

UNDERWATER SYNTHETIC IMAGE GENERATION FOR MULTI-TEMPORAL MONITORING OF CRUSTOSE CORALLINE ALGAE

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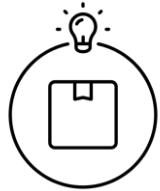
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Presentation Overview

Introduction

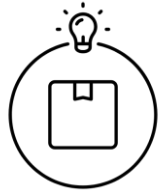


- Challenge of Marine Monitoring



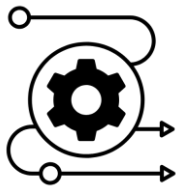
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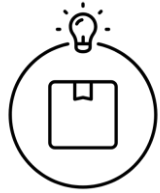
Materials and Methods



- Proposed Solution:
Photogrammetry + NeRF
- Our Workflow
- The Experiment: Costa Paradiso,
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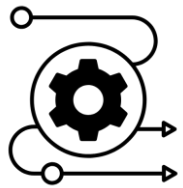
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- Radiometric Correction
- Geometric Validation
- Comparison between Epochs
- Radiometric comparison



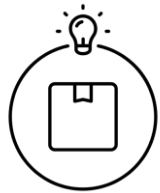
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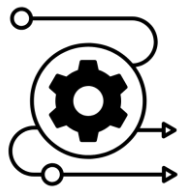
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Conclusion

- Recap
- Current Limitations and Future Developments
- Acknowledgements
- Essential References



INTRODUCTION



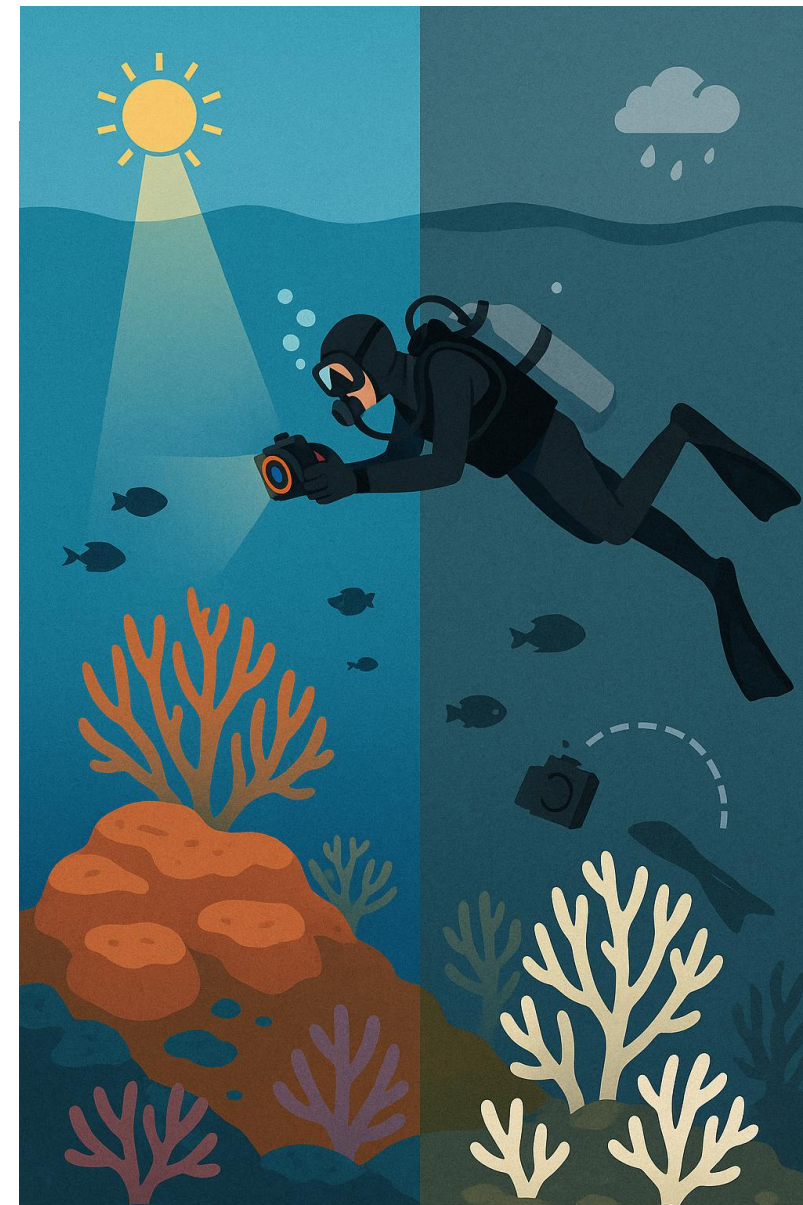
Marine Monitoring: The Challenge

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- **Problem:** Monitoring marine ecosystems is essential to study the effects of climate change
- **Challenge:** Multi-temporal underwater image acquisitions are complex. Lighting conditions, water turbidity, and diver position constantly change.
- **Objective:** Develop reliable tools to compare images over time by eliminating variations caused by conditions and shooting positions, focusing solely on real ecological changes (e.g., bleaching).



MATERIALS AND METHODS



Proposed Solution: Photogrammetry + NeRF

We propose a framework that integrates **two technologies** to create “digital twins” of the underwater scene:

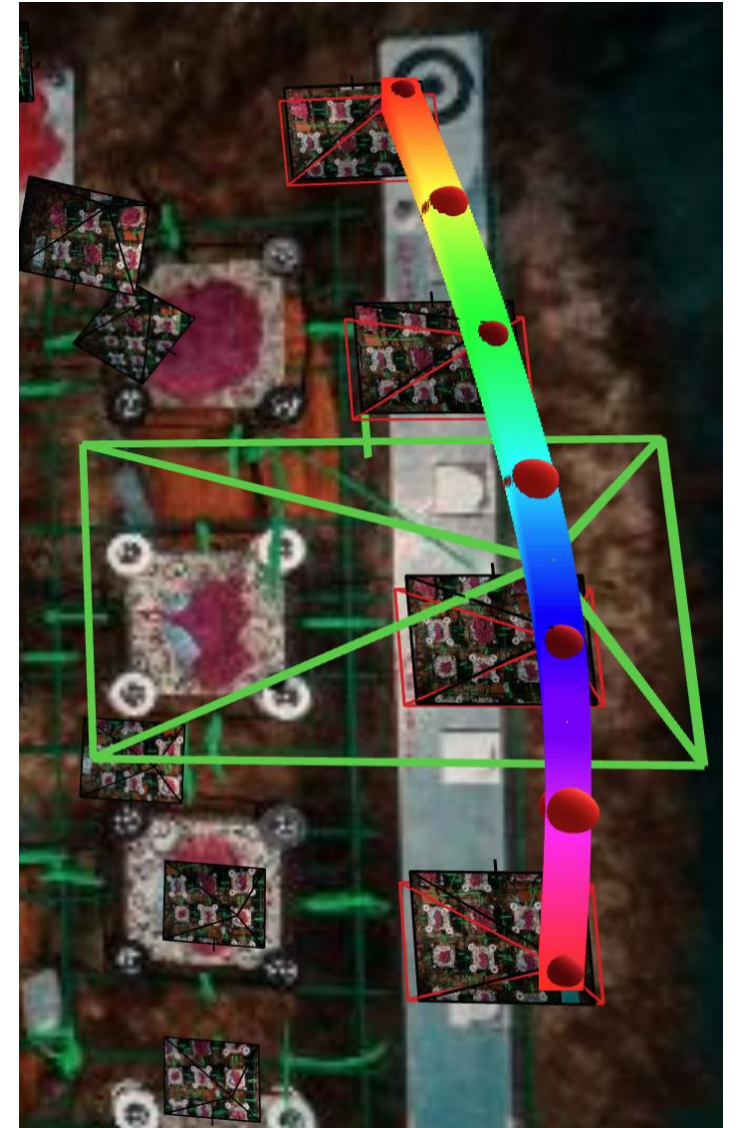
- **Photogrammetry:** Used to calculate the exact position and orientation of the camera for each shot. It creates the geometric “structure” of the scene
- **Neural Radiance Fields (NeRFs):** An Artificial Intelligence technique that replicates the 3D scene based on images and calculated positions (camera centers and orientations).



Proposed Solution: Photogrammetry + NeRF

Advantage:

NeRF allows us to generate **highly realistic synthetic views** of the scene from any perspective.

