Oyster Hack

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There is a state of emergency in the USA- catastrophic coastal erosion,[1] rising sea levels at the rate of one-eighth of an inch per year [2] and poor water quality.[3] Oysters can help. Oysters filter the water, removing toxins. Oyster reefs are living infrastructures that protect coastlines from storms and tidal surges.

But...many of the world's existing oyster reefs are functionally impaired.[4] The Chesapeake Bay is dying. Untreated chemical run-off and human waste is creating 'Dead Zones' where there is no oxygen to support marine life.[5] Much of Hurricane Sandy's damage to New York City could have been prevented.[6] In theearly 1800'sthe Harborwaslinedwithlivingoysterreefs. Now, these are dead or dying, fragile and vulnerable. Miami is flooded on a regular basis reports Miami Herald. Our oyster reefs must be revived or rebuilt - they will help.

Wallsarenottheanswer. 14% of UScoastalcitieshavemassive sea-walls already. [7] National Geographic reports that by 2100 one-third of our coastal cities will be protected by walls, that cost billions of dollars and will not provide protection from the most severe storms.

I believe in the power of the oyster. The oyster is an engineer- its reefs and shells work together as a "system of systems" to protect our waters and coastlines. Without them we are sunk, literally, no matter how many engineered systems we humans try to substitute and pay billions of dollars to implement.

WORK WITH THE OYSTER.

Locally, nationally and internationally, the oyster, its shell and its habitat, the oyster reef, are imperil and in some areas functionally impaired according to The Nature Conservancy. This unique habitat works to stabilize the sand floors and shorelines of our estuaries and bays keeping waters from rising to a level that threatens coastal communities and their built and natural environments. Together, the oyster, its shell, and its reef are responsible for purifying our waters, structuring our shorelines, feeding millions of people, and creating jobs for tens of thousands of people.[8] The endangerment or extinction of this species has critical impacts at both the local and global scale. Addressing the effects of climate change and water pollution, the construction of new artificial reefs, the restoration of existing reefs and the creation of sustainable practices of oyster farming is now urgent. There are challenges that must be confronted when working on reef design as an architectural issue, but also opportunities, offered by an approach based on bio-mimesis, and the use of modular, fractal, reef assembly protocols in the restoration of coastal and estuarine habitats.

For the past twenty years, working as an architectural designer and inventor, I have built a substantial body of work using concrete. In 2008, I began researching oyster habitat and the concrete formulation that oysters make naturally and use to adhere to hard substrates, including other oysters, eventually forming an oyster reef. In what became a profoundly life-changing experience I discovered a design focus, that is simultaneously bio-chemical, bio-mechanical and architectonic, and must work at multiple scales - the precise architecture of a substrate that can initiate and enhance oyster growth, and can be built incrementally. I am committed to two fundamental principles:

1. The substrate should use a concrete formula based on a chemical analysis of oyster shells and their secretions,

2. The behavioral and structural analysis of oyster colonies, as evidence of the oysters' innate ability as an engineer, parametric designer and 'wet computer' should guide the architectural design.

I have developed reef building products and built a business, Grow Oyster Reefs, to provide these products to scientists, NGOs, government agencies, oyster farmers and homeowners. My concrete formula and products are being used by 'The Nature Conservancy' in the USA for one of the first artificial substrate oyster reefs in the state of Maine, and by the U.S. Fish and Wildlife Agency in the Upper Chesapeake Bay. In December 2017, I started work on the design and fabrication of an artificial reef in Florida. This is now complete and will be used as a demonstration site for sustainable oyster reef development in one of the most threatened coastal regions of the USA. This project was built in the context of an underwater museum, allowing public access, facilitating education programs in schools and colleges, and is being executed in collaboration with a team of Architectural Design students from James Madison University.

PRODUCTS

GROW Oyster Reefs' patent-pending technology is inspired by the oyster to accelerate the growth of reefs. We understand the habitat, hydrology, form, structure and material composition that the oyster embryo prefers and adult oyster needs to sustain itself and do its job – building reefs, filtering water, neutralizing acids and providing nutrition. Our systems work with, not against nature. We have developed three products – a

Figure 2: Concrete Oyster Restoration Disk or "Reef Disk" (l) Reef Disk after 3 months in water for the University of Maryland Project, Inner Harbor, National Aquarium Slip, Baltimore, Maryland, 2017; (m) Image of CORRD Disk (r) typical rip rap water break in the Chesapeake Bay showing red circles for placement of CORRD to turn the jetty into a "Living Breakwater."

