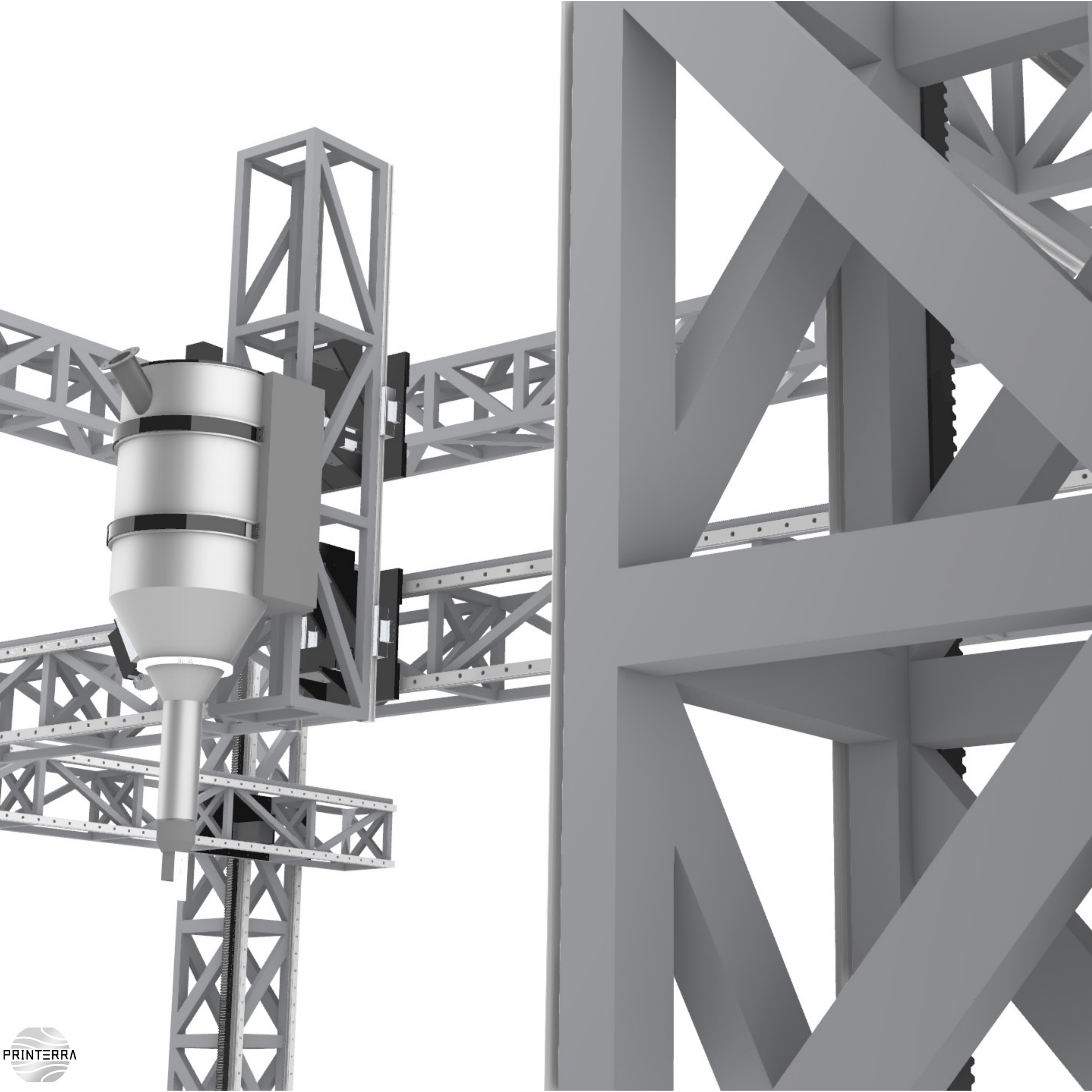
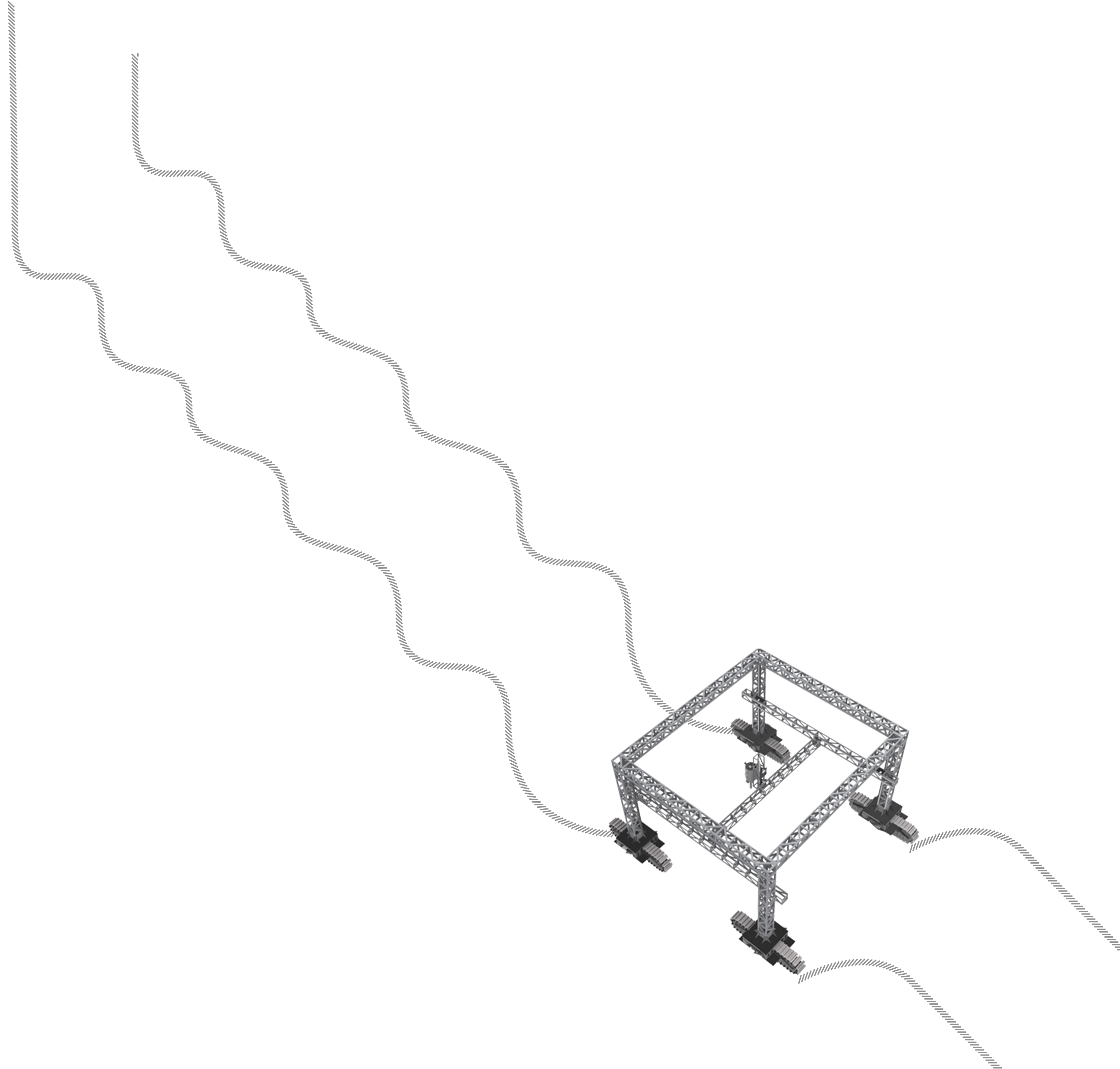

