



國立中山大學
National Sun Yat-sen University

THE MCRAE



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



Processing Coral Reef Imagery Using Structure-from-Motion Photogrammetry: Standard Operating Procedures (2023 Update)

Damaris Torres-Pulliza, Jonathan Charendoff, Courtney Couch, Rhonda Suka, Andrew Gray, Frances Lichowski, Corinne Amir, Mia Lamirand, Mollie Asbury, Morgan Winston, Isabelle Basden, and Thomas Oliver



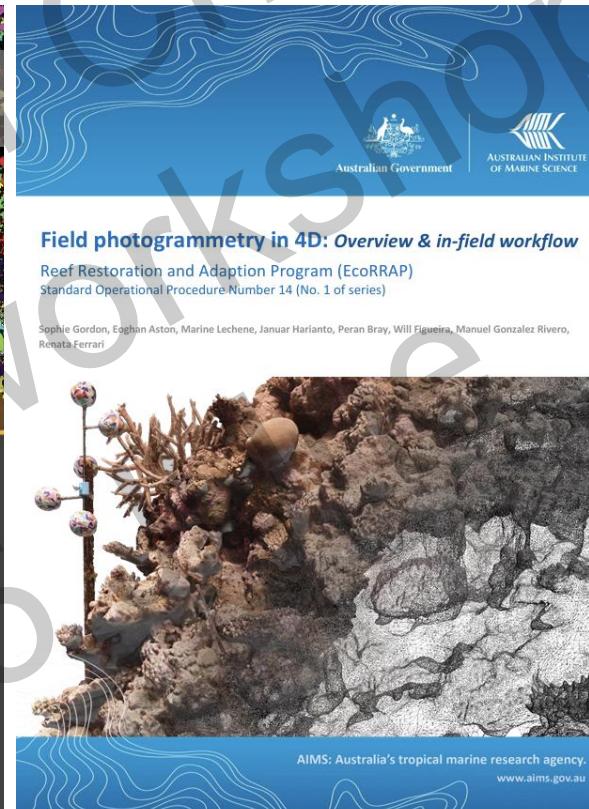
U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Pacific Islands Fisheries Science Center
NOAA Technical Memorandum NMFS-PIFSC-159
<https://doi.org/10.25923/cydz-z260>

April 2024

(Torres-Pulliza et al. 2024)



(Edwards et al. 2023)



(Gordon et al. 2023)



Large Area Imagery Collection & Processing
Standard Operating Procedures

Version 3.0



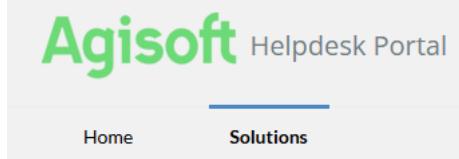
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www.100islandchallenge.org
www.sandinlab.ucsd.edu

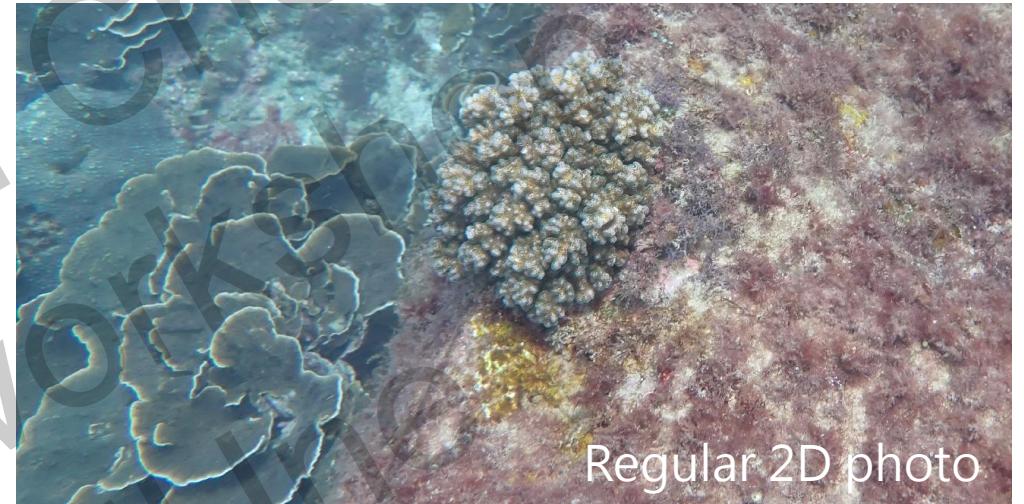
(Sandin et al. 2021)



Why Use 3D Surveys?



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



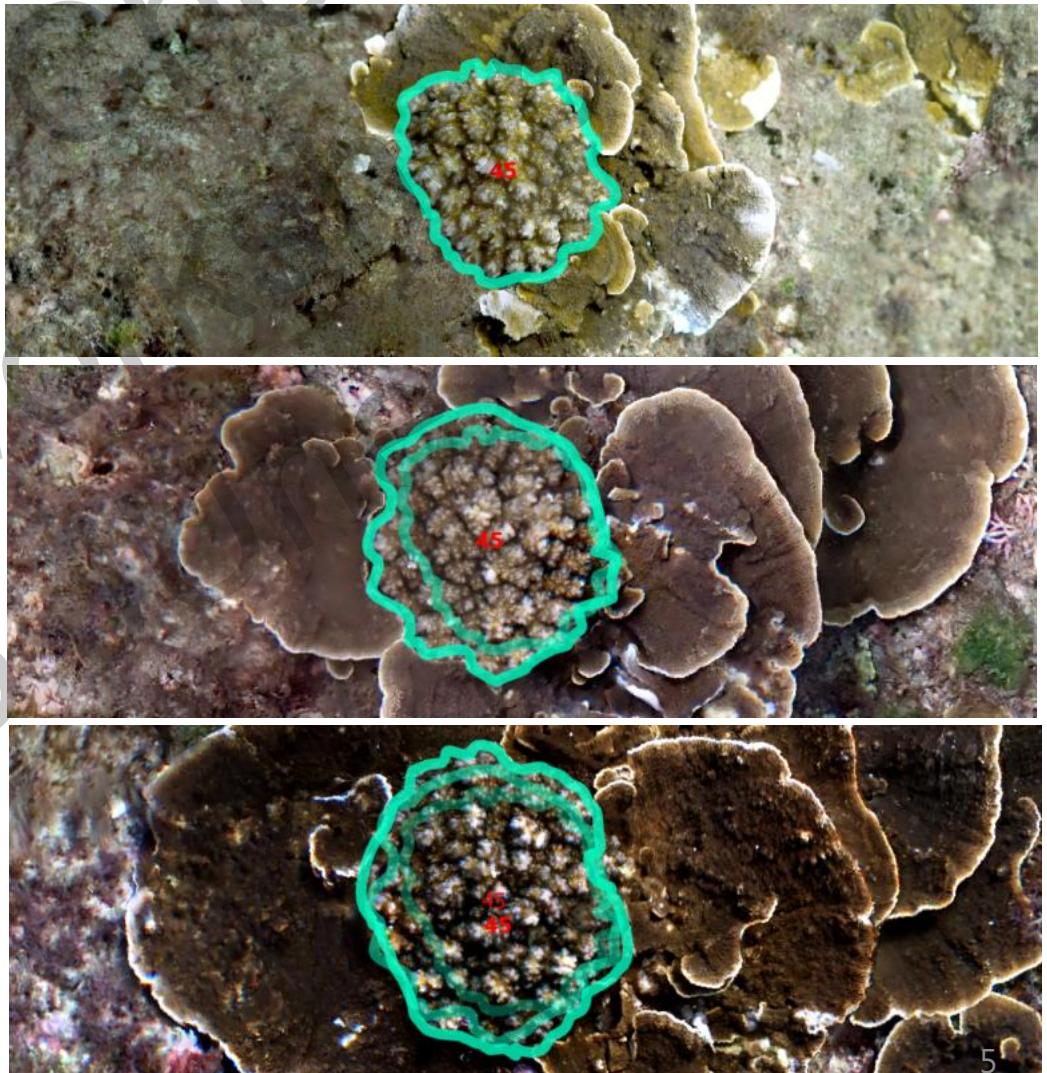
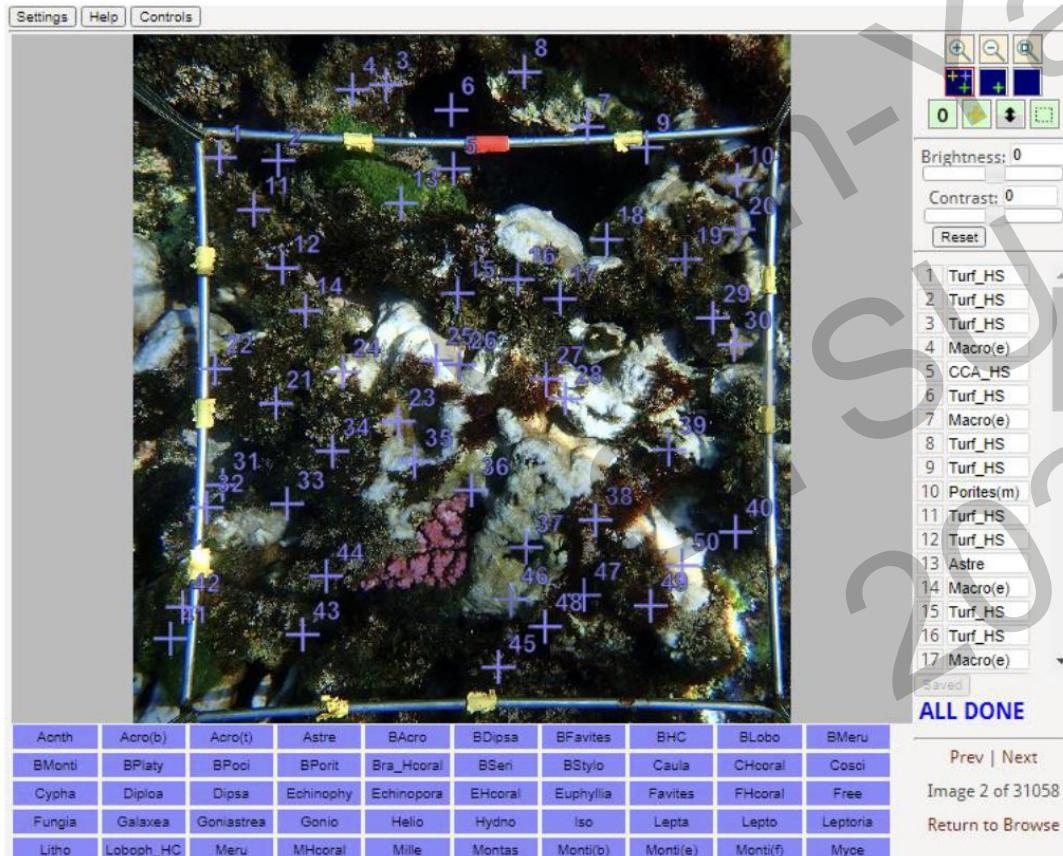
Regular 2D photo



Orthophoto derived from 3D survey

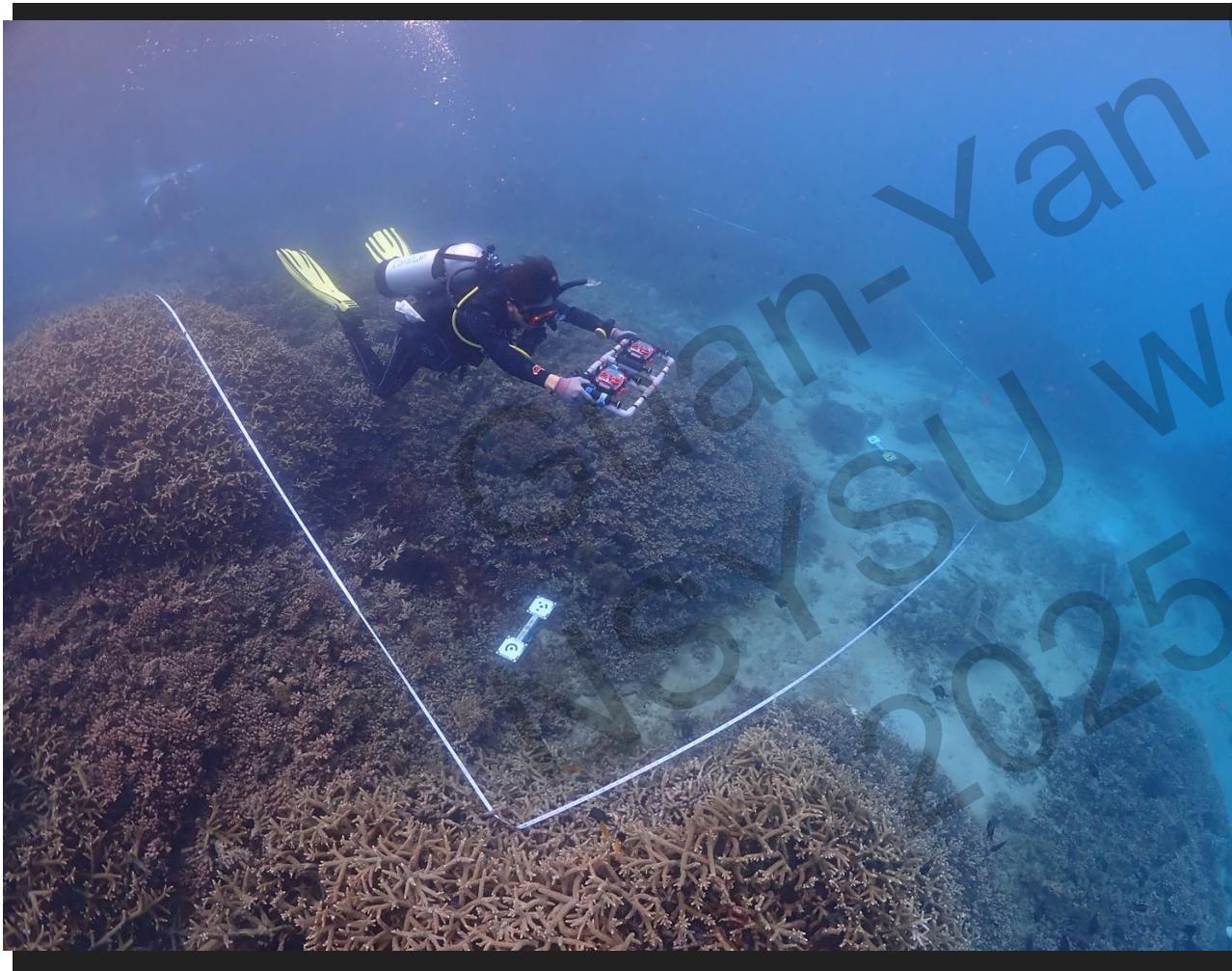
Why use 3D Surveys?

