

04 Emergency Refuge

Architectural and urban parametric modularization against hypothetical extreme context.

August—November, 2024
Future extreme cold environments
Academic work, Individual work
Instructor: Yihan Shi

Inspired by the "Younger Dryas Impact Hypothesis", this project combines Grasshopper parametric design techniques with plant system biomimicry to create a sustainable, highly continuous, and adaptable emergency shelter system in extreme cold environments, addressing the challenges of resource depletion and extreme climate in the future.

Intended to utilize **Grasshopper** and **procedural generation** from game design to rethink new methods of organizing and utilizing **architecture and urban systems**.

BACKGROUND

Surface Air Temperature C

30

20

10

0

ΔSAT (°C)

~18,000 yr BP
LAST DEGLACIAL

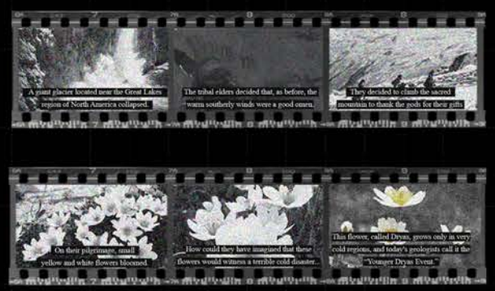
~12,000 yr BP
YOUNGER DRYAS EVENT

PRESENT

+100 yr
GLOBAL WARMING

+500 yr
GLACIAL PERIOD





Atlantic Meridional Overturning Circulation (AMOC)



normal

weakened

Increased heat from the oceans due to global warming, coupled with the melting of the Arctic ice caps and increased freshwater inflow to the oceans, would weaken the AMOC.

Eventually led to the collapse of the AMOC, sending North America, Europe, and even the world into an era of extreme cold.

I II III IV V VI

EMERGENCY

REFUGE

+1000 yr
ERA of FROST RIFT

CONCEPT

ERA of FROST RIFT

resource-poor · cold · threatening

EMERGENCY

SURVIVAL is the first priority!

It survived sucessfully in such an environment

gathered
continuous
adaptable

plant bionics

effective iterative generation tool

WFC

Energy system + Basic function of building

Dryas

① The fundamental structural and functional unit of life.

② The genetic material within cells that controls inheritance and directs cellular functions.

③ Processes by which cells replicate and transform into specialized types, forming distinct plant organs.

④ Specialized structures, like roots, stems, and leaves, that carry out specific functions within the plant.

⑤ Plant

WFC

ⓐ The basic units or elements used to build the structure.

ⓑ Constraints that define the relationships between adjacent modules.

ⓒ The spread of information under local constraints throughout the structure.

ⓓ The final pattern generated by following the rules.

ⓔ Aggregation

The operation logic of wave function collapse (WFC) is very similar to the growth logic of plants. Such a procedural generation method allows the survival activities and behaviors of human society to extend and cycle in the limited scope of the whole system.

① Cells ② DNA ③ Cell Division and Differentiation ④ Plant Organ ⑤ Plant

ⓐ Modules ⓑ Rules ⓒ Propagation ⓓ Solution ⓔ Aggregation

SYSTEMIC BIOMIMICRY

Flower

Dryas is capable of surviving in **extreme cold and mountainous environments**, owing to its unique adaptive biological structure that allows it to thrive in harsh conditions. Through its integrated **energy system**, including efficient energy utilization and recycling mechanisms, the plant adapts to extreme environments. Insights derived from the biological characteristics and energy management strategies developed through its long-term evolutionary process offer valuable guidance for the design of energy systems in new settlements.

I.



Petals

❶Cup-shaped, helping to gather air and light within the flower, keeping the ***ovary*** warm.

❷Reflecting sunlight towards the center of the flower, which is the ***pistil***.

II.



Sepals

❸Reducing heat loss to ensure it opens in extreme conditions.

❹Supporting the petals, keeping the flower stable and aiding pollination.

Stem

❺It has hairy structure that help reduce water loss and provides additional insulation.

❻It supports the plant upright, ensuring the leaves and flowers receive maximum sunlight.

III.



Leaf

❼Carry out photosynthesis: absorbing sunlight and converting it into energy . Chloroplasts in the leaves absorb light energy, using carbon dioxide and water to produce organic compounds and release oxygen.