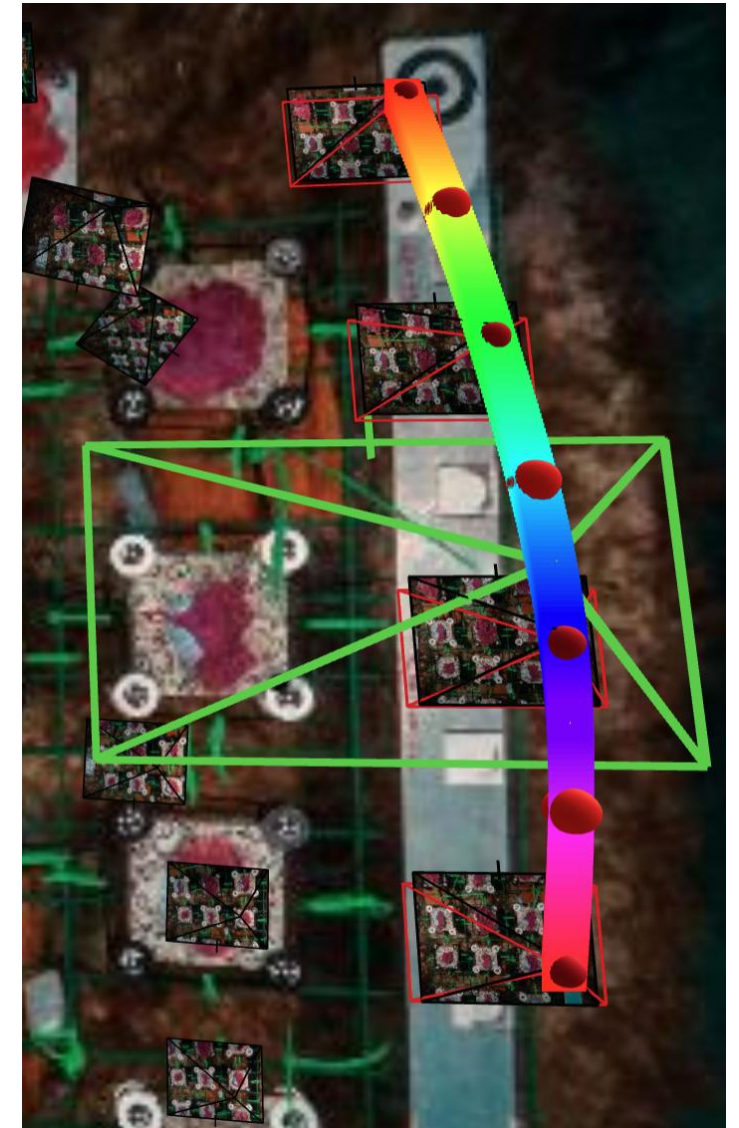
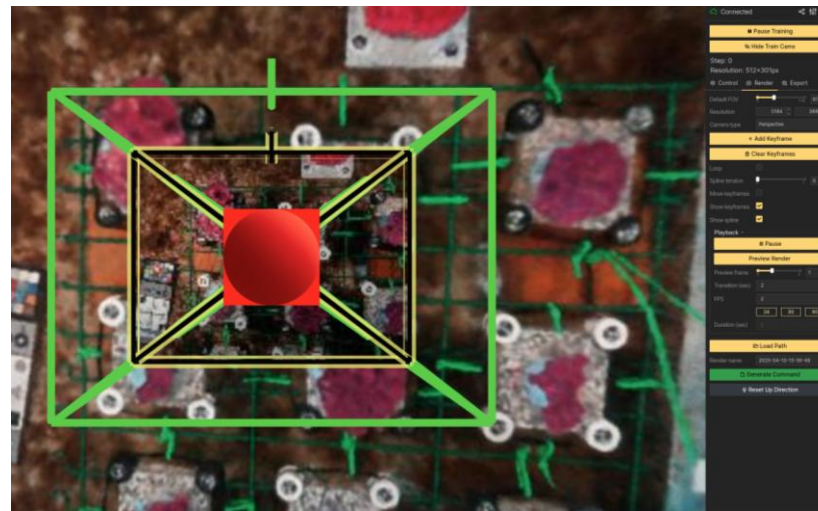


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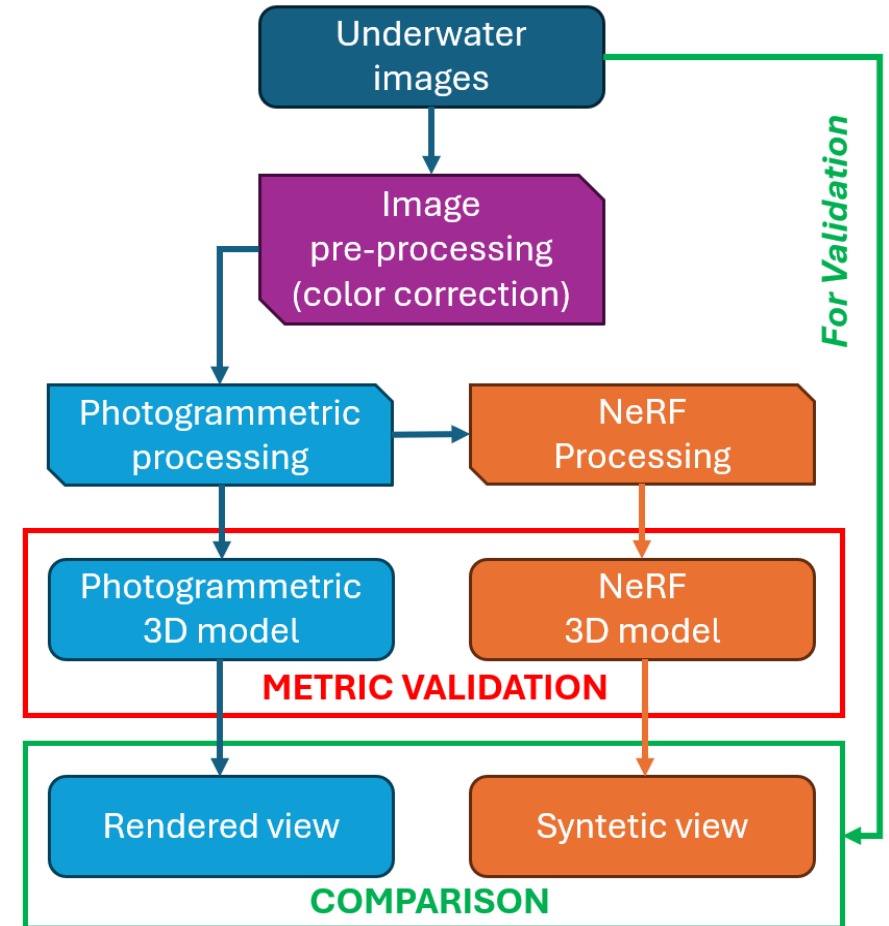
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We have full control over the virtual camera position, allowing **consistent viewpoints across different time epochs**.



