國立中山大學
National Sun Yat-sen University

THE MCRAE Marine ECOLOGY LAB

Intro to 3D Coral Reef Survey

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Jun 05 2025
At National Sun-Yet Sen University

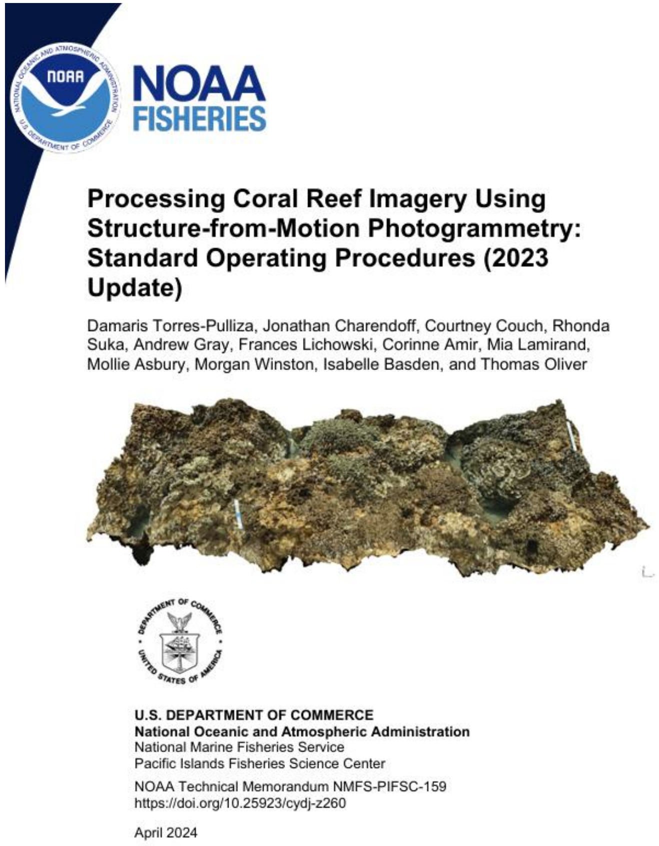
Self Introduction

2015 –2018 NSYSU
Department of Oceanography
Advisor: Dr. Li-Lian Liu

2018 –2020 National Taiwan University (NTU)
Institute of Oceanography
Advisor: Dr. Chang-Feng Dai

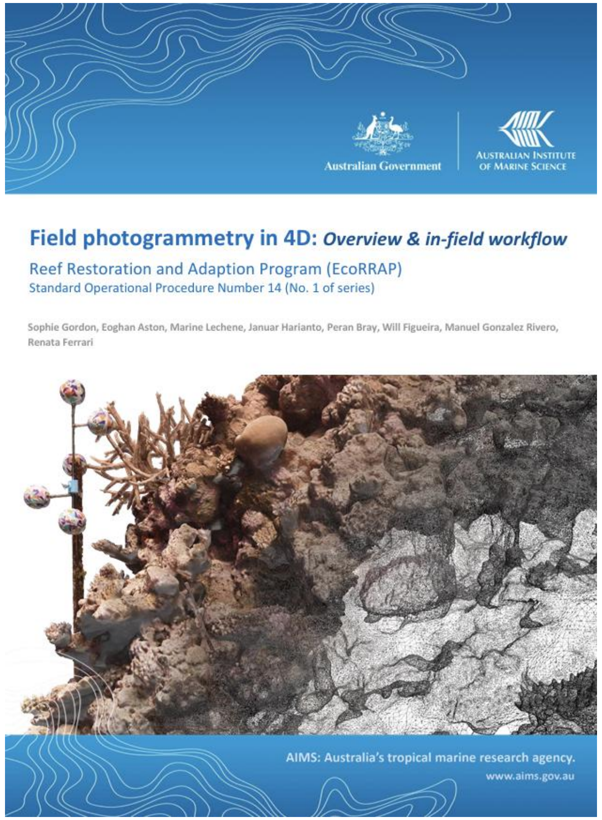
2022– Jul. 2022
Fan Coral lab, NMMBA

Referenced Documents

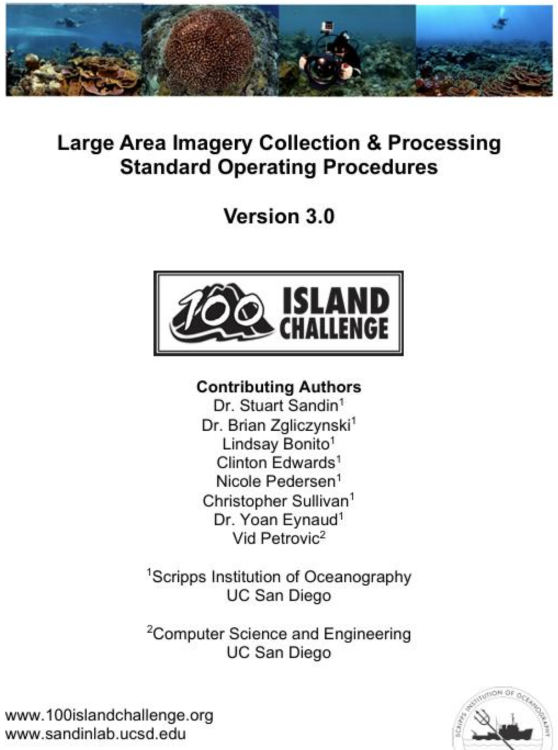


(Torres-Pulliza et al. 2024)

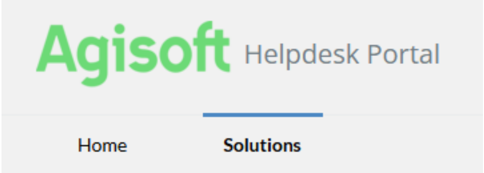
(Edwards et al. 2023)



(Gordon et al. 2023)

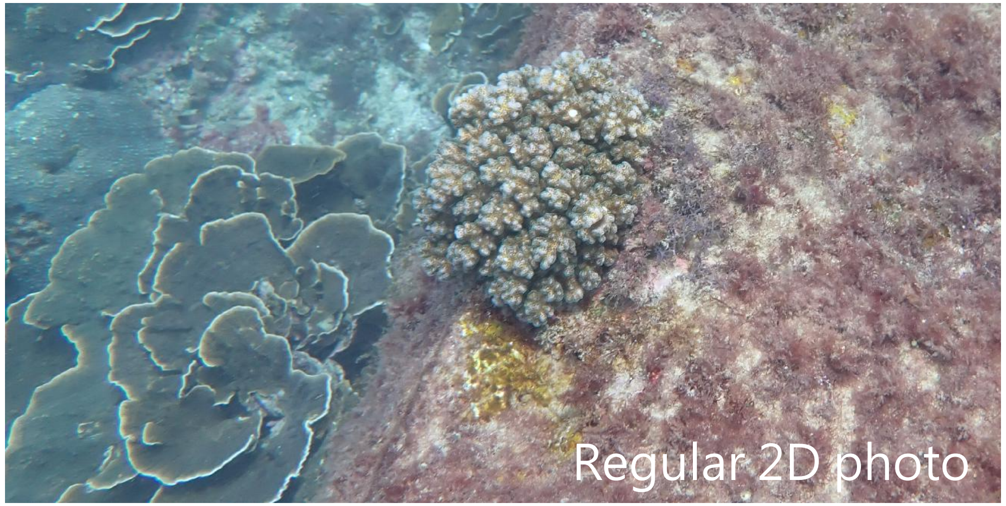


(Sandin et al. 2021)



Why Use 3D Surveys?

Skip the math— just see which is bigger,
the pigeon or the human ?

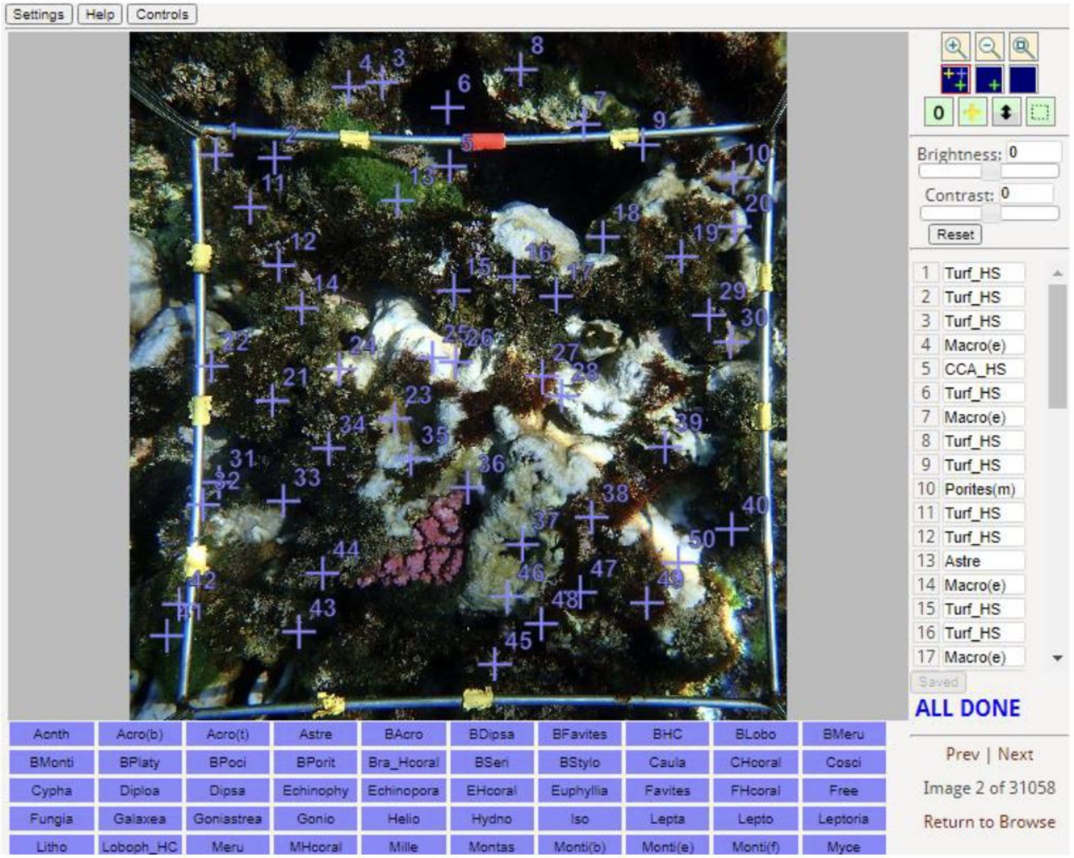


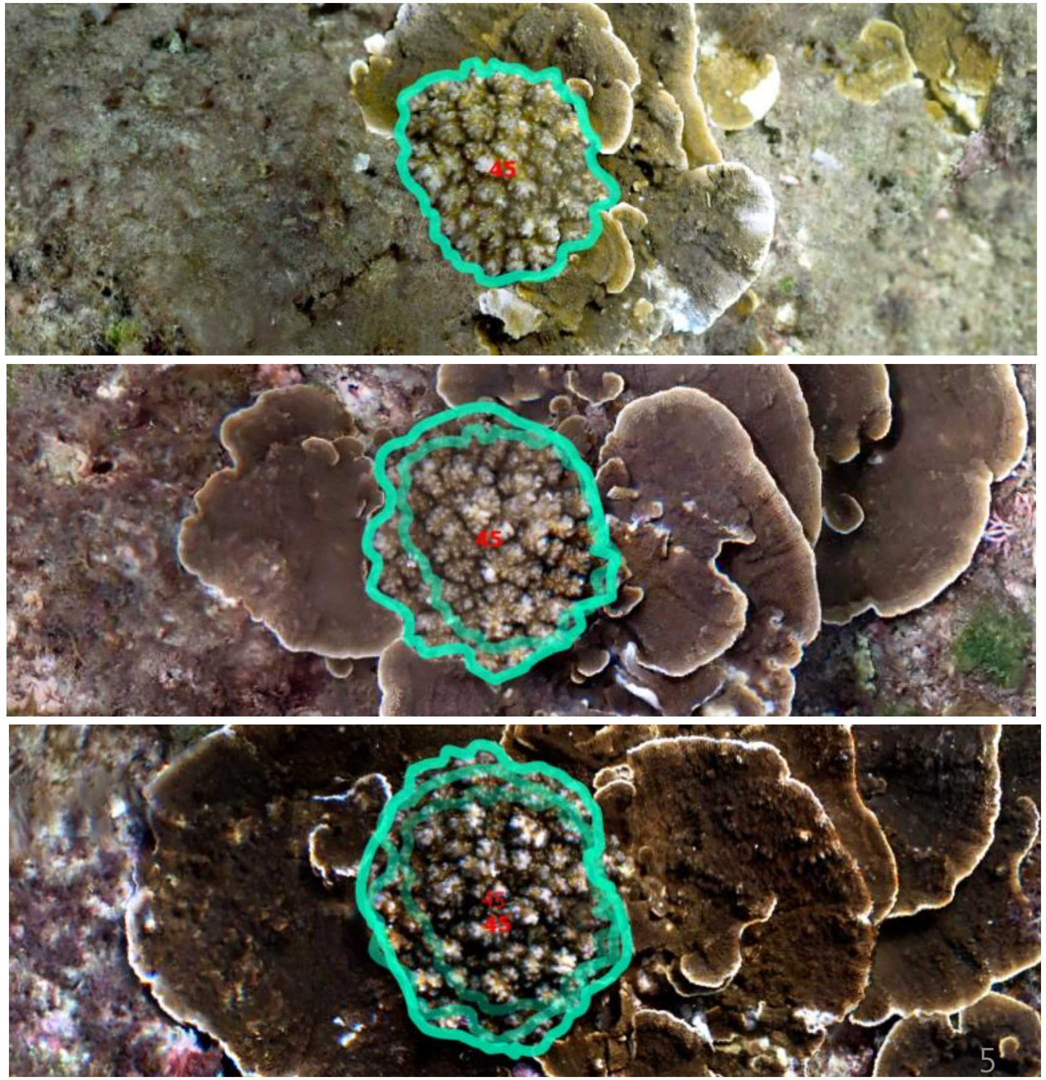
Regular 2D photo

Orthophoto derived from

Why use 3D Surveys?

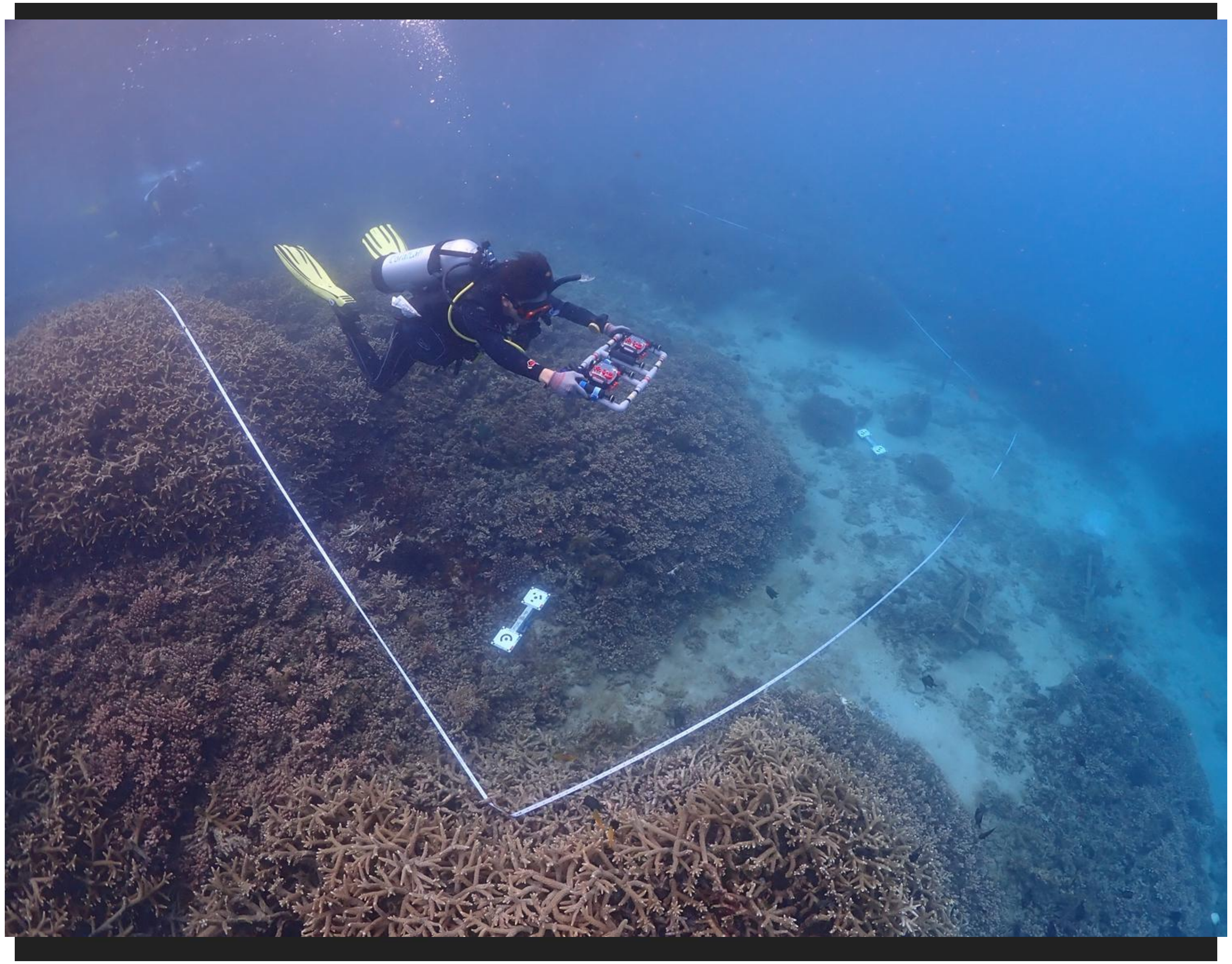
CoralNet gives % cover but not colony-level change
(Size structure, colony fates over time…)



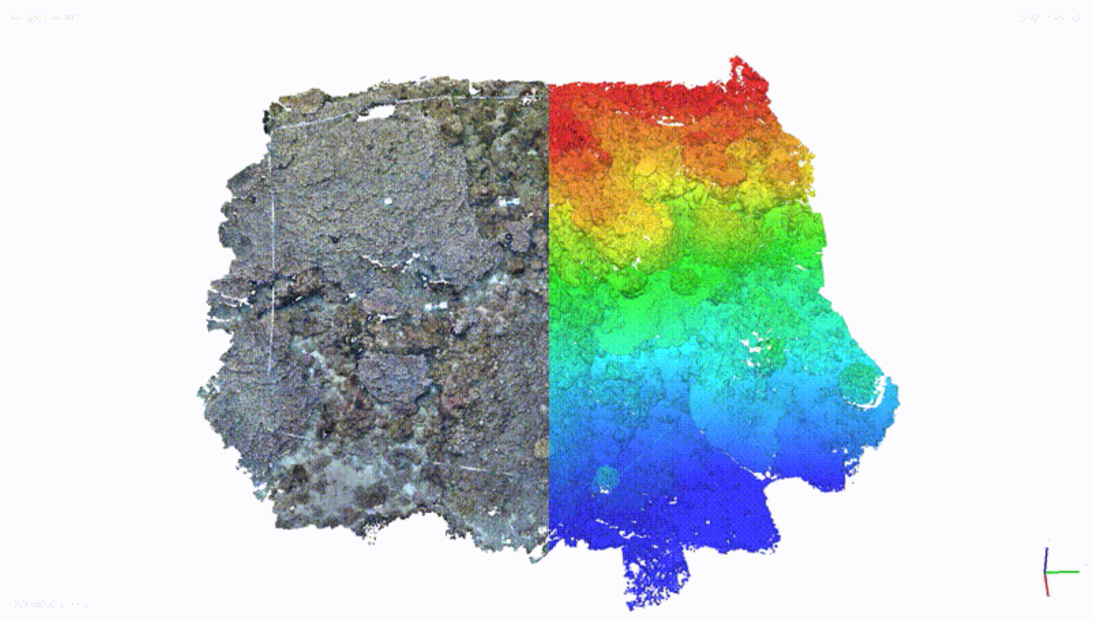


What Is a 3D Reef Survey?

Image-based!