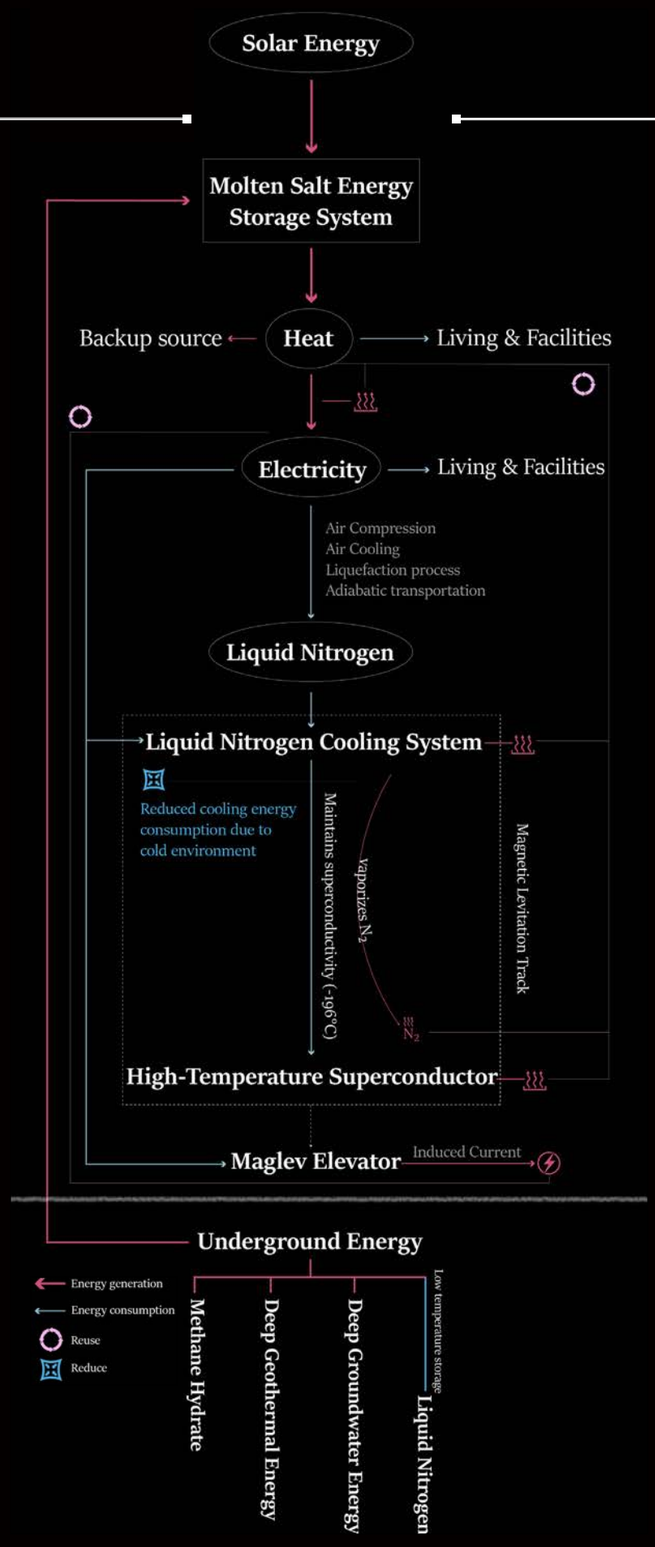
❽Their small, dense shape minimizes damage from wind and snow while improving sunlight absorption.

IV.



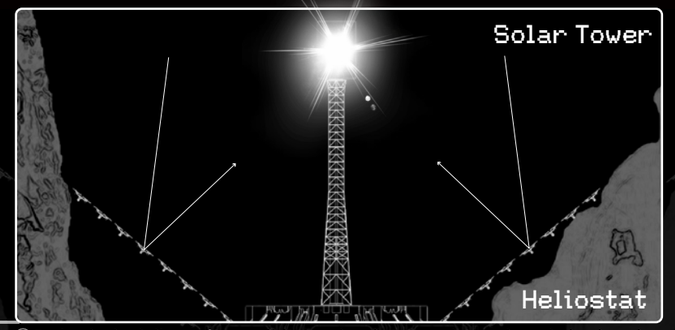
❾Absorb water and nutrients from the soil. ❿Provide stability, preventing displacement due to weather. **Roots**

Energy System



Megastructure

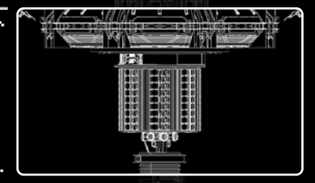
A.



ⓐ During the day, heliostats focus sunlight onto the solar tower, where molten salt absorbs and stores thermal energy.

ⓑ At night or on cloudy days, the salt releases the energy, driving the generator for 24-hour electricity production.

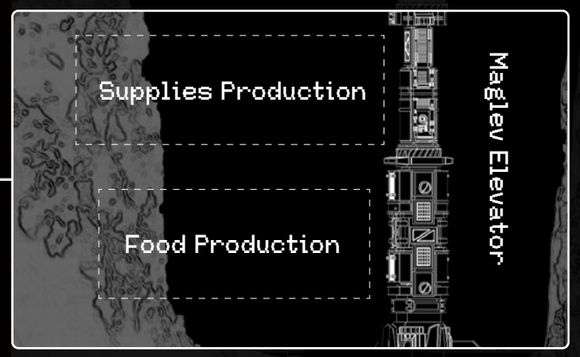
B.