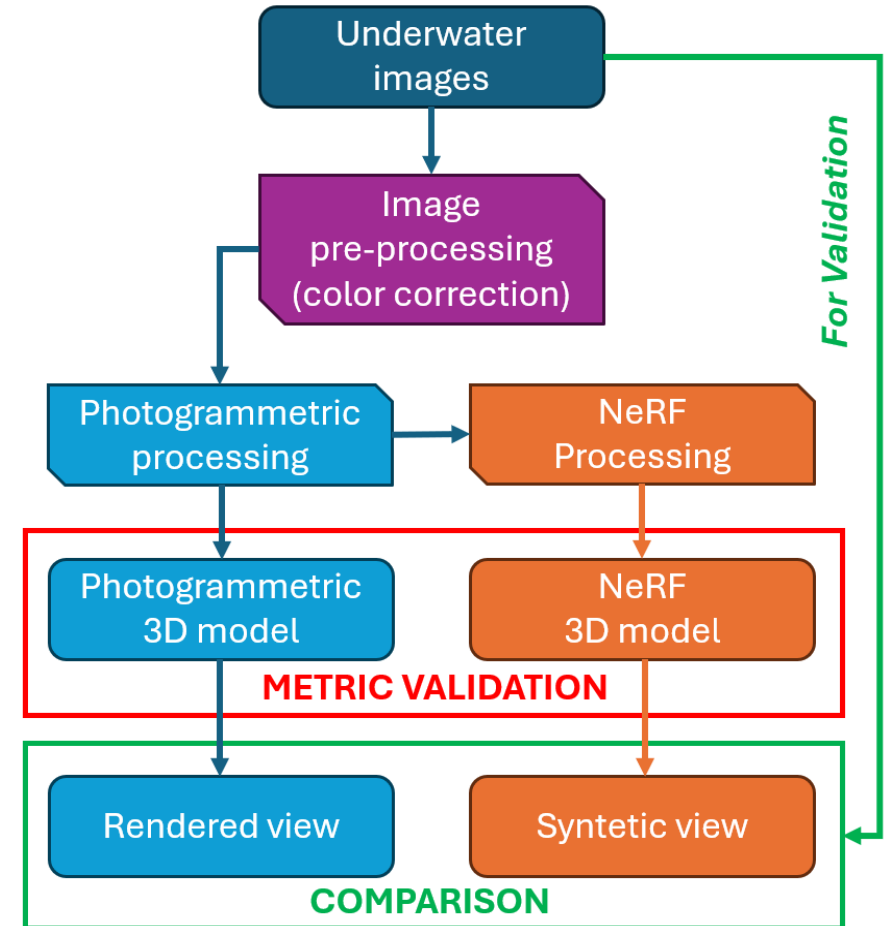
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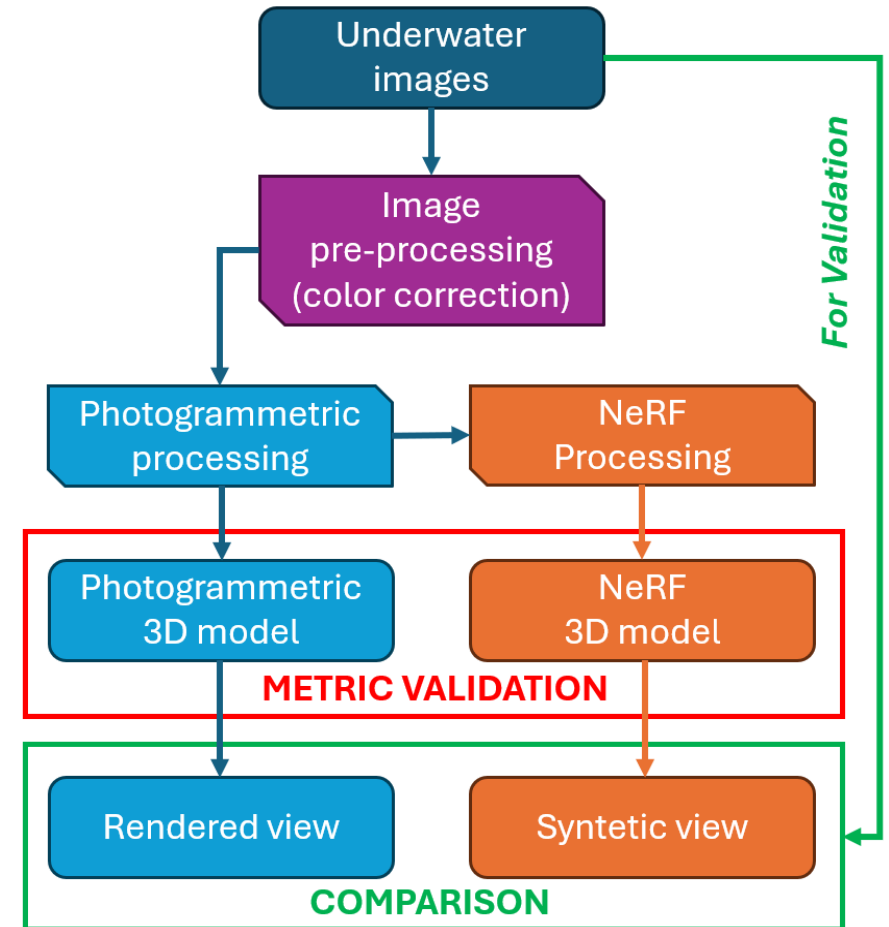
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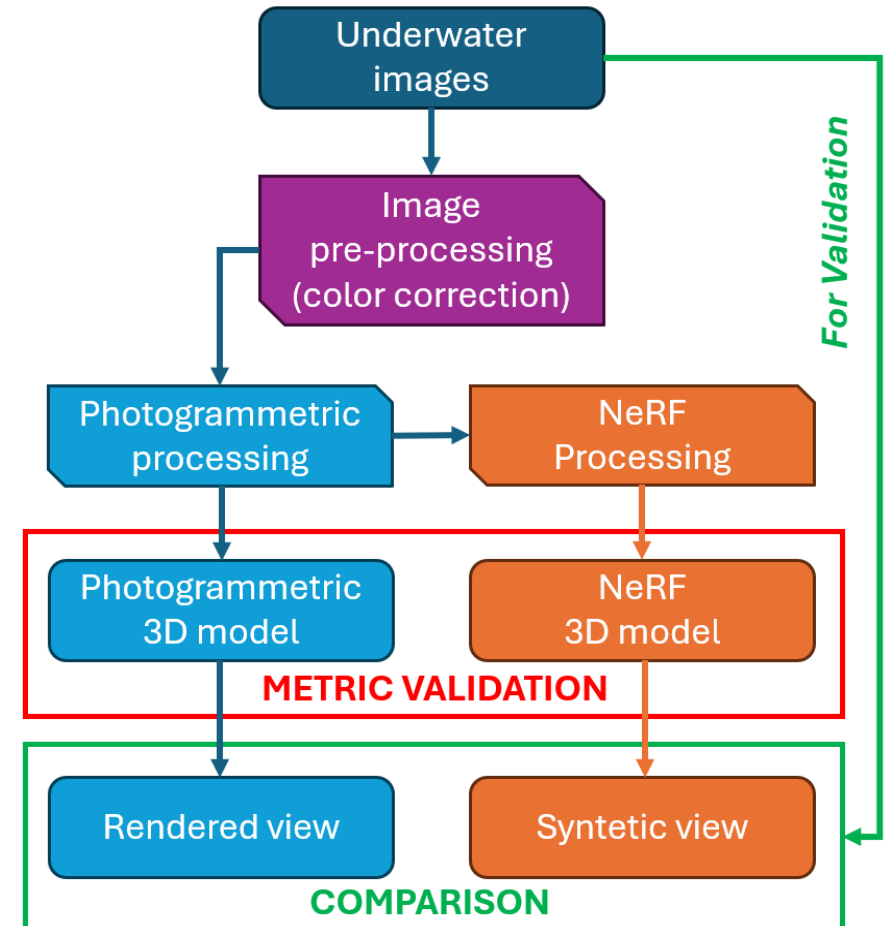
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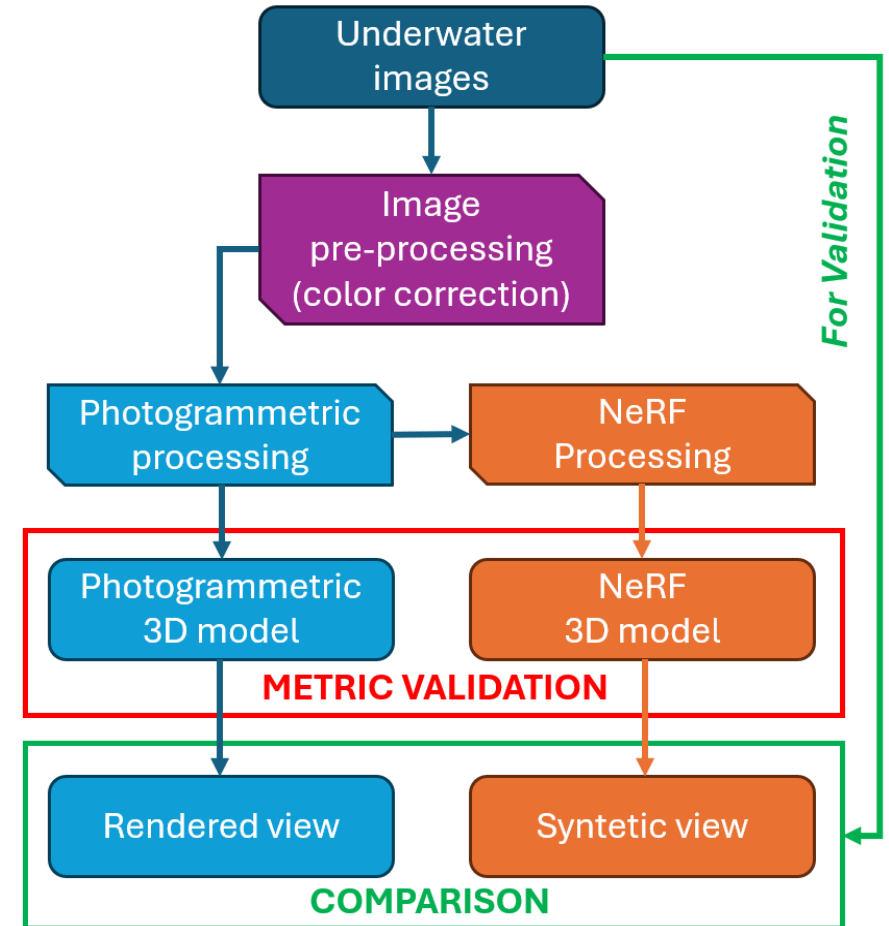
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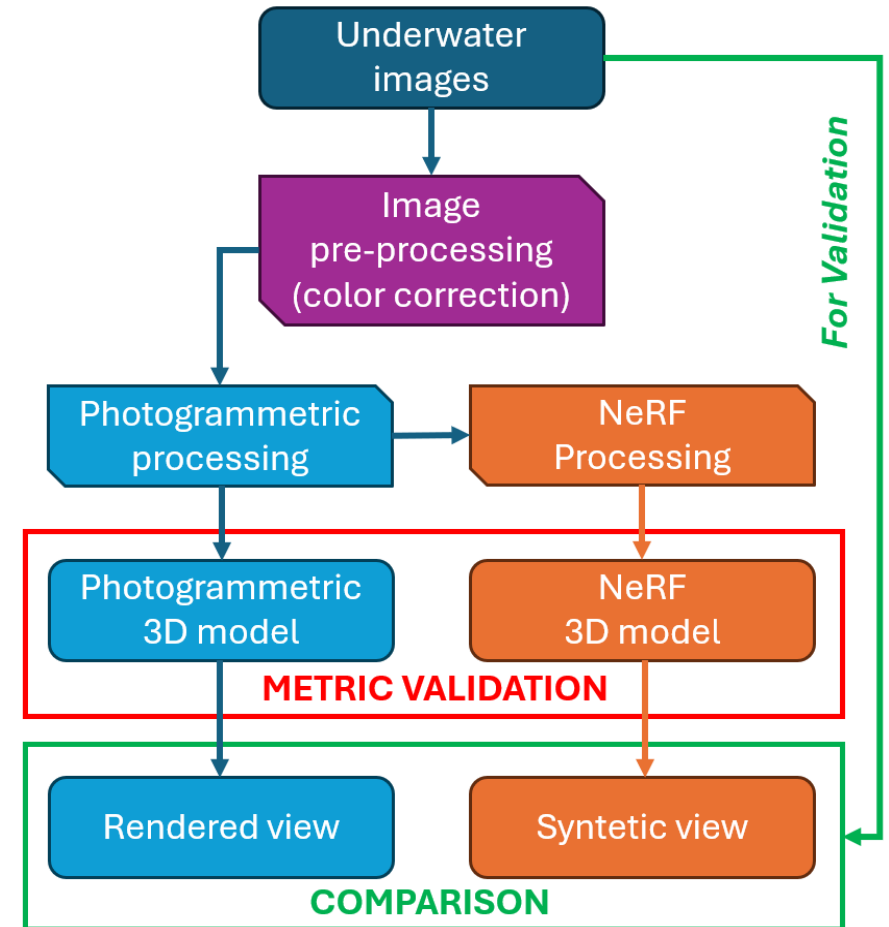
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- 5. Synthetic View Generation:** We create images from identical viewpoints for t_0 and t_1 .
- 6. Comparison:** Differences between the synthetic images are analyzed to quantify changes.



