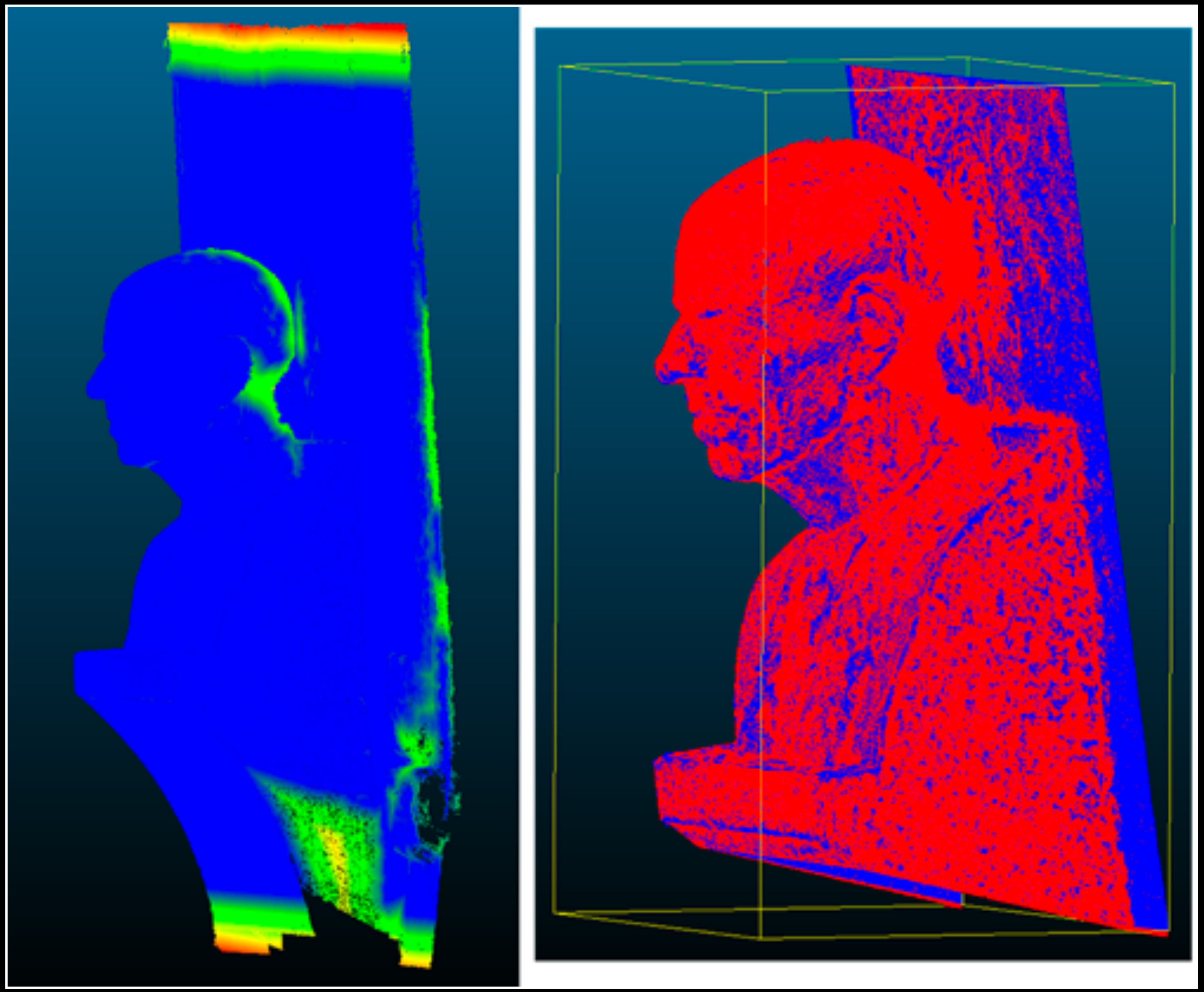
Original



- Ensemble tests of repeatability.
- Over photograph a model. Choose random selections of photographs.
- Or, take multiple photographs from expected optimal positions, each photograph slightly perturbed. Choose random selection from each position.
- Reconstruct and compare variations in the final models.



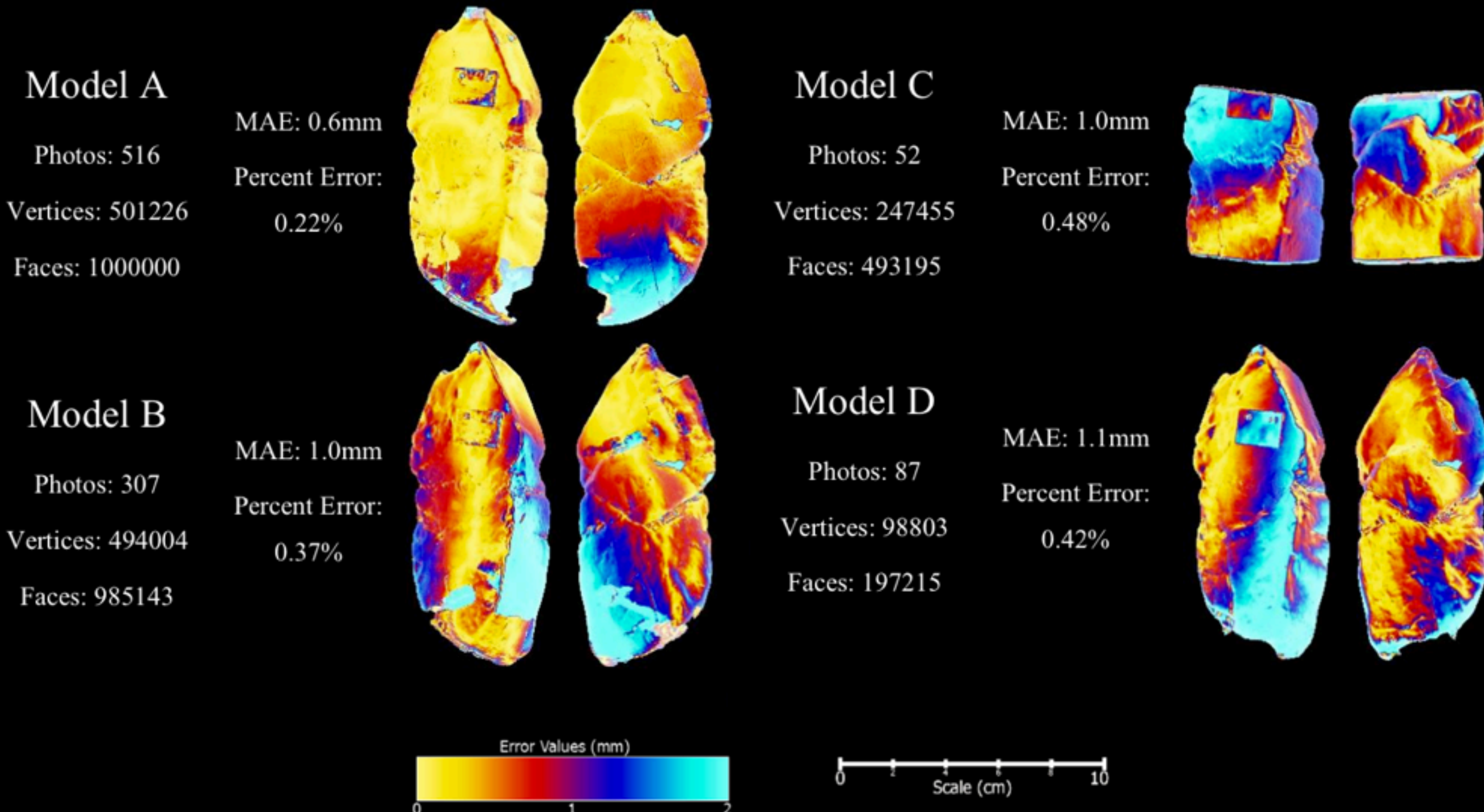
Pairs of models are aligned by choosing 4 reference points. Translation and rotation alignment, no differential scaling permitted.



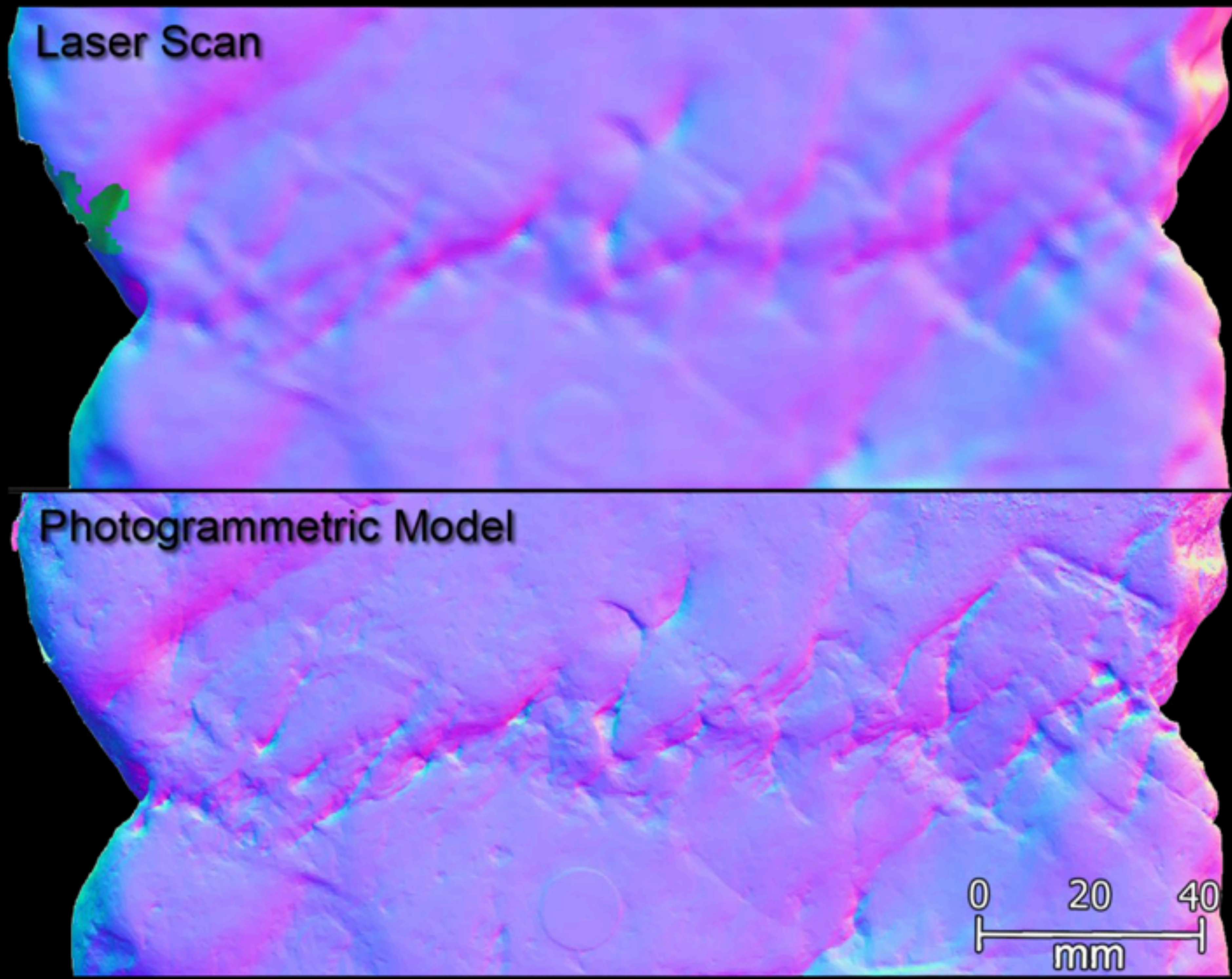
http://paulbourke.net/miscellaneous/reconrepeat/

- Comparing scanning modalities
  - Photogrammetry
  - Laser scanner (NextEngine 2020I HD)
  - CT scan (Siemens SOMATOM Definition AS)
  - Structured light scanner (Artec) discounted
  - Depth camera (Kinect) discounted

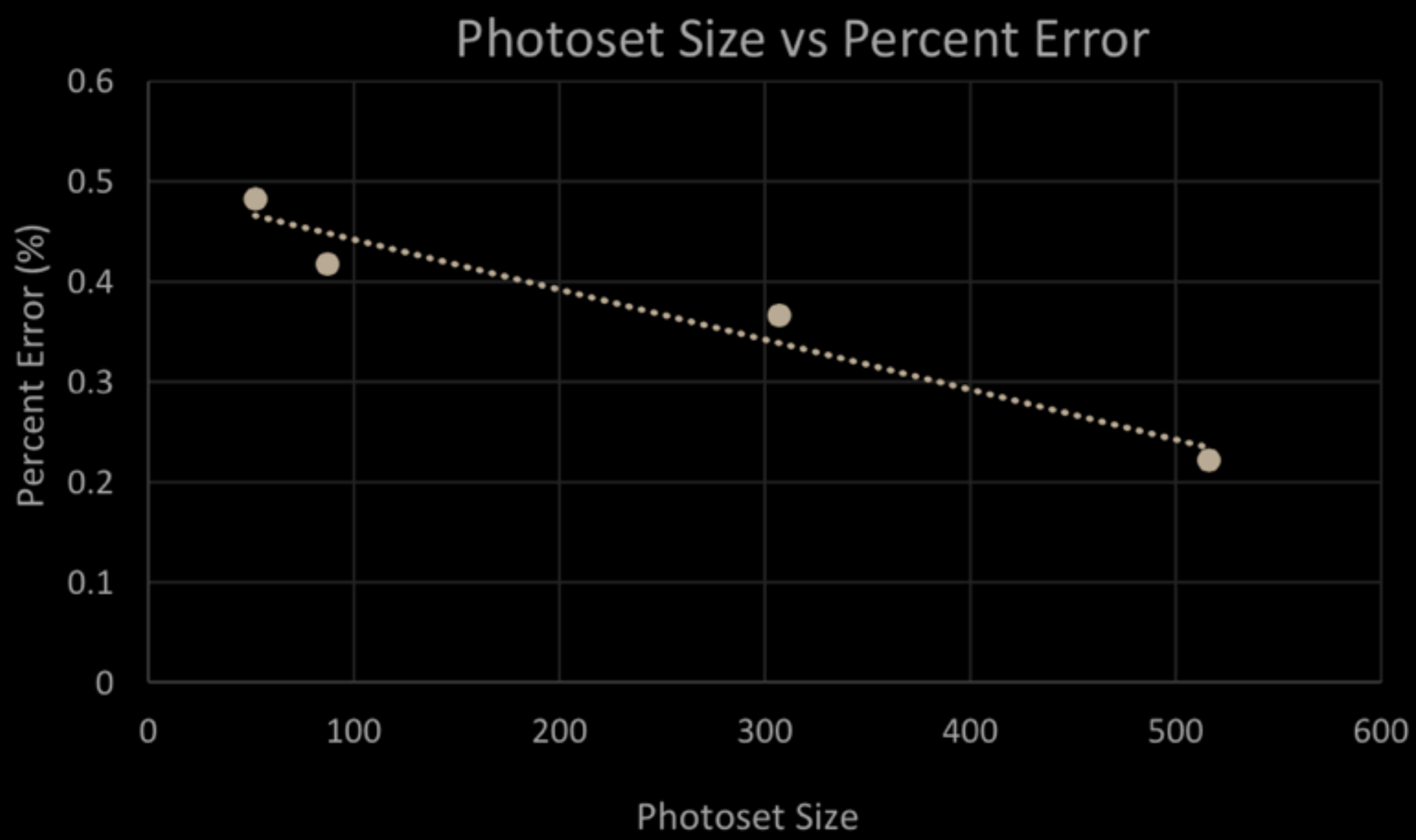
- Geoscience sample


Model A
Photos: 516
Vertices: 501226
Faces: 1000000
MAE: 0.6mm
Percent Error:
0.22%
Model B
Photos: 307
Vertices: 494004
Faces: 985143
MAE: 1.0mm
Percent Error:
0.37%
Model C
Photos: 52
Vertices: 247455
Faces: 493195
MAE: 1.0mm
Percent Error:
0.48%
Model D
Photos: 87
Vertices: 98803
Faces: 197215
MAE: 1.1mm
Percent Error:
0.42%
Error Values (mm)
0
1
2
0
10
Scale (cm)

- Is the laser scanner in this case being used optimally?
- A major problem comparing capture modalities is ensuring it is a fair test.

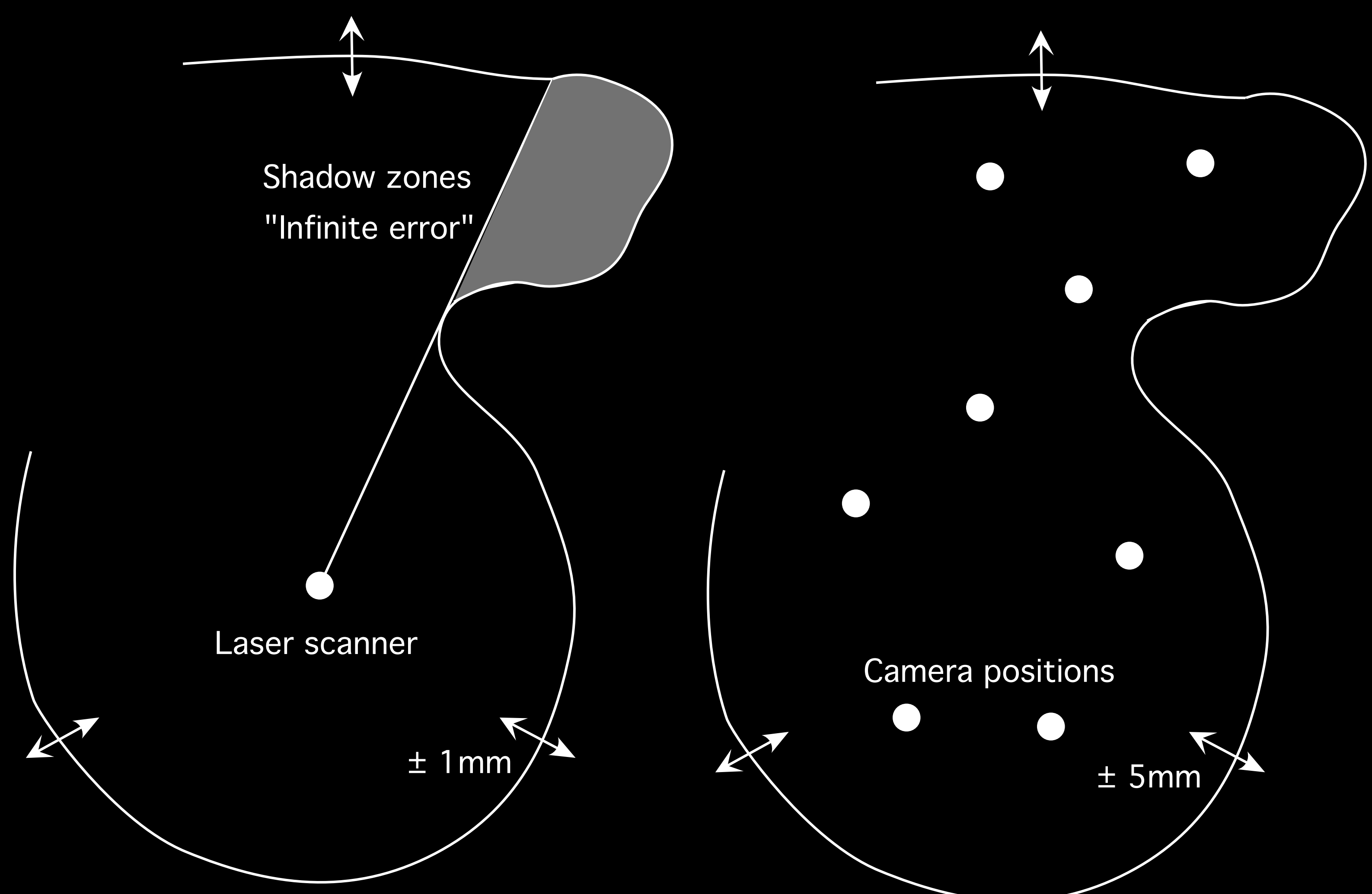


The Mechanics of En-Échelon Sigmoidal Vein Formation Constrained from Ultra-High Resolution Photogrammetric Data. Sam Thiele