ⓒ Molten salt energy storage unit efficiently stores energy, with the energy center carried for shelter in emergencies, ensuring energy availability.

ⓓ Energy conversion and real-time monitoring maintain system stability, ensuring optimal energy usage.

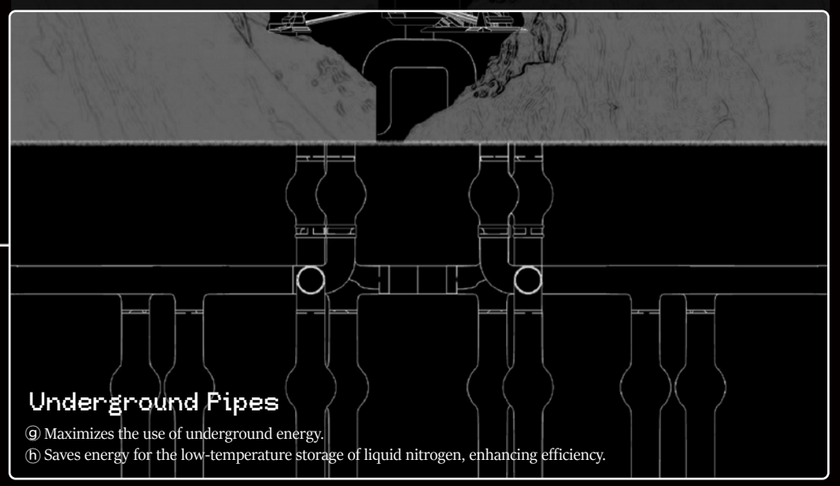
C.



ⓔ The center features a vertically integrated transportation system, primarily using magnetic levitation elevators.

ⓕ The sides are designated for food and material production spaces.

D.



ⓖ Maximizes the use of underground energy.

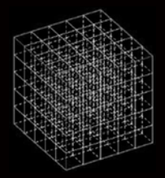
ⓗ Saves energy for the low-temperature storage of liquid nitrogen, enhancing efficiency.

ELEMENTS OF WFC ALGORITHM INPUTS

Main input data types: **Slots**,**Modules** and **Rules**. These inputs are essential and necessary for WFC algorithm to generate asolution.

Slots

Slot is a cuboid (orthogonal box) that represents the basic unit of the Monoceros rigid discrete grid.



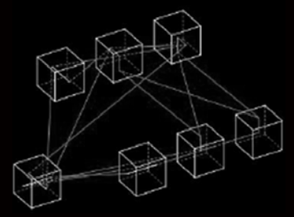
Modules

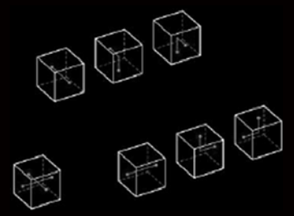
Module is a unit, which is being distributed over the specified Envelope. The purpose of a Monoceros Module is to place predefined geometry into dedicated Slots.

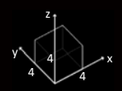


Rules

The rule is a distinct data type describing adjacency of two Modules by aligning their Connectors facing opposite direction.

