Embracing Aquafarm

Ecological Approach to Aquafarm in 2050

This Aquafarm has planned to create the necessary space for aquaculture through an ecosystem-based approach in open waters. By utilizing artificial upwelling technology, we aim to establish a foundation for a balanced food chain within the marine environment. The food chain generated by this aquaculture facility helps mitigate marine pollution resulting from artificial feed supply and prevents unnecessary overfishing of small fish species. By mimicking the form of coral, the preferred habitat for fish, we can induce various behaviors of fish through the aquaculture facility, making it function like a single habitat for them. Expanding from shallow and narrow coastal areas to open and broader offshore waters offers favorable conditions to establish an ecosystem both within and outside the aquaculture facility, reducing exposure to diseases and ensuring greater biodiversity. Rather than having fish intervene in human spaces, this proposal envisions a paradigm shift where humans intervene in the fish's domain.

2023 JACQUES ROUGERIE FOUNDATION AWARDS

Award's category : Architecture and Innovation for the Sea

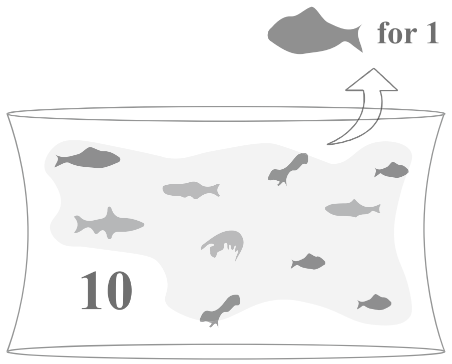
Project's Name: Embracing Aquafarm

Description: Ecological Approach to Aquafarm in 2050

FONDATION JACQUES ROUGERIE

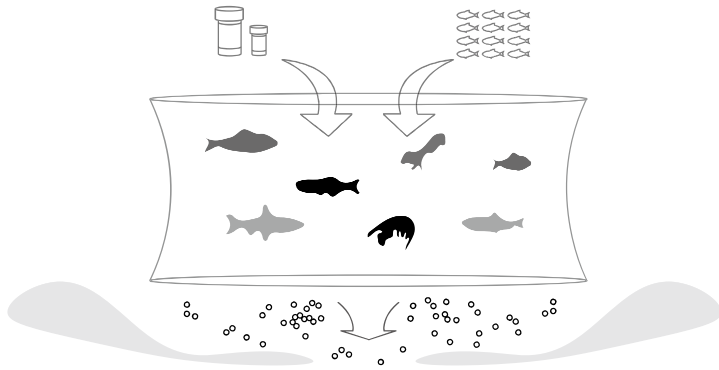
Project Background

The Need for Eco System-based Aquaculture



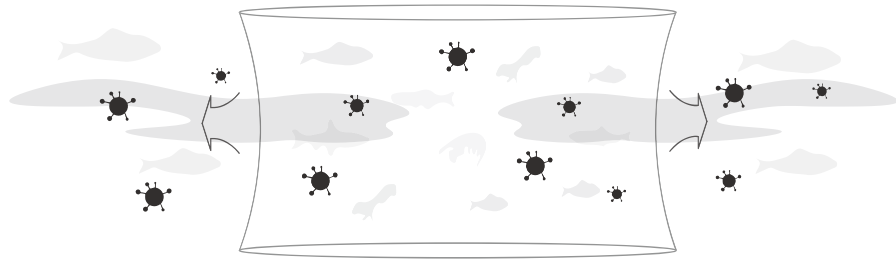
Forage Fish impacts

To produce 1 kg of farmed fish, more than 1 kg of wild-caught fish is required. Approximately 1/5 of the catch from natural fisheries is processed into oil, meal, and other feed ingredients, with over half of it being utilized in aquaculture.



Habitat Destruction

Accumulation of nitrogen-based waste and other pollutants leads to eutrophication and a decrease in dissolved oxygen. As a result, this can lead to marine environmental pollution and habitat destruction.



Disease Transfer

Coastal cage aquaculture with slow water flow and high concentration of fish can lead to the rapid spread of viruses. When it is located along the routes of wild fish, viruses originating within the farms can potentially affect fish outside.

“ The *Aquafarm* in the *Open Sea* through an ecological approach”

Formation of a natural food chain

Healthy proliferation of plankton in aquafarms can enhance the marine food chain, reducing the reliance on human-provided feed. This approach prevents overfishing for fishmeal, minimizes pollution, and sustains a healthier marine ecosystem.

Providing Natural Habitat

Providing habitats that mimic natural environments not only encourages robust ecosystem activity within those habitats but can also have a positive impact on the surrounding ecosystems.

The Spacious Ocean

Wide, open oceans are characterized by fast currents and a substantial volume of water. Deep sea usage offers rich oxygen and nutrients, lowering power needs and improving pollutant purification and reducing fish concentration, virus risk.

Ecological Approach

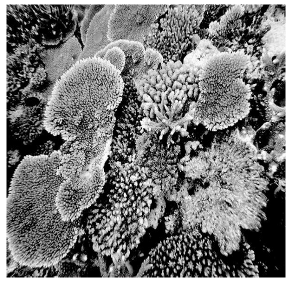
1. Coral

City Under the Sea

Coral formations, consisting of clustered polyps, come in various shapes influenced by their environment. This diversity creates complex, city-like structures that serve as ideal habitats for a range of marine life. These structures feature interconnected passageways and spaces for diverse interactions among underwater organisms, playing a crucial role in forming species clusters within the marine ecosystem. Coral's morphology significantly contributes to these clusters in the marine ecosystem.

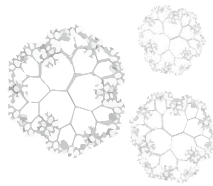
Ecological Contributions of Coral

Coral offers stable habitats and food for fish, along with protection and hiding spots, supporting fish survival. Some fish use coral for breeding, boosting fish populations and benefiting the marine ecosystem.



Structure & Arrangement

A solid structure that can withstand various activities of creatures
A cluster arrangement that can accommodate the diverse behavior.



Complexity

The varying sizes of gaps suitable for incorporating different fish sizes
High share for large void space, high density for small void space.

Diversity of void space

High species diversity and complex food webs
More stable set of fish consisting of resilient interactions.

2. Ecofriendly Material : Bio Plastic

Benefits of using 'Bio Plastic'

Bioplastic not only aids in beach cleanup and reduces plastic waste but also promotes organic recycling. Additionally, it contributes to reducing carbon footprint as the plants absorb CO2 from the atmosphere.

