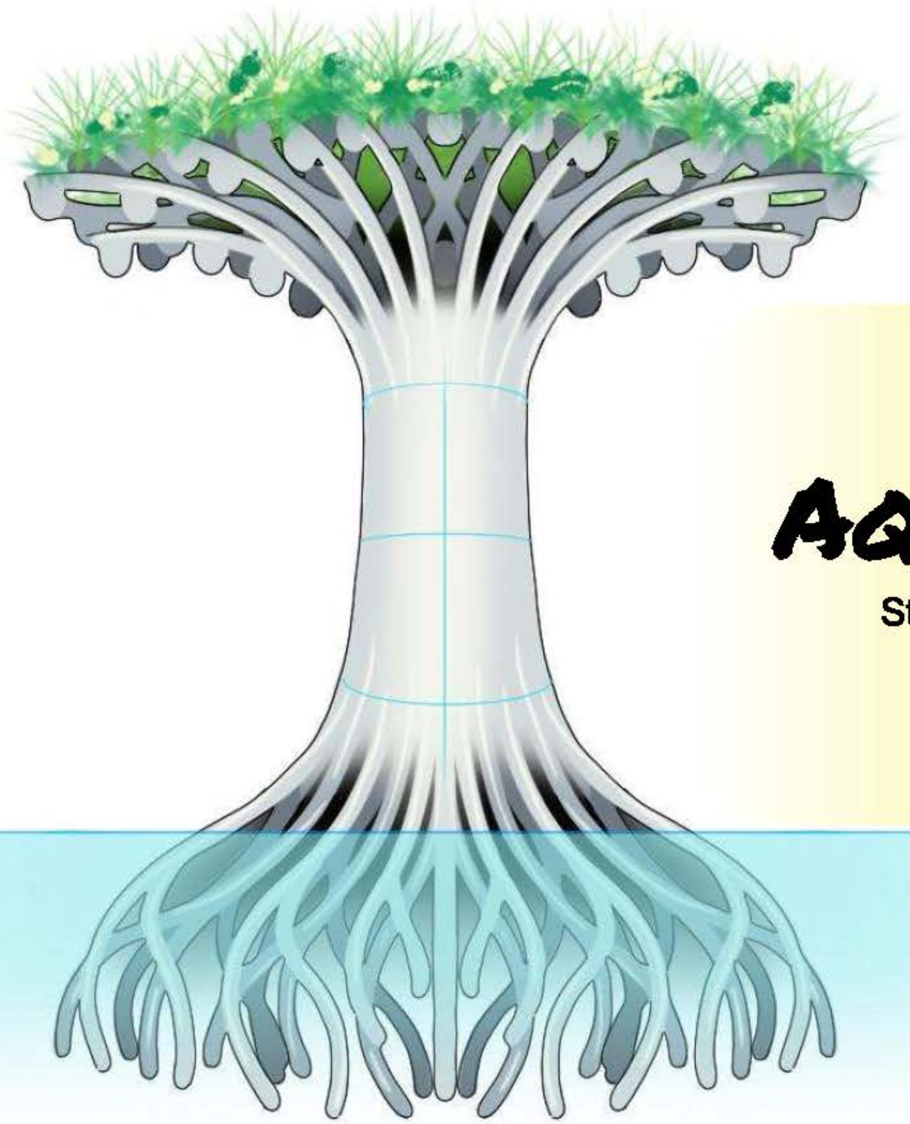
BIOMIMICRY
GLOBAL DESIGN
CHALLENGE



AquaTree

Stabilizing & Reinforcing Shorelines Against Rising Sea Levels

Annika Bergen . George Cook . Zach Elder . Patricia Jacques . Brenna Kelly

Team Members | Minneapolis College of Art & Design

AquaTree was designed by a team of students enrolled in an online Biomimetic Design course through the Minneapolis College of Art & Design (MCAD). Based across the country, the team worked virtually to create this nature-inspired innovation intended to respond to the threat of rising sea levels. The team advisor overseeing this project was Denise DeLuca (ddeluca@mcad.edu).

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Healthcare consultant pursuing an MA in Sustainable Design at MCAD, particularly interested in urban greening and sustainable business models.

Annika enjoys coordinating efforts with and across involved members to support collaborative work throughout the project.

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Consulting Engineer in Apple's U.S. Sales Division, focusing on education. Pursuing an MA in Sustainable Design at MCAD with the objectives of expanding horizons and giving back.

George brings an educational content perspective along with technology and analytical skills.

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Industrial designer with Nike's NXT Footwear Innovation team, pursuing an MA in Sustainable Design through MCAD.

Zachary blends his knowledge of materials, technology, and design innovation processes within the team dynamic to bring clarity of vision to our concept.

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Full-time Illustration and Design student pursuing a BFA at MCAD. Interested in using biomimetics frameworks to develop product designs and create fine and commercial art.

Patricia enjoys investigating ideas and find socio and economic ways to meet both human and ecological needs.

Brenna Kelly
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Senior Court Clerk with the State of Minnesota. Pursuing an MA in Sustainable Design through MCAD, with a passion for sustainable living driving those focuses and goals.

Brenna brings an outsider perspective and enjoys collaborating with a diverse group.