The Experiment: Costa Paradiso, Sardinia



Site: Costa Paradiso, Sardinia, at approximately 38 meters depth.



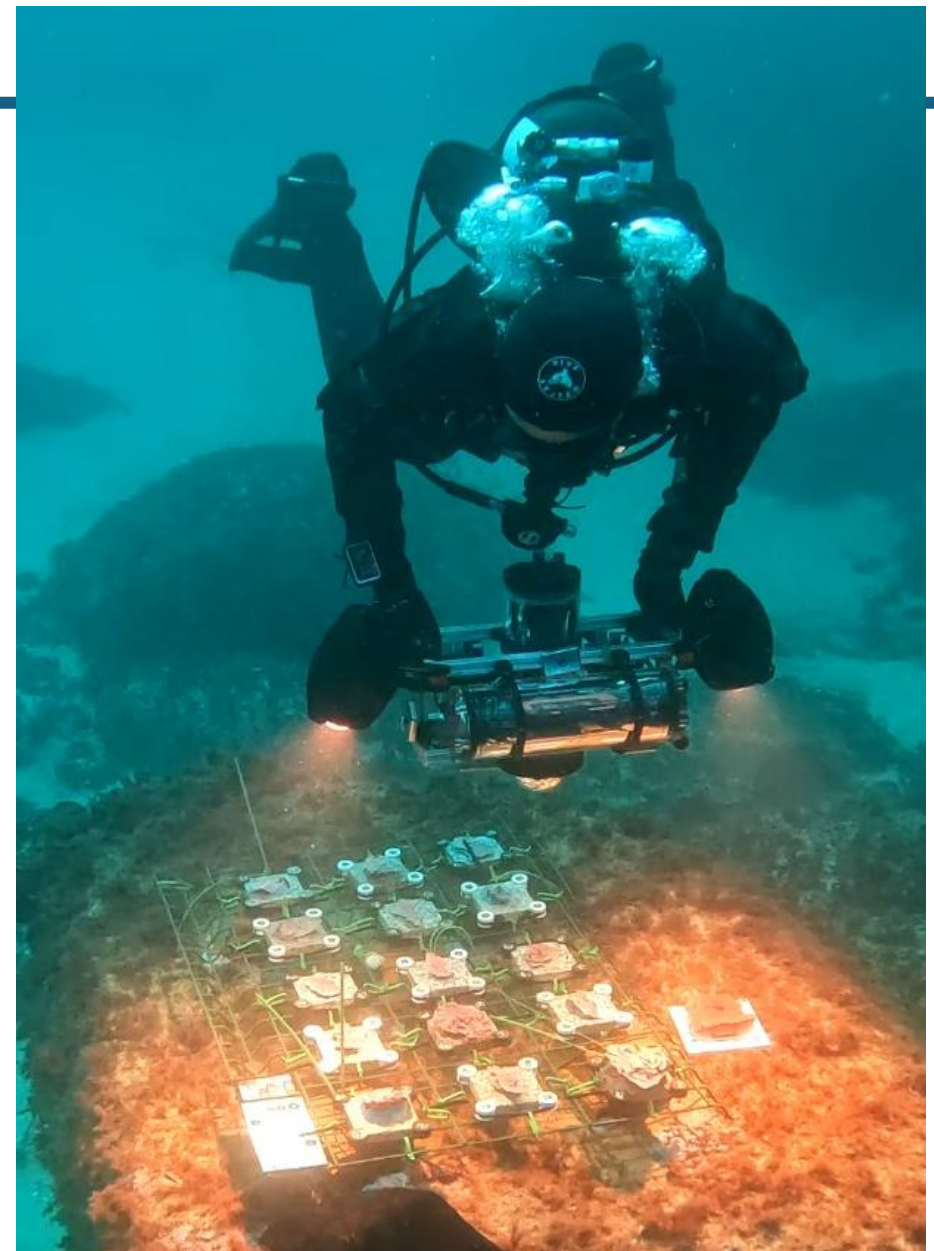
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Equipment: Olympus E-M1 Mark II camera with a 9mm lens and dome port to reduce refraction.