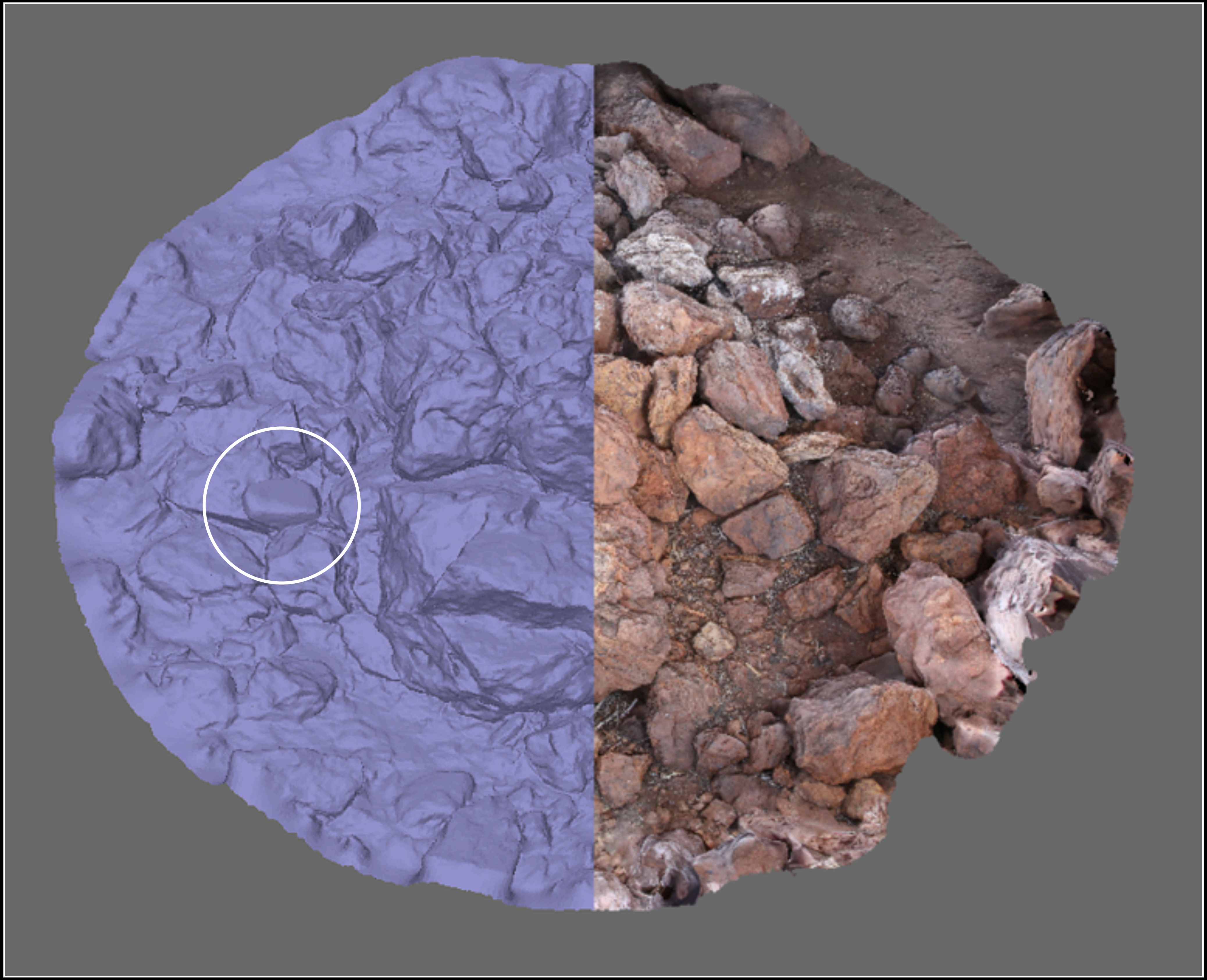


Relationship between photoset size and percentage error. While four points is not nearly enough to define a correlation, there does appear to be a linear relationship. The relationship does not seem to approach a limiting percentage error, suggesting that even greater accuracies are possible with larger photosets.

- Comparing accuracy with laser scanners.
- Not a competition, laser scanners are clearly more accurate in situations where they are suited.
- Indeed the capture modality used should be chosen based upon the desired outcomes and the nature of the scanning technology, no clear winner technology.
- Note that accuracy of laser scanners is not all it is often claimed to be.
- What does it mean for a large model to be 1mm accurate in some places but hugely inaccurate in others, occlusion zones for example?



- How does one laser scan a pile of rocks?



Reconstruction vs Laser Scan summary

- Not a competition!
- One should be choosing the right tool for the job.
- Consideration also given to the purpose the models will be used for.
  Trusted dimensions for visible parts of the model?
  A high fidelity sense of the place?
  High quality textures?

	3D reconstruction	Laser scanning
Geometric accuracy	Improving	High
Effort	Low	High
Time	Fast	Often long
Visual quality	Potentially high	Average
Occlusion issues	Less problematic	More problematic

- Laser scanners generally superior for
  - Rectangular objects
  - Featureless surfaces

Took multiple photographs to reconstruct the plain white ceiling.

Borders are plain white, like ceiling and failed to reproduce smooth surface

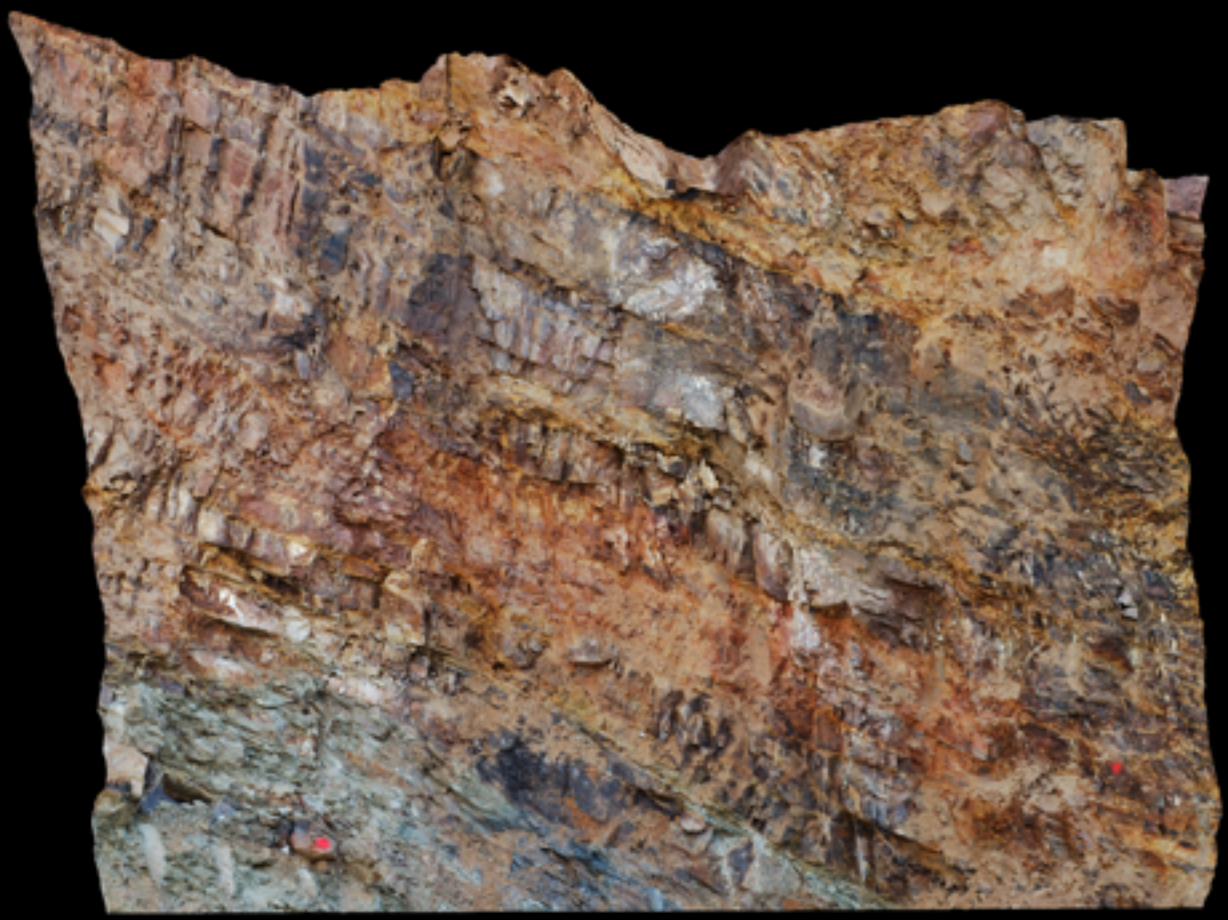
Wall has a texture and reconstructed well

- 20 minutes to take photographs for 3D reconstruction
- 5 hours for 6 laser scan positions ... still lots of occluded areas

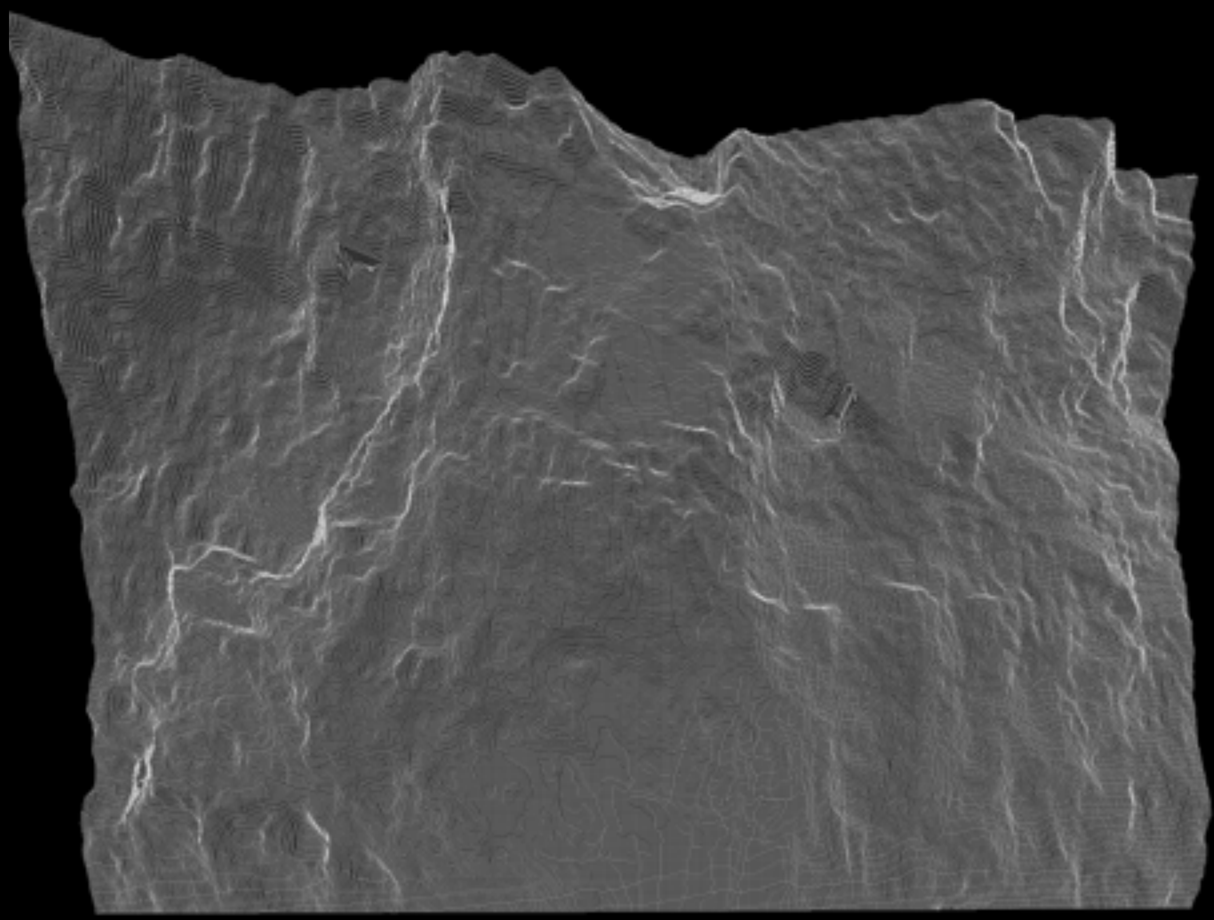
Other topics : Resolution

- Actual mesh resolution vs apparent mesh resolution.
- Texture resolution rather than geometric resolution.
- Requirements vary depending on the end application.
  - Realtime environments require low geometric complexity and high texture detail
  - Analysis generally requires high geometric detail
  - Digital record wants high geometric and texture detail

	Geometric resolution	Texture resolution
Gaming	Low	High
Analysis	High	Don't care
Education	Medium	High
Archive/heritage	High	High
Online	Low/Average	Low/average

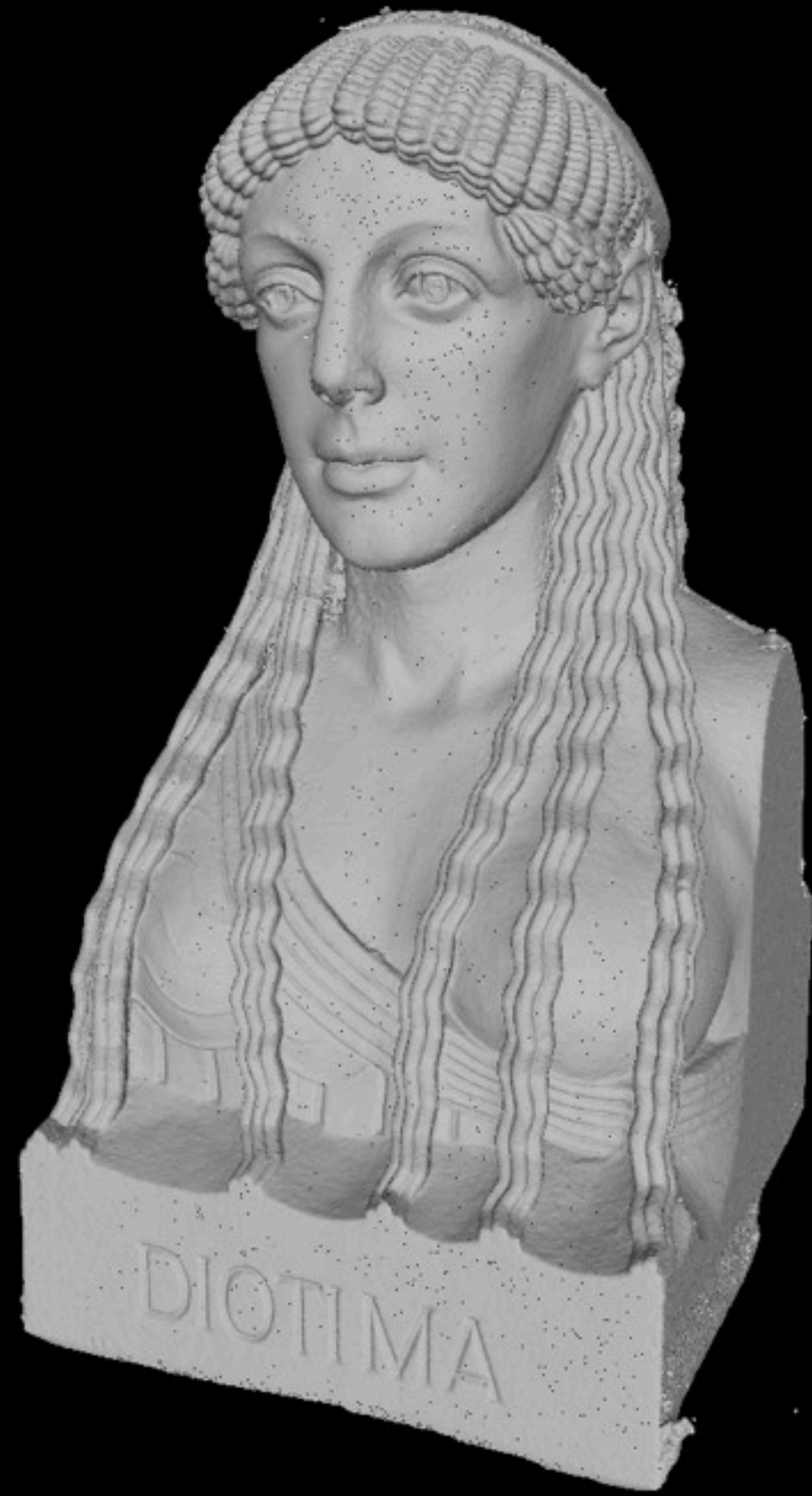


Apparent high resolution



Low resolution mesh

Example from 2010



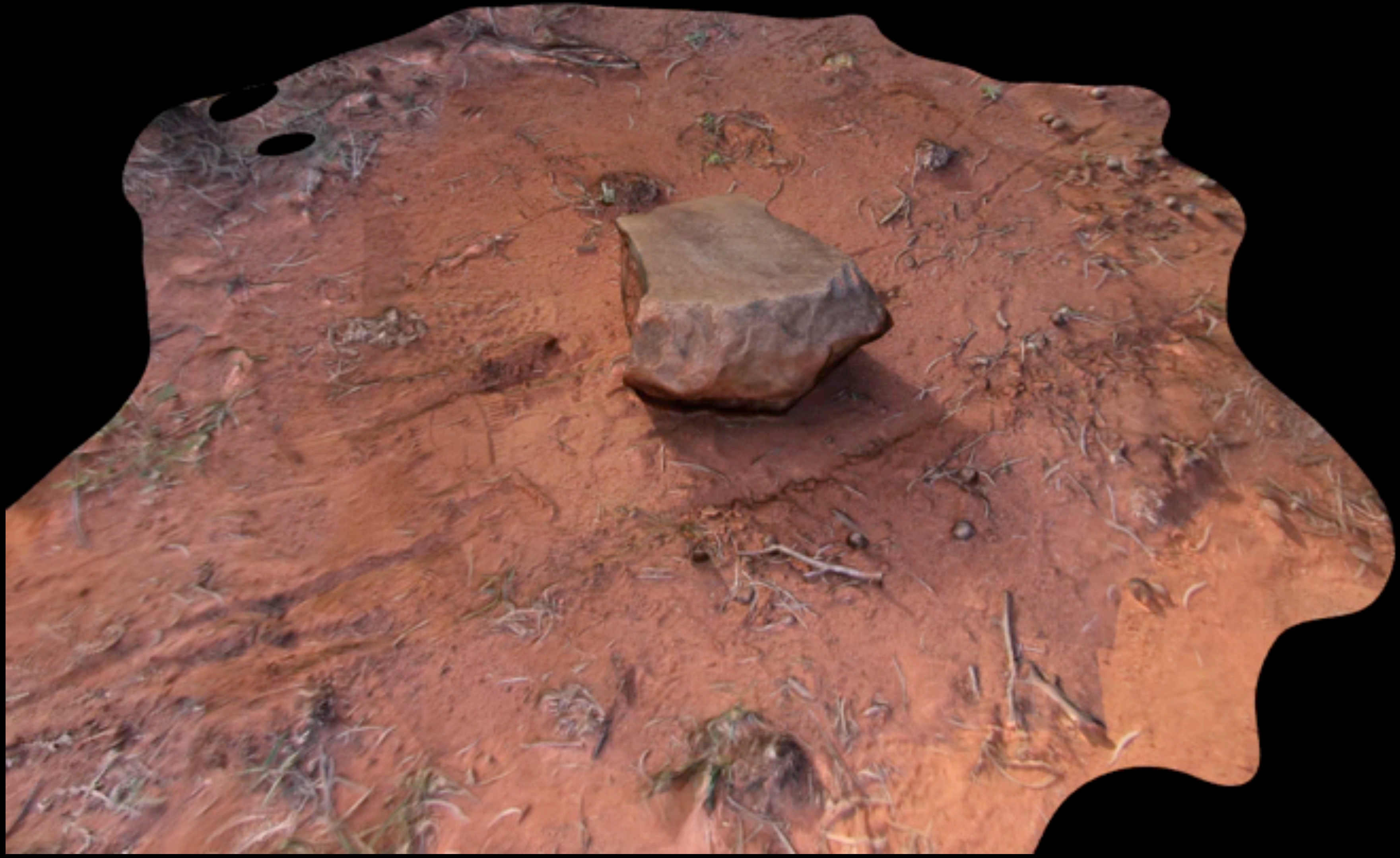
Example from 2014

Other topics : Relighting

- We have a 3D model, can “relight” it.
  For example: cast shadows, adjust diffuse/specular shading.
- Obviously works best with diffuse lit models.
- See later for baked on texture limitations.
- Interesting in the archaeology context since it is well known that some features are “revealed” in different lighting conditions.
- Cannot replicate effects of dyes but can replicate effects due to shading/shadowing of fine details.