PRINTERRA



PRINTTERA

ARCHITECTURAL DESIGN + ROBOTICS

about project :

Robots have become widely recognized tools, that offer a dual purpose: they assist in easing human labor while also serving as replacements in situations requiring high precision or when harsh conditions make human involvement impractical. Moreover, robots prove to be the best option in scenarios where an operating mechanism with limited cognition is necessary and human resources are unavailable.
In the field of architecture, the integration of robotics has gained favor and holds the potential to revolutionize the architectural world. Robots employ various established methods such as modular assembly, subtractive manufacturing, or partial human-robot collaboration to reduce human interaction and labor costs. However, for our current project, additive manufacturing or 3D printing stands out as the most prominent and efficient construction method globally.
Our design presents an advanced moving Cartesian 3D printer, uniquely adaptable to challenging land-scapes.
This innovative robot draws building materials directly from the earth and prints modules, cell by cell, until the entire camp or village is fully constructed. This approach minimizes human involvement and maximizes both construction speed and sustainability.

Instructor

Dr. Morteza Rahbar

Assistant:

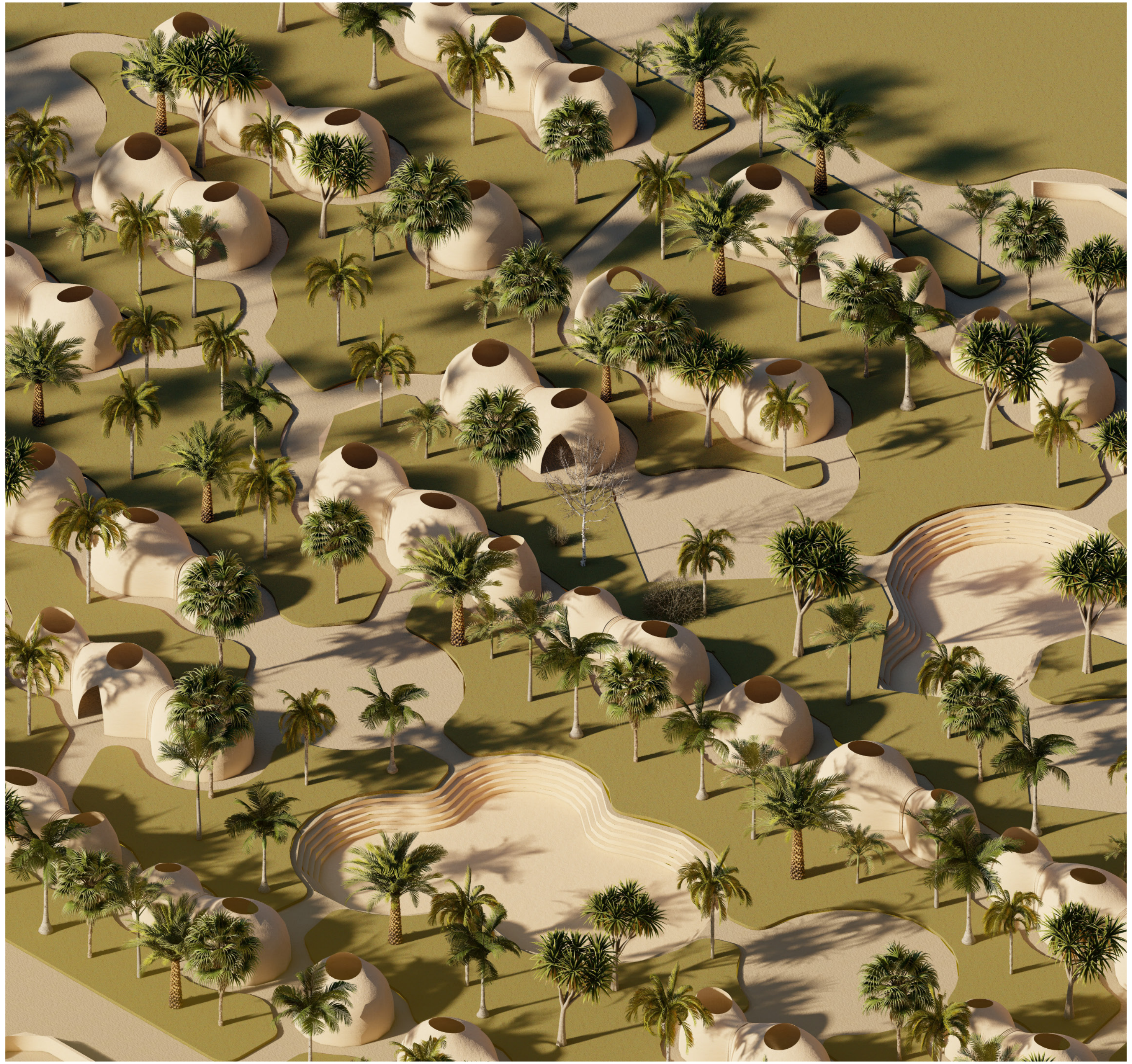
Sajjad Eftekharzadeh

Design Team

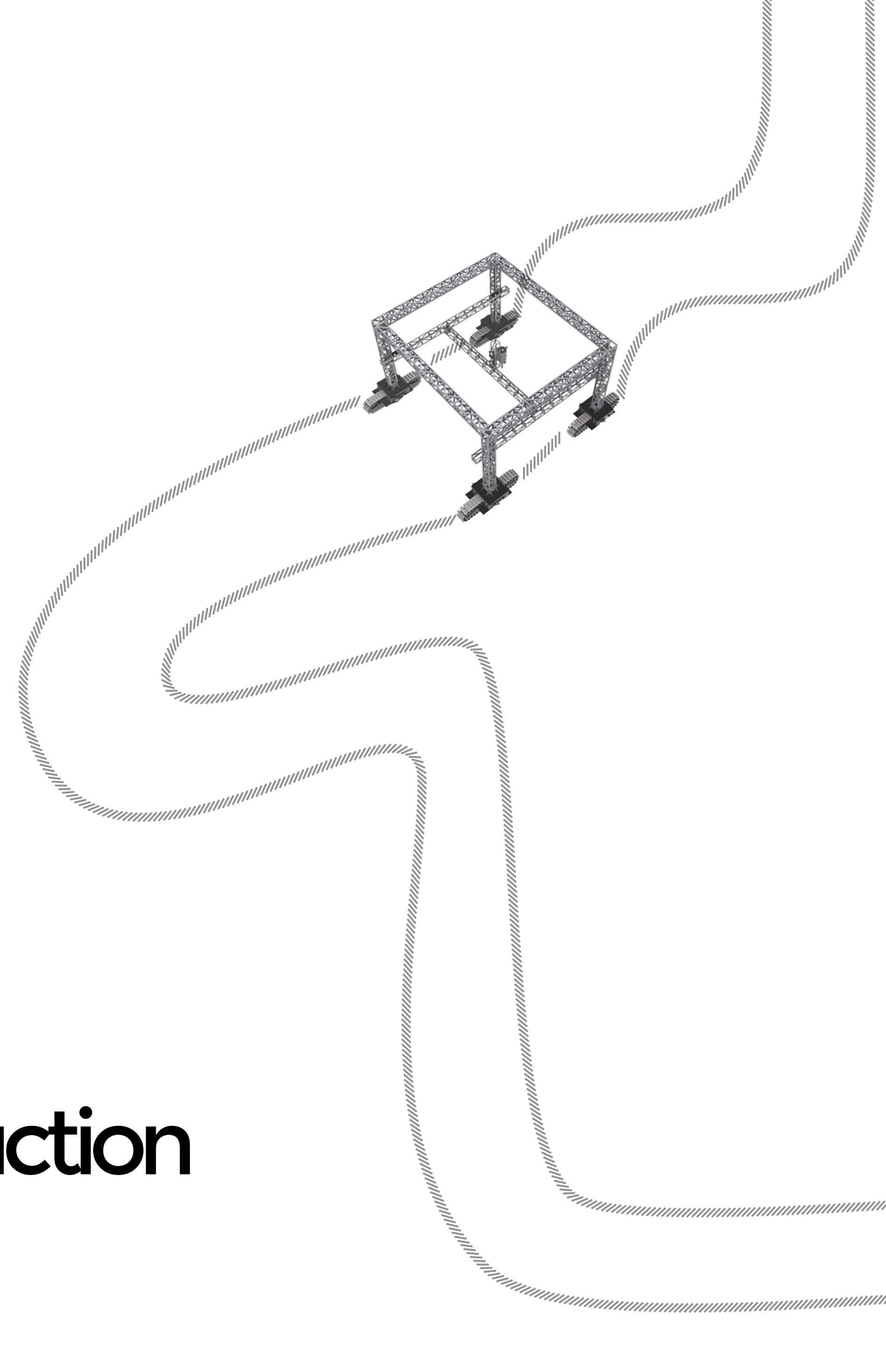
Hossein mortazavi|Mohammad Sajad Amrolahi|Mohammad Moazeni

