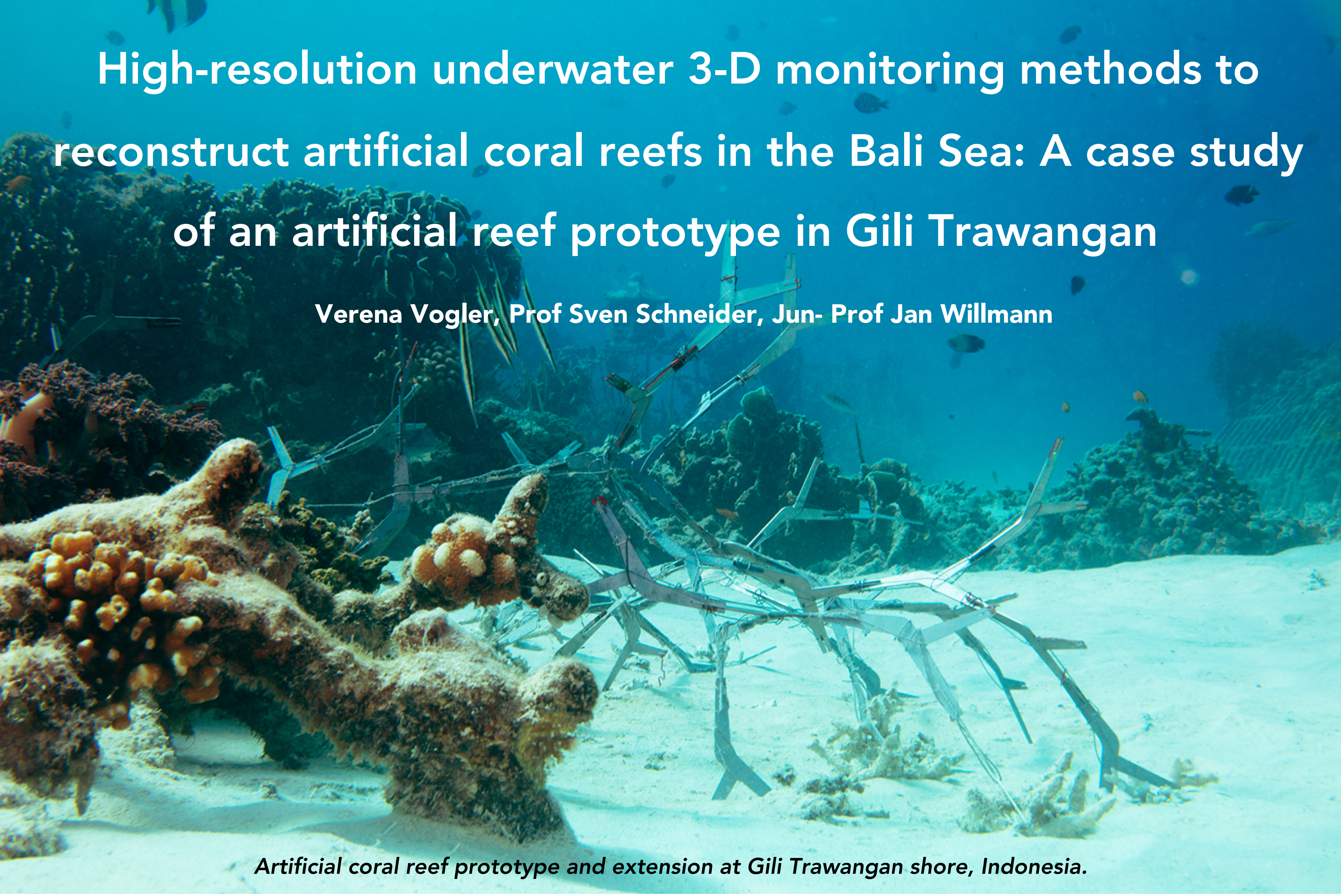
High-resolution underwater 3-D monitoring methods to reconstruct artificial coral reefs in the Bali Sea: A case study of an artificial reef prototype in Gili Trawangan

Verena Vogler, Prof Sven Schneider, Jun- Prof Jan Willmann



Artificial coral reef prototype and extension at Gili Trawangan shore, Indonesia.

Bauhaus-Universität Weimar
Studienstiftung des deutschen Volkes
Andrea von Braun Stiftung voneinander wissen
CORAL REEF ALLIANCE
UWF UnterWasserFotografie
Baars-CIPRO Civil Engineering Professional Diving
GILI ECO TRUST

What are artificial coral reefs?

Reef Ball Foundation placed Reef Balls™ artificial-reef-created-off-phuket-coast, Biorock© reef in Pemuteran Bali.

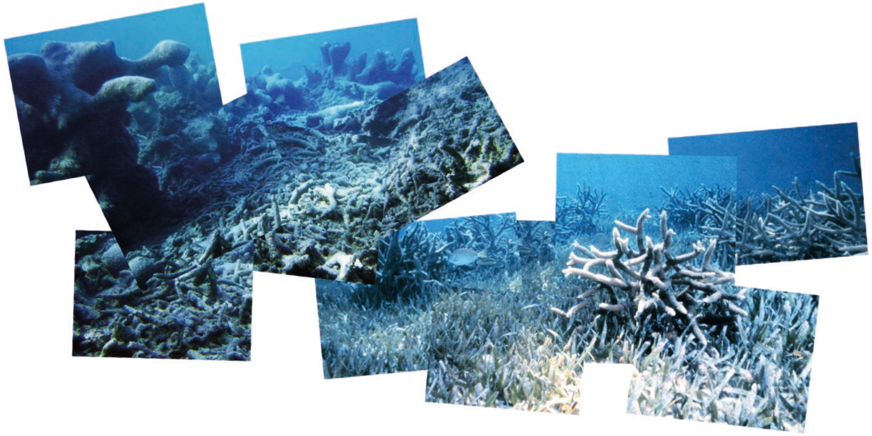
Why do we need help repairing coral reefs?

Coral reefs are the worlds best shore line protection devices (Munk et al, 1948).

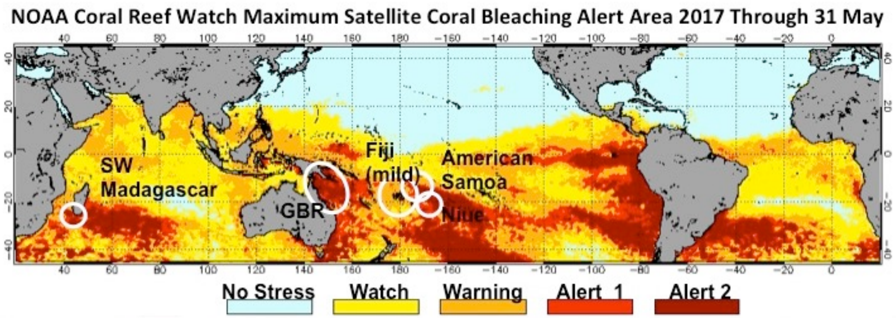
Habitat for corals and fish.

Major economical factor for local fishing-, snorkeling and diving tourism industry.

Currently they are threatened and already partly destroyed: rising sea temperature due to global warming, pollution and elevated levels of CO_2 acidifies our oceans, dynamite fishing



Destroyed and bleached coral reef.



NOAA Coral Bleaching Alert Area 2017.

Munk, W.H., and Sargent, M.C. (1948). Adjustment of Bikini Atoll to ocean waves. Eos, Transactions American Geophysical Union 29, 855–860.
https://coralreefwatch.noaa.gov/satellite/analyses_guidance/global_coral_bleaching_2014-17_status.php

Goals for new artificial reef design

Sustainable approach to artificial coral reef design

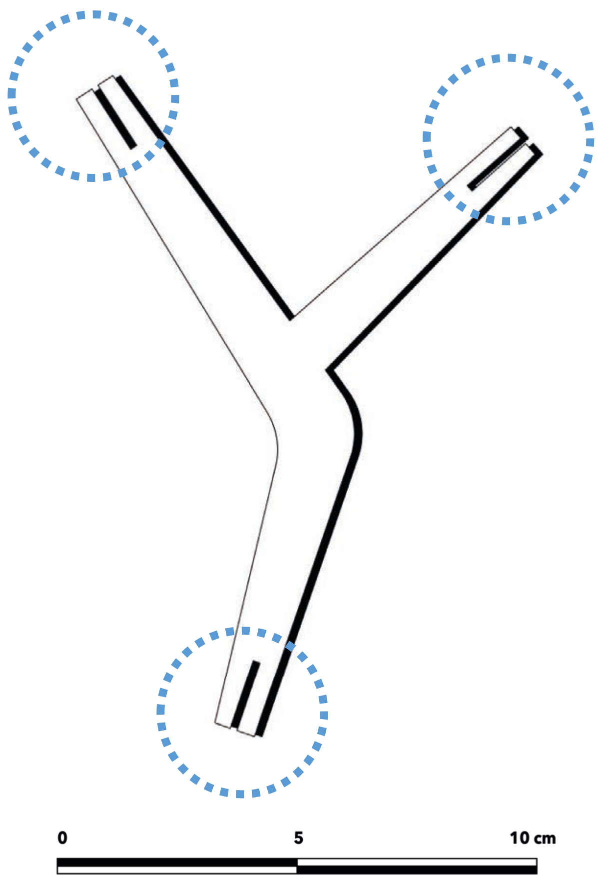
Inspired by the geometry of natural coral reefs