Wanmanna

Other topics : Rendering

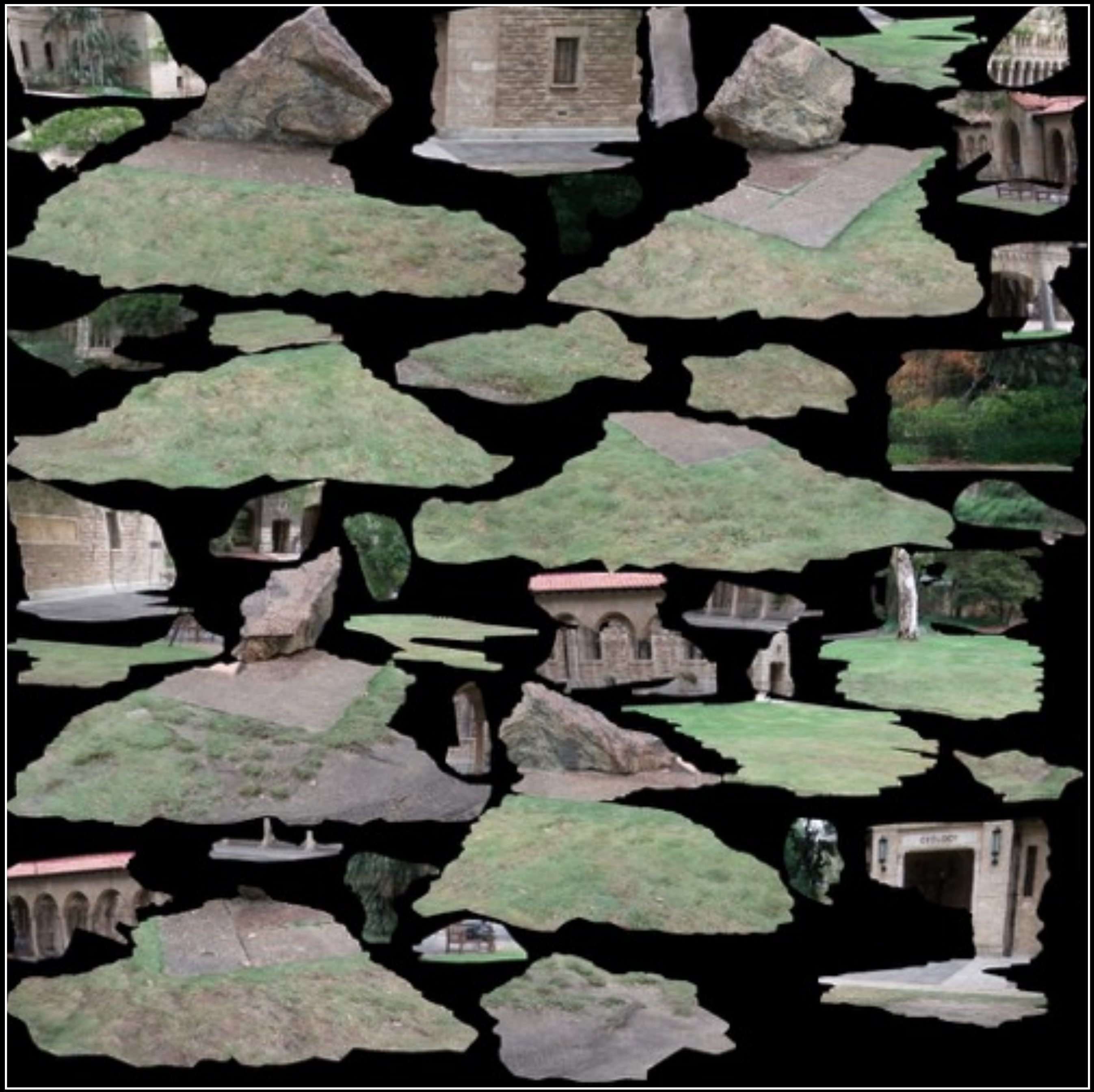


Other topics : Analysis

1000 Buddha temple, Manipal, India

Other topics : Annotating

- Textures from the reconstruction algorithms are often “interesting”.
- Exact form of the texture depends to some extent on the software being used
  Can often identify the software based upon the appearance of the texture maps.
- They are derived from re-projection of the image from the derived camera position onto the reconstructed mesh, hence potentially very high quality (perceived resolution).
- Can generally still be drawn on, treated as an image for image processing in PhotoShop, etc.



Texture map 1

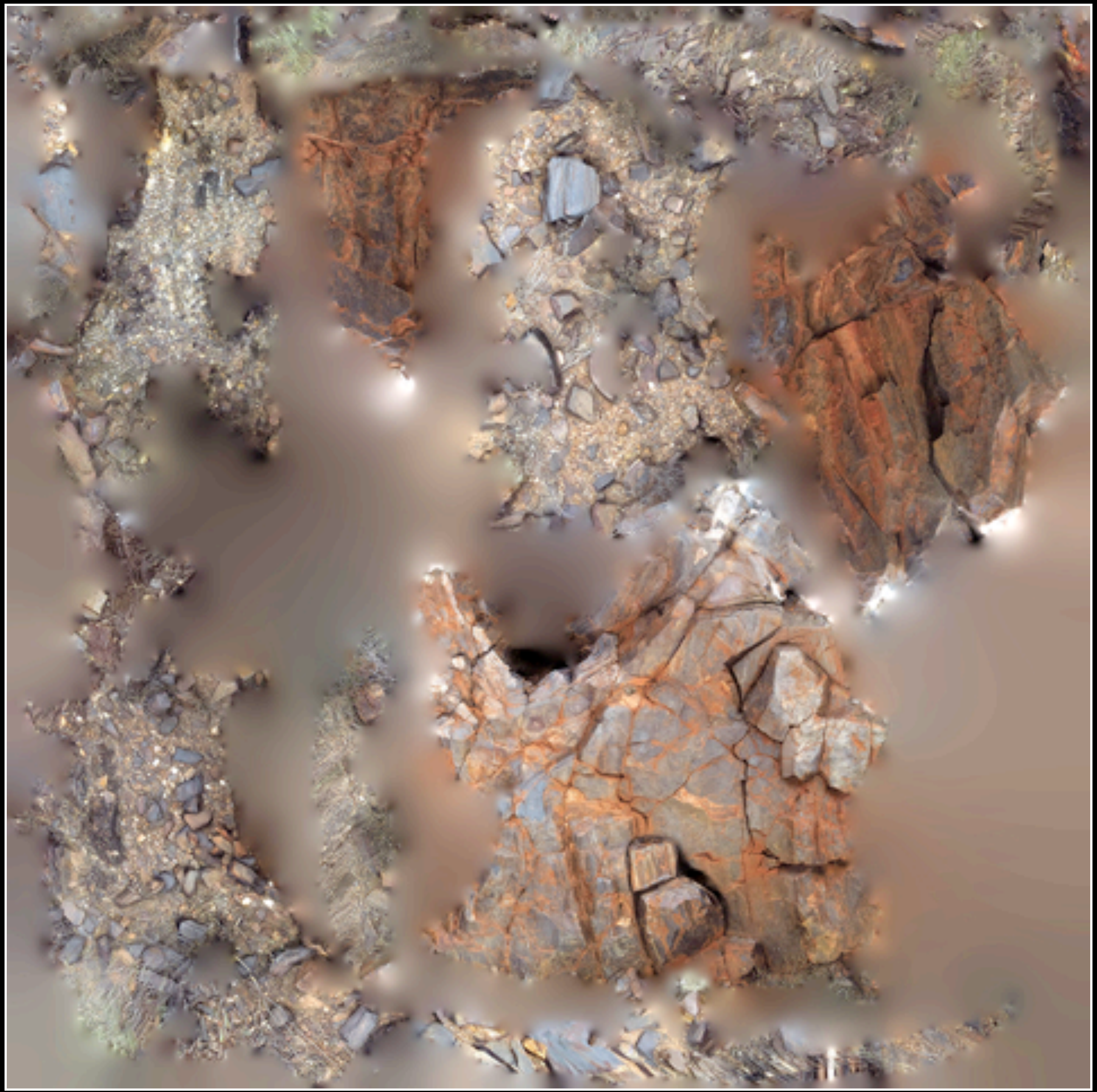
Texture map 2

Textured mesh

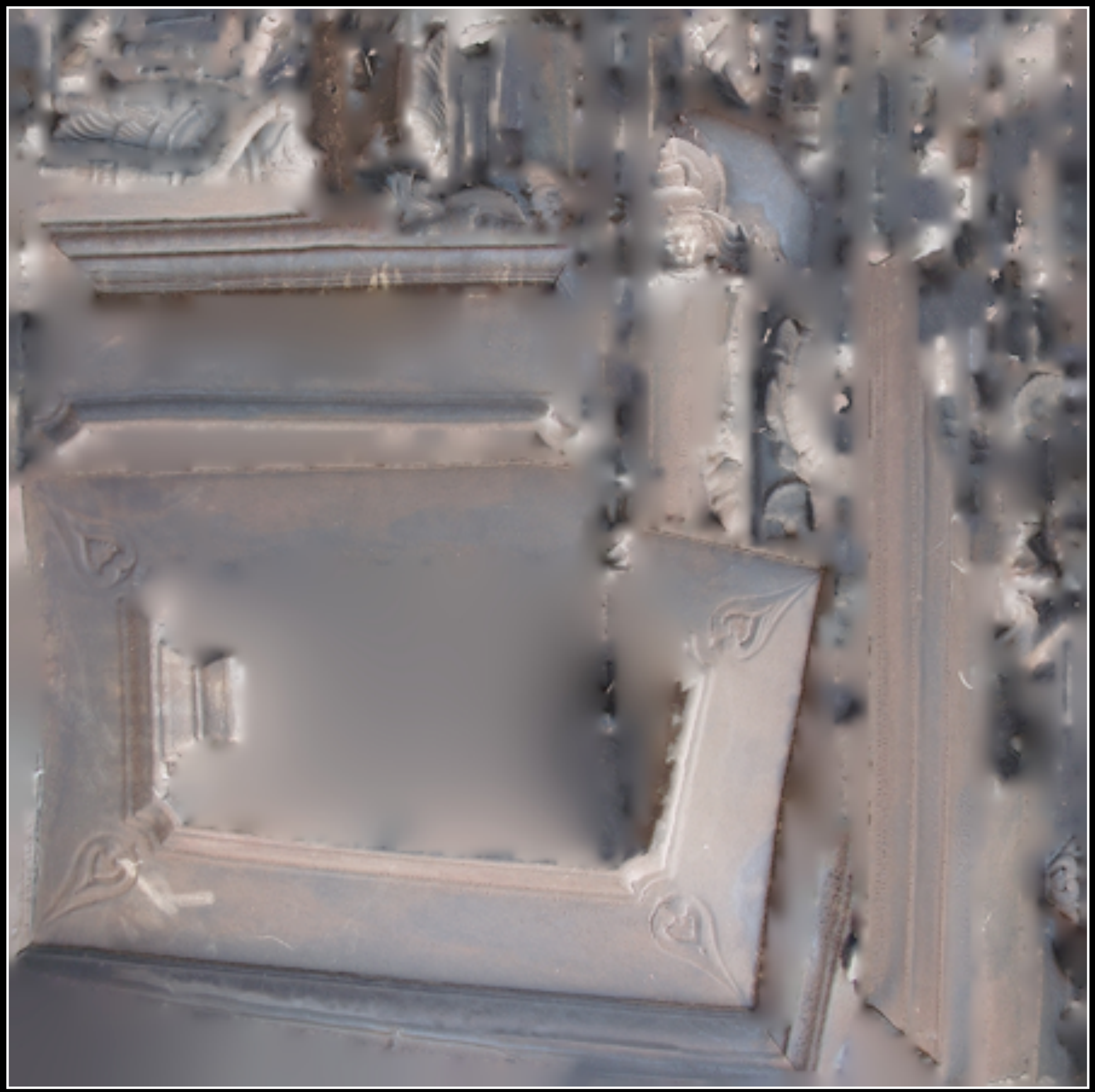

1
v
0
0
u
1

Other topics : Texture editing

- Some texture mapping modes are easier to edit than others
- Can be difficult for per camera reprojected textures (left)
- Easier for orthographic texture maps (right), but not always a supported option.



- Can obviously do colour correction/grading on the texture post reconstruction.
- Need to be careful with filtering which may cause artefacts between texture seams.



Limitations and Challenges

- Occluders - Problematic
- Movement in the scene
- Thin structures
- Baked on shadows
- Lighting changes during capture
- Access to ideal vantage points
- Online and database access
- High level queries for geometric
- Reflective surfaces

Limitations : Occluders

- Algorithms seem to be generally poor at handling foreground occluders.
- For example: columns in front of a building.
- Reason: a small change ins camera position results in a large difference in visible objects.
- Capturing the backdrop behind an object.
  - Often better, assuming possible, to capture them separately

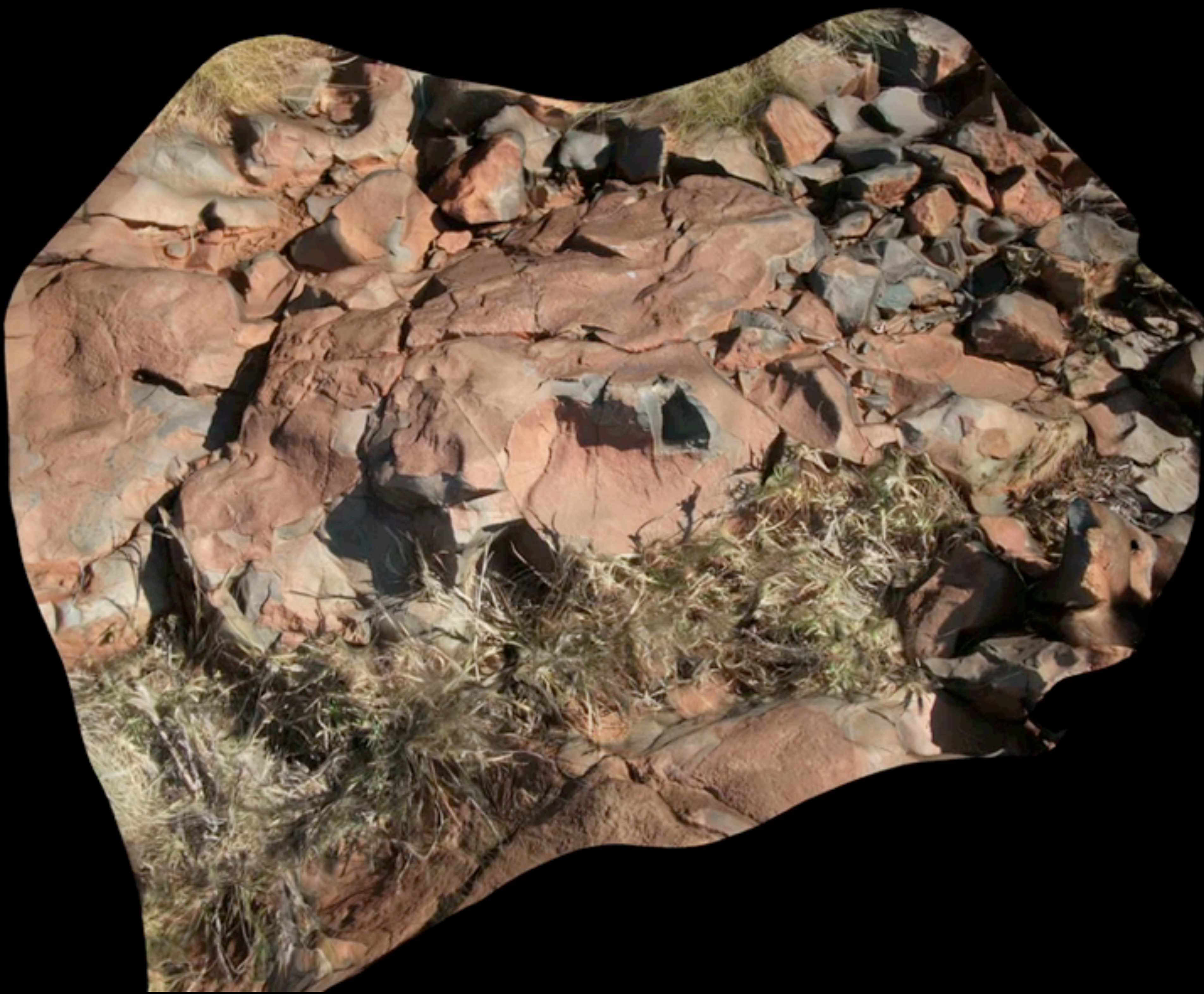
St Lawrence, Manipal, India

Limitations : Movement

- Objects to be reconstructed obviously need to be stationary across photographs.
- Grass moving in the wind is a common problem for field work.
- Solution is to create a camera array for time simultaneous photography.

Limitations : Thin structures

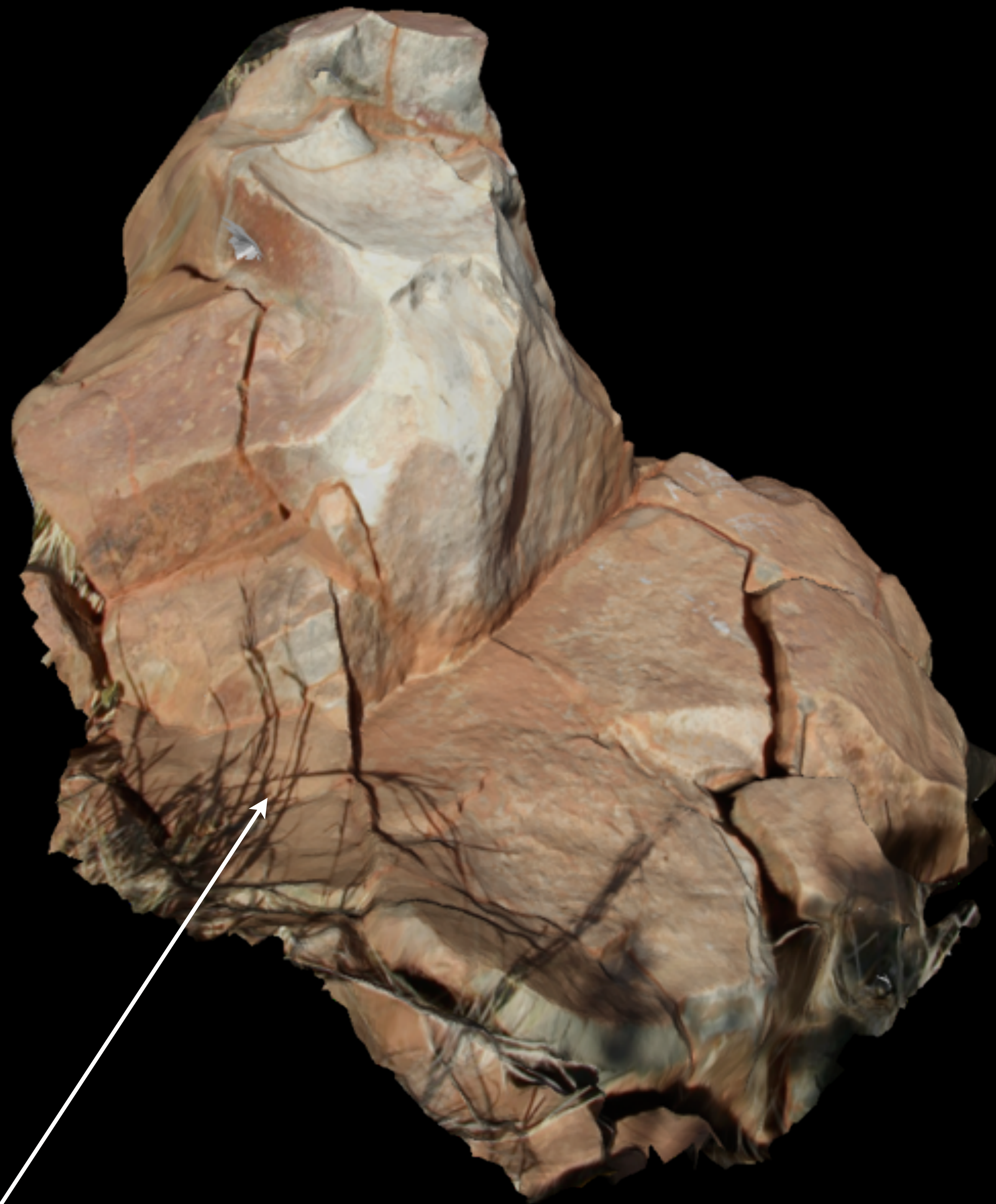
- Difficult to reconstruct objects approaching a few pixels in the images (sampling theory).
- Example of grasses in the rock art reconstruction.



Grass not resolved

Limitations : Baked on shadows

- Shadows obviously become part of the texture maps.
- Can be alleviated somewhat by photographing in diffuse light.
- For outside objects can sometimes choose times when object is not directly lit.
- Can sometimes choose diffuse lit days, cloudy.



HMAS Sydney Cairn, Canarvon

Limitations : Lighting changes and access

- For field work access to preferred positions for photographs may be problematic.
- Similarly capturing photographs from above the object, elevated positions.
- When capturing 30+ photographs for 3D objects the lighting conditions may change eg: clouds passing overhead.
  Processes generally insensitive to this except for variations in resulting textures.
- Shadows of the photographer.

Limitations : Reflective surfaces

- Mirror surface fold the world about the mirror plane.
- Not unexpected then than reconstructions can build the world “behind” the mirror.

- Mirror surfaces can provide a non-linear reflection of the world that will influence the feature point detection.
- Gives rise to a new art form.
  - Photogrammetry that goes wrong in “interesting” ways.
- Bug highly specular surface can also be an issue.