Behzad Maleki asl|Mehrzad Samadi|Amir Farbod Shahverdi|Hossein Nazari|Farnoush Bratlou

Iran University of Science & Technology | School of Architecture
Computational Design & Digital Fabrication | Spring 2023



CONTENTS



01 Introduction

Our project revolves around the utilization of a state-of-the-art 3D printing robot, for construction purposes. This cutting-edge technology plays a crucial role in our efforts to efficiently construct each house in the village, while simultaneously minimizing waste materials and reducing our overall environmental impact. By employing additive manufacturing techniques, we are able to precisely construct every component of the houses using only the necessary amount of materials. This, not only helps to reduce overall waste but also ensures that we are utilizing resources in a sustainable manner.

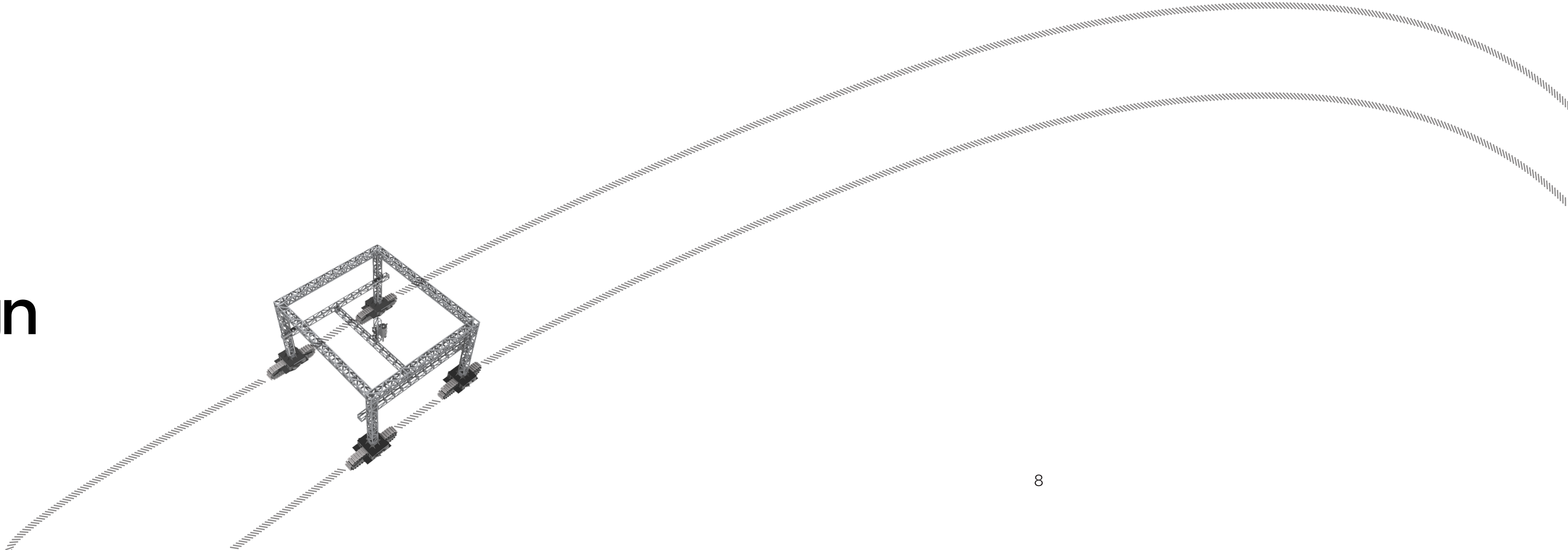
Furthermore, we have made it a priority to source local materials for our construction process. This not only reduces transportation emissions but also supports the local economy and fosters a sense of community and connection to the region. Throughout our project, we remain mindful of carbon emissions and energy consumption, implementing measures to minimize energy usage during both the construction phase and the operation of the village.

To achieve this, we incorporate energy-efficient technologies such as solar panels for electricity generation and passive design strategies to optimize natural lighting and ventilation. By prioritizing these sustainable practices, our ultimate goal is to create an environmentally friendly village that minimizes its carbon footprint.

In summary, our project combines innovative technology with sustainable practices to create an environmentally friendly village in Yazd. We aim to promote sustainable development in the region while minimizing waste materials and reducing environmental impact

02 Robot Design

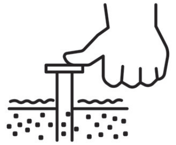
CONTENTS



The fabrication process of this visionary project is a grand endeavor, encompassing a multitude of stages and intricacies. to reach a comprehensive understanding, an expansion, upon each stage and adding additional information is presented:

Stage 1: Site Preparation (Pre-Construction Phase)

1. Surveying and Analysis: A team of highly skilled geologists, environmental scientists, and surveyors conduct an extensive survey of the selected location. They utilize cutting-edge technologies like LiDAR and advanced satellite imaging to analyze the geological formations and assess potential hazards such as seismic activity or soil instability.



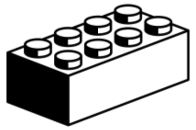
2. Soil stabilization involves two primary techniques: rammed earth construction and soil mixing. When dealing with challenging natural soil compositions, the traditional and reliable approach of rammed earth construction is commonly used. This method entails compacting layers of earth mixed with stabilizing additives such as lime, cement, or chemical stabilizers. By implementing the rammed earth technique, the load-bearing capacity of the soil is significantly improved, effectively preventing ground settling. Not only does this ensure the stability and durability of the structure, but it also presents an eco-friendly and sustainable solution for construction projects.

3. Sustainable Drainage Systems: To manage water runoff and mitigate potential flood risks, innovative sustainable drainage systems are implemented. These systems incorporate permeable pavements, green roofs, and rainwater harvesting to promote water conservation and reduce environmental impact.

