



# MURJAN

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A CLAY 3D-PRINTED CORAL REEF RESTORATION  
BIOMIMICRY · WASP 2040 · AQABA GULF

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BOOKLET  
FABRICADEMY 2025/2026

THESIS PROJECT  
AMMAN · JORDAN

# CONCEPT

## *a clay-printed reef for Aqaba's coral*

Murjan is an interactive ecological design project that explores how computational fabrication can intervene in marine ecosystem collapse. Set in the Gulf of Aqaba — one of the world's most biodiverse coral systems — the project responds to the 2024 bleaching event that struck even this heat-resilient reef.

Through a fusion of architecture, biomimicry, and clay 3D printing, the work makes visible and tangible a designer-led path toward ecological restoration — substrate that doesn't fight the sea but dissolves gently into it, becoming part of it.



*Murjan prototype tested in coral aquarium — Aqaba conditions*

# CONTENTS

## *the booklet*

<b>01</b>	<b>The Problem</b> Aqaba's reef and the 2024 bleaching	<b>04</b>	<b>06</b>	<b>Digital Fabrication</b> Rhino → STL → Simplify3D → G-Code	<b>11</b>
<b>02</b>	<b>Context &amp; Site</b> Jordan · Aqaba Gulf · Ghandour	<b>05</b>	<b>07</b>	<b>Making</b> WASP 2040 · Drying · Bisque firing	<b>12</b>
<b>03</b>	<b>Material Research</b> Clay science · Dhana · Irbid · Pink	<b>06</b>	<b>08</b>	<b>Testing</b> Aquarium · pH · Marine integration	<b>14</b>
<b>04</b>	<b>Coral Research</b> Acropora · Pocillopora · Platygyra	<b>08</b>	<b>09</b>	<b>Reflection</b> Learnings · Vision · Next steps	<b>15</b>
<b>05</b>	<b>Design Process</b> From sketch to brain coral system	<b>10</b>	<b>10</b>	<b>References</b> Sources · Credits · Author	<b>16</b>

# THE PROBLEM *even this reef began to bleach*

Aqaba sits at the northern tip of the Red Sea — a city where the desert meets the water in an improbable burst of life. For centuries, the coral reefs here were the exception to every rule. According to UNESCO, they rank among the best corals worldwide.

While reefs around the world collapsed under warming oceans, Aqaba's corals held on — heat resistant, stubbornly alive, quietly extraordinary.

**Then, in 2024, the bleaching began. Even here. Even this reef.**

That quiet ecological crisis — higher temperature, bleaching, unfolding beneath the surface — is where Murjan begins.