Fort Canning, Singapore

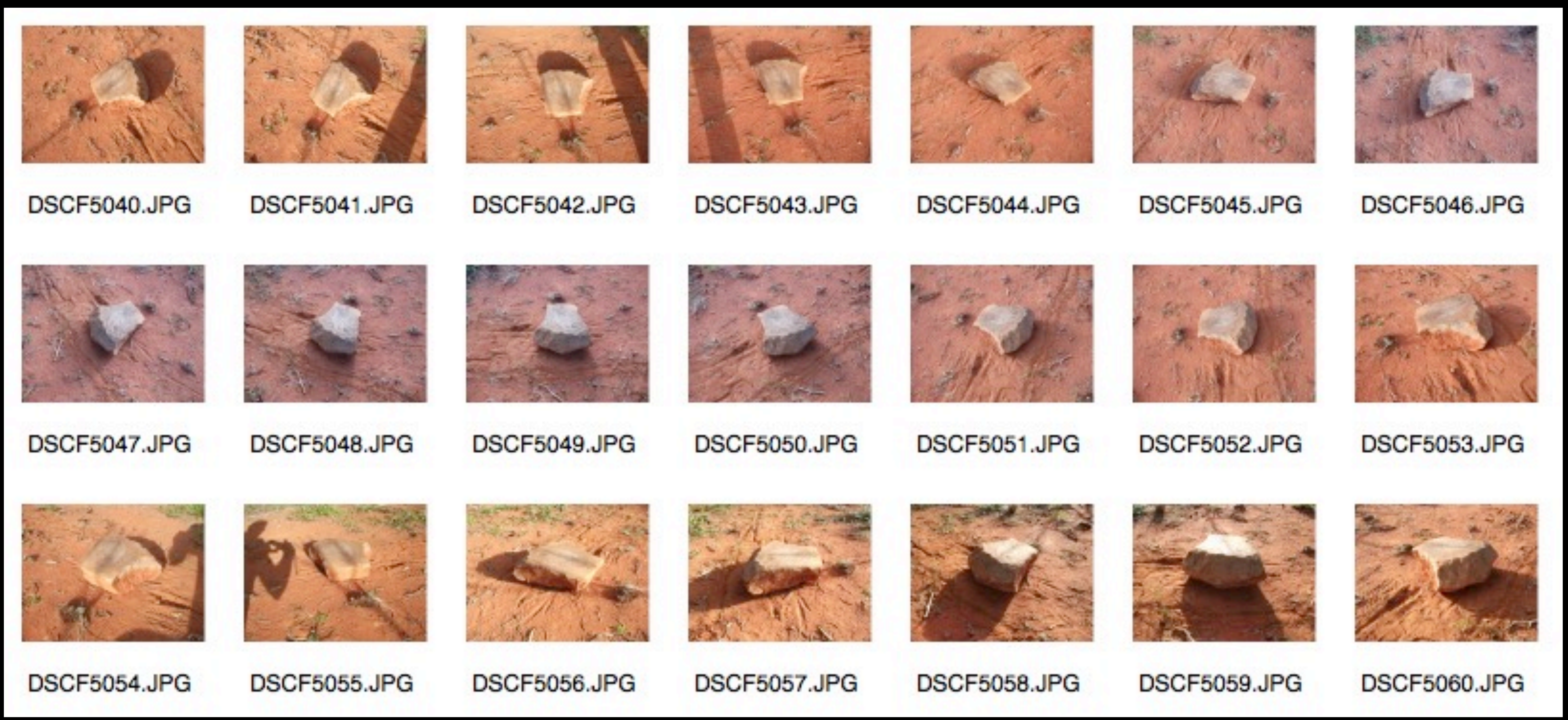
Limitations : Database/online representations

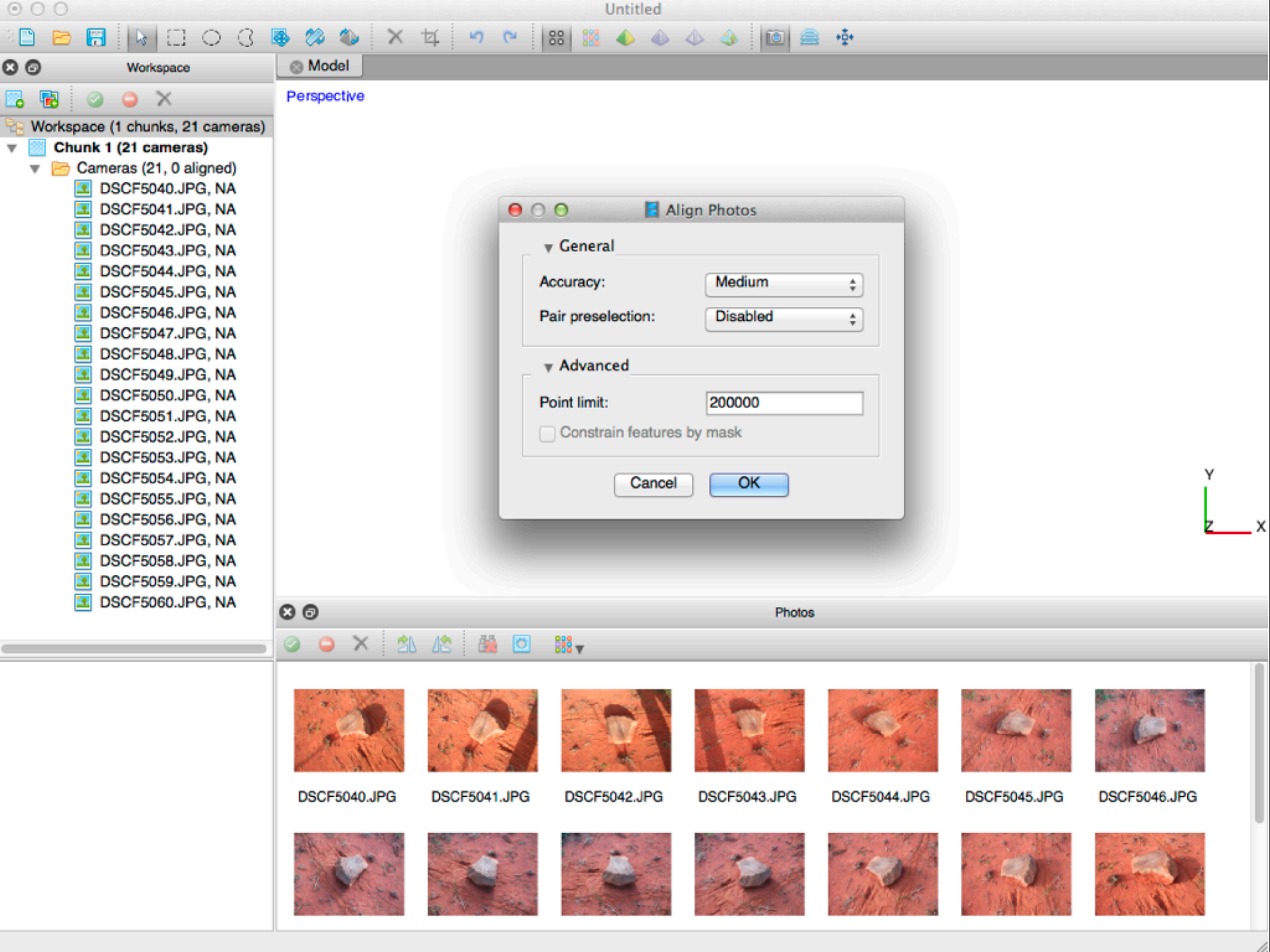
- Claim that the need to store these higher level forms of data capture will increase.
- Will this replace the need for storing photographic data?
- Surprisingly (depressingly) even after all these years of online delivery there are still no entirely satisfactory ways of distributing 3D data.
- Options
  - VRML, x3d : very poor cross platform support
  - 3D PDF : dropped by Adobe some years back
  - WebGL? HTML5 / Canvas?
- Key missing components:
  - progressive texture
  - progressive geometry

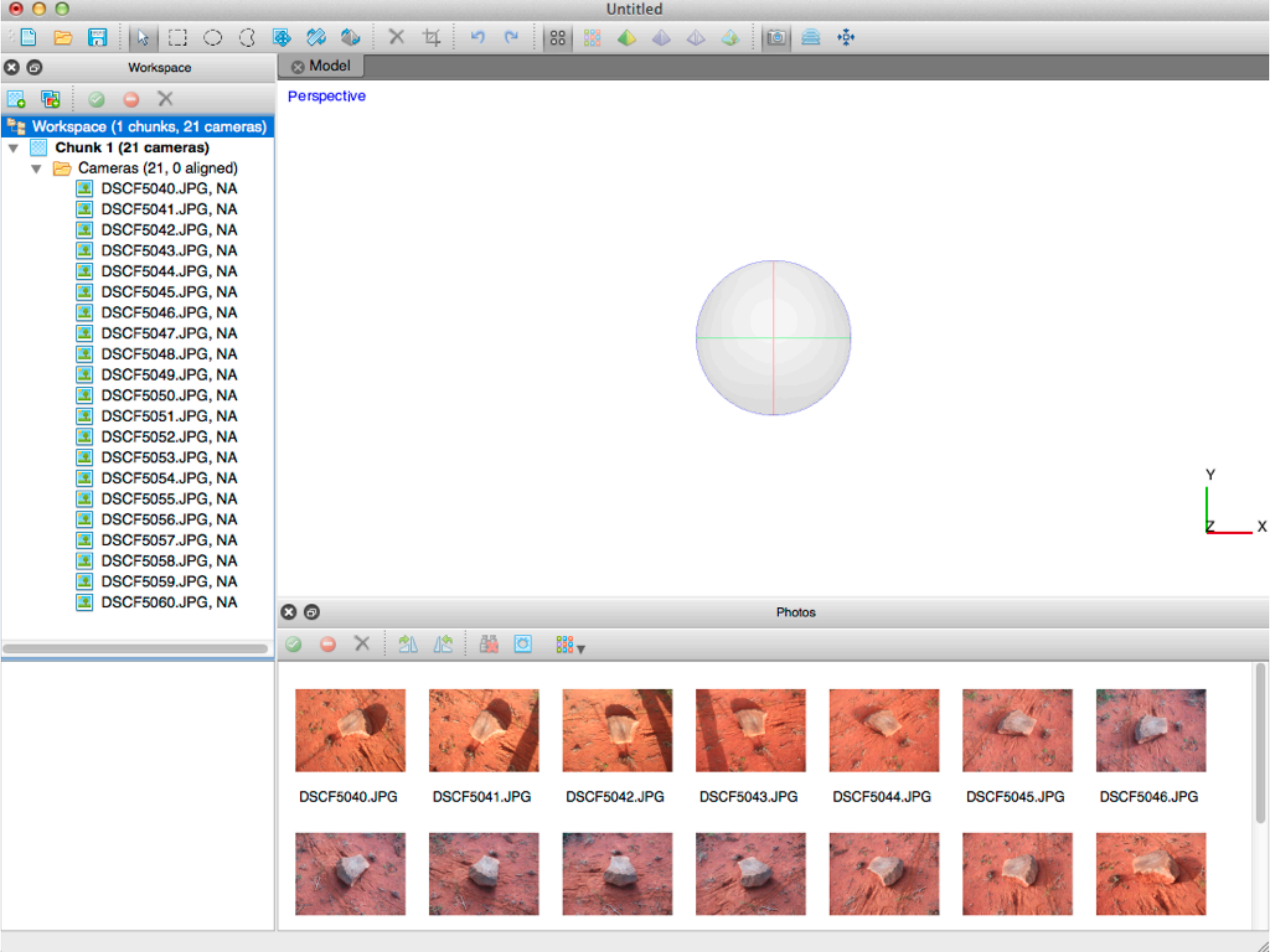
Gommateswara, Manipal, India

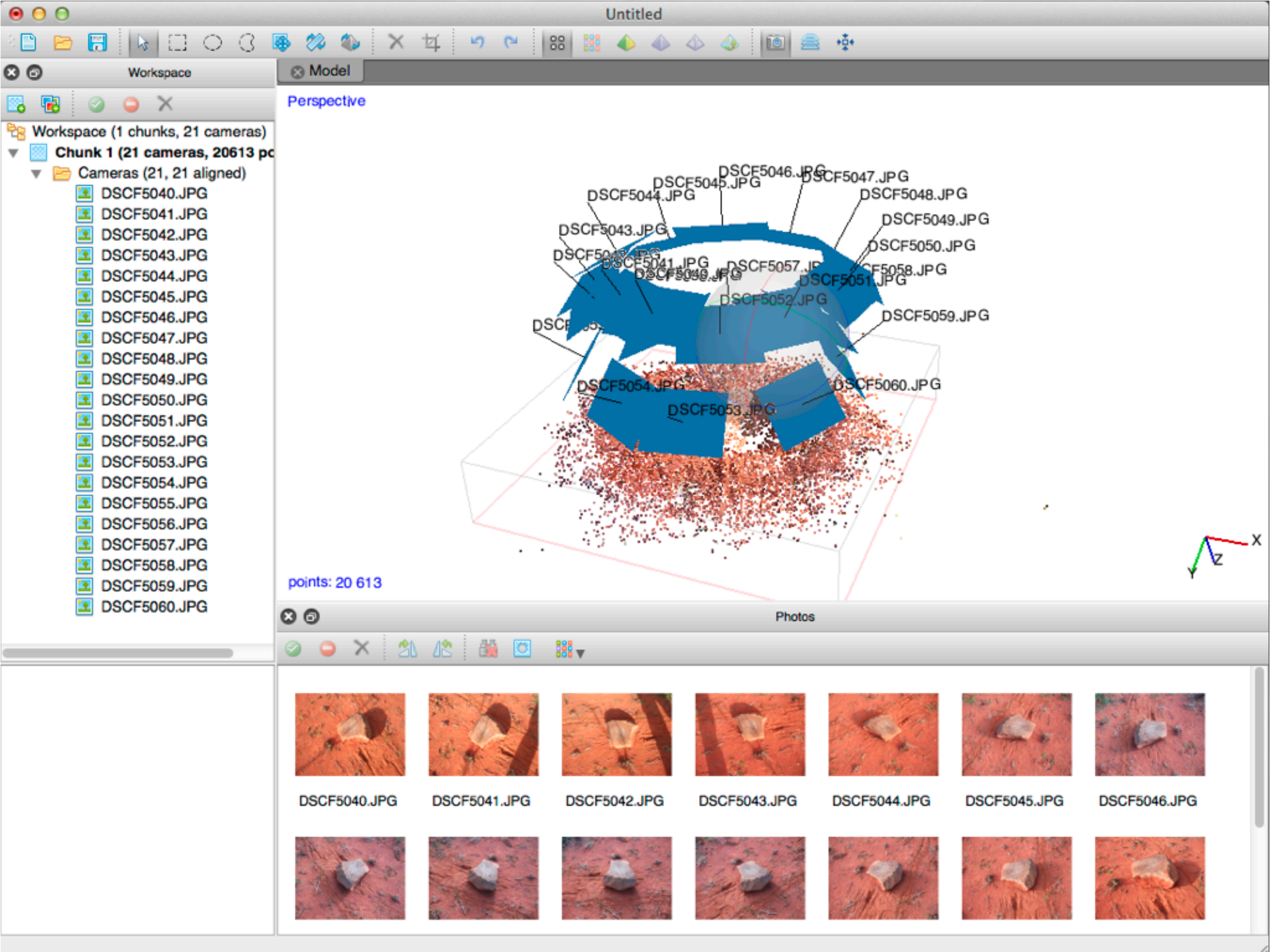
Example 3 : Grinding stone

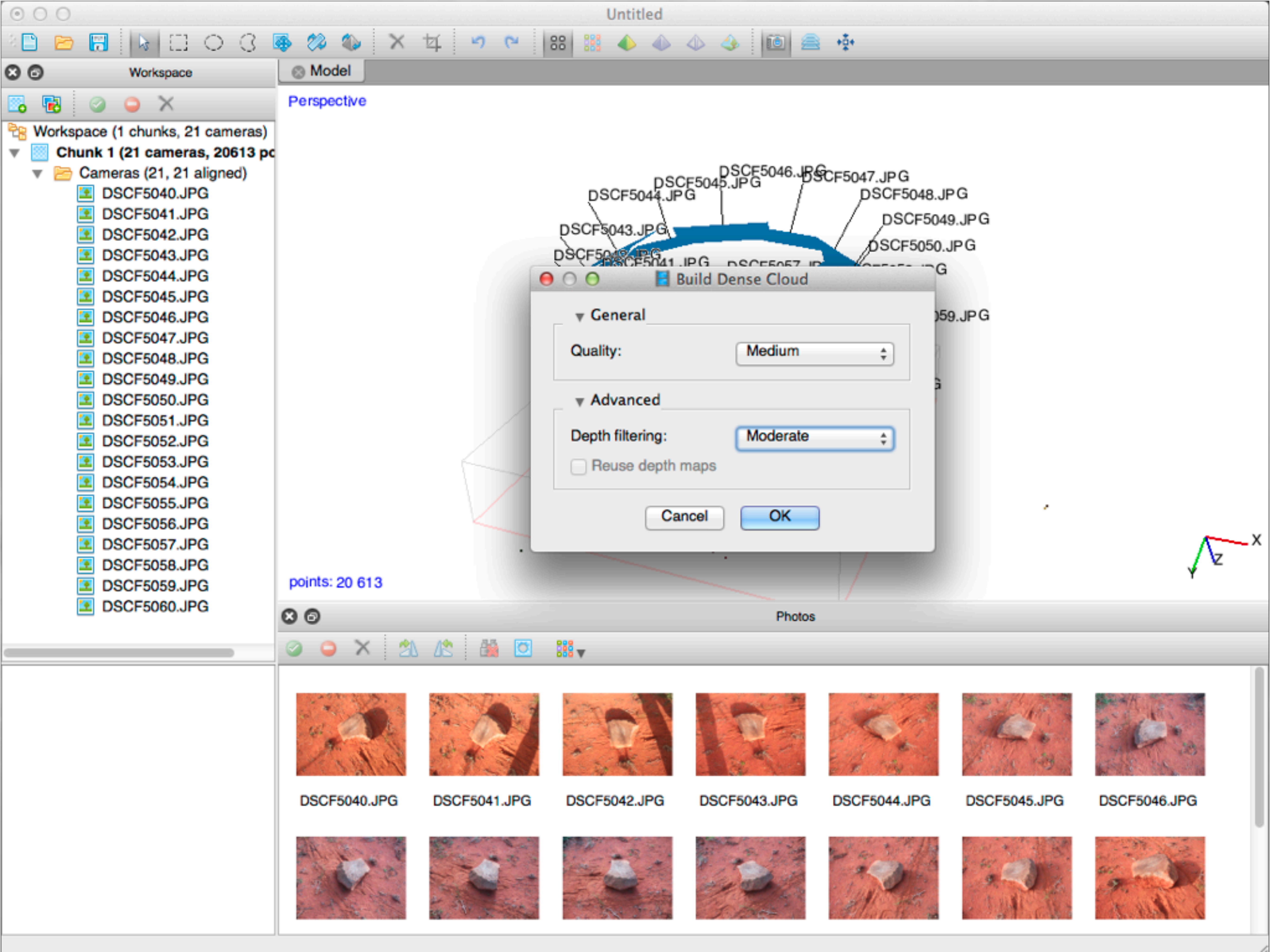
- Will do a full worked example based upon grinding stone from the Ngintaka story
- 22 photographs around the stone
- Example of light/colour changes due to polarising filter and angle to sun direction