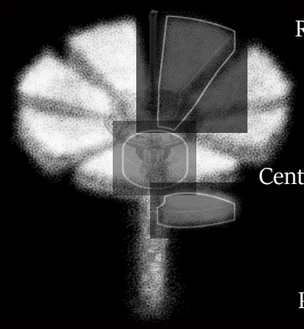






*All modules are operated in a 4x4x4 framework

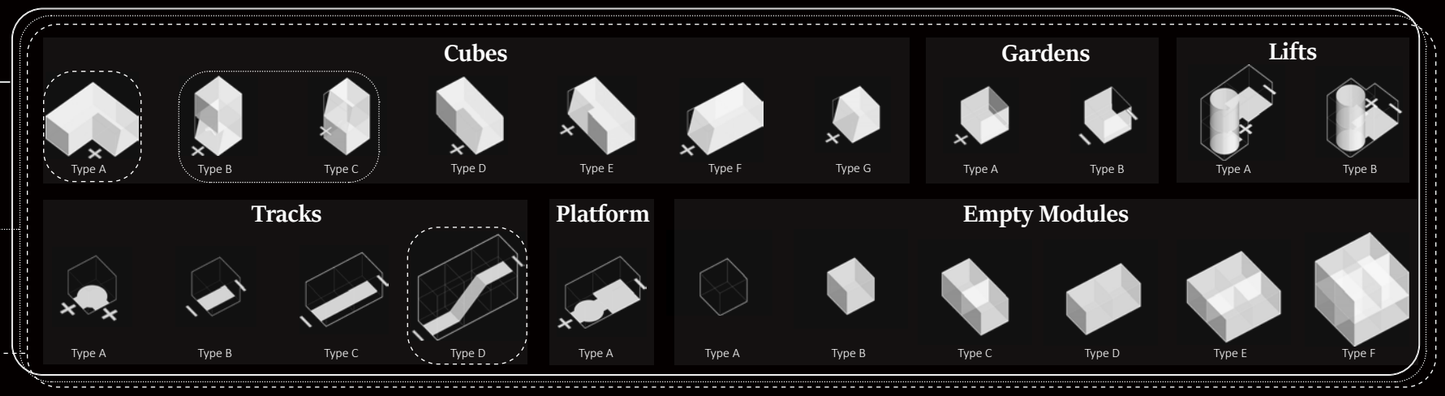
Slots and Modules



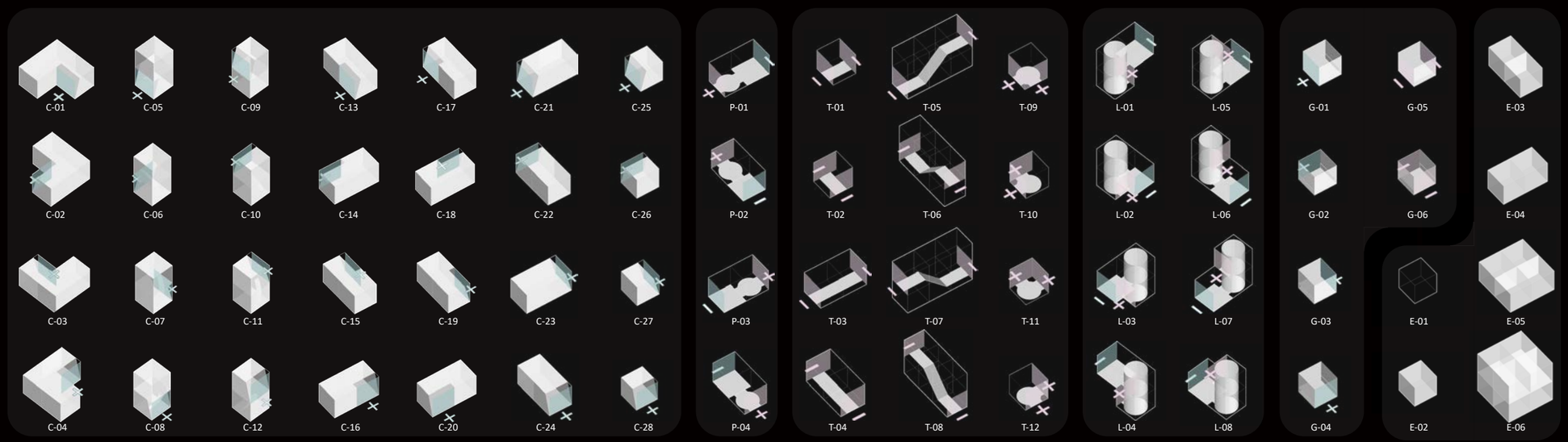
Petal
Residential Slot

Sepal
Central control Slot

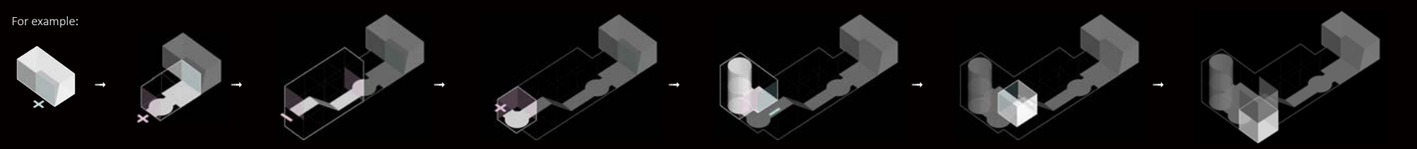
Leaf
Production Slot



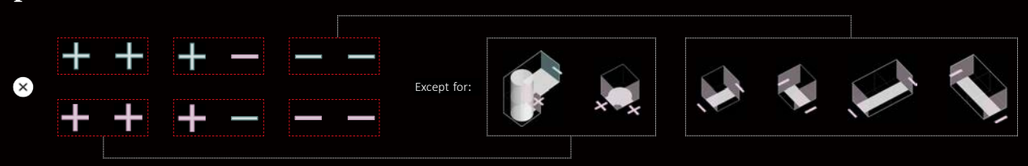
Typed Rules

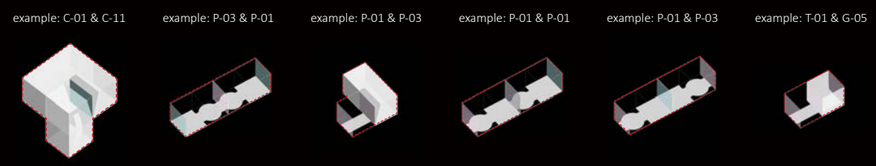