*Aqaba Marine Park, Jordan — UNESCO-recognised marine biodiversity site*

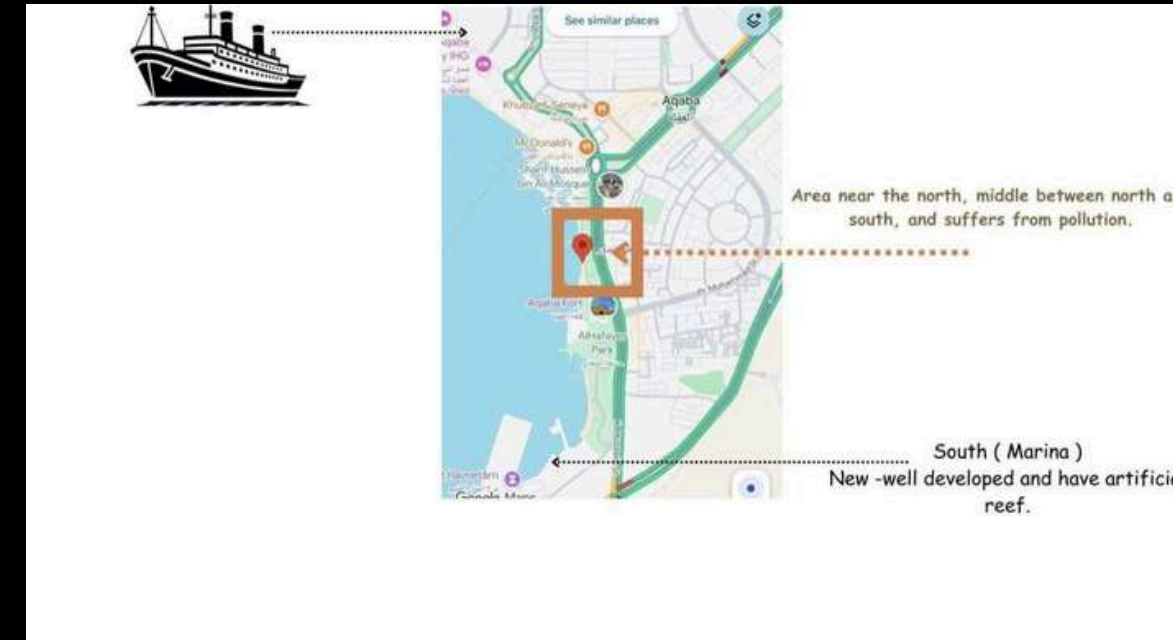
# CONTEXT

## Aqaba Gulf · Ghandour site

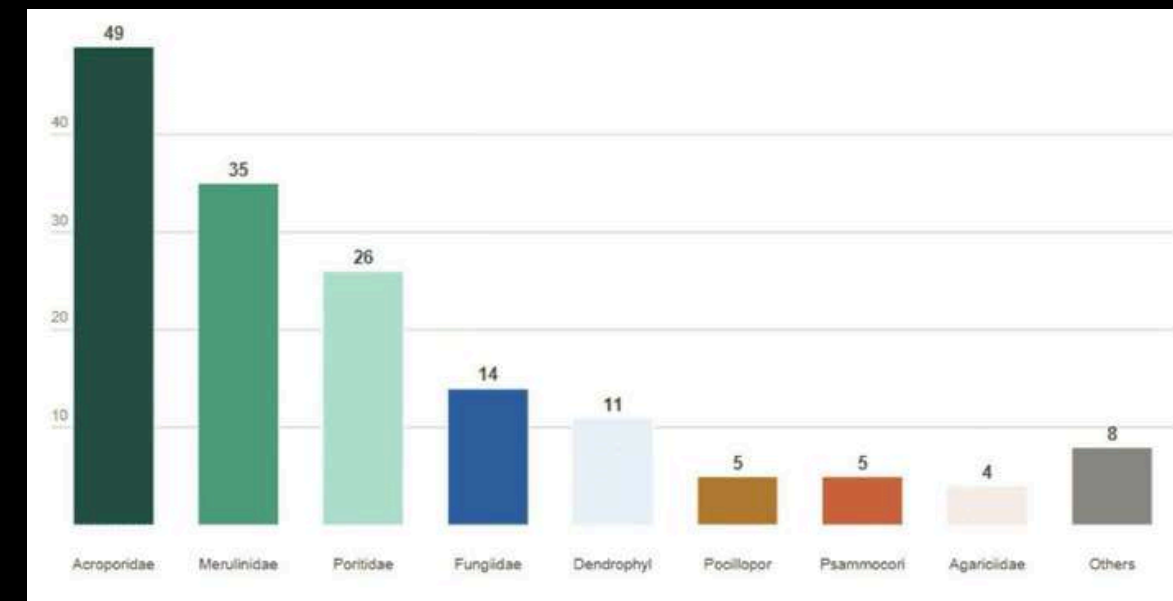
The Gulf of Aqaba supports over **157 hard coral species** in an area of exceptional biodiversity. Three families account for over 70% of all species: Acroporidae (49 spp.), Merulinidae — brain corals (35 spp.), and Poritidae (26 spp.).

Jordan's reef is a **fringing reef** with a narrow flat and dramatic vertical drop-off, making it structurally complex and ecologically rich.

The Ghandour area on the north side of the Aqaba Gulf was once rich with corals for over 20 years. Today only fragments remain. The site suffers from pollution from nearby commercial port activity, making it the priority zone for ecological intervention.



Aqaba Gulf — Ghandour priority site, north of the marina



Coral species count by family in Aqaba Gulf

# MATERIAL

*clay — ancient material, reborn*

The answer wasn't concrete. Not any toxic, rigid material, not steel. It was **clay** — the same material humans have shaped for ten thousand years.

Locally sourced, biodegradable, low-carbon. A material that doesn't fight the sea but **dissolves gently into it** over time, becoming part of it. Clay is also pH-neutral — critical for coral health.

After bisque firing at 1000–1200°C, the porous, unglazed terracotta surface becomes ideal for coral larvae to attach and grow on — a biological choice, not an aesthetic one.



*Fired terracotta Murjan units — bisque 1000–1200°C, unglazed*

# MATERIAL

## *three Jordanian clays tested*

### **DHANA** Southern Jordan

From Wadi Dana — Cambrian-age sedimentary formations.

**Mineral:** Kaolinite (predominant), quartz, illite-muscovite.

**Composition:** ~58% SiO<sub>2</sub>, ~28% Al<sub>2</sub>O<sub>3</sub>.

**Plasticity:** Low–Moderate. **Shrinkage:** Lower.

**Fired use:** Medium–high temp ceramics, refractory.

### **IRBID** Northern Jordan

From northern highland plateau.

**Mineral:** Smectite (~49%) + kaolinite (~13%).

**Classification:** CH — High Plasticity Clay.

**Behavior:** Significant shrinkage-swelling cycles.

**Fired use:** Liners, earthworks, stabilisation.

### **PINK CLAY** Commercial local

Locally available commercial clay — primary WASP 2040 feed.