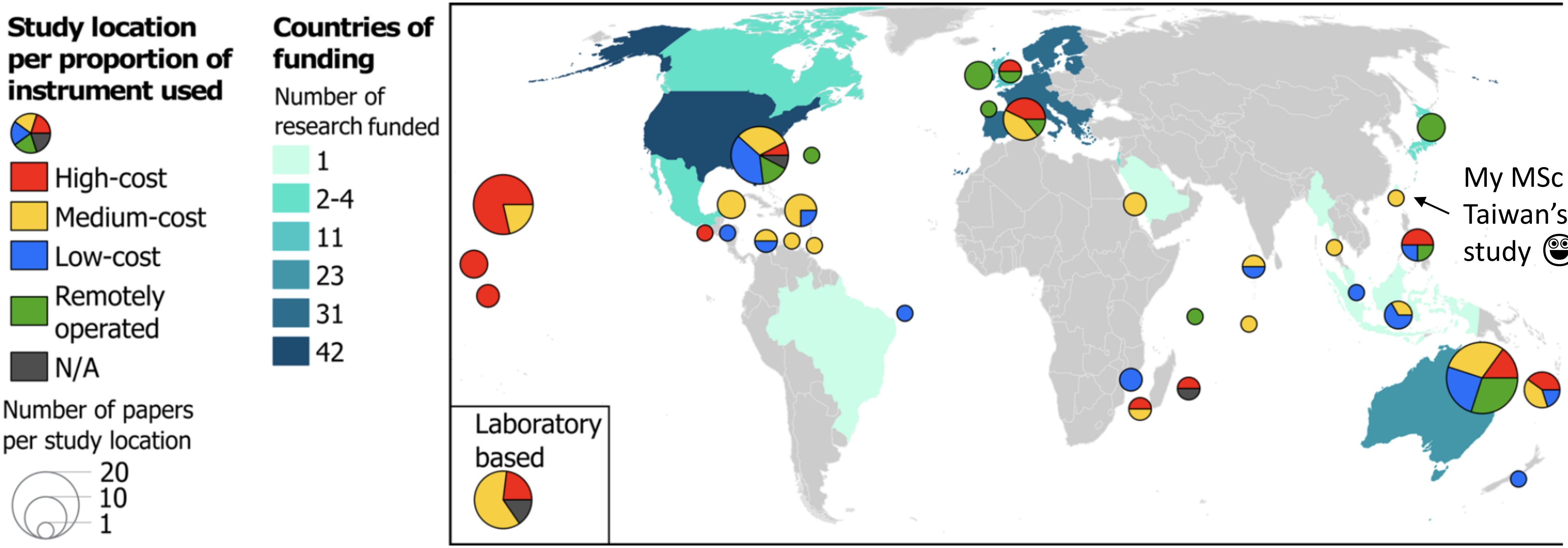


Also known as
- Structure from Motion (SfM)
- Large area imaging (LAI)
- Underwater photogrammetry
- 3D photogrammetric survey



How Many Countries Are Using for Coral Reef Surveys?

Global use; most papers from USA, Australia, France

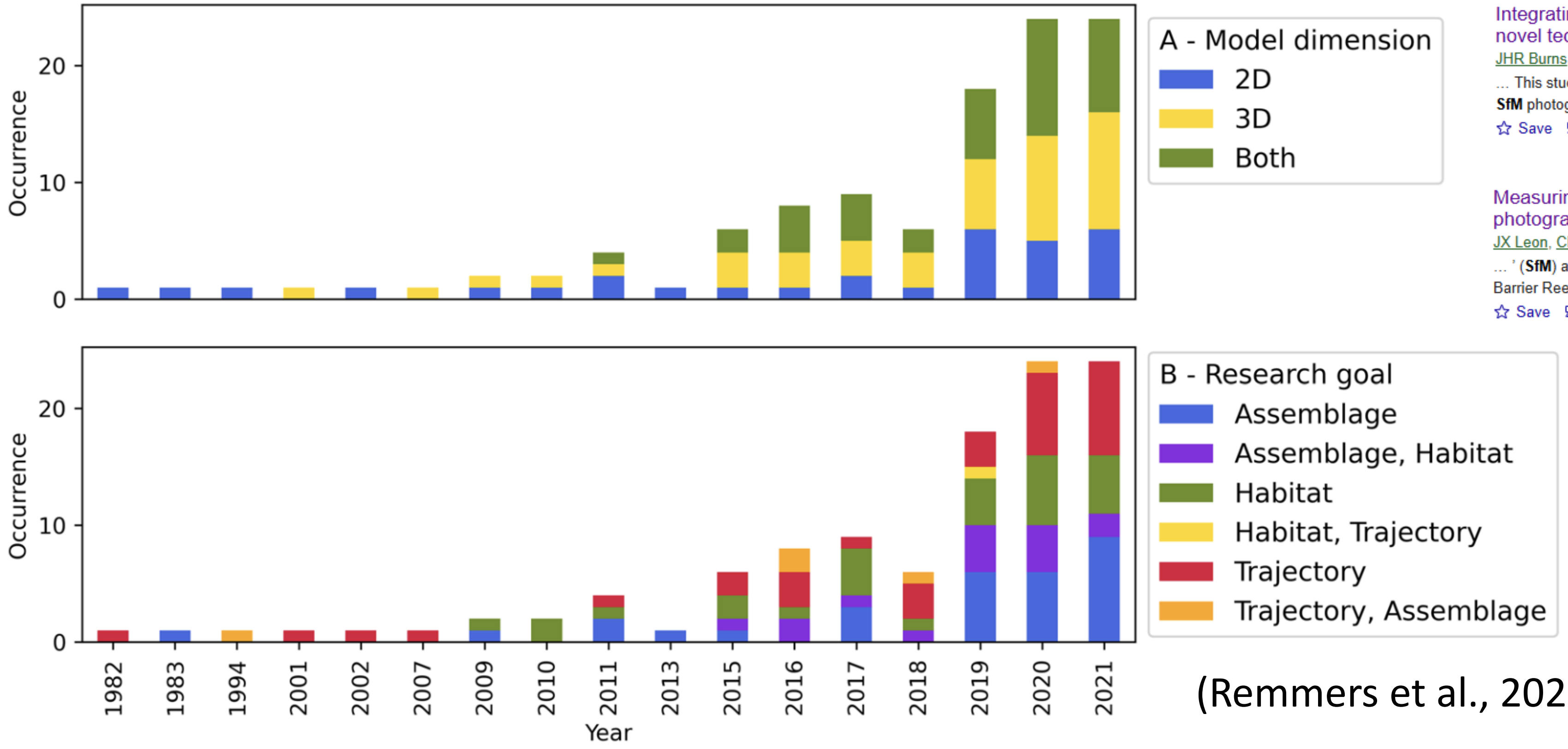


My MSc was Taiwan's first study 😲

(Remmers et al., 2024)

When Did 3D Surveys Become Popular?

After 2010, commercial SfM appeared
Coral-reef applications since 2015



(Remmers et al., 2024)

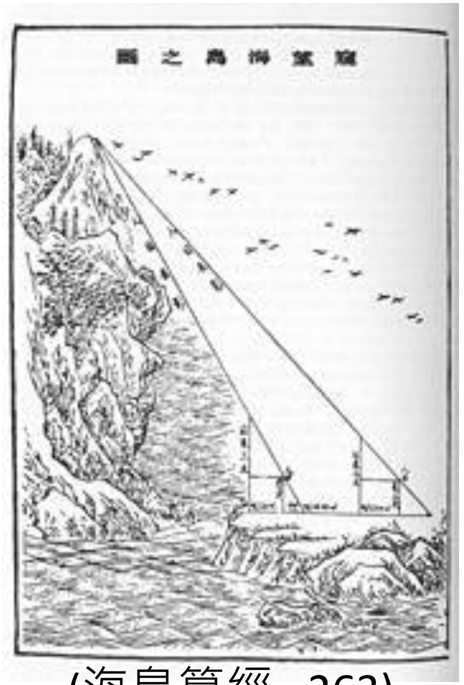
Integrating structure-from-motion photogrammetry with geospatial software as a novel technique for quantifying 3D ecological characteristics of **coral** reefs
JHR Burns, D Delparte, RD Gates, M Takabayashi - PeerJ, **2015** - peerj.com
… This study details a suite of methods for quantifying 3D characteristics of a **coral** reef using **SfM** photogrammetry in conjunction with geospatial software tools. This novel approach …
Save Cite Cited by 326 Related articles All 13 versions

Measuring **coral** reef terrain roughness using 'Structure-from-Motion'close-range photogrammetry
JX Leon, CM Roelfsema, MI Saunders, SR Phinn - Geomorphology, **2015** - Elsevier
… ' (**SfM**) algorithms for a 250 m transect along a shallow **coral** reef flat on Heron Reef, Great Barrier Reef. The precise terrain data were used to characterise surface roughness, a critical …
Save Cite Cited by 237 Related articles All 10 versions

Using Imagery for 3D Modeling Is Not a New Concept

(Fujimoto , 1979)

Old method: triangulation needed known baselines

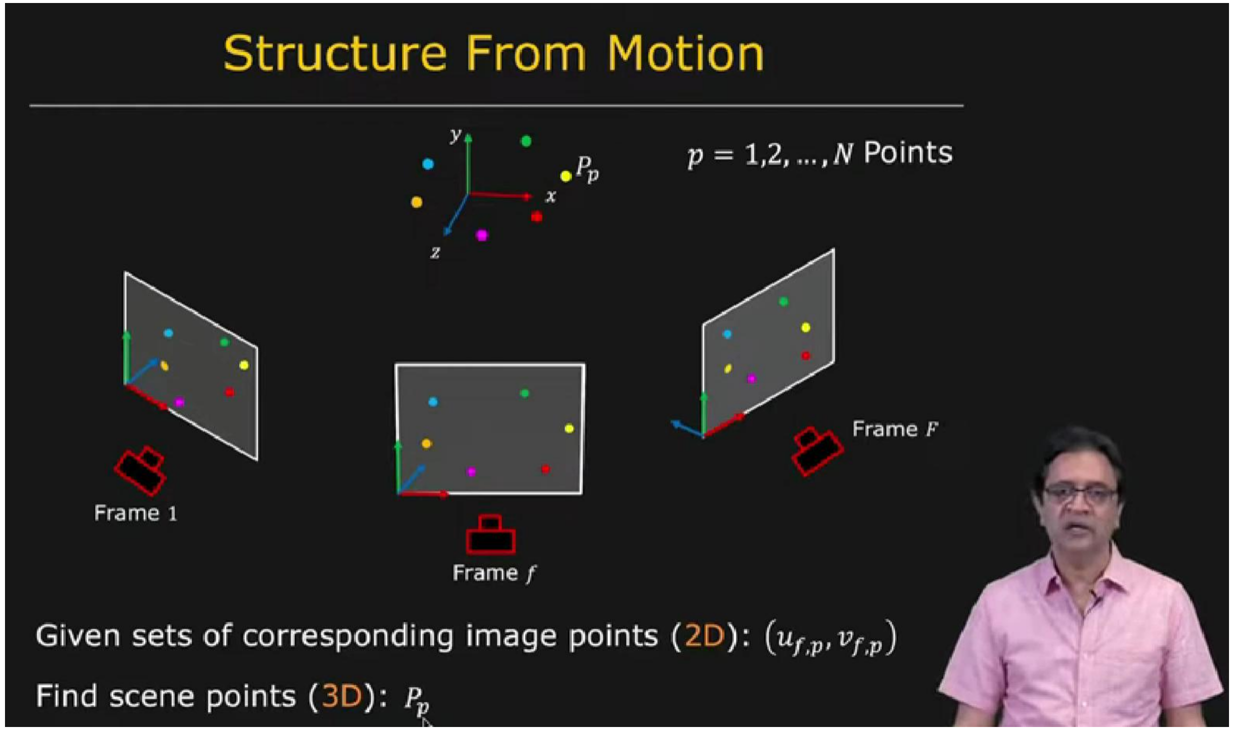


(海島算經 , 263)

Principles of SfM-based 3D Reconstruction

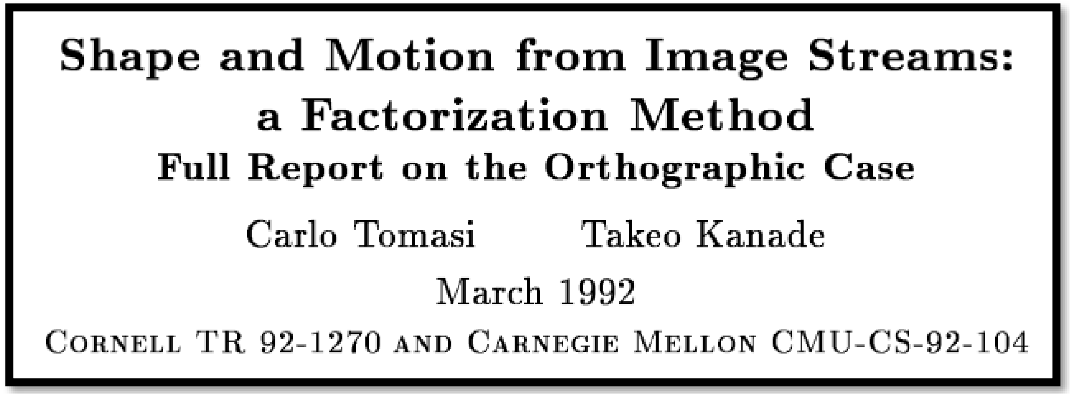
Structure from Motion 運動恢復結構

Recovers the 3D **structure** of a scene **from** the **motion** of the camera as it captures multiple overlapping images.



https://www.youtube.com/watch?v=JlOzyyhk1v0&list=PLKSXtGgYUdGwzZU18HpyLc_QUexFcE_Rr&index=16&ab_channel=FirstPrinciplesofComputerVision

Extract key points via multi-view photos



Shape and Motion from Image Streams: a Factorization Method

Full Report on the Orthographic Case

Carlo Tomasi Takeo Kanade

March 1992

CORNELL TR 92-1270 AND CARNEGIE MELLON CMU-CS-92-104

Born from computer-vision algorithms

Because key points are redundant, partially obscured still allows object reconstruction, and moving elements can be distinguished from static ones.

General types of photogrammetry

Aerial

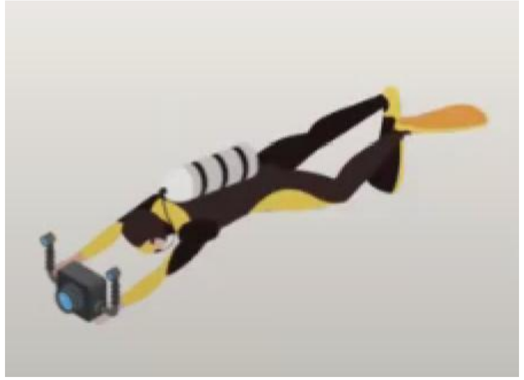
Camera sensor is further away from object or scene

- Unmanned Aircraft (UAV)
- Manned Aircraft
- Satellite

Close-Range

Camera sensor is closer to object or scene

- Ground
- Underwater



Edited from : https://www.youtube.com/watch?app=desktop&v=sYZnO3egZKQ&ab_channel=CoralRestorationConsortium

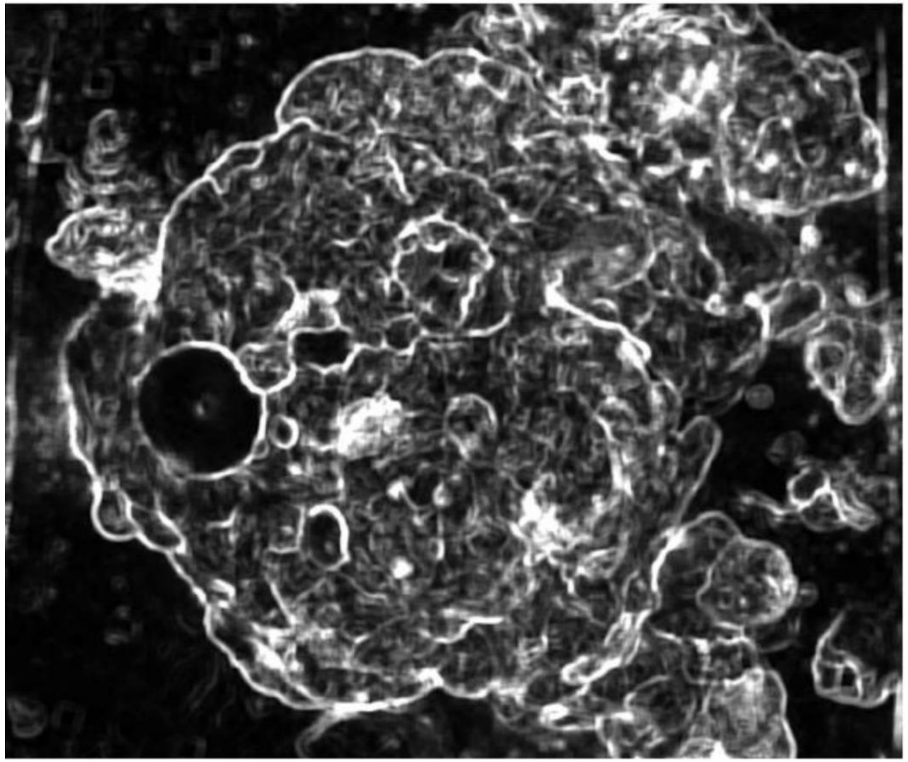
Coral 3D survey in various scales

Branching & colony level

(葉宗旻, 2019)

(鄭庭卉, 2024)

Habitat level



(陳冠言, 2020)

Earlier 3D Reconstructions at the Colony Scale

Although mathematically feasible, past computers lacked the processing power, and manual intervention was extensive.

Wax coating method (Naumann et al., 2009)

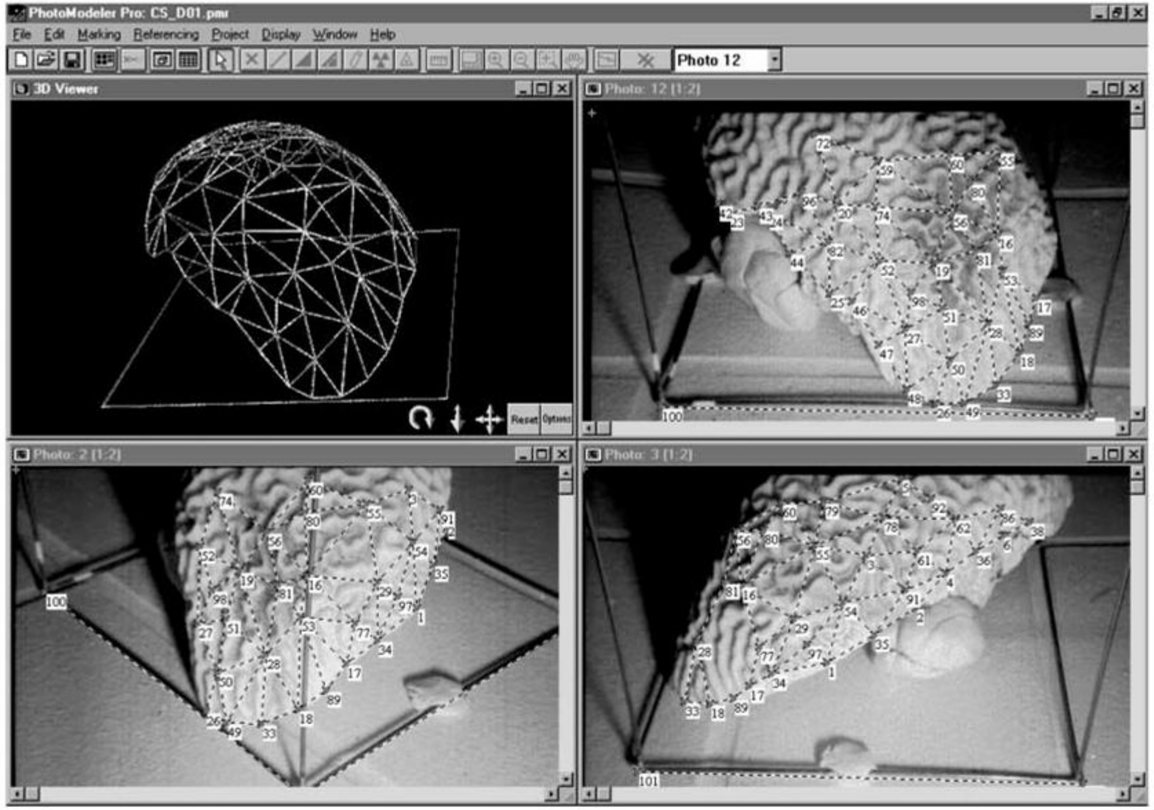


Fig. 1 Marking and referencing control points in PhotoModeler 3.0. Control points are tagged with a unique identifier and identical points on the object are cross-referenced in different photographs. For example, adjacent points 33, 28, and 18 appear in all three photographs. The processed, scaled model is shown *top left*, with orientation similar to that of photograph *top right*. In this example, a cuboid framer has been used to provide a scale, but this is not necessary so long as two points of known distance apart are present in some part of the scene being modeled. Framer cube dimensions are 15 cm on a side

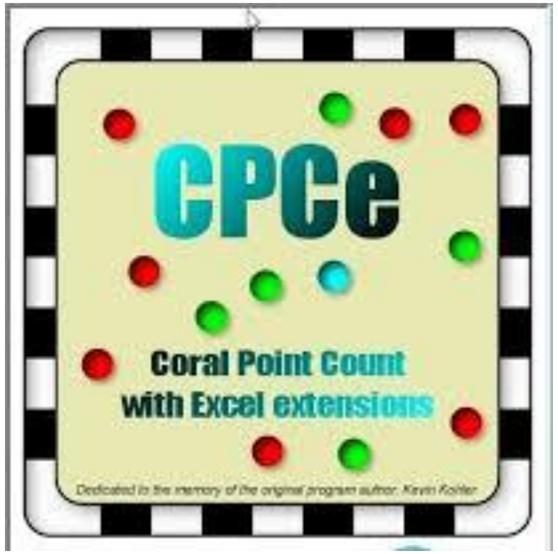
The errors associated with estimating curved surfaces from intersecting triangular planes were investigated by "decomposing" models by removing randomly chosen points from completed models. Since this procedure depends to some extent on the adequacy of the original model, one coral skeleton was repeatedly remodeled using an increasing control point density with control points chosen independently at each stage. Results were compared with those obtained with the standard foil-wrapping technique of Marsh (1970). The relationship between the foil-wrapping technique and the 3-D modeling process was further investigated on a