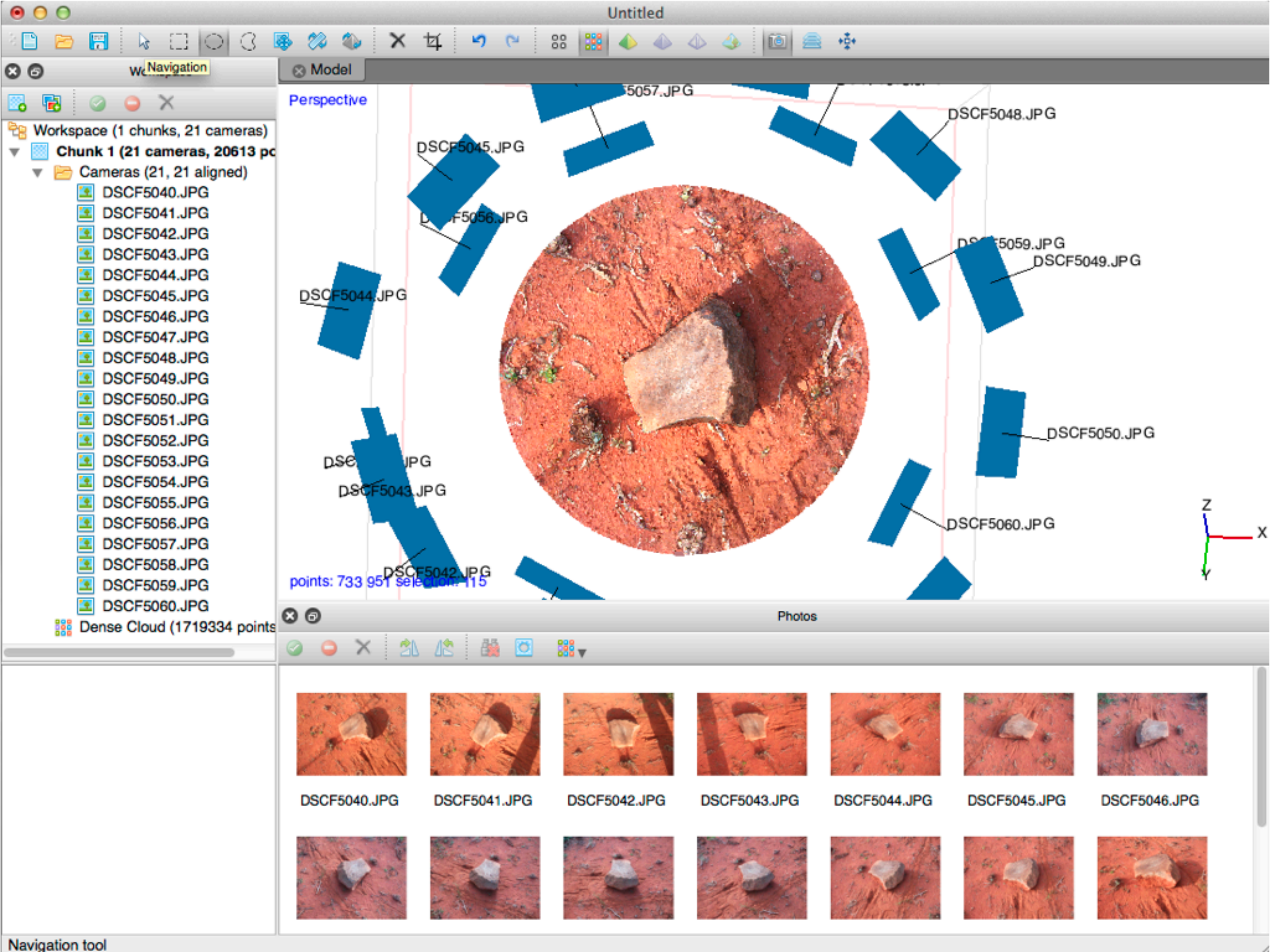


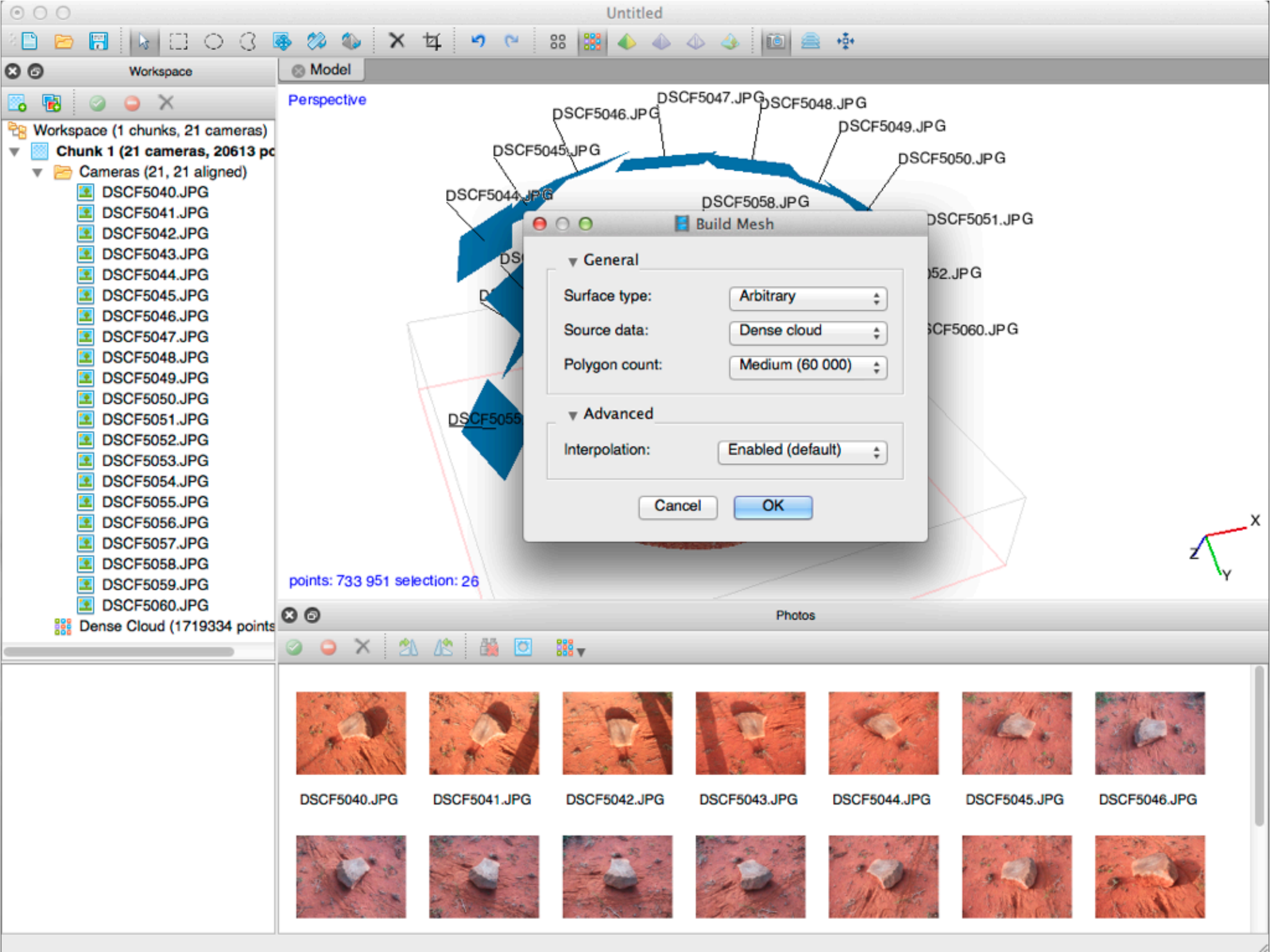

Untitled
Workspace
Model
Perspective
Workspace (1 chunks, 21 cameras)
Chunk 1 (21 cameras)
Cameras (21, 0 aligned)
DSCF5040.JPG, NA
DSCF5041.JPG, NA
DSCF5042.JPG, NA
DSCF5043.JPG, NA
DSCF5044.JPG, NA
DSCF5045.JPG, NA
DSCF5046.JPG, NA
DSCF5047.JPG, NA
DSCF5048.JPG, NA
DSCF5049.JPG, NA
DSCF5050.JPG, NA
DSCF5051.JPG, NA
DSCF5052.JPG, NA
DSCF5053.JPG, NA
DSCF5054.JPG, NA
DSCF5055.JPG, NA
DSCF5056.JPG, NA
DSCF5057.JPG, NA
DSCF5058.JPG, NA
DSCF5059.JPG, NA
DSCF5060.JPG, NA
Align Photos
General
Accuracy:
Medium
Pair preselection:
Disabled
Advanced
Point limit:
200000
Constrain features by mask
Cancel
OK
Y
Z
X
Photos
DSCF5040.JPG
DSCF5041.JPG
DSCF5042.JPG
DSCF5043.JPG
DSCF5044.JPG
DSCF5045.JPG
DSCF5046.JPG

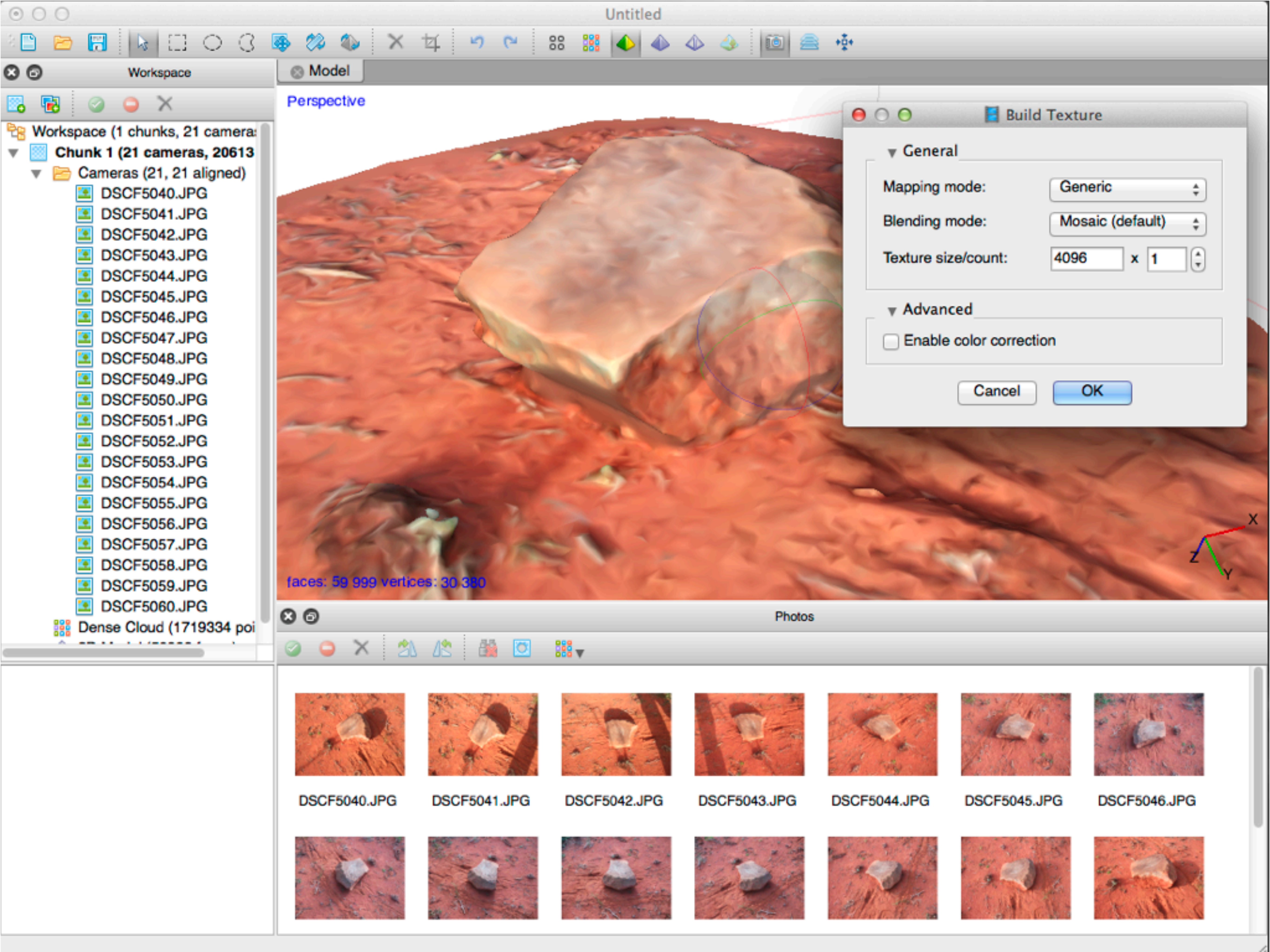

Untitled
Workspace
Model
Perspective
Workspace (1 chunks, 21 cameras)
Chunk 1 (21 cameras)
Cameras (21, 0 aligned)
DSCF5040.JPG, NA
DSCF5041.JPG, NA
DSCF5042.JPG, NA
DSCF5043.JPG, NA
DSCF5044.JPG, NA
DSCF5045.JPG, NA
DSCF5046.JPG, NA
DSCF5047.JPG, NA
DSCF5048.JPG, NA
DSCF5049.JPG, NA
DSCF5050.JPG, NA
DSCF5051.JPG, NA
DSCF5052.JPG, NA
DSCF5053.JPG, NA
DSCF5054.JPG, NA
DSCF5055.JPG, NA
DSCF5056.JPG, NA
DSCF5057.JPG, NA
DSCF5058.JPG, NA
DSCF5059.JPG, NA
DSCF5060.JPG, NA
Y
Z
X
Photos
DSCF5040.JPG
DSCF5041.JPG
DSCF5042.JPG
DSCF5043.JPG
DSCF5044.JPG
DSCF5045.JPG
DSCF5046.JPG


Untitled
Workspace
Model
Perspective
Workspace (1 chunks, 21 cameras)
Chunk 1 (21 cameras, 20613 po
Cameras (21, 21 aligned)
DSCF5040.JPG
DSCF5041.JPG
DSCF5042.JPG
DSCF5043.JPG
DSCF5044.JPG
DSCF5045.JPG
DSCF5046.JPG
DSCF5047.JPG
DSCF5048.JPG
DSCF5049.JPG
DSCF5050.JPG
DSCF5051.JPG
DSCF5052.JPG
DSCF5053.JPG
DSCF5054.JPG
DSCF5055.JPG
DSCF5056.JPG
DSCF5057.JPG
DSCF5058.JPG
DSCF5059.JPG
DSCF5060.JPG
points: 20 613
X
Y
Z
Photos
DSCF5040.JPG
DSCF5041.JPG
DSCF5042.JPG
DSCF5043.JPG
DSCF5044.JPG
DSCF5045.JPG
DSCF5046.JPG

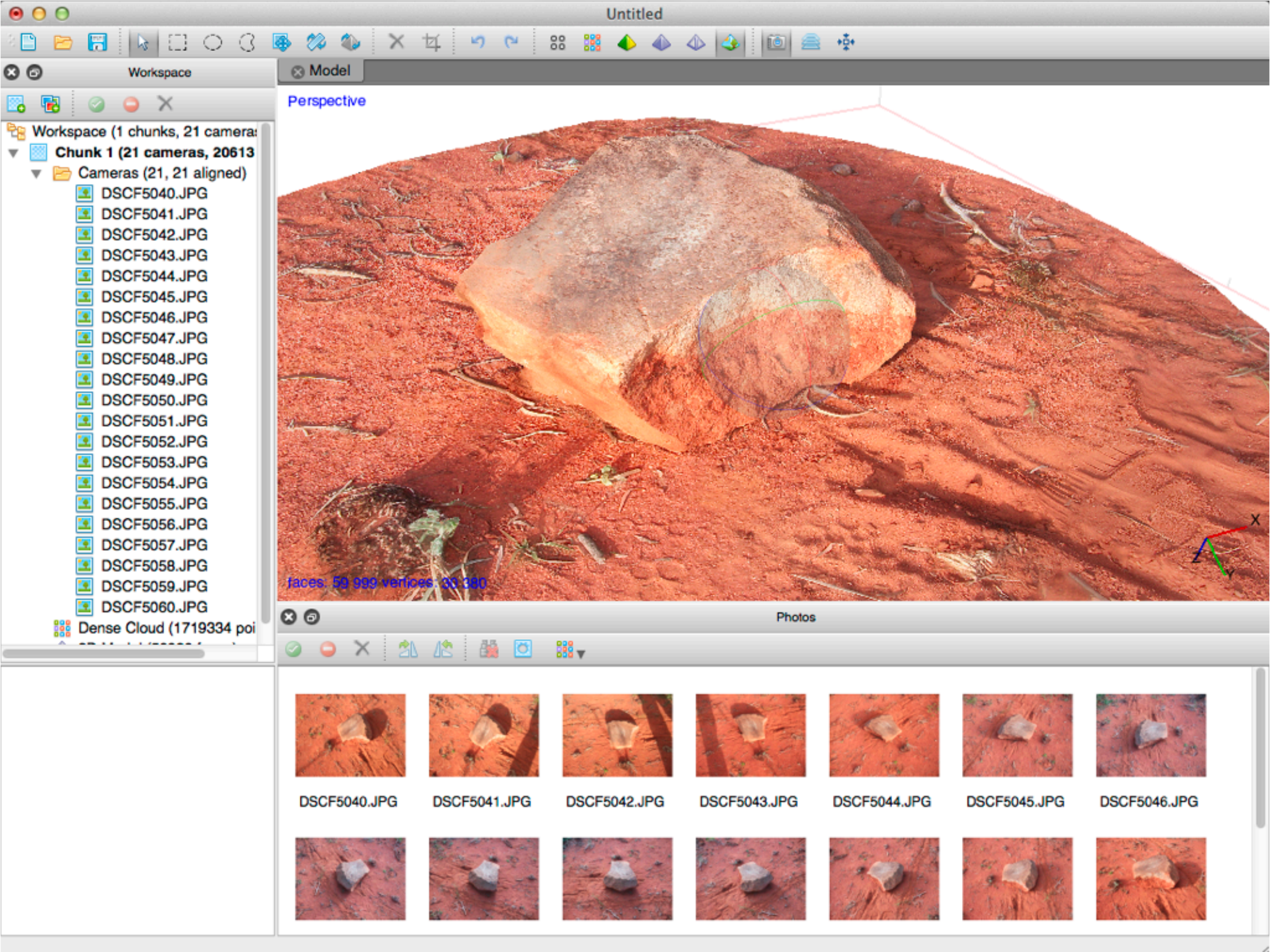

Untitled
Workspace
Model
Perspective
Workspace (1 chunks, 21 cameras)
Chunk 1 (21 cameras, 20613 pc
Cameras (21, 21 aligned)
DSCF5040.JPG
DSCF5041.JPG
DSCF5042.JPG
DSCF5043.JPG
DSCF5044.JPG
DSCF5045.JPG
DSCF5046.JPG
DSCF5047.JPG
DSCF5048.JPG
DSCF5049.JPG
DSCF5050.JPG
DSCF5051.JPG
DSCF5052.JPG
DSCF5053.JPG
DSCF5054.JPG
DSCF5055.JPG
DSCF5056.JPG
DSCF5057.JPG
DSCF5058.JPG
DSCF5059.JPG
DSCF5060.JPG
Build Dense Cloud
General
Quality:
Medium
Advanced
Depth filtering:
Moderate
Reuse depth maps
Cancel
OK
points: 20 613
X
Y
Z
Photos
DSCF5040.JPG
DSCF5041.JPG
DSCF5042.JPG
DSCF5043.JPG
DSCF5044.JPG
DSCF5045.JPG
DSCF5046.JPG

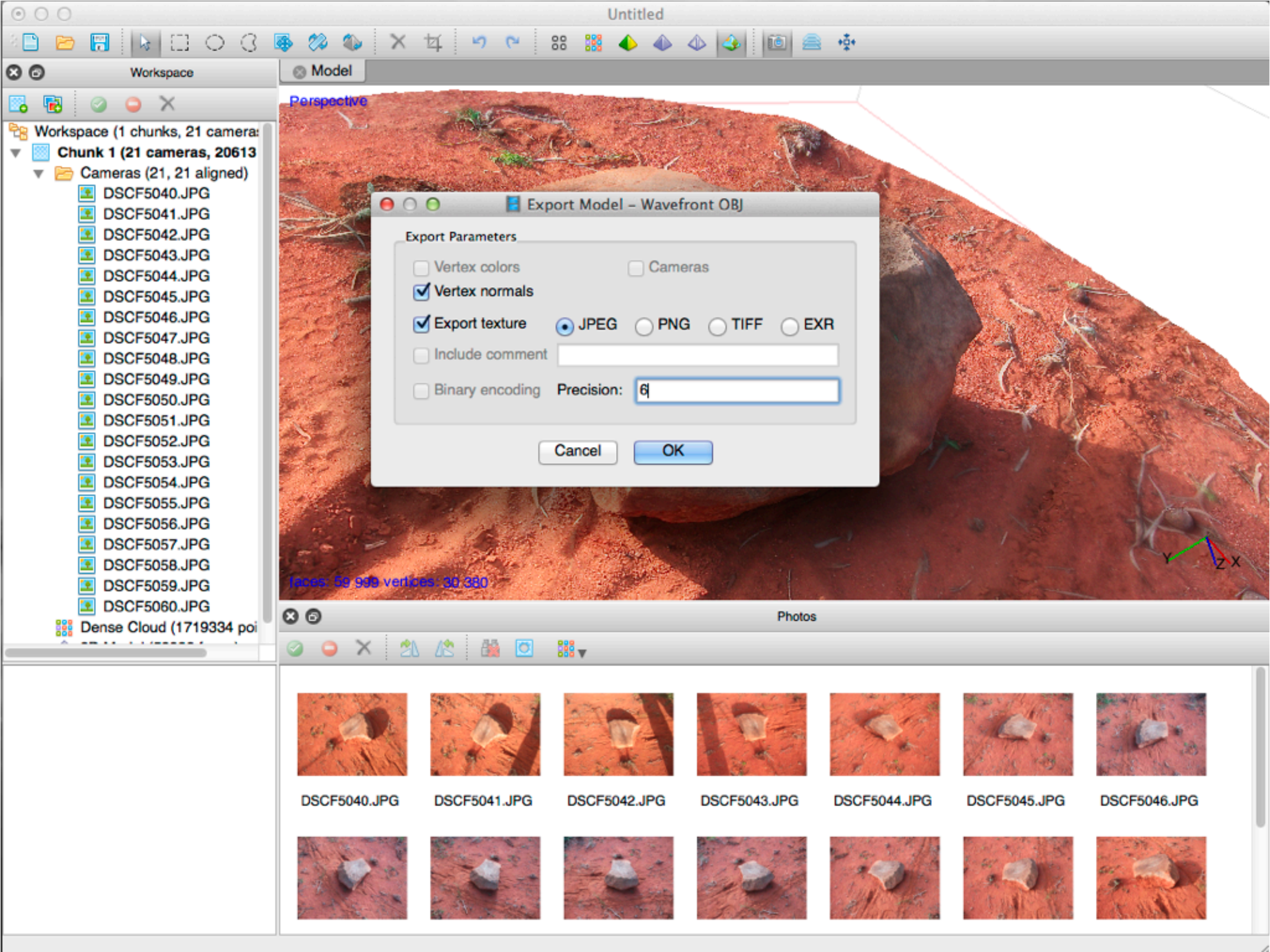

Untitled
Navigation
Model
Perspective
Workspace (1 chunks, 21 cameras)
Chunk 1 (21 cameras, 20613 pc
Cameras (21, 21 aligned)
DSCF5040.JPG
DSCF5041.JPG
DSCF5042.JPG
DSCF5043.JPG
DSCF5044.JPG
DSCF5045.JPG
DSCF5046.JPG
DSCF5047.JPG
DSCF5048.JPG
DSCF5049.JPG
DSCF5050.JPG
DSCF5051.JPG
DSCF5052.JPG
DSCF5053.JPG
DSCF5054.JPG
DSCF5055.JPG
DSCF5056.JPG
DSCF5057.JPG
DSCF5058.JPG
DSCF5059.JPG
DSCF5060.JPG
Dense Cloud (1719334 points
points: 733 951 selection: 115
Photos
Navigation tool