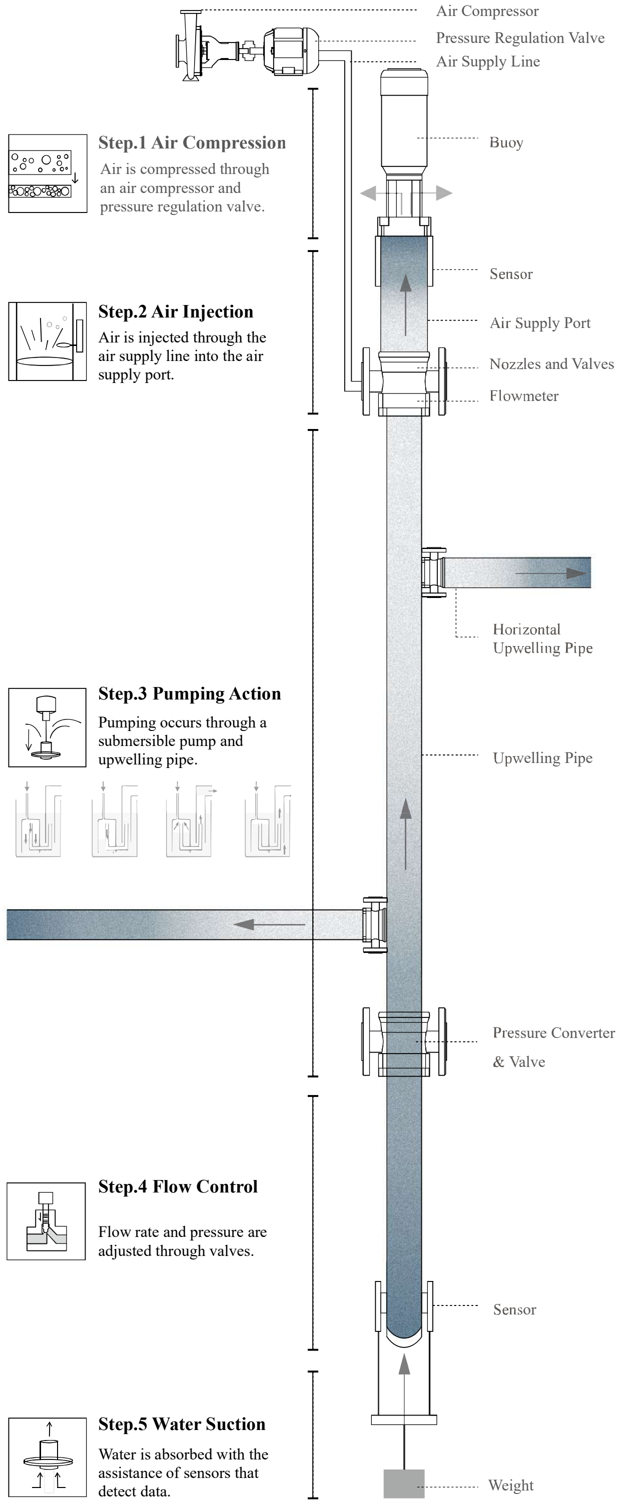
The use of 'Algae' as material

Active research on eco-friendly materials using algae is ongoing due to their natural occurrence, biodegradability, role as a marine food source and habitat foundation.

Process using a '3D Printer'

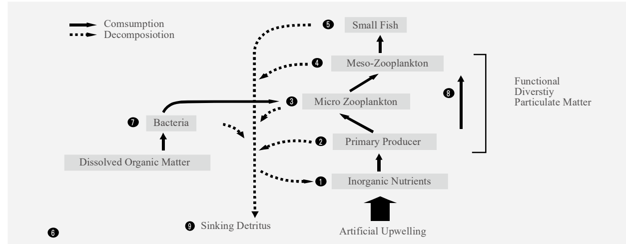
Eco-friendly construction additive printing can employ biopolymers like polylactic acid, offering high printing accuracy for Fused Deposition Modeling.These bio-based plastics are recyclable and suitable for structures.

3. Artificial Upwelling (AU)



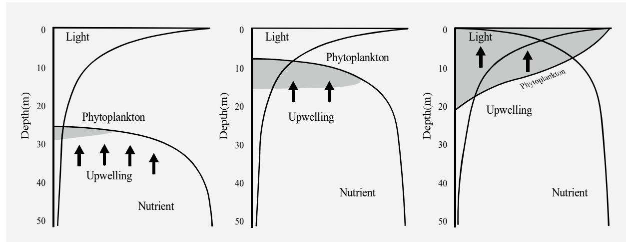
Marine Food Chain Structure

The marine food chain is essential for maintaining marine ecosystems. Upwelling technology enhances the marine food chain, creating favorable fishing grounds.



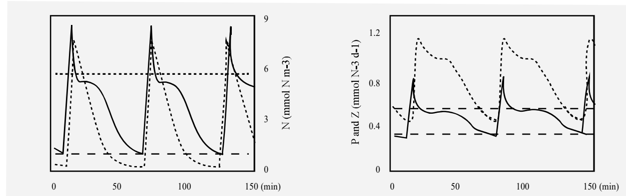
Nutrient Flux and Plankton Movement Due to Upwelling

Upwelling leads to the ascent of nutrient-rich waters and plankton primarily dependent on dissolved oxygen to the surface layer.



Relationship Between Nutrient Flux and Primary Productivity

Primary productivity is the capacity of phytoplankton to produce organic matter essential for organisms through photosynthesis. Vertical circulation enhances marine primary productivity, creating a favorable habitat for fish.