'Concrete Oyster Reef Restoration Tile' - CORRT, or "Reef Tile" and a 'Concrete Oyster Reef Restoration Disk' - CORRD, or "Reef Disk." These are made from a third product, CaC03 CONCRETE MIX, a proprietary Calcium enriched concrete mix that is specifically formulated to closely match the oyster shell's which has recently been discovered to neutralize the excess nitrogen polluting the water[9] plus provides the necessary nutrients for the oysters' health and growth with the extra calcium carbonate. The CORRT Reef Tile provides critical conditions to the oyster 'spat', embryonic oysters, for attachment within micro and macro interstitial spaces modeled following principles drawn from native oyster reef substrate, and provides an ideal habitat, second only to a native habitat, in which oyster 'spat' and mature oysters can flourish. The CORRT is portable and stackable allowing for easy, low-impact, affordable installation and movement between reef locations. It is designed so that the oysters can build arches to the next Reef Tile, as they do in the wild, to form a contiguous oyster reef along miles of shoreline. A CORRD Reef Disk is a small 3.5 pound hollow disk that can be used to transform existing near-shore substrates, within jetties, piers or on rocky shorelines, into oyster reefs. These are also particularly useful when strung on a rope and hung vertically or horizontally for commercial oyster farmers, or coastal property owners who want to grow their own oysters or catch spat to transport to other locations.

Our CaCO3 CONCRETE MIX is currently turned in concrete mixers, and we are actively pursuing a 'Ready-Mix' product line that could be mixed by any local 'Ready-Mix' company. This would arrive at pouring sites in a concrete mixing truck, ready for immediate use. The concrete will be premixed and ready to pour. This will be ideal for large scale pours of 1 ton and more.

We are currently strength testing three different formulas for three different strengths of concrete mix – 'fino' for fine-grade or small projects using under 30 pounds of concrete, 'medio' for medium scale projects using up to 350 pounds, and 'grande' at 3,000 to 5,000 psi, for large scale projects using more than 350 pounds of concrete to construct our new "Living Seawalls," and underwater "ECOinfrastructures."

PROJECTS

GROW works by establishing partnerships with Government Agencies and Non-Governmental Organizations currently deploying artificial substrate. Our CORRT Reef Tiles were purchased by 'The Nature Conservancy' in Maine to be used for the States' first artificial substrate oyster reef testing. Concrete pours have been completed working with volunteers in a joint project with US Fish and Wildlife Agency's Chesapeake Bay Field Office in Maryland's Artificial Reef Initiative. Our CaCO3 Concrete was selected over normal concrete due to the success it has shown in testing to attract significantly more oysters to any artificial substrate that is used to restore or create a reef. GROW also provided the expertise needed to pour 'Reef Balls' - an alternative form that is currently in use. This allows comparative testing, measuring the performance of GROW's tiles and disks and concrete in relation to any available alternatives. Scientific testing has taken us to the Middle and Northern Atlantic Shores and the Gulf of Mexico in the United States.

MAINE

In Maine we were asked to build the first artificial reef to be tested in the State. Maine is very particular about what goes into their waters desiring only "clean concrete" and purely native and natural materials. Their oyster population is at an all-time low and must be replenished. Our CORRT reef tiles were tested against natural shell enclosed in baskets. Half of both test types were "seeded" with oyster embryos at the hatchery, and half of each type were put into the waters without seeding for a natural catch. The invasive, non-indigenous Green Crabs are oyster predators and very problematic for the reestablishment of oysters in the Maine waters[10] and the use of the enclosure baskets potentially protects the substrate from predators. The first set of Reef Tiles went into the water unseeded, without baskets. The second set were seeded and put in baskets. Final results will be available during the Fall of 2018 and the preliminary results are very positive findings for GROW detecting that natural shell

Figure 3: CORRT Reef Tiles and Nature Conservancy in Maine Project using Artificial Substrate in Maine for the first time. Image shows scientist in scubagear about to place the Reef Tile, The Basin near Phippsburg, Maine, 2017.

held in baskets has equivalent early spat attachment in all-round ratios as GROW's Artificial Reef Structures. These early findings for spat recruitment parallel our in-house assessments.

Participating in the process of taking the CORRT Reef Tiles out in small boats, using a team of scuba divers to place them within a weighted rope grid onto the sea-floor of the Basin near Phippsburg, Maine, was very revealing, as we develop a furthered understanding of the installation process. The choreography of the installation has to be designed carefully if the reef is to remain stable.

MARYLAND

In Maryland, Environmental Scientists, Dr. Patrick Kangas and Dr. Peter May, from the University of Maryland invited me to participate in a study that involved adding algae into concrete. Dr. Kangas founded the Algal Ecotechnology Center in 2011 and uses the "Algal Turf Scrubber" to collect algae from Maryland waters[11] and seeks ways to use the captured algae. The team from the University also wanted to conduct a series of experiments that would allow them to understand the effects that algae could have on recruitment of marine species into an artificial reef. The algae was extracted from the surface of Baltimore's Inner Harbor, and included in our CaC03 Concrete. I was extremely interested in this. The science involved in developing concrete formulas for marine species is fundamental to my work. The data set that will be the conclusion of this project is likely to be significant. We tested 240 modified Reef Disks – half divided into normative concrete with and without algae - the other half in CaC03 concrete, with and without algae.