**Firing range:** Cone 01–5.

**Water content:** ±19%. **Drying shrinkage:** 4.6%.

**Firing shrinkage 1130°C:** 10%. **Absorption:** 7%.

**Selected:** Best workability & consistency for printing.



*Local Jordanian clays — Dhana (left) and Irbid (right), tested for printability*

# CORAL

## species studied for biomimicry

### ACROPORA

49 spp. · 2–10m · 92% sensitive

### POCILLOPORA

2 spp. · flat–30m · 70% sensitive

### PLATYGYRA

brain coral · 30% sensitive



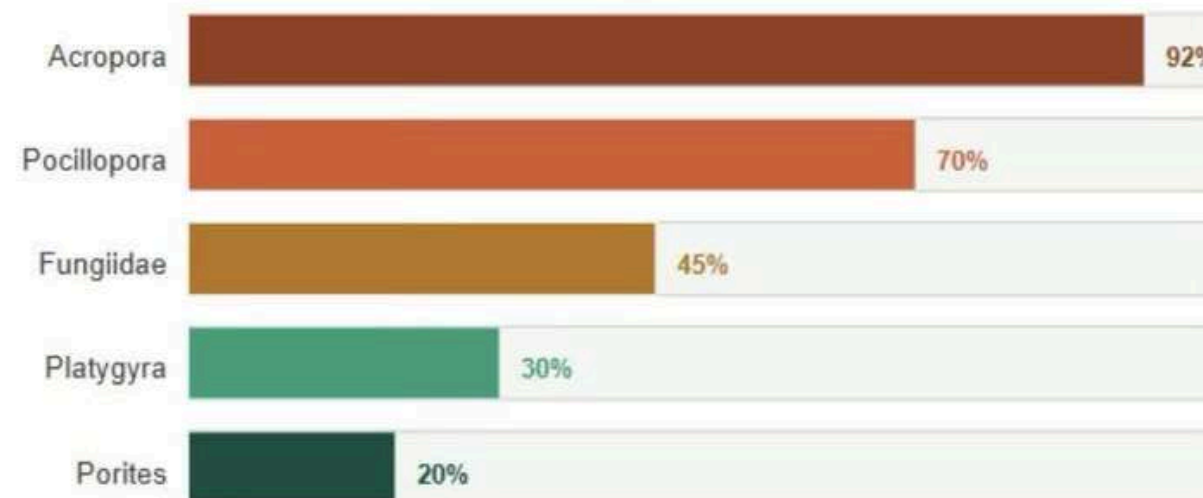
*Acropora gemmifera* — Cedar Pride Reef

*Pocillopora verrucosa* — Coral Garden Reef

*Platygyra sinensis* — Black Rock, Aqaba

### Relative bleaching sensitivity — genus comparison

Bleaching sensitivity (relative)



Relative bleaching sensitivity by genus — *Acropora* most vulnerable; brain coral most resilient

# BRAIN CORAL

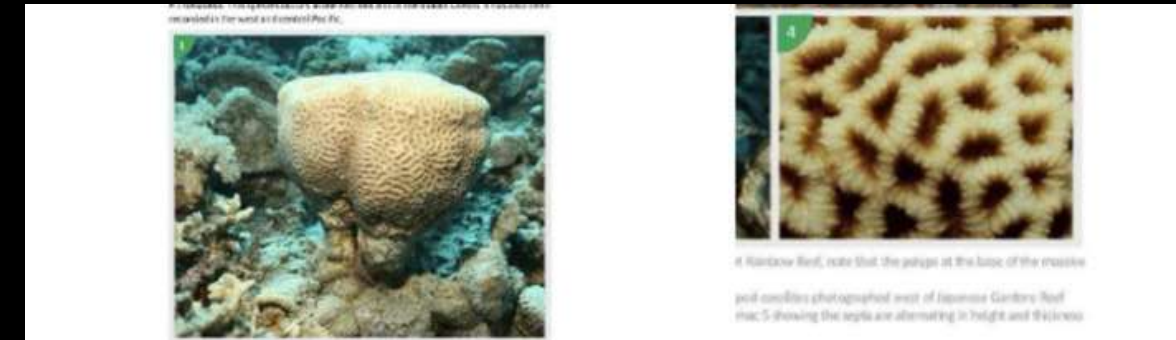
## *Platygyra* · design inspiration

Brain corals are massive, dome-shaped, with circular cross-sections. Unlike solitary corallites, the polyps form continuous series — **elongated valleys 3–10mm wide with fused walls**. Within each valley, 2–5 polyp mouths can be found.