4. Environmental Mitigation: To preserve and protect the local ecosystem, environmental mitigation measures are taken. This includes the establishment of wildlife corridors and the relocation of any endangered flora and fauna found in the vicinity of the construction site.

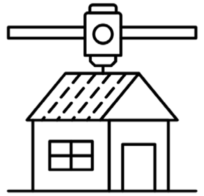
5. Eco-friendly Construction Materials: The site preparation also involves sourcing eco-friendly construction materials locally, reducing transportation-related emissions, and supporting the regional economy.

Stage 2: 3D Printing Process (Construction Phase)



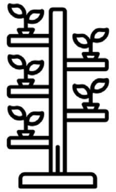
1. Advanced Robotic Control: The giant 3-axis Cartesian robot utilized for 3D printing is equipped with state-of-the-art AI-driven controls. This enables real-time adjustments during the printing process, ensuring precise layering and minimizing material waste.

2. Multi-material Printing: The material mixer attached to the robot is a sophisticated system capable of blending various earth-based materials with recycled elements like plastics or ceramics. This innovative approach reduces the carbon footprint and maximizes the project's sustainability.



3. Automated Quality Assurance: Throughout the printing process, an automated quality assurance system continuously monitors the structural integrity and adherence to design specifications. Any deviations or potential issues are detected promptly, allowing for immediate adjustments.

4. Modular Construction: The 3D printing process is modular, allowing for flexibility in design and easy customization of individual units. This modular approach enables rapid construction and future expansion, accommodating changing needs and preferences.



Stage 3: Final Touches (Post-Construction Phase)

1. The final touches of 3D printed houses include meticulous furnishing with modern and sustainable elements, smart home integration for energy efficiency and convenience, and customizable painting options to add a touch of personality. These details come together to create harmonious and personalized living spaces that exemplify cutting-edge technology while promoting environmental consciousness.

2. Smart Home Integration: The units in the complex are equipped with cutting-edge smart home technology, including energy-efficient appliances, intelligent lighting systems, and automated climate control. Residents can monitor and manage their units remotely for optimal comfort and energy conservation.

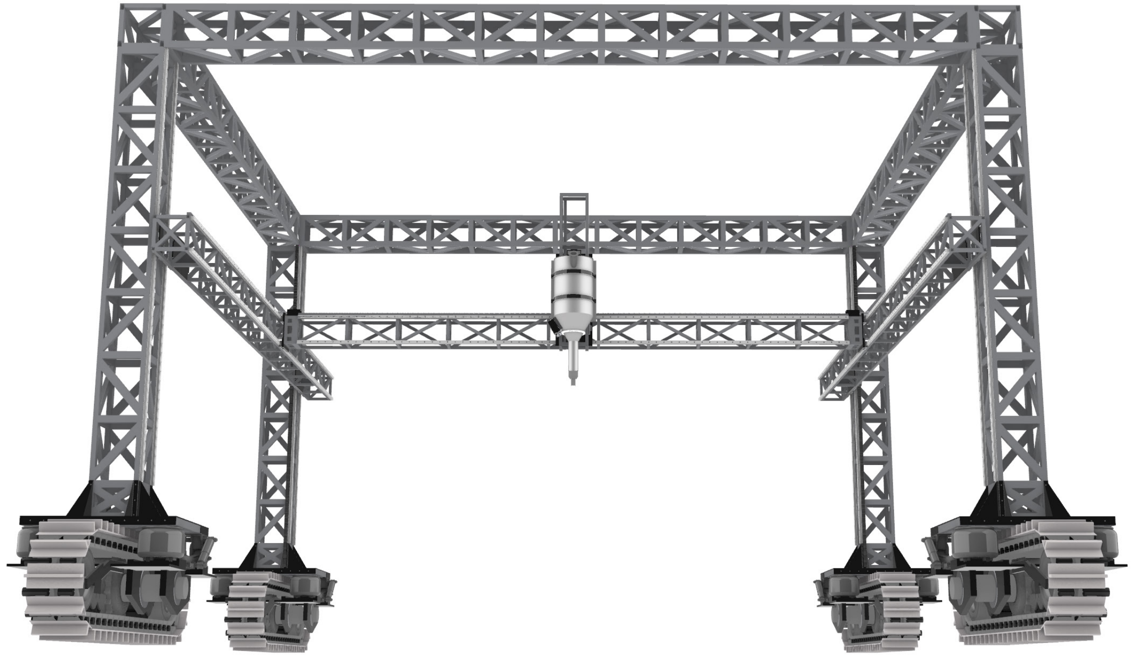
3. Vertical Farming: As part of the landscape design, vertical farming systems are implemented, providing a sustainable source of fresh produce for the residents. These innovative farming solutions maximize land use and minimize water consumption.

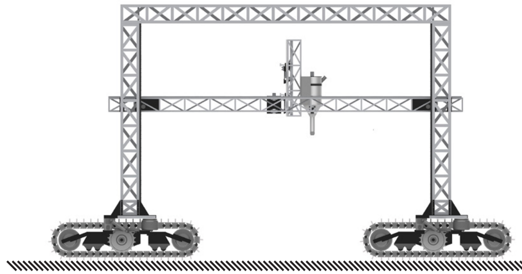
4. Renewable Energy Showcase: The complex serves as a demonstration site for renewable energy solutions, featuring not only the UV power plant but also wind turbines and solar-integrated building facades, showcasing the potential of renewable energy integration in urban environments.

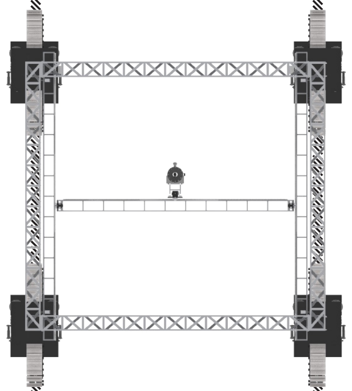
5. Community Engagement: Throughout the project's development, extensive efforts are made to engage the local community. Workshops, educational programs, and job training initiatives are organized, empowering residents to actively participate in the construction and ongoing management of the complex.

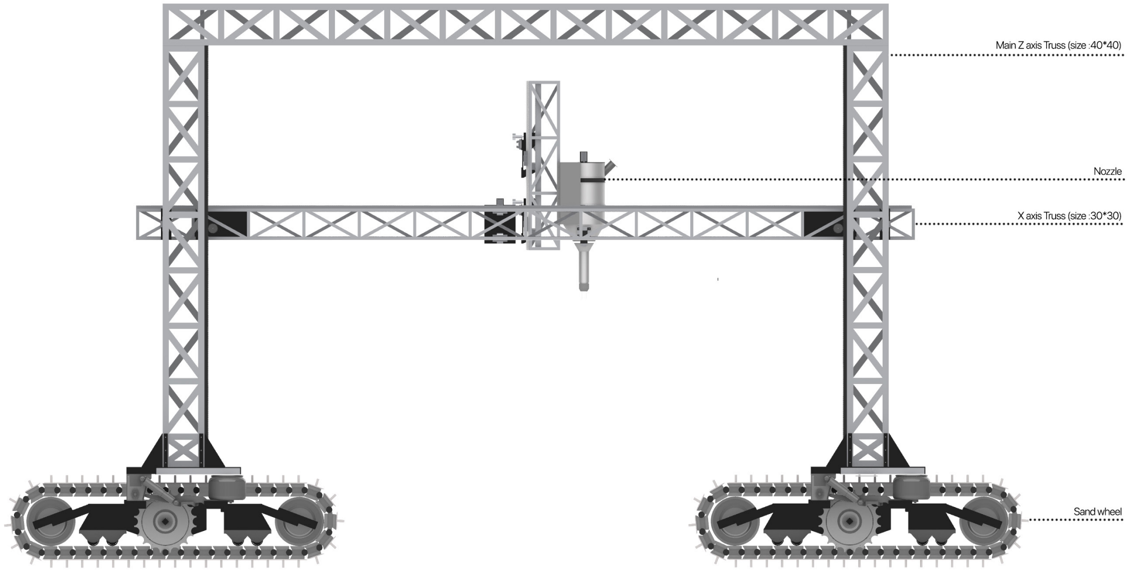
The completion of this revolutionary project stands as a testament to human ingenuity and our commitment to sustainable living. By pushing the boundaries of 3D printing technology and embracing eco-conscious practices, this complex becomes a beacon of hope for a greener and more interconnected future.