RESULTS



Radiometric Correction

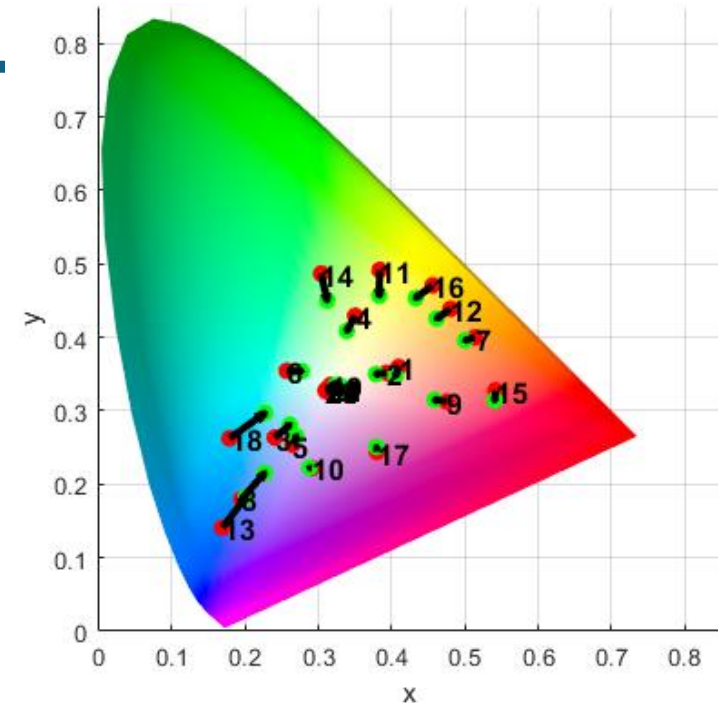
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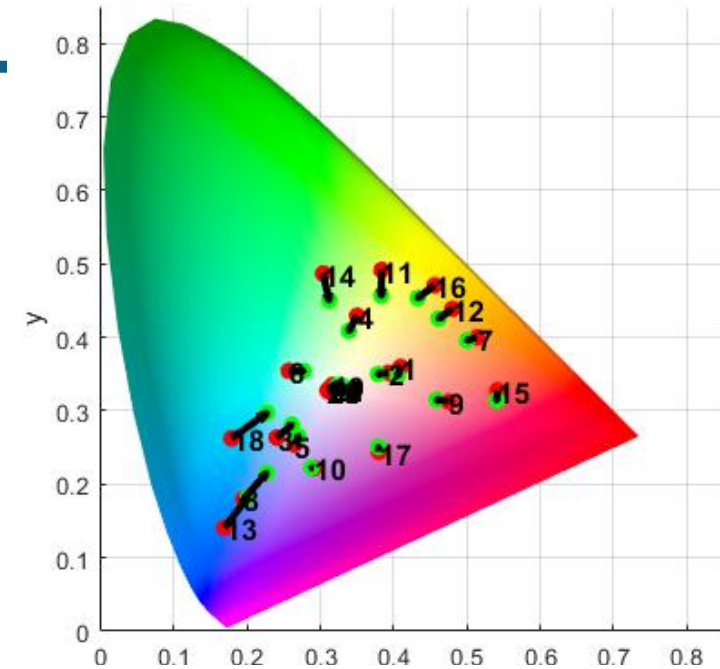
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Validation: Effectiveness was confirmed using a color checker and color comparison algorithms in the CIELAB color space.

All ROIs	Unprocessed Image	Agisoft Metashape Render	Nerfstudio Render
$\Delta E \bar{x}$	8,60	15,94	9,67

NeRF rendering achieves better color accuracy ($\Delta E = 9.67$) than the photogrammetric one ($\Delta E = 15.94$).



Patch 1 $\Delta E = 4.3$	Patch 2 $\Delta E = 4.6$	Patch 3 $\Delta E = 7.6$	Patch 4 $\Delta E = 5.7$	Patch 5 $\Delta E = 5.9$	Patch 6 $\Delta E = 8.9$
Patch 7 $\Delta E = 4.9$	Patch 8 $\Delta E = 12.1$	Patch 9 $\Delta E = 5.2$	Patch 10 $\Delta E = 5.5$	Patch 11 $\Delta E = 15.2$	Patch 12 $\Delta E = 11.0$
Patch 13 $\Delta E = 14.3$	Patch 14 $\Delta E = 12.4$	Patch 15 $\Delta E = 8.9$	Patch 16 $\Delta E = 14.9$	Patch 17 $\Delta E = 5.7$	Patch 18 $\Delta E = 14.1$
Patch 19 $\Delta E = 9.5$	Patch 20 $\Delta E = 5.0$	Patch 21 $\Delta E = 7.6$	Patch 22 $\Delta E = 9.4$	Patch 23 $\Delta E = 7.2$	Patch 24 $\Delta E = 6.6$



Geometric Validation

After radiometric normalization, we verified the geometric accuracy of the NeRF models.

We compared the point cloud generated by NeRF with the photogrammetric 3D model (our ground truth).



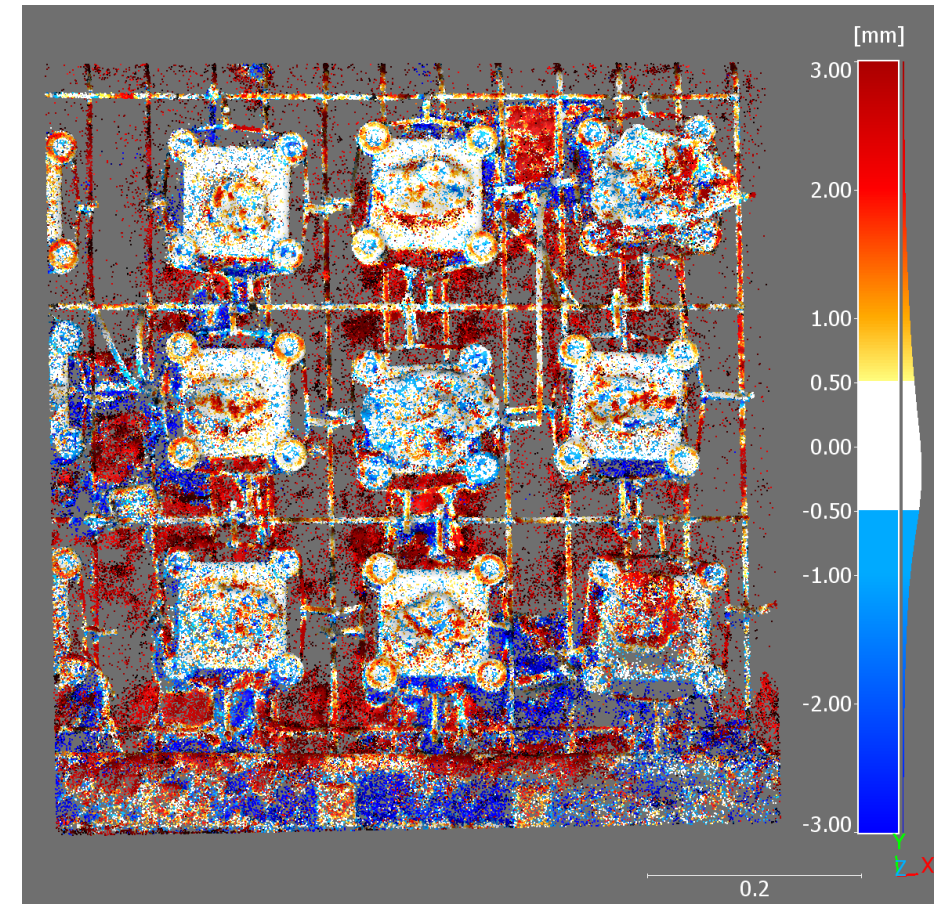
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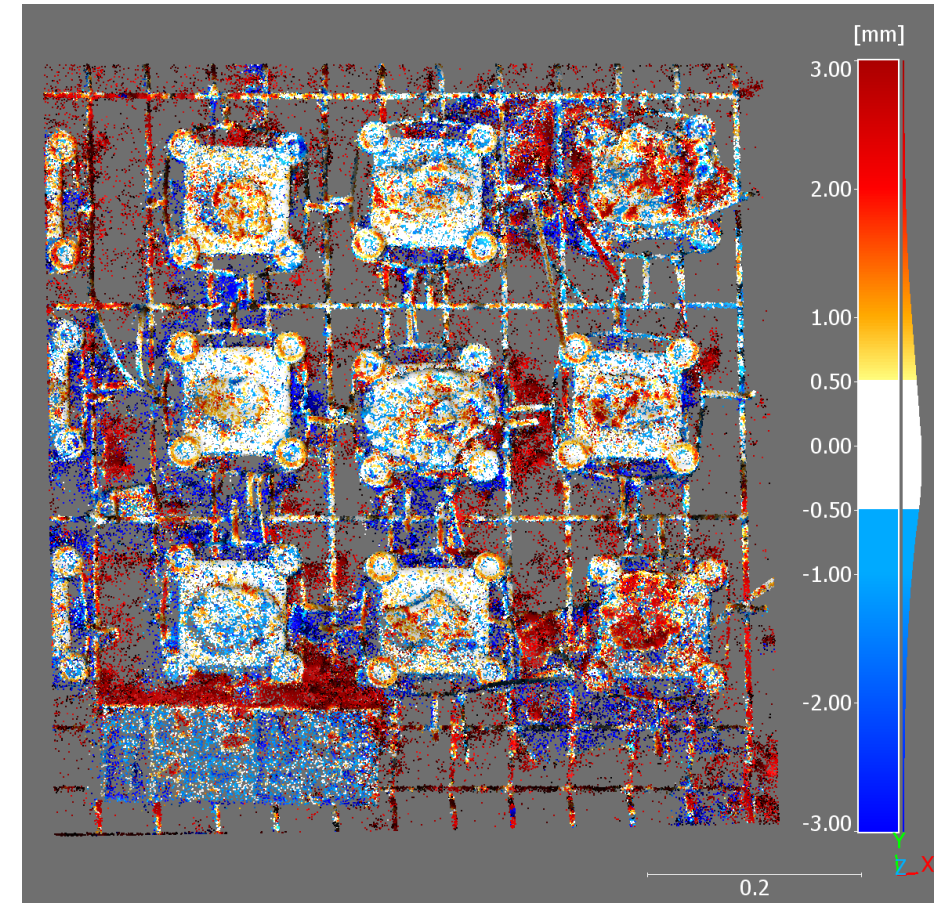
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Conclusion: The NeRF model is geometrically consistent with the photogrammetric ground truth and can be considered metrically reliable for surveying purposes.