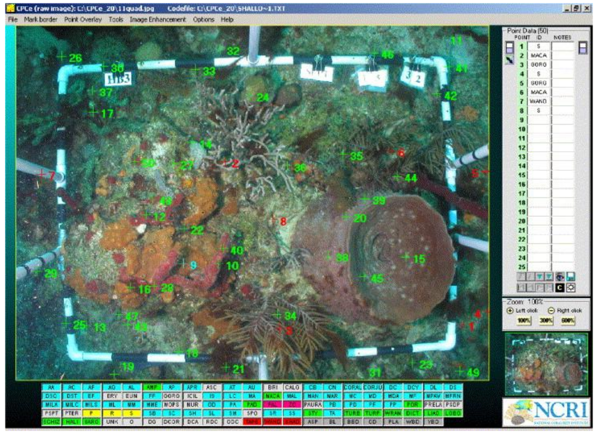
(Bythell et al., 2001)

Evolution of Habitat-Scale Survey

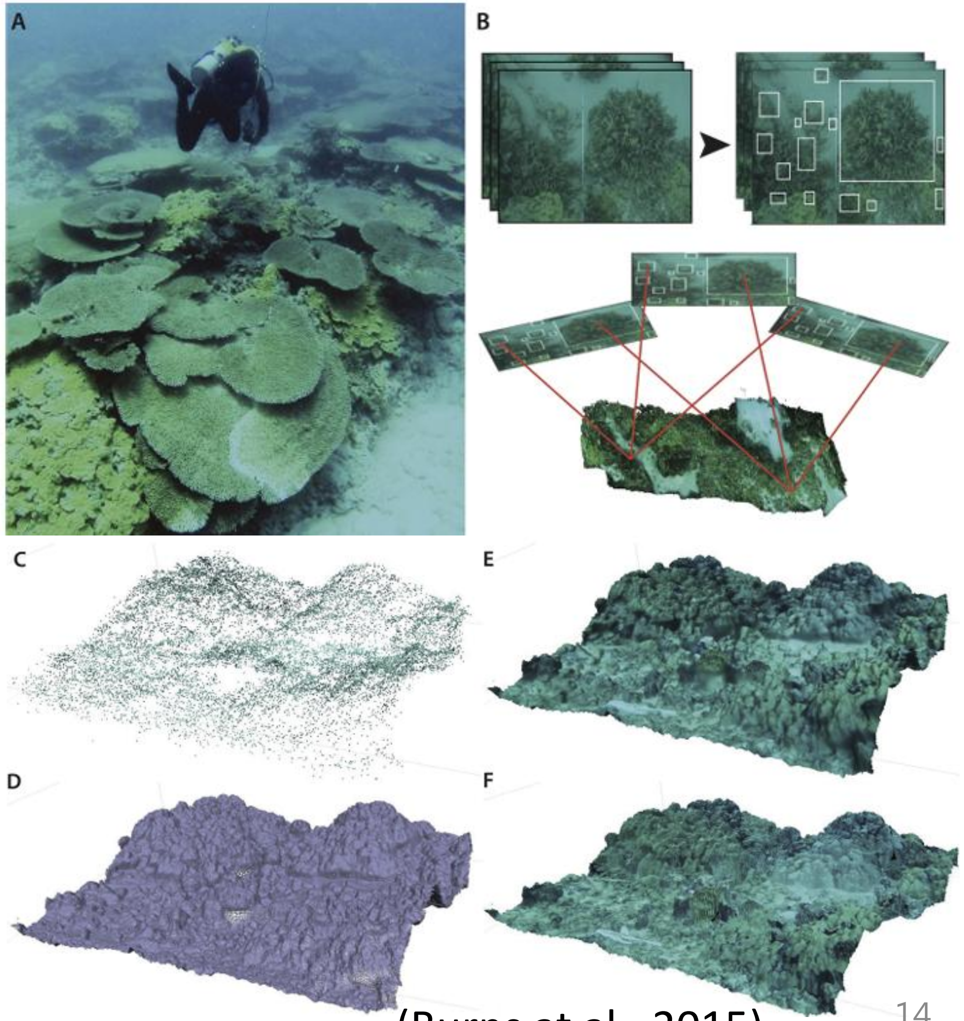
- Line/Point Intercept Transect
- Photoquadrat
- 3D survey

>60 years ago





(Kohler & Gill, 2006)



(Burns at al., 2015)

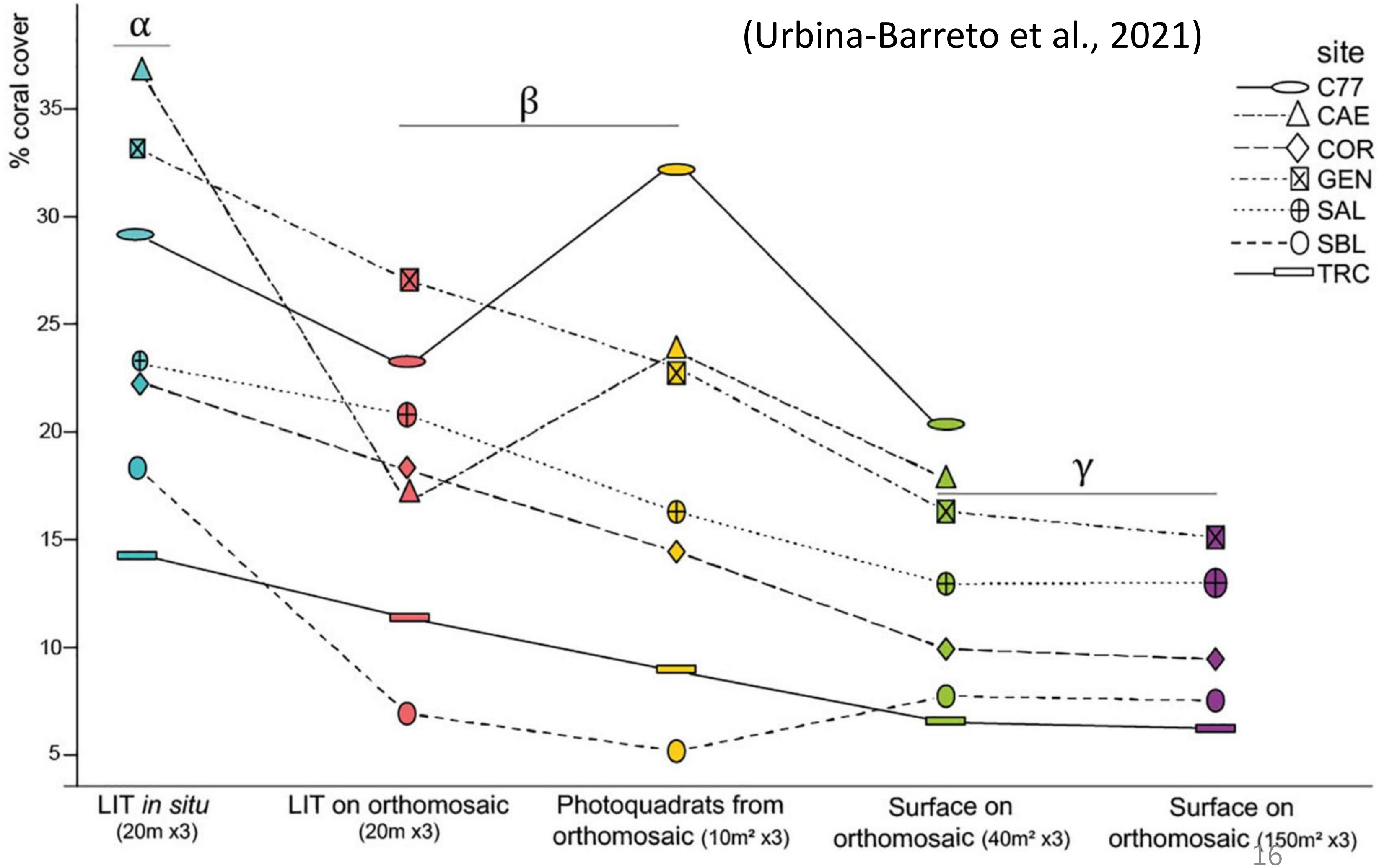
Data products comparison

Data Product	資料項目	線/點截距樣帶 Line/Point Intercept Transect	照片取樣 Photoquadrat (CoralNet)	正射影像鑲嵌圖 Orthomosaic (3D survey)
Percent Cover	百分比覆蓋度	✓	✓	✓
Coral Health	珊瑚健康狀況	✓	✓	✓
Recruitment	珊瑚補充量		✓	✓
Virtual Archive	虛擬檔案庫		✓	✓
Size Distribution	大小分佈			✓
Growth	生長			✓
Mortality	死亡率			✓
Competition	競爭			✓
Structural Complexity	結構複雜度			✓

Edited from: Coral Restoration Consortium’s Monitoring Working Group webinar

SfM vs. Traditional Coral Survey

- Traditional methods tend to overestimate actual cover, by up to 1.5×.



Comparison of Cameras for 3D Survey

	DSLR	TG-series	GoPro
Cost	10	3	1
Efficiency	1.5	1.2	1
Resolution	0.5	0.7~0.8	1

	Canon EOS Rebel SL3	GoPro Hero 7
Cost		
Camera	~$600.00	~$220.00
Underwater housing	~$1,700.00	*NA*
Total Cost	**~$2,300.00**	**~$220.00**
Photos		
Photo file format	jpeg	jpeg
Photo resolution	24 Megapixels	12 Megapixels (from 4K video)
Aligned photos / total photos	3125 / 3125	3125 / 3125
Photogrammetry metrics		
Sparse cloud points	2,848,358	2,630,543
Dense cloud points	787,450,347	225,835,648
Faces (3D model)	11,919,451	3,834,651
Digital elevation model (DEM) resolution	0.831 mm/pixel	1.77 mm/pixel
Orthomosaic resolution	0.208 mm/pixel	0.442 mm/pixel
Processing times		
Sparse cloud generation	1 h 23 min	1 h 27 min
Dense cloud generation	4 h	3 h 11 min
Mesh model rendering	3 h 32 min	1 h 49 min
Texture rendering	19 min	12 min
Total computer processing time	**9 h 14 min**	**6 h 39 min**

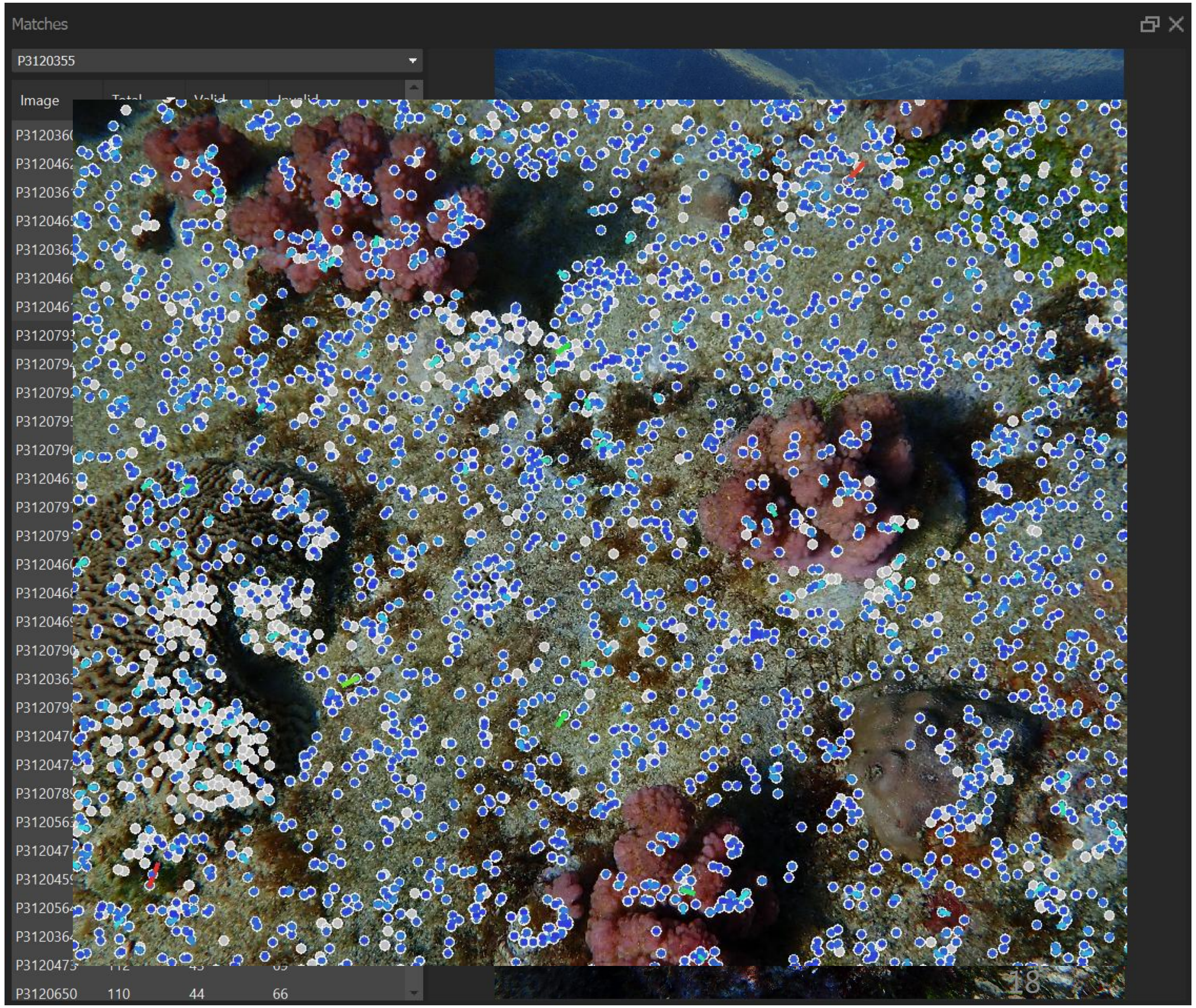
Table 1: Detailed information about setup cost, photos used to construct the models, photogrammetry metrics, and processing time. Processing was done using the same settings for both models. Note that processing time does not include time for various steps such as photo editing, extracting images from video, re-aligning photos, and editing and scaling the models.

TG cameras are a cost-effective option for large-area coral surveys.

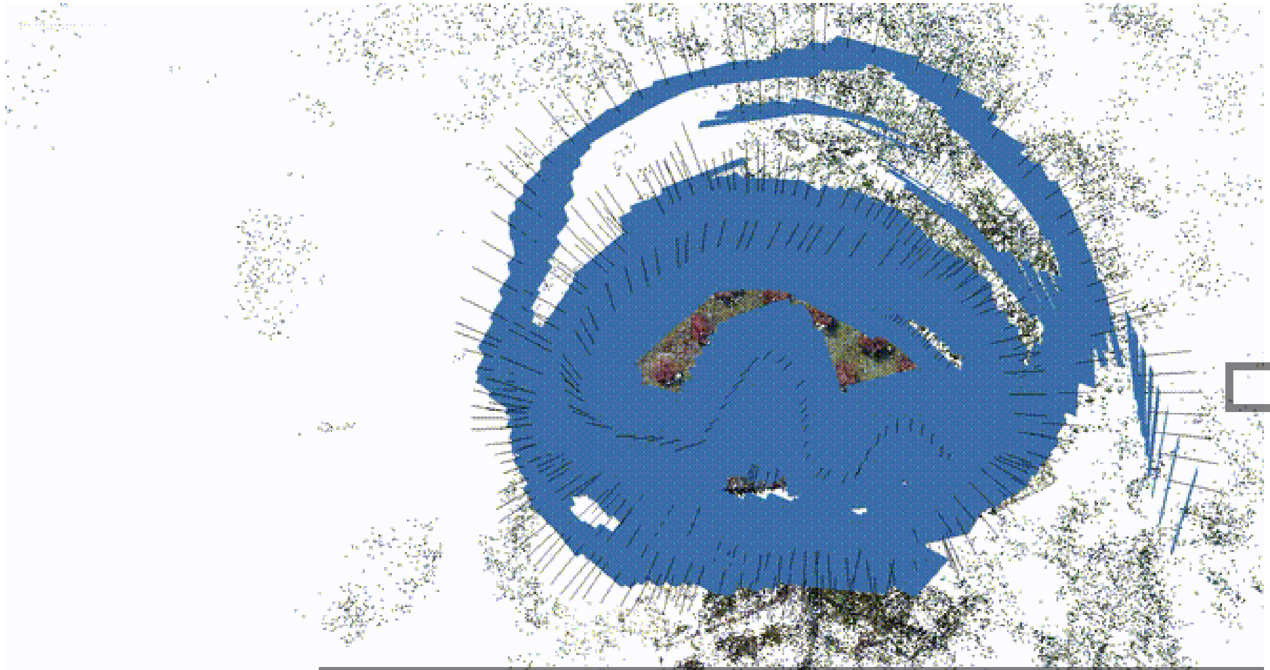
(Roach et al. 2021)

Image sequence and alignment

Capture a continuous image sequence with at least 60–80% overlap between frames.



3D modeling products – 點雲 Point cloud

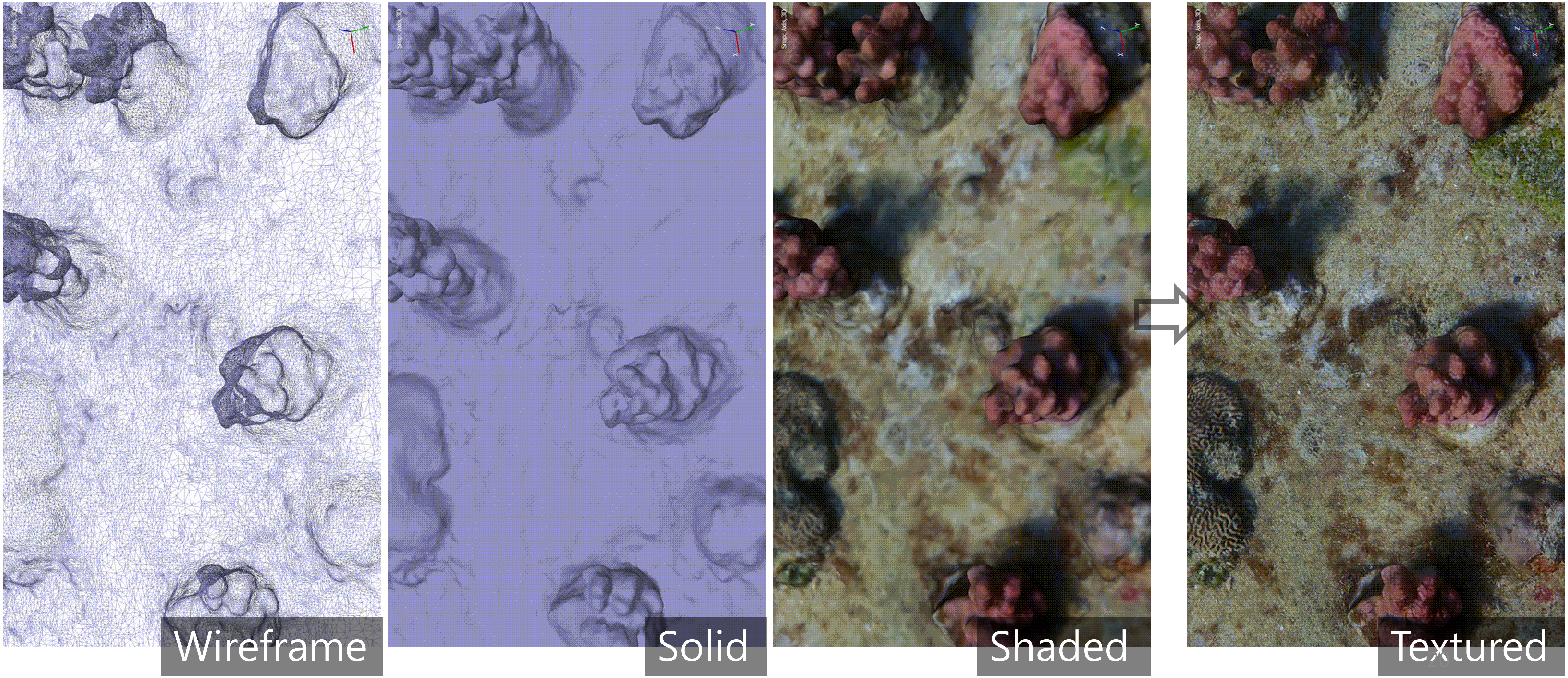


Tie points (sparse point cloud)

Point cloud (dense point cloud)

After alignment, generate tie points, filter outliers, optimize alignment, then build the dense point cloud.

