

Shore Thing

Multiscale Eco-Morphogenesis (MEMo)

Alain Goriely Ph.D., Negar Kalantar Ph.D. & Evan Jones

Environmental stress is a fundamental driver of evolution, shaping the form, function, and stability of ecosystems. The Maldivian atoll system provides a natural laboratory for studying this process in real time. With over 1100 coral islands no more than 1.5 meters above sea level, dynamic shorelines, ocean acidification, and temperature rise are creating strong selective pressures on marine calcifiers, beachrock microbial communities, which have historically protected the shoreline. We hypothesize that these environmental fluctuations drive the morphodynamic evolution of bioconstructed coastal formations, such as shells, coralline algae, and beachrocks, by altering the coupled physical and biological processes of biomineralization.

Our research develops **integrative models linking environmental forces, novel morphodynamic adaptation, and microbial mediation** of lithification to understand how these systems evolve and maintain stability under stress to prevent erosion and protect the ecosystem. By leveraging the ecological feedbacks that connect microbial evolution, material formation, and morphodynamic changes at multiple scales from sand grains to islands, MEMo will reveal the fundamental principles governing the co-evolution of organisms and their physical environments in dynamic coastal ecosystems.

Real-Time Crises. The need for immediate implementable prototypes is being driven by global climate changes which are threatening fragile tropical coastal systems and habitable lands. Geologic impacts are already being felt through sea-level rise, increased storm surges and rising ocean temperatures and coral bleaching driven by dramatic rises in CO2 levels. Nature based solutions coupled with biochemical research occupy distinct and separate fields that have little overlap in applied research to date. The project brings together groups of researchers which have already been implementing proof of concept prototypes where further development within an integrated workflow would allow for synthesized strategies to align geometric, biologic and material research among specialists in diverse academic fields of study. Unlike traditional science problems, the urgency of the situation requires us to carry out the fundamental science and remediation method in parallel.

Shore Thing Interdisciplinary Team:



Margaret Ikeda
Founder / Associate Professor of Architecture, (CCA). Co-Director AEL



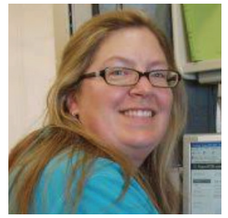
Evan Jones
Founder / Architect, Sr. Adjunct of Architecture, CCA. Co-Director AEL



Negar Kalantar (Ph.D.)
Founder / Associate Professor of Architecture, CCA. Co-Director DCL



Al Borhani
Co-founder of [trans]LAB, is an inter-disciplinary designer working across scales and technologies.



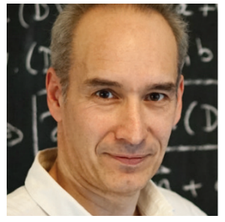
Kamille Hammerstrom (M.S.)
Moss Landing Marine Laboratories, Research Faculty.Associate, Coastal Conservation and Research.



John Oliver (Ph.D.)
Moss Landing Marine Laboratories, Research Faculty. Founder, Coastal Conservation and Research



Dyche Mullins (Ph.D.)
Mullins Lab, University of California, San Francisco. Chair and Professor of Cellular and Molecular Pharmacology



Alain Goriely (Ph.D.)
Professor of Mathematical Modelling at the University of Oxford. Director of the Oxford Centre for Industrial and Applied Mathematics



Gábor Domokos (Ph.D.)
Professor in the Department of Morphology and Geometric Modeling at the Budapest University of Technology



Anastasia H. Muliana (Ph.D.)
Professor in the Department of Mechanical Engineering at Texas A&M University