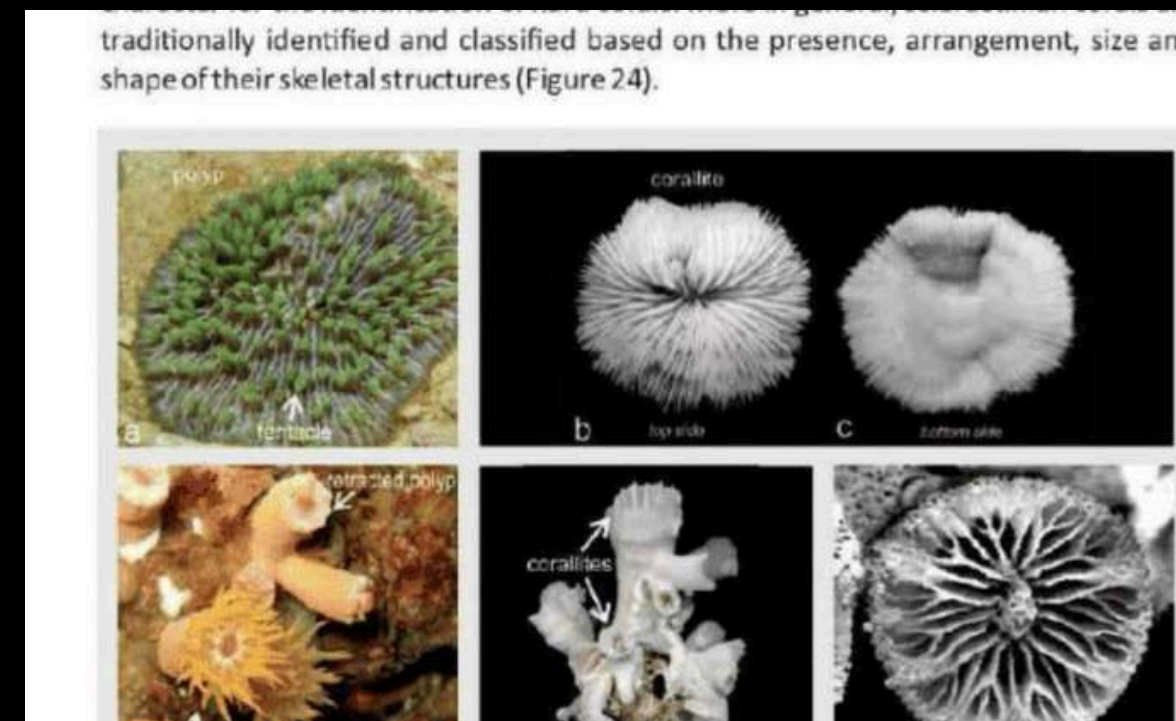
Colony diameter: 20–40 cm. Found across **all depth zones** from reef crest to 30 m. Slow-growing, long-lived, significantly **more thermally tolerant** than branching species.

Brain corals are among the most structurally resilient corals on the reef. Their massive calcium carbonate skeletons create the complex microhabitat architecture — **shaded overhangs, sheltered pockets, varied surfaces** — that smaller organisms depend on.

The **labyrinthine surface geometry** of brain corals is the direct morphological inspiration for the Murjan clay reef prototypes.



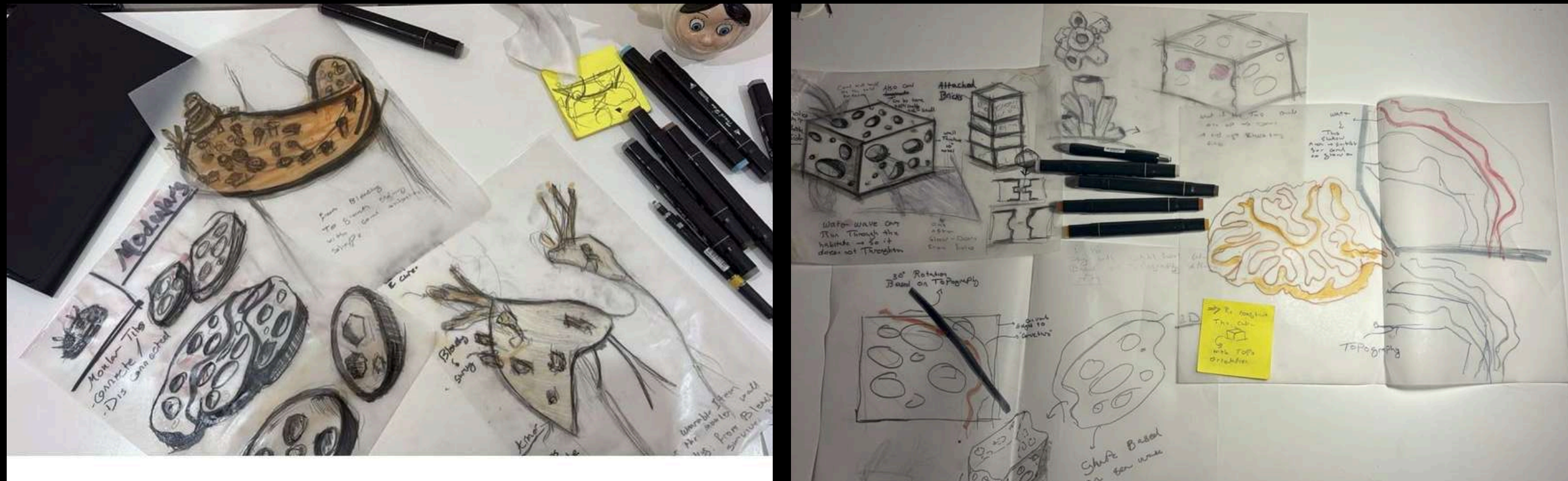
*Platygyra* — meandroid valleys, the morphological reference for Murjan



*Acropora* coral morphology — JREDS research, Aqaba Gulf

# THE MAKING

*a computational process*



*Early ideation sketches — modular units + wearable concept*

inspired from coral structure and site topography underwater and the water flow through the shafts .

- The concept behind the shape that inspired from coral morphology

The maze-like geometry creates a range of **microhabitats**, offering both shelter and movement paths for different marine species while controlling water flow and improving nutrient circulation.