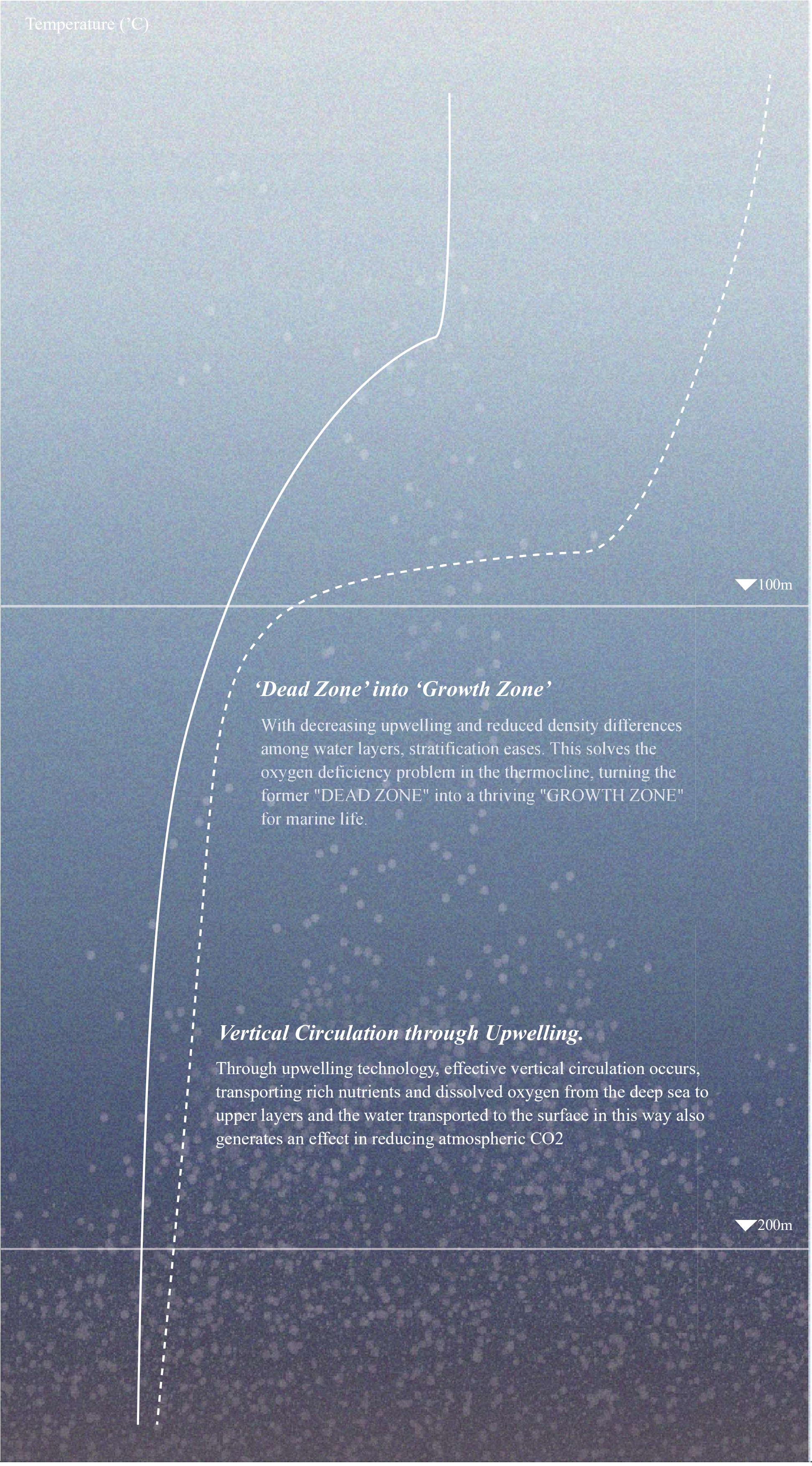


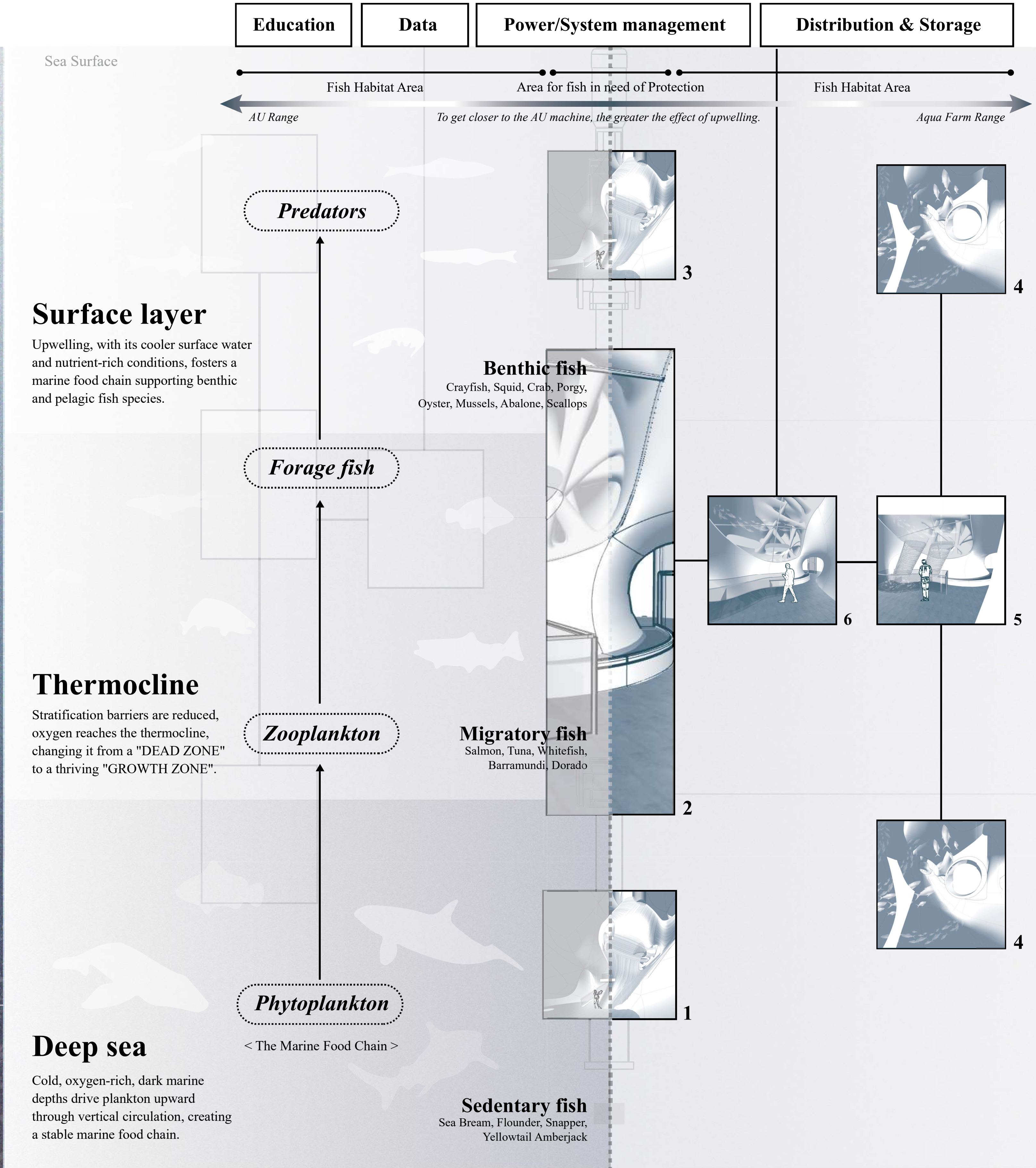
(left) Primary productivity (solid lines) and residual nutrient concentration (dark dashed lines). (right) Phytoplankton (solid lines) and zooplankton concentrations (dark dashed lines) as functions of time, for a fixed ratio T a /T = 0.12

Improving Environments through AU

Upwelling is the rise of nutrient-rich deep-sea water to the surface, creating an ideal marine environment for fish. Artificial upwelling technology induces this phenomenon using cold, nutrient-rich deep-sea water to enhance ocean currents and improve aquaculture water quality. Future developments in "upwelling diffusion systems" and "air pressure devices" aim to control aquaculture facilities and water quality, potentially generating horizontal water flow. These air pressure devices may also serve as power sources for human and fish movement mechanisms by 2050.

Zoning & Program





Infra

Marine infrastructure supports upwelling aquaculture facilities and enables human involvement in operations. It's designed for facility operation and maintenance.

1 Spawning / Hatching

This area, strategically located in the lower layer with the greatest upwelling influence and the lowest water temperature, serves as a space for spawning and hatching using stable deep-sea conditions (low temperature, ample oxygen, darkness).

2 Fingerling

This area houses juvenile fish as they grow before entering the aquaculture facility. These young fish are in a critical growth stage and require optimal conditions. To accommodate various fish species found at different depths, they are positioned vertically near the pipes with the strongest upwelling effect.

3 Fishway

Small fish mainly live near the surface, feeding on plankton brought up by upwelling. They enter and exit pens, becoming prey for larger fish,strengthening the food chain. This area enhances the food chain.

4 Catching

This area gathers fish from different depths for harvesting. Upwelling creates a stable current circulation environment, enabling fishing grounds in both surface and lower layers to capture diverse fish species effectively.

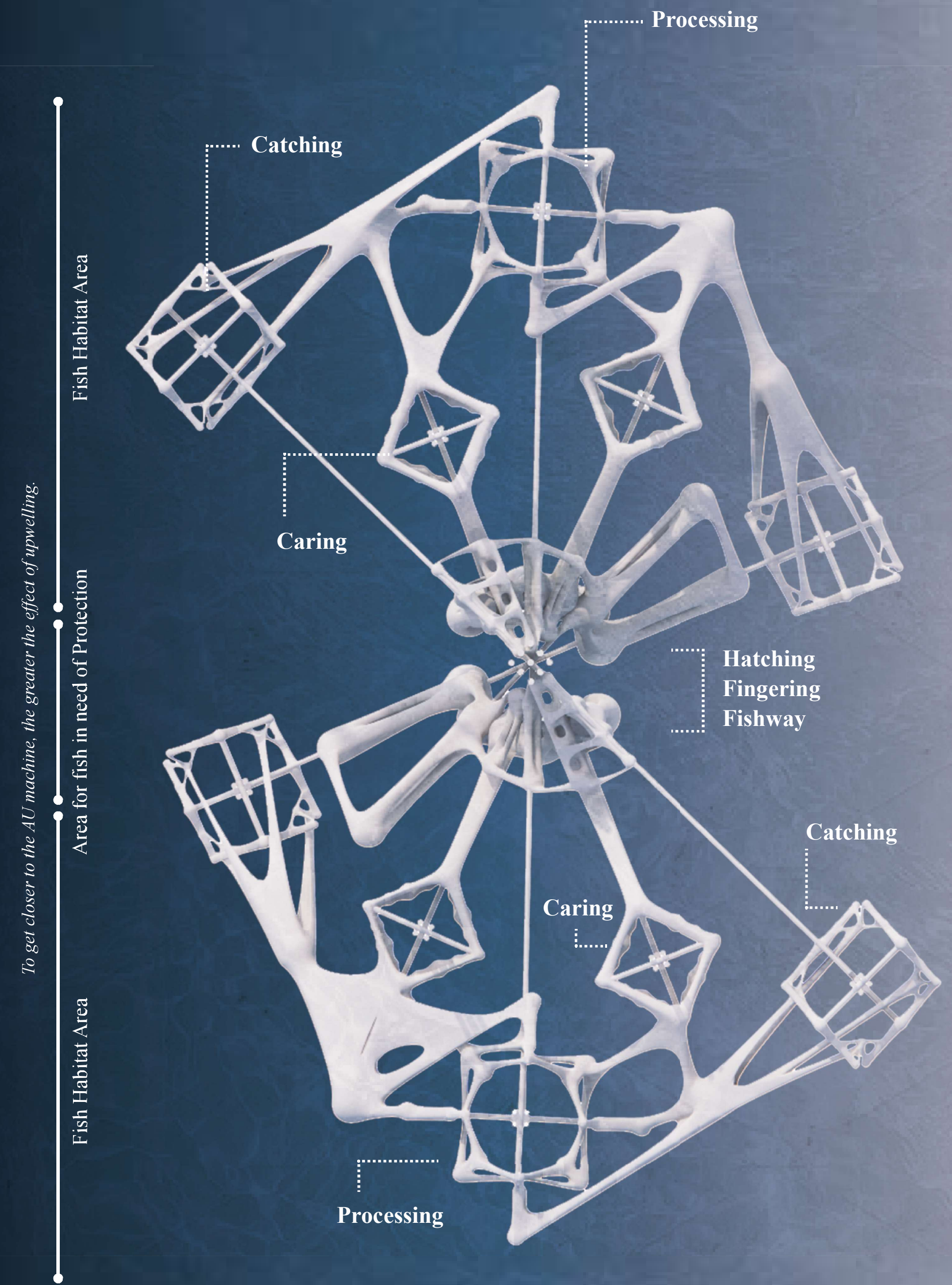
5 Processing

This is a space where harvested fish are transported and sorted according to their degree of growth. To gather fish caught in the surface and lower layers, they are placed in the intermediate layer known as the thermocline.