Ahmed Fariz Nizar
Lecturer HOD - Department of Architecture



Ibrahim Mohamed (Ph.D.)
Specialist in Environmental Sciences

Collaborating Across Disciplines. The team brings together empirical and cultural knowledge specific to the problems faced by the islands of the Maldives through Dr Ibrahim Mohamed, a locally based environmental social scientist and an experienced policy advisor, formerly with the government, and, Ahmed Fariz Nizar, director of Architecture [Maldives National University]. Coastal marine biologist, Dr. John Oliver[Benthic Lab], and Kamille Hammerstrom studies this ecosystem from the perspective of the project implementation and in California has participated in many ecological projects focused on nature-based solutions on the coastal edge. Biological support at the scale of the microbial level investigating bio-cementation will be provided by Dr. Dyche Mullins [Mullins Lab] who will provide insight into the structures of self-assembly at the bacterial level. The understanding of the overall multiscale dynamics underlying this process and possible new solution require overall mathematical modelling carried out by Prof. Alain Goriely [Oxford University] and Dr. Gábor Domokos. The outcome of these models will engage with material computational fabrication at the scale of the physical prototype with Dr. Negar Kalantar and Al Borhani at the Digital Craft Lab [California College of the Arts], and, Margaret Ikeda and Evan Jones at the Architectural Ecologies Lab [California College of the Arts] With these material prototypes, strength and durability will be tested at Texas A&M[ACTOR Lab] with Dr. Anastasia Hanifah Muliana.

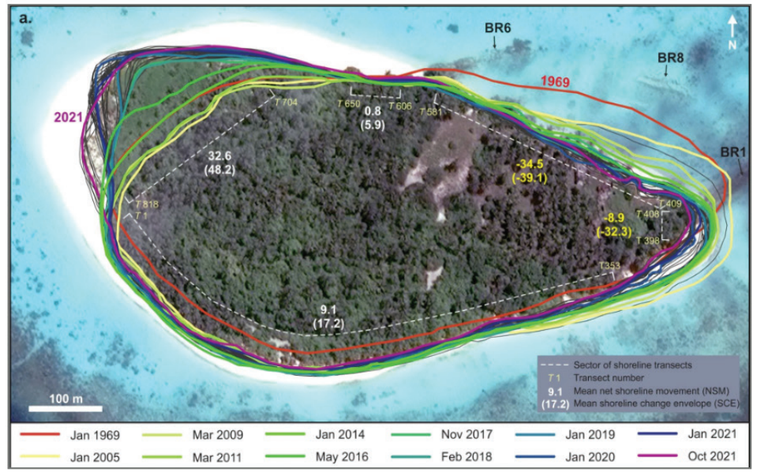
*Other contributors to this project during its development team: Ali Farajmandi (Fabrication Specialist); Autodesk Technology Center Residency Program, San Francisco; and CCA students Alexandra Huerta, Yna Bariring; UCSF Ph.D. students **Asa Kalish**, Ashley Lasko, post-doc. Austin Graham; MNU students Aishath Leesha Abdull, Hassan Haleem. Special thanks to the work of **Marek Michalowski** [CCA], **Kinga Kocsis** [Budepest University], and, the Biodesign Challenge in New York City for the platform to 'seed' this project.*

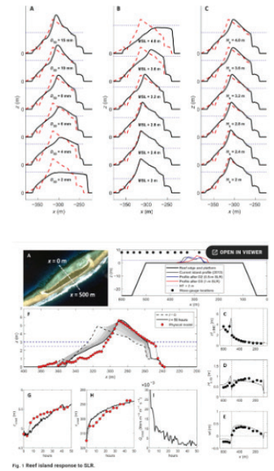
Background

Placed in the inter-tidal zone is a bio-based beachrock designed to dissipate ocean currents and nourish beaches through specifically designed geometric shells made with coral beach sand, coconut coir fibers and a safe bacterium. These bio-cementation shells are designed to work with the natural dynamics of the island to accrete sand and degrade productively at the end-of-life back into the ecosystem.