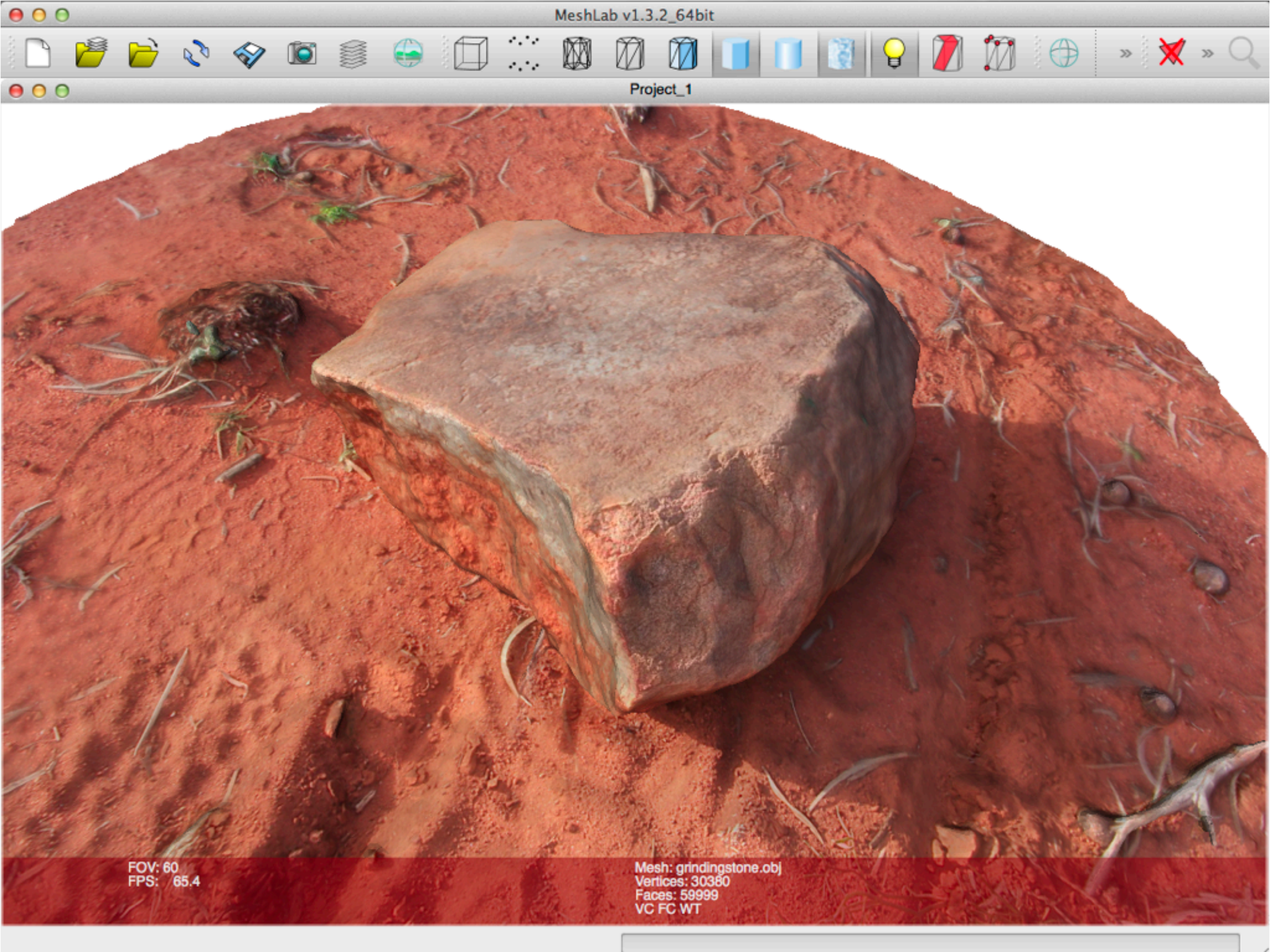

Untitled
Workspace
Model
Perspective
Workspace (1 chunks, 21 cameras)
Chunk 1 (21 cameras, 20613 pc
Cameras (21, 21 aligned)
DSCF5040.JPG
DSCF5041.JPG
DSCF5042.JPG
DSCF5043.JPG
DSCF5044.JPG
DSCF5045.JPG
DSCF5046.JPG
DSCF5047.JPG
DSCF5048.JPG
DSCF5049.JPG
DSCF5050.JPG
DSCF5051.JPG
DSCF5052.JPG
DSCF5053.JPG
DSCF5054.JPG
DSCF5055.JPG
DSCF5056.JPG
DSCF5057.JPG
DSCF5058.JPG
DSCF5059.JPG
DSCF5060.JPG
Dense Cloud (1719334 points
Build Mesh
General
Surface type: Arbitrary
Source data: Dense cloud
Polygon count: Medium (60 000)
Advanced
Interpolation: Enabled (default)
Cancel
OK
points: 733 951 selection: 26
Photos
DSCF5040.JPG
DSCF5041.JPG
DSCF5042.JPG
DSCF5043.JPG
DSCF5044.JPG
DSCF5045.JPG
DSCF5046.JPG

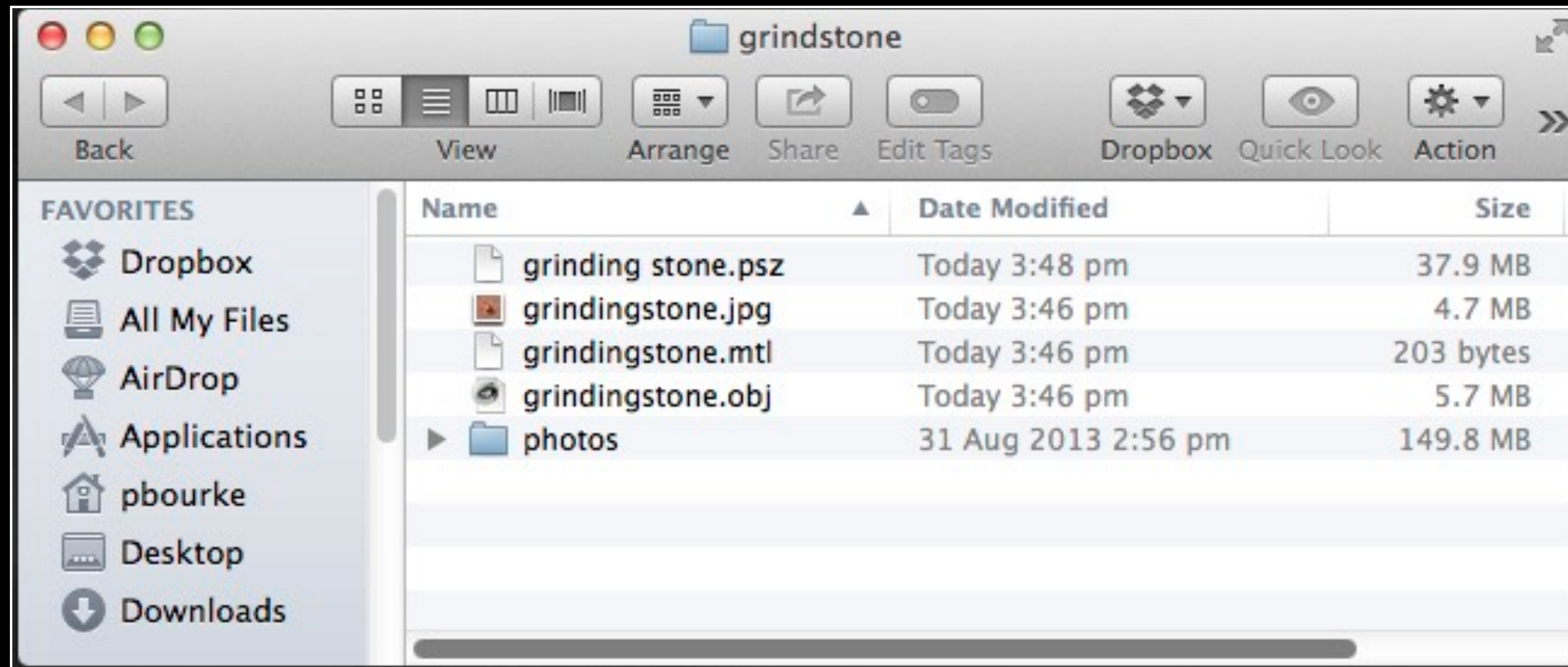


Untitled
Workspace
Model
Perspective
Workspace (1 chunks, 21 camera
Chunk 1 (21 cameras, 20613
Cameras (21, 21 aligned)
DSCF5040.JPG
DSCF5041.JPG
DSCF5042.JPG
DSCF5043.JPG
DSCF5044.JPG
DSCF5045.JPG
DSCF5046.JPG
DSCF5047.JPG
DSCF5048.JPG
DSCF5049.JPG
DSCF5050.JPG
DSCF5051.JPG
DSCF5052.JPG
DSCF5053.JPG
DSCF5054.JPG
DSCF5055.JPG
DSCF5056.JPG
DSCF5057.JPG
DSCF5058.JPG
DSCF5059.JPG
DSCF5060.JPG
Dense Cloud (1719334 poi
Build Texture
General
Mapping mode:
Generic
Blending mode:
Mosaic (default)
Texture size/count:
4096
x
1
Advanced
Enable color correction
Cancel
OK
faces: 59 999 vertices: 30 380
X
Y
Z
Photos
DSCF5040.JPG
DSCF5041.JPG
DSCF5042.JPG
DSCF5043.JPG
DSCF5044.JPG
DSCF5045.JPG
DSCF5046.JPG


Untitled
Workspace
Model
Perspective
Workspace (1 chunks, 21 cameras
Chunk 1 (21 cameras, 20613
Cameras (21, 21 aligned)
DSCF5040.JPG
DSCF5041.JPG
DSCF5042.JPG
DSCF5043.JPG
DSCF5044.JPG
DSCF5045.JPG
DSCF5046.JPG
DSCF5047.JPG
DSCF5048.JPG
DSCF5049.JPG
DSCF5050.JPG
DSCF5051.JPG
DSCF5052.JPG
DSCF5053.JPG
DSCF5054.JPG
DSCF5055.JPG
DSCF5056.JPG
DSCF5057.JPG
DSCF5058.JPG
DSCF5059.JPG
DSCF5060.JPG
Dense Cloud (1719334 poi
faces: 59 999 vertices: 30 380
Photos
DSCF5040.JPG
DSCF5041.JPG
DSCF5042.JPG
DSCF5043.JPG
DSCF5044.JPG
DSCF5045.JPG
DSCF5046.JPG

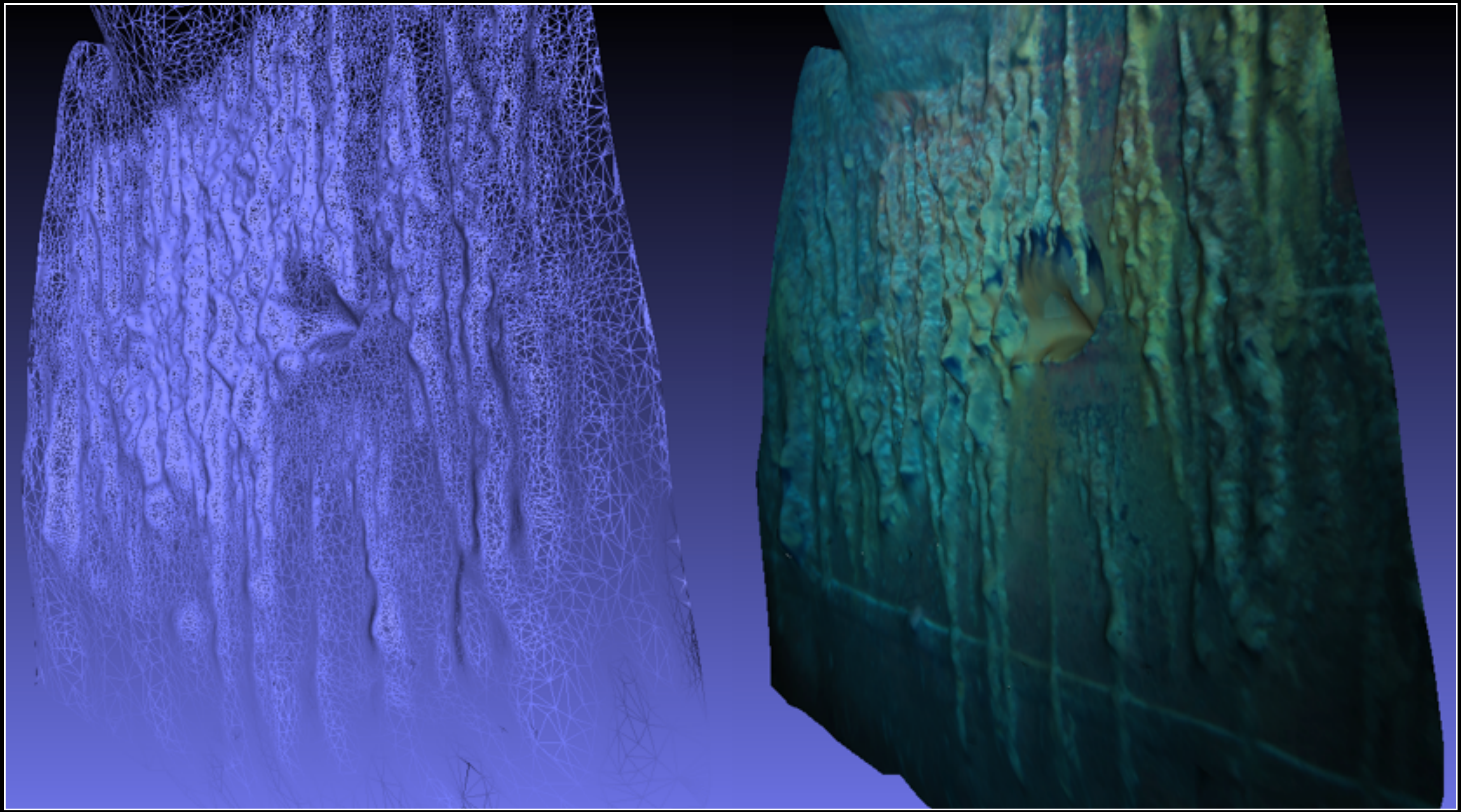

Untitled
Workspace
Model
Perspective
Workspace (1 chunks, 21 camera
Chunk 1 (21 cameras, 20613
Cameras (21, 21 aligned)
DSCF5040.JPG
DSCF5041.JPG
DSCF5042.JPG
DSCF5043.JPG
DSCF5044.JPG
DSCF5045.JPG
DSCF5046.JPG
DSCF5047.JPG
DSCF5048.JPG
DSCF5049.JPG
DSCF5050.JPG
DSCF5051.JPG
DSCF5052.JPG
DSCF5053.JPG
DSCF5054.JPG
DSCF5055.JPG
DSCF5056.JPG
DSCF5057.JPG
DSCF5058.JPG
DSCF5059.JPG
DSCF5060.JPG
Dense Cloud (1719334 poi
Export Model – Wavefront OBJ
Export Parameters
Vertex colors
Cameras
Vertex normals
Export texture
JPEG
PNG
TIFF
EXR
Include comment
Binary encoding
Precision:
6
Cancel
OK
faces: 59 999 vertices: 30 380
Photos
DSCF5040.JPG
DSCF5041.JPG
DSCF5042.JPG
DSCF5043.JPG
DSCF5044.JPG
DSCF5045.JPG
DSCF5046.JPG


MeshLab v1.3.2_64bit
Project_1
FOV: 60
FPS: 65.4
Mesh: grindingstone.obj
Vertices: 30380
Faces: 59999
VC FC WT


grindstone
Back
View
Arrange
Share
Edit Tags
Dropbox
Quick Look
Action
FAVORITES
Dropbox
All My Files
AirDrop
Applications
pbourke
Desktop
Downloads
Name
Date Modified
Size
grinding stone.psz
Today 3:48 pm
37.9 MB
grindingstone.jpg
Today 3:46 pm
4.7 MB
grindingstone.mtl
Today 3:46 pm
203 bytes
grindingstone.obj
Today 3:46 pm
5.7 MB
photos
31 Aug 2013 2:56 pm
149.8 MB