Design Concept Overview

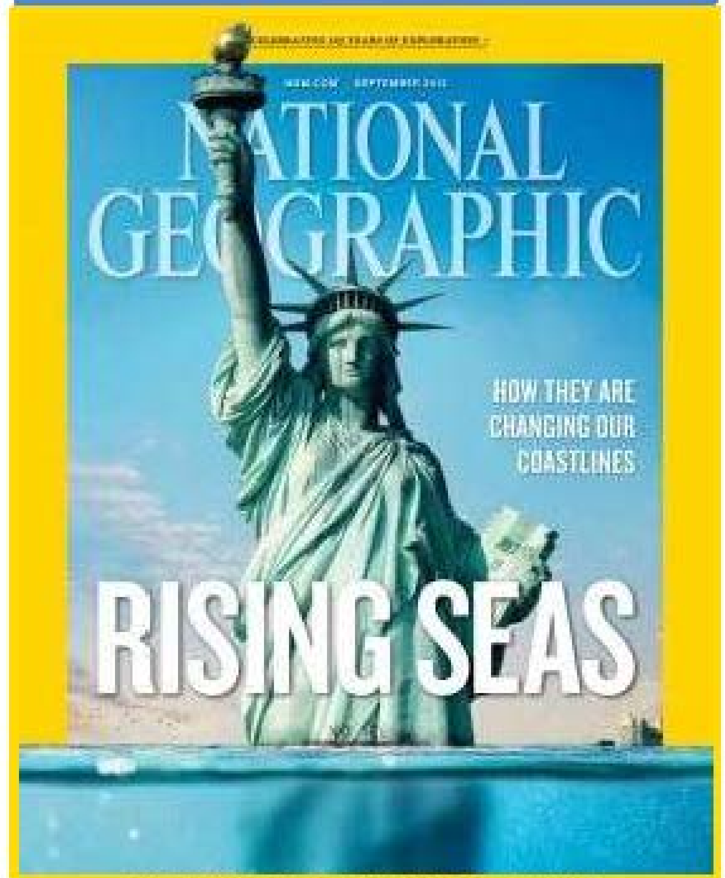
Rising sea-levels, attributed to melting land ice and expanding sea water due to temperature fluctuations, are a significant threat to coastal regions around the globe. Exacerbated by explosive population growth and the removal of natural barriers in these areas, this threat has already begun to destroy and displace human communities and natural ecosystems. As sea-levels continue to rise, large areas of land are likely to become either permanently submerged in water or highly vulnerable to continuous flooding with storm surges and volatile wave action.[1]

AquaTree is an innovative, adaptable biomimetic structure designed to address these coastal climate change challenges by:

- **Providing physical protection and minimizing land destruction and erosion**
- **Incorporating ecosystem restoration and stabilization**
- **Collecting and storing freshwater**

AquaTree accomplishes these functions through multiple biomimetic strategies. The main frame and root foundation of AquaTree combine functional strategies from the Dragon's Blood Tree and Red Mangroves. This creates a flexible, yet strong structure designed to be flood tolerant, retaining soils and preventing erosion. The structure absorbs wave energy, enhancing shoreline habitat protection. With an expensive canopy structure built with individual, Bromeliad-shaped "leaf" pods, AquaTree collects water into a Hottentot plant inspired water storage. Collected freshwater supports carbon-capturing plants in AquaTree's canopy. These functions are sustained with the free energy of sunlight and the water cycle. AquaTree is manufactured using carbon-capturing materials and processes to ensure that even during the build phase these structures provide benefits to the coastal communities they will protect and support.

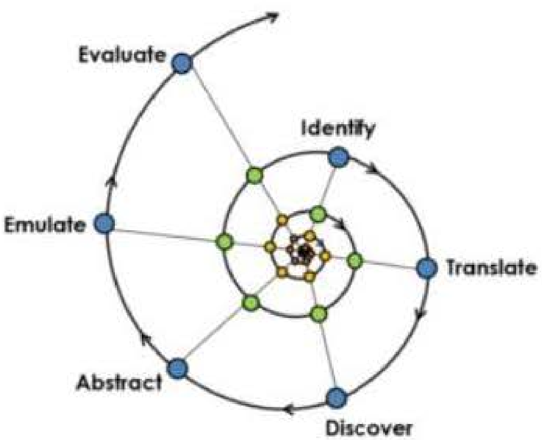
AquaTree Design Video Link



nationalgeographic.com/magazine/

Scoping Process

Utilizing the 'Challenge to Biology' design spiral, this innovation started by identifying key objectives, translating them into functions, and discovering strategies of living organisms and processes.