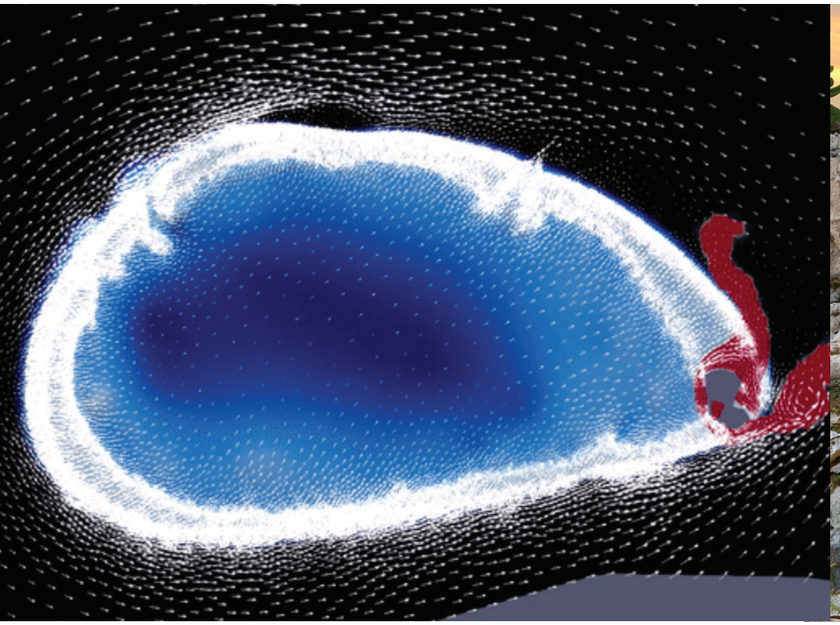


Kench, P.S., Liang, C., Ford, M.R. *et al.* Reef islands have continually adjusted to environmental change over the past two millennia. *Nat Commun* 14, 508 (2023)



Problem

The Maldives, a low-lying island nation heavily reliant on healthy coral reefs, is experiencing the devastating impacts of climate change firsthand. Rising ocean temperatures due to global warming, combined with more frequent and intense El Niño events, have led to repeated coral bleaching and widespread coral death across the globe. The Maldives has been particularly hard hit, with multiple mass bleaching events causing severe damage to its reefs. The islands are dynamic.....

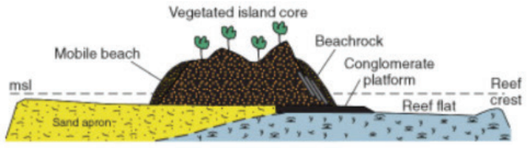










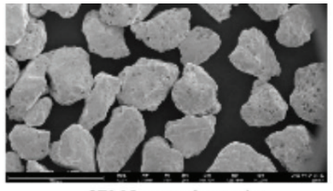




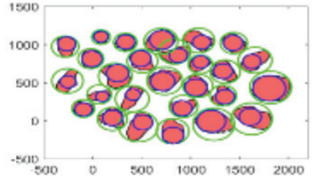
Plan of Action

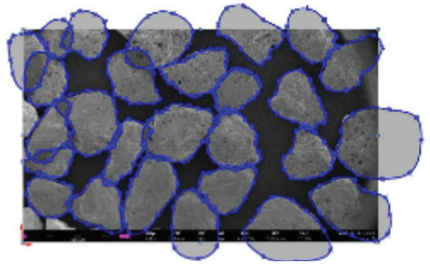
Across Scales. The processes which influence the hydrodynamic scale of island shorelines are impacted by biological and chemical operations occurring at much smaller scales (Fig.1). Coral barrier reefs form through symbiotic relationships of algae and their hosts. These algae sequester calcium carbonate available in ocean water to form material structures capable of wave dissipation and accretion of suspended sediments which over long-time scales formed the islands. Analogous bacterial processes occur at the shoreline within the intertidal zones forming 'beach rock', a stratified/lithified material operating to stabilize the edges of shorelines forming over many years (Fig. 3). These processes involve complex interactions of many scales from the nano to kilometer, integrating biochemical reactions capable of being harnessed for formal approaches along the edges of active shorelines. These natural precedents can be understood biologically, structurally, chemically and environmentally, as a way to develop novel engineered solutions (Fig. 4). A key ambition for the project will be to integrate more iterative and directed methods of synthesizing these evolutionary processes. (Fig. 2).





SEM Image of granules





Black – Extracted granule boundaries
Green – Circumscribing Circle
Blue – Inscribing circle

Granule morphology (Computed values)
Sphericity = 0.6607 +/- 0.1001
Roundness = 0.5079 +/- 0.0979

--- Volume-Based Particle Size Distribution ---
D10 : 224.73
D50 : 260.33 (Median)

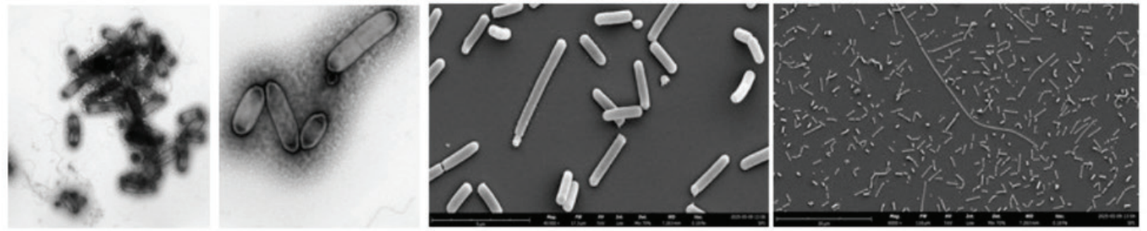


Figure 1. Transmission electron micrographs of *Bacillus subtilis* (two left) and scanning electron micrographs of *Sporosarcina pasteurii* (two right).