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



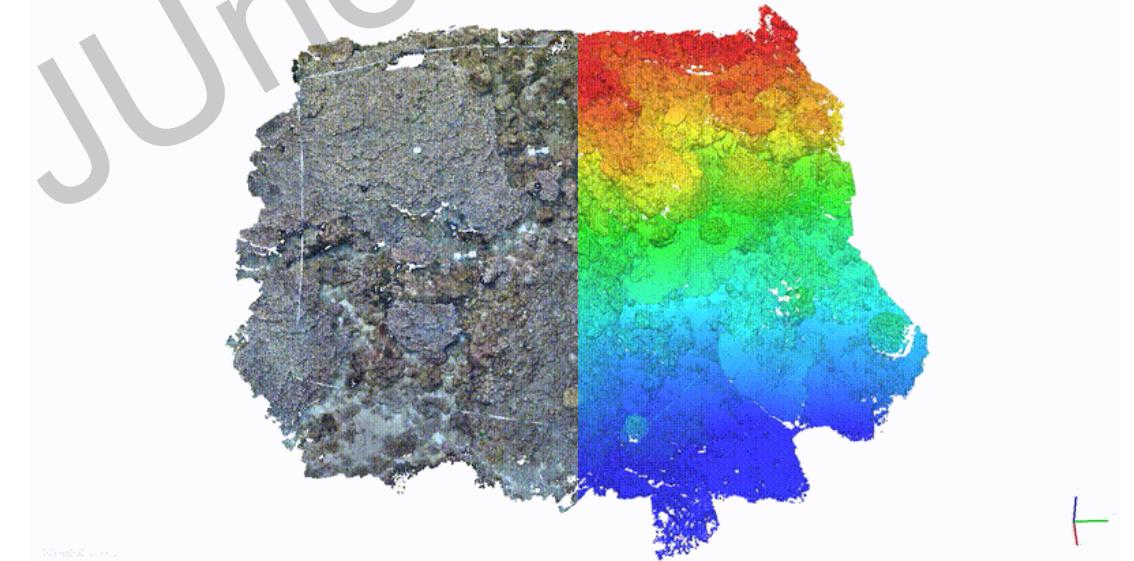
What Is a 3D Reef Survey?

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

Study location per proportion of instrument used

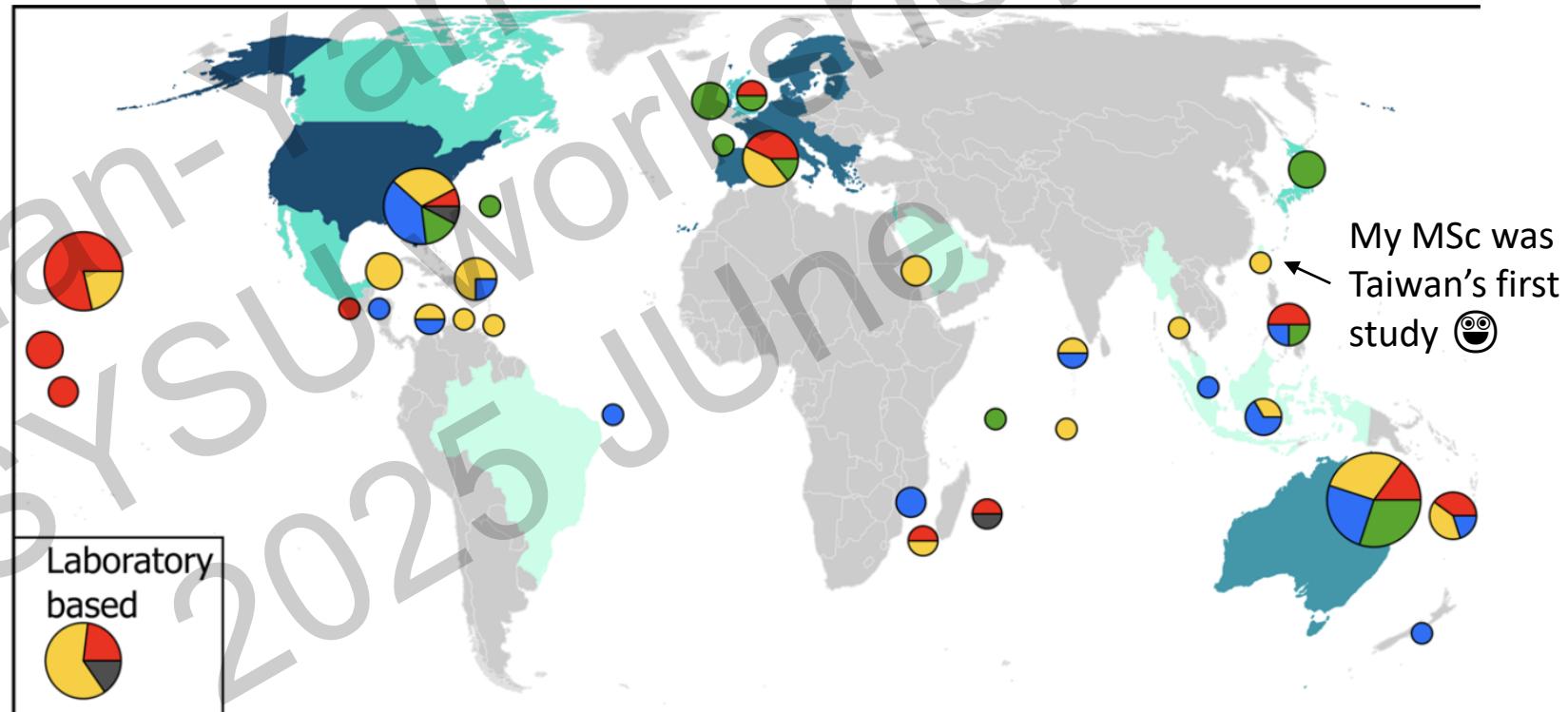
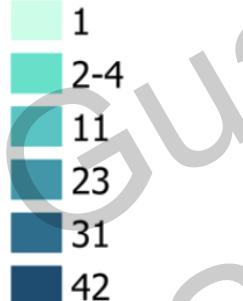
- High-cost
- Medium-cost
- Low-cost
- Remotely operated
- N/A

Number of papers per study location



Countries of funding

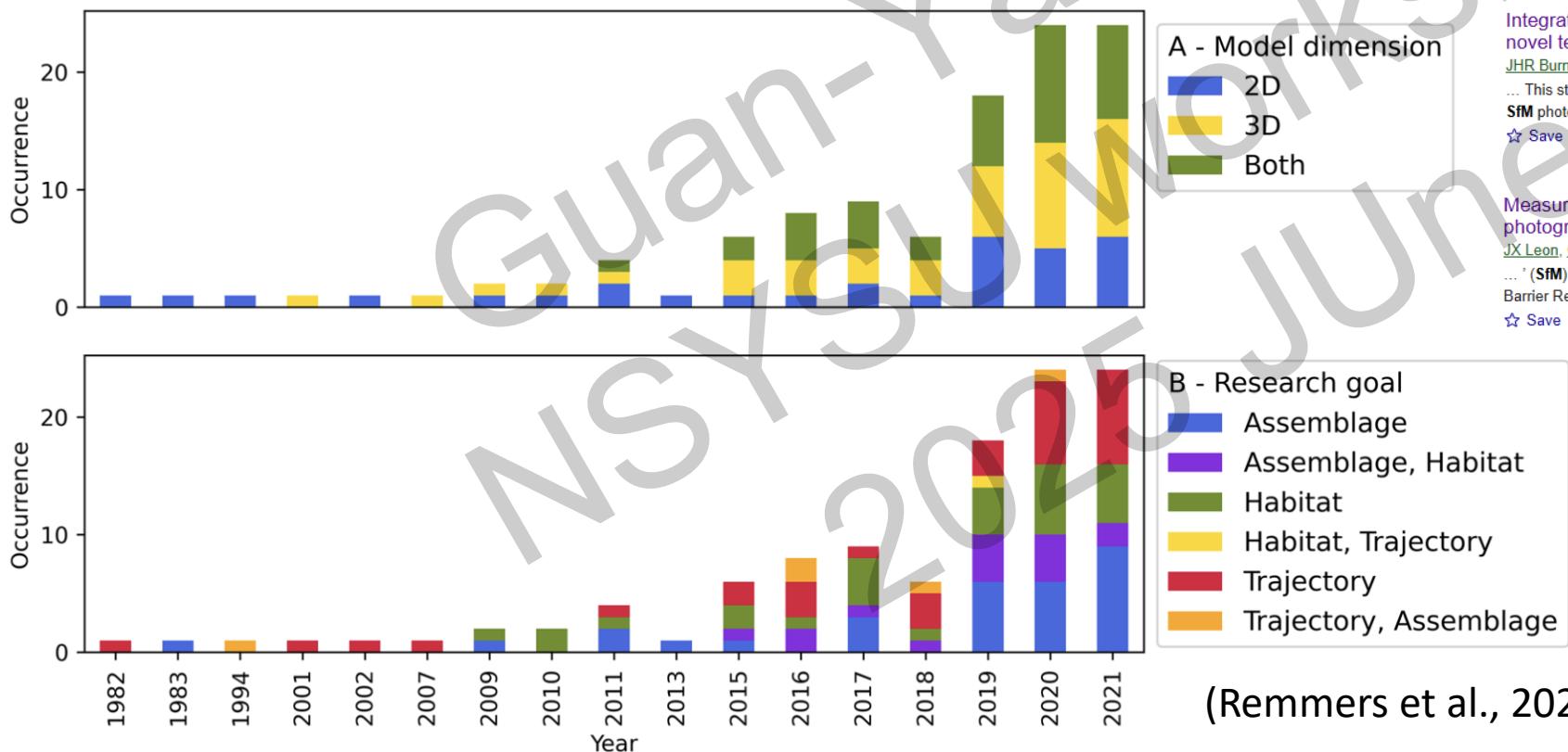
Number of research funded



(Remmers et al., 2024)

When Did 3D Surveys Become Popular?

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



Integrating structure-from-motion photogrammetry with geospatial software as a novel technique for quantifying 3D ecological characteristics of coral reefs
[JHR Burns, D Delaporte, 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 99 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 ...

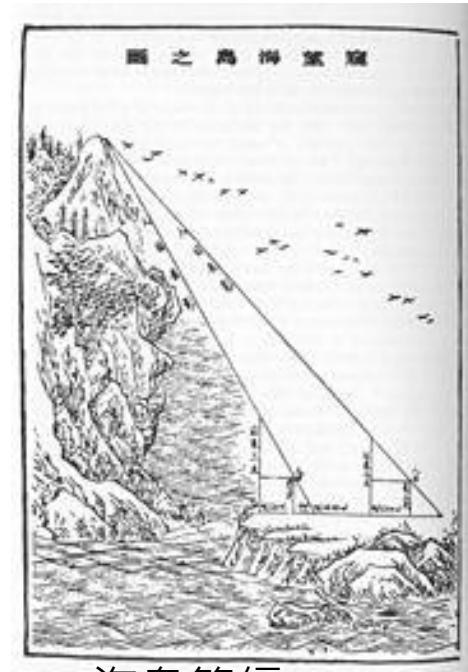
☆ Save 99 Cite Cited by 237 Related articles All 10 versions

(Remmers et al., 2024)

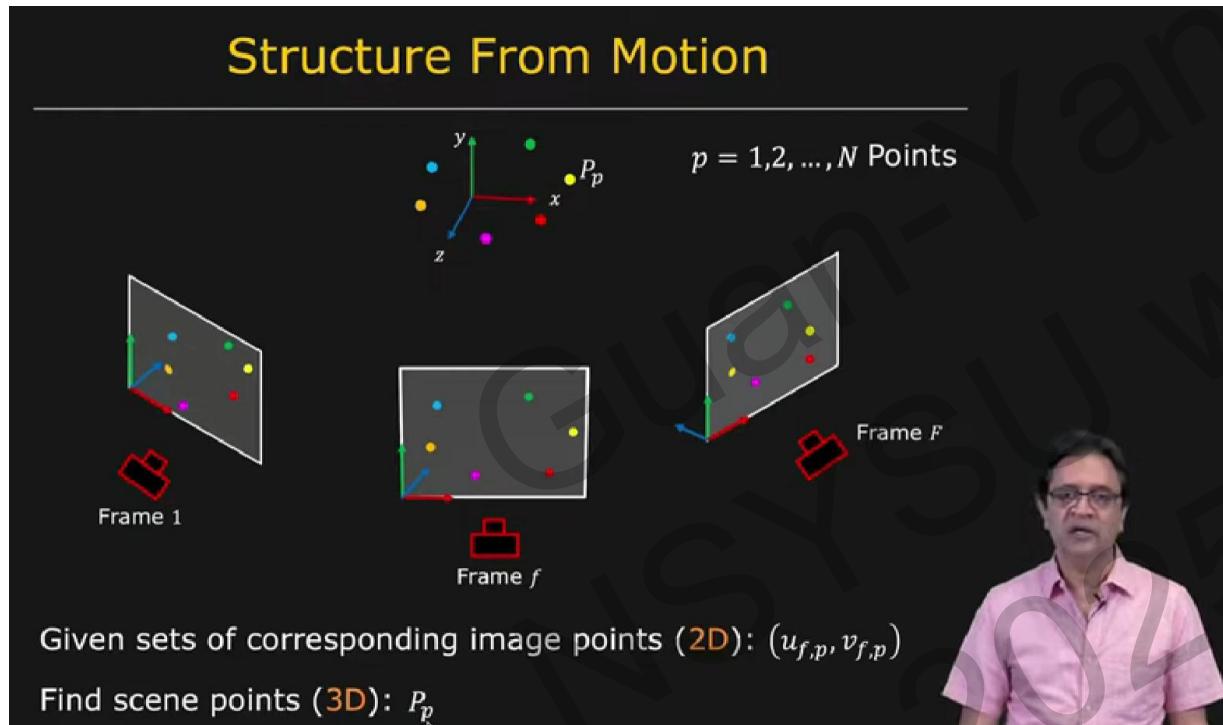
Using Imagery for 3D Modeling Is Not a New Concept



Old method: triangulation
needed known baselines



Principles of SfM-based 3D Reconstruction



https://www.youtube.com/watch?v=JlOzyhk1v0&list=PLKSXtGgYUdGwzZU18HpyLc_QUexFcE_Rr&index=16&ab_channel=FirstPrinciplesofComputerVision

Extract key points via multi-view photos

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.

**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

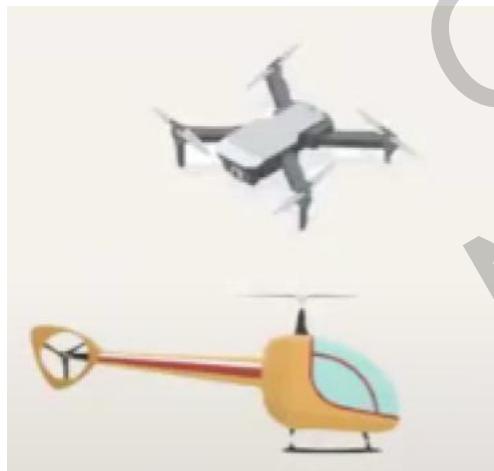
Because key points are redundant, partially obscured
still allows object reconstruction, and moving elements
can be distinguished from static ones.