Biomimicry Institute

What should the design do?	What are the associated functions?
Utilize and sequester carbon from the atmosphere	Capture atmospheric CO_2
	Filter air
Cycle water and nutrients back into ecosystems	Generate oxygen
	Distribute water
	Cycle nutrients
Support human communities	Provide food through canopy plantings and aquaculture
	Create employment and recreational opportunities
Store and distribute water	Store and regulate dispersion of liquids
Resourcefully use renewable energy sources	Use free energy to power system
Protect the shoreline from erosion	Control erosion and sediment
	Physically assemble structure
Enrich and protect habitats for local species	Coordinate systems
	Regulate habitat response to disturbance

Biological Inspirations

Red Mangroves / Regulate Water Flows ; Filter + Remove Salt from System

Red Mangroves are small trees that can thrive in salty water. Mangroves regulate water flows with stilt roots that stabilize soil without barricading an area. Normally a higher concentration of salt in surrounding water drives salt ions into plant cells. Different species of mangroves have developed strategies to work against the concentration gradient. These strategies all allow mangroves to grow where other plants cannot survive. [10, 11]

Beavers / Regulate Water Flows

Beavers' strategy for regulating water flows is quite well-known given how visible the dam structures are in an area. Beavers cut down trees and build structures that reduce the speed and amount of water moving within and between systems. This establishes more static environments like wetlands, and also changes the availability and amounts of other organic materials.[5]

Texas Horned Lizard / Capture Water

The Texas Horned Lizard is able to capture water by utilizing channels and structures on its skin. It is then capable of moving this water to its mouth for drinking. The splayed stance and interscalar channels on the skin assist in water capture. During rain-harvesting, the stance of the lizard changes: They raise their abdomen in an arch, splay and extend their legs, utilize dorsoventral flattening and lateral spreading of the body, lowering of head and tail resulting in drinking water being collected on dorsal body surface and capillary action carries water over the body surface to the jaws for drinking.[18]

Bromeliads / Capture Water ; sequester carbon

Bromeliad plants are areal based flowering plants that use their exposed root systems to anchor themselves on tree branches and other structures, allowing them better access to sunlight. To compensate for the lack nutrients available their open air root systems, Bromeliads create micro-ecosystems within the water collected in their flowering structures as an alternate method of accessing nutrients. They can also capture water and nutrients in a storage tank via hydrophobic surfaces and the structure of their leaves.[4]

Dragon's Blood Tree / Capture Water ; Create Shade

The leaves of the Dragon's Blood tree form a dense canopy that collects airborne moisture through condensation. This condensation is then channeled along its branches and down to its root system. The dense umbrella like canopy also provides shade that prevents the water condensation from evaporating on its journey down to the root system.[8]

Biological Inspirations

Fog-Basking Beetle / Capture Water

Fog-basking beetles have evolved a beaded surface that collects water from dew and fog.[17] The structures combine hydrophilic (water attracting) and hydrophobic (water repelling) areas, increasing dew-harvesting efficiency.[19]

Aquaporin Membranes / Filter Water

Aquaporins are membrane bound proteins that facilitate efficient water transport through cell membranes by channeling water molecules between hydrophilic materials.[2, 13]

Plant Leaves and Stems / Move Water ; Cooling

Transpiration in plant leaves moves water upward by leveraging evaporation and capillary action. Leaf cells are equipped with stomatal apertures that influence the rate of evaporation. Transpiration provides water and minerals to plant structures and also cools plants through evaporation.[22]

Hottentot bread plant / Store Water

The desert Hottentot Bread Plant stores vast amounts of water in a large partially underground corky tuber. The Hottentot has an extremely large root system where water is absorbed via osmosis and stored partially underground where it is safe from animals. The roots are protected by a bark-like material. Hottentot plants extremely large root system means a larger surface area and the ability for more water to travel into the plant.[7]

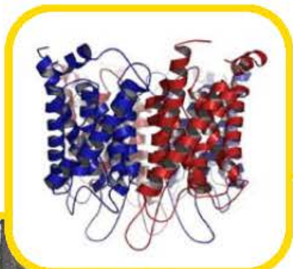
Mycorrhizal networks (fungal Networks) / Water Distribution

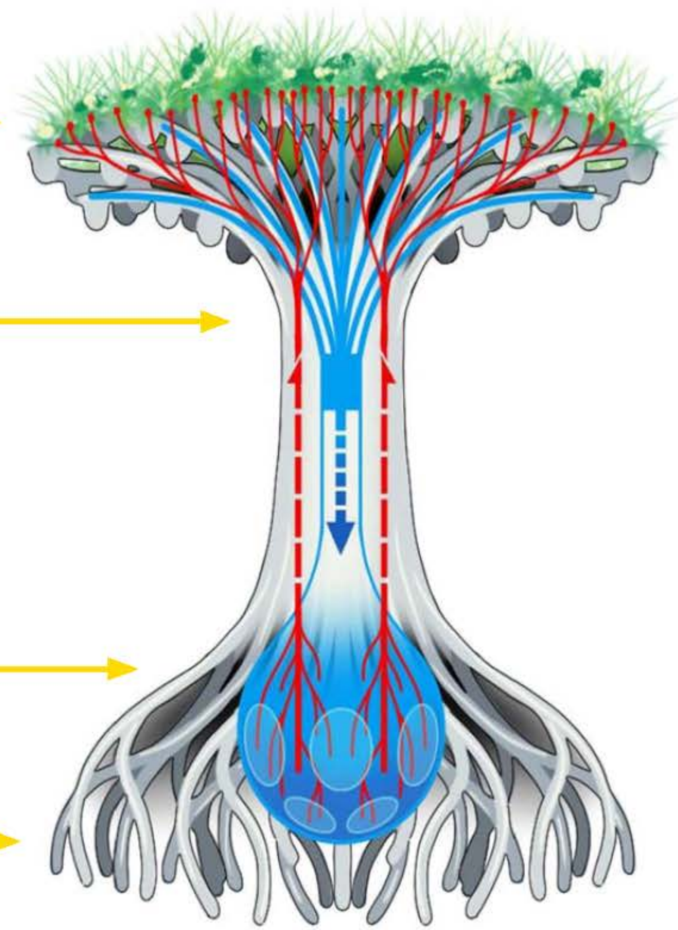
Mycorrhizal fungal networks offer symbiotic relationship between plants and subsoil fungi that allow for the distribution of water and nutrients from plants in high resource areas to plants in areas of less resource accessibility. This relationship is facilitated by the rhizomorphs and hyphae of various Mycorrhizae that form interconnected vascular networks that link plant roots of different species together.[3]