Component based system (3-D puzzle) to enable underwater assembly

Adaptable to different topographies of the sea floor

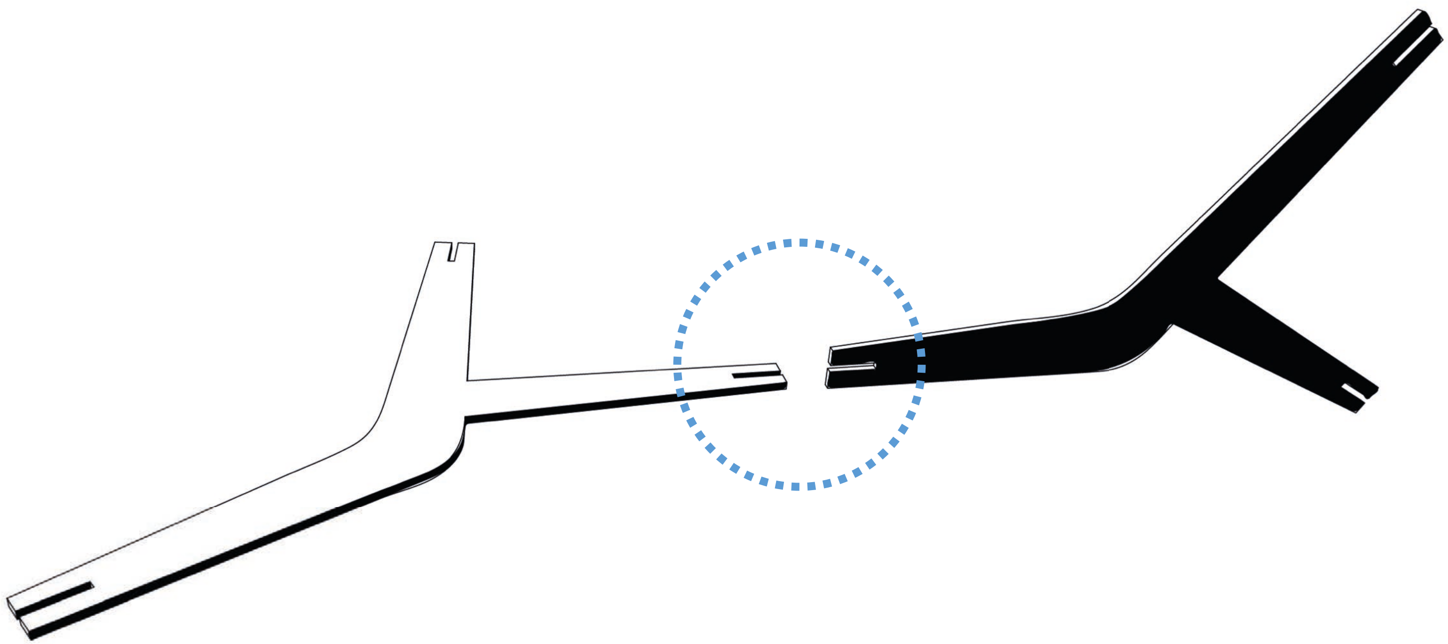
Extendable

Design of an Artificial Reef Prototype (ARP)



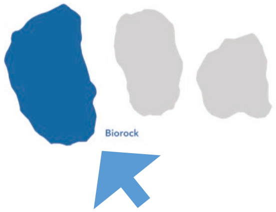
Design of construction element with 3 connection points with a dimension of 140 mm length and 100 mm width.

Design of an Artificial Reef Prototype (ARP)



Push-fit connections for Artificial Reef Prototype.

ARP launch in Gili Trawangan, Indonesia



Maps of Indonesia, Bali and Lombok and the Gili Islands.

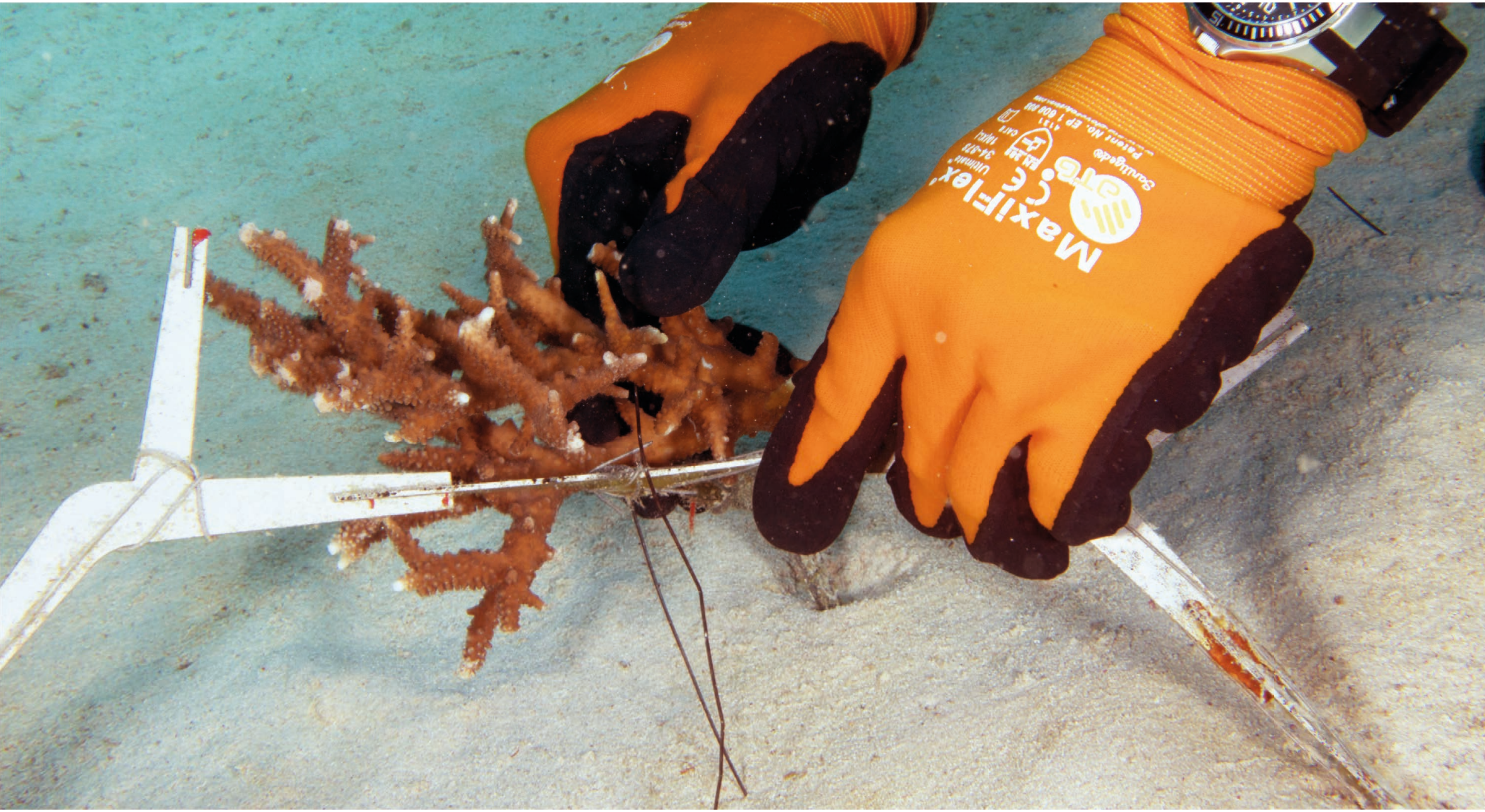
Artificial Reef Prototype (ARP) in 2012

Artificial Reef Prototype test launch at the beach during the 8th Biorock Reef Restoration Workshop in November 2012 in Gili Trawangan, Lombok in Indonesia. 100 construction elements were used.

ARP launch in Gili Trawangan, Indonesia

Artificial Reef Prototype underwater launch ***at our study area in the south east of Gili Trawangan island.***

ARP launch in Gili Trawangan, Indonesia



Attachment of broken pieces of coral.

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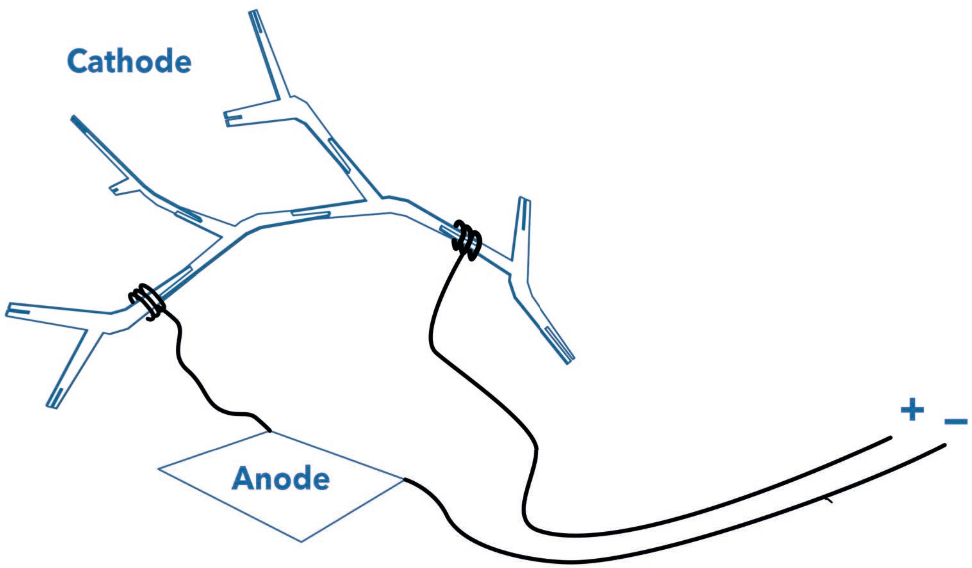

Artificial Reef Prototype works as cathode and a titanium mesh as anode in underwater electrolysis that dissolves minerals from seawater to build a calcium carbonate layer around our construction elements, where corals can start to settle (Hilbertz, 1979).

HILBERTZ, W. H. (1979). Electrodeposition of minerals in sea water: Experiments and applications. IEEE Journal of Oceanic Engineering 4, 94–113.