3D modeling products – 網格模型 Mesh



Scale bars

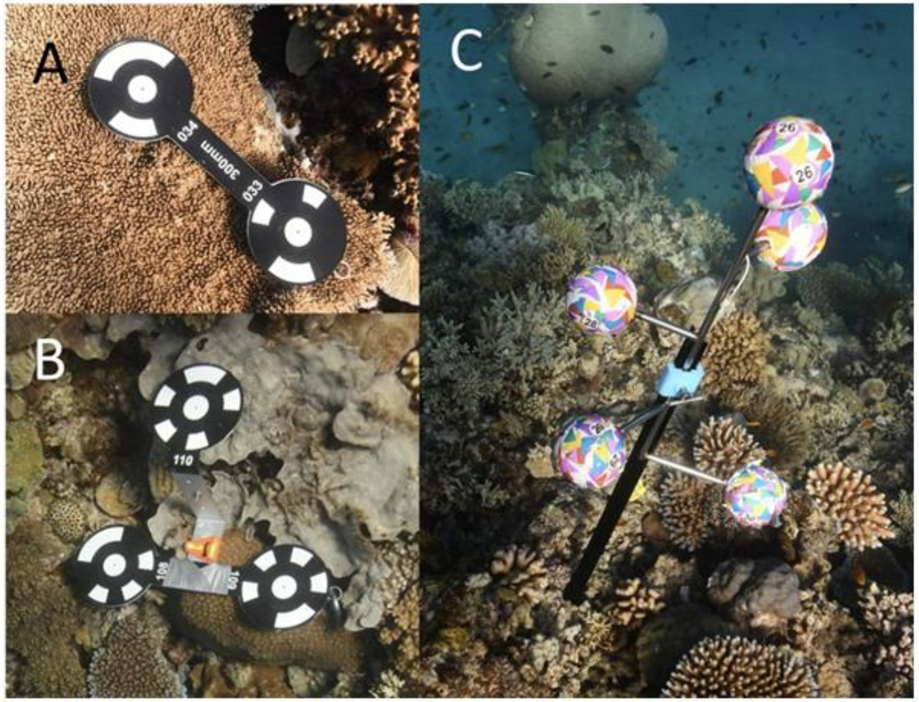
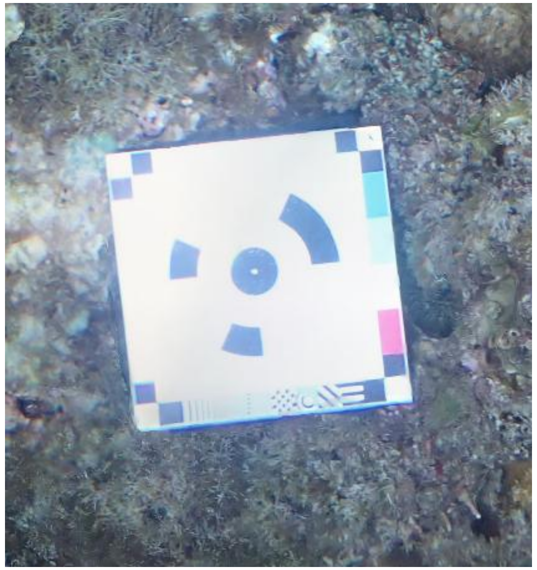
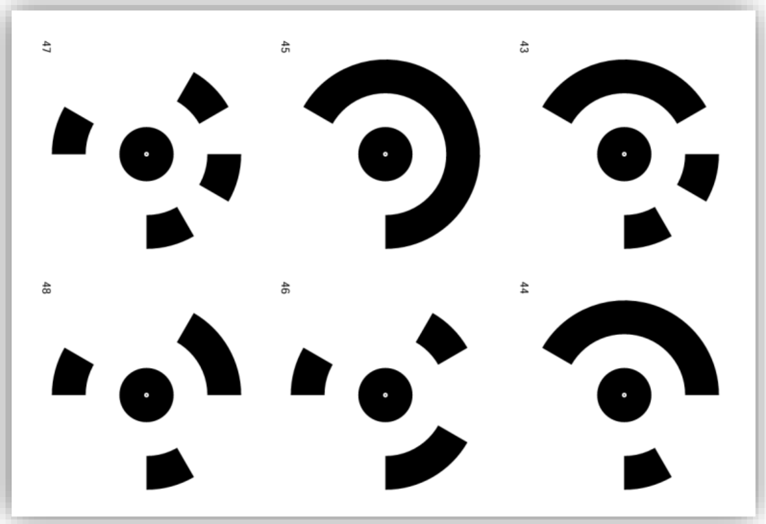


Figure 8. Photogrammetry ground control points used in the current workflow; (A) dumbbells; (B) triads, and; (C) sphere trees. Image: S. Gordon.





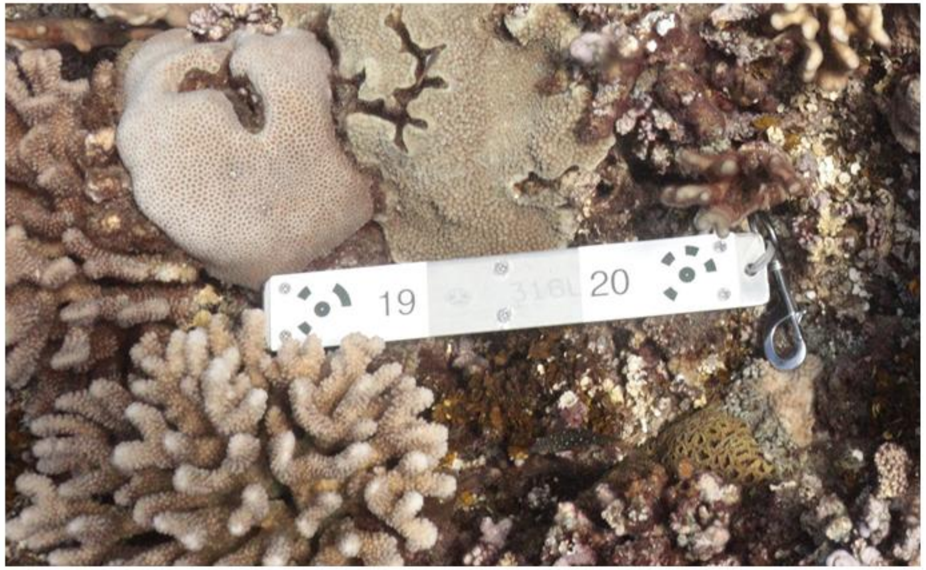
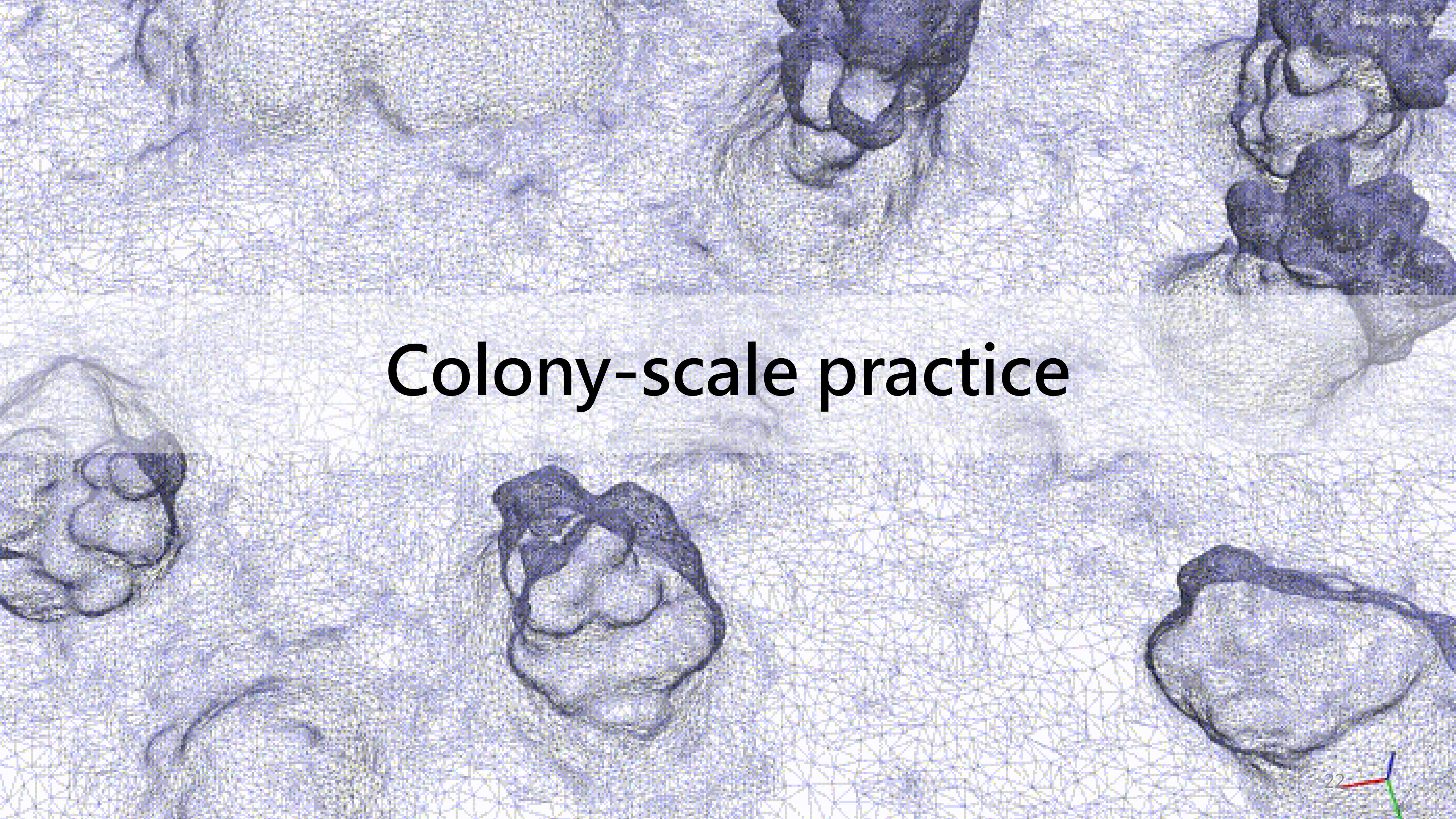
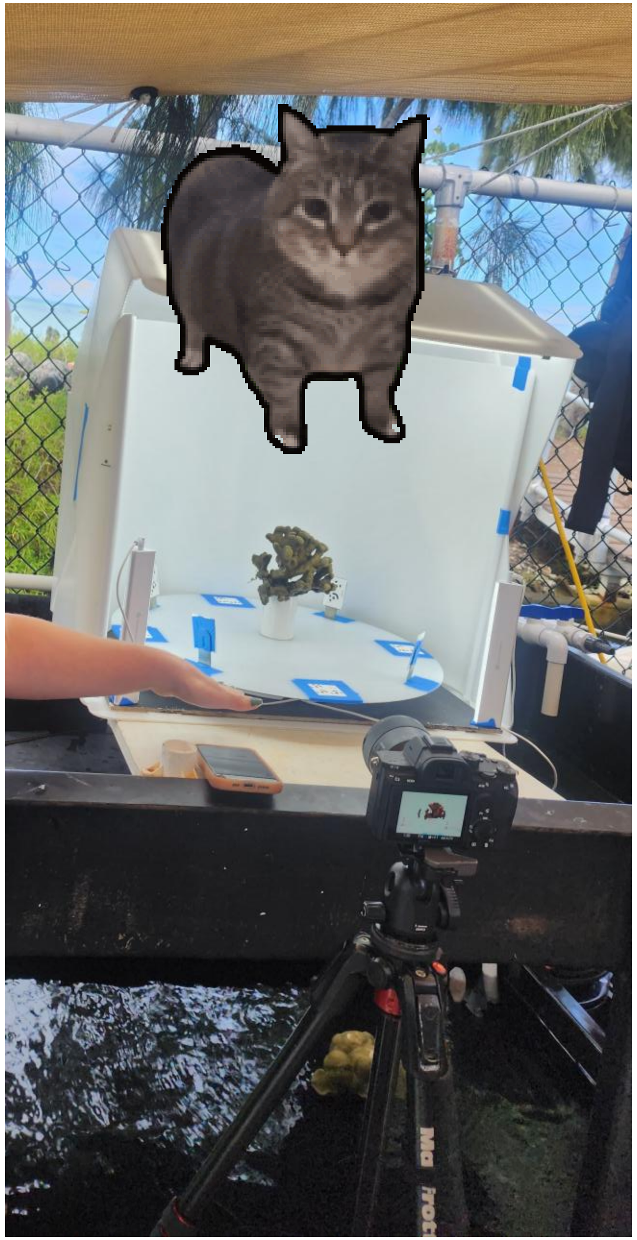


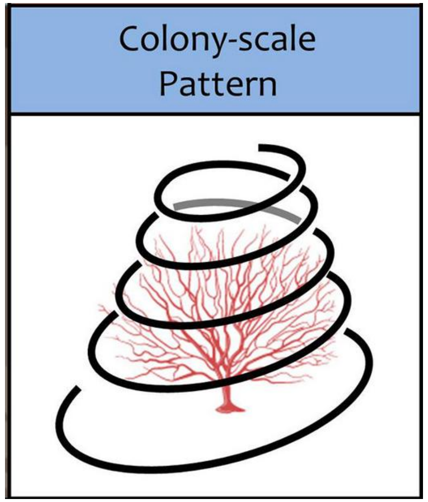
Figure 1.5 A scale bar with two coded Metashape target patterns (also known as ground control points) as end markers whose centers are about 0.25 m apart from each other. These markers can be automatically detected by the software and used as model checkpoints and horizontal geospatial scaling.



Colony-scale practice

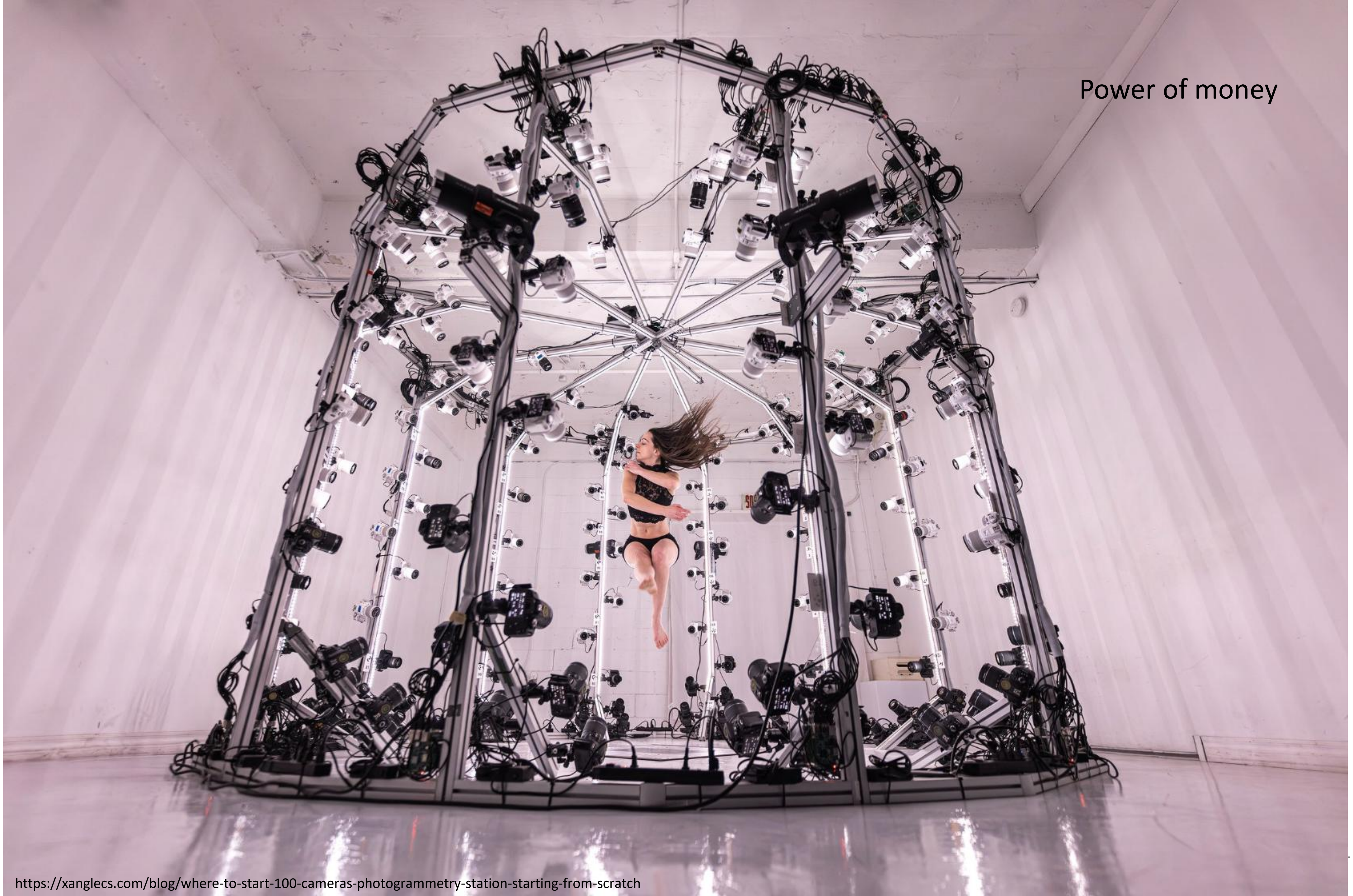
Rotating object





Rotating camera

Power of money



https://xanglecs.com/blog/where-to-start-100-cameras-photogrammetry-station-starting-from-scratch

Images Must Be Clear and Unobstructed

Unacceptable Captures

Too Blurry

Floating Debris Interference

Filming in wave conditions is challenging

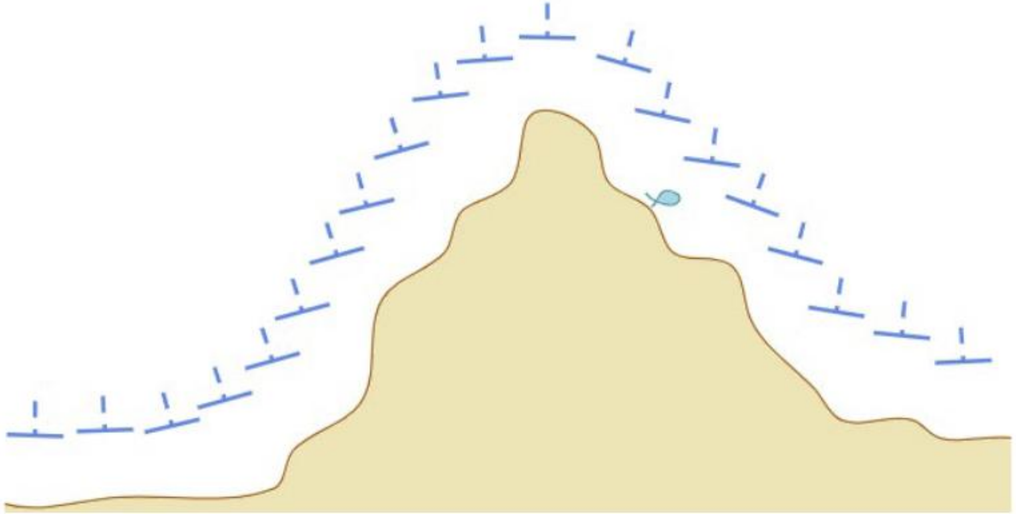
Overexposed

Irrelevant to the Subject

Try to put your hand inside, and check the result

Ensuring High-Quality Models
Maintain Consistent Filming Distance

- Move with the Terrain; Avoid Drastic Field-of-View Changes



(Damaris et al., 2024)

Camera setting

Camera Choices (Perry Institute for Marine Science)

- Nikon D850 in Sea & Sea Housing
- Lens choice – balance of overlap and resolution
- Time-lapse mode with 1 second interval
- Natural lighting only
- Shutter speed faster than 1/320s
- Smallest aperture possible – maximize DoF (Depth of field)
- Auto ISO

Canon SL2/3 (NOAA)

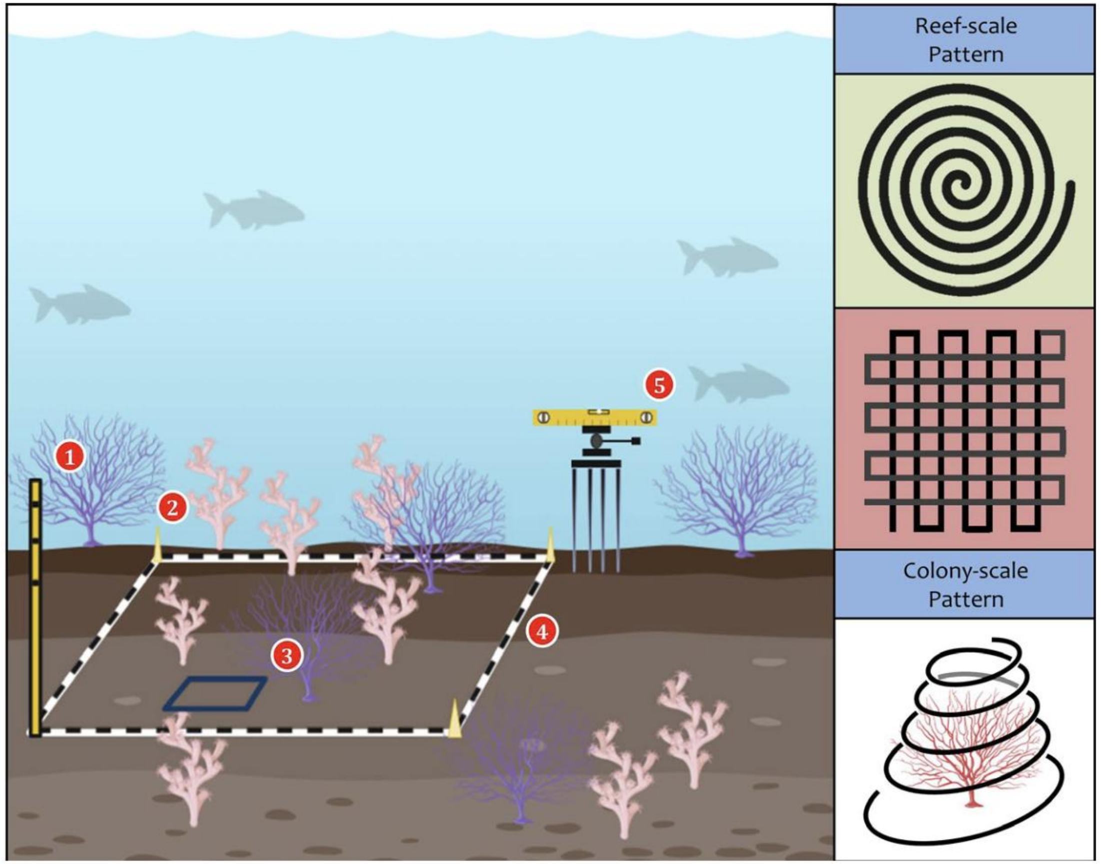
TG-6 (NMMBA)