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



Coral 3D survey in various scales

Branching & colony level

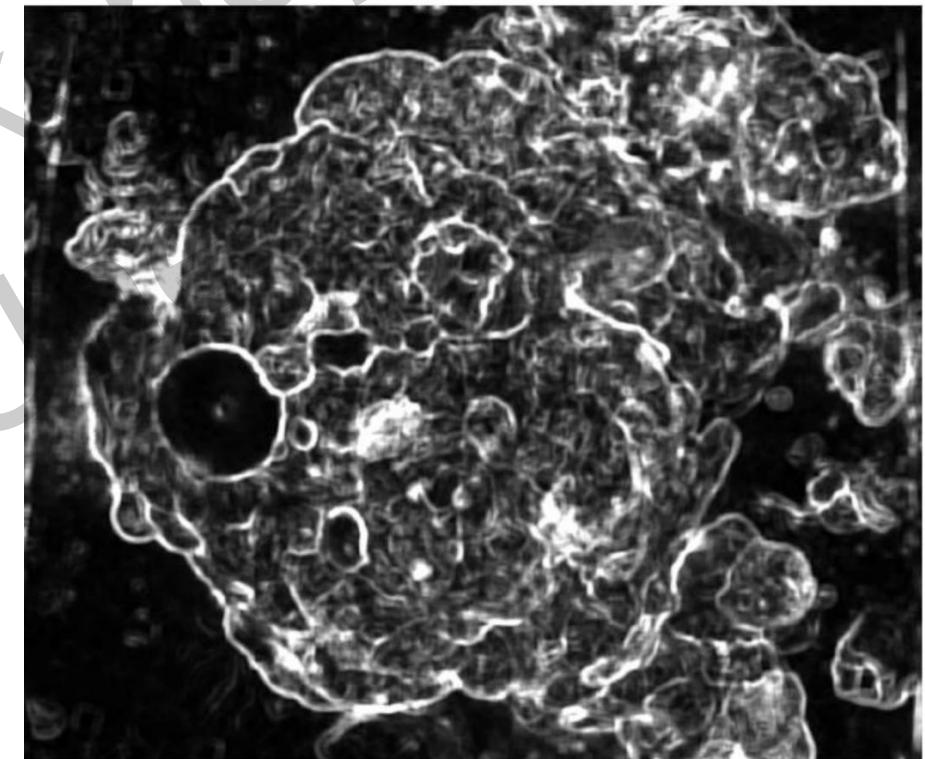


(葉宗旻, 2019)



(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)

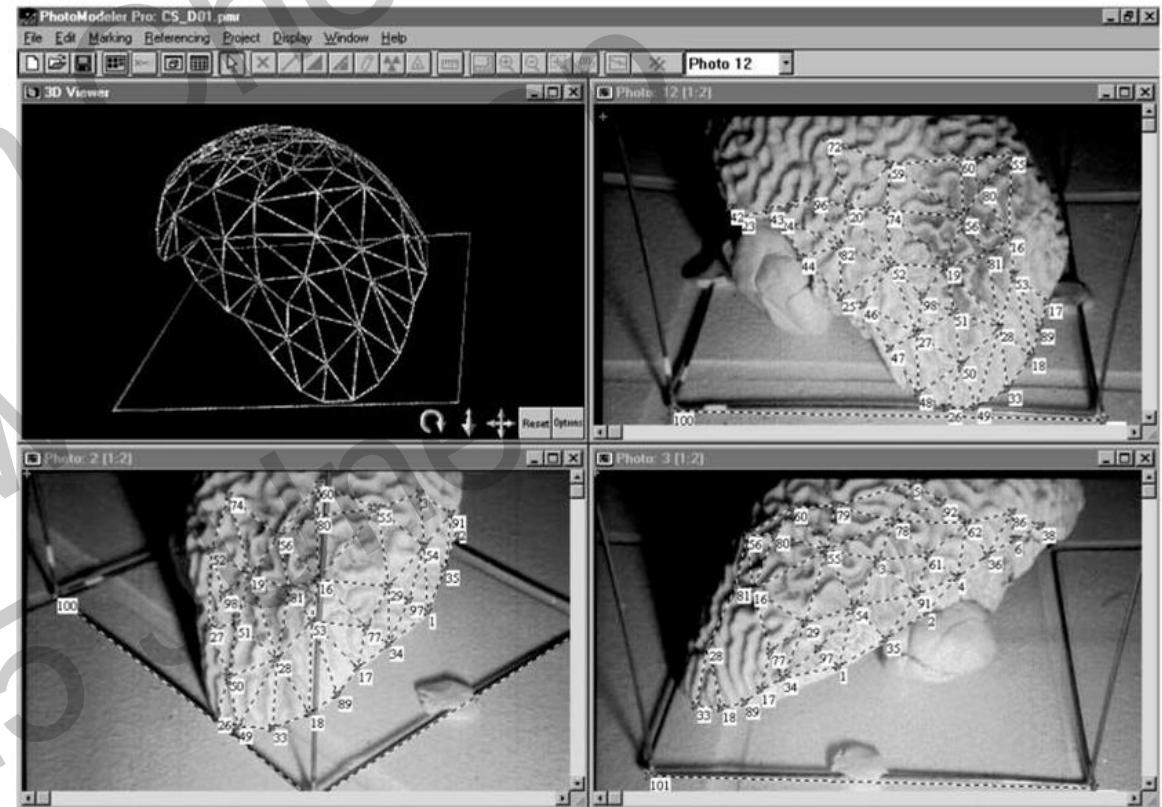


Fig. 1 Marking and referencing control points in PhotoModeler 3.0. Control points are tagged with a unique identifier and identical points on the object are cross-referenced in different photographs. For example, adjacent points 33, 28, and 18 appear in all three photographs. The processed, scaled model 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

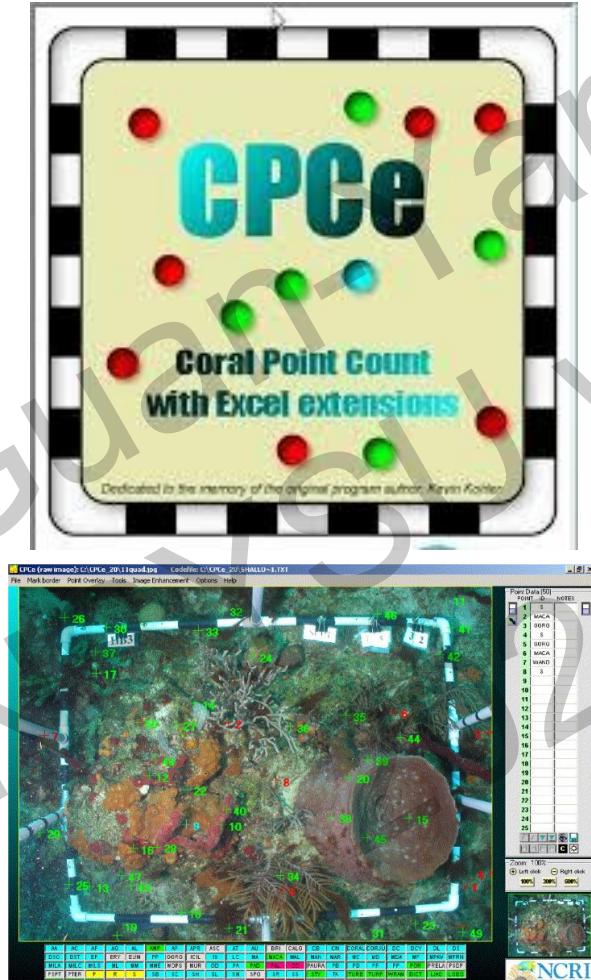
(Bythell et al., 2001)¹³

Evolution of Habitat-Scale Survey

- Line/Point Intercept Transect

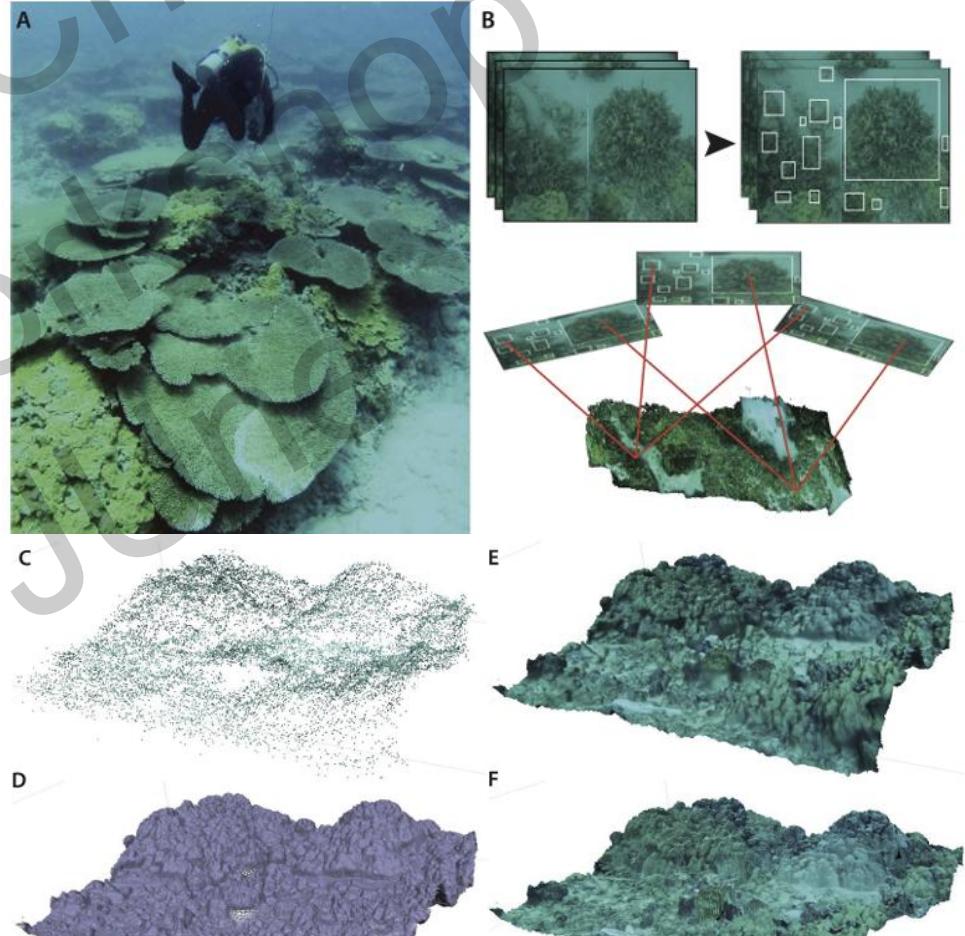


- Photoquadrat



(Kohler & Gill, 2006)