Robot design









Robot:

The robot is transported to the site by a trailer with a 10-meter length ,
unassembled and separate main components, and all the components of the rail and motors are assembled inside the factory.

Consuming materials:

A. Water: 0.3 cubic meters of water is used for every cubic meter of mortar used, according to the single unit of our collection that consumes 4.08 cubic meters of mortar, water equal to 1.22 cubic meters is used. For the whole project, we need 132,000 liters of water, which is achived by transferring water by 7 tankers of 20,000 liters.

B- Soil: It has no need to be transferred because it is extracted from construction area.

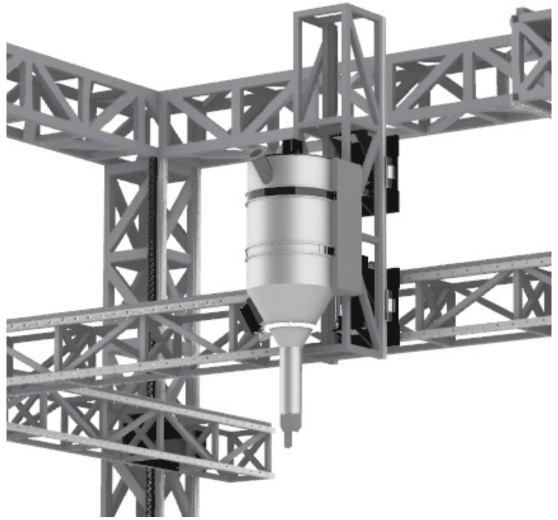
c- Retardant catalyst: we need 13.4 liters of additive retardant catalyst, which is transported to the site along with the trailer carrying the robot.

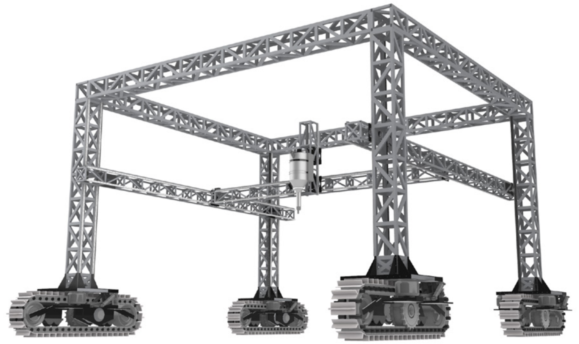
Optimal temperature conditions for execution

The best time to print is before sunrise and in the evening, when the sun shines vertically on the project between 12:00 and 16:00 PM, it causes premature drying of the disconnections and causes breakage between the layers. (not recommended during rain and storm)

Estimating the cost of making a robot

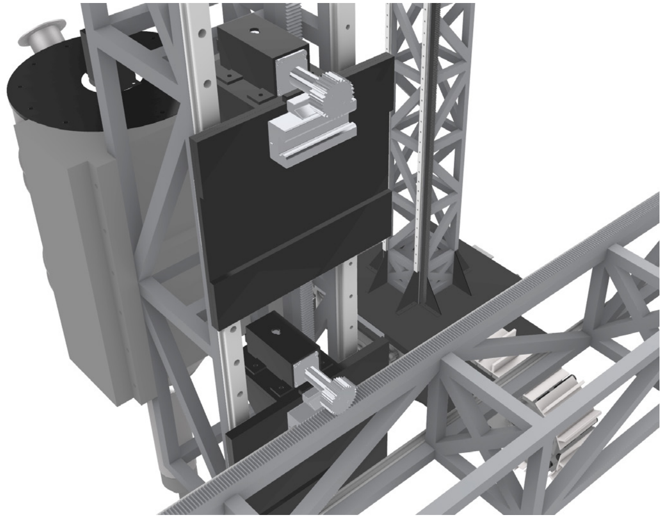
The overall estimation for the construction and operation of the robot has been calculated as six billion and eight hundred million tomans, which includes such things as engines, forging and factory trusses, rails and wagons guide, shoulder gears, gears, stoppers, sand wheels, and rims.
, nozzle, mobile septic tank, pulley, concrete pump, CCTV camera, spacer plate, box screw, and ect.

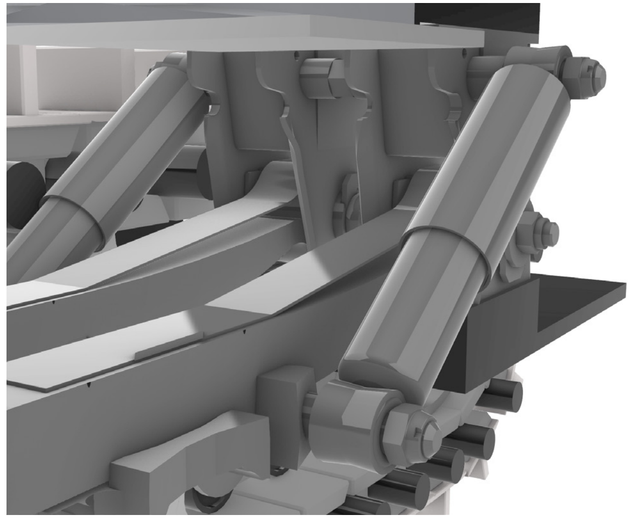




Project completion time:

The whole project is equal to 95 residential units and the calculated total area is 9258 square meters, which according to the printing speed and the way the machine moves and the engine recovering time, every 80 square meters is printed in 20 hours, which in total, the whole complex takes 2314 hours equal to 97 day takes time.





Human contribution

In this project, humans contribute in the following ways:
- Transfers of consumables and devices
- Assembling the device at the project site
- Leveling the soil and transferring it to the septic tank for mixing
- Primary nailing with sand bolts (wall foundations)
- 3 operators 24 hours a day
- construct the streets of the complex
- Planting vegetation
- Implementation of wiring and solar cells
- Installation of the cut/seam Joints between the units
- Implementation of doors and windows

(According to the above, the human share in the whole project is 30%.) This percentage is the ratio of the amount of days spent by the robot and the human.