Following deep coral morphology study, the brain coral's natural labyrinth became the defining design language. The prototype was developed through computational simulations alongside an analysis of Aqaba's topography, depth, and water-movement patterns.

# BRAIN CORAL INSPIRED MARINE LIFE SUPPORT STRUCTURE

## TERRACOTTA HABITAT FOR CORAL RESTORATION

Inspired by the natural labyrinth of brain coral, this terracotta structure provides a complex, safe, and stable habitat for marine life, encouraging coral growth and supporting biodiversity.

			
CORAL GROWTH	MARINE LIFE HABITAT	PROTECTION & SAFETY	ECO-FRIENDLY MATERIAL

### HOW IT SUPPORTS MARINE LIFE

- 1 COMPLEX HABITAT**  
The maze-like design creates numerous microhabitats for fish, invertebrates, and other marine organisms.
- 2 CORAL GROWTH**  
The surface texture of terracotta provides an ideal substrate for coral larvae to settle and grow, restoring coral reefs.
- 3 PROTECTION & SHELTER**  
The structure offers shelter from predators and strong currents, supporting young marine life.
- 4 ENHANCED BIODIVERSITY**  
By mimicking natural reef structures, it helps increase biodiversity and supports a healthy ecosystem.

### CORAL GROWTH & RESTORATION STAGES



**INSPIRED BY NATURE**  
The intricate pattern is inspired by brain coral, maximizing surface area and creating natural pathways for water flow and life.

### TERRACOTTA

- 100% natural clay
- Non-toxic & reef safe
- Durable & long-lasting
- pH neutral
- Promotes coral adhesion



Modular units  
Stackable & scalable  
Easy to deploy

### IDEAL FOR RESTORATION



Deployed in degraded reef areas to accelerate coral regrowth and ecosystem recovery.

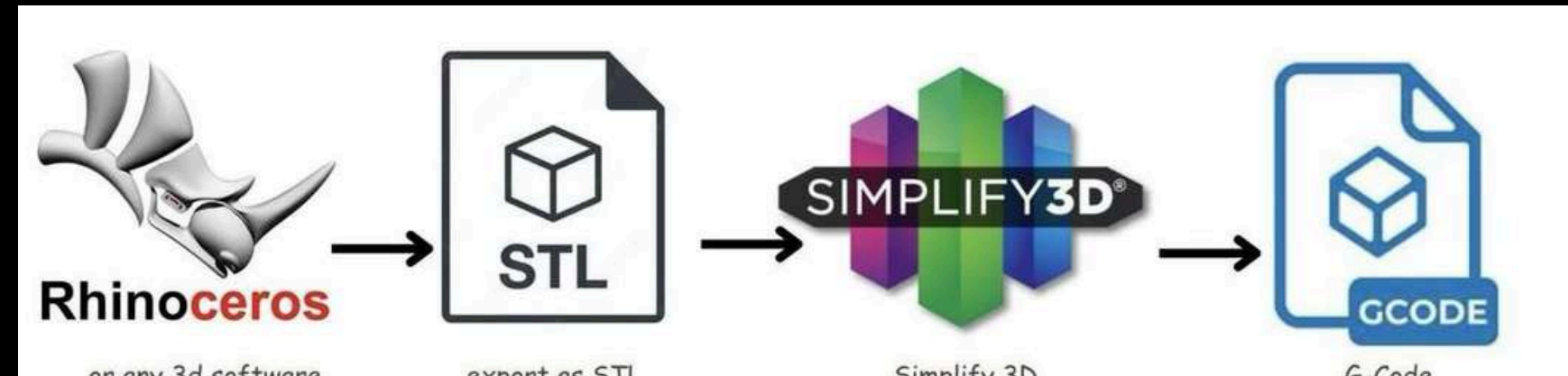
### KEY BENEFITS

- |  |   |   |  |  |
|--|---|---|--|--|
|  Supports coral restoration |  Increases marine biodiversity |  Improves ocean health |  Sustainable & long-lasting |  Designed for easy deployment |
|--|---|---|--|--|