1. 相機調至P模式
2. 關閉閃燈
3. 調整曝光值 (視當天光照強度設定在 -0.3~0之間)
4. 調整ISO為AUTO
5. 將白平衡設為 深潛 模式
6. 畫面比例4:3
7. 調整至ESP測光模式
8. 拍攝模式設定為Natural
9. 對焦點設定為 單點
10. 設定間隔/定時拍攝模式: 將影像數目設定為299張、間隔時間1秒、定時短片關、開始等待時間2秒

Time to have funs

Rule of thumb

- Sharp images
- Good overlap
- Complete coverage of the object

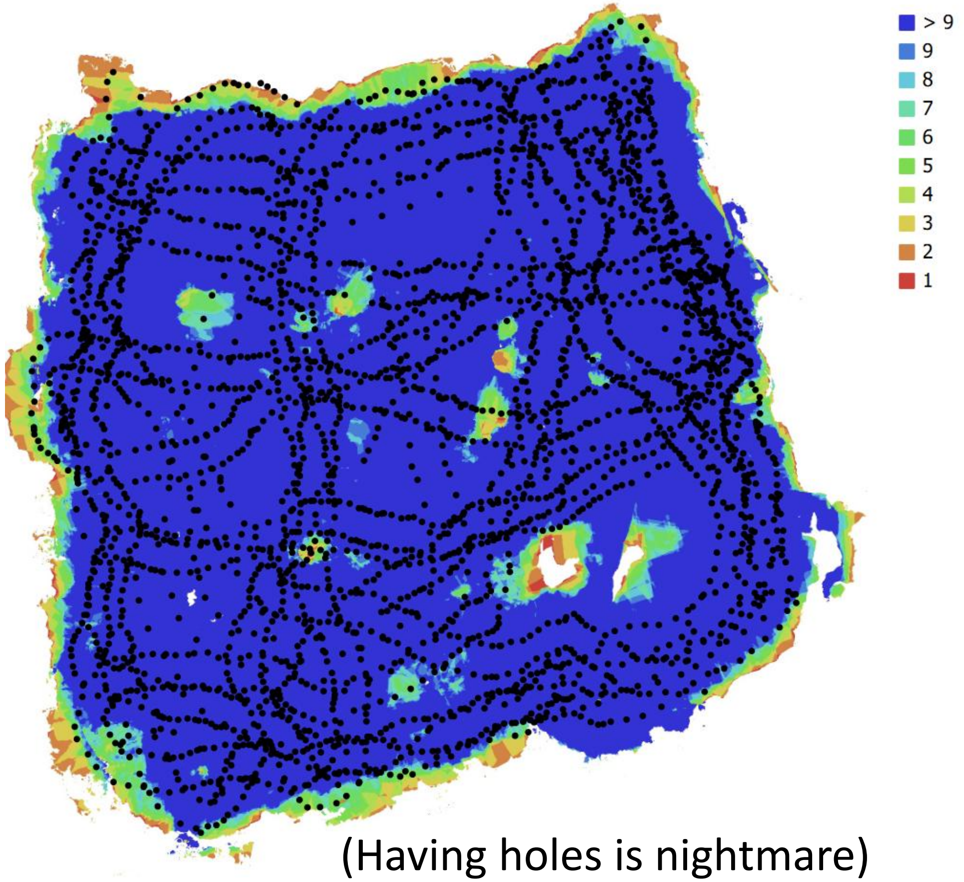


(Bayley et al. 2020)

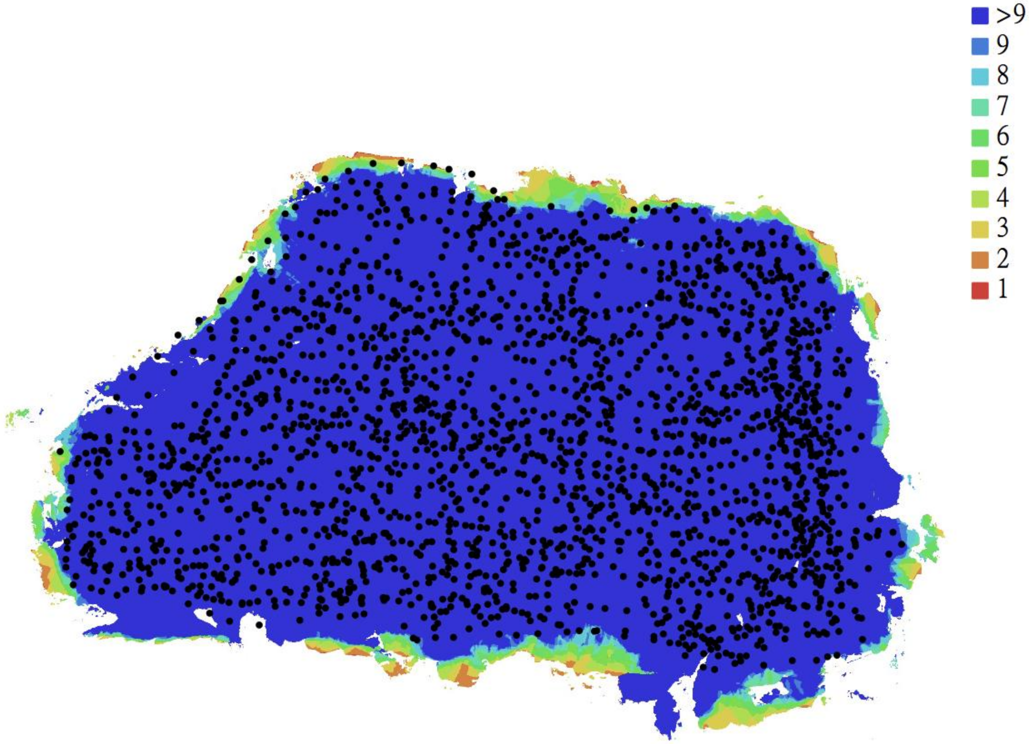
Habitat-scale practice

Criteria for Building High-Quality Models

- 60–80% overlap between consecutive photos
- Aim for even coverage and capture multiple angles



(Having holes is nightmare)

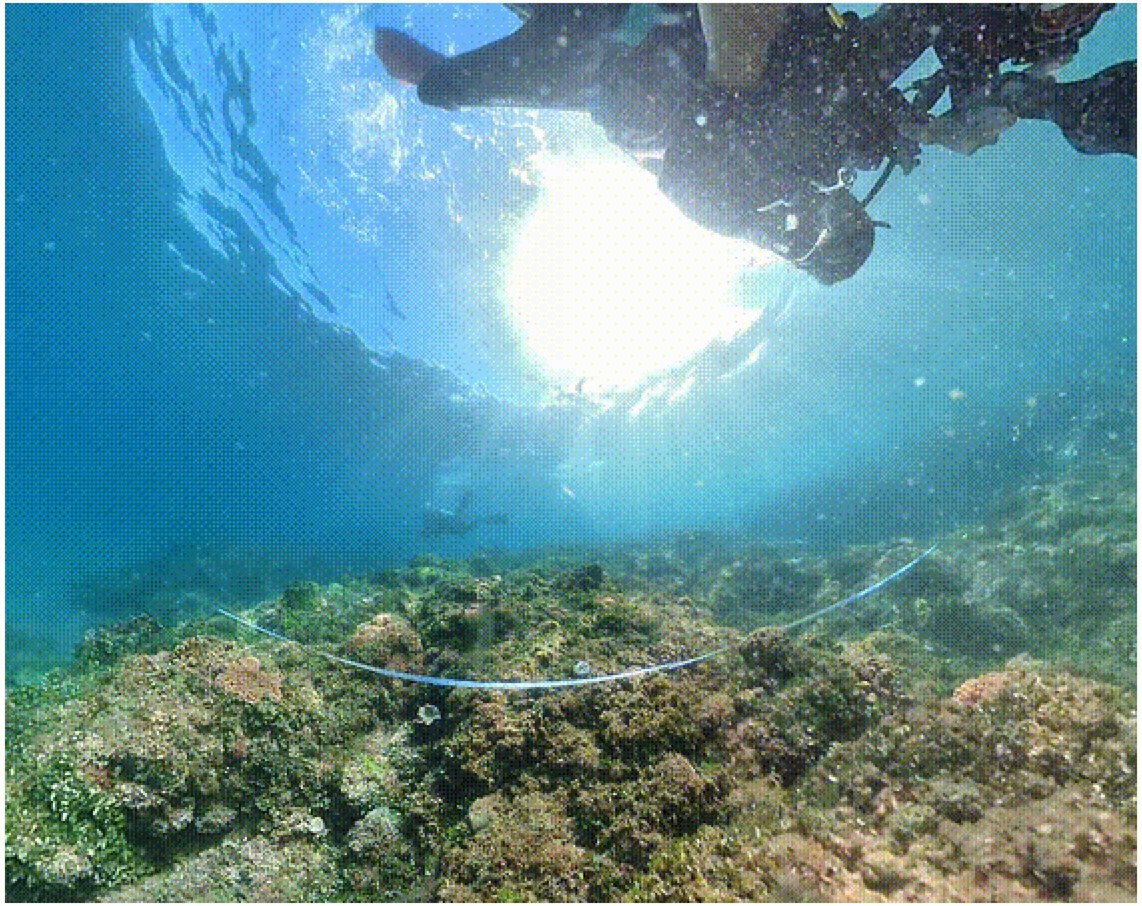


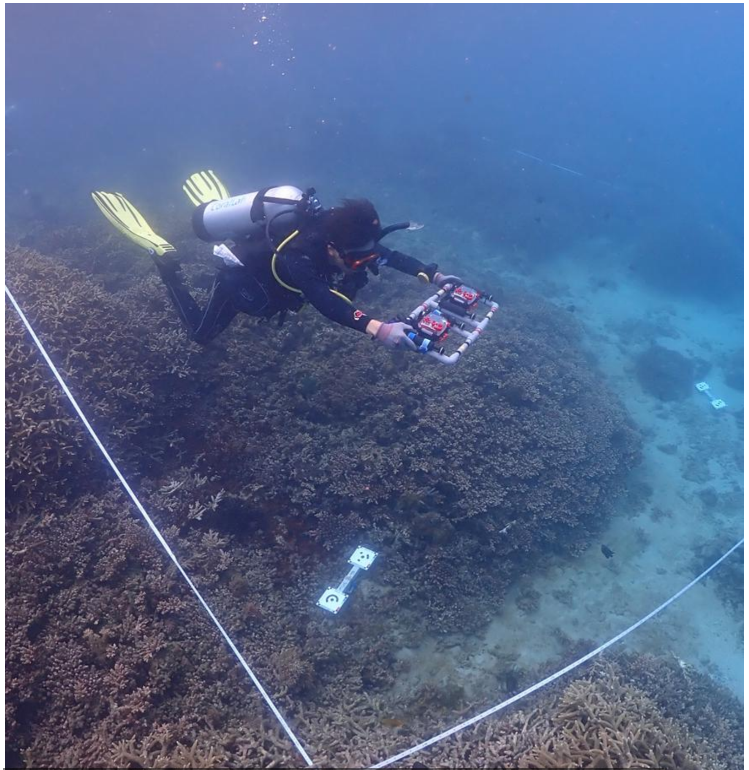
(>9 additional photos yield minimal structural gain)

(Boustrophedon、牛耕式路徑)

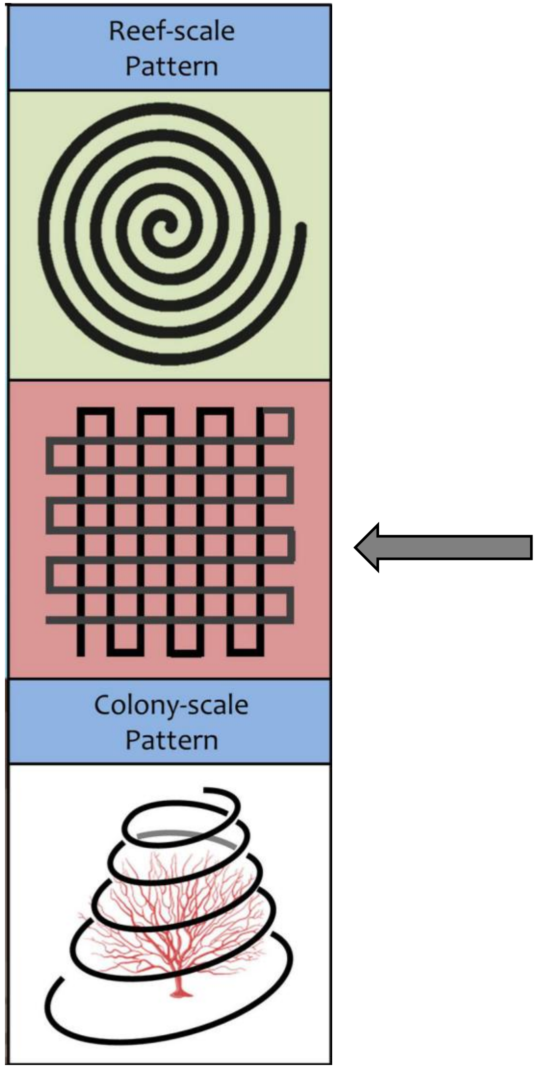
Lawn-mowing Survey Method

- Secure four corners, deploy plot, link multiple cameras, follow the path



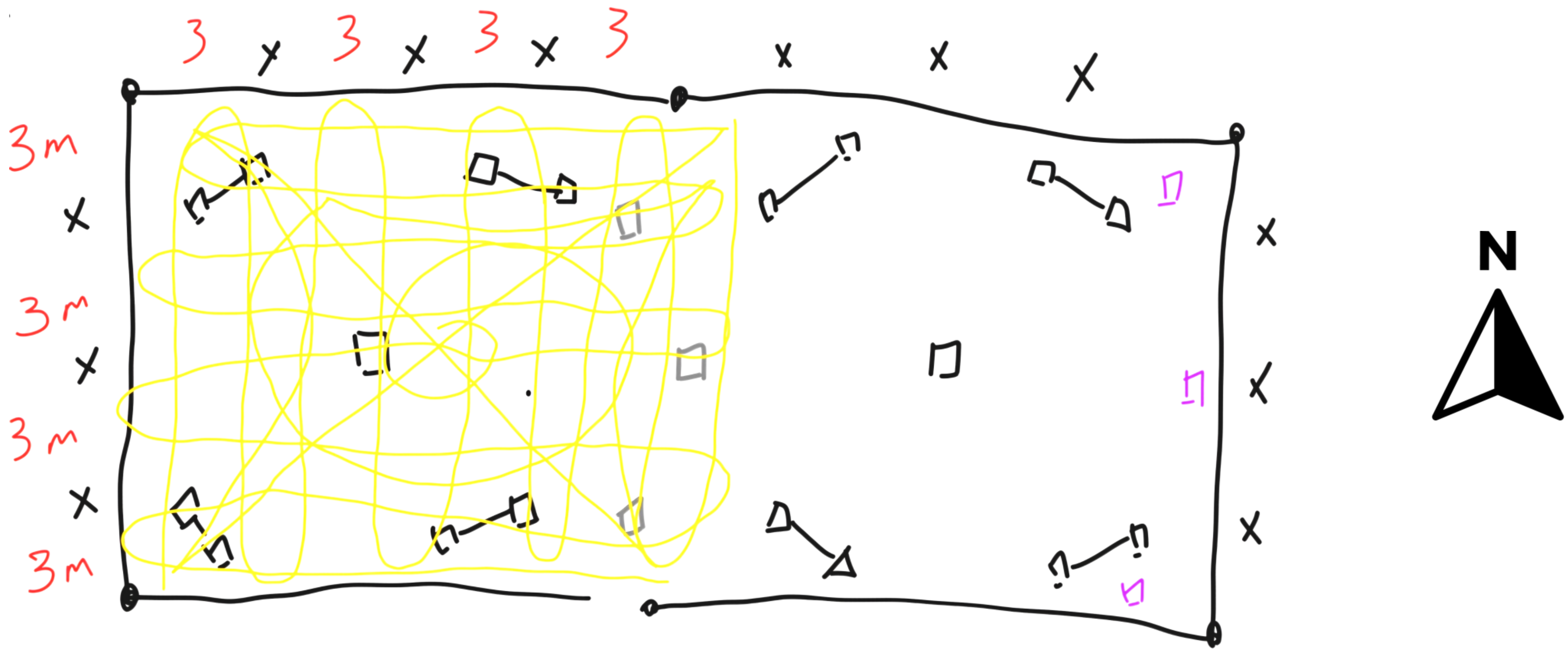


Suited for Complex Terrain;
Captures More Viewing Angles



(Bayley et al., 2020)

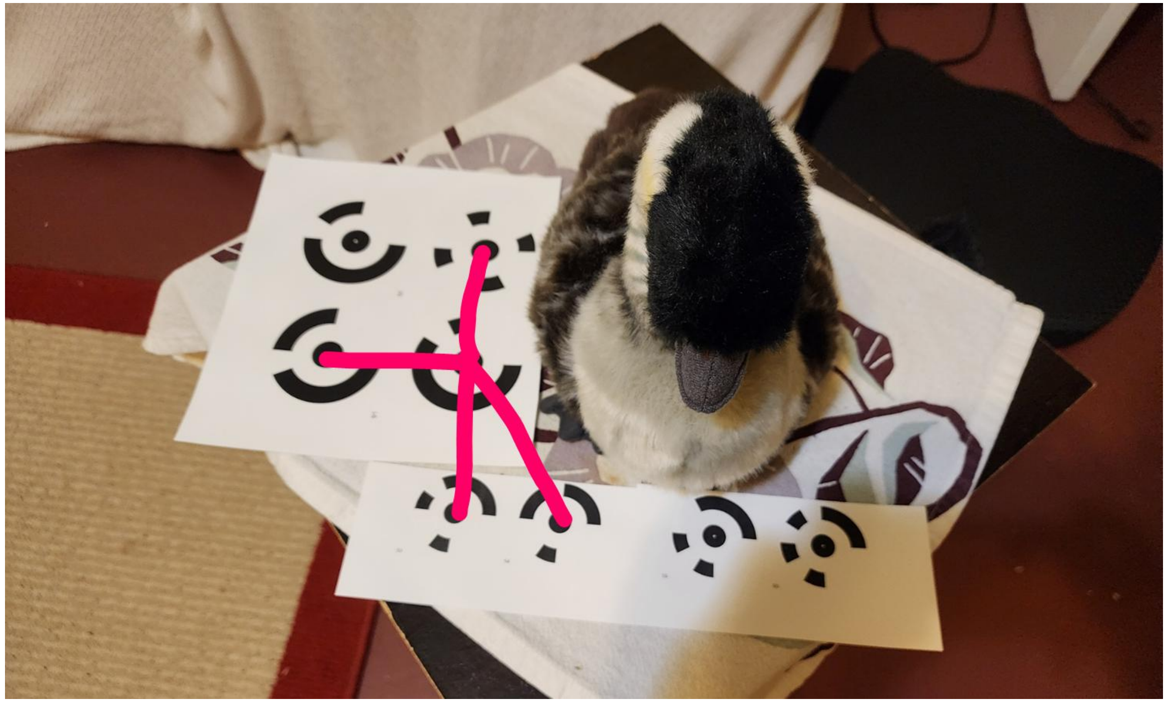
How to Set Up the Sampling Plot

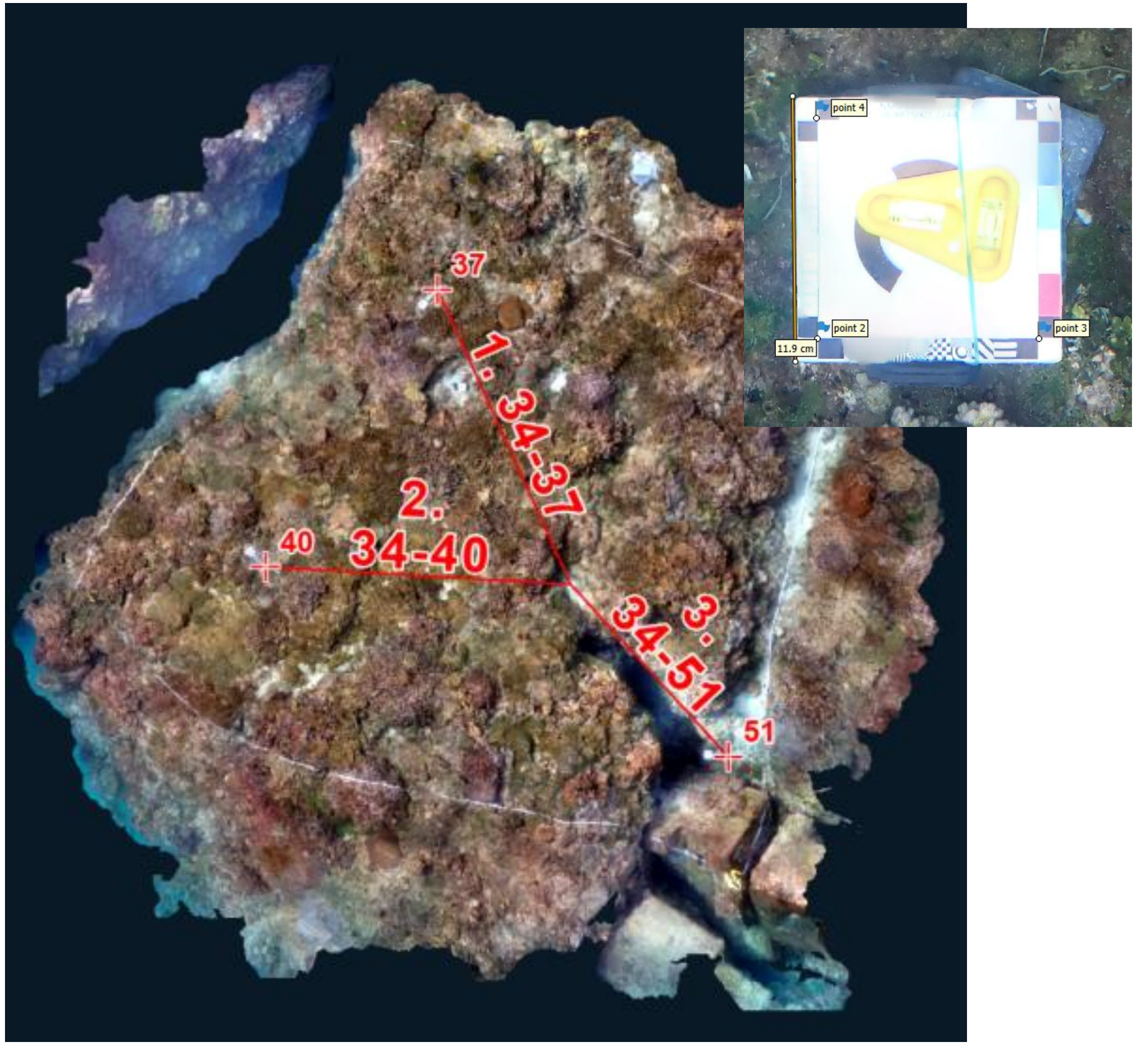


Consecutive Plots Must Overlap, Sharing ≥3 Fixed GCPs Spaced ≥3 m; Repeat Same Method for Extensions