Coral / Carbon Capture

Coral's synthesize their hard exoskeletons by dissolving CO2 in seawater to form carbonate and then mixing it with calcium to form a solid. Corals mineralize prolifically and rapidly at ambient temperatures to create some of the largest biological structures on the planet.

EMULATED STRATEGIES

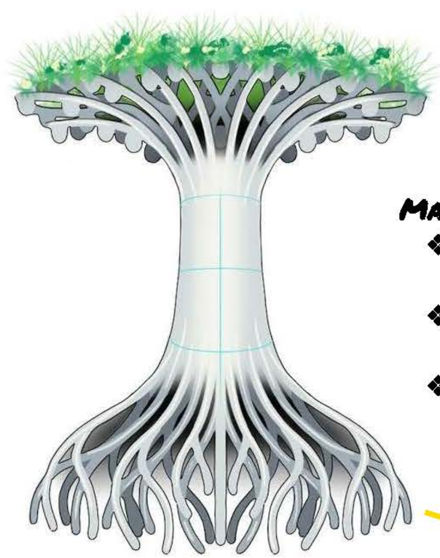


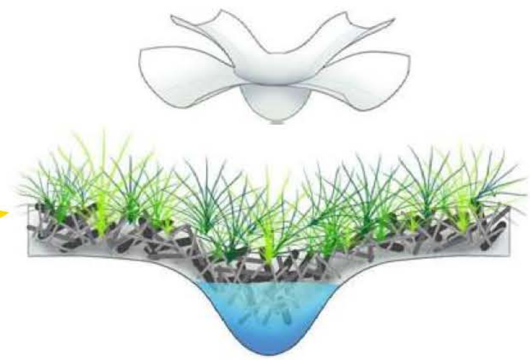


- **CONVEX LEAVES** [4]
  Using the structural strategy of the **Bromeliad**, AquaTree:
  - Collects and guides water into curved reservoirs to filter through the system.
  - Collects and composts organic materials that provide nutrients for canopy flora.
- **STRONG TRUNK + BRANCHING CANOPY** [8]
  Using the structural strategy of the **Dragon's Blood Tree**, AquaTree:
  - Optimizes its ability to house flora on its canopy and sequester CO_2.
  - Establishes a base stable enough to weather intense wave activity.
- **AQUAPORIN MEMBRANE** [13]
  Using the biological strategy of the **Aquaporin membranes**, AquaTree:
  - Addresses the function of capturing and filtering salt from water.
  - Creates fresh water for other living things unable to process seawater with such high levels of salt.
- **STILT ROOTS** [10, 11]
  Using the structural strategy of the **Red Mangrove** stilt roots, AquaTree:
  - Controls and minimizes the erosion of sandy coastal substrate.
  - Regulates seawater flows, effectively protecting shoreline habitats.

AquaTree

The tree canopy structure creates habitats for birds, insects, and other native species. In areas where rising sea levels eliminated natural plant growth, animals and insects are left without places to rest, feed, and reproduce.



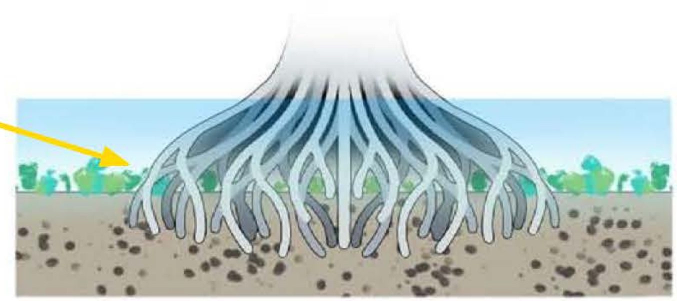


Bromeliad inspired microbiomes are planted with coastal, salt tolerant plants and naturally forming algae. The structure of the bromeliad inspired design captures and collects rainwater and condensation for storage and irrigation of the fauna planted in the branches. These plants in turn purify the air for the coastal communities, and filter pollutants from the rainwater that enters the system. Additionally, atmospheric carbon dioxide is absorbed and captured by these organisms.

Materials

- Superstructure: Reinforced carbon negative concrete provides adequate strength and weight to anchor AquaTree.[6]
- Internal irrigation system: Blend of recycled and virgin bio-derived polypropylene for durability and resistance to corrosion.
- Bromeliad foundation: Porous mycelium skeletons converted to calcium carbonate.