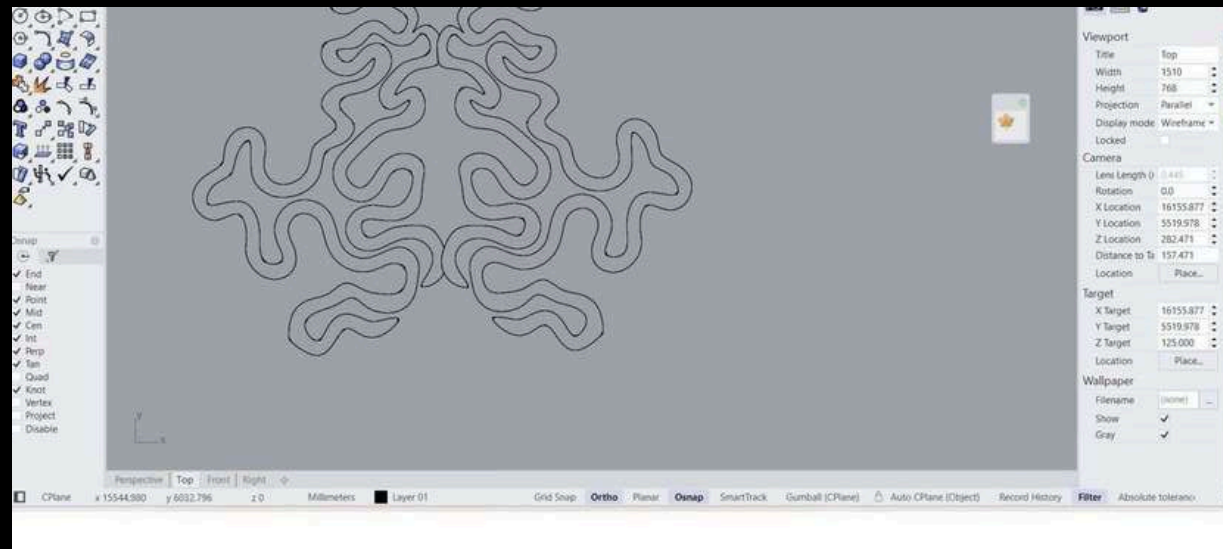


# DIGITAL

Rhino → STL → G-Code

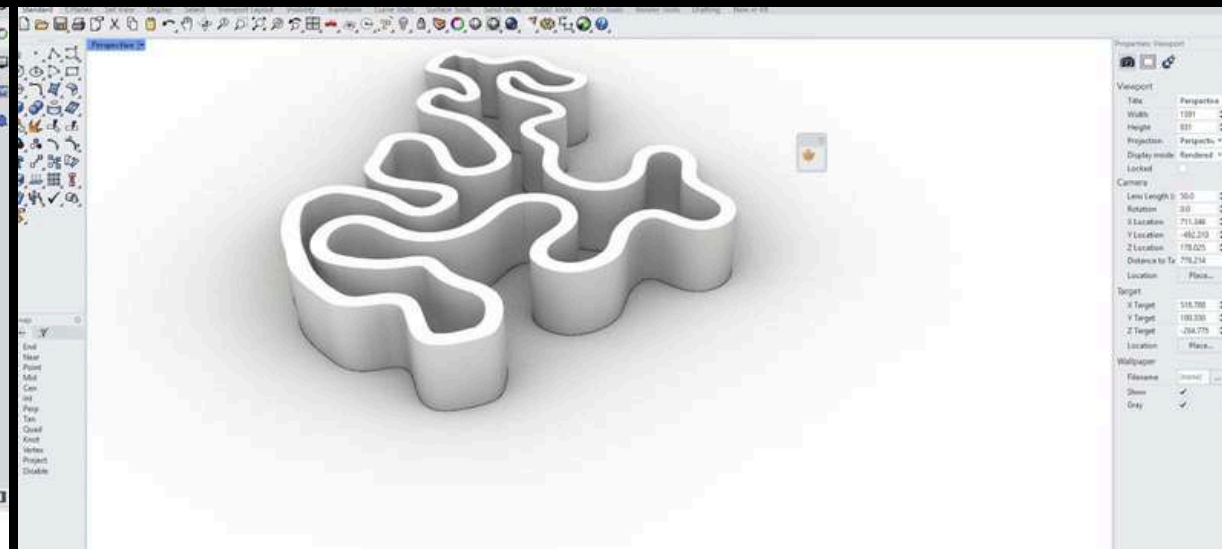


Design-to-print pipeline — Rhinoceros, STL, Simplify3D, G-Code, WASP 2040



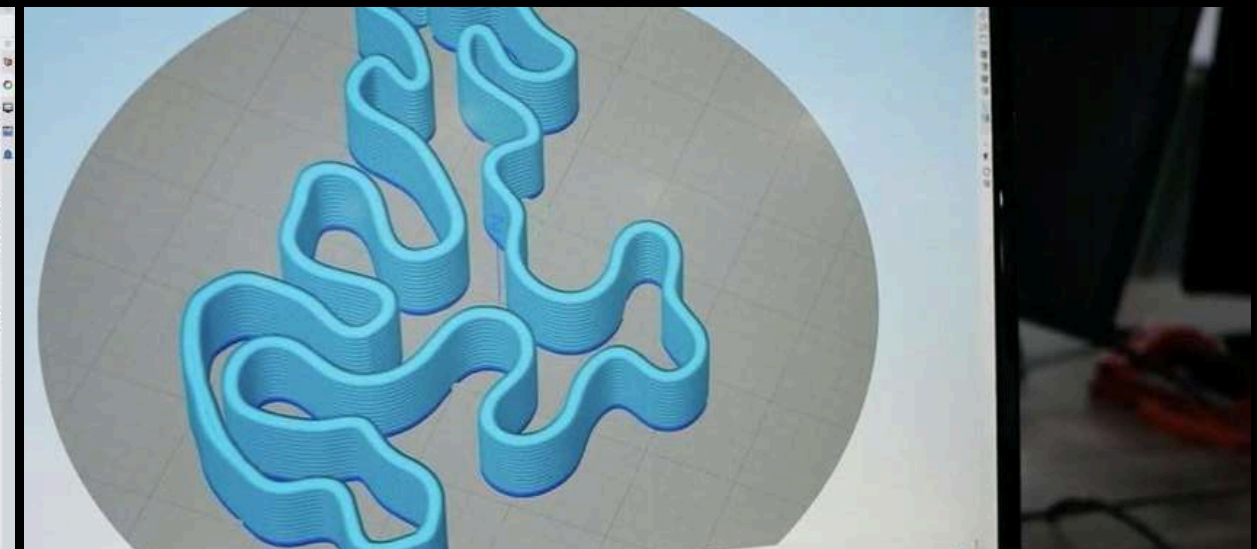
Brain coral labyrinth in Rhino — top view wireframe