Ground control points measurement

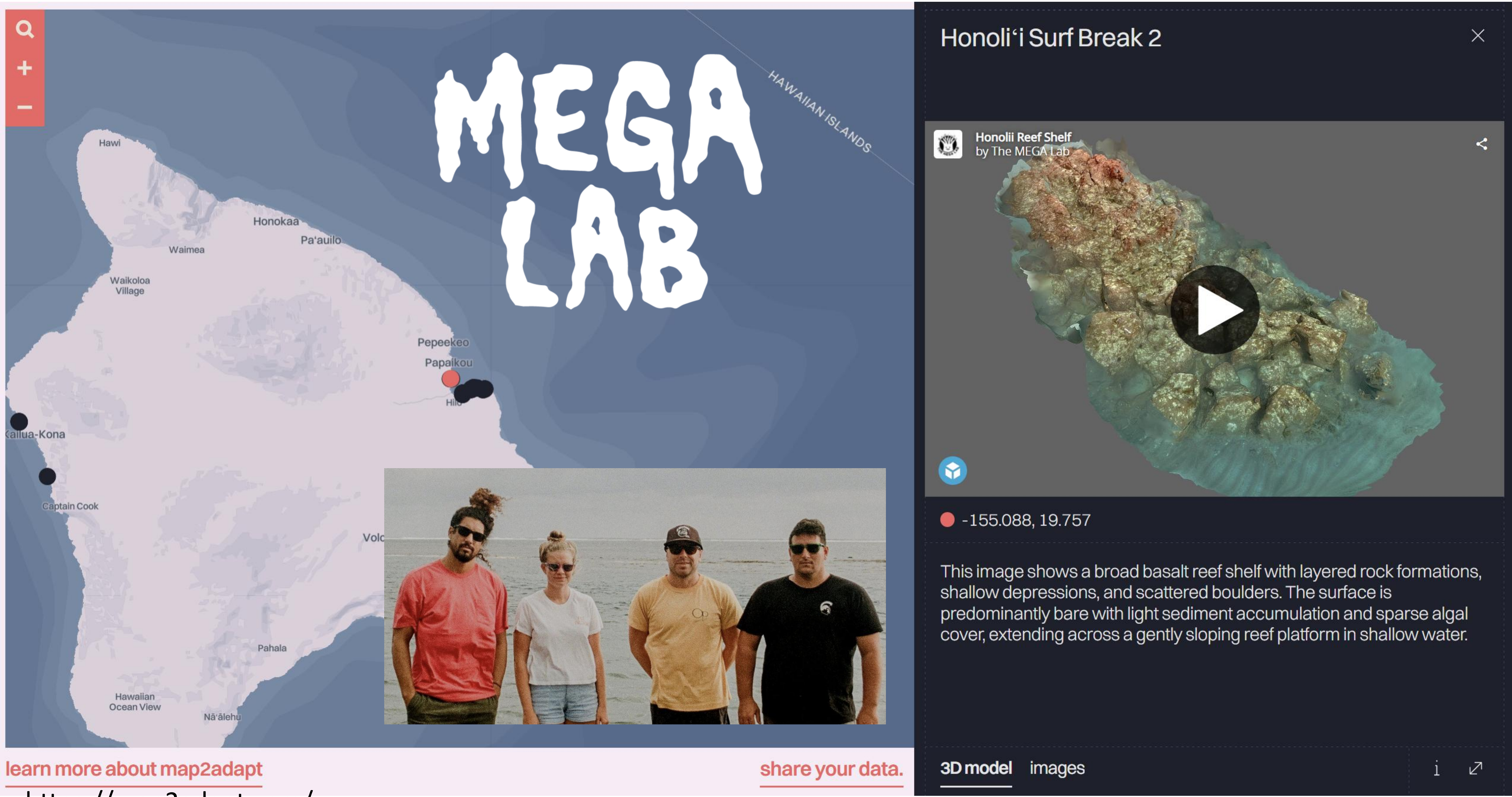
1. Latitude and longitude of the center point
2. Distances from the center point to 3 reference points
3. Bearings from the center to 3 points
4. (Depth at each point) or (Level 3 points)





Start Metashape Practice

sfm_workshop/docs/NSYSU-MetashapeSOP-2505.pdf



https://map2adapt.com/

SfM softwares

Commercial Software

Metashape
Agisoft

REALITYCAPTURE

PIX4D

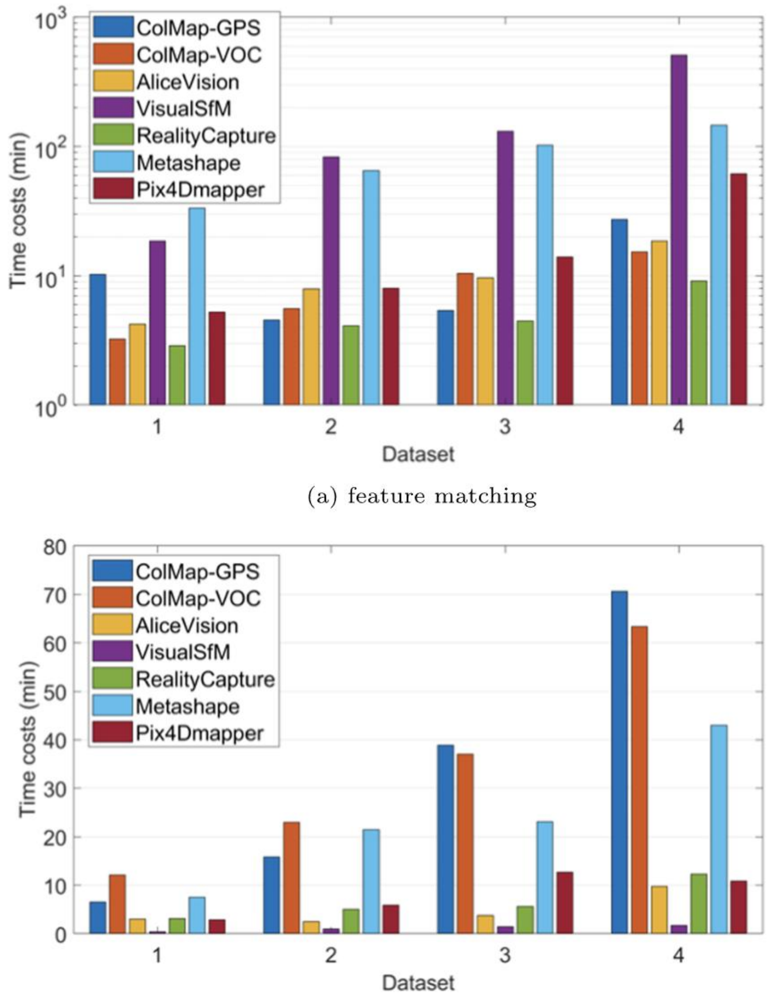
Open-Source Software

MESHROOM

SfM softwares comparison

By contrast, Agisoft Metashape:

- Longer processing time for modeling
- Capable of producing higher-quality point clouds
- User interface is relatively intuitive



(a) feature matching

(b) bundle adjustment

Fig. 10. The time costs in feature matching and bundle adjustment (in minutes).

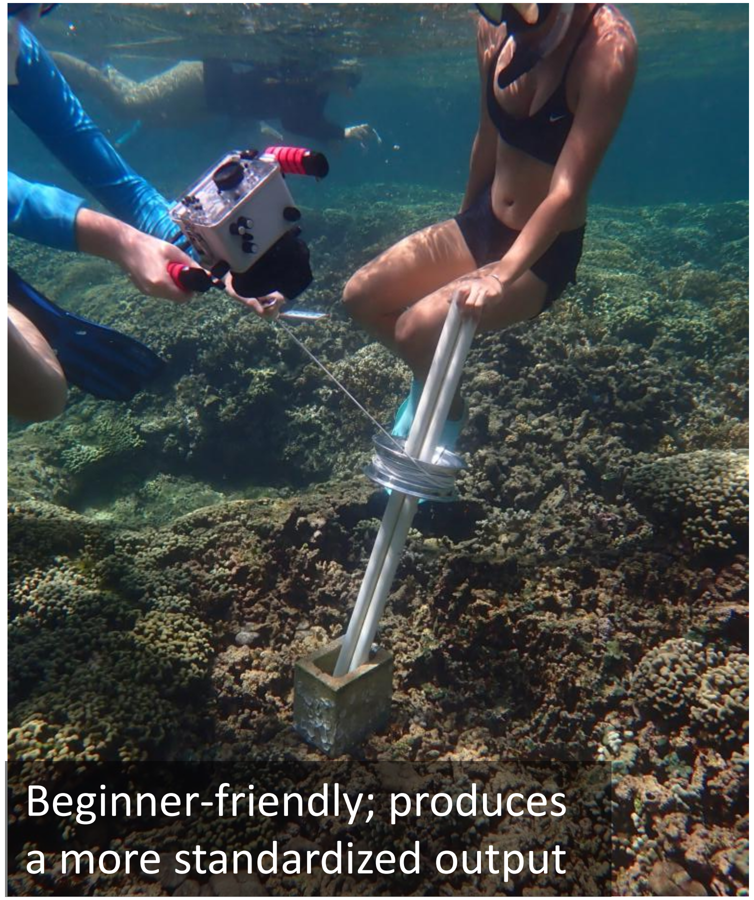
Table 7
Statistical results of completeness for SfM-based reconstruction. The largest point numbers are shown in bold values.

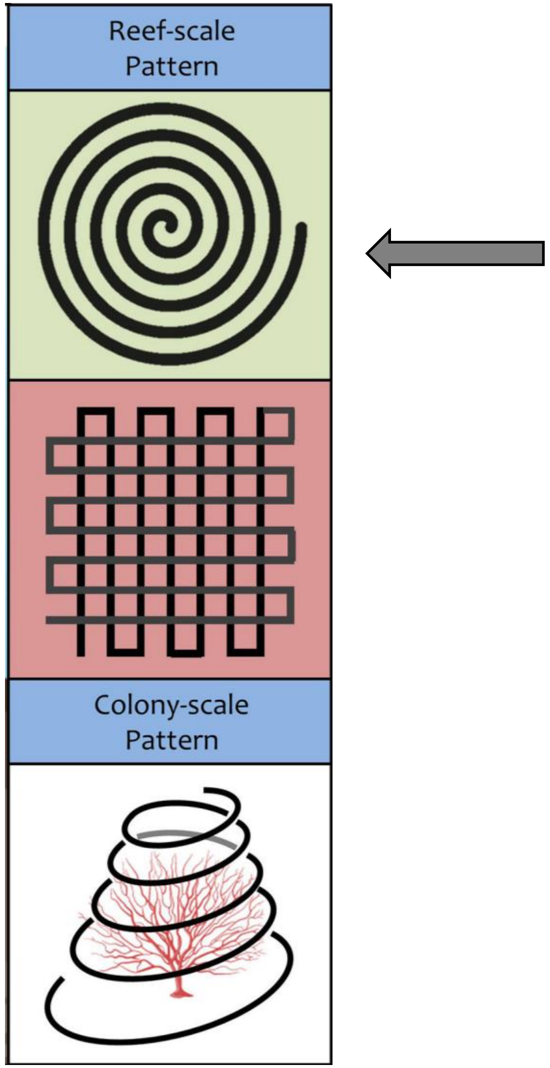
Method	Dataset 1		Dataset 2		Dataset 3		Dataset 4	
	Images	Points	Images	Points	Images	Points	Images	Points
ColMap-GPS	157/157	132,706	320/320	200,301	390/390	362,665	750/750	453,483
ColMap-VOC	157/157	142,218	320/320	277,638	390/390	374,732	750/750	432,360
AliceVision	157/157	167,825	320/320	310,209	390/390	415,793	750/750	626,724
VisualSfM	155/157	38,627	315/320	83,186	385/390	155,330	741/750	241,478
RealityCapture	157/157	126,010	320/320	230,347	390/390	273,539	750/750	373,528
Metashape	157/157	**393,674**	320/320	**711,808**	390/390	**785,513**	750/750	**905,815**
Pix4Dmapper	157/157	202,820	320/320	381,824	390/390	538,017	750/750	627,919

(Jiang et al., 2020)

Underwater Spiral Survey Method

Anchor a central point, work in pairs, mount cameras on axis, shoot in a spiral path





(Bayley et al., 2020)

Underwater Survey Comparison

Why I prefer lawn-mowing method:

- The lawn-mowing method can be operated by just 1 people
- Spiral method makes bearing and relative positioning harder
- A square grid avoids area loss and eases mosaicking

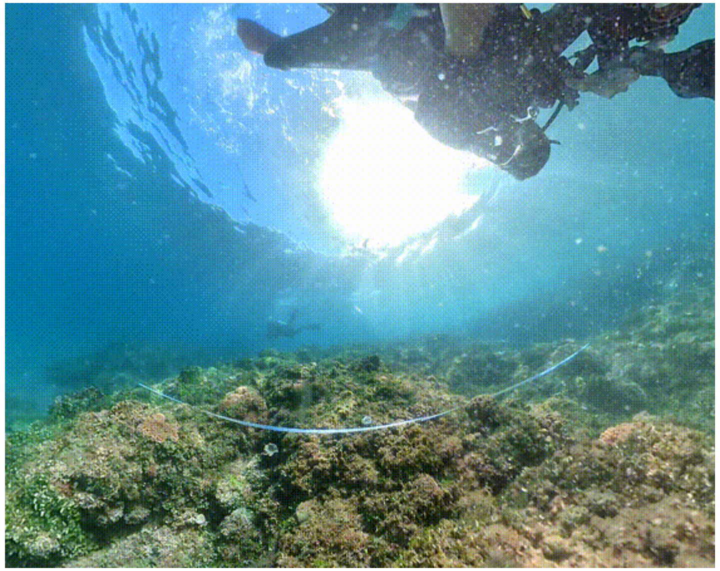


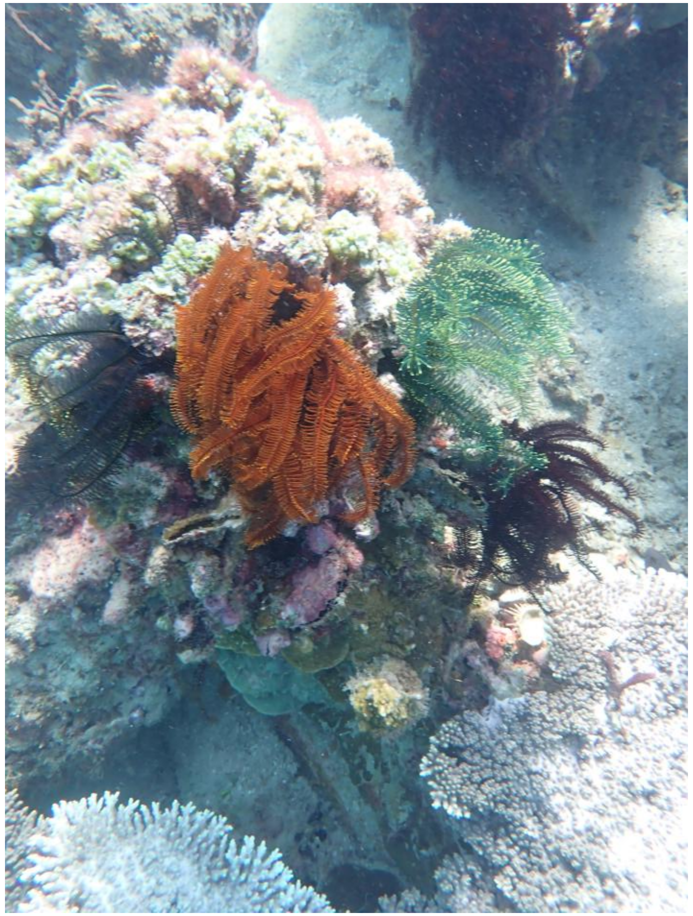
Table 2. Qualitative comparison between a “mow the lawn” and spiral surveys for contiguously covering an area with overlapping imagery

Parameter	“Mow the lawn” survey	Spiral survey
Equipment	Two parallel lines fixed to substrate marking the start and end of each parallel leg, one guide line held by assistants and followed by swimmer. Stakes or similar to fix parallel lines	Pole with drum and line. Star picket and hammer
Preparation effort	**High.** Lay visual guides for two parallel sides of box (10–30 min)	**Low.** Drive star picket and fasten pole (1–2 min) Drive star picket and fasten pole (1–2 min)
Skill level of swimmer	**High.** Keep constant distance to guide line while swimming in a straight line, turn 180° at end of each line	**Low.** Swim forward and keep tension. Unclip camera from line once fully uncoiled
Skill level of assistants	**High.** Maintain constant step size between tracklines, coordinate with assistant at other end of guide line to move same amount when swimmer completes a trackline, keep guideline over same place in the presence of currents and waves	**Low.** Keep pole roughly vertical. Remove pole once line is uncoiled from drum and exit survey area with pole and line
Reliability	**Low.** Difficult to achieve tight trackline spacing. Prone to gaps across parallel tracklines, loss of synch between assistants resulting in lines that are no longer parallel	**High.** Robust to swell and currents. Easy to achieve tight trackline spacing using narrower drum

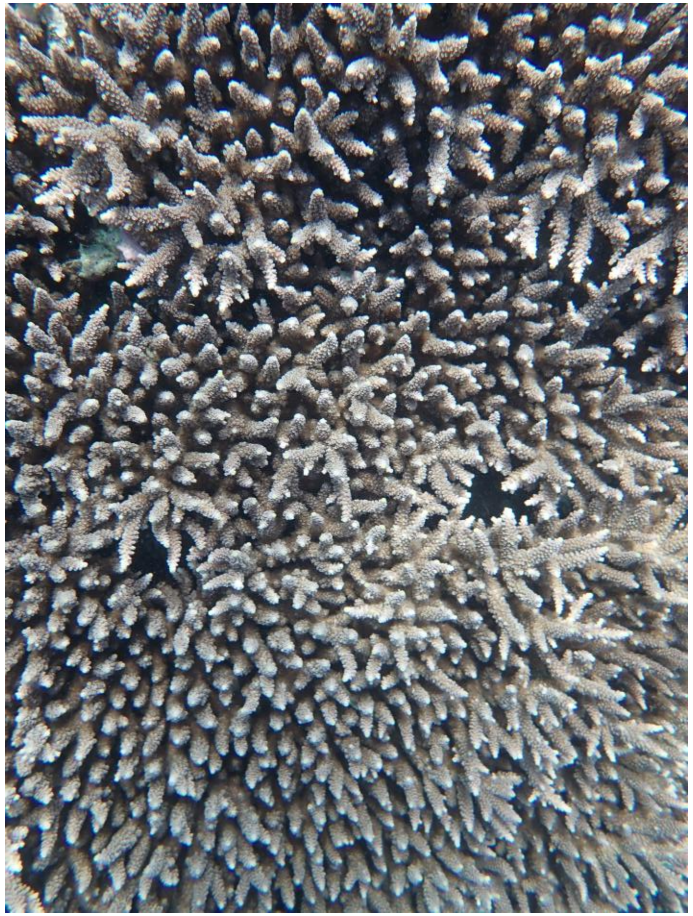
(Pizarro et al. 2017)