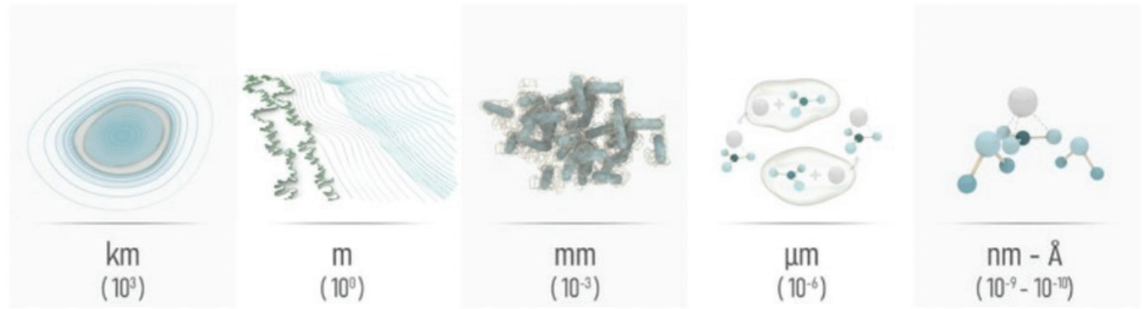


Figure 2: Biological Systems across Length Scales

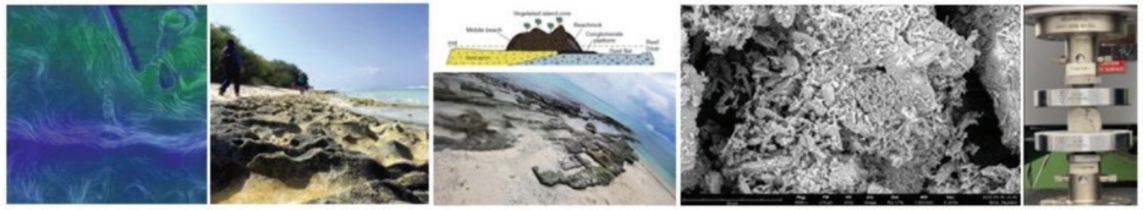


Figure 3. From left to right: representative views of the Maldivian atoll system; beachrock formations along the shoreline; micrographs showing calcium carbonate crystal morphology; and mechanical testing of lithified specimens.

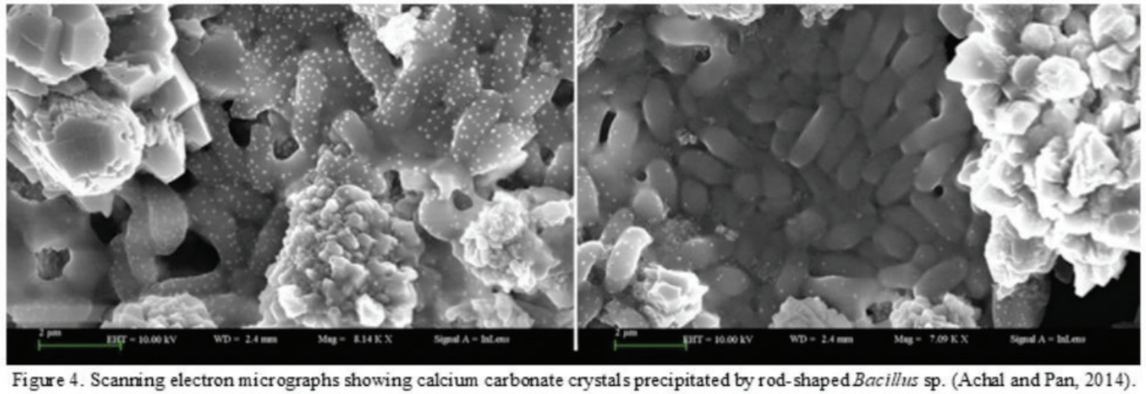


Figure 4. Scanning electron micrographs showing calcium carbonate crystals precipitated by rod-shaped *Bacillus* sp. (Achal and Pan, 2014).