**Rhinoceros modeling.** The 2D brain coral outline was traced in Rhino, capturing the meandroid valley pattern of *Platygyra*. The closed curve was extruded to 3 cm using *ExtrudeCrv Close*. The full model exceeded the WASP 2040 print bed, so it was halved to fit the 3 mm nozzle's wall-thickness constraint.



Brain coral - half shape extruded

To fit the bed of wasp 2040 . used half of the shape and close it for better clay toolpath.



Simplify3D slicing — toolpath preview before G-Code export

**Slicing in Simplify3D.** Three height variations were sliced and exported as separate G-Code files: 2 cm, 5 cm, and 10 cm — systematic testing of how structural height affects printability and habitat quality.

# MAKING

## *the WASP 2040 process*

Two months with the WASP 2040 clay printer proved both inspiring and demanding. Every failure was a lesson — clay is alive: it shrinks, breathes, and surprises at every stage.

**Cartridge preparation.** Clay must be packed with no air gaps. If the mixture drops from the cartridge under compression — the consistency is too liquid. The fix: reduce temperature to setting 4 or lower, or add extra dry clay and remix.

**Drying.** Slow and controlled. Pink clay showed predictable drying behavior. Smectite-rich clays show significant shrinkage-swelling — careful management prevents cracking.



*WASP 2040 — clay extrusion in progress*



*Clay colour shifts as moisture evaporates during drying*



**PROTOTYPES**  
Different length : 2cm , 5cm ,10cm



# MAKING

## *post-process and bisque firing*

**Post-print repair.** Small air-bubble openings closed manually before firing. These don't affect fired structural integrity but were addressed for improved marine performance.

**Sanding.** Edges softened with an electric sander, surfaces uniformed — removing irregular clay particles before kiln.

**Bisque firing — the transformation.** Kiln at 1000–1200°C removes chemically bound water, burns off organic matter, and sinters clay into durable, porous, unglazed ceramic. The pieces remain **intentionally unglazed** — the rough porous terracotta surface is optimal for coral larvae settlement. A biological choice, not an aesthetic one.