6 Caring

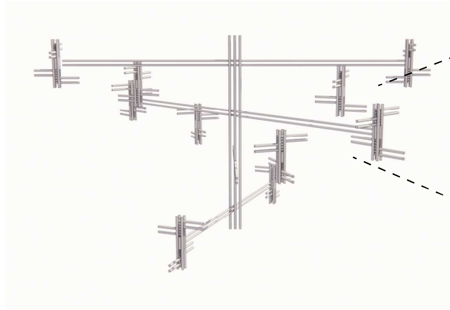
It is an overall care center where research can be conducted for the condition of fish or a better environment. It provides a separation space for a certain period of time if humans directly treat fish or need recovery

Design Process

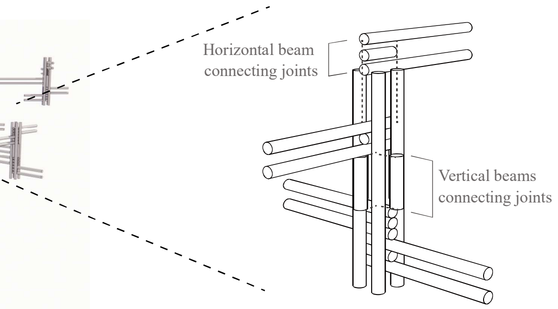


Creating a Coral Growth Environment

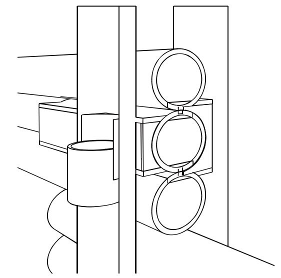
We planned the placement of coral based on the marine environment created by upwelling technology. Upwelling horizontal pipes were placed at a depth of 27m, with a length set to a diameter of 100m, considering the influence range of the machinery. The coral's growth environment extended from the upwelling pipes and formed within the pipe structure. The coral structures are joined by joints. The connecting joints secure modules on the outside of the structure, while inside, they form spaces with walls and slabs.



The growth environment of the coral is formed by extending from the pipes, based on the environment created by upwelling technology.



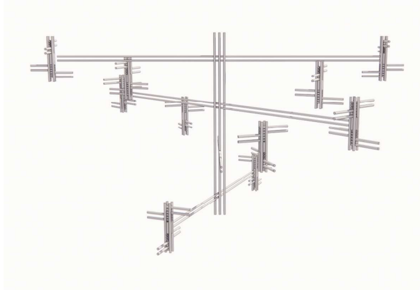
The coral structures are connected and secured by joints, which link the members together



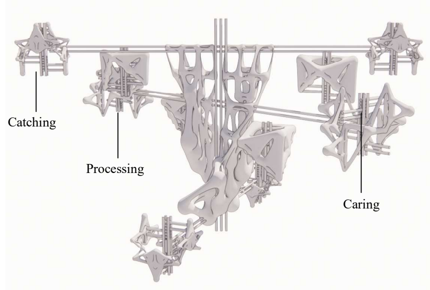
Joints serve not only as structural connections but also as spatial elements within the interior.

Formation of a Coral City

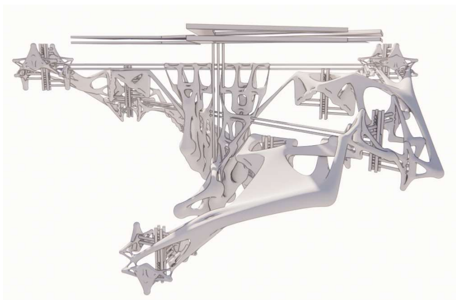
Corals' diversity within a colony refers to different coral species living together and cooperating. Each coral has a specific role within the colony, working together with other corals to ensure the colony's survival. This communication among corals leads to the formation of a larger colony, and this diversity encourages active interactions among various groups. This process suggests the possibility of coral colonies evolving into vast and magnificent underwater cities as they grow.



① Considering the transformed marine environment through upwelling technology, coral's growth environment was established as the fundamental structure of the aquaculture facility.



② Different forms of corals within the entire coral colony have specific functions.

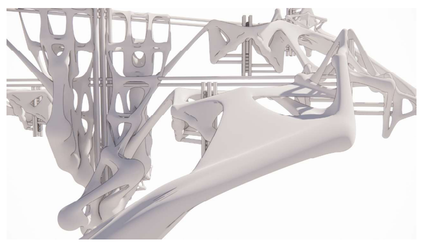


③ Corals were connected according to the aquaculture system to create a coral city. The offshore infrastructure was integrated with upwelling pipes and the coral structures to complete an aquaculture facility based on the upwelling system.

Connections *based on the ecological characteristics of fish habitats*

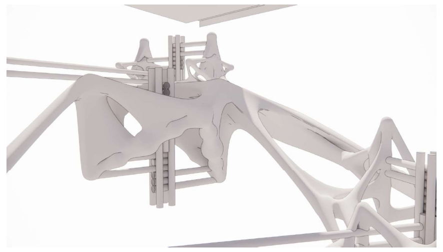
Clusters of diverse coral formations within coral reefs, shaped by the landscape's characteristics, create both vertical and horizontal spaces. The resulting complex structures serve as suitable spaces for marine organisms to hide and reside. In reality, numerous aquatic species form groups based on their respective species within different segments of these massive city-like coral reef structures. They are organized into various large and small groups, akin to societal fragmentation, interacting as neighbors and spending their lives within these reef sectors.

Flat type



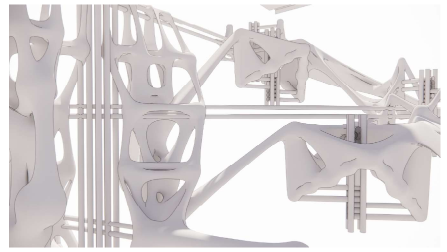
A flat type of terrain creates an environment suitable for the settlement of sessile species, providing favorable conditions for their habitat.

Slope type



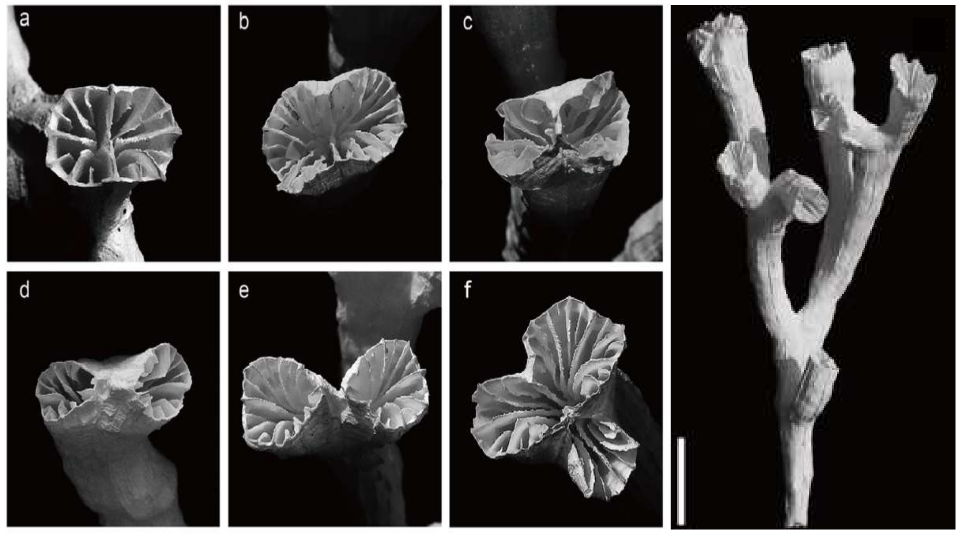
Slope terrains create overlapping spaces for species inhabiting the upper and lower regions, promoting a richer food chain.