C2M Distance [mm]	t_0 NeRF	t_1 NeRF
Media	1.30	0.38
Std. dev	6.37	6.51

t_1 NeRF <- C2M -> t_1 Photogrammetry

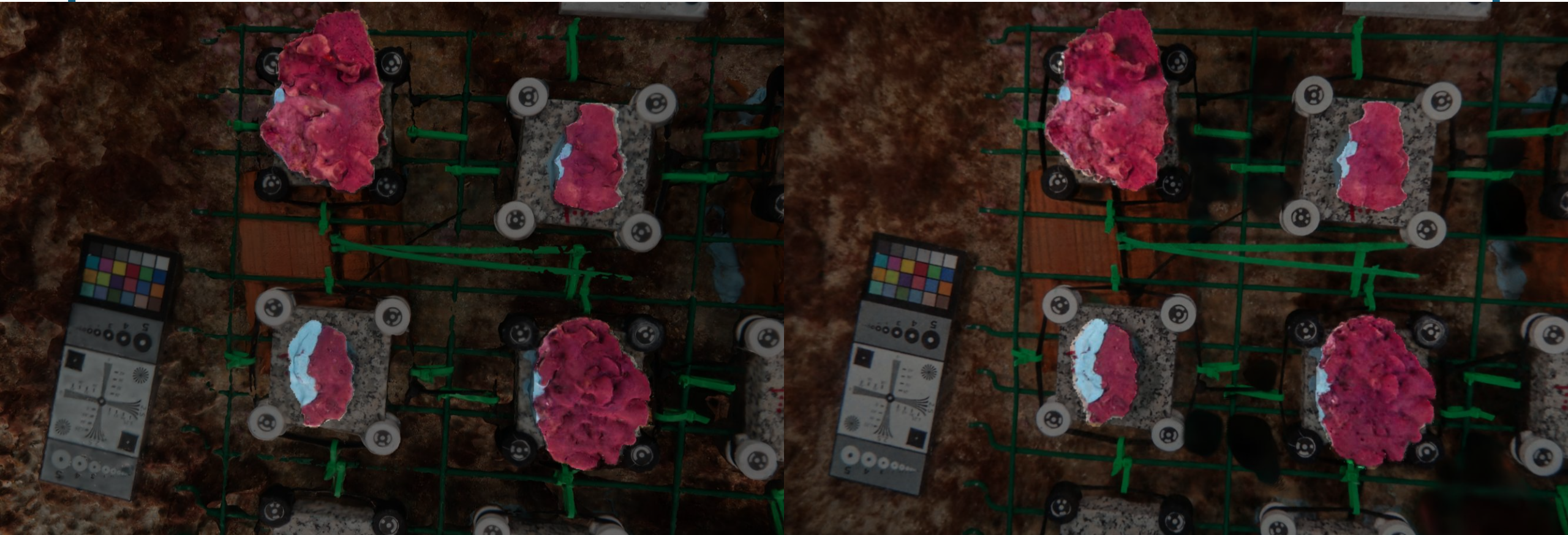


Comparison between t_0 and t_1

We generated identical synthetic views for the two epochs and performed a comparison focused solely on the region containing the four thalli.

 **Metashape**

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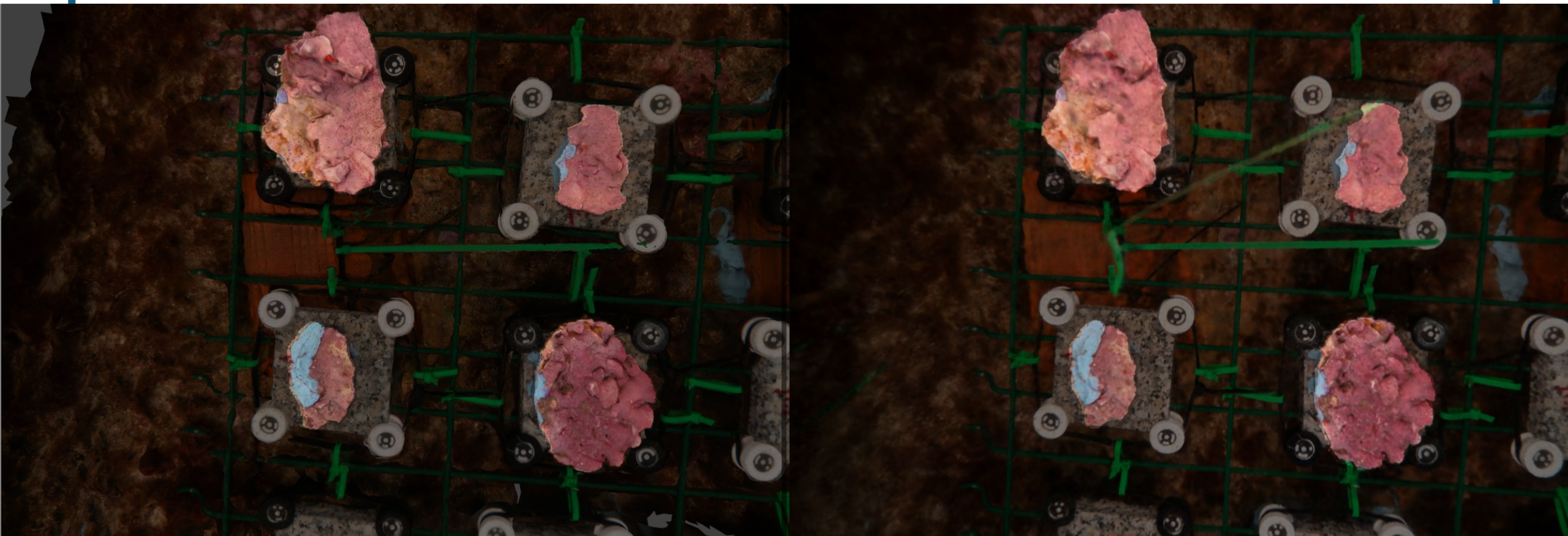