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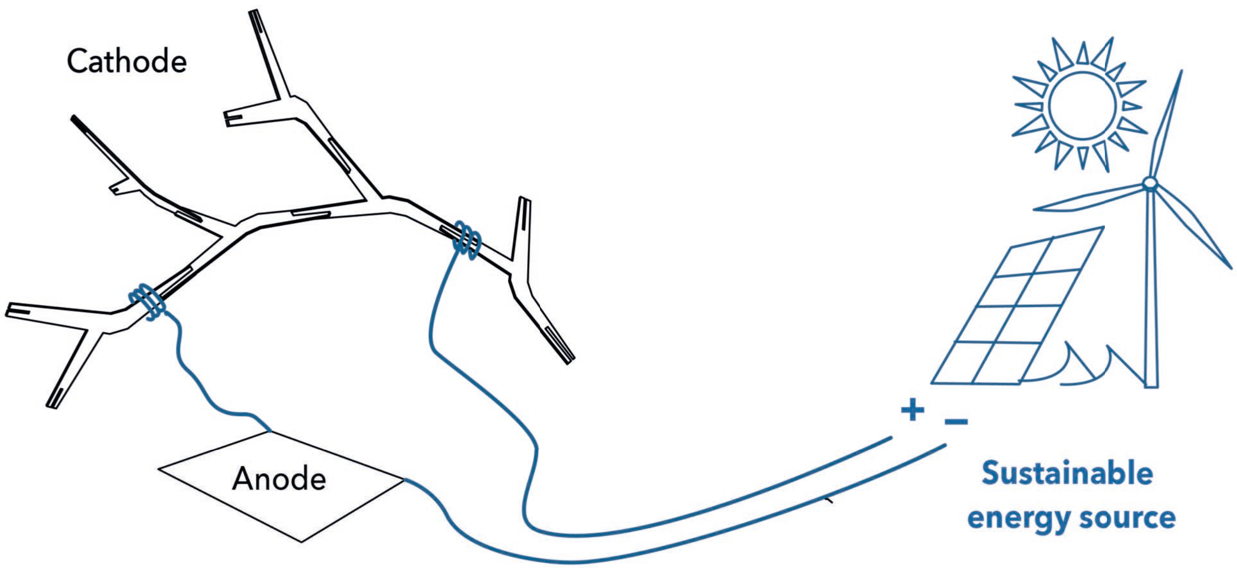

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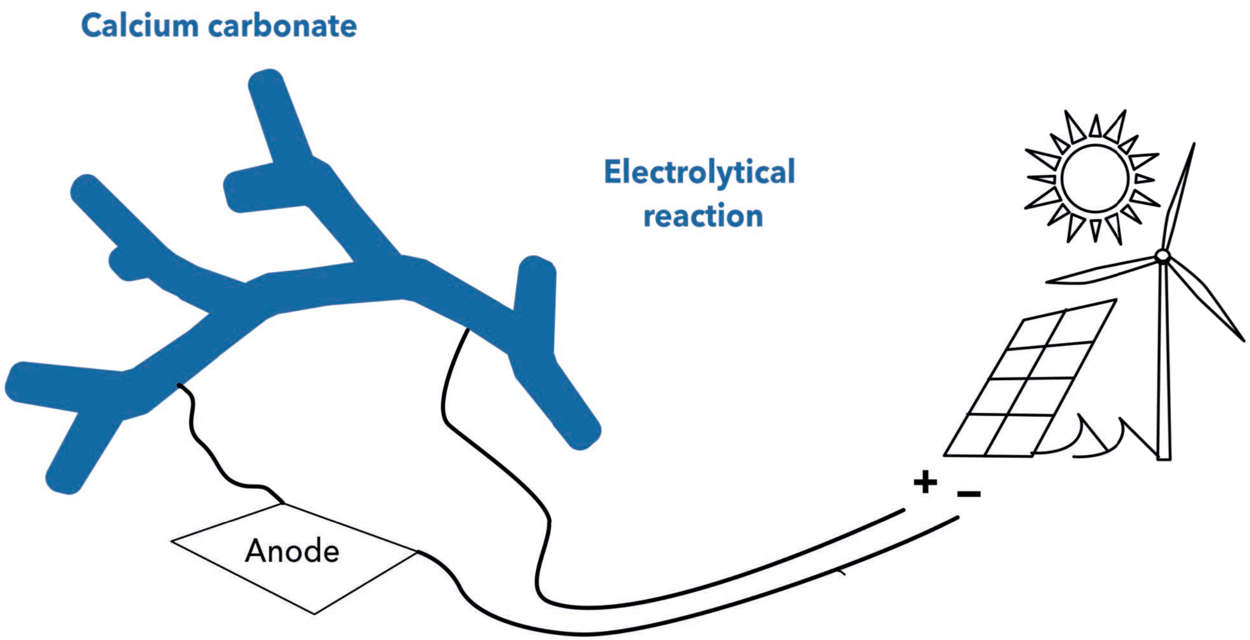
Biorock© Technology



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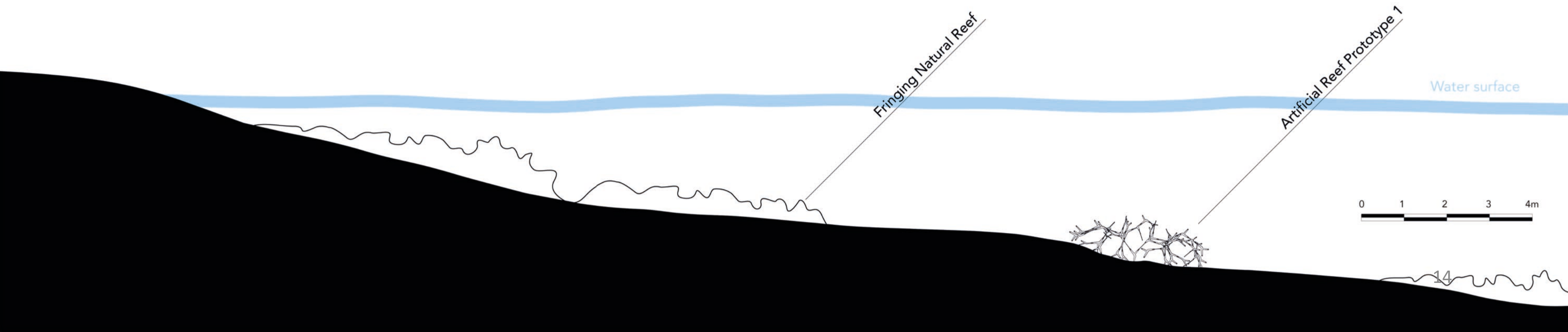
Underwater Monitoring

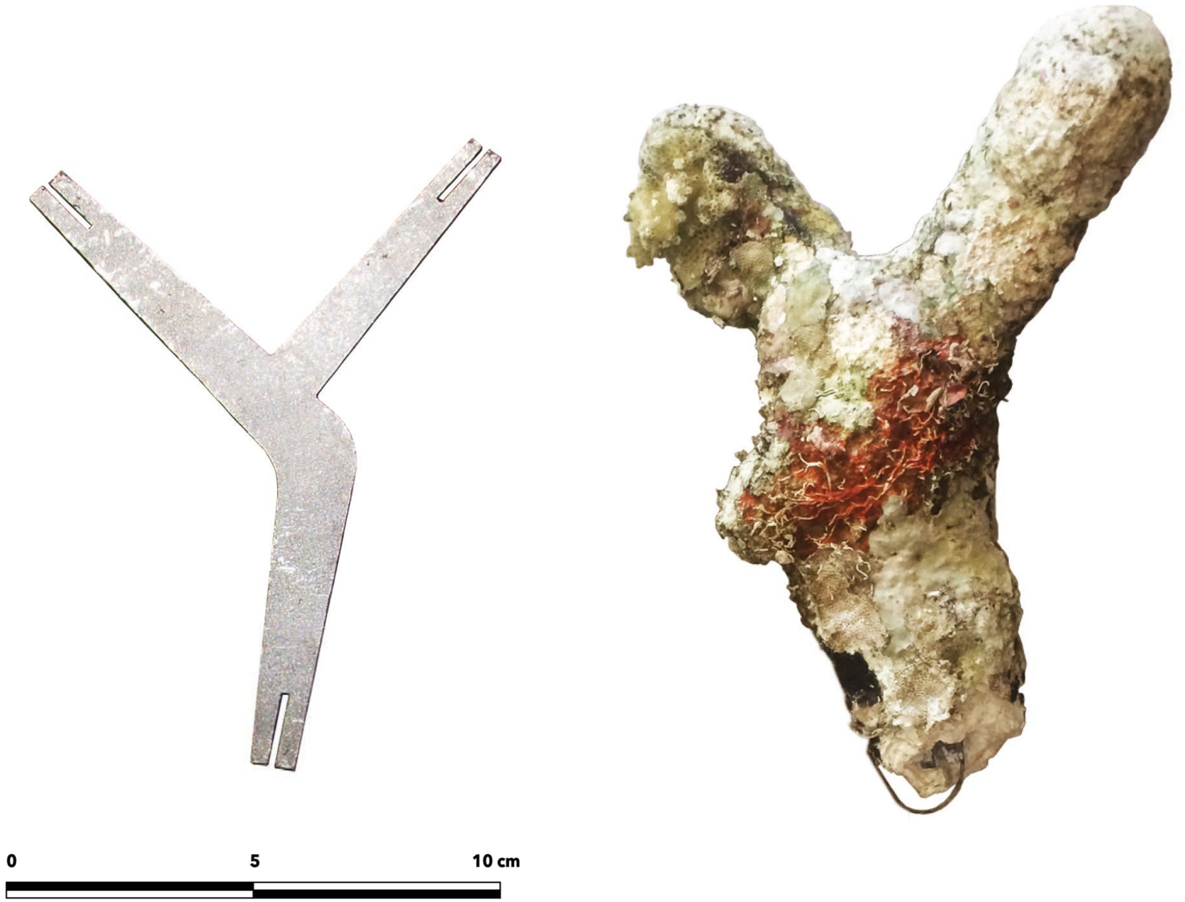
Documented Artificial Reef Prototype growth over five years 2012-2017.

Artificial Reef Prototype Extension

Extension using 100 additional construction elements in October 2017.



Growth



Comparison construction element with and without grown calcium carbonate layer of ARP after 5 years. Calcium carbonate layer has grown 1.5- 2.5 cm around the construction element.