Shore Thing Research

Methods. In close collaboration with all the PIs, we are developing an overall multiscale framework to model the morphodynamic evolution of islands by linking biological, mechanical, and environmental processes across spatial and temporal scales (Goriely, 2017). At the **microscopic level**, we will describe microbial and organismal biomineralization through coupled systems of partial differential equations capturing chemical kinetics, mechanical stress, and morphoelastic growth. These models will incorporate the influence of microbial activity and calcification on material deposition and stiffness evolution. At the **mesoscale**, we will use homogenization and asymptotic techniques to derive effective constitutive laws that describe how microscale lithification and biological adaptation modify the mechanical and morphological response of beachrock and sedimentary layers. At the **macroscale**, morphodynamic models will simulate shoreline evolution under fluctuating hydrodynamic forces, temperature, and acidification, integrating field data and feedback from local erosion and accretion patterns. The resulting multiscale system will enable the prediction and design of stable morphological configuration that naturally resist erosion by identifying feedback loops between biological growth, material, and environmental forcing, thereby providing a quantitative basis for restoring and maintaining the island's dynamic equilibrium. This will constitute the overall theoretical umbrella that will be used for field study of the evolution of the ecosystem and engineering solution for possible remediation.

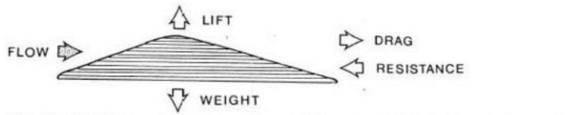
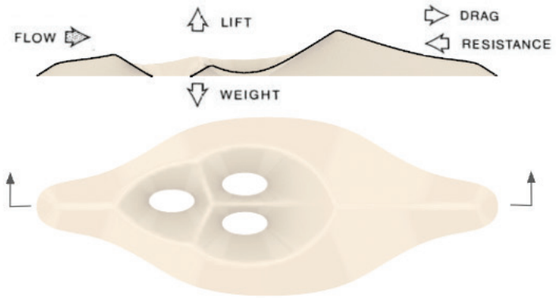


Fig. 2. *Mellita quinquiesperforata.* Diagram of forces acting on a sand dollar in moving water. As flow increases so does lift, thus reducing the effective weight of the sand dollar. It remains stable until drag is equal to the frictional resistance, which is given by the product of effective weight and coefficient of static friction