Suitable vs. Unsuitable Environments

Sandy substrates and highly mobile organism (algae, soft corals)



Repetitive geometry (extensive branching coral)



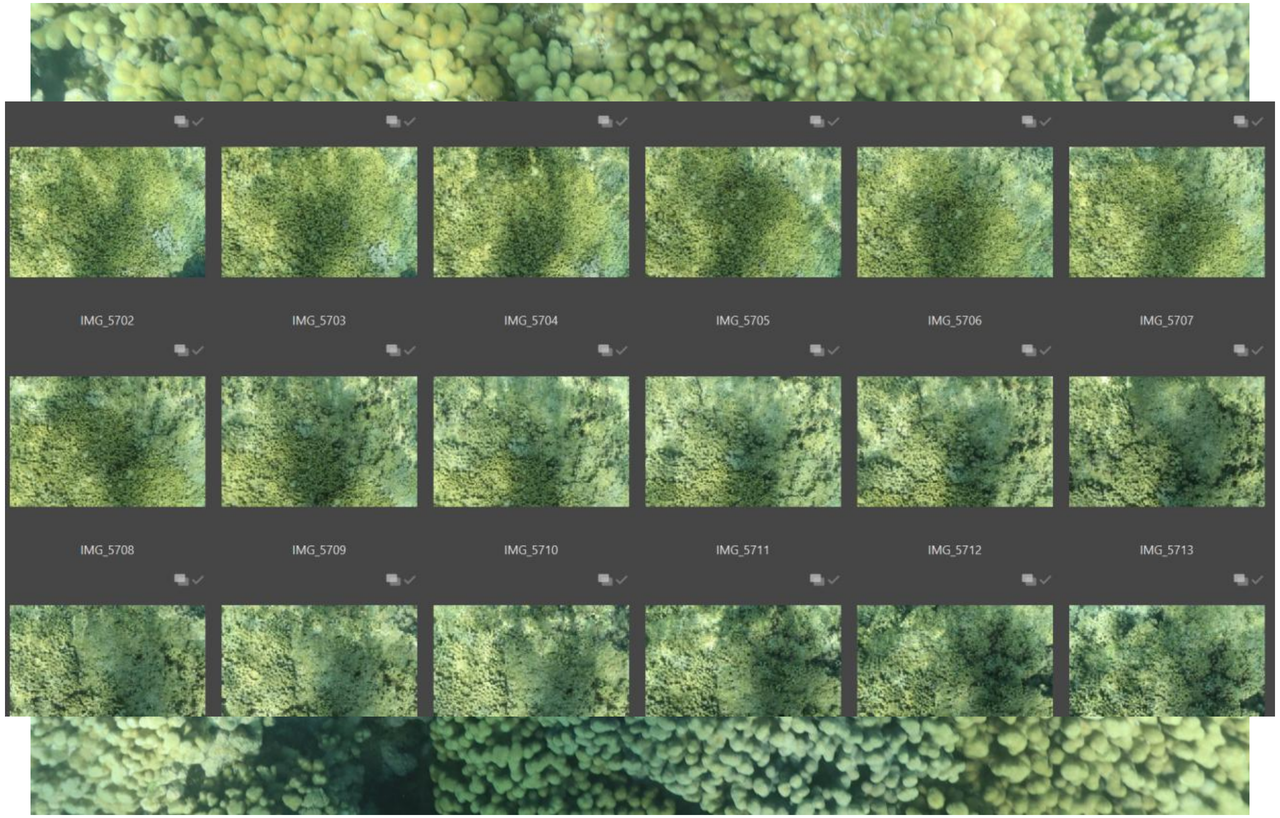
Consider adding artificial markers to introduce key features

Suitable vs. Unsuitable Environments

Keelung 基隆

Insufficient lighting: pick an optimal time of day, or move closer to the subject.

Hawaii 夏威夷



Excessive lighting: avoid shooting at noon, or position the camera further from the torso.

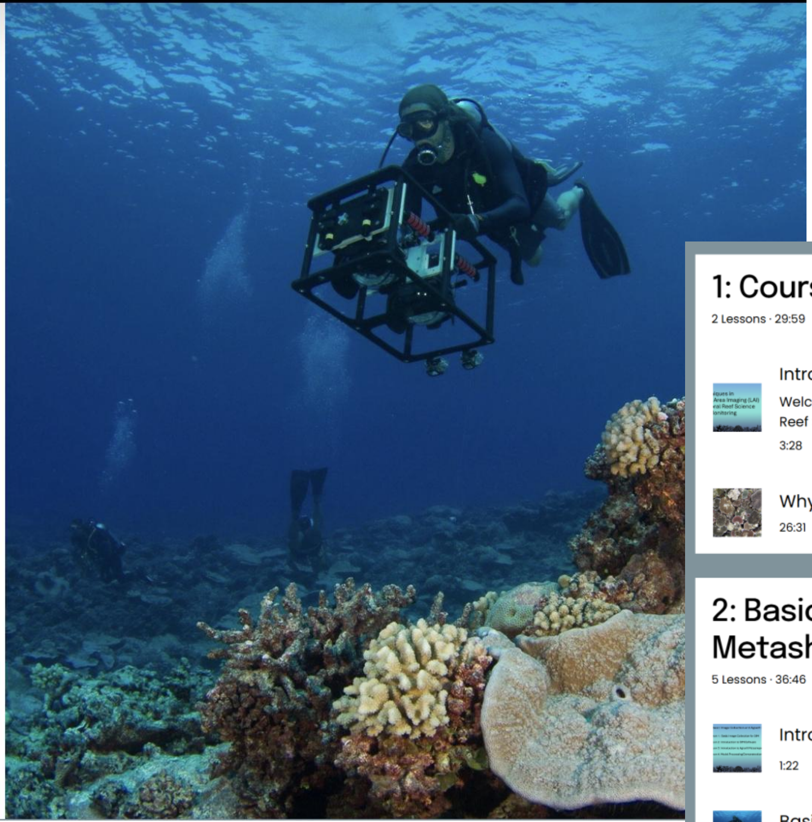
Relevant Learning Resources 1/3

LAI NETWORK   Course   Resources   Connect

Large-Area Imaging Network

The Large-area imaging (LAI) Network is founded to provide community resources for mapping coral reefs. Technological innovations have offered new avenues for describing, archiving, and sharing information about the composition and structure of the world's coral reefs. However, access to these technologies are not broadly available.

The LAI Network offers a working environment for sharing information about image-based mapping, including access to training materials, data, and a community of practitioners with shared interests. We welcome you to learn more about LAI and to join our network, as we strive to accelerate our efforts of coral reef monitoring, management, and restoration worldwide.



1: Course Introduction

2 Lessons · 29:59

- Introduction to Chapter 1
  Welcome to the "Techniques in Large-Area Imaging for Coral Reef Science and Monitoring" course!
  3:28
- Why are we here?
  26:31

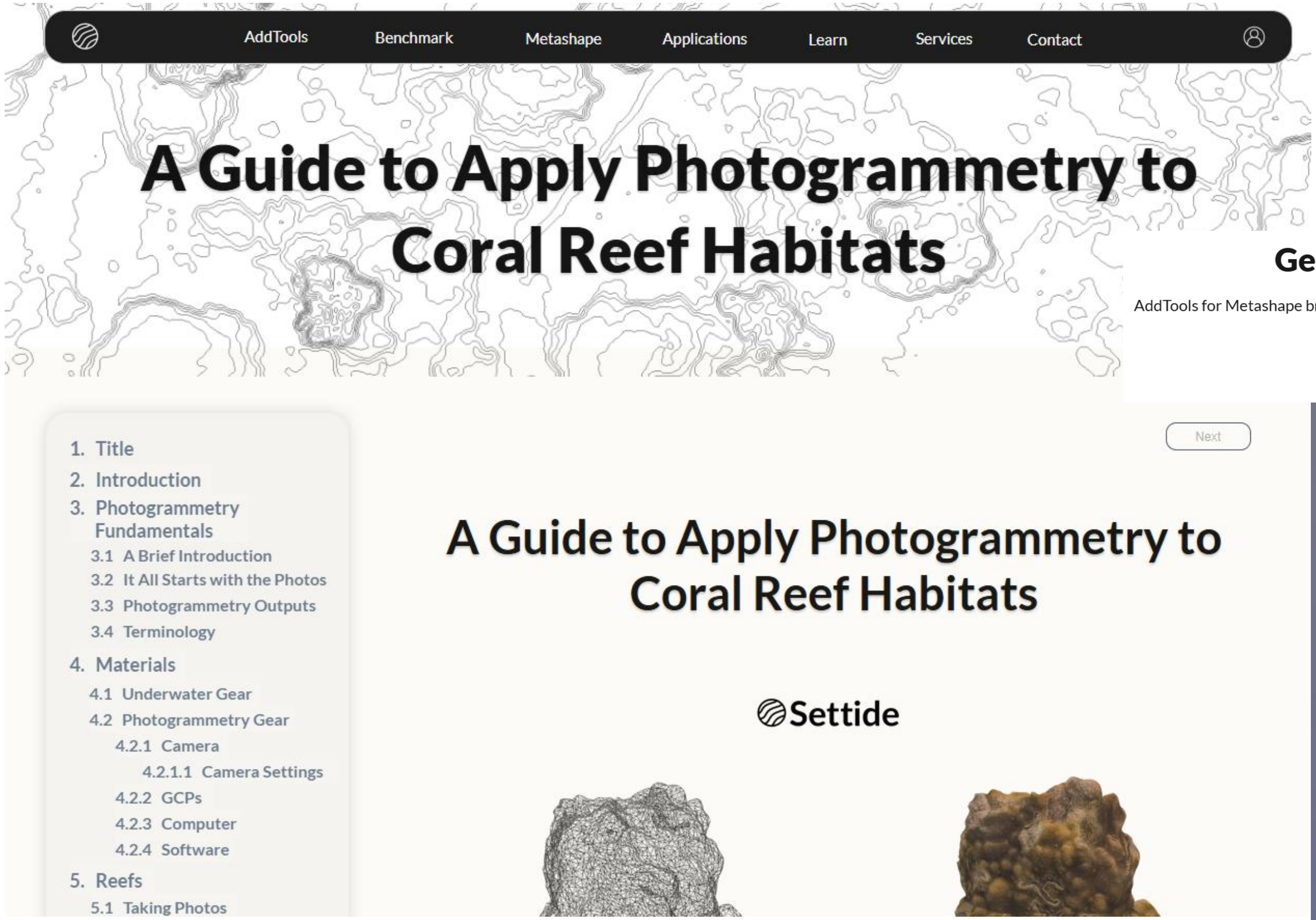
2: Basic Image Collection and How to Use Agisoft Metashape

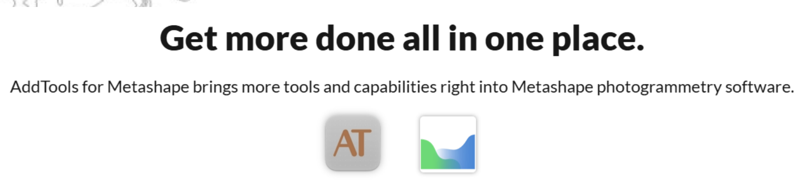
5 Lessons · 36:46

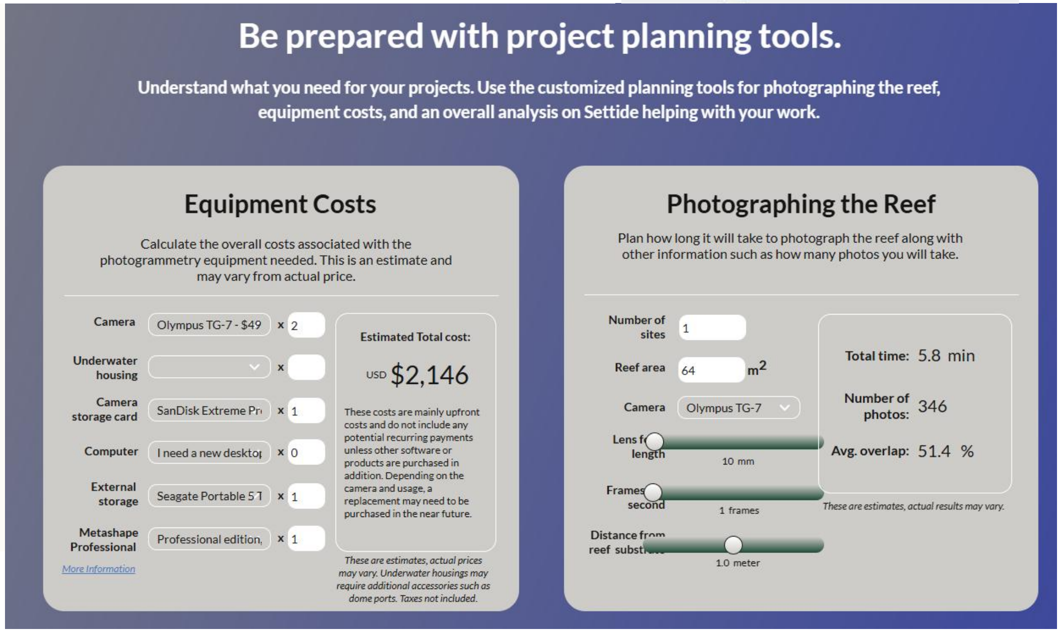
- Introduction to Chapter 2
  1:22
- Basic Image Collection for SfM
  5:13

https://www.lai-network.org/

Relevant Learning Resources 2/3

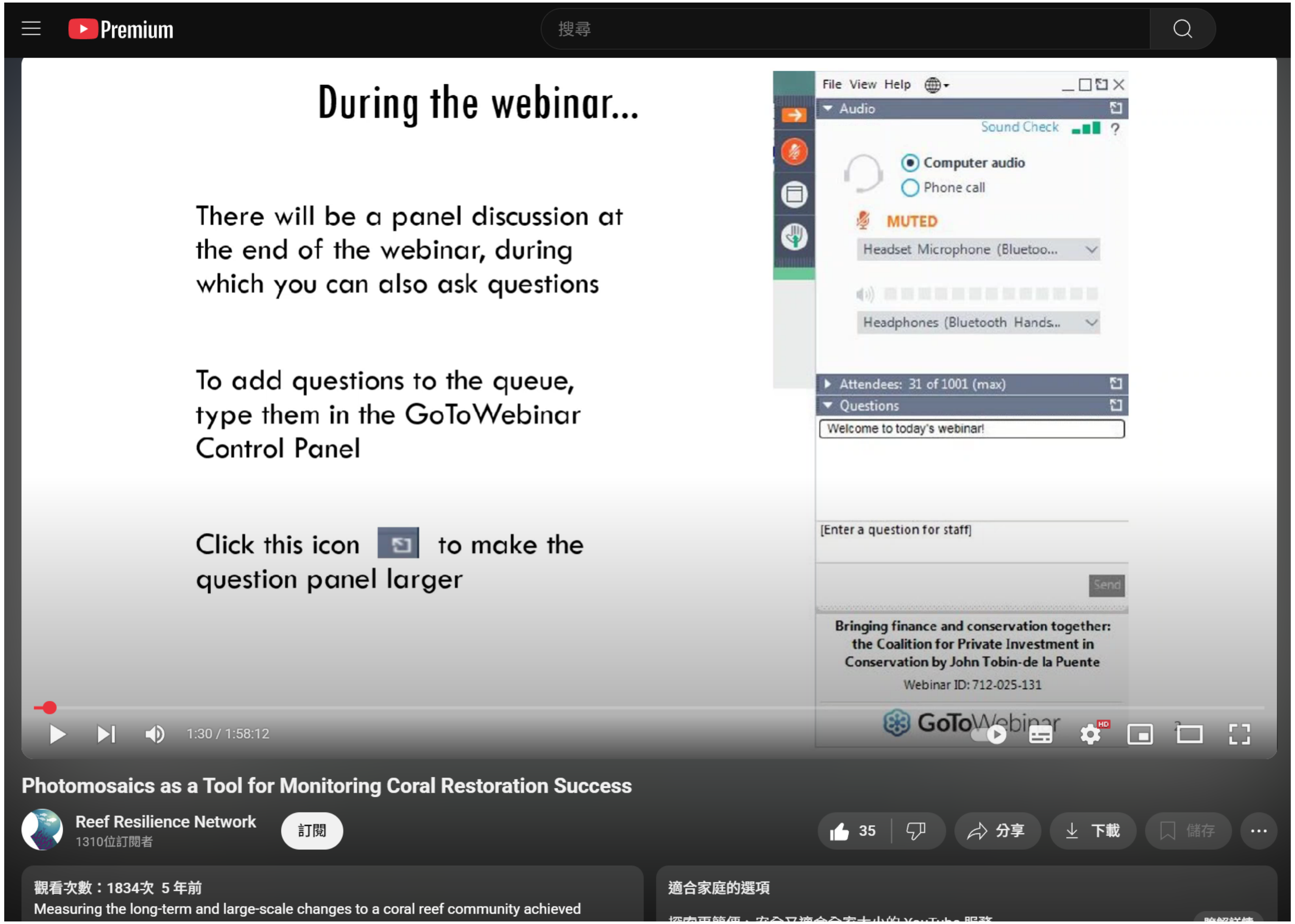






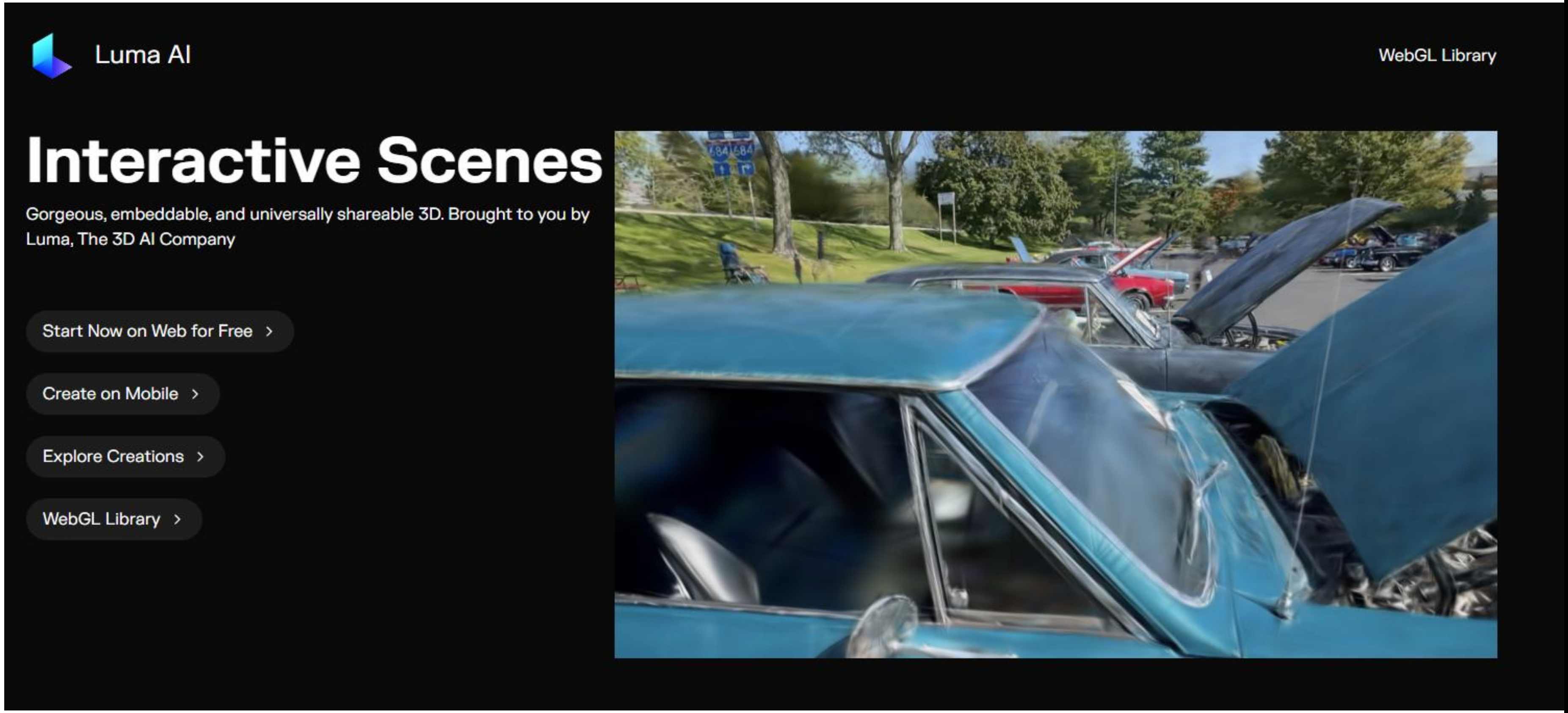
[Settide - Guide to Apply Photogrammetry to Coral Reef Habitats](https://settide.com/coral-reef-habitats-guidebook)
https://settide.com/coral-reef-habitats-guidebook