Motors:

1- Servo motor Sanyo model 750w-3000RPM torque 2.4 Nm (with brake)
(quantity:9)

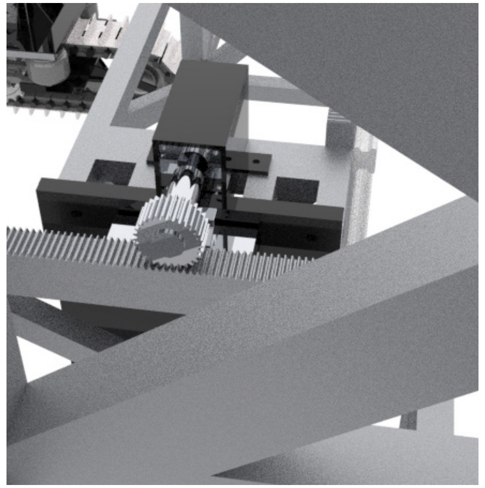
POWER : Hourly power consumption of the servo motor (KW/h)
0.75

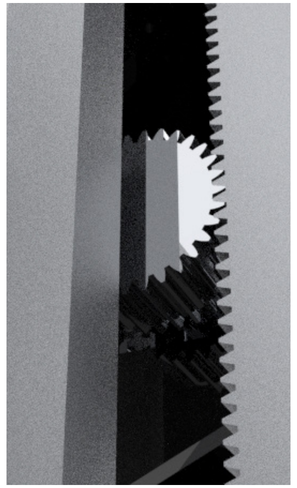
2- Servo motor Leadshine model ES-M32320 NEMA 23 in the axis of the nozzle
(quantity:2)
Hourly power consumption of the servo motor (KW/h)
0.63

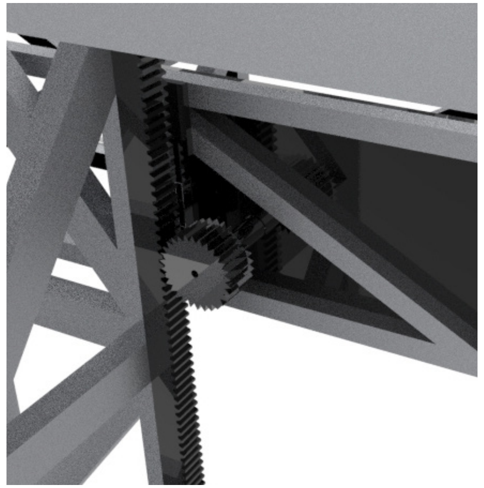
3- Three-phase stepper motor 863S nema34 series 4.3 Nm
(quantity:1)
Hourly power consumption of the servo motor (KW/h)
0.5

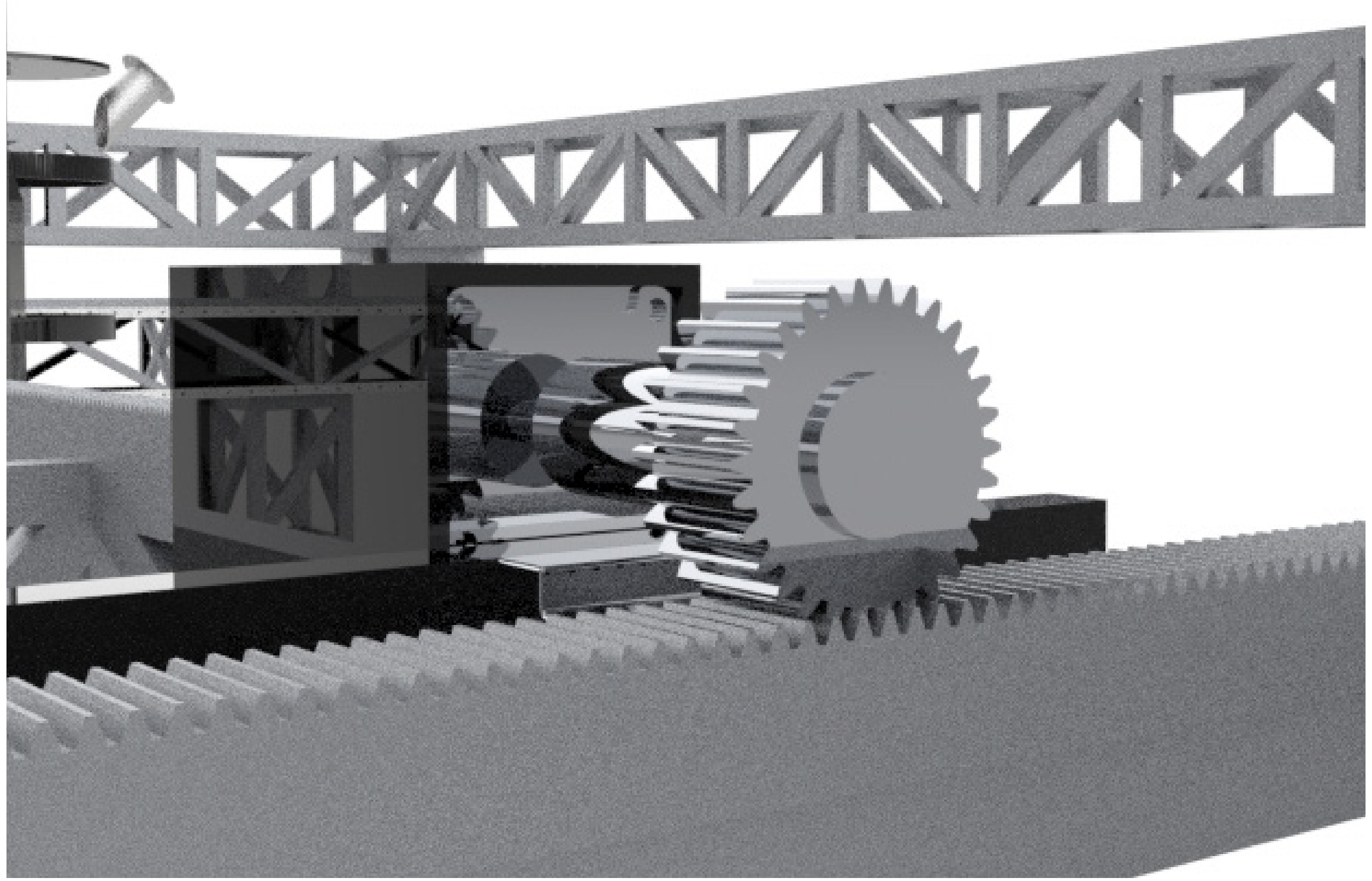
4- Motor side 2200kg (3phases) 8inch tube diameter for wheel drive
(quantity:4)
Hourly power consumption of the servo motor (KW/h)
1.9

Notice: all these dimensions are at the standard engine temperature, which is different for each model, and the maximum temperature for engines is between 80 and 110 degrees.