Conclusions- Design of ARP

Sustainable approach to reef restoration as it uses dissolved minerals in seawater (material) and sustainable energy resources (tidal, wave, wind and solar), and binds CO2 in calcium carbonate CaCO3

Component based system; compared to concrete elements lightweight and can be deployed underwater by a single diver

ARP works as cathode and accumulated calcium carbonate

ARP works as habitat for sea life

ARP can be extended using additional pieces that adapt to to the topography of the seafloor

ARP resisted strong storms each January and one earth quake of 6.9 (Aug 2018) and multiple aftershocks > 5.0

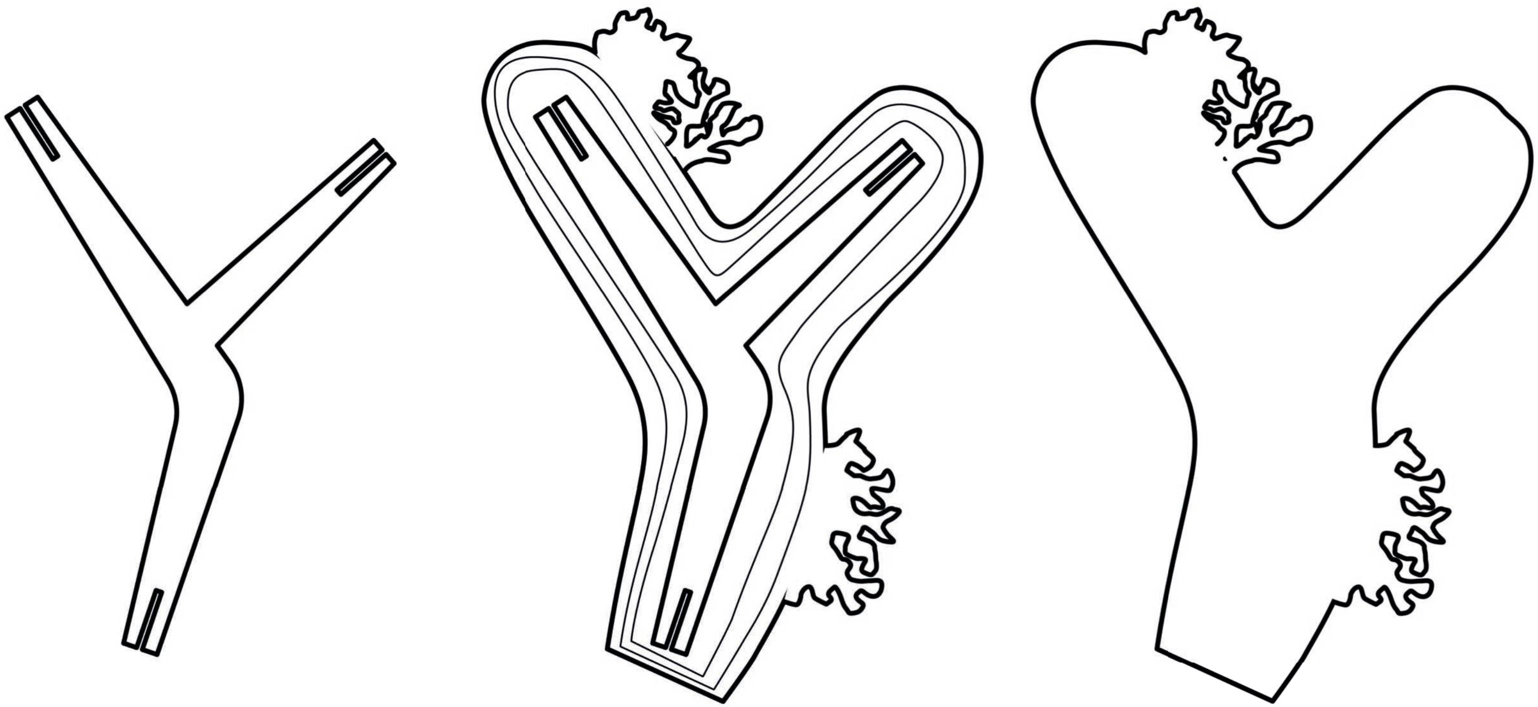
From design to monitoring

How to deeply understand such a system?

How to sytemize such an approach?

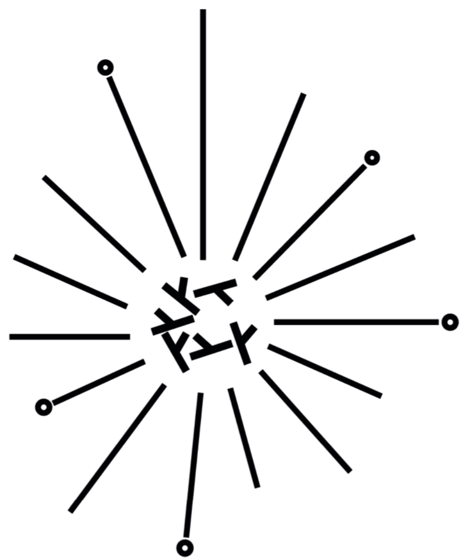
How to enable a growth- aware design approach for underwater artificial coral reefs purposes?

High- resolution monitoring: Typology of different 3-D Models

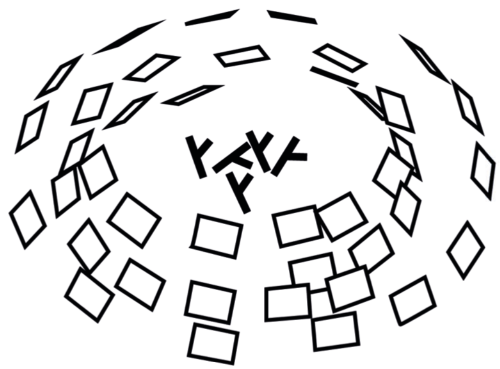


Original construction element, voxel model and surface model.

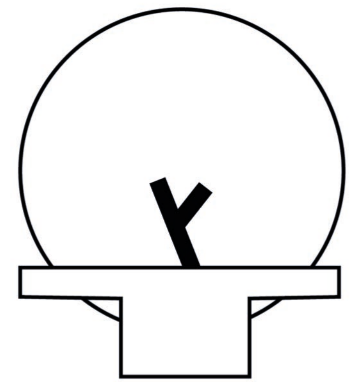
High-resolution underwater 3-D monitoring methods



Underwater Laser Scanning



Underwater Photogrammetry

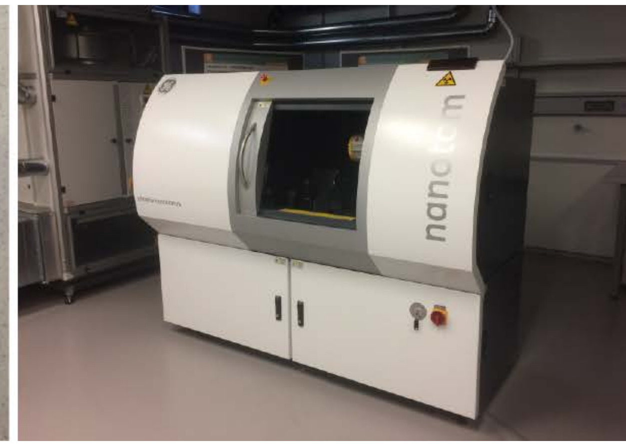


CT Scanning

Underwater

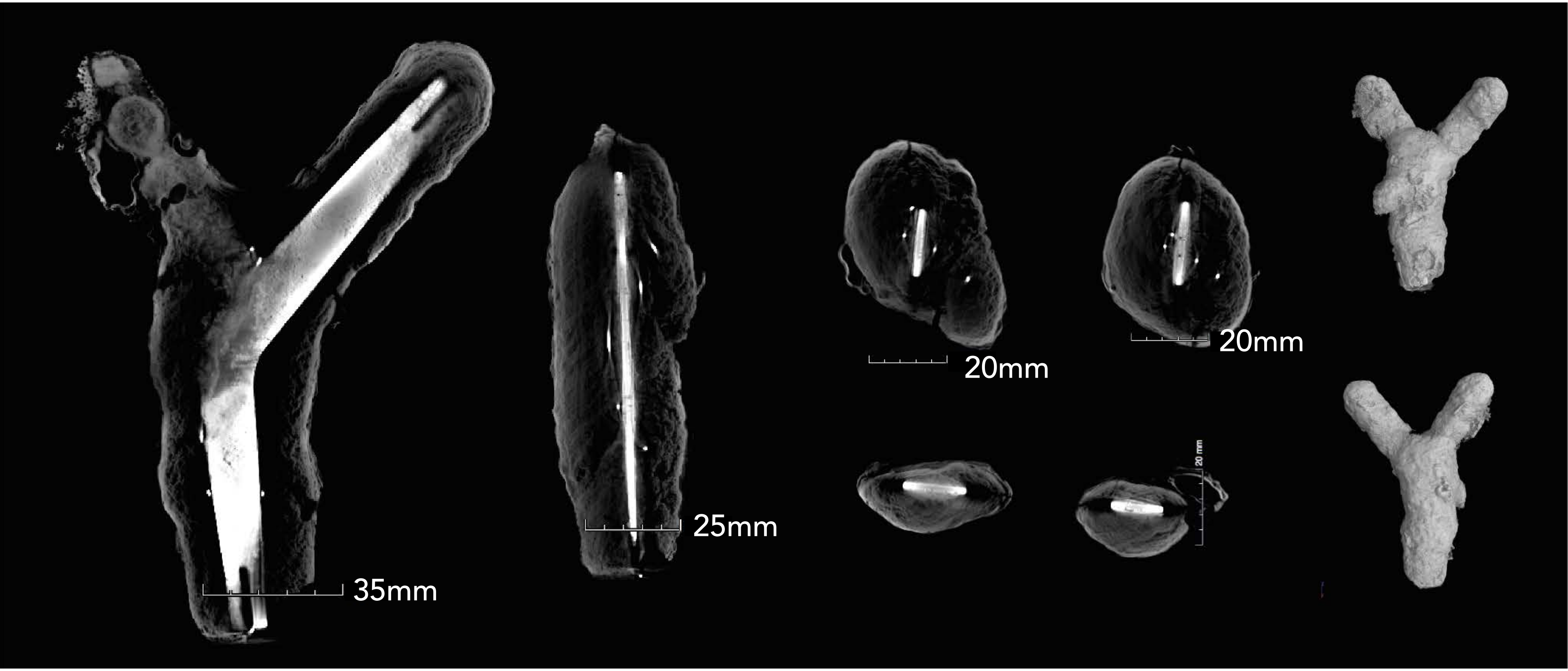
Lab

CT Scan (Lab)



Extraction of sample, CT Scanner Nanotom M "research edition" at F.A. Finger-Institute for Materials Science of the Bauhaus- University Weimar.

CT scan results



Grey scale analysis , Voxel model displayed in Volume Graphics VGStudioMAX shows growth of calcium carbonate layer and condition of metal piece inside of the artificial coral reef.

Resolution of 0.1333mm

Two experimental underwater setups for high-res measurements

Lab

Test setup at Dive4Life Center in Siegburg, Germany, August 2017.

Underwater Laser Scanning
Underwater Photogrammetry

Field

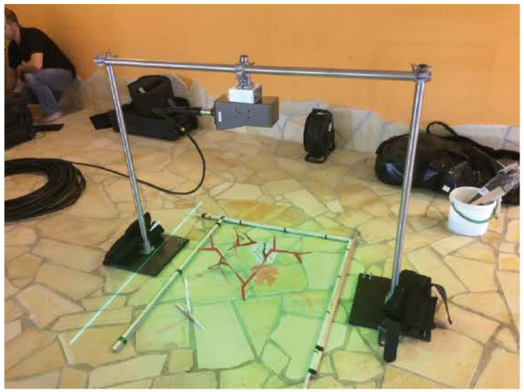
Field setup at Gili Trawangan, Indondesia, September 2017.