Explicit Rules Disallowed





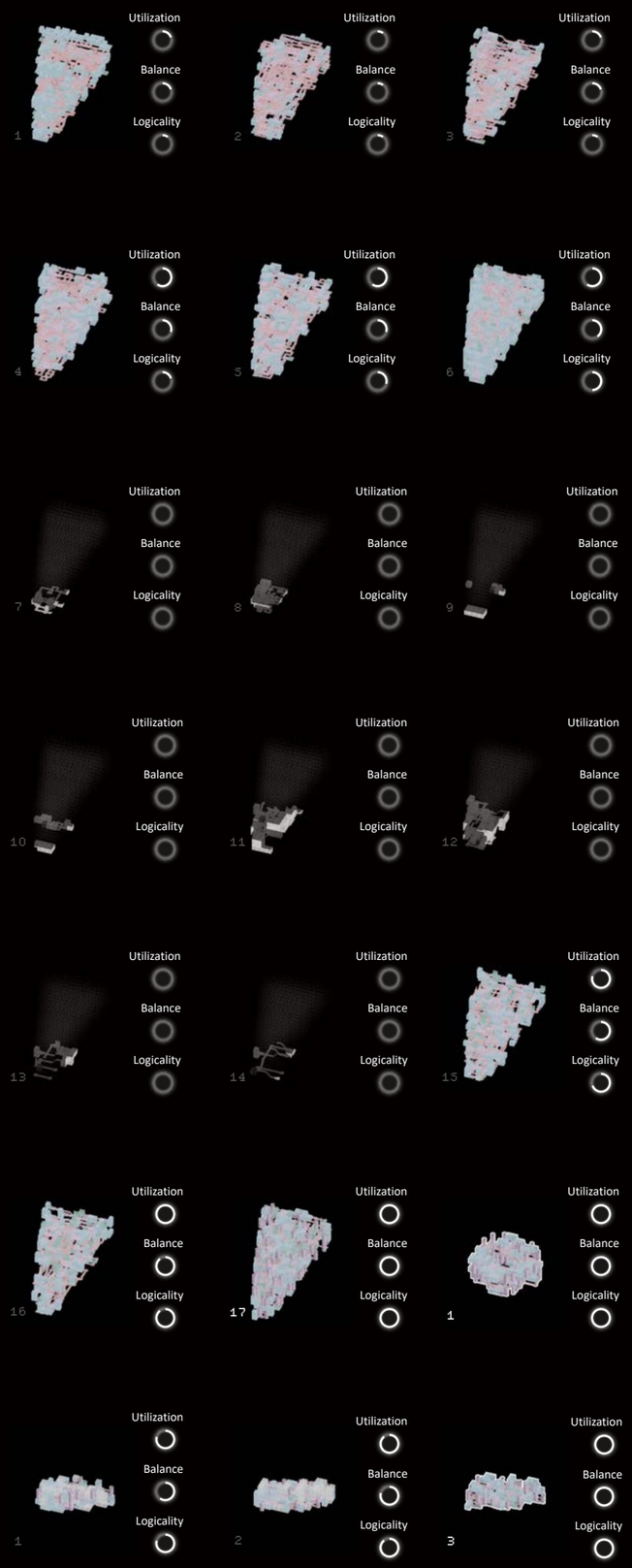
*Empty module: It is possible that the Modules cannot be stacked together without leaving blank Slots, which is considered a contradictory and therefore invalid result. WFC solver needs to fill every slot. Empty module is therefore often necessary.

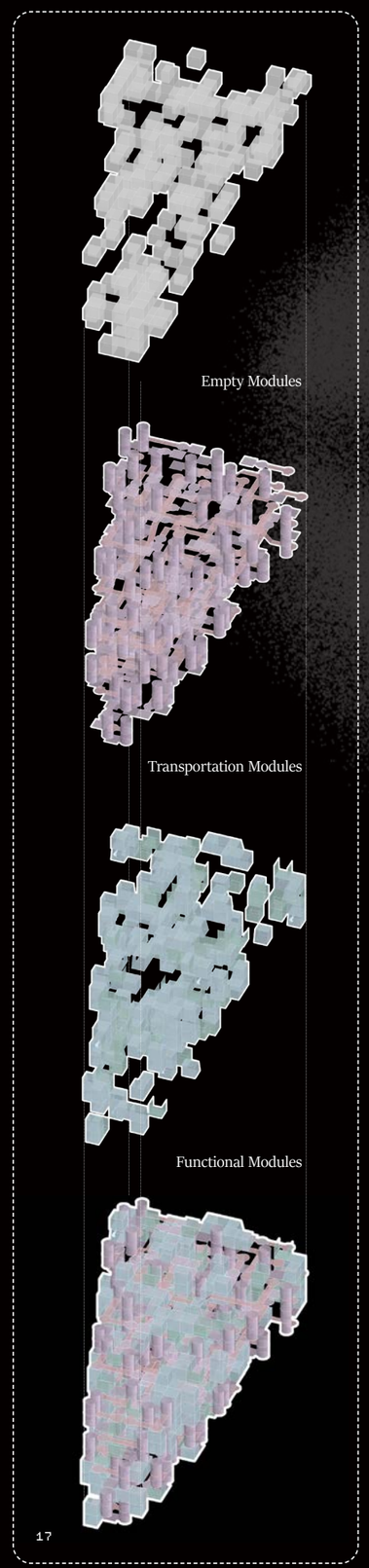
*Typed Rules: List of allowed neighbor modules for each module in each direction.