- 3D survey

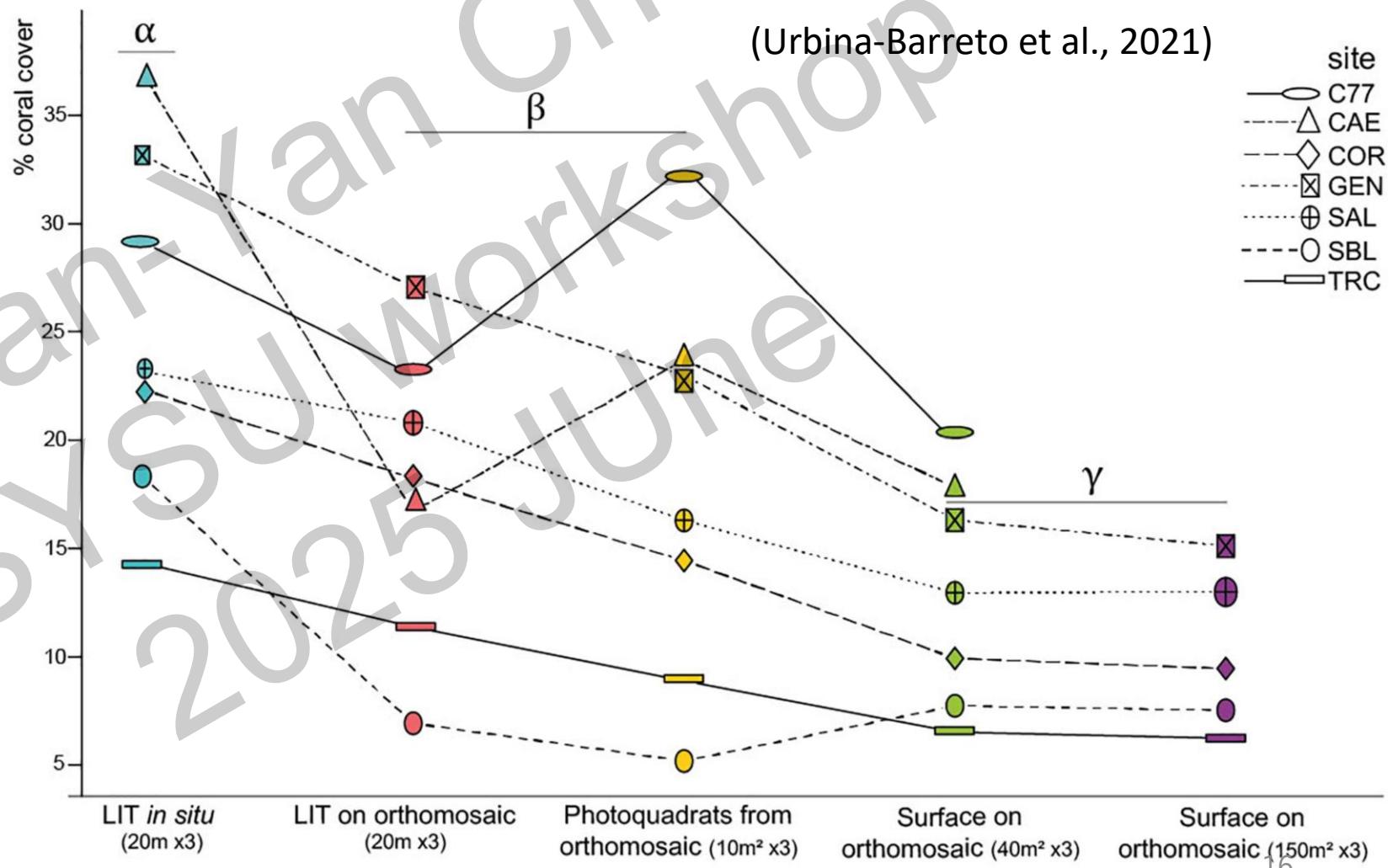


Data products comparison

| 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 | | | ✓ |

SfM vs. Traditional Coral Survey

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



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 |



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

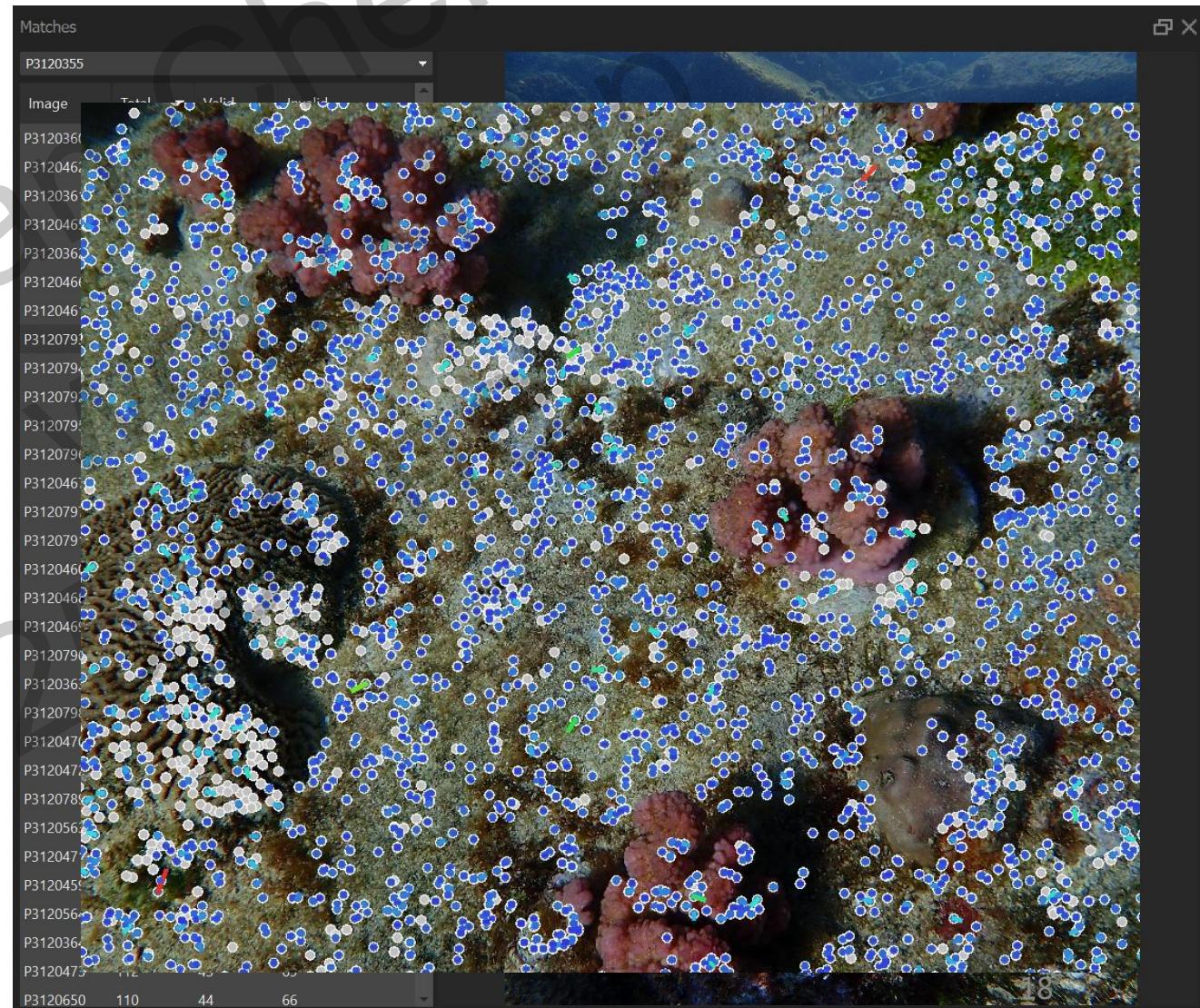
| | Canon EOS Rebel SL3 | GoPro Hero 7 |
|--|----------------------------|-------------------------------|
| Cost | | |
| Camera | ~\$600.00 | ~\$220.00 |
| Underwater housing | ~\$1,700.00 | NA |
| Total Cost | ~\$2,300.00 | ~\$220.00 |
| Photos | | |
| Photo file format | jpeg | jpeg |
| Photo resolution | 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.

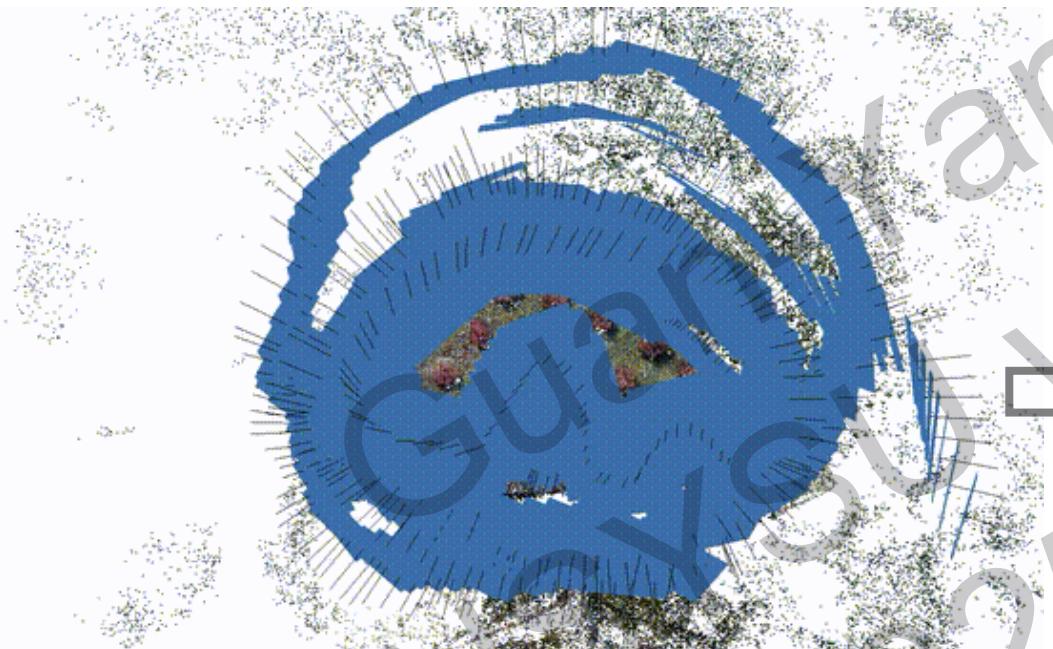
(Roach et al. 2021)

Image sequence and alignment

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



3D modeling products – 點雲 Point cloud



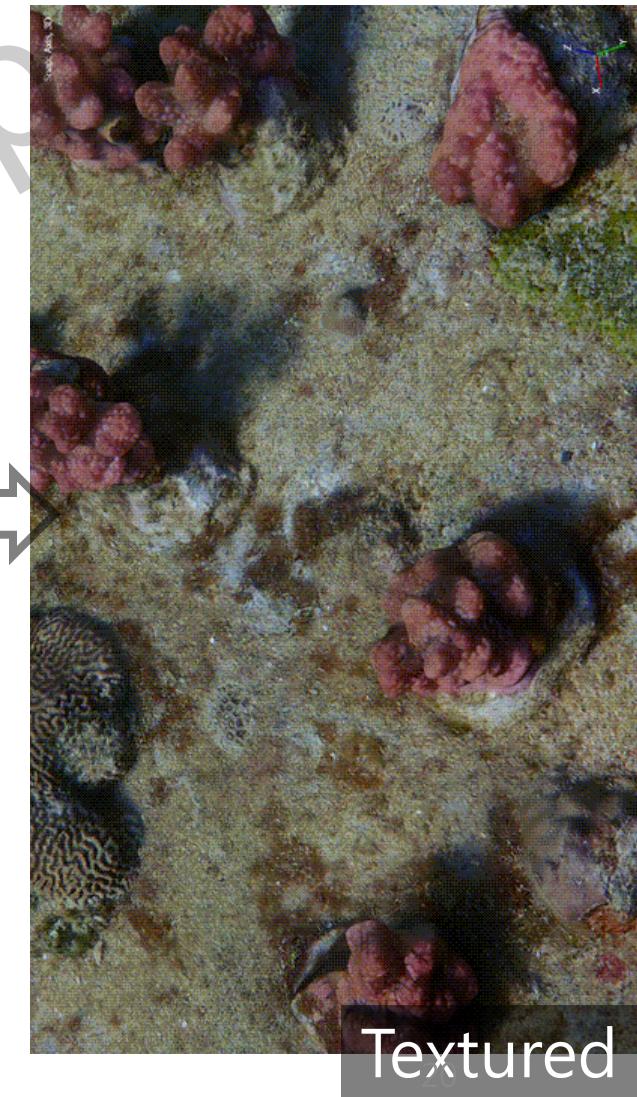
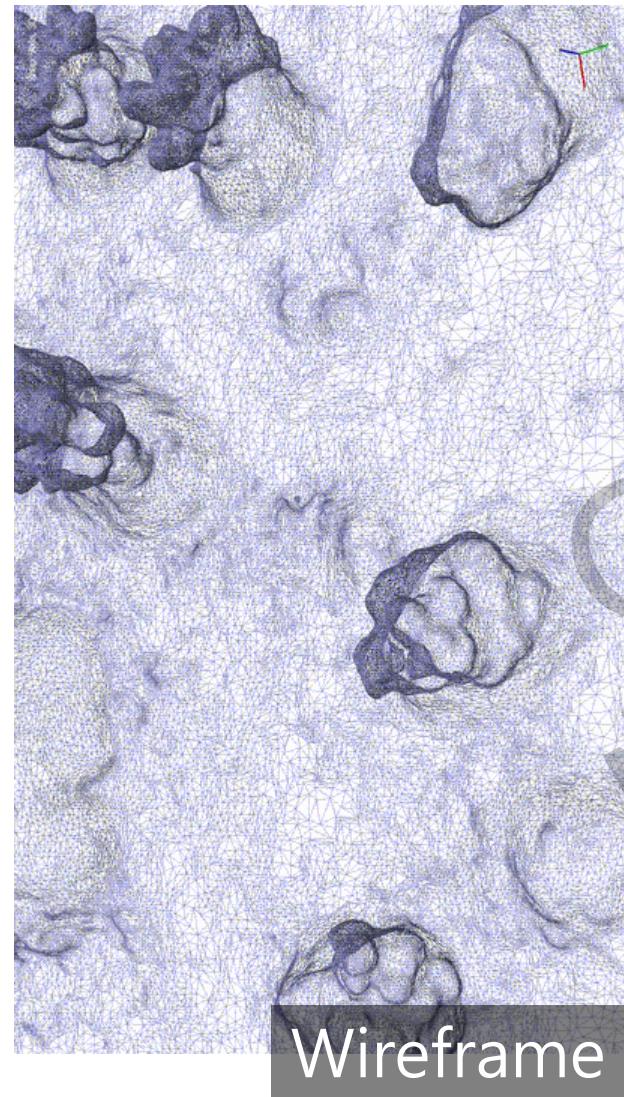
Tie points (sparse point cloud)



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

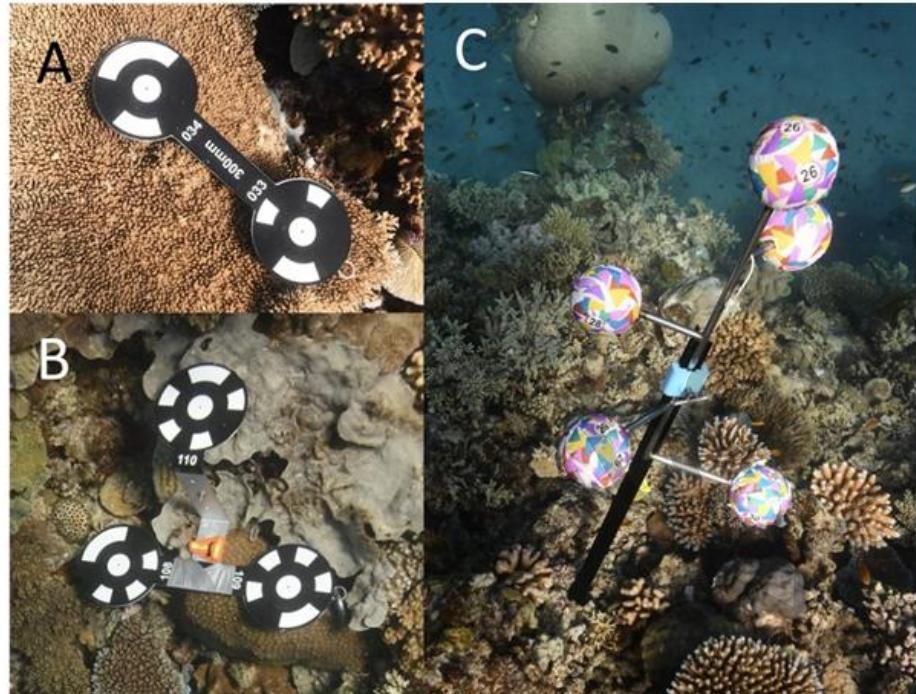


Figure 8. Photogrammetry ground control points used in the current workflow; (A) dumbbells; (B) triads, and; (C) sphere trees. Image: S. Gordon.

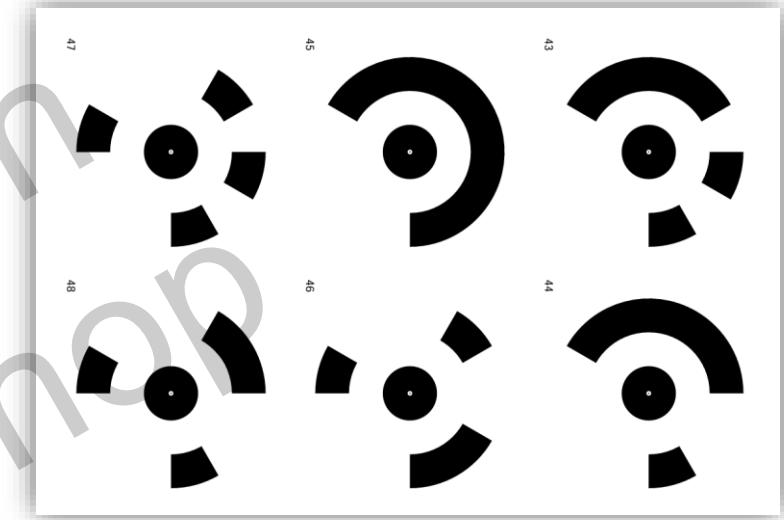
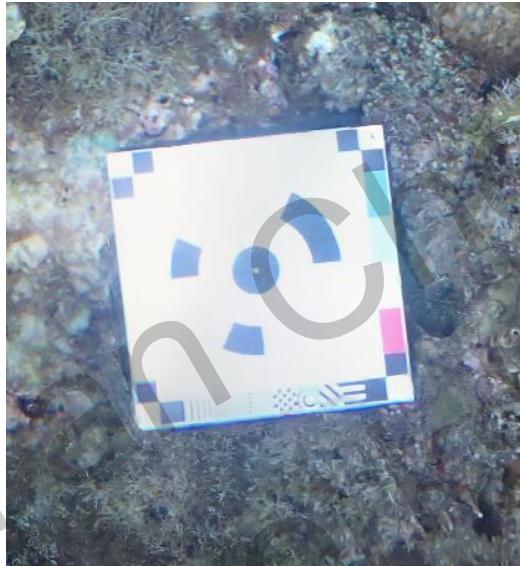
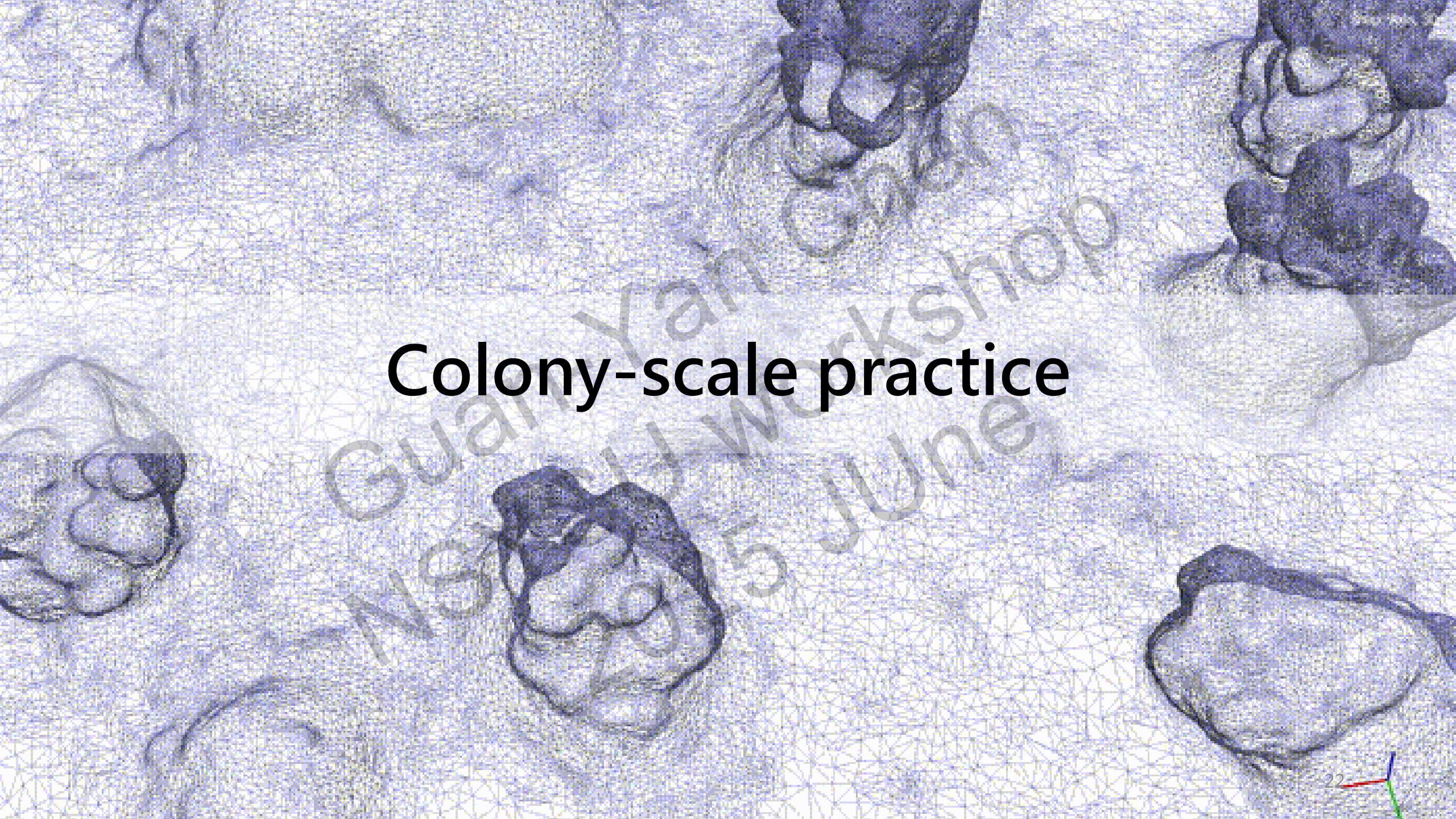


Figure 1.5 A scale bar with two coded Metashape target patterns (also known as ground control points) as end markers whose centers are about 0.25 m apart from each other. These markers can be automatically detected by the software and used as model checkpoints and horizontal geospatial scaling.