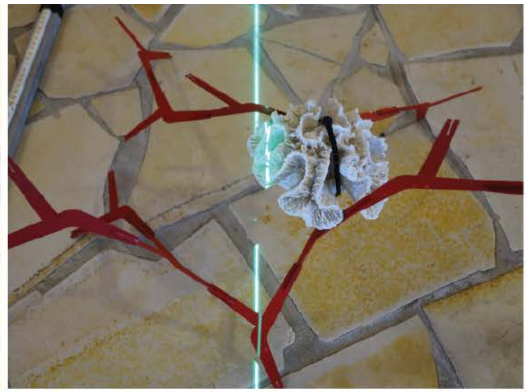
Underwater Photogrammetry

UWF UnterWasserFotografie

Baars-CIPRO Civil Engineering Professional Diving

Underwater laser scanning with M210UW Newton Labs





M210UW Underwater Laser Scanner

M210UW Underwater Laser Scanner; 22 individual scans of 610,000 points each.

Average deviation - submillimeter

Baars-CIPRO
Civil Engineering
Professional Diving

Underwater photogrammetry at Dive4Life

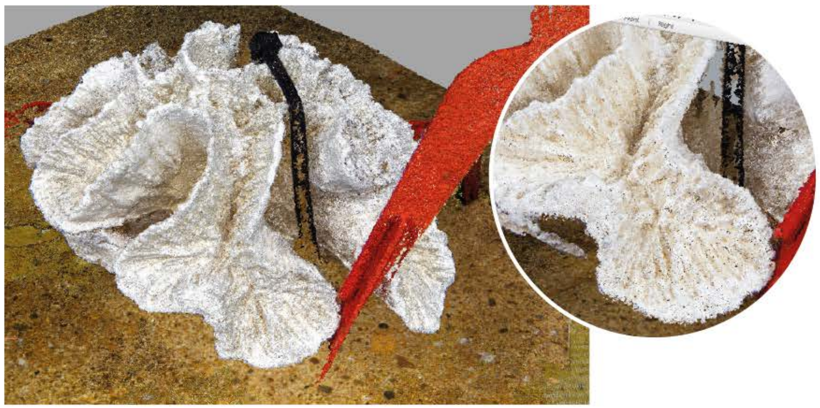
Sony Cyper-shot RX100 II

Average deviation - ±1.8 mm.

Point cloud model of millimeter accuracy, 16,901,081 points. 185 still images processed in PhotsScan Pro Version 1.4.4.

Sony Cyper-shot RX100 II, CMOS sensor of 20 MP (5472 x 3648 pixel), Underwater Housing, one video light.

Canon EOS 5DS R



Average deviation - ±1.1 mm.

Point cloud model of millimeter accuracy, 16,399,865 points. 190 still images processed in PhotsScan Pro Version 1.4.4.

Canon EOS 5DS R , CMOS sensor of 50.6 MP (8688 x 5792 pixel), a Canon 50 mm 2.5 Macro Lens, SEACAM Underwater Housing 5DMKIII, two SEACAM strobes (SF150D) and one video light.

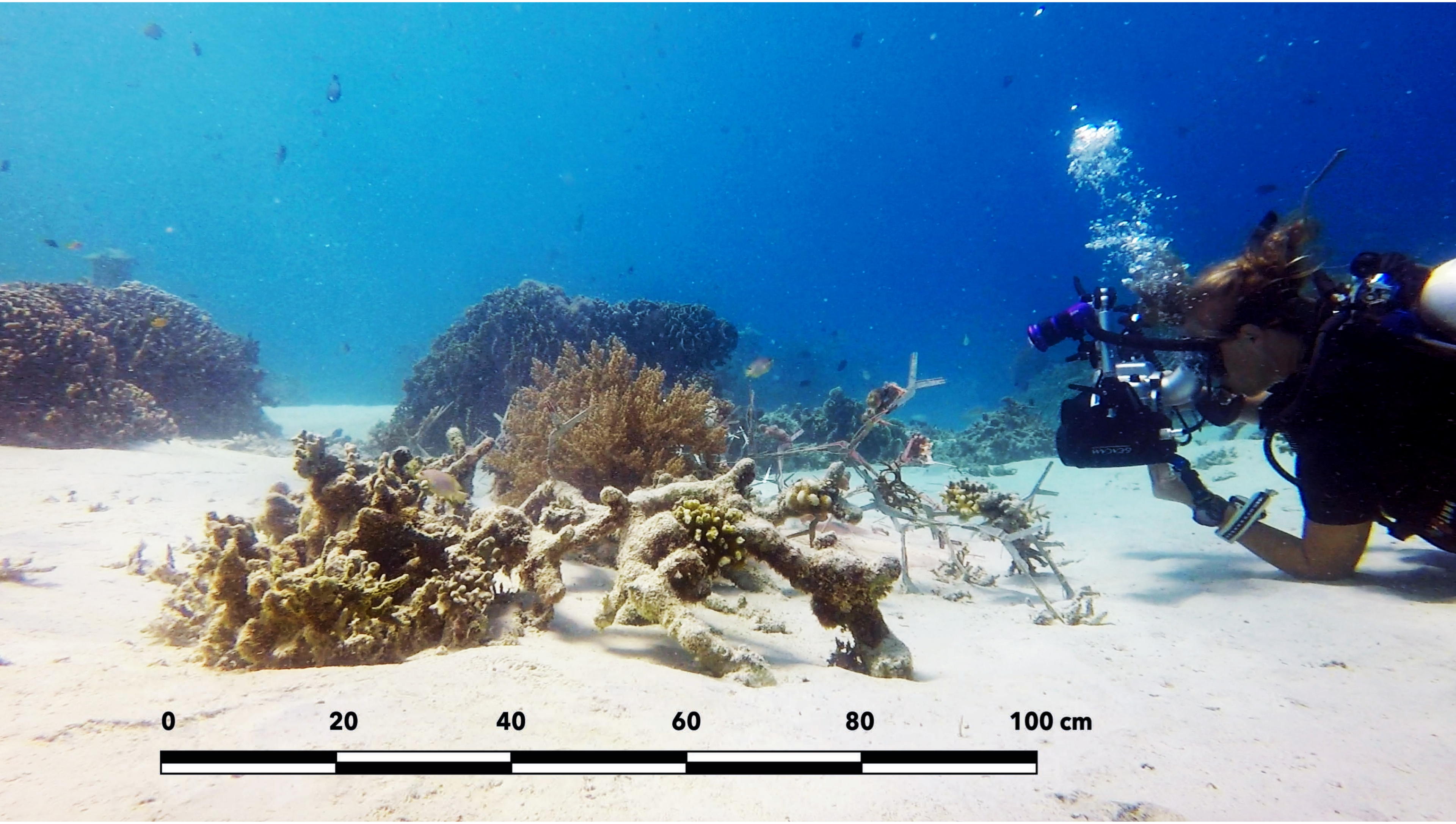
Comparison UW laser scanning vrs. UW photogrammetry

UW LS 22 point cloud models, precision five times higher than UW Photogrammetry

Handling in the field of UW LS equipment more difficult compared to UW photogrammetry equipment

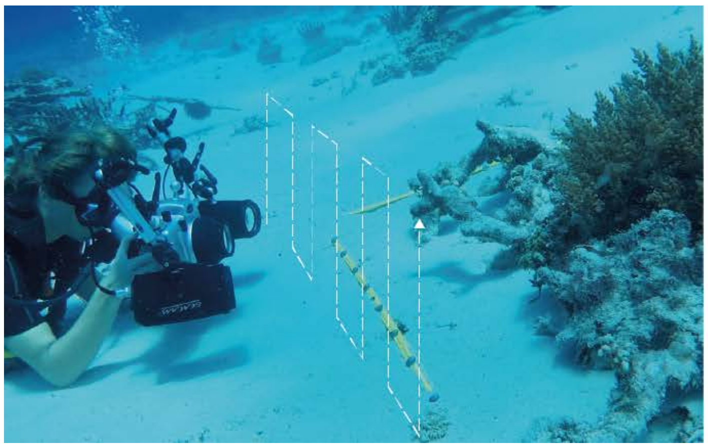
UW laser scanning experimental setup needs greater financial resources

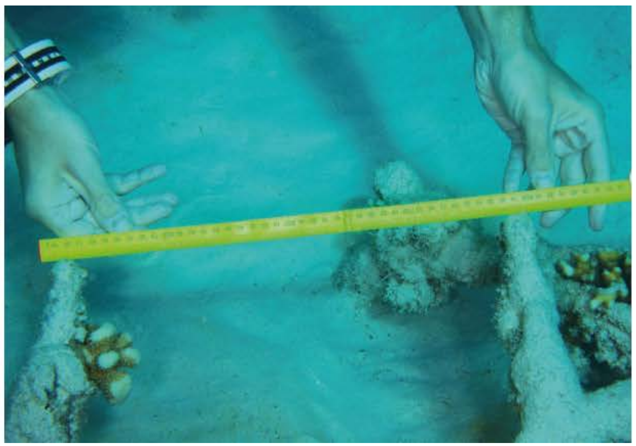
Underwater photogrammetry in the field



Data collection, September- October 2017 using Canon EOS 5Ds R in the field.

Underwater photogrammetry in the field





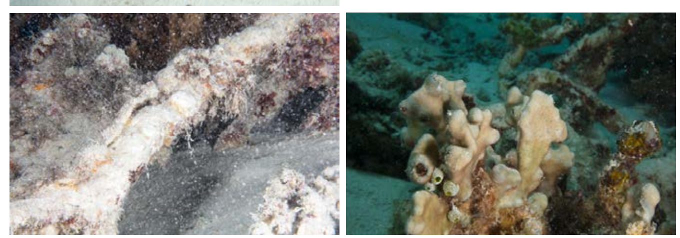
Following lawn-mower pattern of one of the faces of ARP, Portable plastic rulers with led attached were placed as reference next to ARP 1; about 200 manual measurements of ARP were taken and documented.