Linear type



The vast voids formed between linear terrains provide advantageous spaces for the attraction and movement of pelagic species.

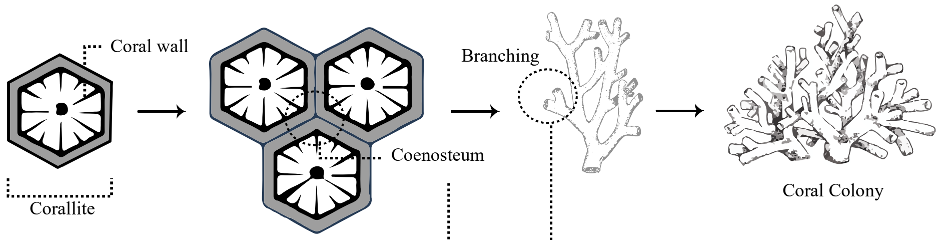
Design Process

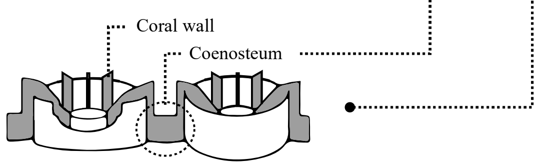


Corallite budding and new branch formation

Coral Structure and Connecting Method

The skeletal structure forming an individual unit within a coral colony is called a "Corallite," and it has a structure on it where polyps can sit. The columnar skeletal tissue that develops at the center of the corallite is referred to as the "Columella.". The skeletal structure that connects numerous corallites is called the "Coenosteum."



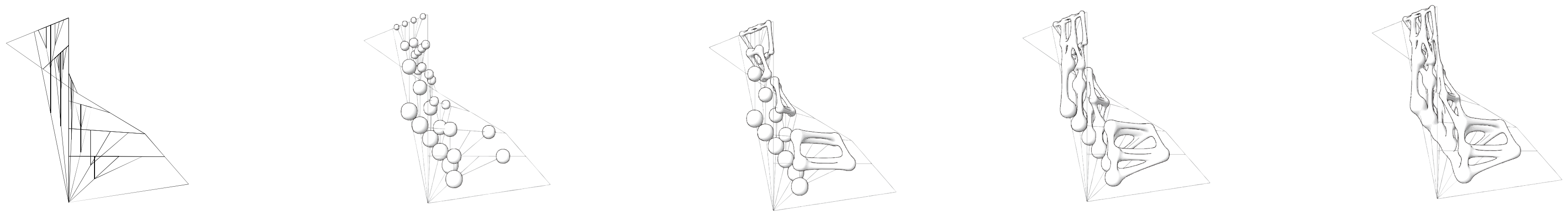


Branching

Coral forms new branches as it produces more substances during its growth. As these branches intersect and connect with each other, coral reefs are formed. These reefs constitute coral colonies and provide habitats for various marine organisms.

Coral Formation (1): Spawning/Hatching/Fishway - Single-Point Branching

The entire grid was formed using the branching characteristic of coral growth. (①)
At each branching point of the grid, coral skeletons (coral polyps) were placed and interconnected to create a coral colony.(②~⑤)



① Generation of Branching (Growth Axis): The grid was formed by connecting the endpoints of horizontally spreading pipes extending from the upwelling structure to the central point.

② Hierarchical arrangement of polyps: To place polyps on the branching points, 1, 3, 5, and 8-meter spheres(morphological characteristics of the coral) were arranged based on their functions.

③ Function-based connecting: Corals of the same size were connected each other to create spaces and assigned functional programs to them (Initial stage of spatial formation)

④ Establishing Circulation: function-specific spaces were connected vertically to create movement pathways/routes. (Secondary stage of spatial formation)

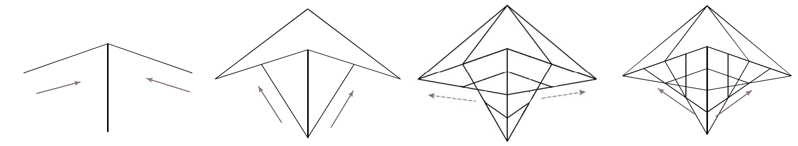
⑤ The completion of coral: The interior of the completed coral serves as a growth space for fish, while the exterior functions as a complex habitat where matured fish are released into breeding facilities to live.

Coral Formation (2): Fishing, Processing, and Caring - Multi-Point Branching

Step1. 2D Grid Formation

To facilitate coral formation, a grid was created using the branching growth pattern of coral. The grid follows the same method as the single-point branching on the polylines reflecting various functions.

Catching Large quantities of fish from the breeding facility are gathered in one location and captured.



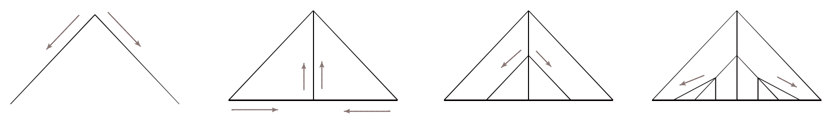
①Creating a baseline: The function of gathering in one place.

②Connecting endpt and midpt: Creating the primary fishing point

③Connecting endpoints and midpoints: Establishing the secondary fishing point

④Completion: Formation of points of human intervention.

Processing After capture, the transported fish are sorted in the processing module and then transported to their respective facilities.



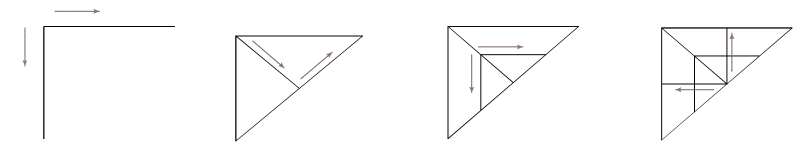
①Creating a baseline: The function of classification.

②Creating a closed line: The function of pre-facility storage before relocation.

③Connecting center points: Placement into multiple facilities.

④Completion of processing grid: More detailed placement of facilities.

Caring The point of human intervention, responsible for healing and managing the fish.



①Creating a baseline: Functionality of vertical and horizontal pathways considering points of human intervention.

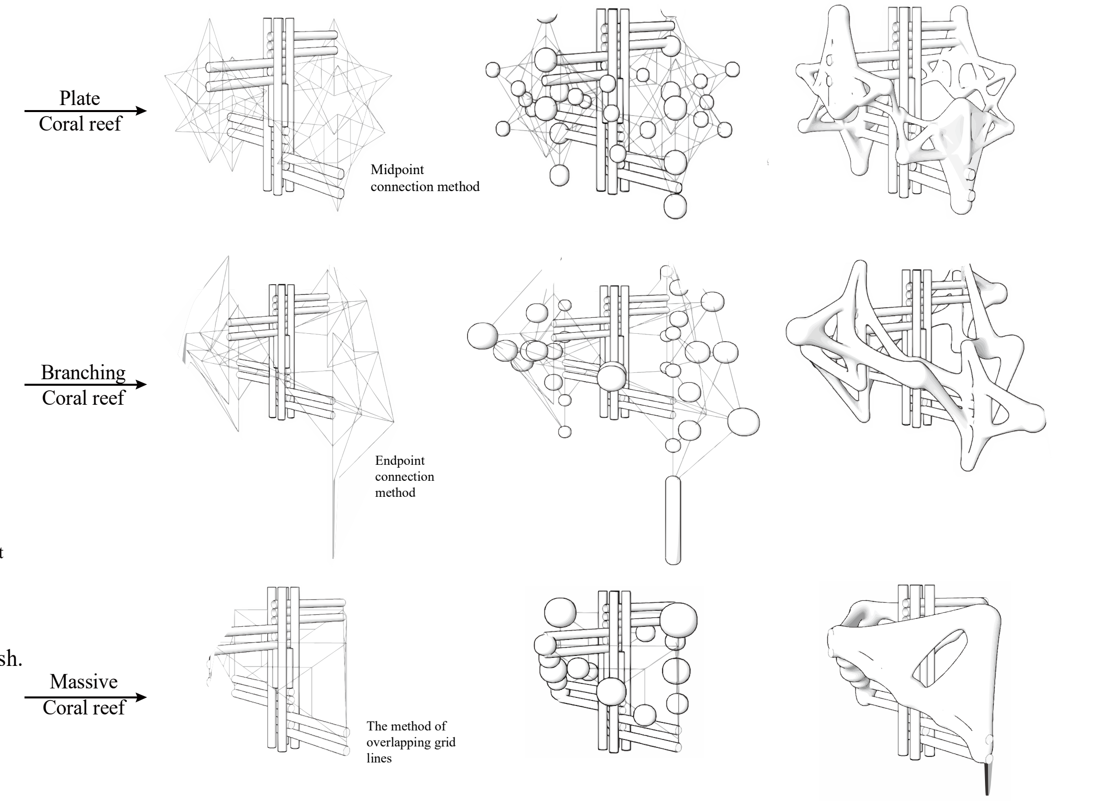
②Creating diagonal lines: Considering the movement of fish for the function of healing.