Additional applications

- Underwater
- Aerial photography
- Rapid Prototypes



Kormoran

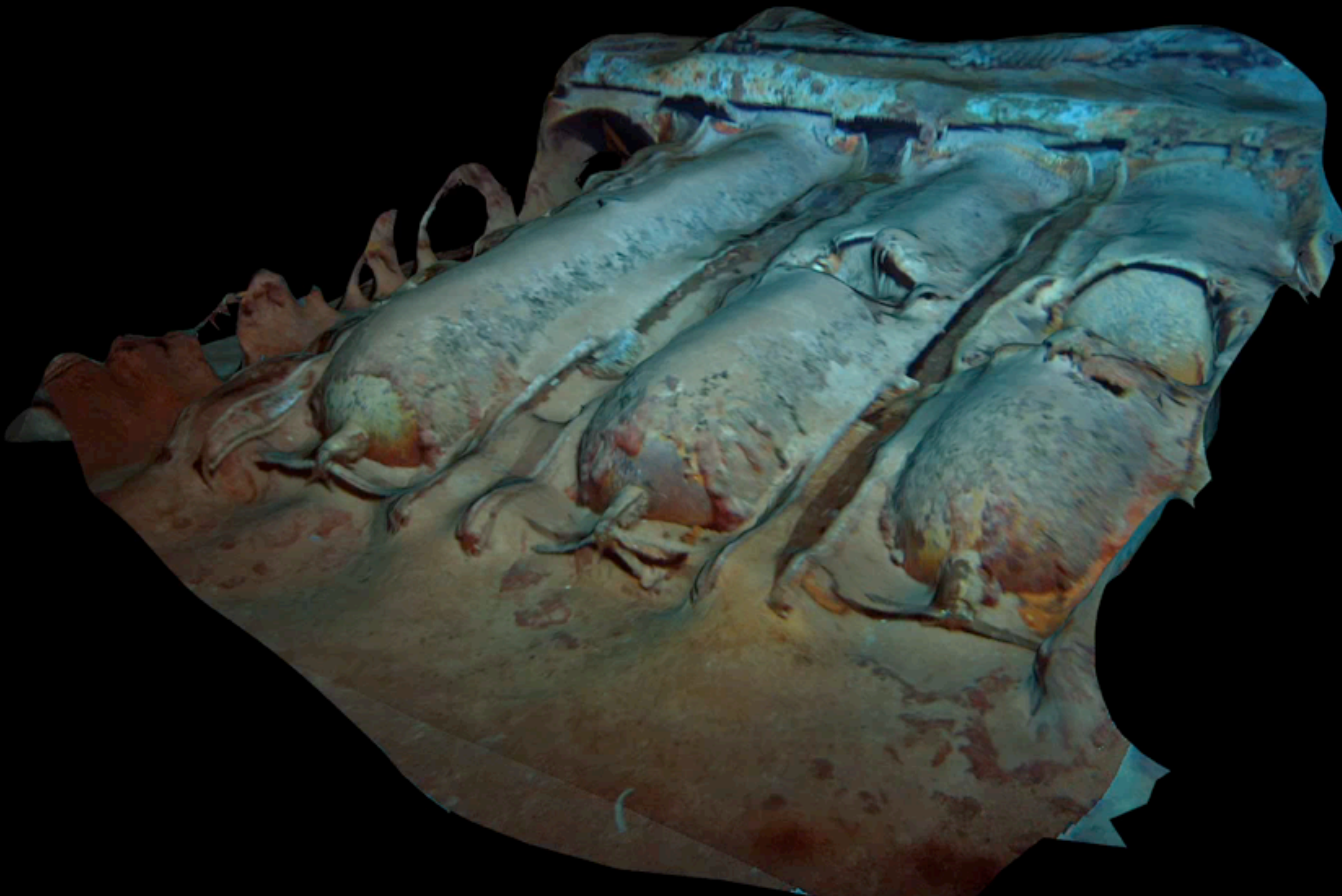
Additional applications : Underwater

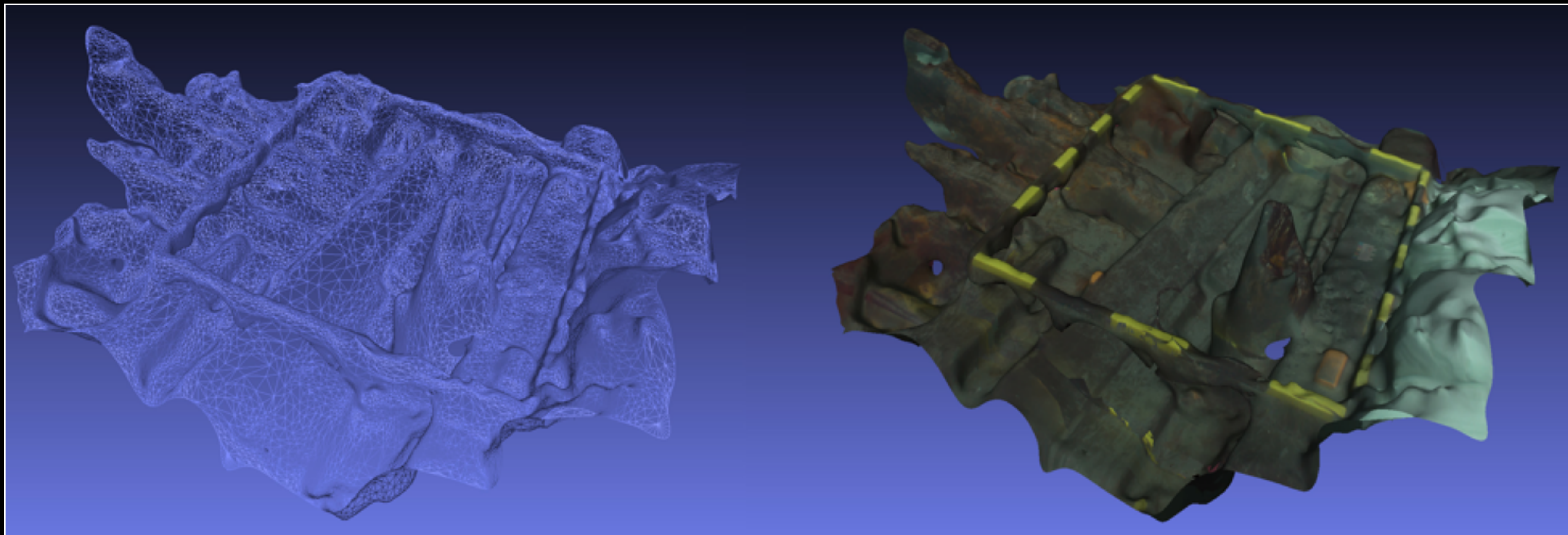
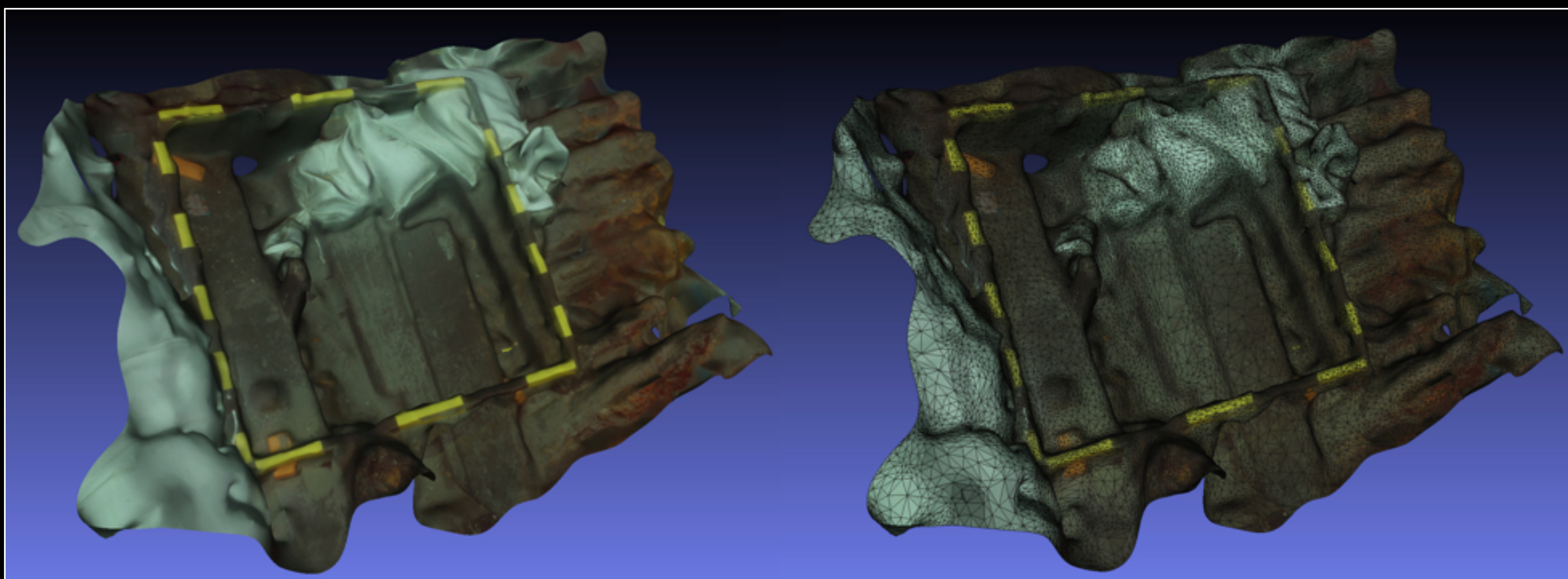
- Capture of underwater object more challenging.
- How to compensate for the light absorption through a column of water.
- Example: HMAS Sydney in 2.5KM of water.





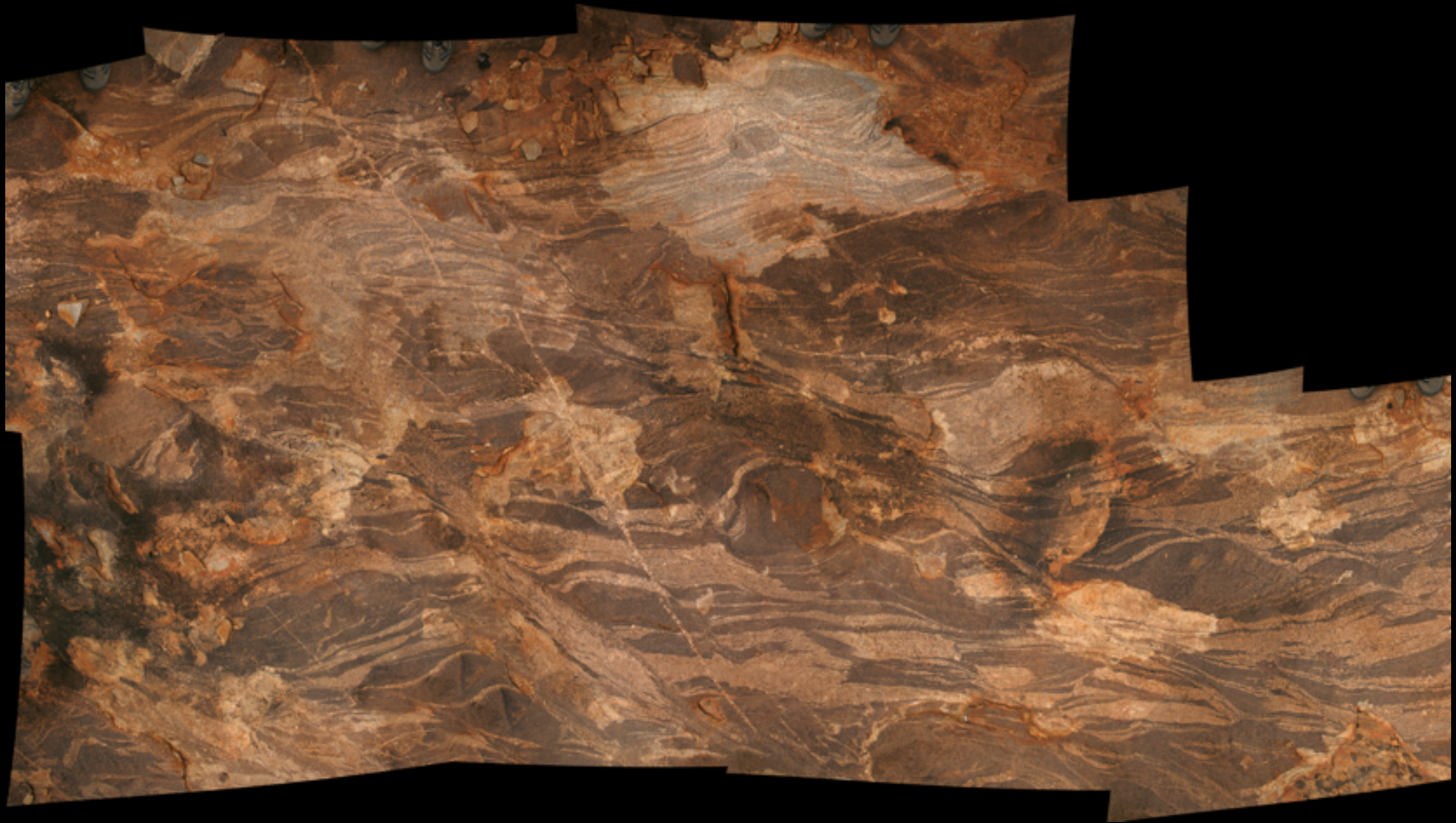
HMAS Sydney



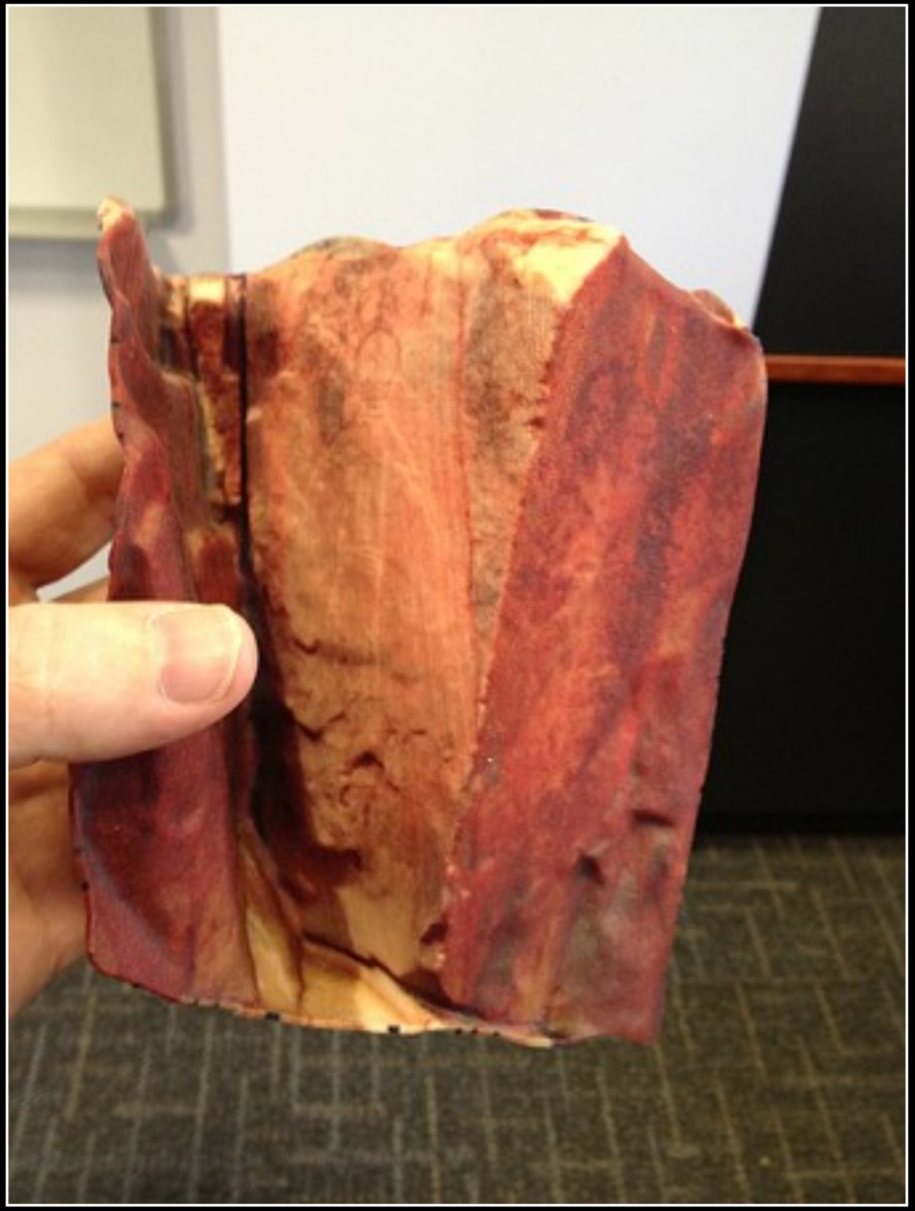
Additional applications : Aerial photography

- Capturing inaccessible geological formations.
- Also building structures out of reach.
- Vibration and rolling shutter issues.



Additional applications : Rapid prototypes

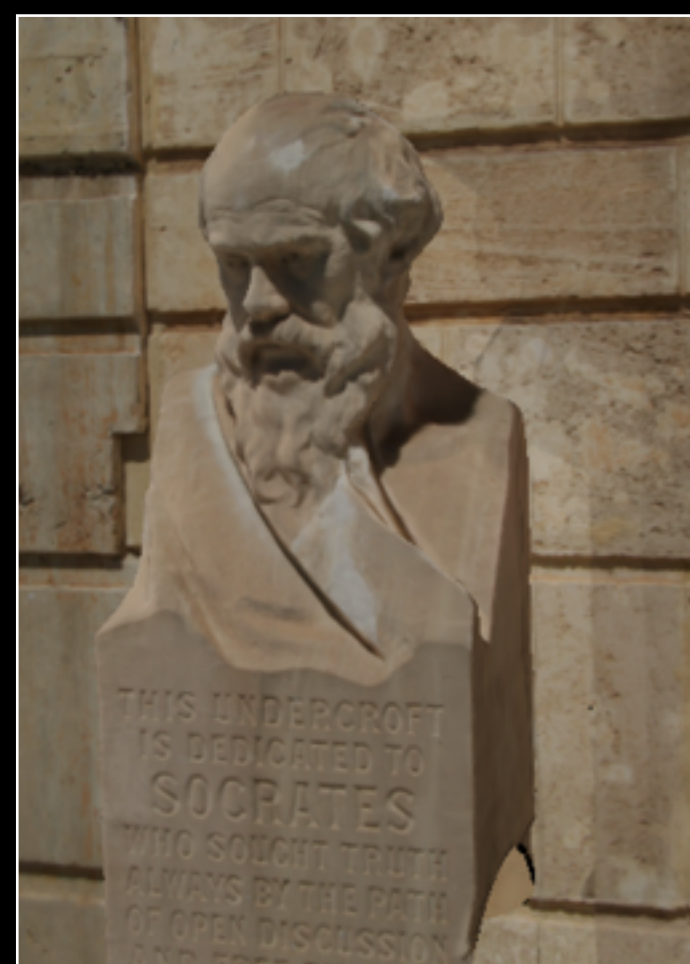
- Can complete the loop:
  capture a real object photographically - reconstruct it - generate a real object.
- Requires a solid object (thickened), with enough structural integrity.
- Models need to be “watertight”, hence hole closing algorithms.



Advanced topics : Reference images

- Creating a library of reference photographs by which to compare algorithms.
- Not just “good” photographic sets but also poorly captured photographs.
- Distinguish three categories: 2.5D, 3D simple object (topological sphere), 3D complex object.

2.5D

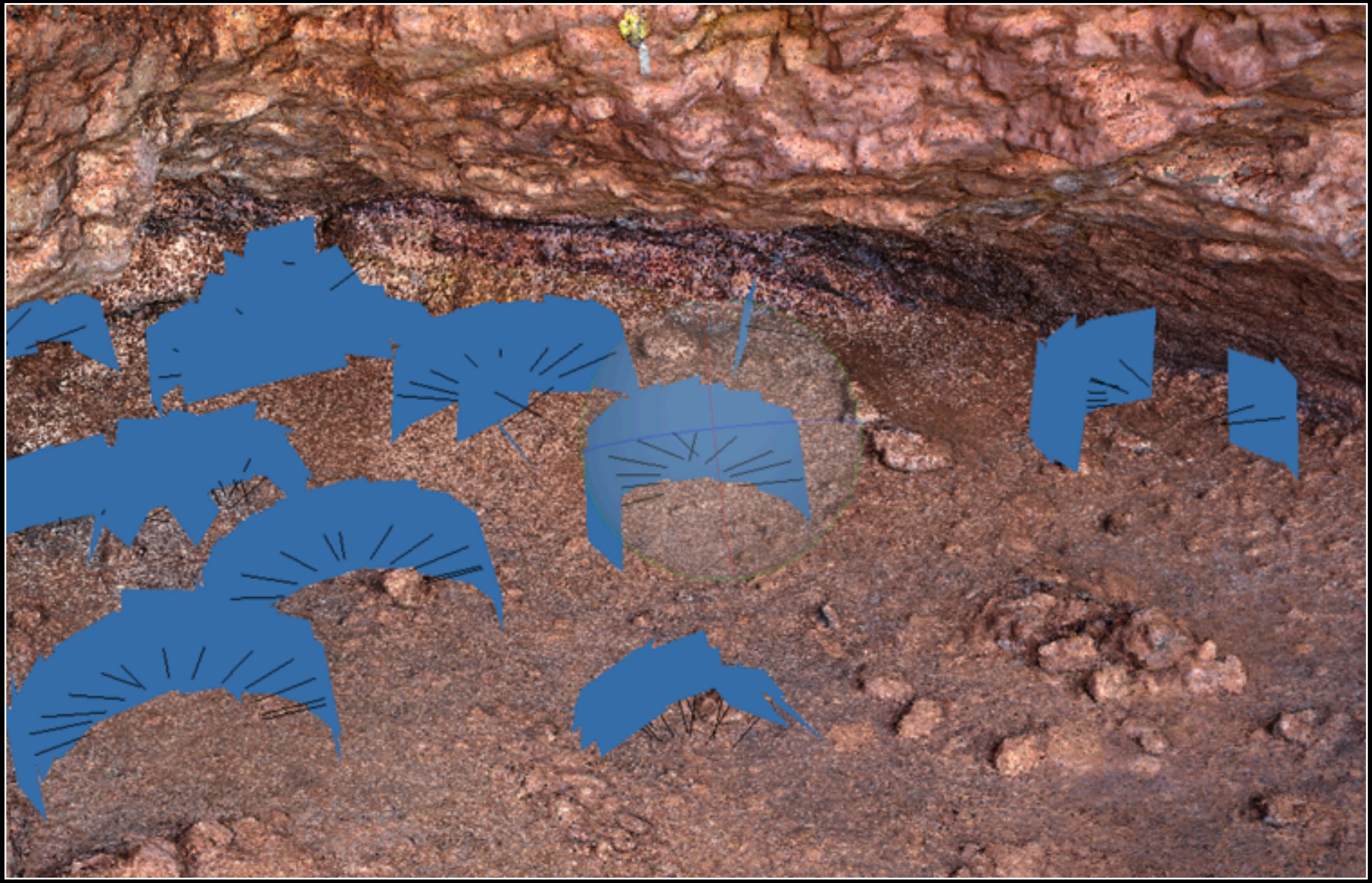


topological sphere

topological N-sphere (N>2)