Challenges for UW photogrammetry in the field

High amount of moving objects

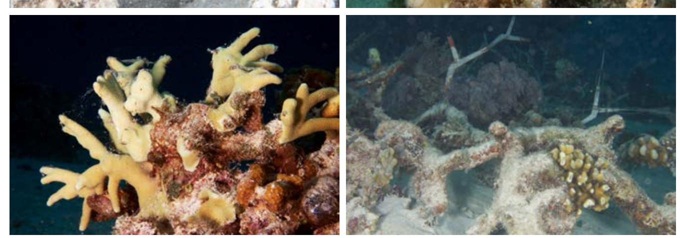
Shadows caused by sunlight and strobes

Moving particles by currents, backscatter

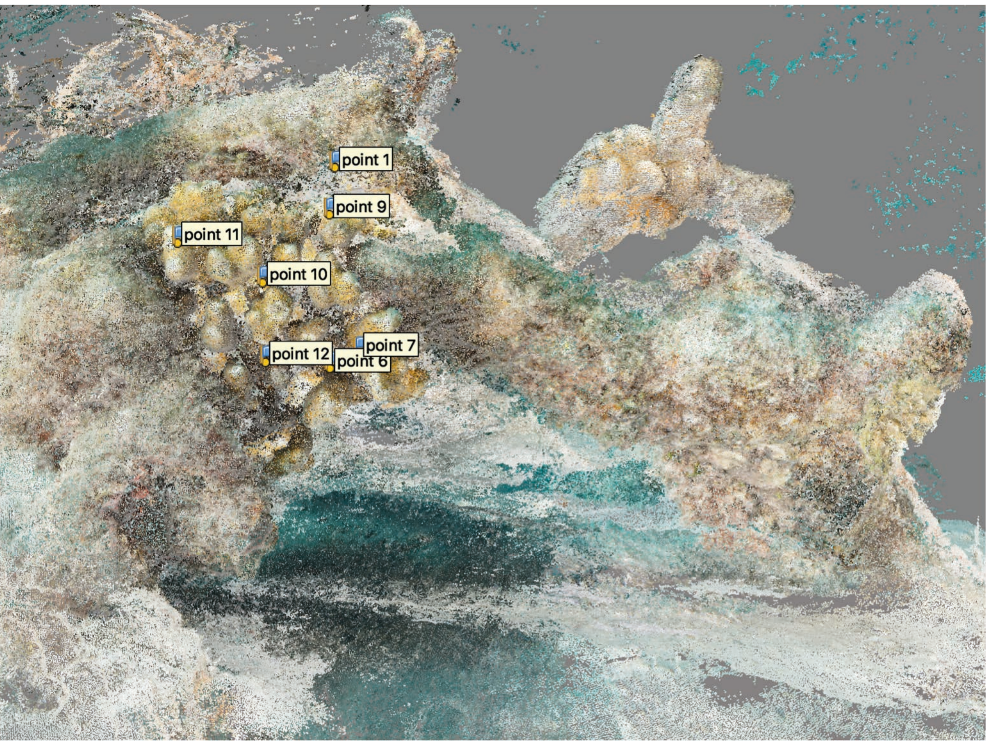


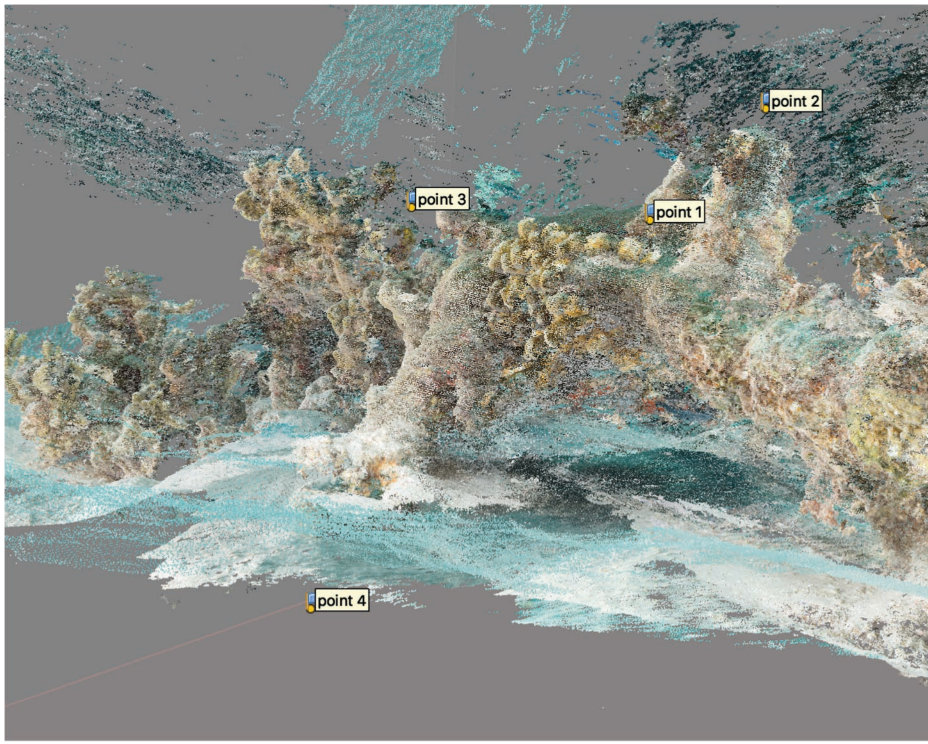
Visibility

Overall number of dives and resulting partial models



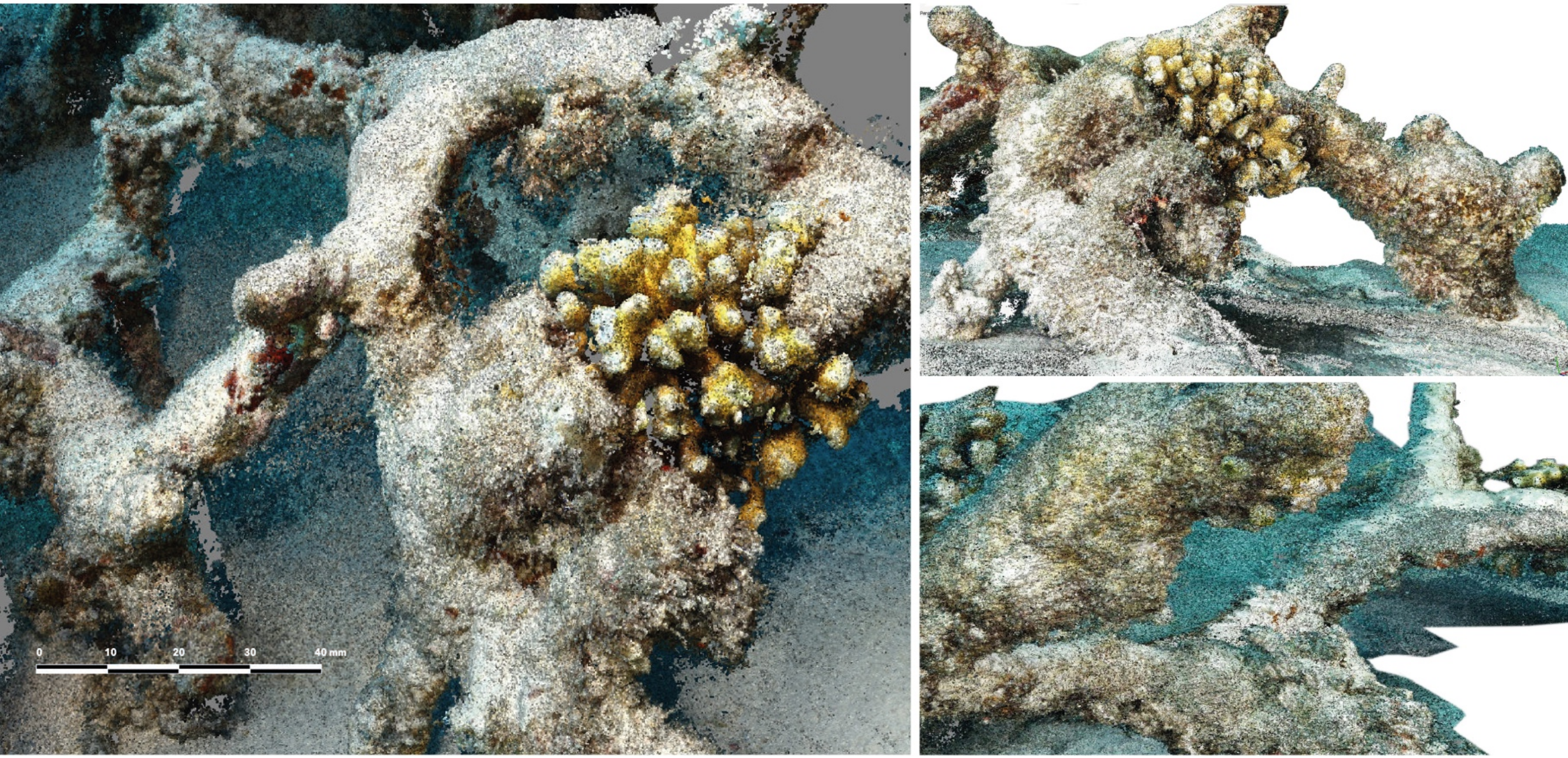
Underwater photogrammetry data processing results at **low** resolution



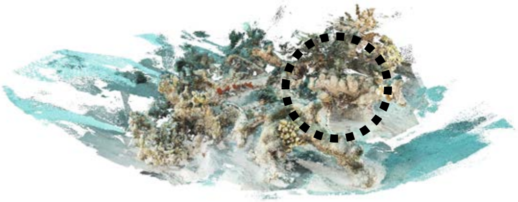


We aligned all 4058 still images collected at low resolution (each still 300KB).