③Connecting center points: Functionality for fish healing.

④Completion of processing grid: Function as the exit point for the fish

Step2. Formation of coral with diverse characteristics

To create three coral characteristics: branching, plate, and massive, variations were introduced in the 3D grid connectivity approach. Coral was formed by placing structures resembling coral polyps at branching points to mimic the coral's morphology.



1. 3D Grid Formation

To create corals with different shapes, 2D grids were connected in various ways to form branching axes.

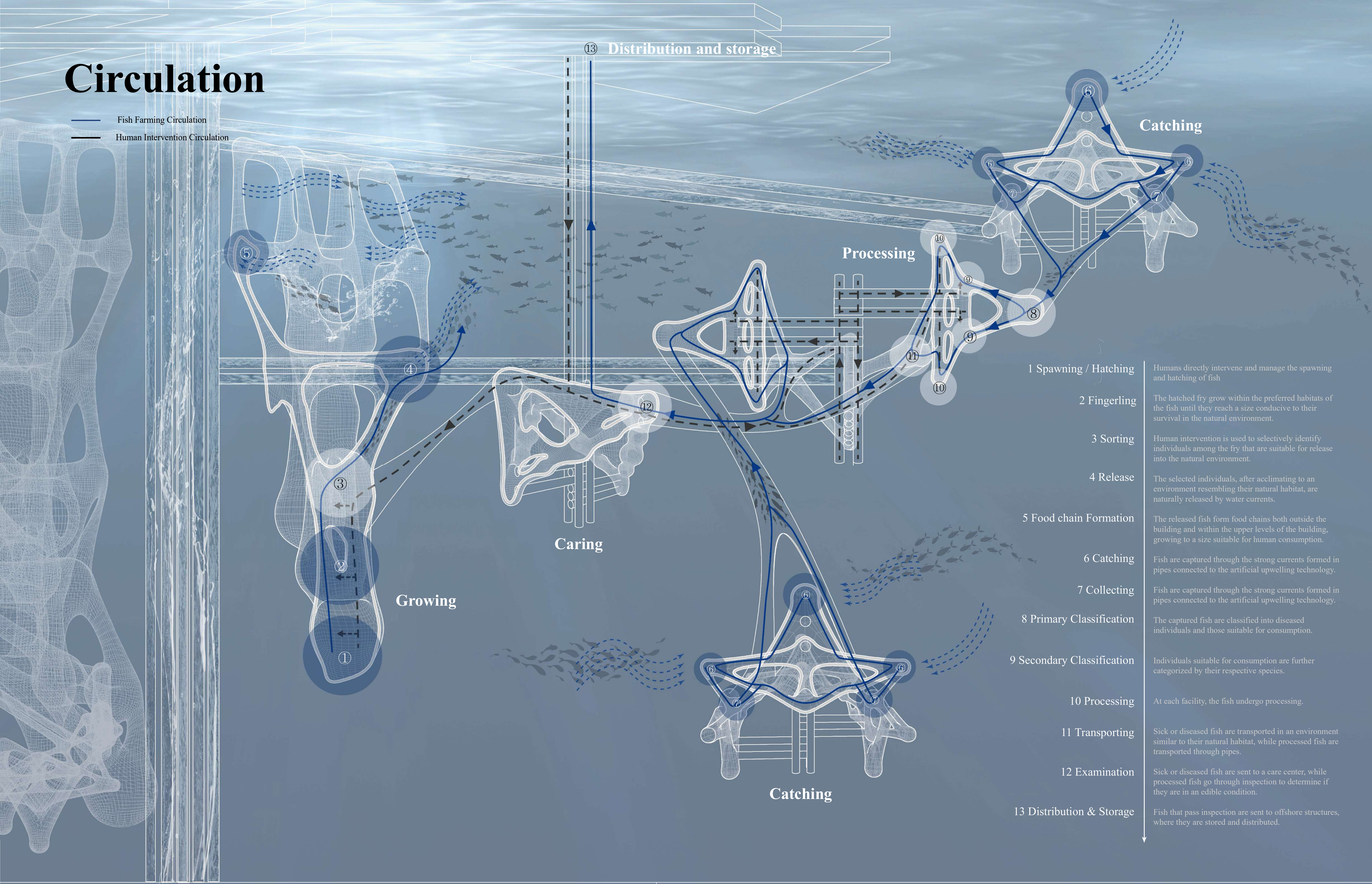
2. Arrangement of Polyps

At the intersections of the 3D grid (branching), structures resembling coral polyps were placed