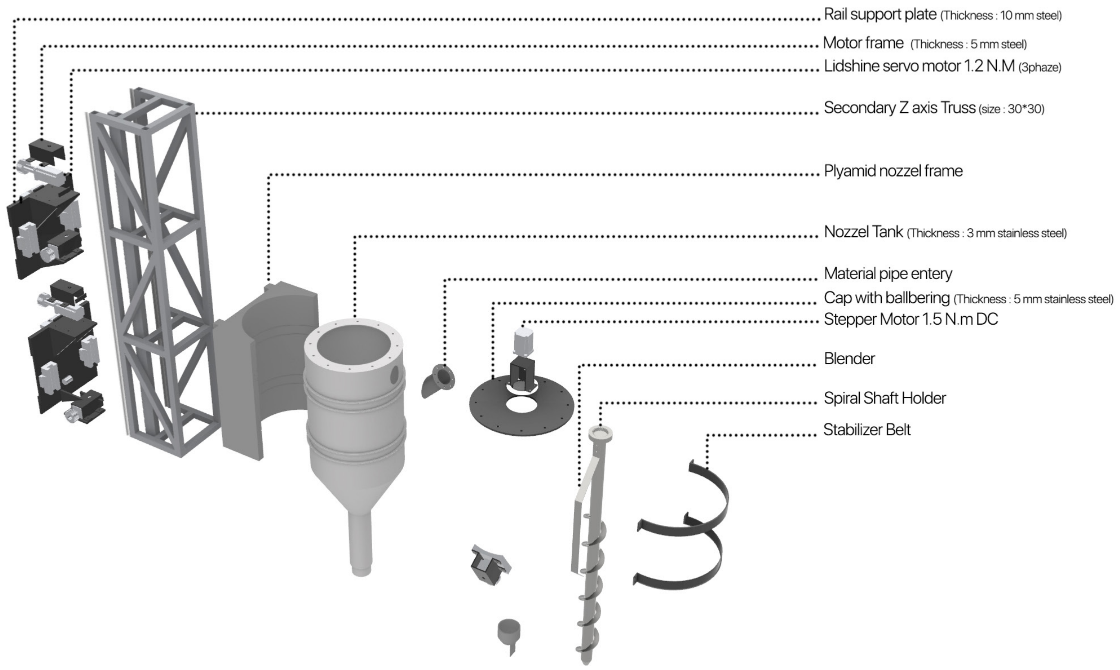


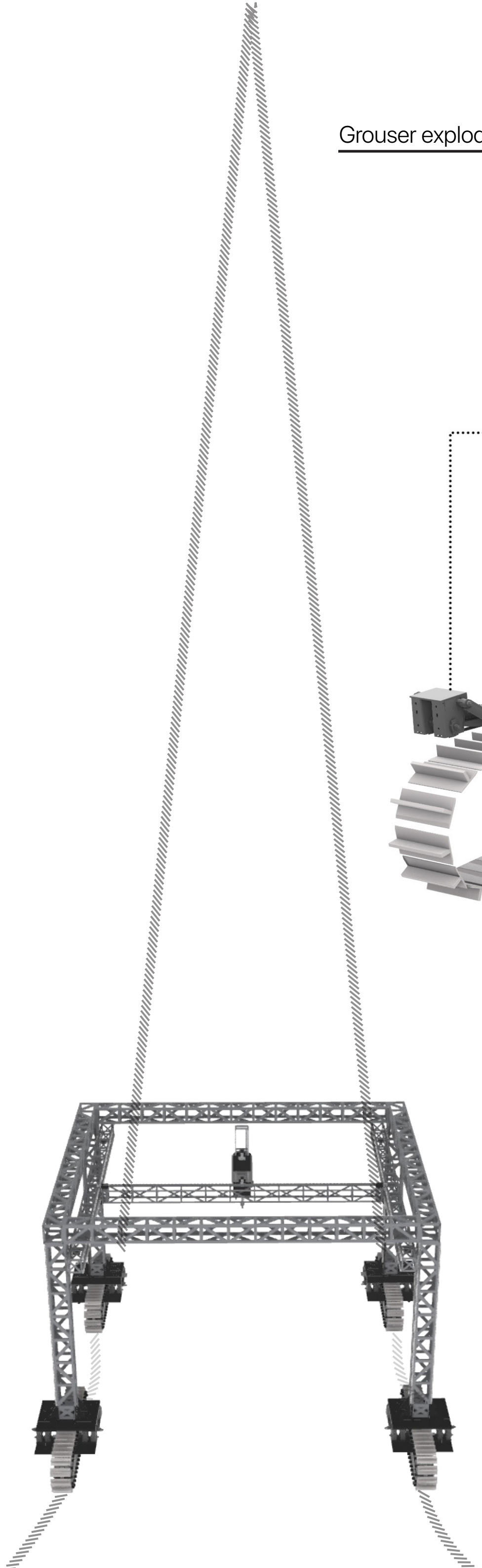




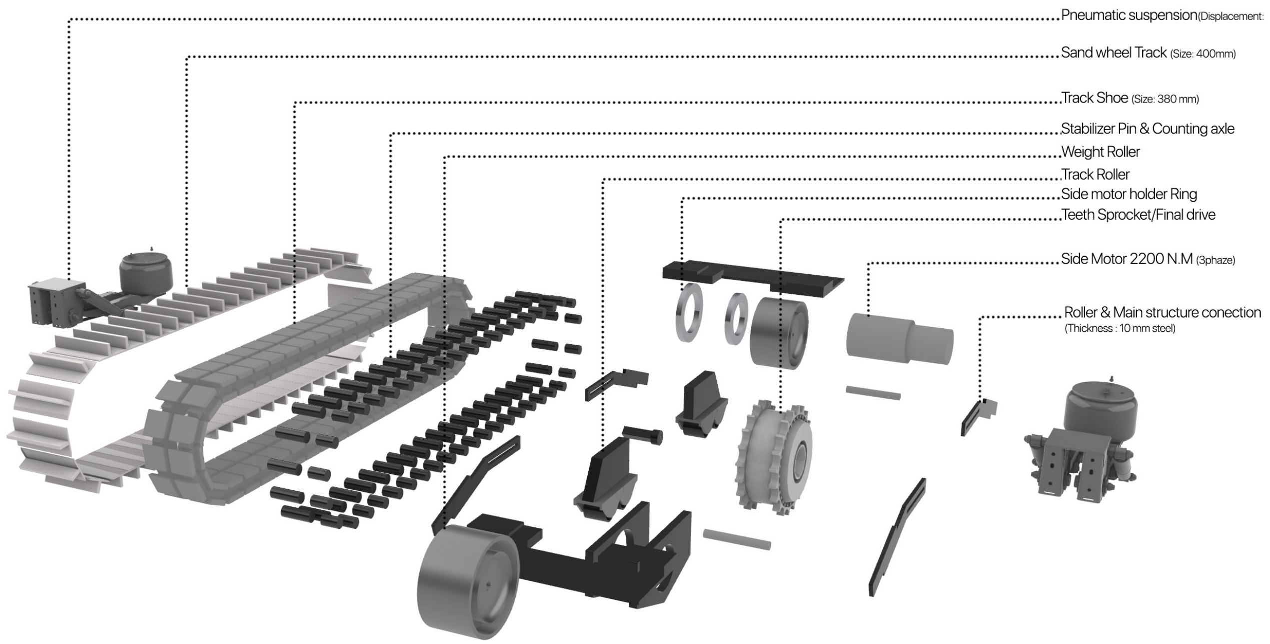


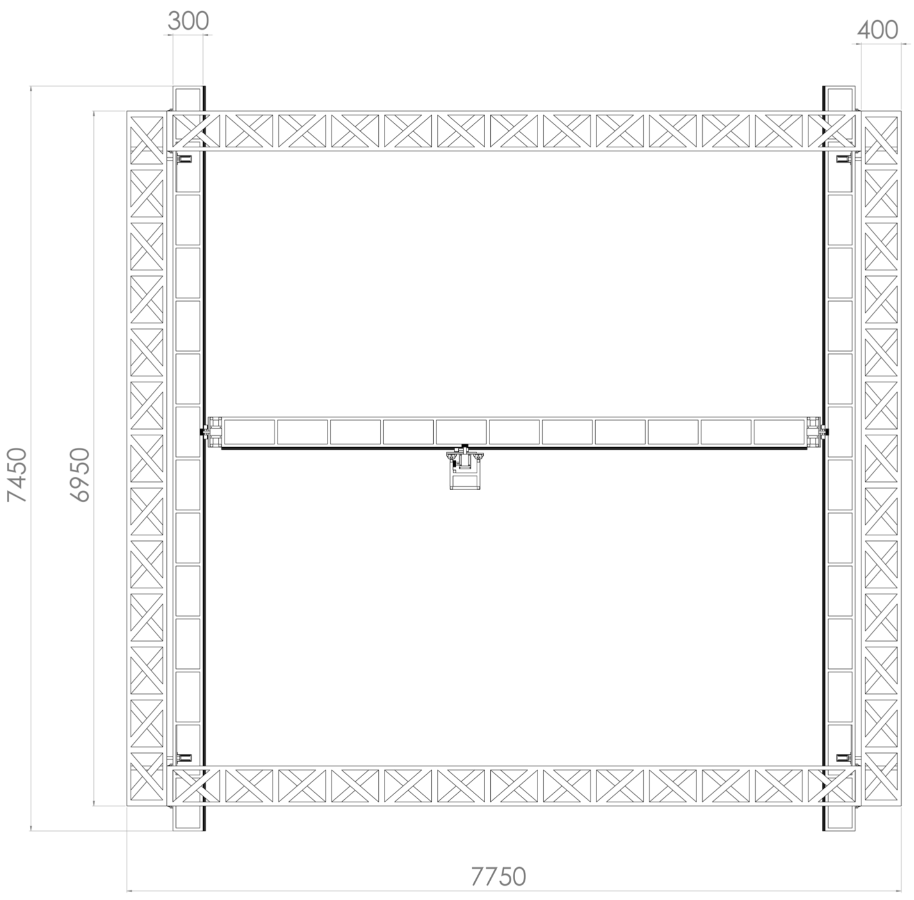
Nozzel exploded model



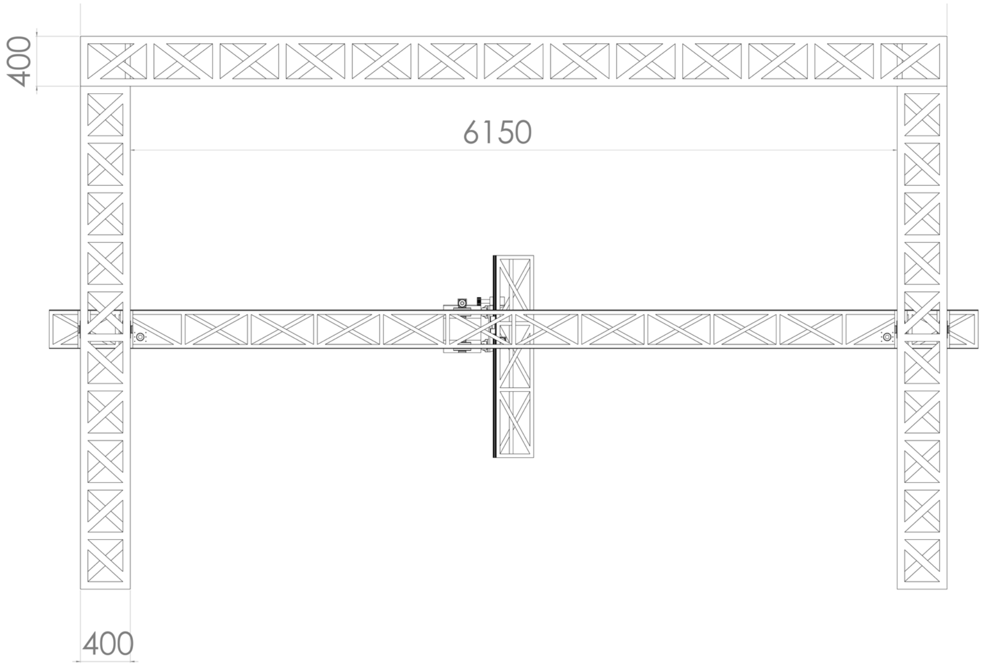


Grouser exploded model

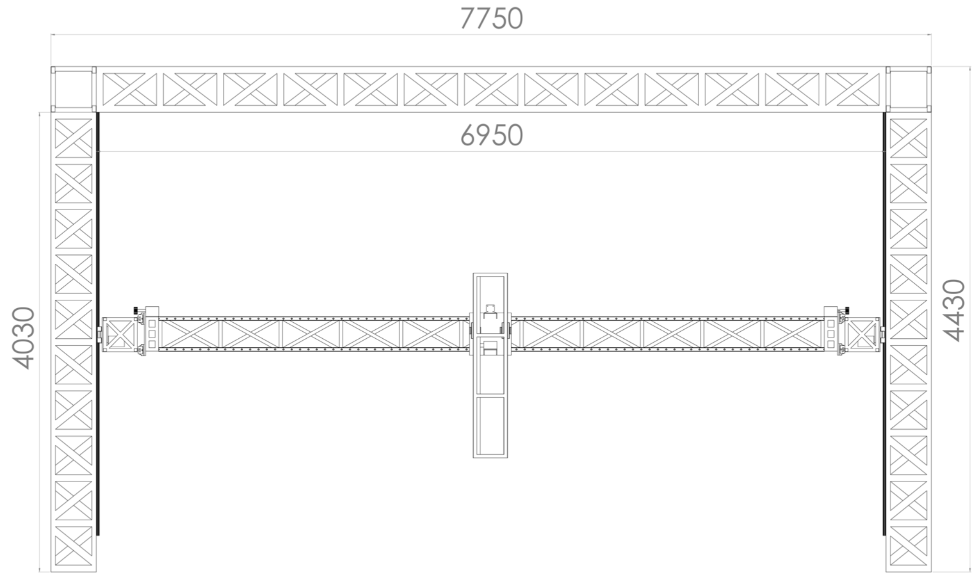




Top view



Right view