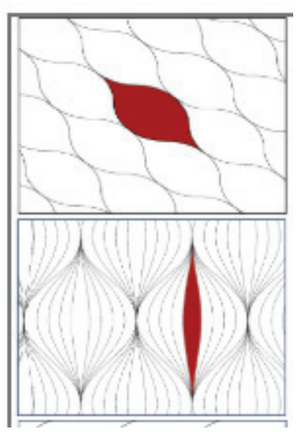
Adamaris Muniz Tirado & Dr. Rich Mooi

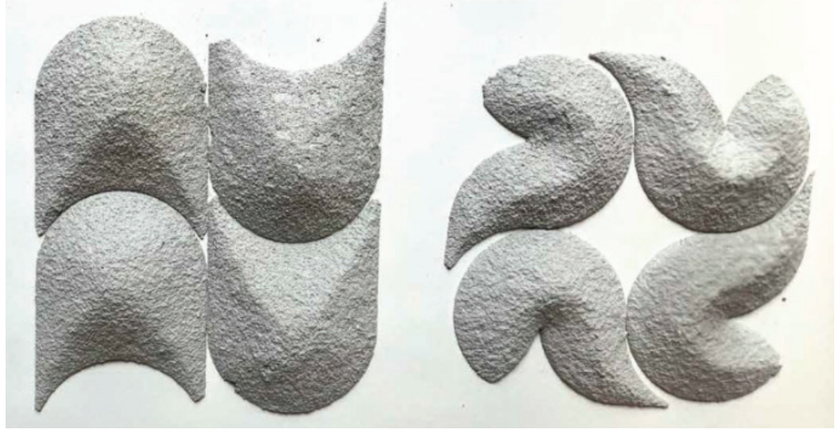


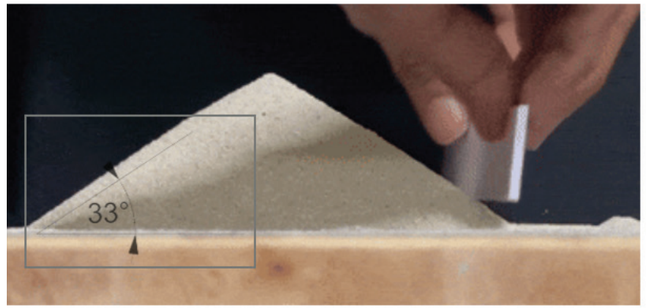












Maldivian Sand Angle of Repose: 33°

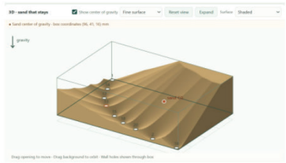






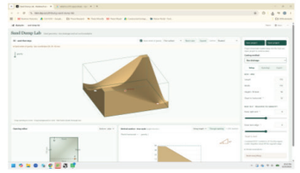


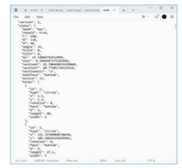


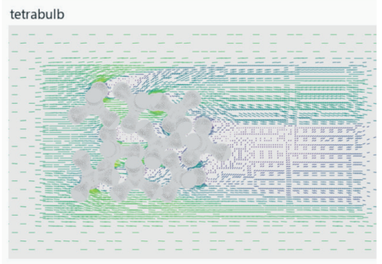


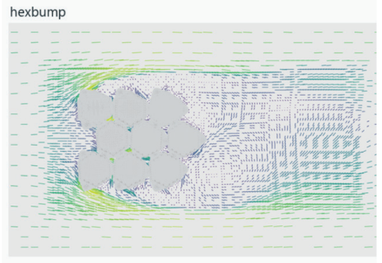




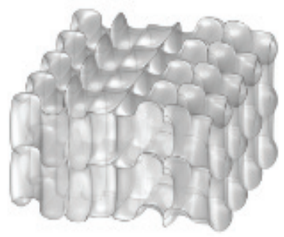




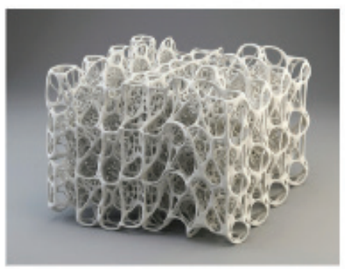






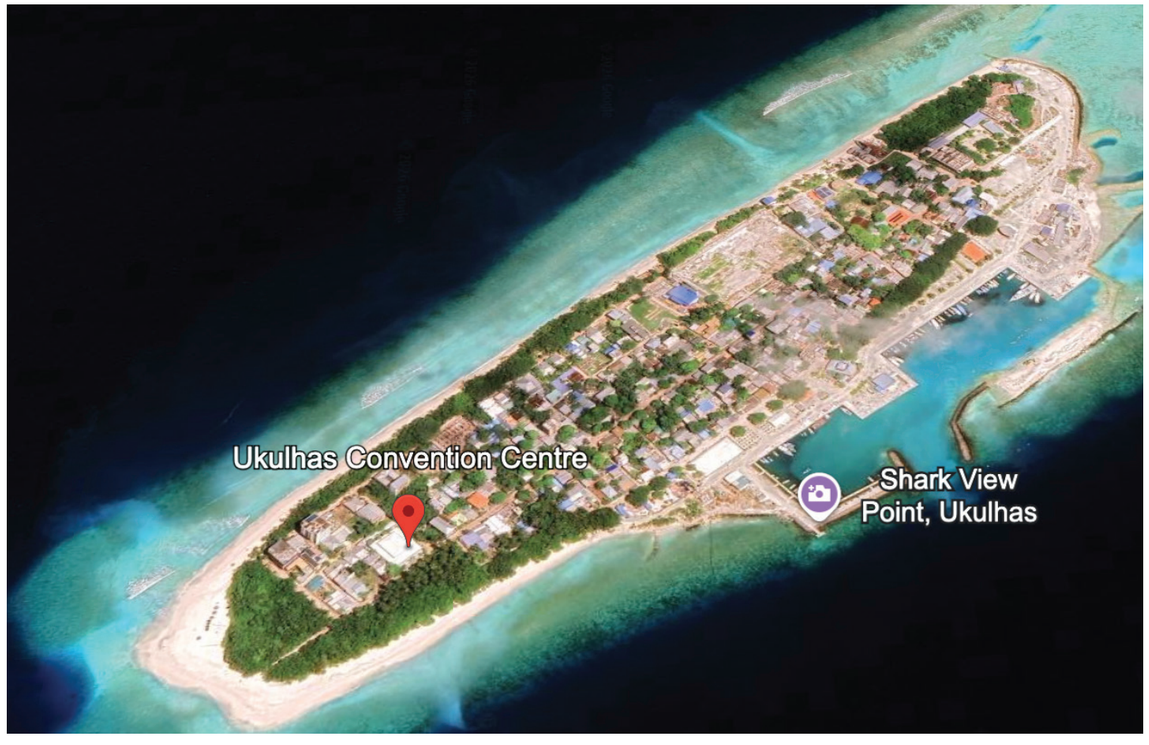






Ukulhas Convention Centre

The Ukulhas convention Centre is an iconic building in Ukulhas targeted towards MICE (Meetings, incentives, conferencing, exhibitions) and tourism. The Ukulhas Convention Center was completed on the 26th of August 2019, during the time of President Ibrahim Mohamed Solih, with an expenditure of MVR 22 million and with immense support from the government Maldives. The finance for the project was raised through a free grant by the government of India. The Ukulhas convention Centre became the first building of such high standard to be completed in Maldives.





2027 International Maldive Research Forum Conference

The final full day of the International Maldive Research Forum will take place at the Ukulhas Convention Centre, located approximately 45 minutes by boat from Rashdoo and 1.5 hours from Malé. This event brings together invited guests from Malé, stakeholders from nearby islands, and resort representatives to listen to presentations by keynote speakers from three research projects who will share and discuss their results with the Maldivian community.

DAY 5: Saturday, January 9

7:30am- Invited guests leave by speed boat from Malé to Ukulhas (~1.5hrs)
8:00am- Researchers travel by boat to Ukulhas from Rashdoo (~45min)
9:00am- Mixer/coffee, tea
9:30am- Welcome
10:00am- Keynote, PlanktoPod
11:00am- Keynote, Reef Weave
12:00pm- Keynote, Shore Thing
1:00pm- Lunch break
2:00pm- Panel Discussion: Selected community leaders & visiting researchers
2:45pm- Breakout sessions
3:30pm- Closing remarks
4pm-5pm- Mixer/coffee, tea, appetizers
5pm- Visiting researchers return by boat to Rashdoo