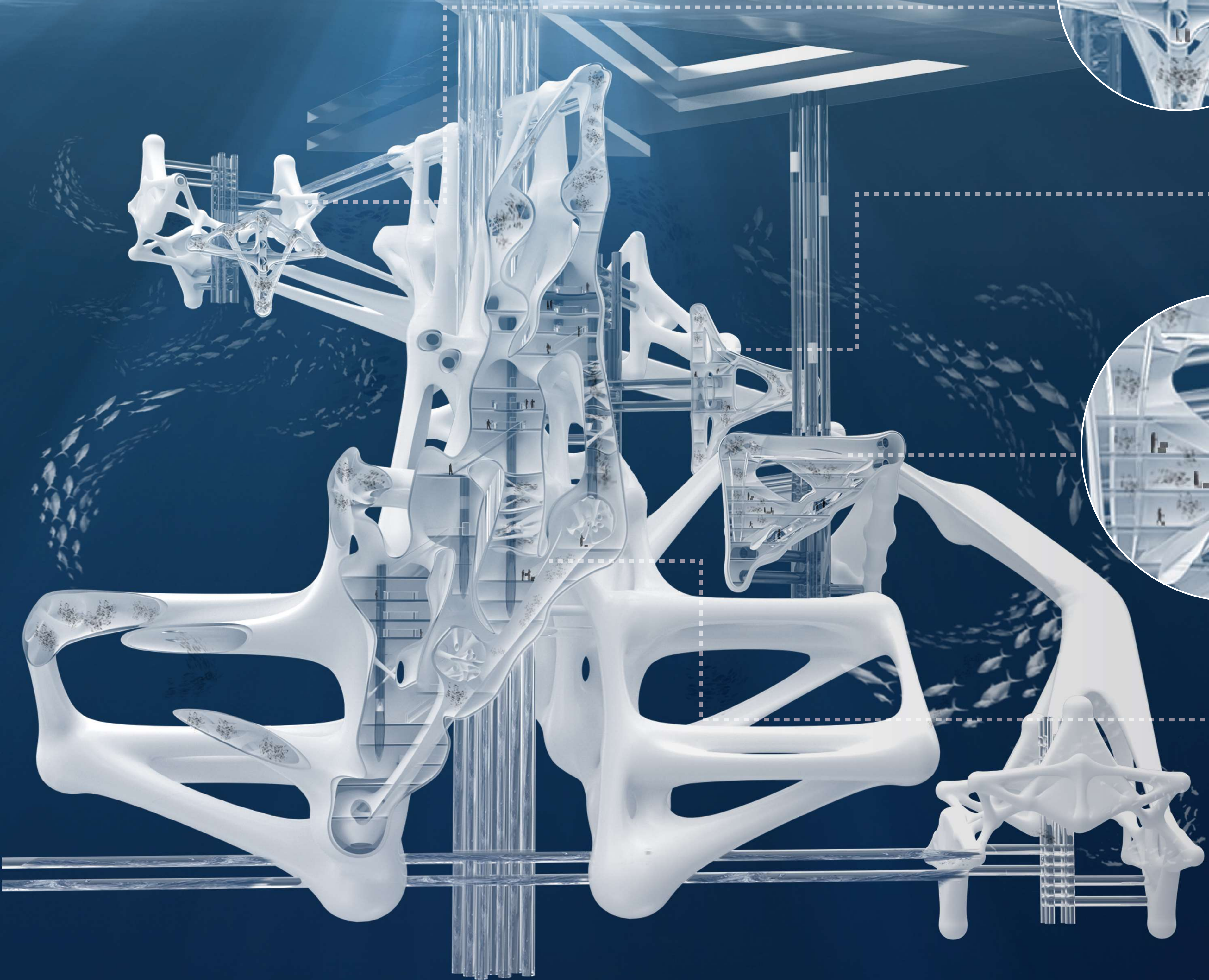
3. Formation of Coral

Coral formation was completed by connecting the structures (coral polyps)

Circulation



1 Spawning / Hatching	Humans directly intervene and manage the spawning and hatching of fish
2 Fingerling	The hatched fry grow within the preferred habitats of the fish until they reach a size conducive to their survival in the natural environment.
3 Sorting	Human intervention is used to selectively identify individuals among the fry that are suitable for release into the natural environment.
4 Release	The selected individuals, after acclimating to an environment resembling their natural habitat, are naturally released by water currents.
5 Food chain Formation	The released fish form food chains both outside the building and within the upper levels of the building, growing to a size suitable for human consumption.
6 Catching	Fish are captured through the strong currents formed in pipes connected to the artificial upwelling technology.
7 Collecting	Fish are captured through the strong currents formed in pipes connected to the artificial upwelling technology.
8 Primary Classification	The captured fish are classified into diseased individuals and those suitable for consumption.
9 Secondary Classification	Individuals suitable for consumption are further categorized by their respective species.
10 Processing	At each facility, the fish undergo processing.
11 Transporting	Sick or diseased fish are transported in an environment similar to their natural habitat, while processed fish are transported through pipes.
12 Examination	Sick or diseased fish are sent to a care center, while processed fish go through inspection to determine if they are in an edible condition.
13 Distribution & Storage	Fish that pass inspection are sent to offshore structures, where they are stored and distributed.



Catching

The fish that used to inhabit outside the aquaculture facility are drawn into it by the strong currents of the pipes. Inside the aquaculture facility, various passageways have been designed to resemble the natural habitat of the fish.

Processing

After the initial sorting process, edible fish are directed upwards, while fish requiring care are directed downwards. Nets installed from the fish passageways are used in the secondary sorting process, and fish that have undergone this secondary sorting process are then transported to the facility located on the far left for further processing.

Caring

The processed fish go through preparations for distribution to the surface through the uppermost layer.Fish that are affected by diseases or in need of prevention pass through a net that penetrates the slabs and are directed to suitable layers for each individual. They receive concentrated management in tanks with organic forms preferred by the fish and are later released through the passageways.

Growing

Fish utilize stable deep waters for their growth. During the spawning season, they undergo fertilization in organic passageways similar to natural ones and attach their eggs to a hatching site. Hatched fry then move within the building to spaces designed for them. Individuals grown in these spaces are selected by humans and go through a process of being raised again and released back into the upper areas.

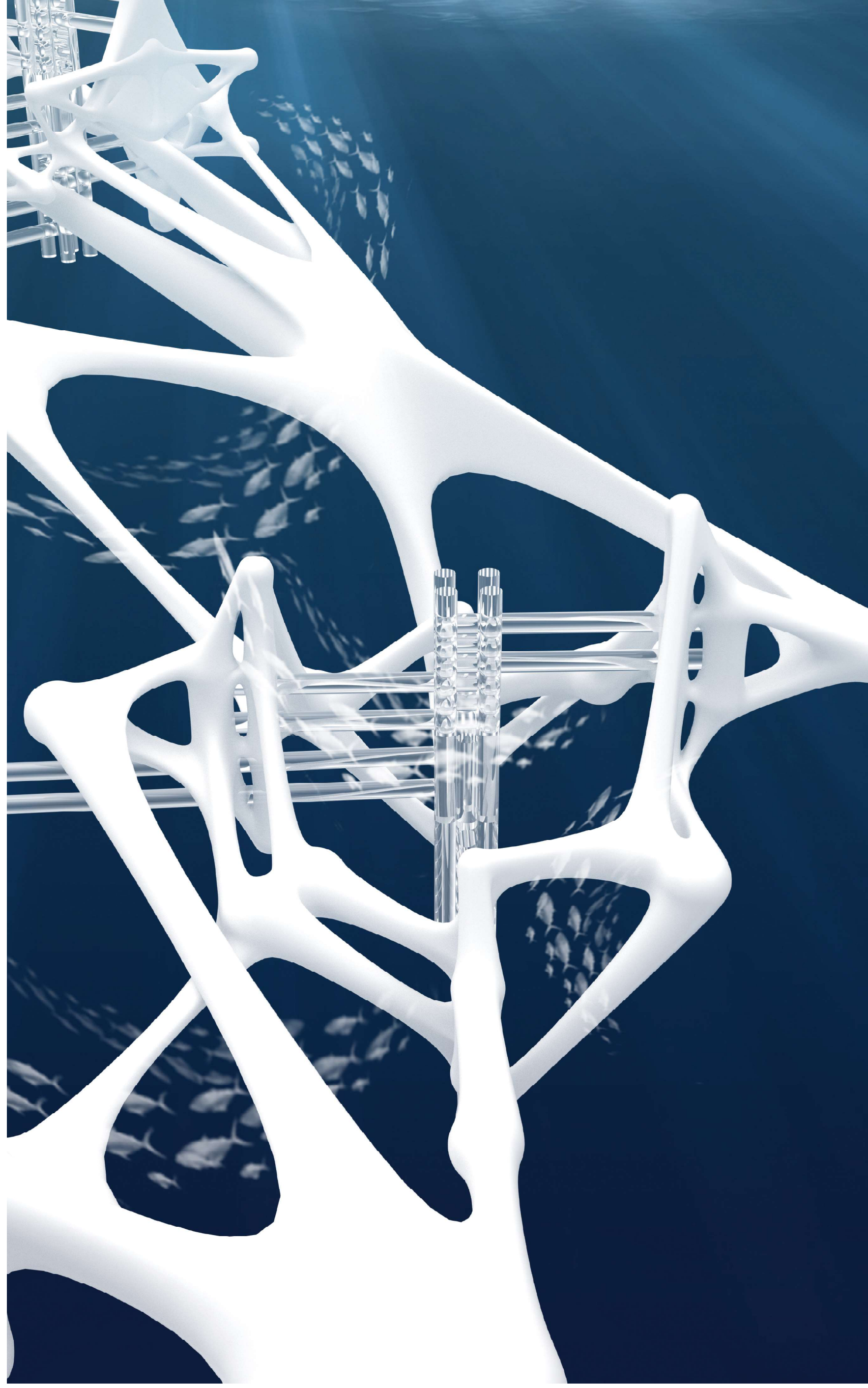
2023 JACQUES ROUGERIE FOUNDATION AWARDS

Award's category : Architecture and Innovation for the Sea

Project's Name: Embracing Aquafarm

Description: Ecological Approach to Aquafarm in 2050

FONDATION JACQUES ROUGERIE



The external environment of the aquaculture; Habitat for fish

The various fish habitat preferences resulting from the form of the aquaculture facility induce a wide range of fish behaviors. For example, spaces like deep tunnels become suitable environments for fish to rest or engage in breeding activities. These fish behaviors can be observed by people moving through transparent pipes.