*Manual repair — closing small openings before firing*



*Fired terracotta — post-kiln 1000–1200°C, ready for testing*

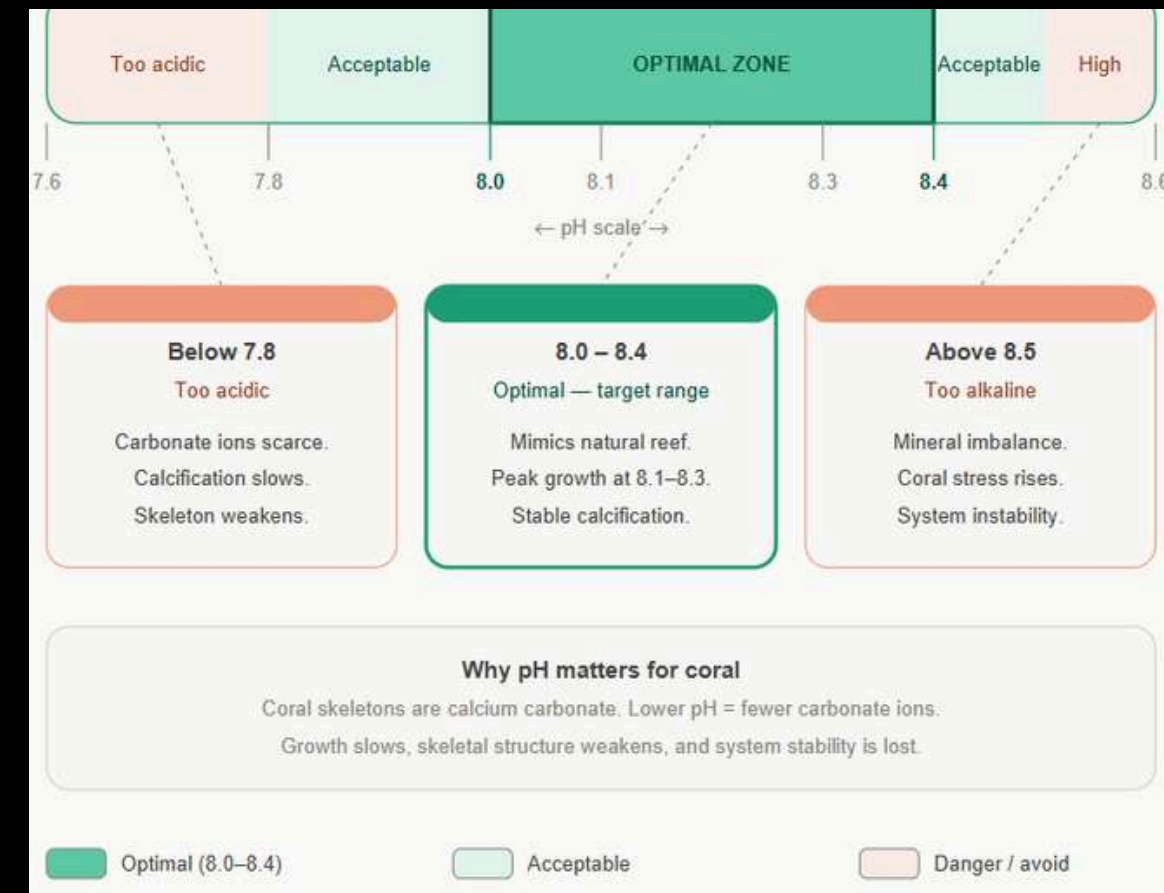
# TESTING

## *underwater conditions*

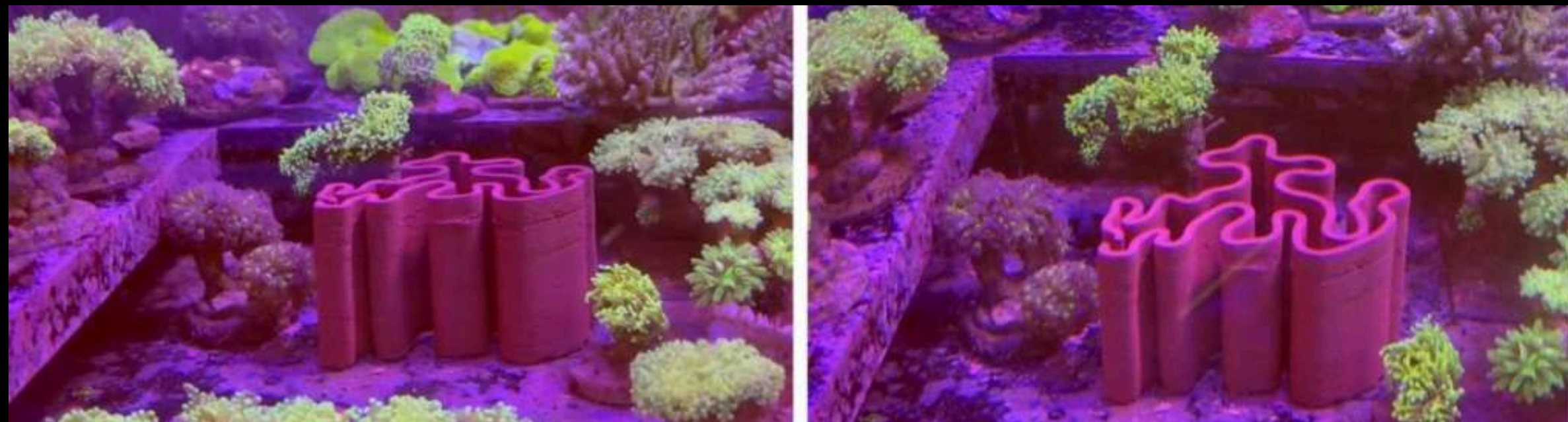
Prototypes were tested in a scientific aquarium with controlled pH, specifically used for coral planting research. Tests were conducted across standard salt water and Red Sea composition water.

**Why pH matters.** Coral skeletons are calcium carbonate. Lower pH means fewer carbonate ions — calcification slows, skeletal structure weakens, system stability is lost.

Maintaining pH between **8.0–8.4** is essential. Importantly, the unglazed terracotta clay is pH-neutral — unlike conventional concrete which can push pH toward dangerously alkaline levels.



*pH scale for coral health — optimal zone: 8.0–8.4*



*Murjan tested in coral aquarium — surrounded by living corals*

# REFLECTION

*what I learned, what's next*

**What worked.** Brain coral morphology translated beautifully into clay. The labyrinthine geometry creates genuine microhabitats — not just aesthetically but functionally. The unglazed bisque-fired terracotta surface is ideal for coral larvae settlement.

**What I learned.** Two months with the WASP 2040 taught more about material behaviour than any course could. Cartridge preparation is as critical as the print itself. The Dhana / Irbid / Pink clay comparison was essential groundwork.

**What's next.** Testing prototypes at the actual Ghandour site. Scaling the modular system for larger deployment patches. Monitoring coral larvae settlement on the terracotta surface in collaboration with JREDS. Grasshopper parametric scripts for site-specific morphologies. A replicable model deployable across other damaged areas of the Red Sea — and beyond.



*Murjan integrating with existing coral colonies*

***"What if the thing we built to save the reef looked like the reef itself?"***

# CREDITS

## *references and acknowledgements*

### CONCEPT & REALIZATION

**HANEEN KHALEEL**

### MENTORING & SUPPORT

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Coral species photographs: extracted from JREDS Field Guide 2019 under fair use for non-commercial educational and conservation reference. All other photographs and documentation: © Haneen Khaleel, 2026.

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