5pm- Invited guests return to Malé by speed boat
7:30pm- Dinner celebration, location in Rashdoo TBD



Support



PLANNING ADVISORS

Ukalhas Former Council Member, Shaukath Ibrahim
Mohamed Maujood Hussain, Hospitality, Rashdoo

CONSULTANTS

Richard L. (Rick) Rundell, FAIA, NCARB, LEED AP
Founder and Principal Advisor, Track 5
Ignacio Barandiaran, Principal, Arup Engineers, San Francisco office

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Digital Craft Lab, California College of the Arts, San Francisco
Ali Farajmandi, Architectural Technology Designer
Jeffrey Day, Architect

INTERNATIONAL PhD RESEARCHERS

Asa Kalish, UCSF Ph.D. candidate
Kinga Kocsis, Budapest University, Ph.D. candidate
Marek Michalowski, CCA, M Arch, Architecture

MALDIVES ARCHITECTURE RESEARCHERS

Aishath Leesha Abdulla, MNU architecture
Hassan Haleem, graduate of MNU architecture

Conclusion

Challenges: Traditional funding mechanisms are ill-suited to support multiscale, multidisciplinary projects. They are structured around disciplinary silos, short funding cycles, and narrowly defined deliverables that cannot accommodate the integrative, long-horizon nature of research spanning molecular biology, mathematical modeling, materials science, and ecology. **These project's hybrid approach—combining theoretical, experimental, and field-based methods with community engagement and design implementation**—challenges the conventional separation between fundamental science and applied engineering. It demands iterative field experimentation that exceeds the temporal flexibility of standard grants.

Only programs **designed to foster long-term, cross-disciplinary collaborations that link genetic and ecological evolution to material and environmental processes** can effectively sustain research of this scope. By partnering with local communities in the Maldives on three distinct, climate-driven projects, we aim to generate early momentum. Ultimately, **this work will establish scalable, community-driven strategies** that empower residents **to adapt tools and methods as their needs evolve**—with ongoing support from researchers worldwide. Their challenges are our own.