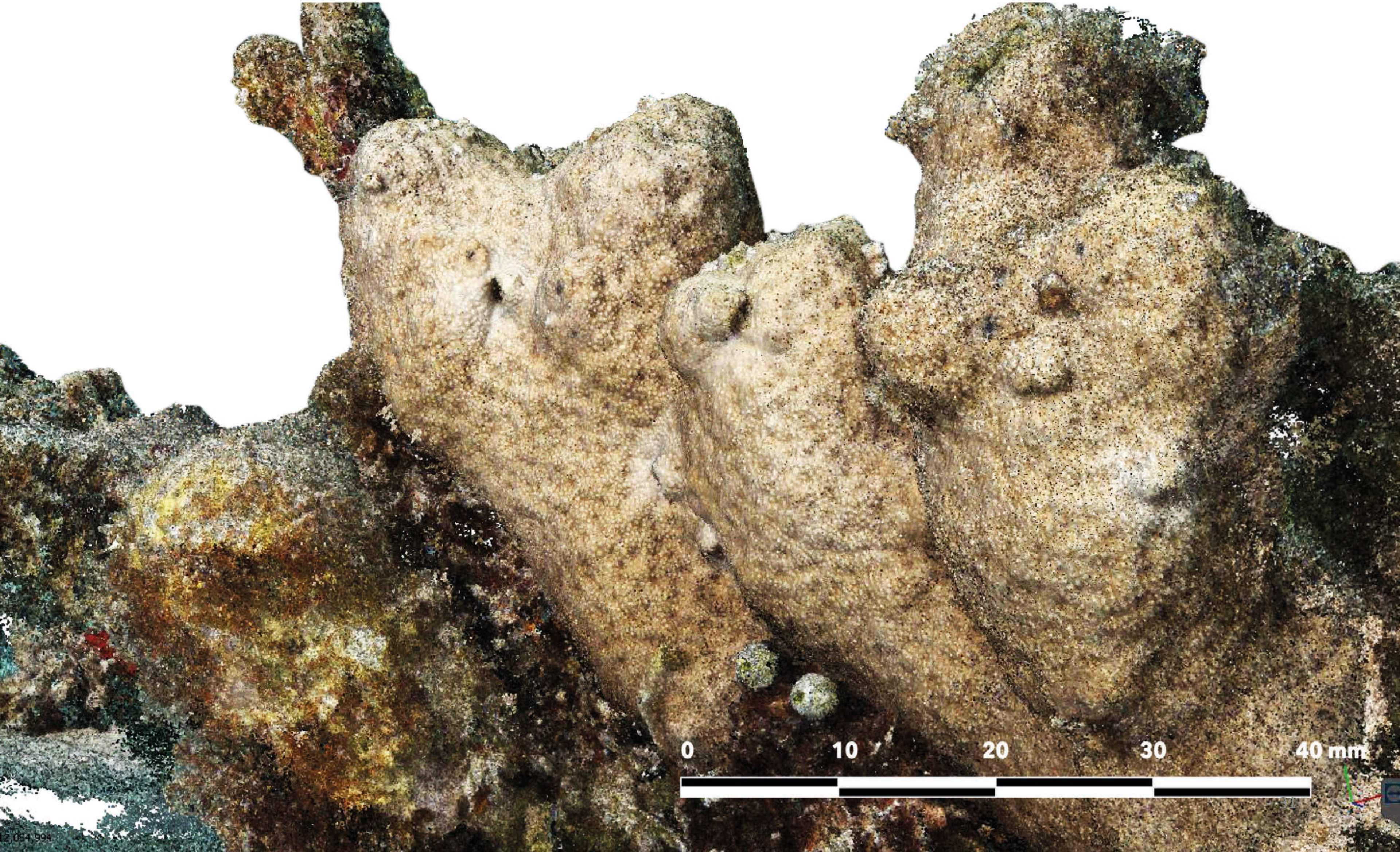
Underwater photogrammetry reconstructed **high** resolution point cloud models

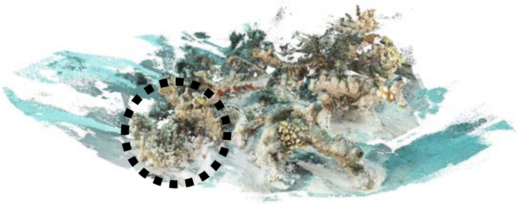


3-D reconstructed point cloud model from still images (8688 x 5792 pixels).