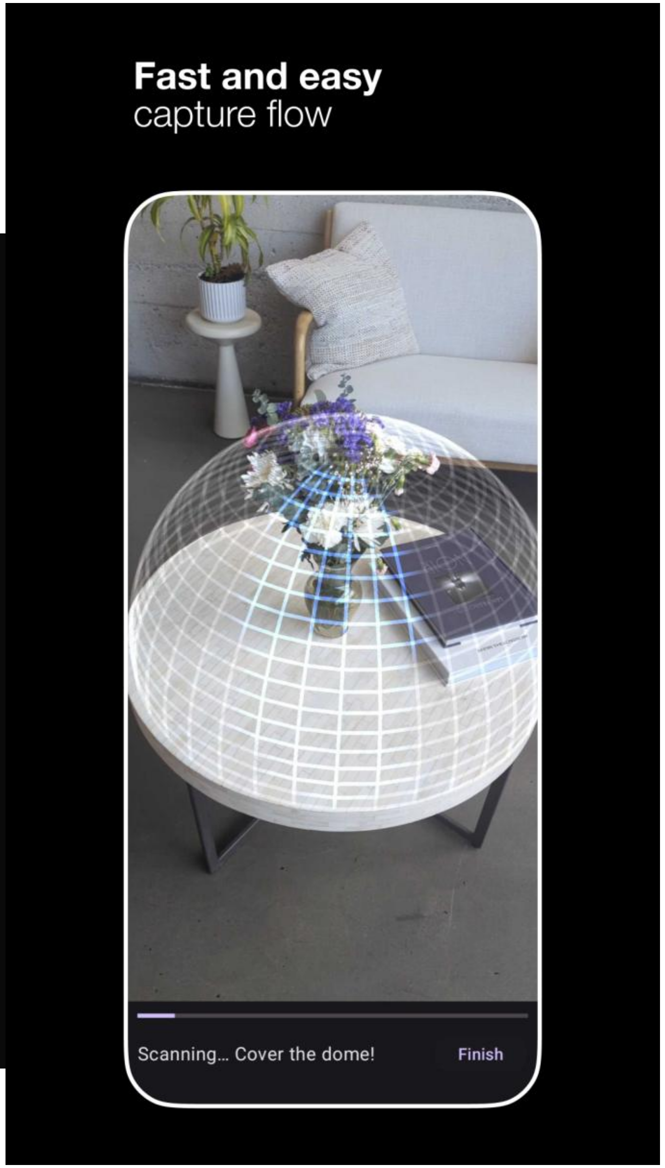
Relevant Learning Resources 3/3



https://www.youtube.com/watch?v=7T5XvNHbdSk&t=6218s&ab_channel=ReefResilienceNetwork

Build 3D models on phone

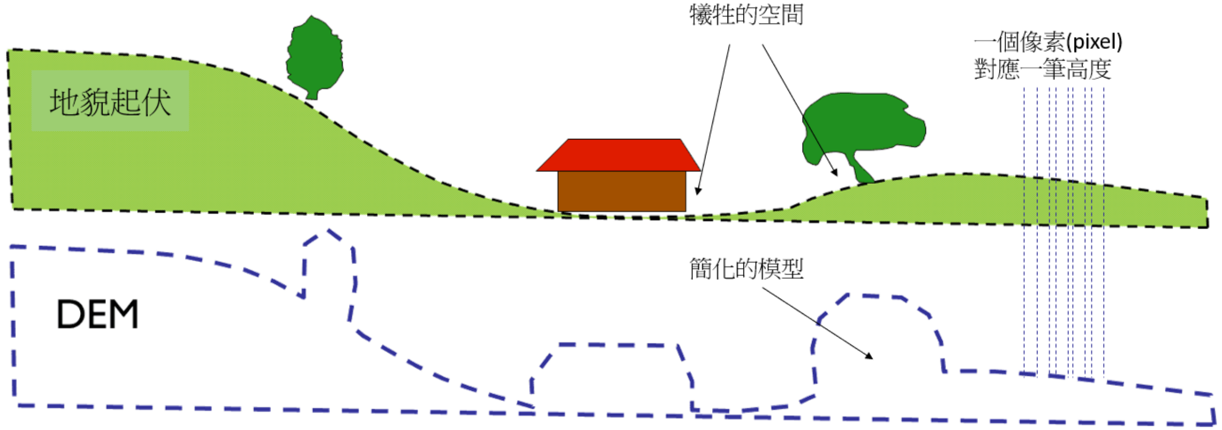




https://lumalabs.ai/interactive-scenes

3D Outputs – DEM & Orthomosaic

- Simplified 2.5D DEM enhance analysis efficiency over large areas and standardize workflows (usable meshes require more photos and post-processing)



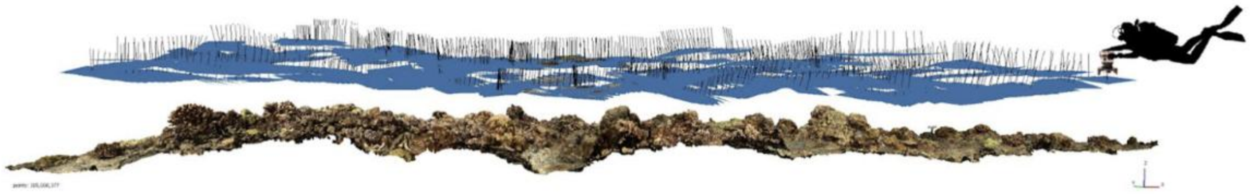
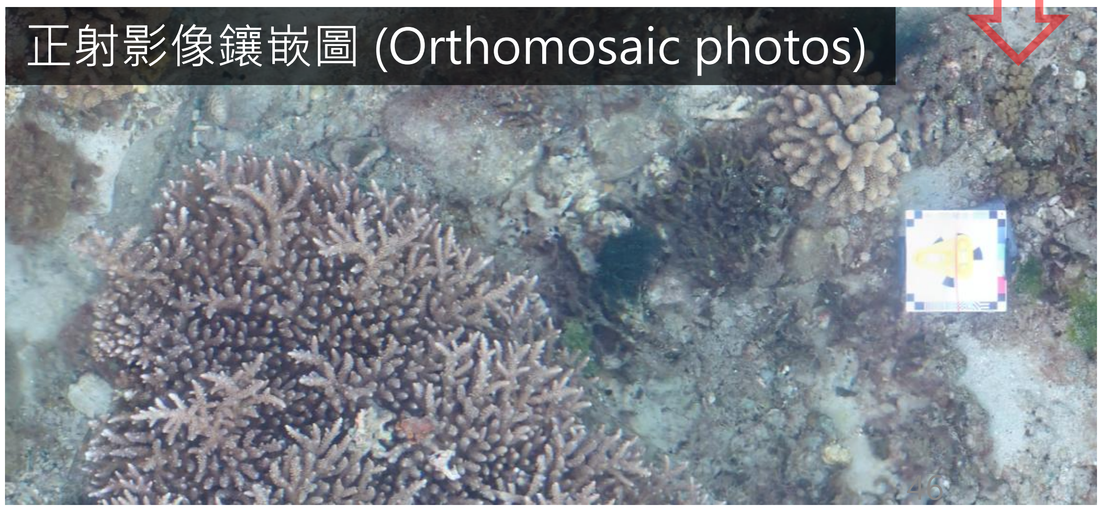


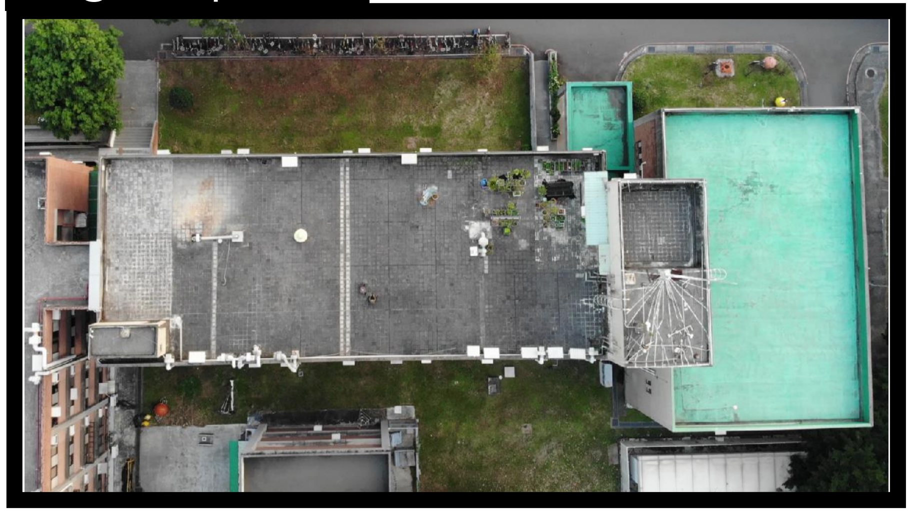
Figure 2.6 Side view of a SfM-derived model showing camera poses (blue) and orientation (black lines). The estimated camera poses recreate the diver's swim path position and height during data collection. Height variation also shows how closely the diver followed the reef's contour at 1m distance above the substrate.

(Damaris et al., 2024)



Advantages of 3D monitoring

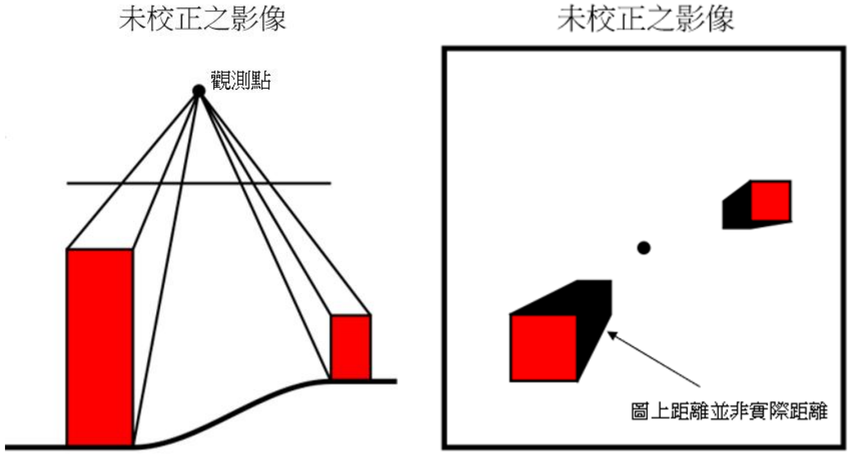
Regular photo

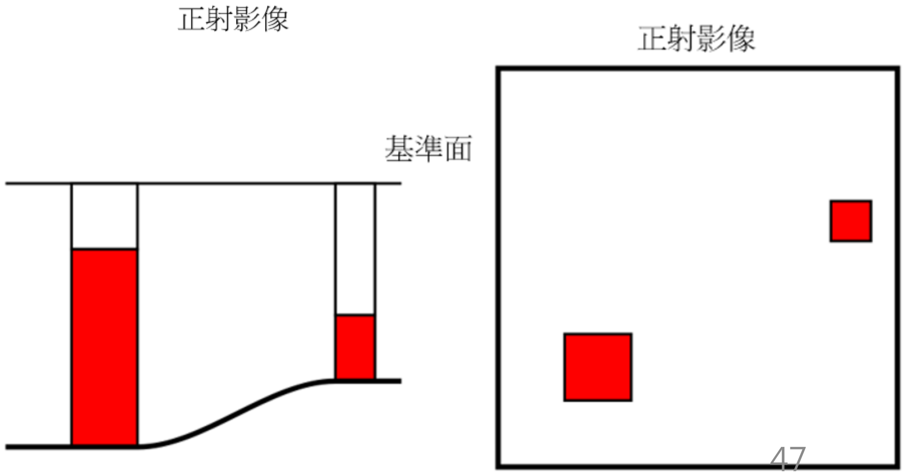


Orthomosaic derived from 3D

Enables accurate calculation of projected areas

Object depth and camera angle have no impact on measurement

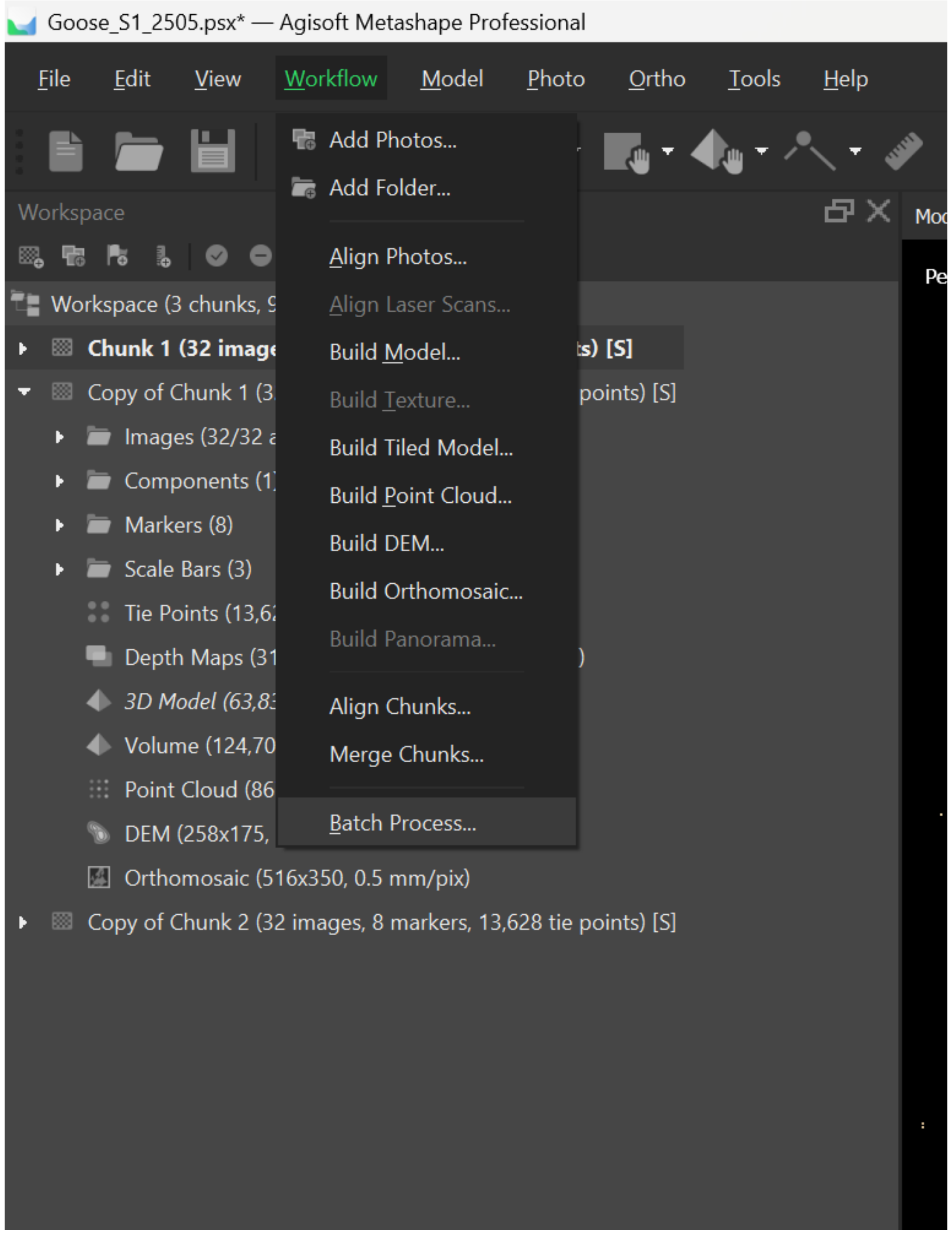


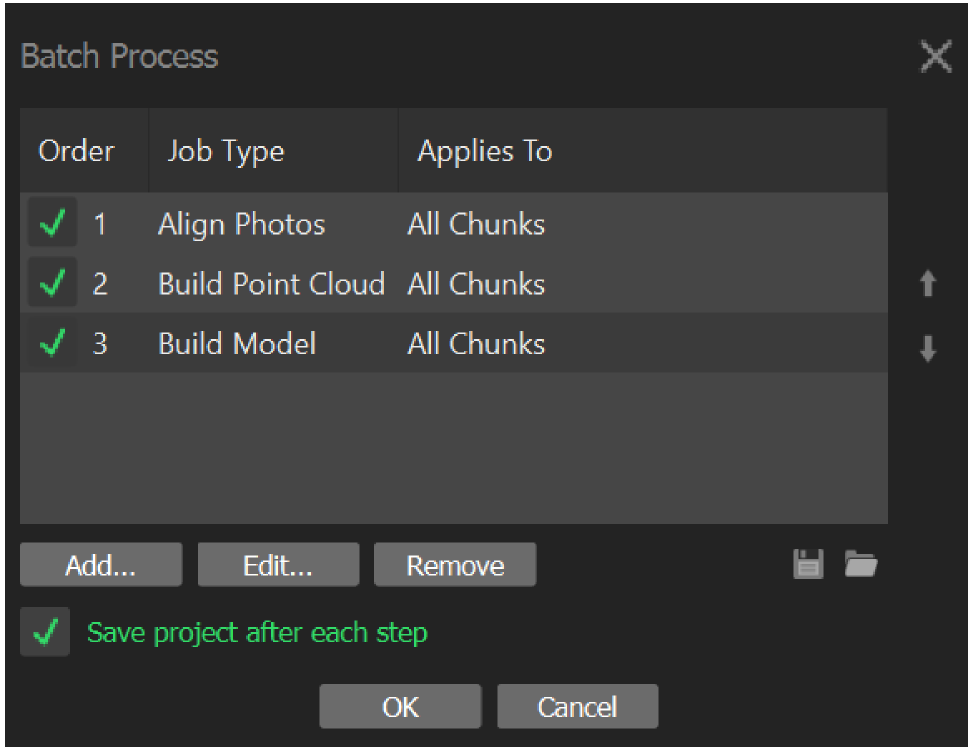


Q&A

回家作業 照群體尺度的方法 建立棲地尺度的3D模型

Homework: Build a habitat-scale 3D model using the same method as for colony-scale


Goose_S1_2505.psx* — Agisoft Metashape Professional
File
Edit
View
Workflow
Model
Photo
Ortho
Tools
Help
Add Photos...
Add Folder...
Align Photos...
Align Laser Scans...
Build Model...
Build Texture...
Build Tiled Model...
Build Point Cloud...
Build DEM...
Build Orthomosaic...
Build Panorama...
Align Chunks...
Merge Chunks...
Batch Process...
Workspace
Workspace (3 chunks, 9
Chunk 1 (32 image
ts) [S]
Copy of Chunk 1 (3
points) [S]
Images (32/32 a
Components (1
Markers (8)
Scale Bars (3)
Tie Points (13,62
Depth Maps (31
3D Model (63,83
Volume (124,70
Point Cloud (86
DEM (258x175,
Orthomosaic (516x350, 0.5 mm/pix)
Copy of Chunk 2 (32 images, 8 markers, 13,628 tie points) [S]


Batch Process
Order
Job Type
Applies To
1
Align Photos
All Chunks
2
Build Point Cloud
All Chunks
3
Build Model
All Chunks
Add...
Edit...
Remove
Save project after each step
OK
Cancel

https://github.com/keelungchen/Agisoft_workflow/tree/main

Agisoft_workflow / code / agisoft_clean_points_script.py

keelungchen add independent clean points

Code Blame 121 lines (102 loc) · 4.7 KB

```python
import Metashape
import os
import pandas as pd

# 定義根資料夾路徑
base_folder = r"F:\Kenting field trip 2412"

# 定義比例尺資訊路徑
scale_bar_file = r"F:\Kenting field trip 2412\scale_bars.xlsx"
# 讀取比例尺與資訊
scale_bar_data = pd.read_excel(scale_bar_file)

doc = Metashape.Document()
doc.open(project_path)
chunk = doc.chunk

# 檢查專案狀態，例如相機數量和照片對齊狀態
print(f"相機數量: {len(chunk.cameras)}")

# Step 6: Gradual Selection and Remove Points (逐步選擇並刪除點)
# 在稀疏點雲中執行逐步選擇，選取誤差較大的點，level 設定為 16
f = Metashape.TiePoints.Filter()
f.init(chunk, criterion=Metashape.TiePoints.Filter.ReconstructionUncertainty)
f.selectPoints(threshold=16)
# 刪除選取的點
chunk.tie_points.removeSelectedPoints()
doc.save()

# 優化對齊
chunk.optimizeCameras(fit_f=True, fit_cx=True, fit_cy=True, \
```

Python 3 Module

Python module for the previous Metashape version.

Windows

macOS

Linux

Solution home / F.A.Q. / Python scripting

How to install Metashape stand-alone Python module

Print

Modified on: Mon, 4 Mar, 2024 at 5:35 PM

The *stand-alone Metashape Python* module allows to integrate Metashape functionality to the custom scripts without a need of full application installation.

- Installation
  - on Windows (64-bit)
  - on Linux
  - on macOS
- Activation
- Offline activation

https://agisoft.freshdesk.com/support/solutions/articles/31000148930-how-to-install-metashape-stand-alone-python-module

Installation

First, ensure that you have *Python 3.5, 3.6, 3.7, 3.8, 3.9, 3.10 or 3.11* installed on your system. After that download the .whl package from the following page:

Downloads - https://www.agisoft.com/downloads/installer/

Then install Metashape module as a regular wheel package. The procedure may be slightly different depending on the OS used:

on Windows (64-bit)

```
python3.exe -m pip install Metashape-2.1.0-cp37.cp38.cp39.cp310.cp311-none-win_amd64.whl
```