*Indifferent connection: A module with no explicit connection in certain direction is indifferent in that direction and can connect to any module indifferent in the opposite direction.

*Explicit rule: Single rule explicitly allowing two modules to be neighbors in the specified direction. Just like any other Rule, Typed or Explicit, also the Indifferent Rule can be assigned to a Connector that already is described by another Rule. It can also be used as a disallowed Rule with the Collect Rules component.

EXPERIMENTS WITH BASIC MODULES





Petals' slot



Input
1217slots
166 typed rules
592 rules indifferent
228 explicit rules disallowed
30297 rules

Monoceros WFC Solver found a solution.
Data preprocessing: 97ms
WFC Solver: 439707ms
WFC Pre & Post-processing: 7223ms
WFC Attempts: 432484ms; Fastest: 250ms; Slowest: 10643ms

Rule count: 30395
Part count: 145
Slot count (including outer Slots): 5520
Solution random seed: 2000209495
Solve attempts: 124
Approach to entropy calculation: linear
Solver observations limited to: 4294967295
Observations required to find the solution: 588
Average observation count per attempt: 4

Sepals' slot

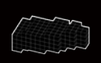


Input
640slots
132 typed rules
488 rules indifferent
116 explicit rules disallowed
20942 rules

Monoceros WFC Solver found a solution.
Data preprocessing: 60ms
WFC Solver: 8358ms
WFC Pre & Post-processing: 2442ms
WFC Attempts: 5916ms; Fastest: 1147ms; Slowest: 3184ms

Rule count: 21033
Part count: 123
Slot count (including outer Slots): 1680
Solution random seed: 470454661
Solve attempts: 3
Approach to entropy calculation: linear
Solver observations limited to: 4294967295
Observations required to find the solution: 305
Average observation count per attempt: 101