Dragon’s Blood tree inspired frame includes a strong mangrove like base that can withstand intense wave action. Unlike typical breakwater structures, mangrove roots are more porous, slowing waves yet allowing for tidal flows

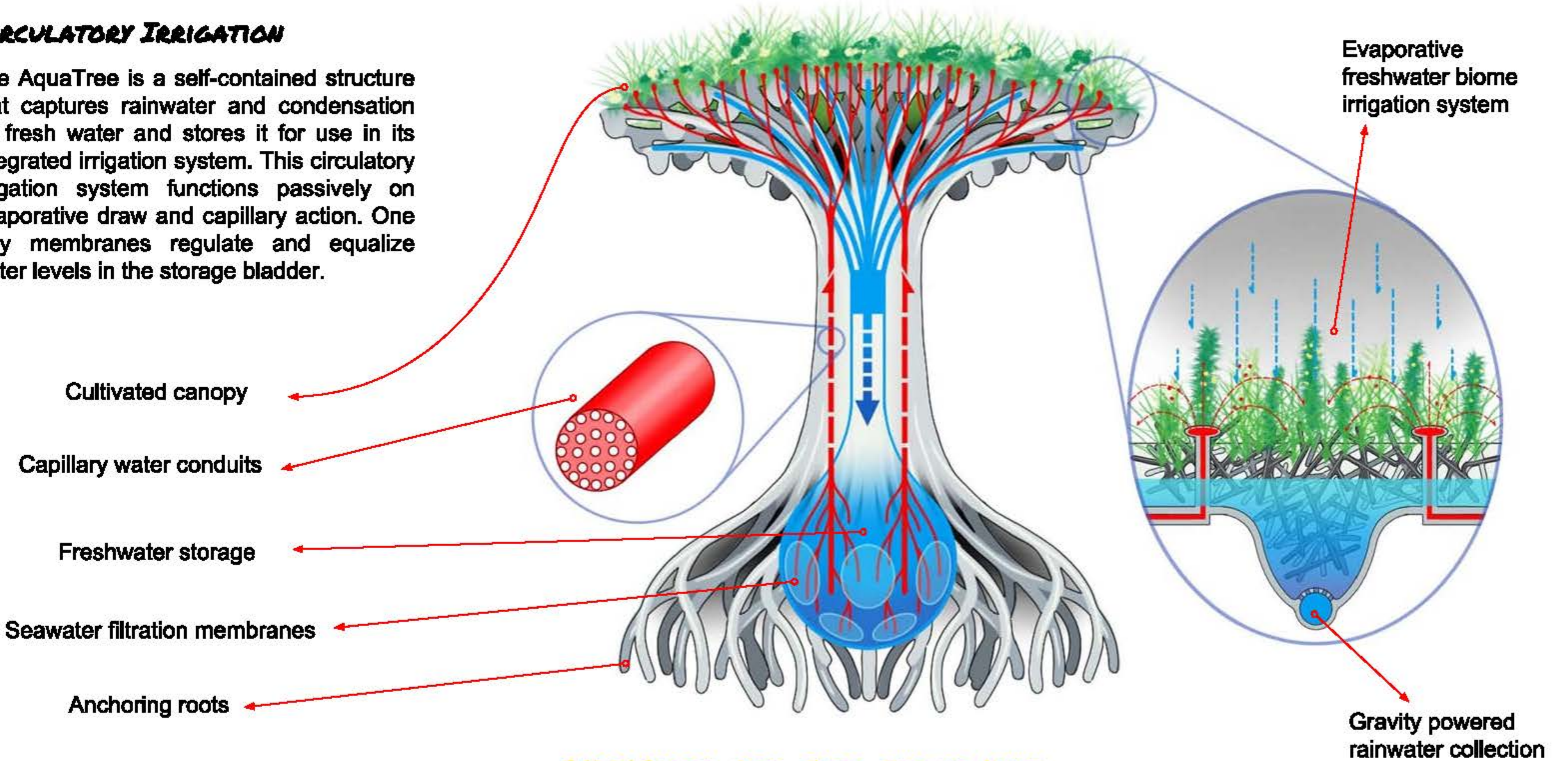


Mangrove inspired stilt root structures are key for soil binding, and stabilizing the coast as less sediment erodes from the shoreline when trapped by the stilt roots. They also provide habitat for marine species, offering shelter and protection from predators and weather. As native plants, such as seagrass, establish alongside the AquaTree roots, the coastline is further stabilized.

AquaTree

Circulatory Irrigation

The AquaTree is a self-contained structure that captures rainwater and condensation as fresh water and stores it for use in its integrated irrigation system. This circulatory irrigation system functions passively on evaporative draw and capillary action. One way membranes regulate and equalize water levels in the storage bladder.