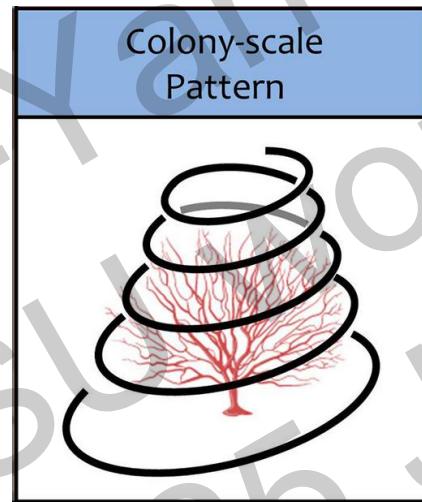


Colony-scale practice

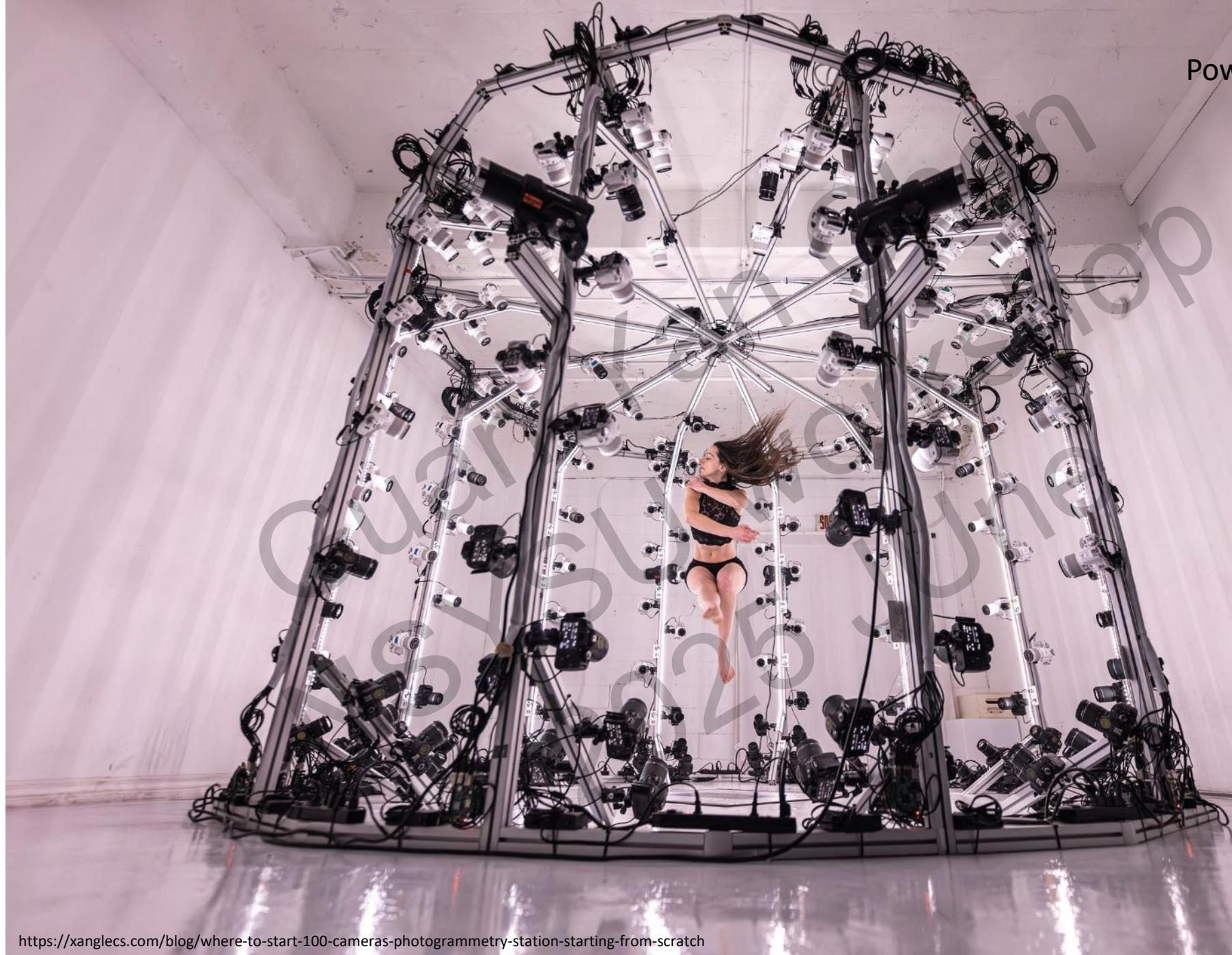
Rotating object



Rotating camera



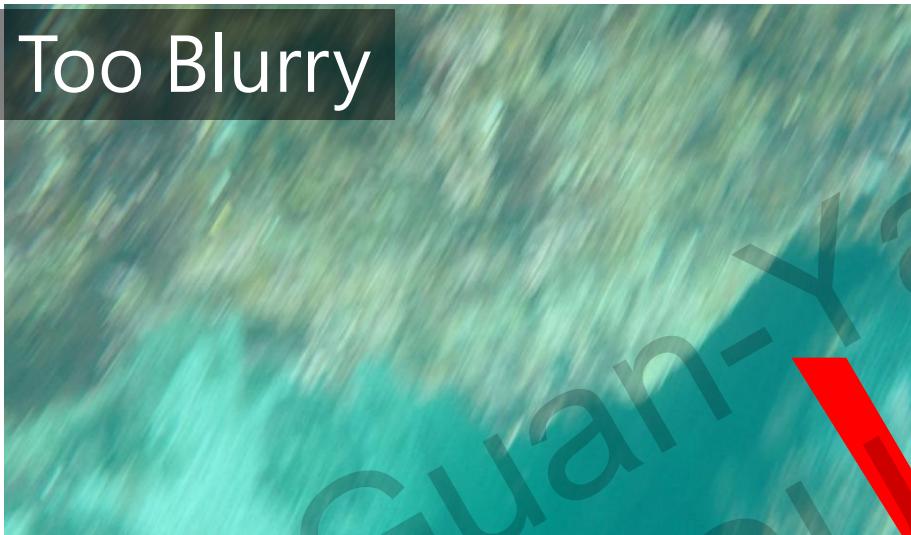
Power of money



Images Must Be Clear and Unobstructed

Unacceptable Captures

Too Blurry



Floating Debris
Interference



Filming in wave
conditions is
challenging

Overexposed



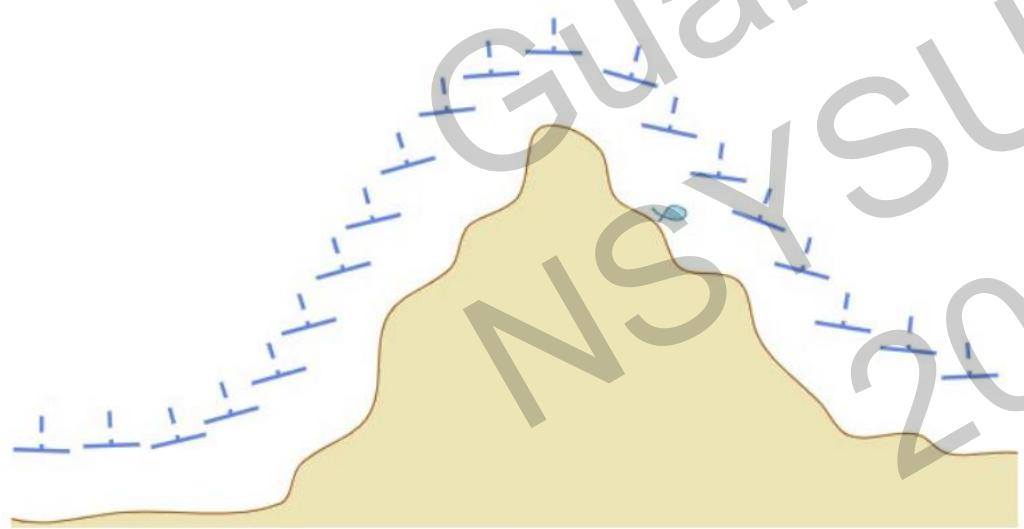
Irrelevant to the Subject



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

Canon SL2/3 (NOAA)



TG-6 (NMMBA)

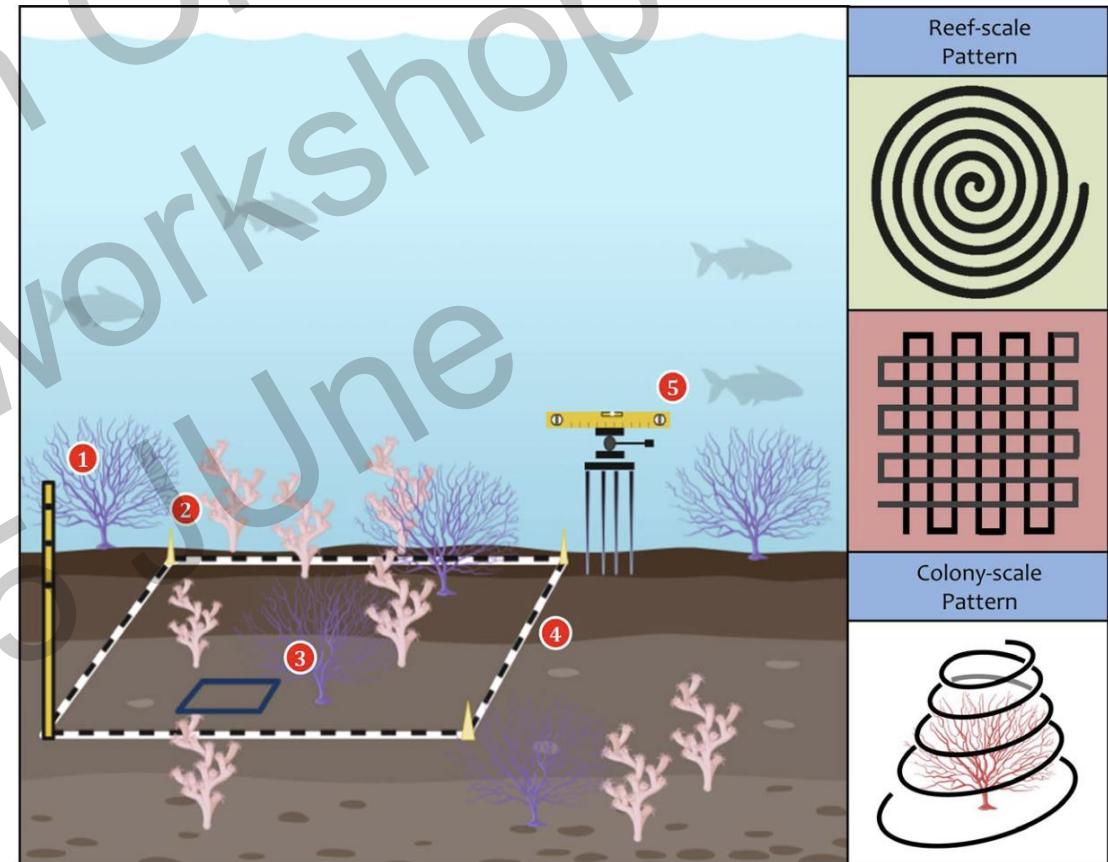
1. 相機調至P模式
2. 關閉閃燈
3. 調整曝光值 (視當天光照強度設定在 -0.3~0之間)
4. 調整ISO為AUTO
5. 將白平衡設為 深潛 模式
6. 畫面比例4:3
7. 調整至ESP測光模式
8. 拍攝模式設定為Natural
9. 對焦點設定為 單點
10. 設定間隔/定時拍攝模式: 將影像數目設定為299張、
間隔時間1秒、定時短片關、開始等待時間2秒

- 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

Time to have funs

Rule of thumb

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



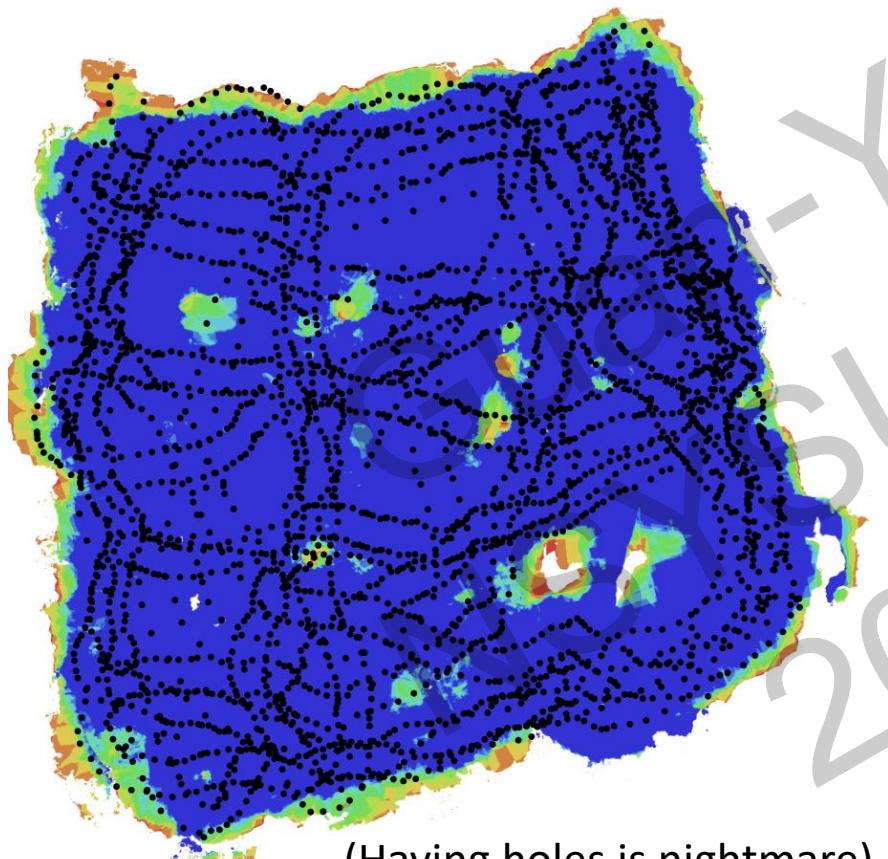
(Bayley et al. 2020)