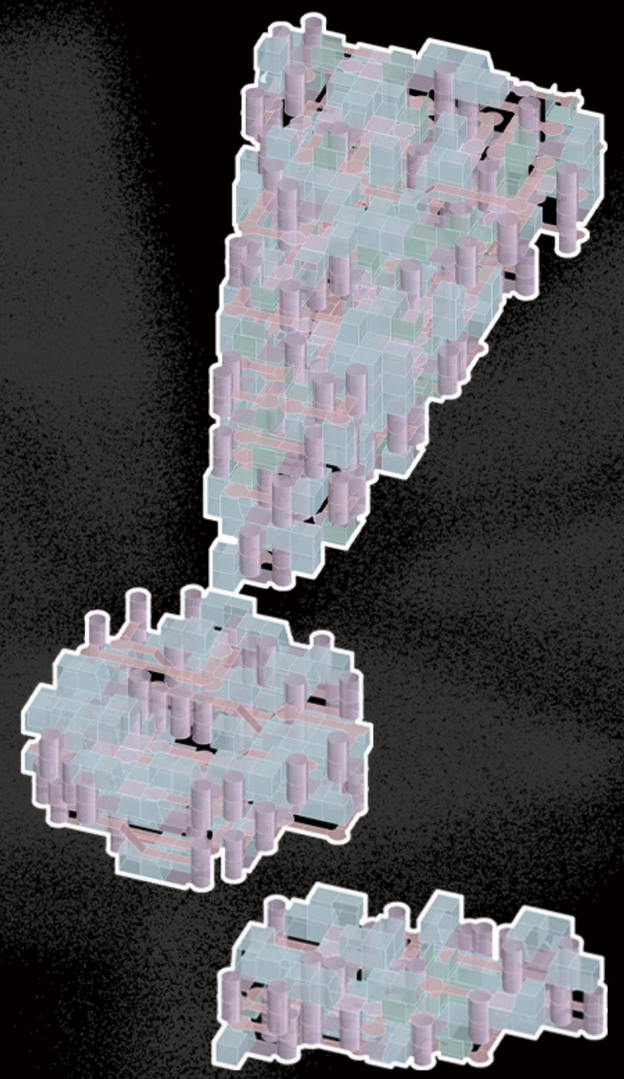
Leaves' slot

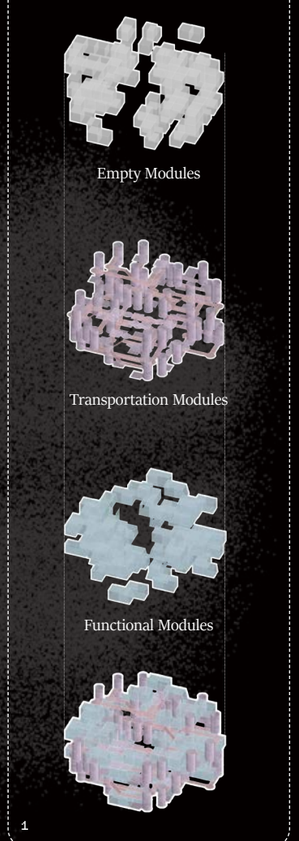


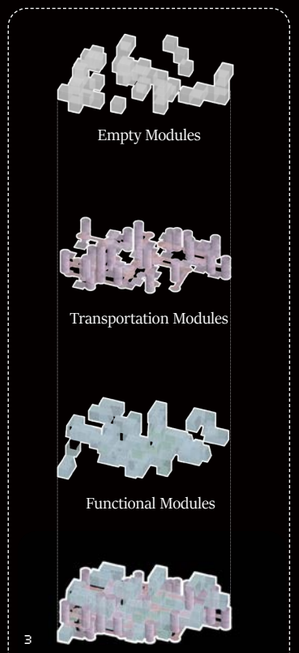
304 slots
116 typed rules
428 rules indifferent
138 explicit rules disallowed
16000 rules

Monoceros WFC Solver found a solution.
Data preprocessing: 52ms
WFC Solver: 2458ms
WFC Pre & Post-processing: 936ms
WFC Attempts: 1522ms; Fastest: 521ms; Slowest: 1001ms

Rule count: 16063
Part count: 103
Slot count (including outer Slots): 1224
Solution random seed: 1912463980
Solve attempts: 2
Approach to entropy calculation: linear
Solver observations limited to: 4294967295
Observations required to find the solution: 158
Average observation count per attempt: 79