BGDC / Bergen . Cook . Elder . Jacques . Kelly

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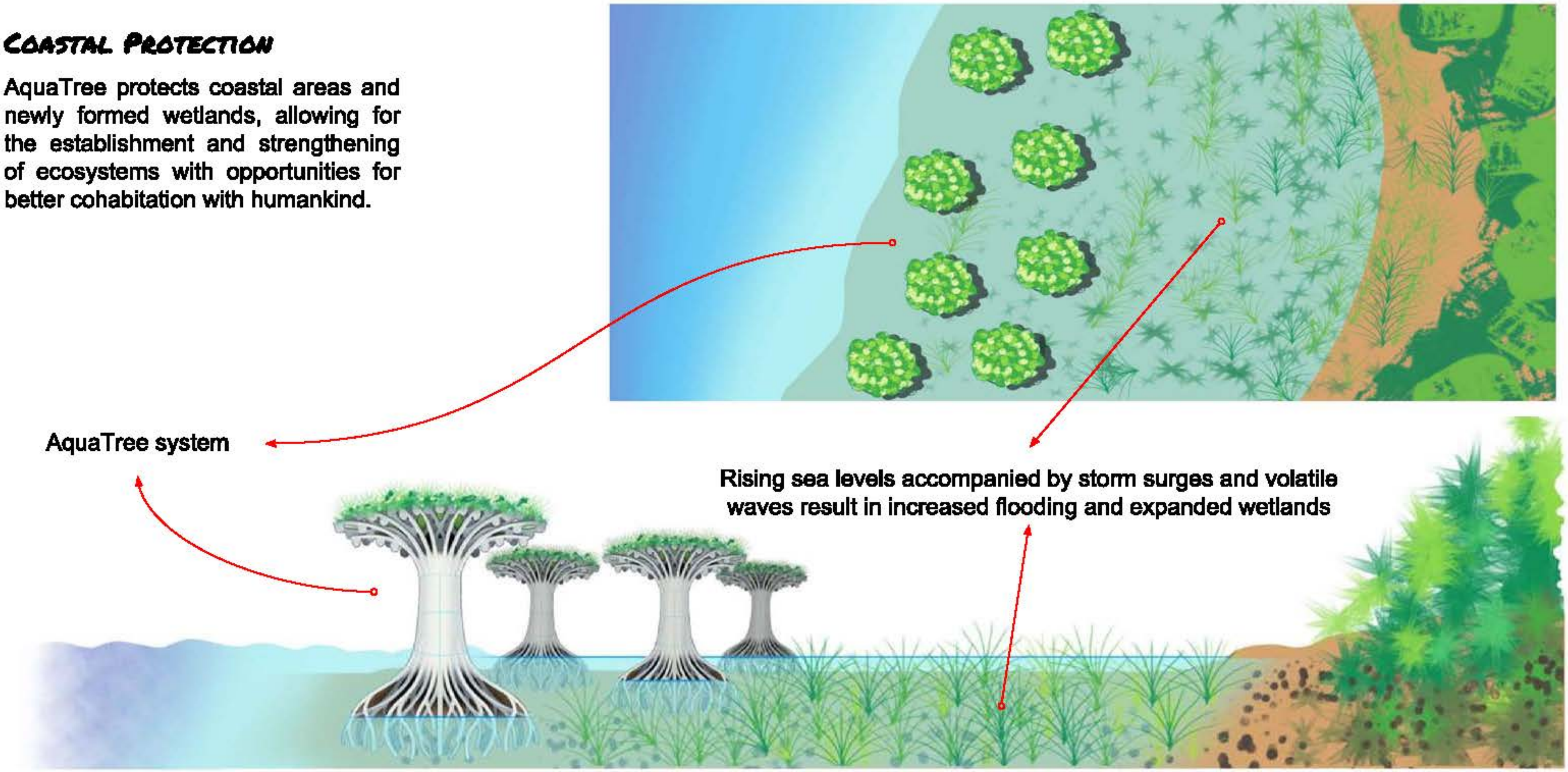
Coastal Protection

AquaTree protects coastal areas and newly formed wetlands, allowing for the establishment and strengthening of ecosystems with opportunities for better cohabitation with humankind.