This project also provided an opportunity for my students to participate in a 'live' project. Two current Architectural Design students, Kaitlin Berger and Maya Chandler and one Alumna, Andrea Murchie, from James Madison University worked as Research Assistants joining University of Maryland Research Assistant, Samantha Francis, to fabricate and install the modified Reef Disks. Managing this was complicated by the demanding schedule - as our work must be timed according to the oysters' and other shellfish spawning periods, not a typical academic calendar. The quantity of disks needed, and the speed of the project, required a modification to the design and the formwork for Reef Disk production. This used off-the-shelf materials that could be easily cut and assembled in Baltimore and Harrisonburg by non-architecture students, assisted by JMU Architectural Design students, who have experience making things with precision and pouring concrete in our Concrete Lab. We used digital fabrication techniques to accelerate the cutting time for the production of the formwork, and the modifications to the prototype design and the formwork allowed us to make fifty units in a single pour. The disks were strung onto ropes – four to a rope, each at specific heights above the bay floor, making 'necklaces' of disks. For testing purposes each necklace' had all four types of concrete arranged in a different order according to a scientific diagram, top to bottom, across 60 necklaces.

The preliminary results indicate that our CaC03 Concrete Mix has larger recruitment weight which means that either we are growing a faster shellfish, or more quantity are attracted to our disks, or both! The algae did not increase recruitment significantly with either type of concrete. We are waiting to see if it was neutral or had a marginal impact. If it did not alter or increase recruitment this would indicate that the algae could be used as an neutral additive to the concrete. We did find that the amount of algae would need to be determined very carefully, as it lightened the weight of the individual disks considerably and made them more susceptible to water based deterioration. The other interesting finding was that 85 % of the recruits were mussels as we did not seed the reef disks with oyster spat. We wanted to work with a natural catch environment, indicating that there are no oysters in our site - the slip next to the National Aquarium in Baltimore on the Inner Harbor. Another test that includes the algae at a site where oysters are present might yield more beneficial results for the algae additive. Early testing suggests that this may be the case.

FLORIDA

In Florida 'The Underwater Museum of Art' in association with Cultural Arts Alliance, and the National Endowment of the Arts opened the United States' first underwater museum, dedicated to reintroducing productive coral and oyster reefs on the barren floor of the Gulf of Mexico. The Museum is located at Latitude N 30 18.754, Longitude W86 09.522.

I answered an open call by the Museum, in the Summer of 2017, for artists to make proposals. I invented a new type of material - a

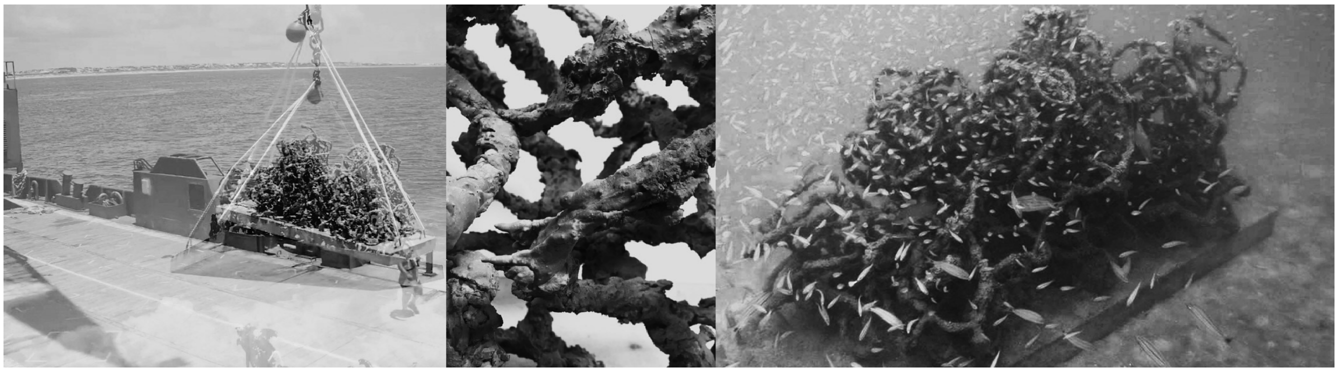

Figure 4: Concrete Rope Reef Tangles; Underwater Museum of Art, Grayton Beach, Gulf of Mexico, Florida, Latitude N 30 18.754, Longitude W86 09.522. (l) deployment, 2018. (m) closer range view of surface, (r) underwater view one week after installation, 2017.