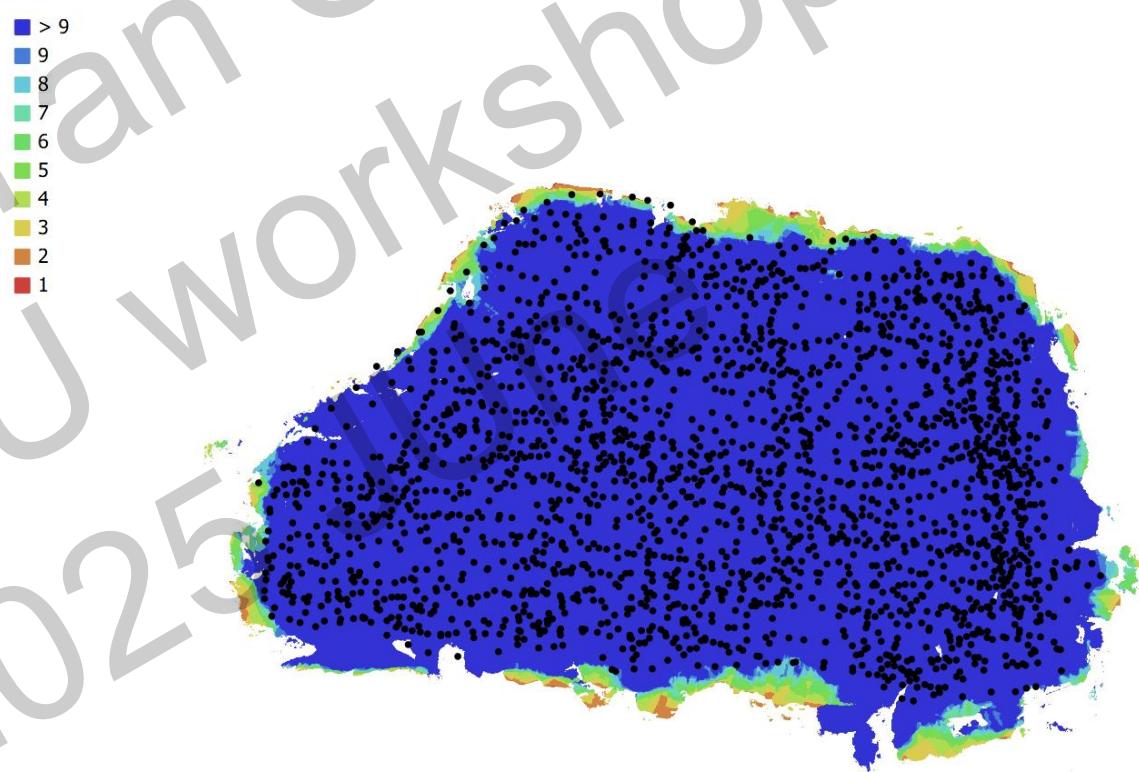
Habitat-scale practice

Criteria for Building High-Quality Models

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



(Having holes is nightmare)



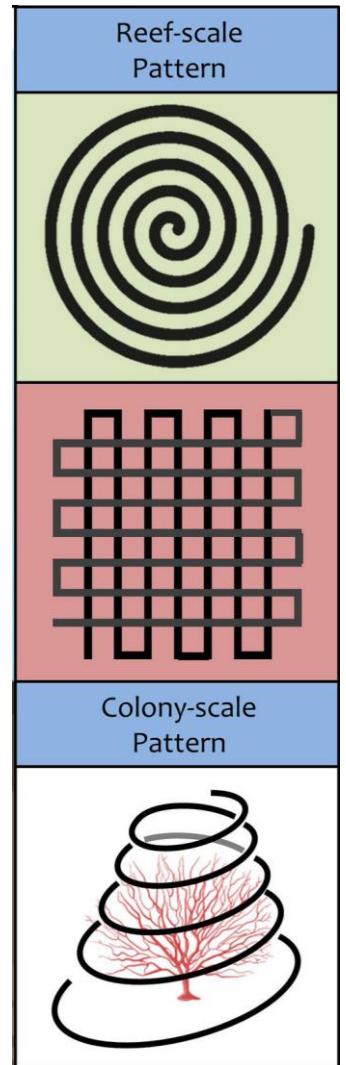
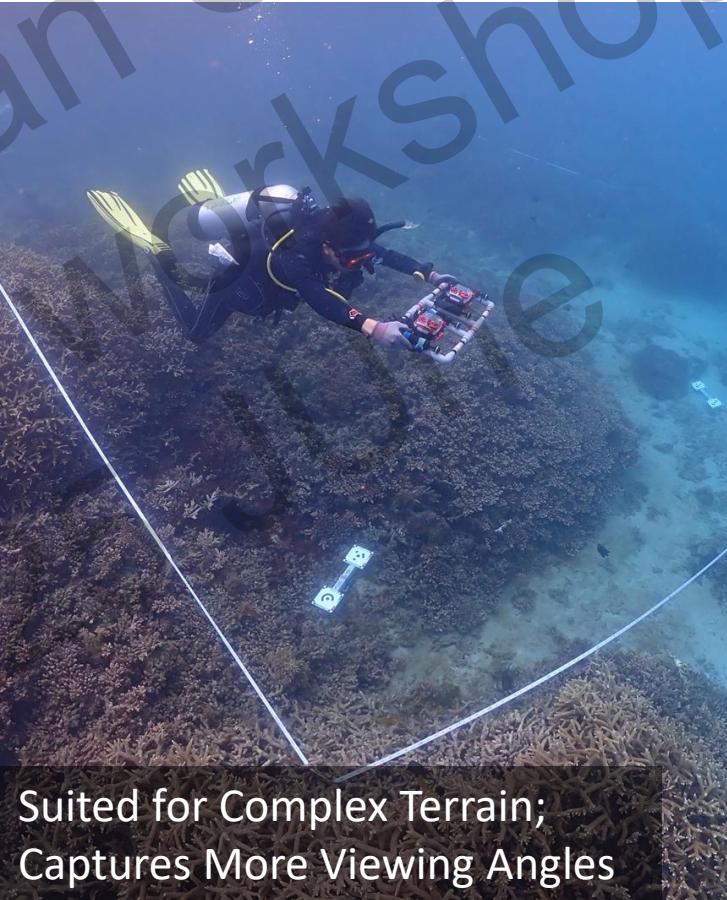
(>9 additional photos yield minimal structural gain)

>9
9
8
7
6
5
4
3
2
1

(Boustrophedon、牛耕式路徑)

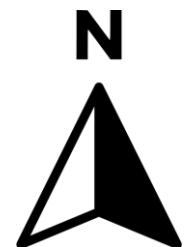
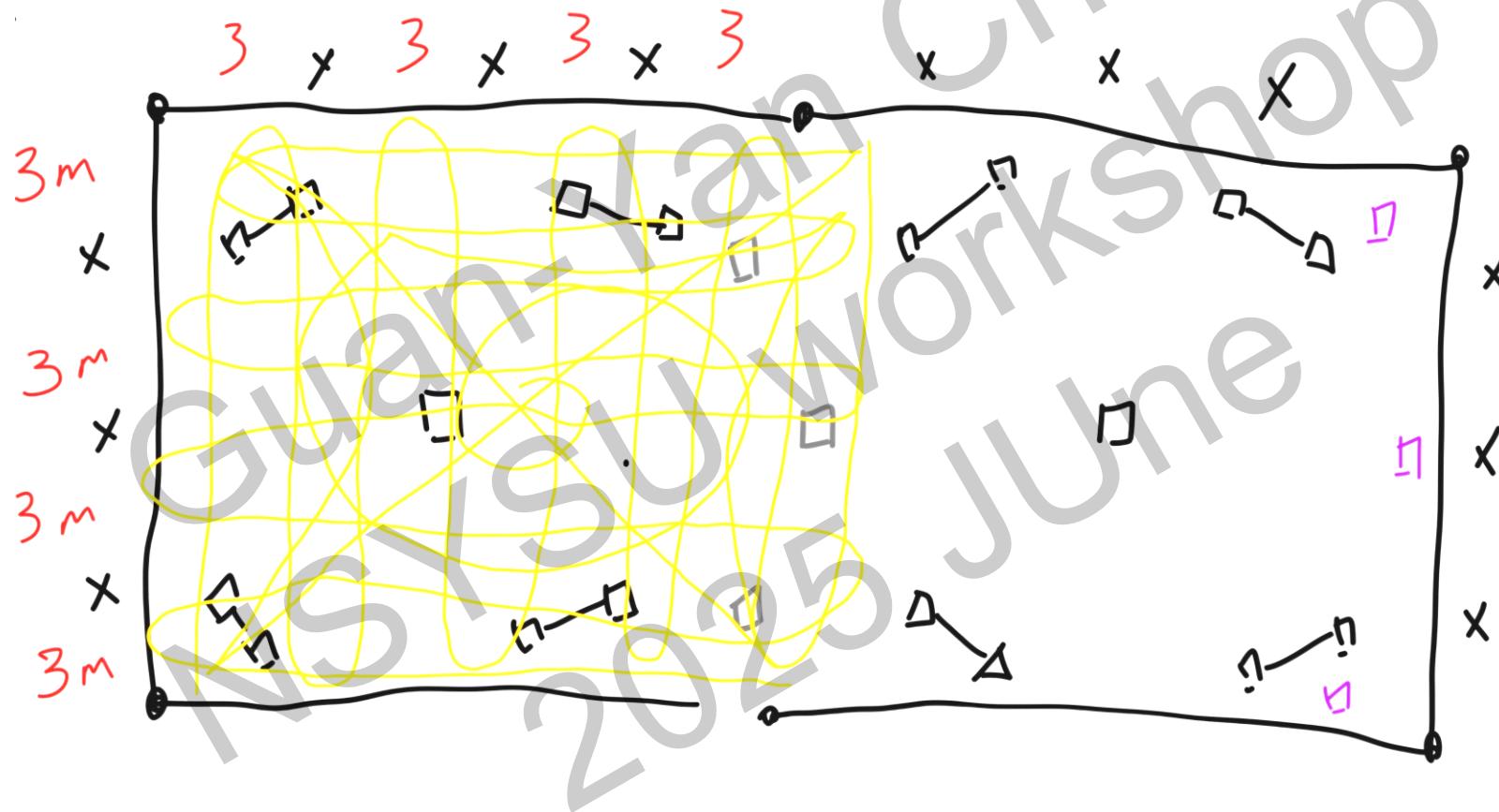
Lawn-mowing Survey Method

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



(Bayley et al., 2020)³¹

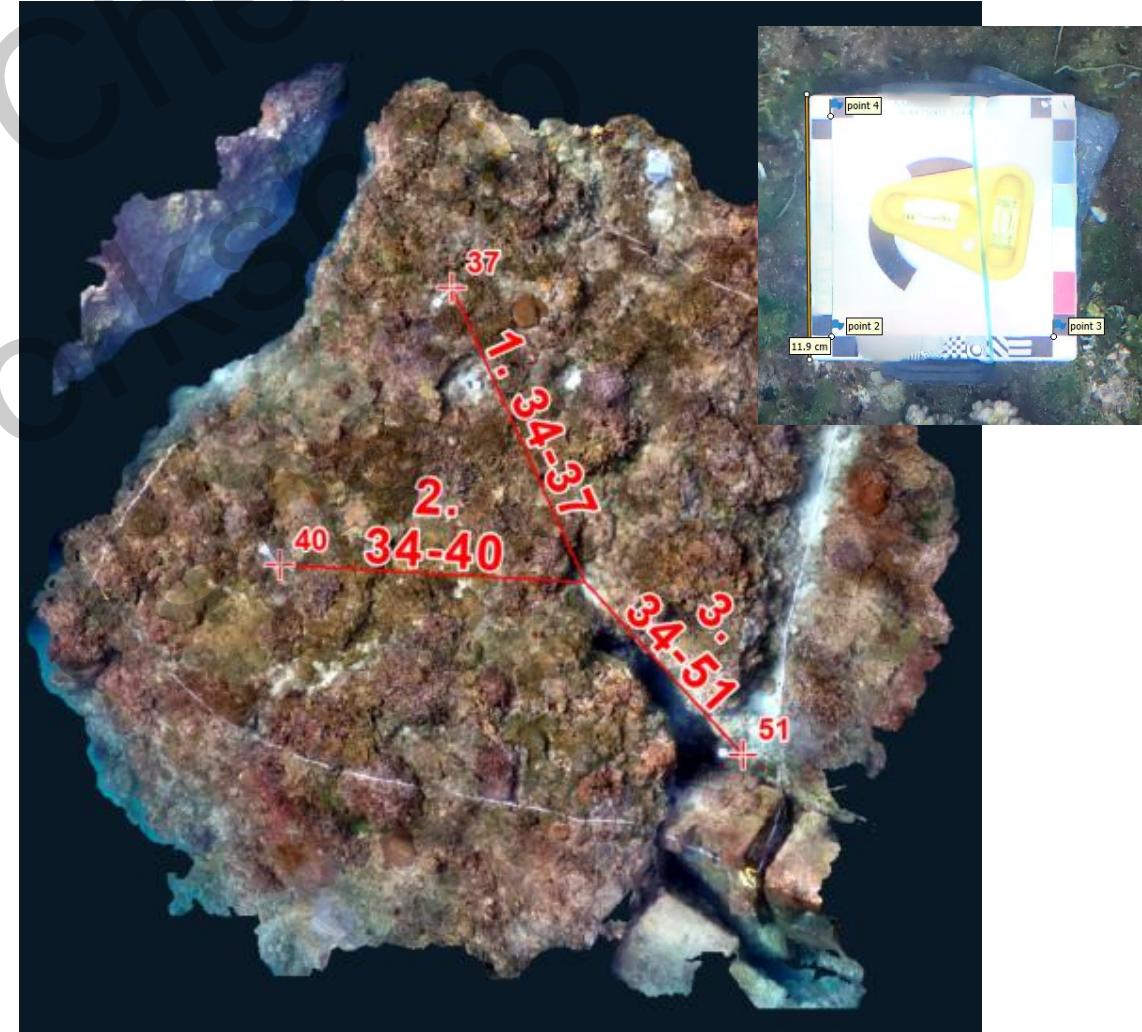
How to Set Up the Sampling Plot



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

**MEGA
LAB**

HAWAIIAN ISLANDS

learn more about map2adapt
<https://map2adapt.com/>

Honoli'i Surf Break 2

Honoli'i Reef Shelf
by The MEGA Lab

-155.088, 19.757

This image shows a broad basalt reef shelf with layered rock formations, shallow depressions, and scattered boulders. The surface is predominantly bare with light sediment accumulation and sparse algal cover, extending across a gently sloping reef platform in shallow water.