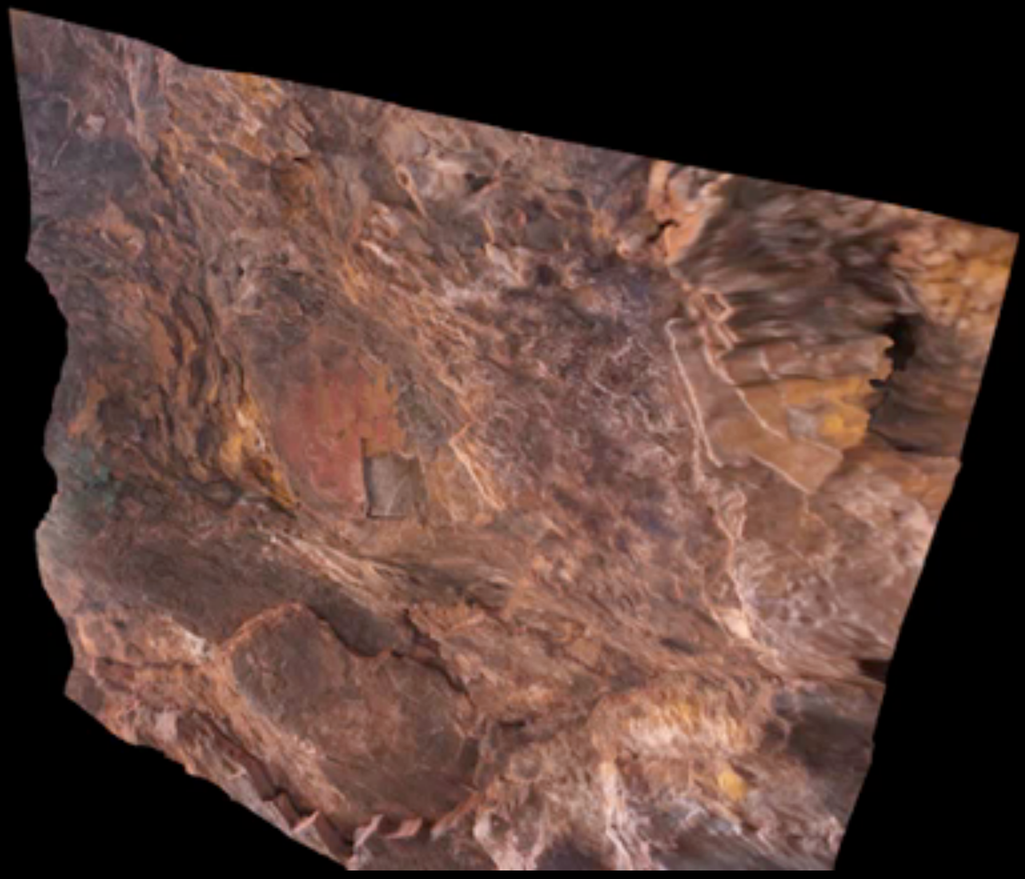
Advanced topics : Interior spaces

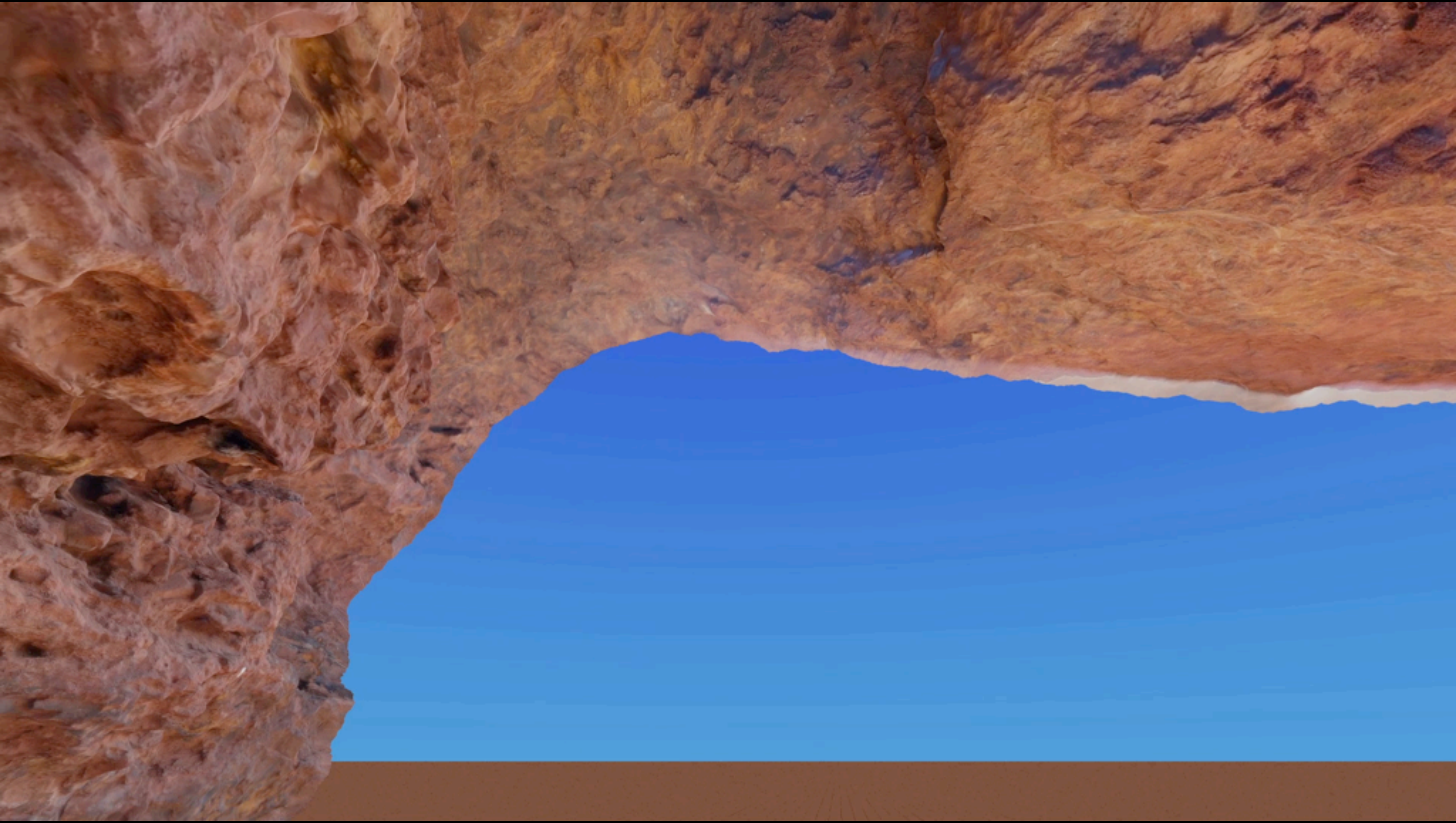
- These can be difficult due to to the lack of space to move for different camera shots.
- Multiple shots can be taken from a single position in order to get coverage, but they should be viewed a single perspective view.

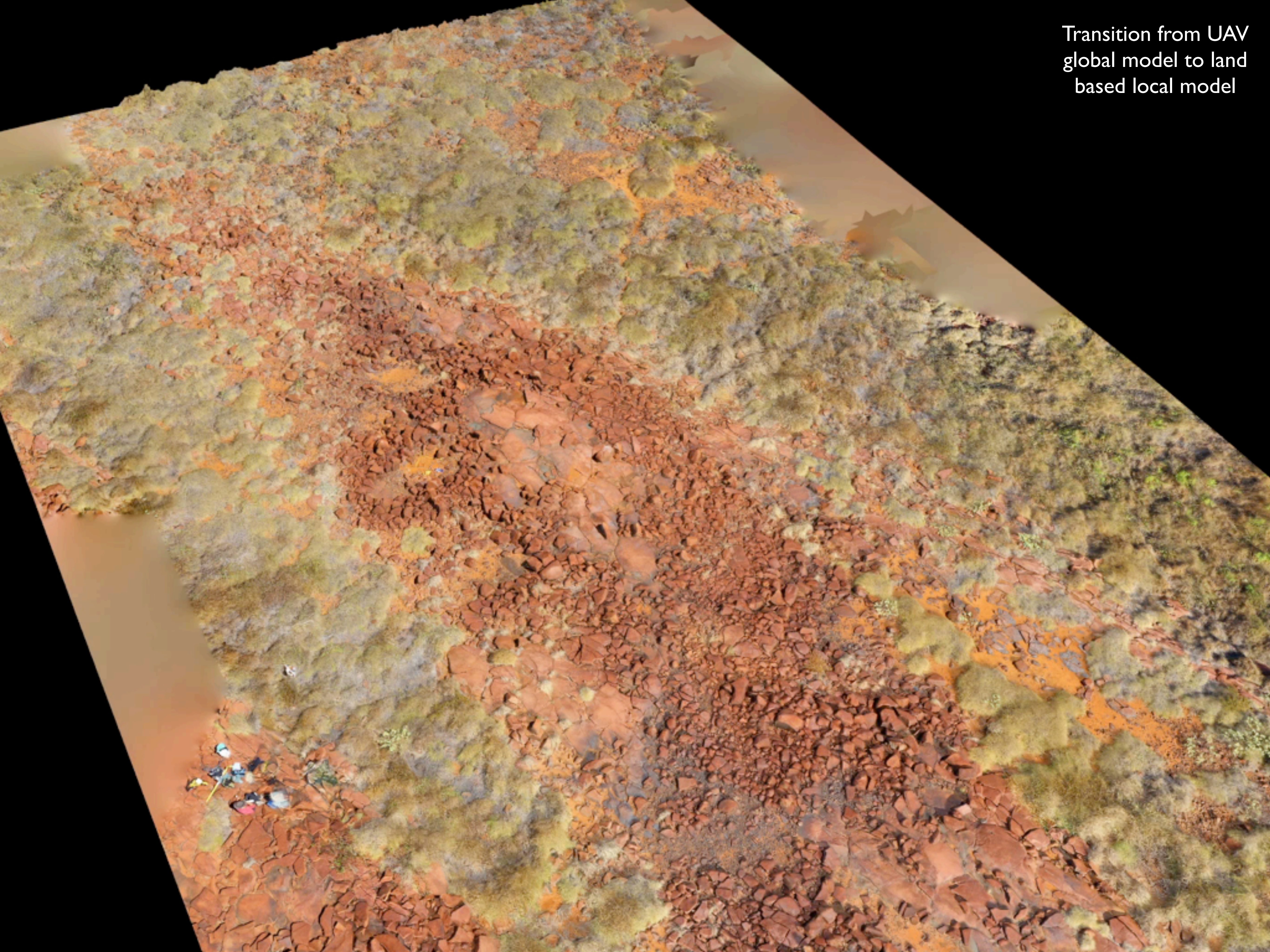


Advanced topics : Multi-resolution

- Similar to multi-resolution or hierachical images, can we do the same for 3D meshes.
- Large scale reconstruction at one resolution, smaller higher resolution parts of interest.







Transition from UAV global model to land based local model

Reading / references

- Barazzetti, L., Scaioni, M. and Remondino, F. (2010), Orientation and 3D modelling from markerless terrestrial images: combining accuracy with automation. The Photogrammetric Record, 25: 356–381. doi: 10.1111/j.1477-9730.2010.00599.x
- Percoco, G. (2011), Digital close range photogrammetry for 3D body scanning for custom-made garments. The Photogrammetric Record, 26: 73–90. doi: 10.1111/j.1477-9730.2010.00605.x
- Remondino, F., Rizzi, A., Girardi, S., Petti, F. M. and Avanzini, M. (2010), 3D Ichnology—recovering digital 3D models of dinosaur footprints. The Photogrammetric Record, 25: 266–282. doi: 10.1111/j.1477-9730.2010.00587.x
- Bill Jeffery. (2006), From Seabed to Computer Screen—digital mapping of submerged and shipwreck sites. Bulletin of the Australian Institute for Maritime Archaeology, 23:86-94
- Bryan, P. G. and Clowes, M. (1997), Surveying Stonehenge By Photogrammetry. The Photogrammetric Record, 15: 739–751. doi: 10.1111/0031-868X.00082
- Barazzetti, L., Remondino, F. and Scaioni, M. (2009) Combined use of photogrammetric and computater vision techniques for fully automated and accurate 3D modelling of terrestrial objects. SPIE Optics+Photonics, 7447, 2-3 August, San Diego, CA, USA.
- Barthelsen, J., Mayer, H., Hirschmuller, H., Kuhn, A, Michelini, M. 92012) orientation and dense reconstruction from bordered wide baseline image sets. PFG 2012.
- Besl, P. McKay, N. (1992) A method for registration of 3D shapes. IEEE Transactions on pattern analyse and machine intelligence. PAMI 14 (2).
- Cignoni, P., Callieri, M., Corsini, M., Dellepaine, M., Ganovelli, F., Ranzuglia, G., (2008). MeshLab: an opensource mesh processing tool. Eurographics Italian Chapter Conference, The Eurographics Association, 129-136.
- C. Wu, 2011. "VisualSFM: A Visual Structure from Motion System", http://homes.cs.washington.edu/~ccwu/vsfm/ (31 Jan. 2013)
- Courchay, J., Pons, J.P., Monasse, P., Keriven, R., (2010). Dense and accurate spatio-temporal multiview stereovision. Computer Vision ACCV 2009, Lecture notes in computer Science, 5995, 11-22

Reading / references

- Noah Snavely, Steven M. Seitz, Richard Szeliski. Photo Tourism: Exploring image collections in 3D. ACM Transactions on Graphics (Proceedings of SIGGRAPH 2006), 2006.
- Noah Snavely, Steven M. Seitz, Richard Szeliski. Modeling the World from Internet Photo Collections. International Journal of Computer Vision, 2007.
- M. Favalli n, A. Fornaciai, I. Isola, S. Tarquini, L. Nannipieri. Multiview 3D reconstruction in geosciences. Computers & Geosciences, 44 (2012) 168–176
- Besl, P.J., McKay, N.D., 1992. A method for registration of 3-D shapes. IEEE Transactions on Pattern Analysis and Machine Intelligence 14, 239–256.
- de Matı ́as, J., de Sanjose ́, J.J., Lo ́pez-Nicola ́s, G., Sagu ̈e ́s, C., Guerrero, J.J., 2009. Photogrammetric methodology for the production of geomorphologic maps: application to the Veleta Rock Glacier (Sierra Nevada, Granada, Spain). Remote Sensing 1, 829–841.
- Dowling, T.I., Read, A.M., Gallant, J.C., 2009. Very high resolution DEM acquisition at low cost using a digital camera and free software. In: Proceedings of the 18th World IMACS/MODSIM Congress, Cairns, Australia.
- Furukawa, Y., Ponce, J., 2007. Accurate, dense, and robust multi-view stereopsis. In: Proceedings, IEEE Conference on Computer Vision and Pattern Recognition CVPR 2007, pp. 1–8.
- Furukawa, Y., Ponce, J., 2009. Accurate camera calibration from multi-view stereo and bundle adjustment. International Journal of Computer Vision 84, 257–268.
- Hartley, R.I., Zisserman, A., 2004. Multiple View Geometry in Computer Vision. Cambridge University Press.
- Levoy, M., Pulli, K., Curless, B., Rusinkiewicz, S., Koller, D., Pereira, L., Ginzton, M., Anderson, S., Davis, J., Ginsberg, J., Shade, J., Fulk, D., 2000. The Digital Miche- langelo Project: 3D scanning of large statues. Computer Graphics (SIGGRAPH 2000 Proceedings).

Reading / references

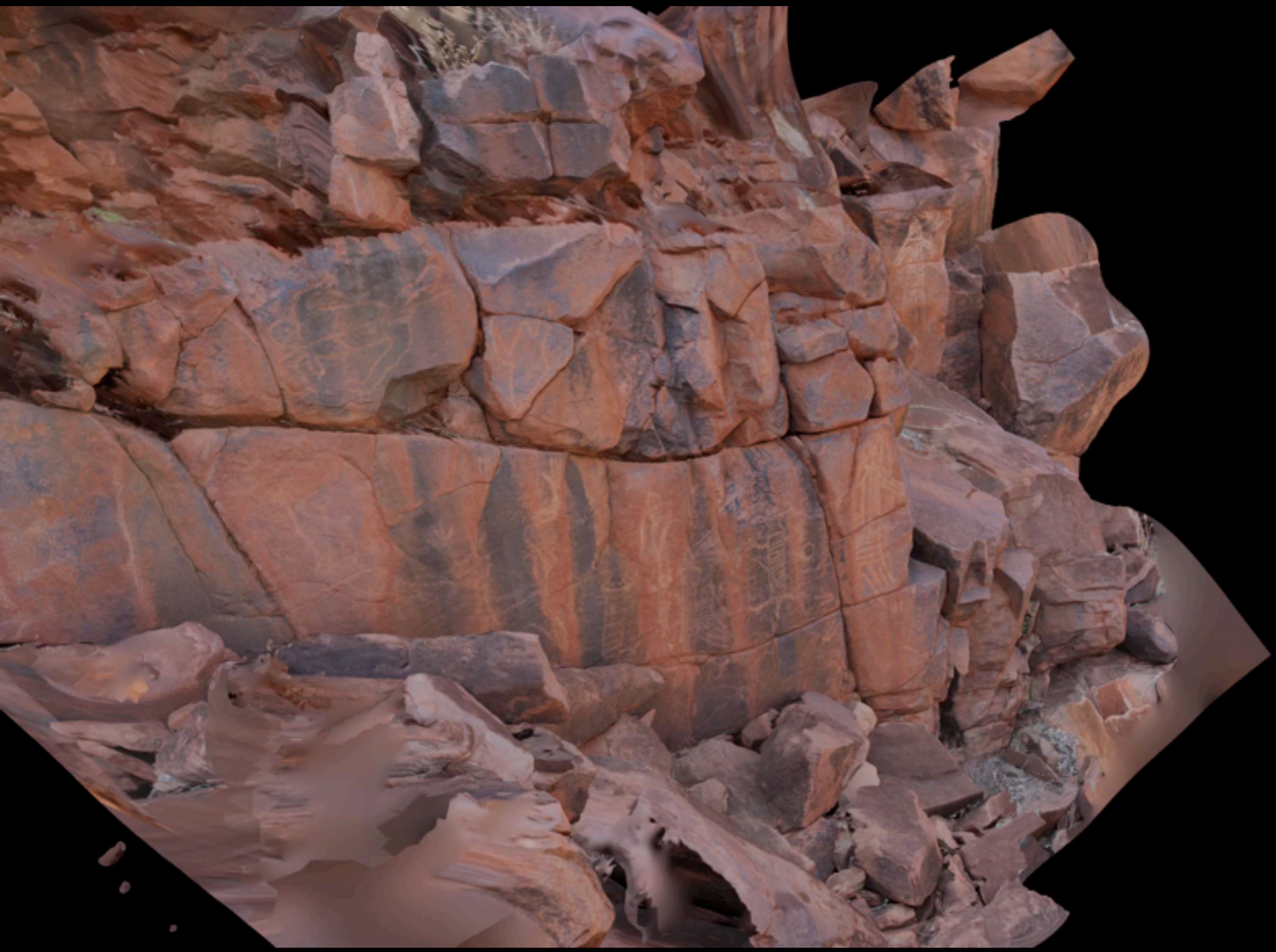
- Lourakis, M., Argyros, A., 2008. SBA: A generic sparse bundle adjustment C/Cþþ package based on the Levenberg-Marquardt algorithm. /http://www.ics.forth. gr/lourakis/sbaS.
- Mikhail, E.M., Bethel, J.S., McGlone, J.C., 2001. Introduction to Modern Photogrammetry. John Wiley & Sons, Inc., New York.
- Nister, D., 2004. Automatic passive recovery of 3D from images and video. In: Proceeding of the Second IEEE International Symposium on 3D Data Proces- sing, Visualization and Transmission, pp. 438–445.
- Snavely, N., Seitz, D., Szeliski, R., 2007. Modeling the world from internet photo collections. International Journal of Computer Vision 80, 189–210.
- Triggs, B., McLauchlan, P., Hartley, R., Fitzgibbon, A., 2000. Bundle adjustment—A modern synthesis. in: Triggs, W., Zisserman, A., Szeliski, R. (Eds.), Vision Algorithms: Theory and Practice, LNCS, Springer–Verlag, pp. 298–375.
- T. P. Kersten and M. Lindstaedt, Automatic 3D Object Reconstruction from Multiple Images for Architectural, Cultural Heritage and Archaeological Applications Using Open-Source Software and Web Services. Photogrammetrie - Fernerkundung - Geoinformation, Heft 6, pp. 727-740.
- S. Lowe. 2004. Distinctive Image Features from Scale-Invariant Keypoints. International Journal of Computer Vision. 60 (2), pp 91-110.
- Agarwal, N. Snavely, I. Simon, S. M. Seitz and R. Szeliski, Building Rome in a Day. International Conference on Computer Vision, 2009, Kyoto, Japan.
- M. Jancosek and T. Pajdla, 2011. Multi-View Reconstruction Preserving Weakly-Supported Surfaces, IEEE Conference on Computer Vision and Pattern Recognition 2011
- M. Hanif and A. Seghouane, 2012. Blurred Image Deconvolution Using Gaussian Scale Mixtures Model in Wavelet Domain. IEEE 2012 International Conference on Digital Image Computing Techniques and Applications

Summary for high quality reconstruction

- High quality SLR camera (and know how to use it)
- Good quality prime lens
- Perform lens calibration for wide angle or otherwise extreme lenses
- Err on the side of taking more images
- Strong linear reference objects in shot can assist reconstruction
- Select best software currently on the market
  (PhotoScan is hard to beat at time of writing)
- Results benefit from crisp high resolution photographs
  Not particularly sensitive to colour detail

Summary : An exciting time to be in this game

- Algorithms are improving at a steady pace.
- Our expectations are steadily rising.



Questions / discussion

The new digital tourist?