'Concrete Rope' and designed a habitat that I called a 'Concrete Reef Rope Sphere'. I was one of seven artists selected. The project needed to be completed and installed within 6 months. I used this as an opportunity to prototype new products and worked with a group of seven Architectural Design students who were taking an Independent Study with me as Research Assistants to aid in the fabrication of the pieces in the Concrete Lab. The pieces were modeled by the end of the Fall semester, and fabricated over the Spring semester of 2018. They were delivered to Grayton Beach, Florida, for deployment in May. South Walton Artificial Reef Association, a significant supporter of the new museum and reef deployed all seven pieces in June. The 'Concrete Tangle' is settling in well and fish are swimming through it. It will take a year to evaluate coral and oyster recruitment even in the warm waters of the Gulf of Mexico.

This work has prompted the development of another underwater museum that will work as a ecosystem, dive site, and a memorial and education resource for the 'Central Slave Passage' in the Caribbean. I have been asked to assist in the design and programming of the museum, to supply concrete and to put in a much larger Concrete Sphere that could be used as an environment that is large enough for divers to swim through. The promise has become clear - all underwater concrete structures can be reefs, with careful design, and all reefs can become 'smart reefs'.

SMART REEFS

A smart reef monitors its behavior - minimal mapping has been done to note the existence, successes and failures of oyster reefs internationally and what is known is typically hidden in hard to find scientific papers. We need to do something about this. If we do not know how much we do not know, it is hard to improve conditions. If we do not know which reef building techniques work well, supporting oyster growth, and which do not, we cannot make progress addressing global water quality and coastal resilience. Our next step will be the construction of an open source network through a website that will allow the world's citizens, aqua-farmers and scientists to locate the existence of oysters and the performance of reefs, of all kinds, with an 'app' that allows them to locate and note reef conditions, and detect water quality through submersible sensors and to try our some Augmented Realityon the oysters! Building the 'Smart Reefs' will contribute to a deeper understanding of the challenges that are faced by the oyster - a keystone species, and humanity. This collective research effort is now obligatory.

ENDNOTES

1. Dahl KA, Spanger-Siegfried E, Caldas A, Udvardy S. "Effective inundation of continental United States communities with 21st century sea level rise." *Elementa Science of Anthropocene*, 2017.
2. National Oceanic Atmospheric Association (NOAA), Ocean Facts, National Ocean Service website, "Is sea level rising? Yes, sea level is rising at an increasing rate.," https://oceanservice.noaa.gov/facts/sealevel.html, accessed on 7/23/18.
3. Breitburg et al, "Oyster reef restoration: convergence of harvest and conservation strategies," *Journal of Shellfish Research*. 2000.
4. W.Beck et al, "Oyster Reefs at Risk and Recommendations for Conservation, Restoration, and Management." *BioScience*, 2011.
5. Chesapeake Bay Foundation, Issues, "Dead Zones," http://www.cbf.org/issues/dead-zones/, accessed 7/22/18.
6. Christine Brandon, Jonathon D. Woodruff, "Evidence for elevated coastal vulnerability following large-scale historical oyster bed harvesting," *Earth Surface Processes and Landforms*, Volume 41, Issue 8, pp 1136-1143 (John Wiley & Son Ltd) (2016); University of Massachusetts Amherst, News and Media Relations, "New York Harbor's Oyster Beds Once Protected Against Severe Storms and Extreme Wave Damage," https://www.umass.edu/newsoffice/article/new-york-harbor%E2%80%99s-oyster-beds-once, 3/07/16.
7. NBC Science, Technology and Innovation- Mach, Environment, "Walls Won't Save Our Cities From Rising Seas, Here's What Will," https://www.nbcnews.com/mach/science/walls-won-t-save-our-cities-rising-seas-here-s-ncna786811, 07/27/17.
8. Kirby MX. Fishing down the coast: historical expansion and collapse of oyster fisheries along continental margins. *Proceedings of the National Academy of Sciences of the United States of America*, 2004.
9. Arfken A, Song B, Bowman JS, Piehler M , Denitrification potential of the eastern oyster microbiome using a 16S rRNA gene based metabolic inference approach. PLoS ONE, 2017; Virginia Institute of Marine Science, "Study suggests that oysters offer hot spot for reducing nutrient pollution," http://www.vims.edu/newsandevents/topstories/2017/oyster_microbiome.php, 11/16/17.
10. Snyder, Caitlin, THE IMPACT OF THE EUROPEAN GREEN CRAB (CARCINUS MAENAS) ON THE RESTORATION OF THE OLYMPIA OYSTER (OSTREA LURIDA) IN TOMALES BAY, CALIFORNIA. Master's project, Duke University, 2004.
11. College of Agriculture and Natural Resources at The University of Maryland, Environmental Science and Technology, "Bright Green Future; Algal Turf Scrubber," https://enst.umd.edu/news/bright-green-future-algal-turf-scrubber, 5/30/13.