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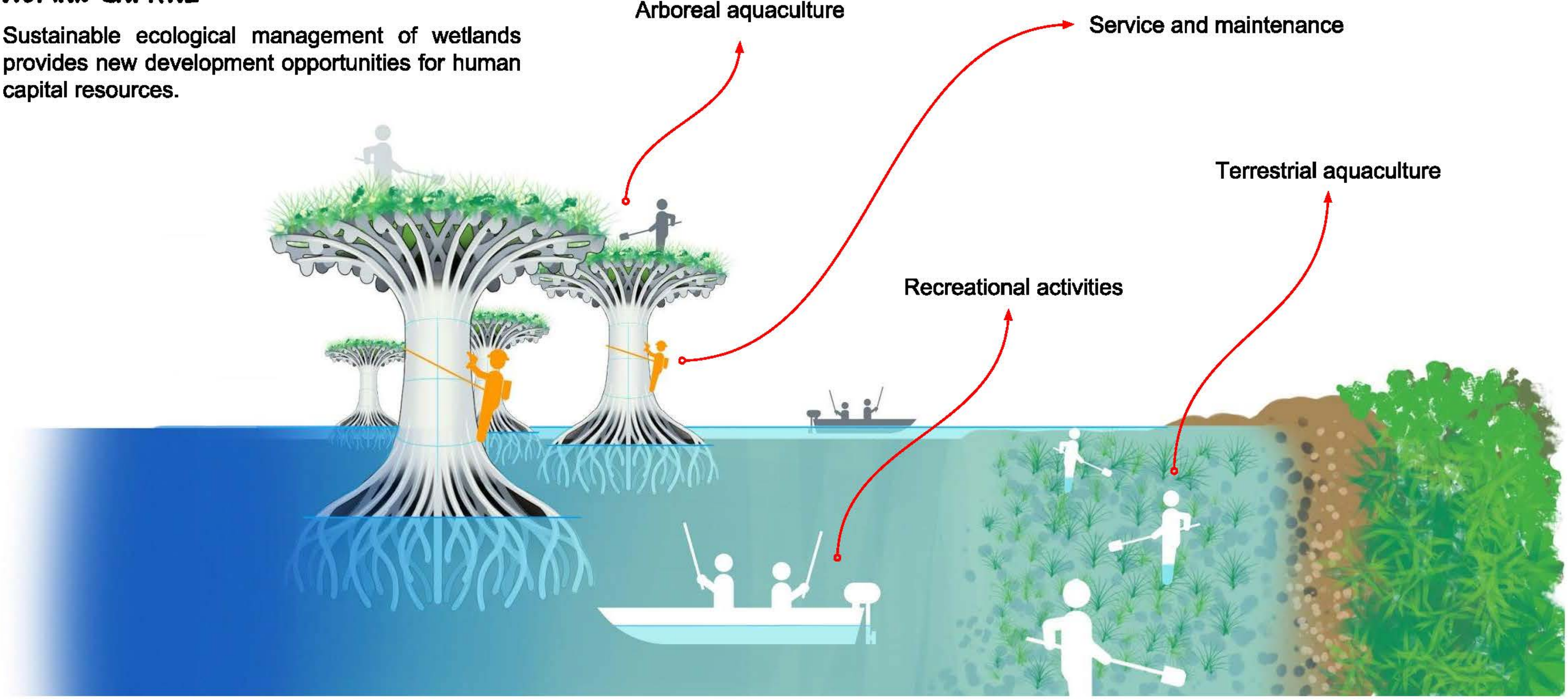
Human Capital

Sustainable ecological management of wetlands provides new development opportunities for human capital resources.



NATURE'S UNIFYING PATTERNS / LIFE'S PRINCIPLES

DOES THE DESIGN ADAPT + EVOLVE?

Is the design locally attuned and responsive?

- AquaTree systems can be configured to fit the local landscape and needs (different tree heights and/or more roots in areas with greater wave action, different fauna in the upper branches depending on the weather of the region, etc.)
- The "leaf" shells use shape instead of energy or material to guide the flow of water into the system.
- AquaTree structures can be scaled by combining multiple root structures with biomimetic marine cement. This design also allows the structures to be repaired/healed.

Does the design integrate cyclic processes?

- One of the main features of AquaTree is its ability to revitalize the cyclic processes of shoreline stabilization, securing sediment that would otherwise erode with increased wave action.
- Using plant aspiration cycles, AquaTree filters the air to reduce pollution levels.

Is the design resilient?

- Redundancy is nested in the system via a branched water collection and distribution - if one component fails or falters, others can compensate.
- AquaTree includes cross-pollination by combining macro-scale capture of wave energy (shoreline protection) with nano-scale structures (water collection and distribution).
- AquaTree's modular stilt roots branch out and establish a firm, yet adaptable base. The design supports resilience to disturbances from increased wave action, while at the same time optimizing natural flows and enhancing habitats.

DOES THE DESIGN CREATE CONDITIONS CONDUCIVE TO LIFE?

Does the design optimize rather than maximize?

- AquaTree contains multi-functional elements by stabilizing the shore, collecting and distributing water, capturing atmospheric CO_2, and providing shade and protection with its large, branching structure.
- AquaTree draws energy and resources from the water cycle with its water collection and distribution structures.
- Typical shoreline barriers maximize defense with inflexible, unforgiving structures. AquaTree optimizes shoreline protection with a modular root system that stabilizes areas and prevents erosion.

Does the design use benign manufacturing?

- Both the mycelium foundation and the carbon negative concrete superstructure are formed with minimal manufacturing impact, limiting the amount of energy needed for production.

Does the design leverage its interdependence in the system?

- AquaTree creates the necessary stability for coastline communities (plant, animal, and human) by reducing the amount of damage and destruction from wave action and storm surges.
- AquaTree provides an irrigated structure for growing food and supporting local biodiversity. Shade and calmer seas generated by the structure also provide habitat and potential for shoreline aquaculture.
- The manufacturing, installation, and maintenance of the AquaTree provides jobs for individuals, and also aesthetically improving coastal regions that may be otherwise desolate due to destruction from climate change.

Business Case

Value Proposition

AquaTree, a beautiful, multi-functional vertical marine biomimetic structure, provides nature-based solutions to protect and help rebuild ecosystems and communities located in coastal zones. Areas suffering, or at risk of suffering from the worst effects of flooding, freshwater depletion, and destruction due to climate change are protected by the structural and functional benefits of AquaTree. Additionally, AquaTree provides economic and recreational opportunities for community members, connecting individuals to their local ecosystem.