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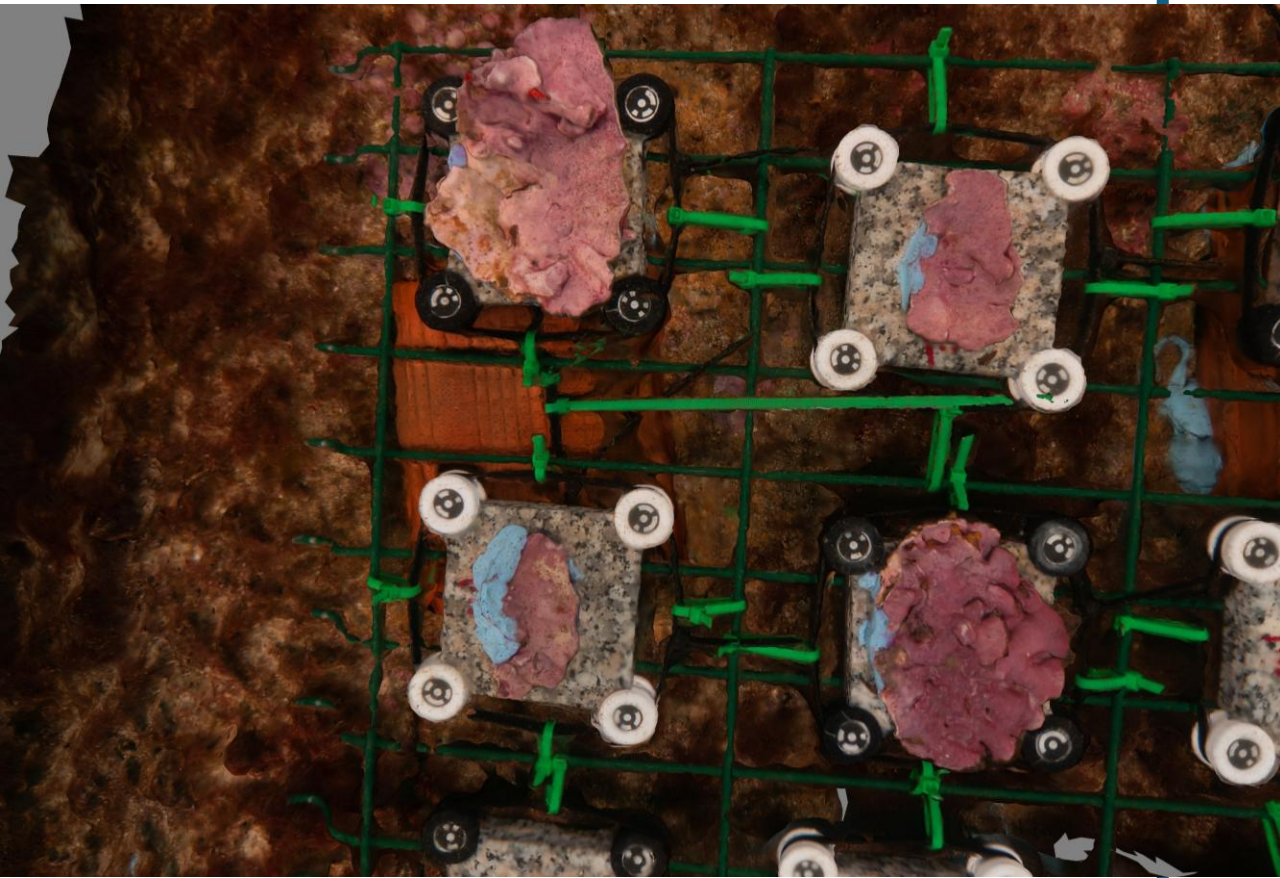
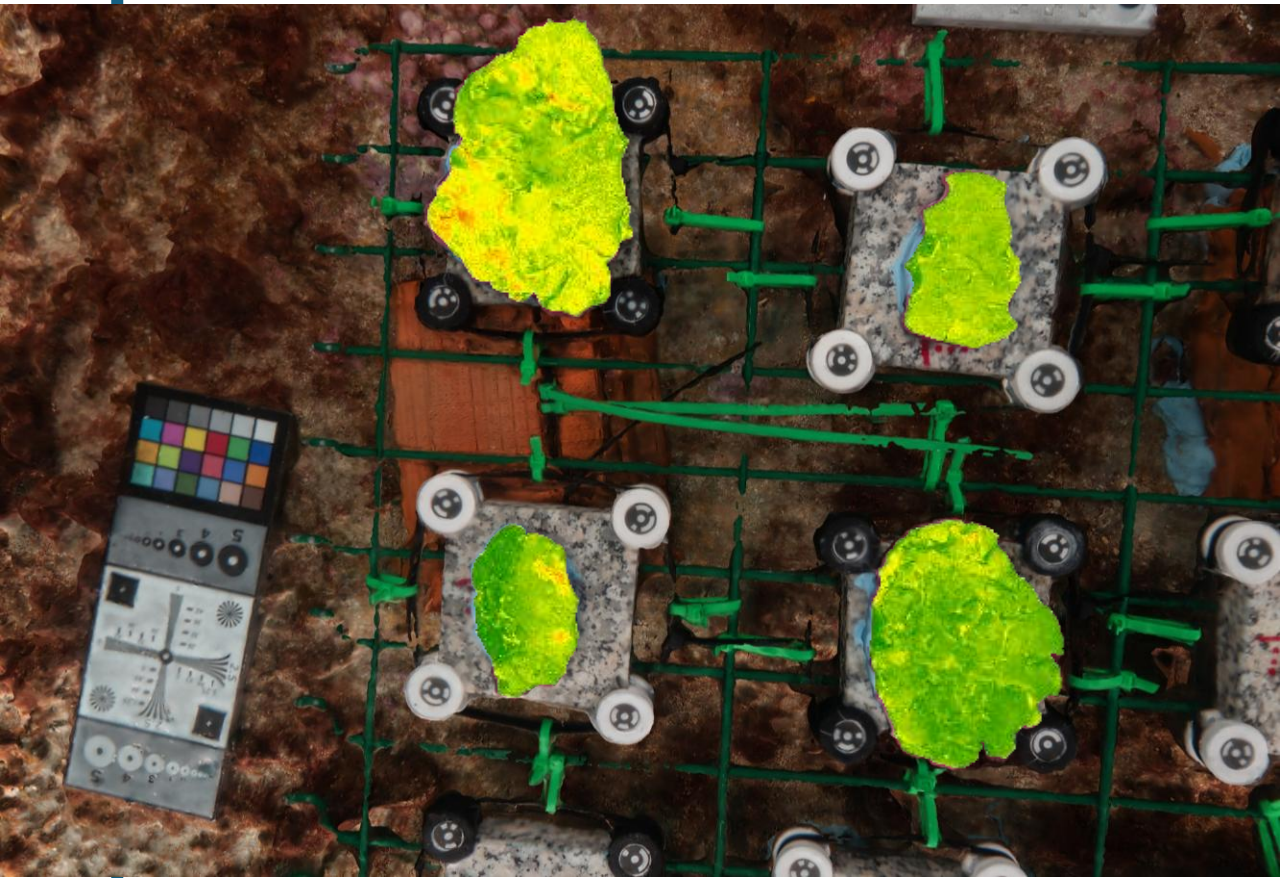
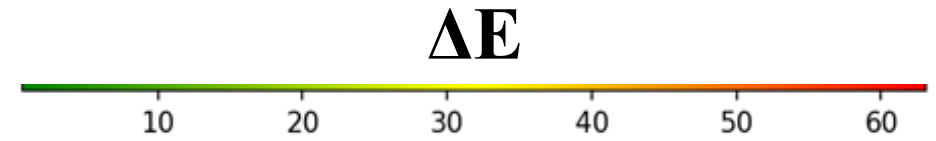
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This tool enables ecologists to quickly identify the most stressed areas and focus their analyses accordingly.