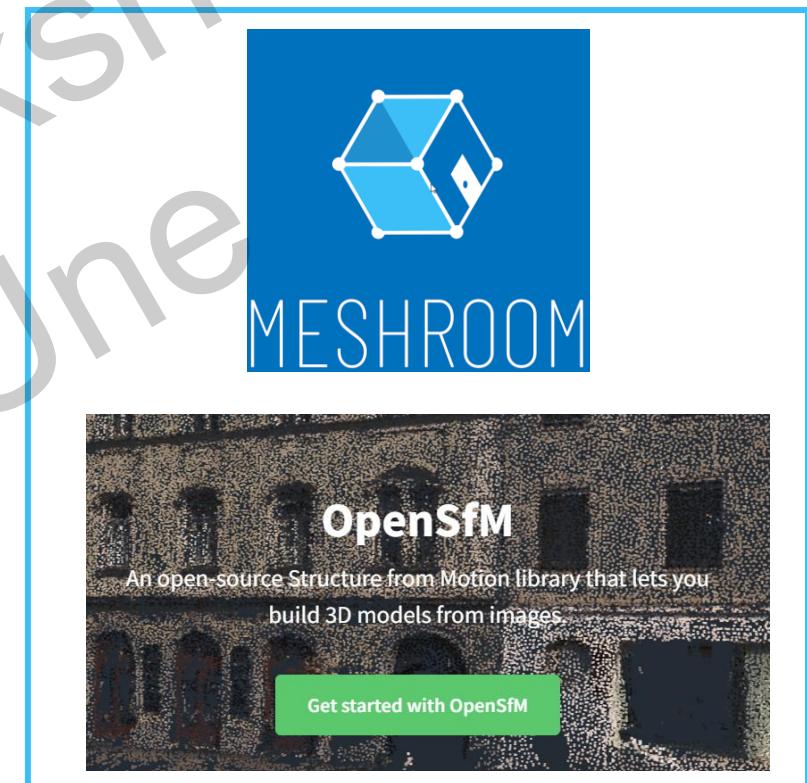
3D model images

SfM softwares

Commercial Software



Open-Source Software



SfM softwares comparison

By contrast, Agisoft Metashape:

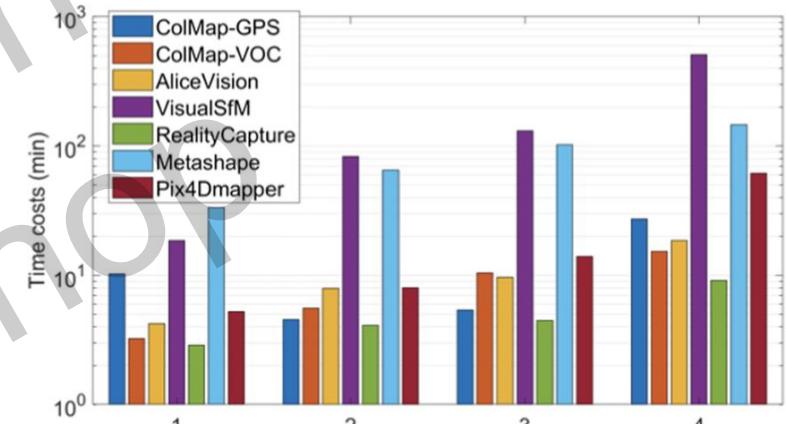
- Longer processing time for modeling
- Capable of producing higher-quality point clouds
- User interface is relatively intuitive

Table 7

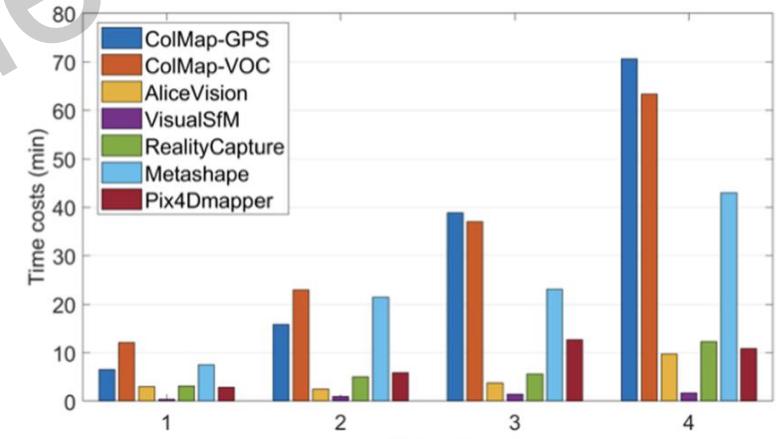
Statistical results of completeness for SfM-based reconstruction. The largest point numbers are shown in bold values.

| 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)



(a) feature matching

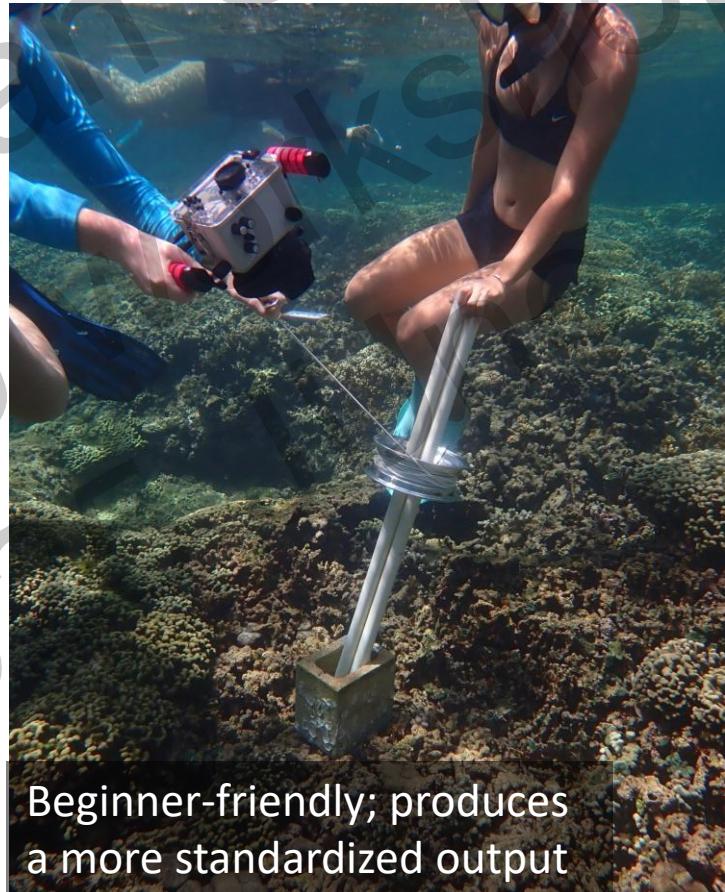


(b) bundle adjustment

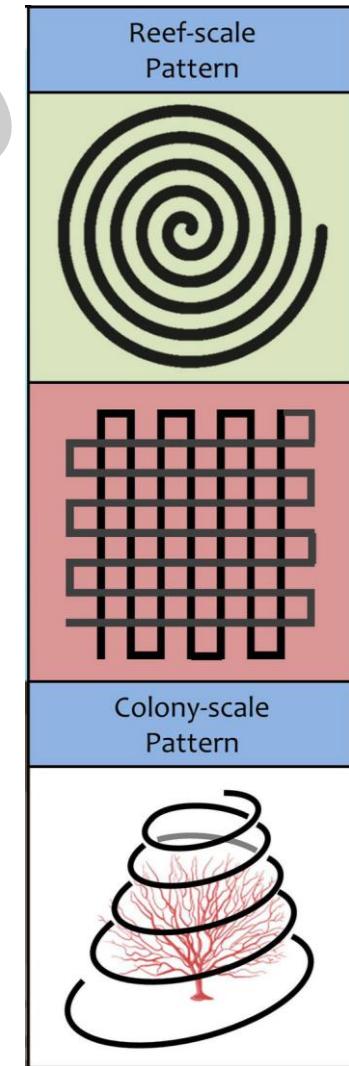
Fig. 10. The time costs in feature matching and bundle adjustment (in minutes).

Underwater Spiral Survey Method

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



Beginner-friendly; produces
a more standardized output



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 |

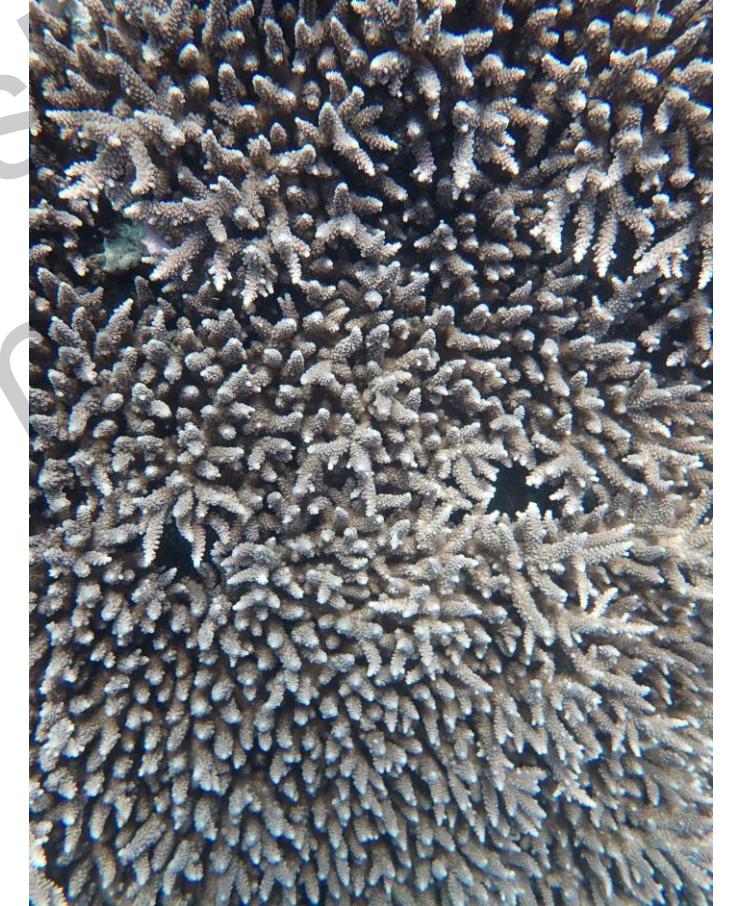
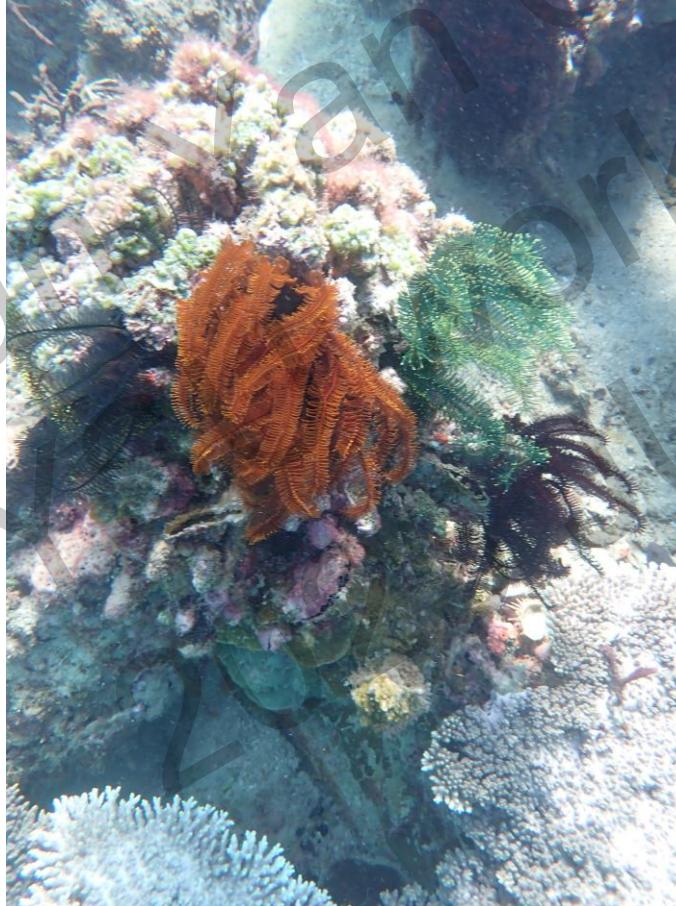
(Pizarro et al. 2017)

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

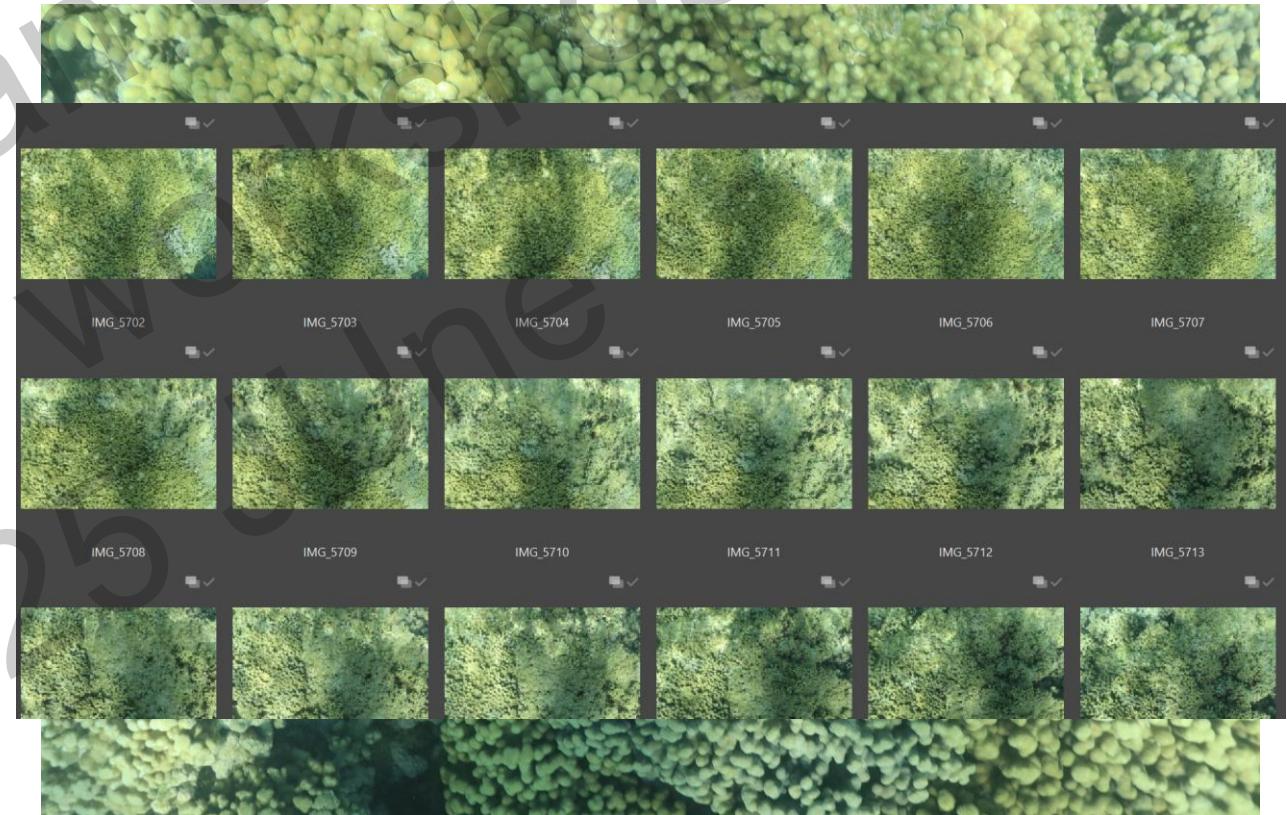
Suitable vs. Unsuitable Environments

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.