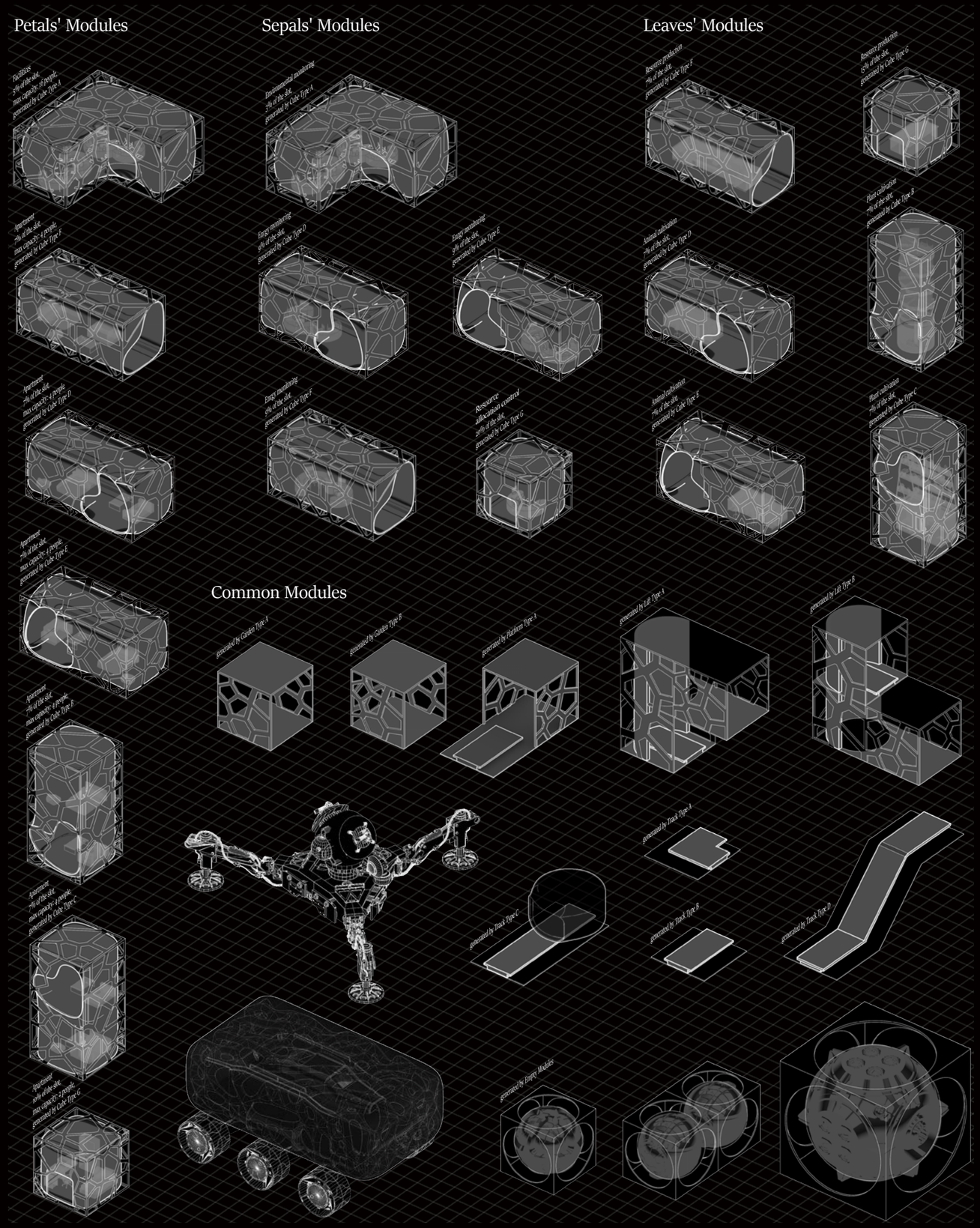








DEVELOPED MODULES





EXPLOSION ANALYSIS of CONSTRUCTION



① Solar Tower & Nanostructured Optical Metamaterial Envelope

The outer membrane reflects sunlight onto the central solar tower, where photovoltaic systems and thermal collectors convert it into usable power. The membrane's precise control of reflectivity, color, and refraction enhances solar energy capture. Its superhydrophobic surface prevents snow accumulation, ensuring uninterrupted light reflection and maintaining functionality even in extreme cold.

② Nanofiber Composite Aerogel Structures

The nanofiber composite aerogel structure offers structural support, self-cleaning, and frost resistance. It forms a biomimetic mesh protective layer, creating a double skin for building units, enhancing thermal insulation and protection from harsh conditions.

③ Nanostructured Optical Metamaterial Inner Layer

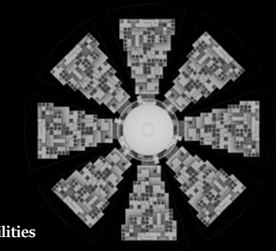
The inner membrane, bonded to nanofiber composite aerogel, adapts transparency to optimize light and reduce energy loss. It allows natural light by day and retains heat at night or in cold conditions, enhancing energy efficiency while regulating heat transfer for indoor comfort with minimal heating reliance.

④ Supported Truss Structure

The outer shell serves primarily as a structural support, with a truss system that extends into the adjacent mountain cliff, anchoring the building and enhancing stability. This design ensures both the strength and resilience of the facade while integrating the structure seamlessly with its environment.

SLOTS' PLANS

Each section contains basic **residential**, **transportation**, and **energy storage areas**. Additionally, every two symmetrical petals share the same type of infrastructure, including



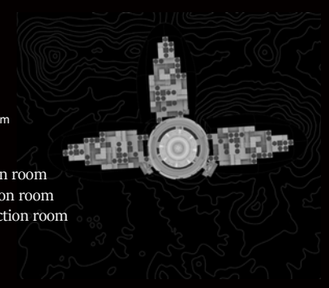
A. **Hospitals**
B. **Schools**
C. **Churches**
D. **Entertainment facilities**

The energy slot functions as the central control hub for the entire settlement.



E. Energy monitoring room
F. Environmental monitoring room
G. Resource allocation control room

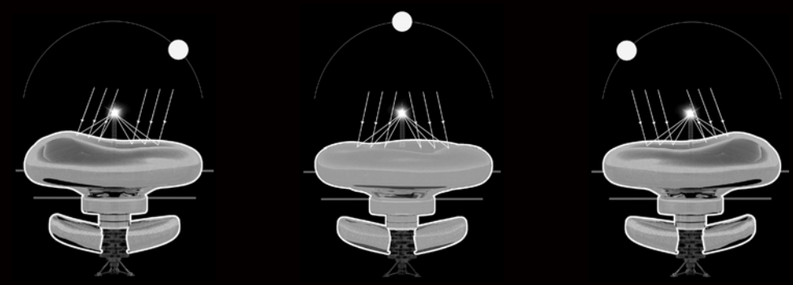
The production area is primarily responsible for manufacturing and recycling.



H. Plant cultivation room
I. Animal cultivation room
J. Resource production room

ENVIRONMENTAL RESPONSE STRATEGY

The nanophotonic metamaterial outer membrane can adjust its angle and modify parameters such as reflectivity and refractive properties in response to changing light conditions, optimizing sunlight capture and energy efficiency throughout the day.



OVERALL BIRD'S-EYE VIEW



ENERGY ZONE SCENARIO



VERTICAL ELEVATOR SCENARIO



RESIDENTIAL ZONE SCENARIO