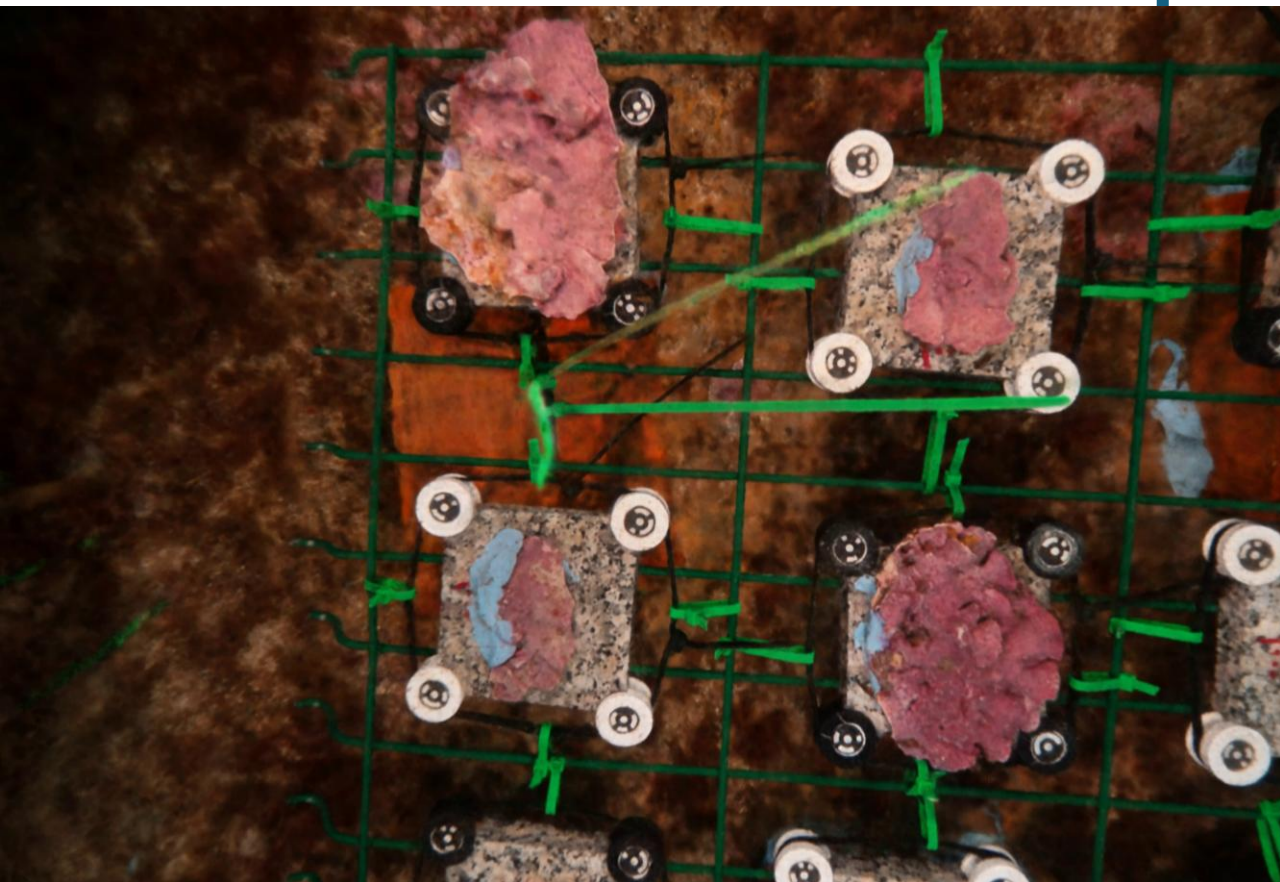
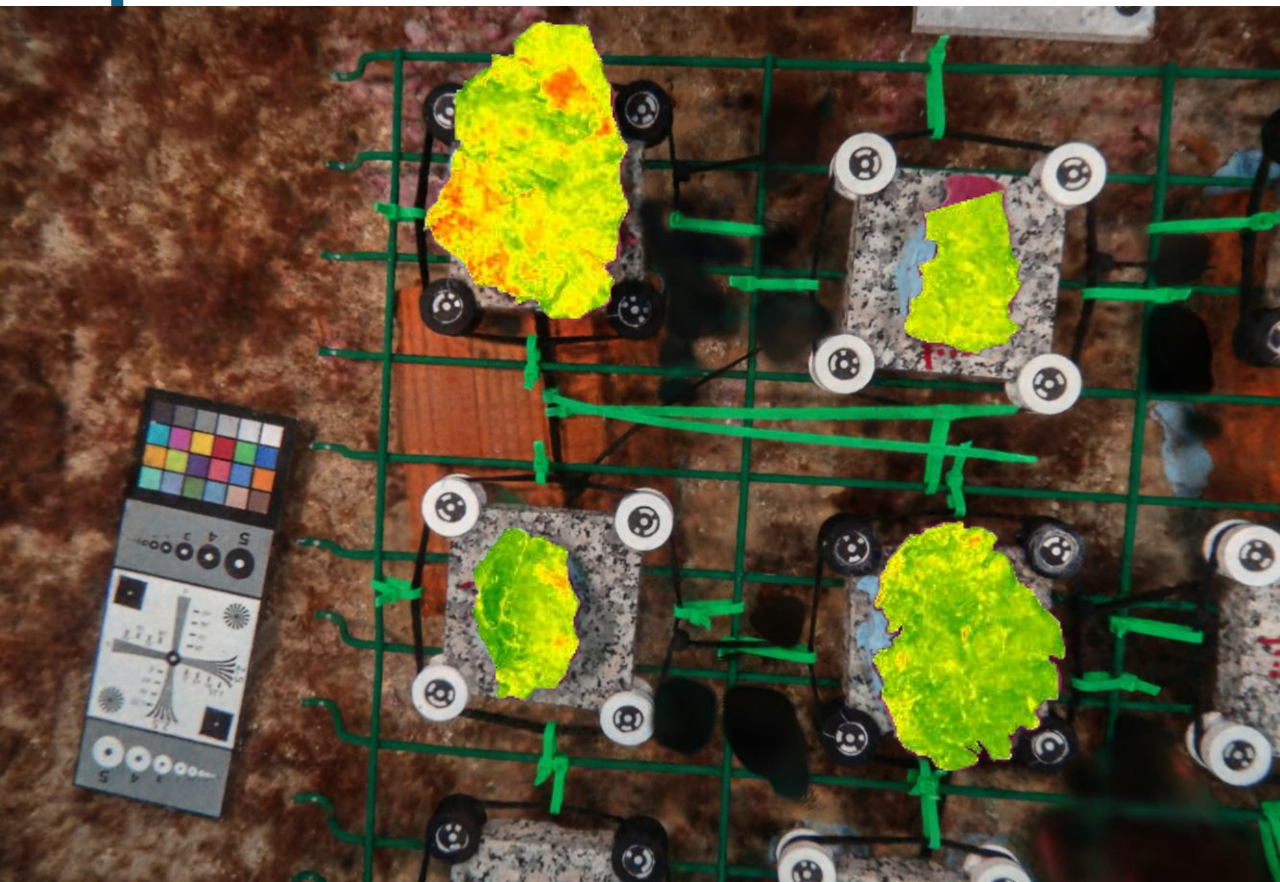
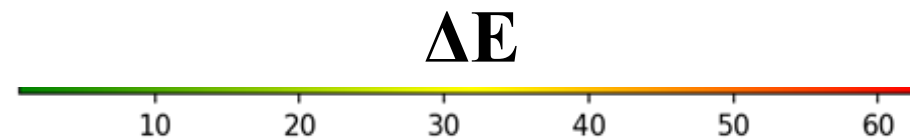


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Radiometric comparison

Our results show average ΔE values.

SfM $\Rightarrow \Delta E = 21.5$

NeRF $\Rightarrow \Delta E = 24.3$

Metric	t_0 vs t_1 SfM	t_0 vs t_1 NeRF
ΔE Max	68.94	63.06
ΔE Mean	21.57	24.37
ΔE Median	21.12	23.58



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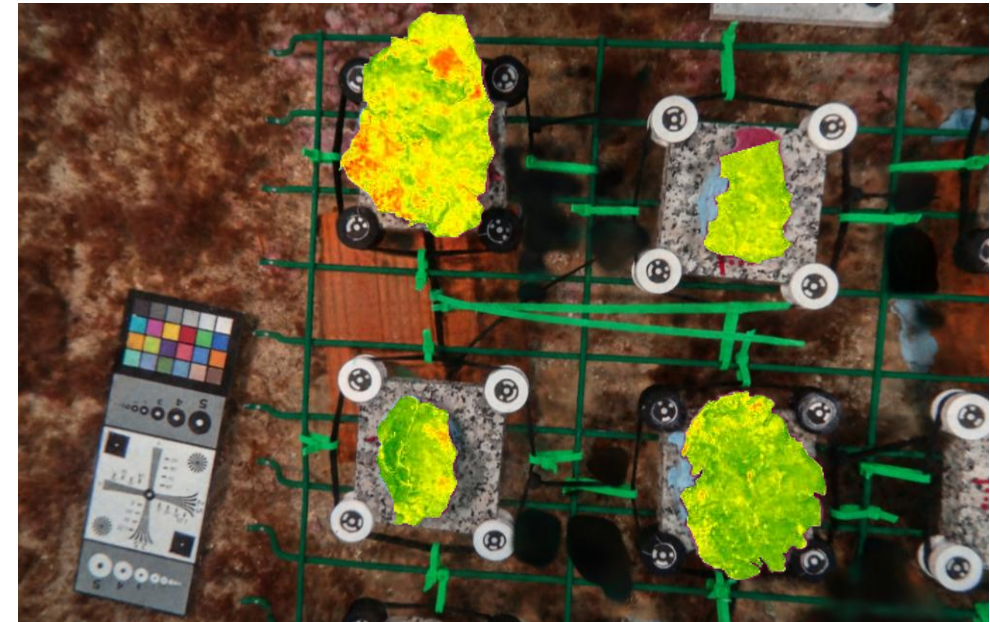
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Widespread and clearly perceptible radiometric changes were observed on the algae between acquisitions, potentially due to bleaching or other biological factors.

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CONCLUSIONS



Recap



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Main Finding: Our method enables the detection and quantification of significant radiometric changes over time, overcoming the limitations of traditional image acquisitions.



Innovation: Generating images from consistent viewpoints solves the issue of varying camera positions across different time points, ensuring objective and repeatable comparisons.



Impact: This framework provides a solid foundation for developing automated monitoring tools and supporting domain experts in the conservation of marine habitats.



Current Limitations and Future Developments



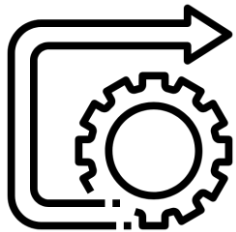
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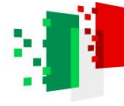


Future Developments:

- Test the methodology in more complex marine environments.
- Experiment with NeRF models that explicitly handle refraction.
- Aim for integration into real-time monitoring systems.



Acknowledgements



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Project title: **MANATEE – Monitoring and mApping of mariNe hAbitat with inTegrated gEomatics technologiEs**
CUP: **I53D23001970006**

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