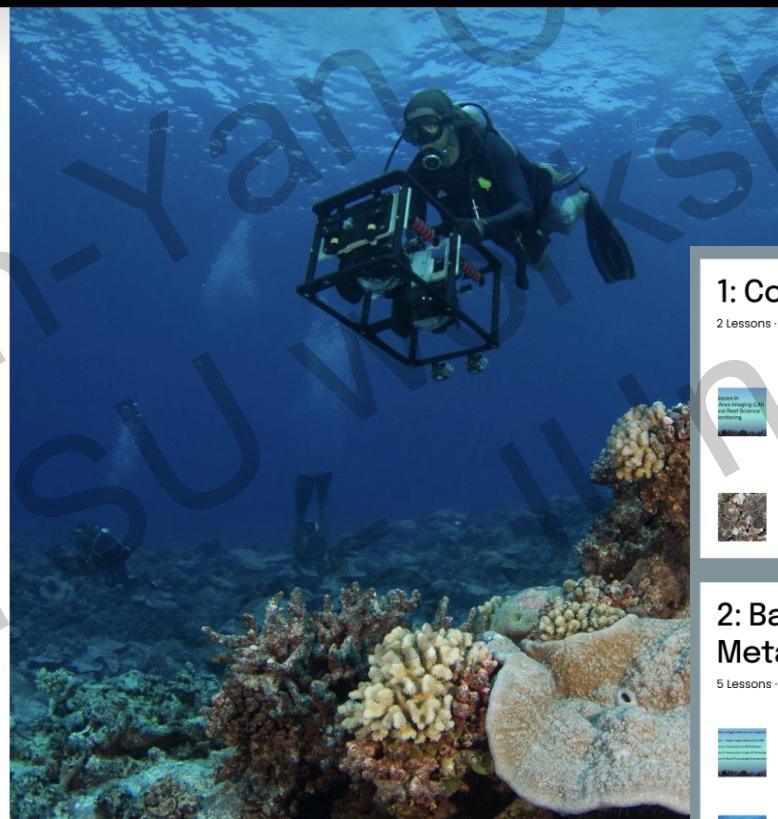
Relevant Learning Resources 1/3

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.



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

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

Relevant Learning Resources 2/3



Spencer Miller

Research Technician /
Photogrammetrist

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The screenshot shows the homepage of the Settide guide. At the top, there's a navigation bar with links: AddTools, Benchmark, Metashape, Applications, Learn, Services, and Contact. Below the navigation is a large title: "A Guide to Apply Photogrammetry to Coral Reef Habitats". To the right of the title is a sub-headline: "Get more done all in one place." and a description: "AddTools for Metashape brings more tools and capabilities right into Metashape photogrammetry software." There are two icons: "AT" and a camera icon. On the left side, there's a sidebar with a table of contents:

| |
|-----------------------------------|
| 1. Title |
| 2. Introduction |
| 3. Photogrammetry Fundamentals |
| 3.1 A Brief Introduction |
| 3.2 It All Starts with the Photos |
| 3.3 Photogrammetry Outputs |
| 3.4 Terminology |
| 4. Materials |
| 4.1 Underwater Gear |
| 4.2 Photogrammetry Gear |
| 4.2.1 Camera |
| 4.2.1.1 Camera Settings |
| 4.2.2 GCPs |
| 4.2.3 Computer |
| 4.2.4 Software |
| 5. Reefs |
| 5.1 Taking Photos |

Below the sidebar are two images: a wireframe reconstruction of a reef structure and a close-up photograph of a coral colony.

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

The screenshot shows two main sections: "Equipment Costs" and "Photographing the Reef".

Equipment Costs: This section allows users to calculate costs for various equipment items. The estimated total cost is USD \$2,146. A note states: "These costs are mainly upfront costs and do not include any potential recurring payments unless software or products are purchased in addition. Depending on the camera and usage, a replacement may need to be purchased in the near future." A "More Information" link is available.

Photographing the Reef: This section provides a planning tool with sliders and input fields. The total time is 5.8 min, and the number of photos is 346. The average overlap is 51.4%. Other settings include: Number of sites (1), Reef area (64 m²), Camera (Olympus TG-7), Lens focal length (10 mm), Frames per second (1 frames), and Distance from reef substrate (1.0 meter). A note at the bottom right says: "These are estimates, actual prices may vary. Underwater housings may require additional accessories such as dive ports. Taxes not included."

Relevant Learning Resources 3/3

The screenshot shows a YouTube video player with a semi-transparent overlay for a GoToWebinar session. The video title is "Photomosaics as a Tool for Monitoring Coral Restoration Success". The overlay contains the following text:

- During the webinar...**
- There will be a panel discussion at the end of the webinar, during which you can also ask questions
- To add questions to the queue, type them in the GoToWebinar Control Panel
- Click this icon  to make the question panel larger

The GoToWebinar control panel overlay displays the following information:

- File View Help
- Audio: Computer audio (selected), Phone call
- MUTED
- Attendees: 31 of 1001 (max)
- Questions: Welcome to today's webinar!
- [Enter a question for staff]
- Send
- Bringing finance and conservation together:
the Coalition for Private Investment in Conservation by John Tobin-de la Puente
- Webinar ID: 712-025-131
- GoToWebinar

At the bottom of the player, there are standard video controls (play/pause, volume, progress bar) and social sharing buttons.

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

Build 3D models on phone

Luma AI

Interactive Scenes

Gorgeous, embeddable, and universally shareable 3D. Brought to you by Luma, The 3D AI Company

[Start Now on Web for Free >](#)

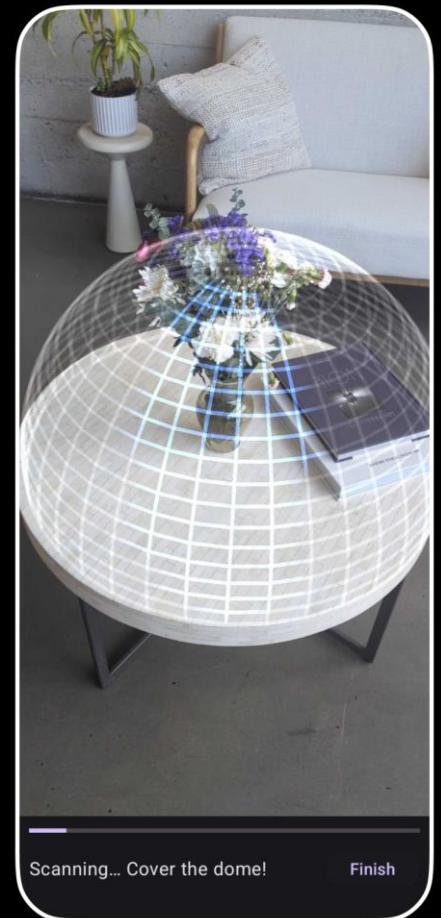
[Create on Mobile >](#)

[Explore Creations >](#)

[WebGL Library >](#)

WebGL Library

Fast and easy
capture flow



<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)

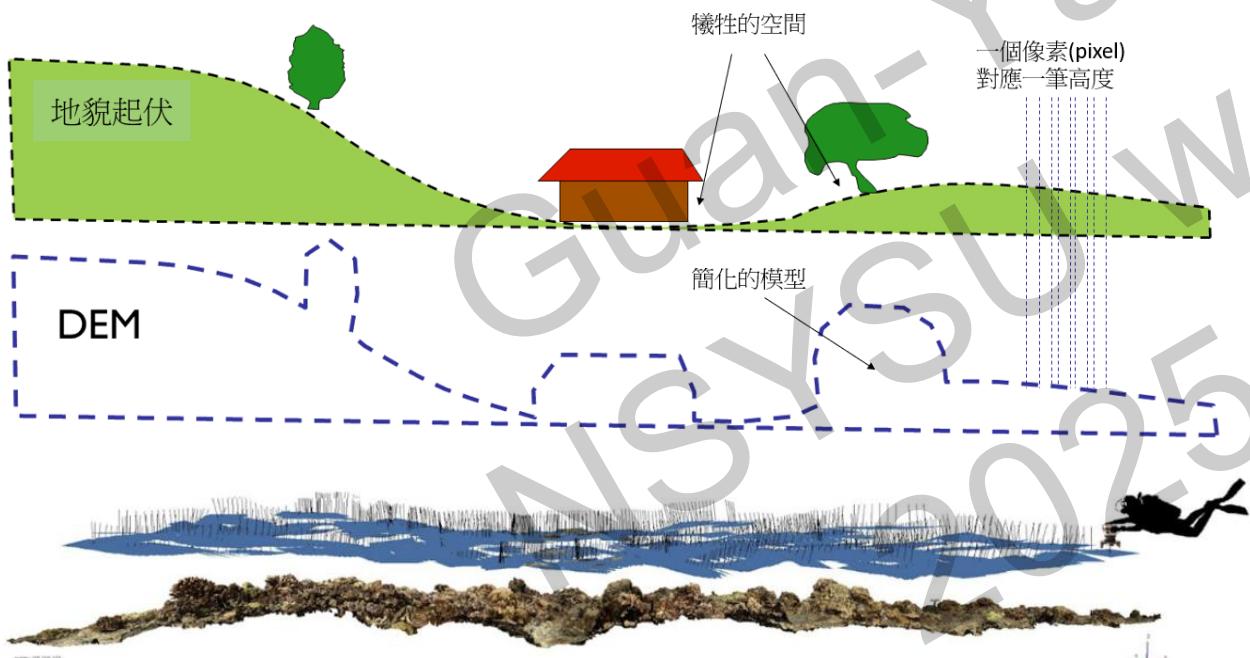
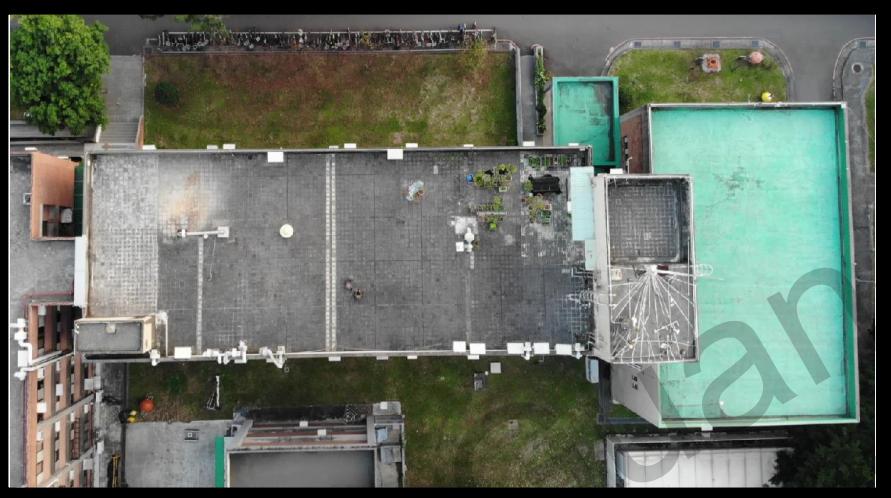


Figure 2.6 Side view of a SfM-derived model showing camera poses (blue) and orientation (black lines). The estimated camera poses recreate the diver's swim path position and height during data collection. Height variation also shows how closely the diver followed the reef's contour at 1m distance above the substrate. (Damaris et al., 2024)



Advantages of 3D monitoring

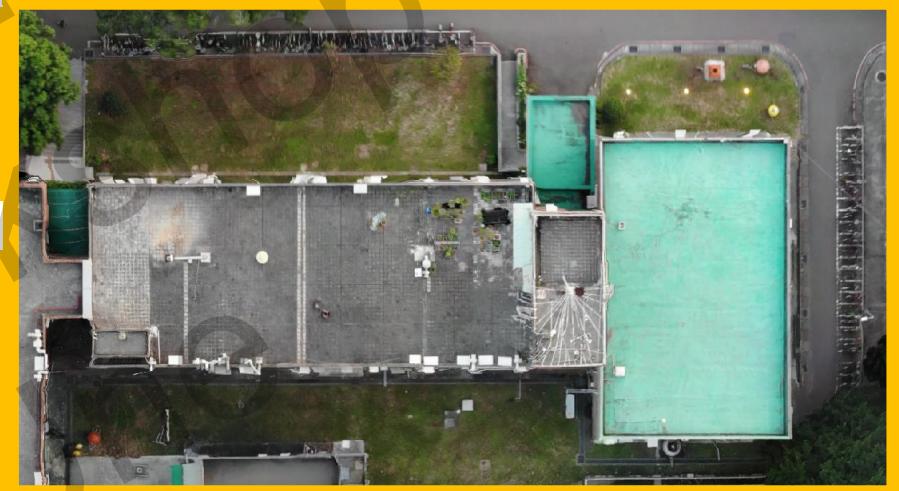
Regular photo



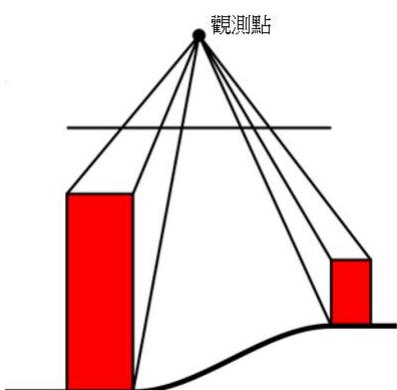
Enables accurate calculation of projected areas

Object depth and camera angle have no impact on measurement

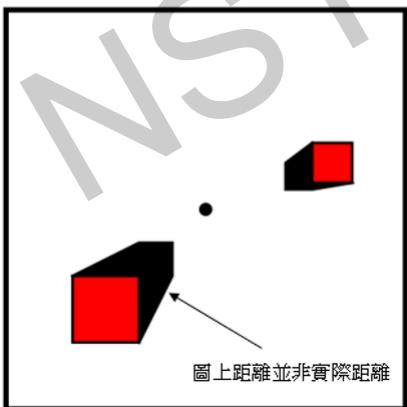
Orthomosaic derived from 3D



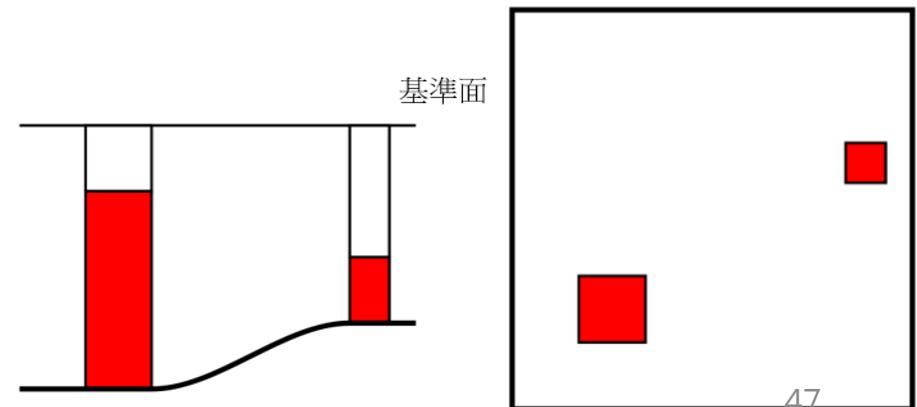
未校正之影像



未校正之影像



正射影像



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