Target Customer Segments

The European Environment Agency describes a coastal zone as "the zone in which most of the infrastructure and human activities directly connected with the sea are located."[1] Unfortunately **coastal towns on most continents**, including **large metropolitan** areas such as Boston or Miami, are threatened by "mounting pressure on the coastal zone environment [that has] resulted in a rapid decline in open spaces and natural sites, and a lack of space to accommodate coastal activities without significant harmful effects."[1]

In addition, the Federal Emergency Agency Management (FEMA) suggests that "it's as important to keep people away from the water as it is to keep the water from them."[21] Water events like Katrina, or Sandy, reminds us that relocating millions of individuals to higher ground or away from at-risk areas although ideal, is often an herculean task a number of cities appear unwilling (or are unable) to undertake. So, preserving and protecting communities where they are currently geographically located may very soon become an urgent local, if not regional, matter.

As a result, AquaTree's **primary target markets are dense urban coastal communities which have already experienced the destructive forces of rising sea levels** and are actively seeking to protect their ecologies (residential, social, economical, natural) from future losses or recover from past ones. Like community gardeners, residents of an affected area can choose to become stewards of the new ecosystem as they "grow and raise" AquaTree structures in their coastal zones through investing directly in a community fund and/or with sweat equity.

As AquaTrees are re-stabilizing shorelines, they will help municipalities protect themselves from financial disaster, while creating economic opportunities in phases: 1) through the planning, design, installation and seasonal care of each AquaTree ecology, 2) through arboreal and aquaculture plantings and harvesting and /or 3) through low-impact marine tourism and recreation as the natural ecosystems are rebuilding themselves. Finally, coastal communities will also have the option to build these new marine vertical ecologies through land trusts or cooperative enterprises. Alternatively, communities with a lack of expertise, could also decide to convince their local aldermen and mayors to implement the AquaTree system and manage its organic growth through a consortium of regional organizations.

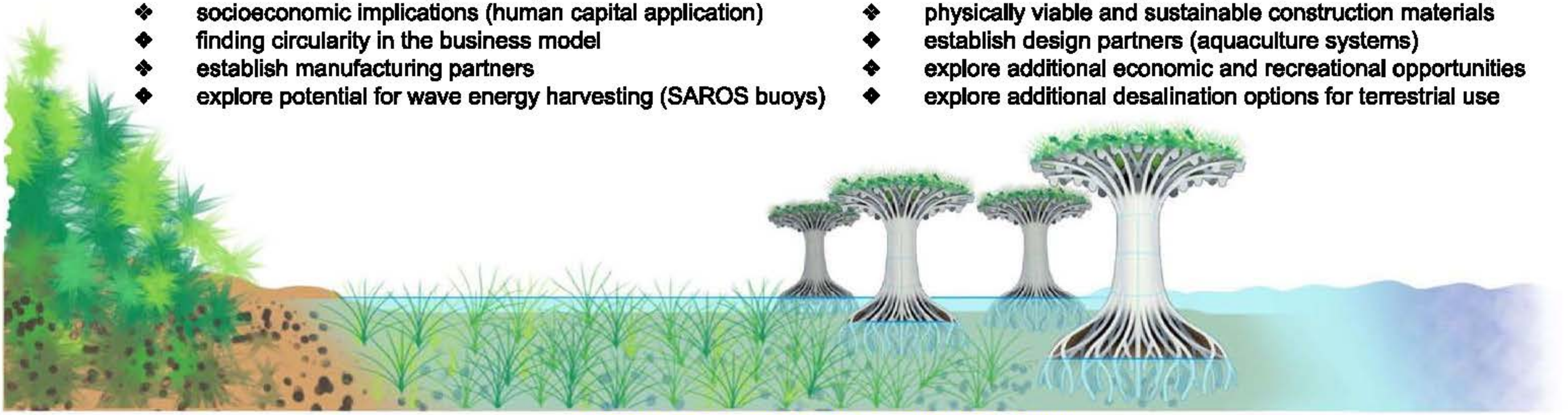
Next Steps

Moving this concept to the next phase will require a series of feasibility studies that will need to be conducted. Long term geological and ecological impacts will need to be simulated and assessed to determine proper application or modification of design strategy. Material applications and structural integrity of the tree superstructure will need to be modeled, computationally simulated, and physically tested. Additionally, further consideration and research into human related factors such as social, economic, and political will need to be conducted to determine contextual viability and long-term development potential.

Exploring symbiotic relationships with other innovative coastline systems is warranted. For example, seawater desalination using wave powered SAROS buoys[15] or food production with Jellyfish Barge[12] or Seawater Greenhouse.[16] Combining AquaTree's functions with complementary systems could increase the value proposition for AquaTree via holistic synergies.

Challenges to be addressed in the next phase

- maintaining structural integrity in harsh conditions
- effectiveness, efficiency, durability of tree subsystems
- socioeconomic implications (human capital application)
- finding circularity in the business model
- establish manufacturing partners
- explore potential for wave energy harvesting (SAROS buoys)
- micro-biome ecology and assessment of species strategies
- ecological and geological impacts (short and long term)
- physically viable and sustainable construction materials
- establish design partners (aquaculture systems)
- explore additional economic and recreational opportunities
- explore additional desalination options for terrestrial use



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