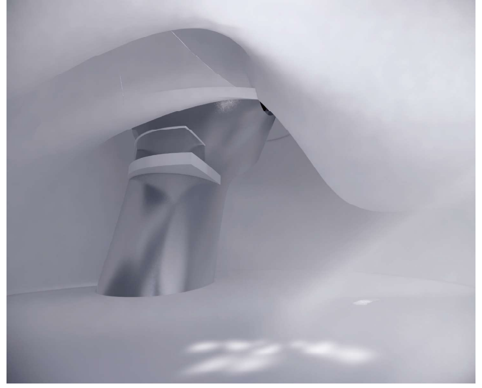
2023 JACQUES ROUGERIE FOUNDATION AWARDS

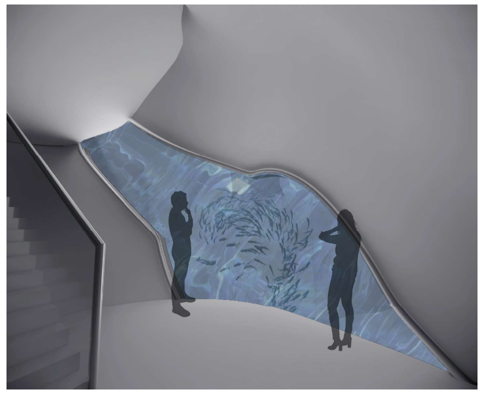
Award's category : Architecture and Innovation for the Sea

Project's Name: Embracing Aquafarm

Description: Ecological Approach to Aquafarm in 2050

FONDATION JACQUES ROUGERIE
GÉNÉRATION ESPACE MER
ACADÉMIE DES BEAUX-ARTS

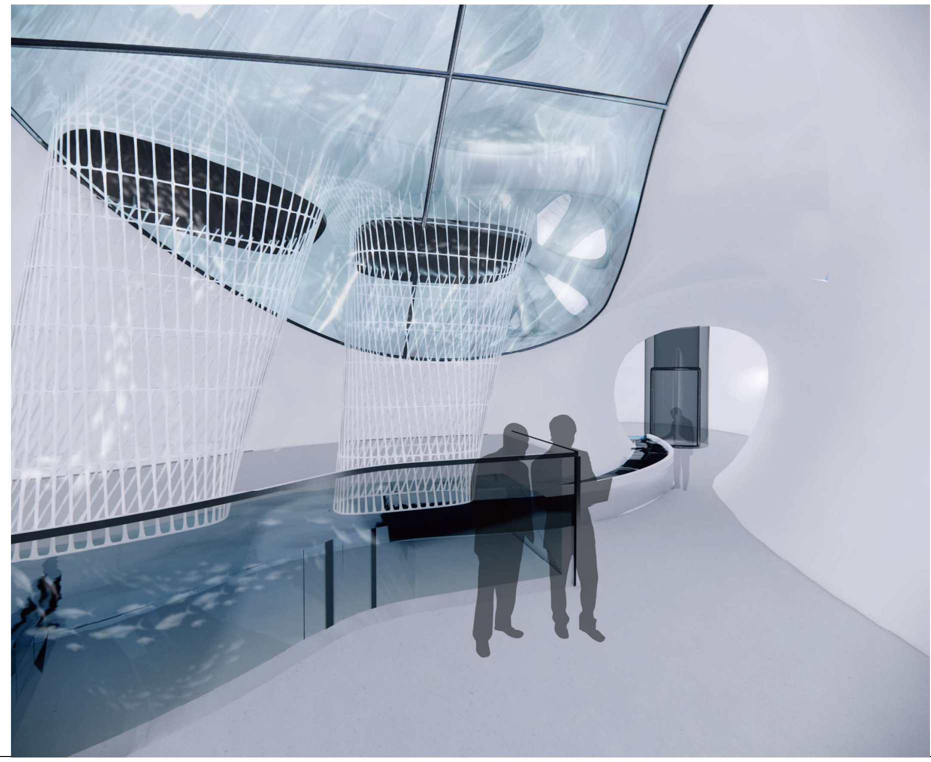




Diverse functional spaces within the aquaculture facility

The interior of the aquaculture facility, where fish grow and human intervention coexists, is designed with organic beams crisscrossing throughout the space, creating complexity to ensure that incoming fish from the outside do not perceive significant differences.

In addition, the strong water flow connected to the upwelling pipes transports fish, reducing stress and preventing disease spread. Through windows scattered throughout the space, people can monitor the condition and movement of the fish. Using nets that penetrate the organic-shaped spaces, people selectively harvest the necessary aquatic resources.



1. Angelicque,W. (2009) An Open Ocean Trial of Controlled Upwelling Using Wave Pump Technology, Research Gate, 385-392. doi: 10.1175/2009JTECHO679.1

2. A. Bakun & B. A. Black & S. J. Bograd & M. Garcia-Reyes & A. J. Miller & R. R. Rykaczewski & W. J. Sydeman. (2015) Anticipated Effects of Climate Change on Coastal Upwelling Ecosystems, Springer International Publishing, 385-392. doi: 0.1007/s40641-015-0008-4

3. Na, W.B. (2019). Artificial reefs and their issues and scientific basis. Science of Fisheries and Oceanography 28 (2), 77-82. doi:10.22714/SFO.2019.28.2.1.

4. C. Pasquero & A. Bracco & A. Provenzale (2005). Impact of the spatiotemporal variability of the nutrient flux on primary productivity in the ocean (2), Journal of Geophysical Research Atmospheres 110(7),77-82. doi:10.1029/2004JC002738

5. Lim, W. H.(2014), Hydrodynamic numerical experiments at upwelling region in the East Sea of Korea, Pukyung National University Graduate School, 56-58.

6. Kim, D. S. and S. B. Hwang(2006b), The Variation of Current by the Building of Artificial Upwelling Structure, Journal of th Korean Society of Marine Environment & Safety, Vol. 12, No. 4, 301-306.

7. Seo, H. S. and Kim, D. S.(2015), Variation of Physical Environment near the Artificial Upwelling Structure during the Summer, Journal of th Korean Society of Marine Environment & Safety, Vol. 21, No. 4, 372-380.

8. Dafforn, K. A. et al. (2015), Marine urbanization: an ecological framework for designing multifunctional artificial structures. Front. Ecol. Environ. 13, 82–90

9. Champion, C., Suthers, I. M. & Smith, J. A. (2015), Zooplanktivory is a key process for fish production on a coastal artificial reef. Mar. Ecol. Prog. Ser. 541, 1–14.

10. Bulleri, F. & Airoldi, (2005), L. Artificial marine structures facilitate the spread of a non-indigenous green alga, Codium fragile ssp. tomentosoides, in the north Adriatic Sea. J. Appl. Ecol. 42, 1063–1072 .

11. Avery B. Paxton & Charles H. Peterson & J. Christopher Taylor & Alyssa M. Adler & Emily A. Pickering1 & Brian R. Silliman, (2019), Artificial reefs facilitate tropical fish at their range edg, Communications Biology, 168. doi: 10.1038/s42003-019-0398-2

12. Kim, H.-J. & Miller, A. J. (2007), Did the Termocline Deepen in the California Current afer the 1976/77 Climate Regime Shif? J. Phys. Oceanogr. 37, 1733–1739.

13. Bakun, A. et al. (2015), Anticipated efects of climate change on coastal upwelling ecosystems. Curr. Clim. Change Rep. 1, 85–93.

14. Pauly, D. & Christensen, V. (1995), Primary production required to sustain global fsheries. Nature 374, 255–257.

15. Steinacher, M. et al.(2010)Projected 21st century decrease in marine productivity: a multi-model analysis. Biogeosciences 7, 979–1005.

16. Oded Antman. (2019), Algae, https://www.futurematerialsbank.com/material/algae-4/

17. E. Turak.&L.Devantier & M.Erdmann. (2012),(Cnidaria: Anthozoa: Scleractinia: Euphylliidae): A new species of reef coral from Indonesia, Zootaxa 3422(3422):52-61. doi: 10.11646/zootaxa.3422.1.3

18. Bakun, A. (1990), Globalclimate change and the intensifcation of coastal upwelling. Science 247, 198–201.

19. . Wang, D., Gouhier, T. C., Menge, B. A. & Ganguly, A. R. (2015),Intensifcation and spatial homogenization of coastal upwelling under climate change. Nature 518, 390–394.