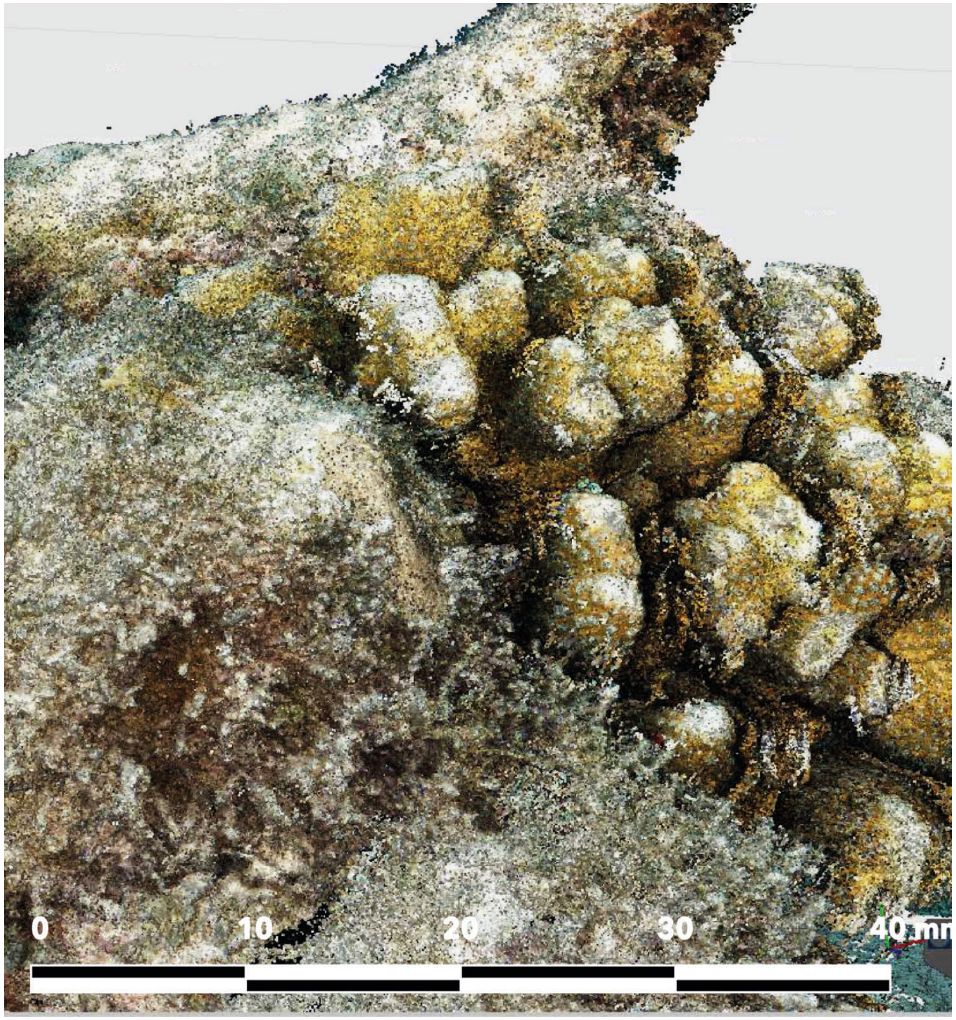


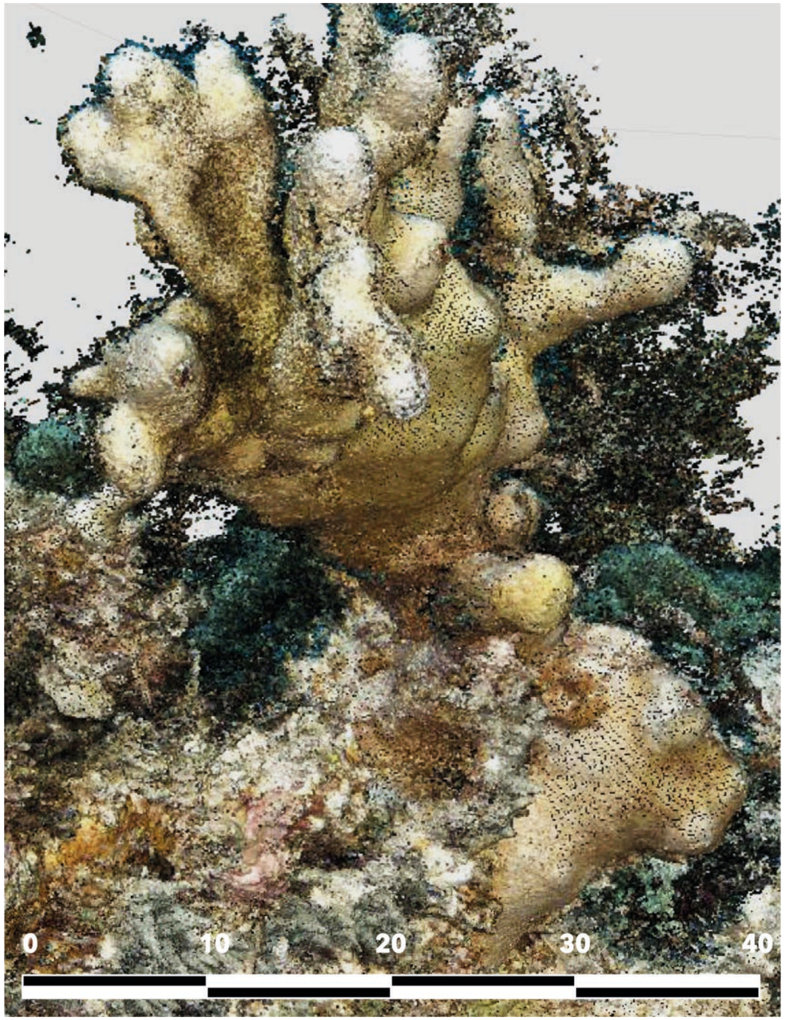
Underwater photogrammetry results

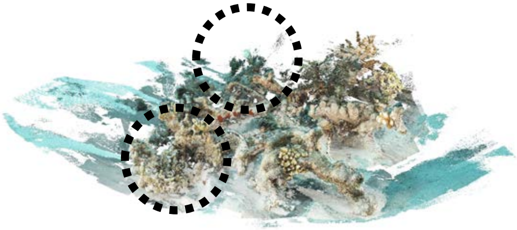




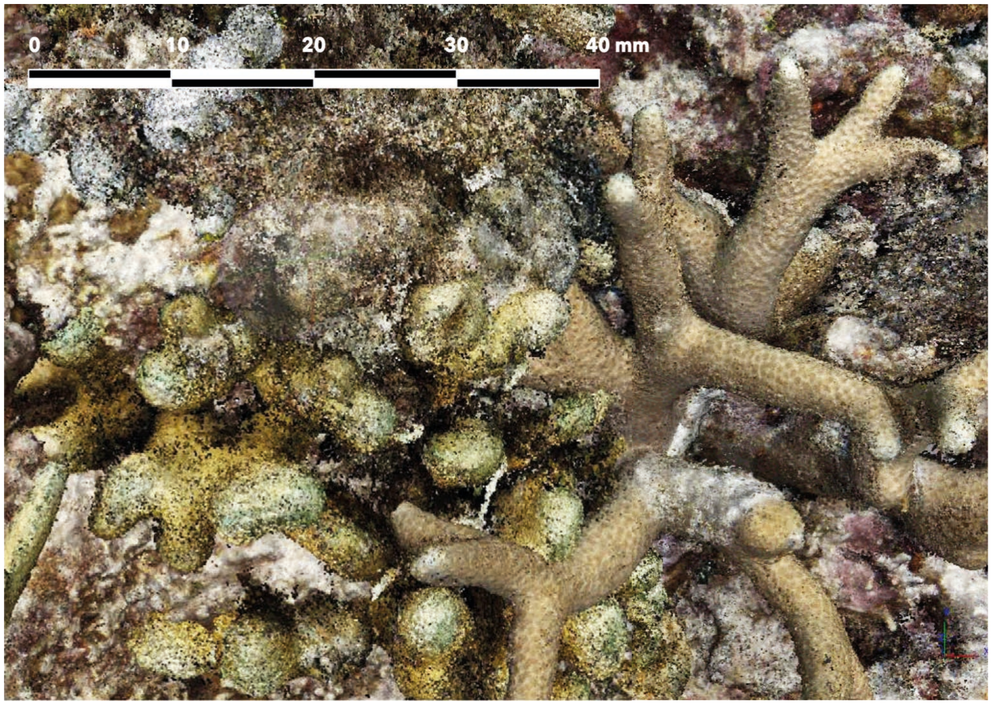
Underwater photogrammetry results

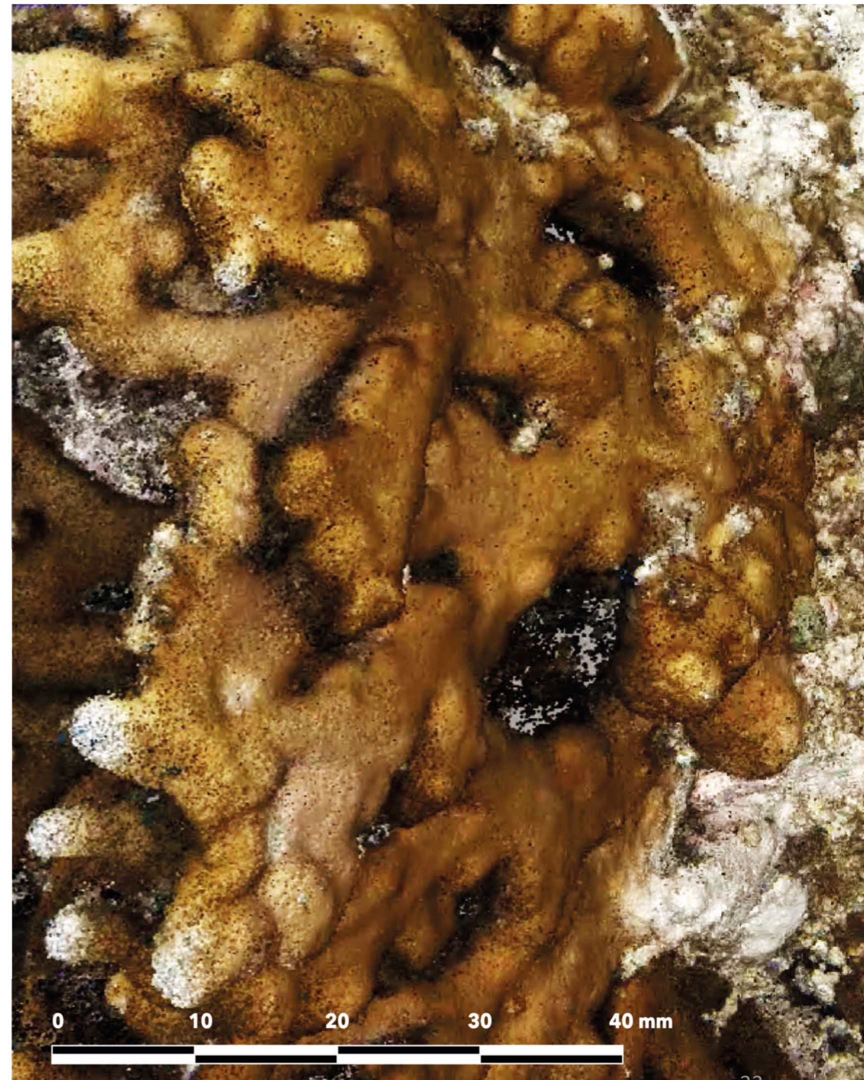


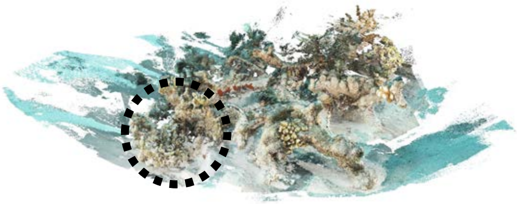




Underwater photogrammetry results







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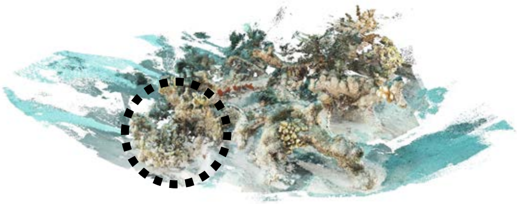
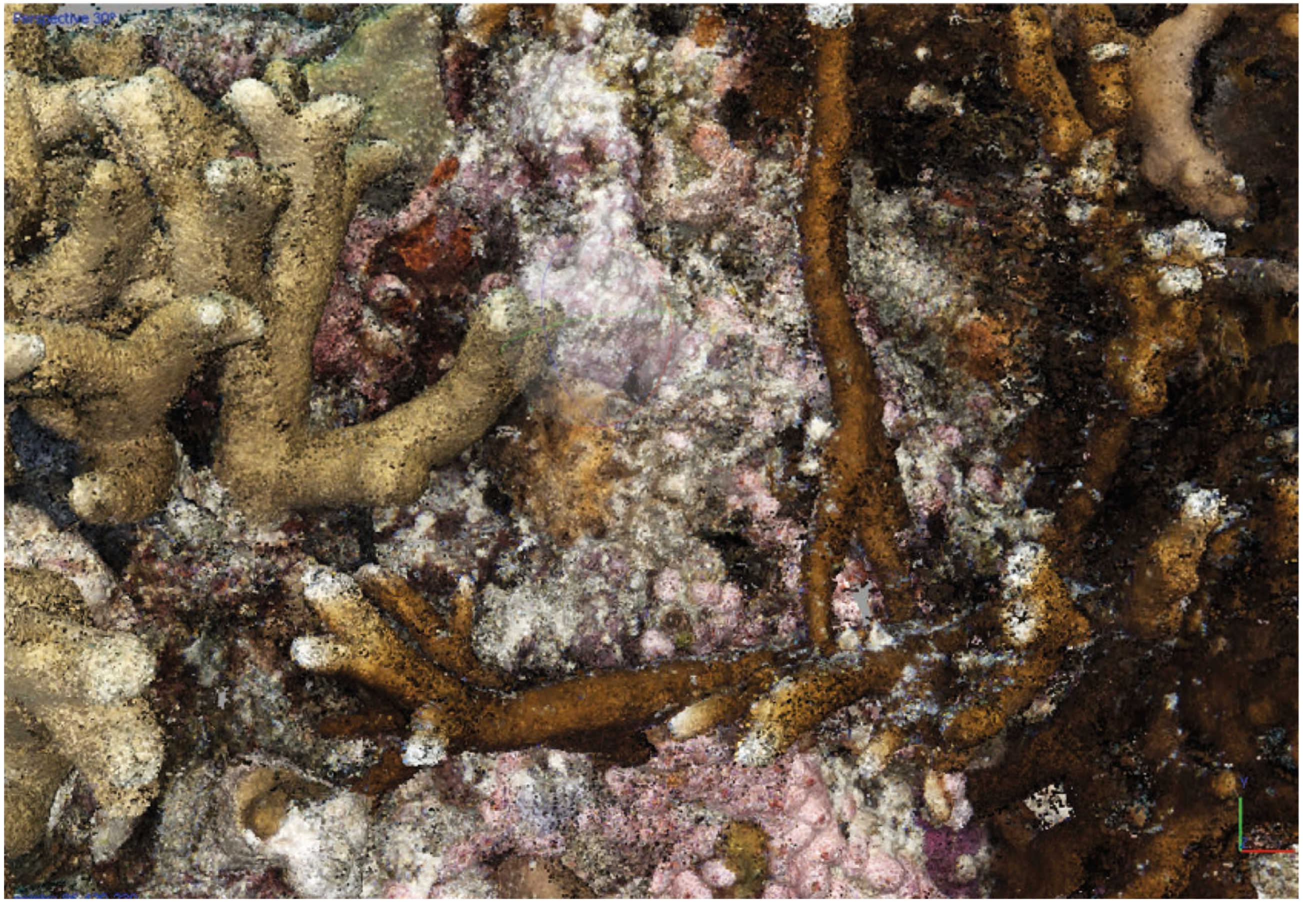


Underwater photogrammetry results



Conclusions

Developed techniques for close-range three-dimensional underwater survey processes.

Specific experimental setup including a computationally designed artificially constructed coral reef prototype.

Defined key parameters and constraints for design and monitoring.

Implementation of different state-of-the-art techniques to scan and model coral reefs in real-world underwater configurations.

Outlook

Underwater point cloud models could be converted into digital surface models, e.g. mesh models computational design studies, growth and structural analysis hydrodynamic modelling, and digital fabrication

3-D printing of coral reefs using calcium carbonate based additive manufacturing methods

Opening up new ways of thinking about computational design and three-dimensional scanning and modelling

Thanks

Supervisors

Prof. Sven Schneider, InfAR Group, Faculty of Architecture, Bauhaus University Weimar

Jun. Prof. Jan Willmann, Faculty of Arts and Design, Bauhaus University Weimar

Collaborators

Bert van der Togt (Baars CIPRO), Georg Nies (UWF Deutschland), Delphine Robbe (Gili Eco Trust), Thomas J. Goreau (Global Coral Reef Alliance)

Field assistance

Philipp Semenchuk (Conservation Biology, University of Vienna), Steve Willard (Central Gili Dive)

Funding

German National Scholarship Foundation,

Andrea von Braun Foundation, Munich