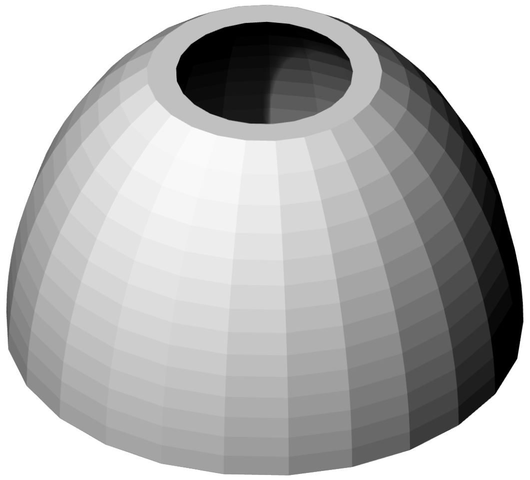
Front view

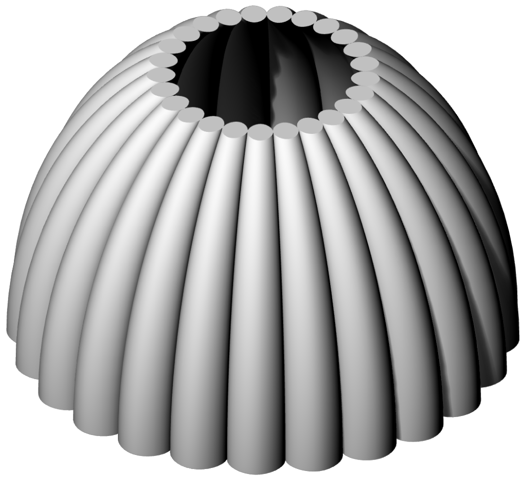
04 Form Finding

"Most programs employ the horizontal cutting method as the primary approach for building a toolpath. However, in this particular case, while still utilizing the horizontal cutting method, the process varies significantly. The primary objective is to enhance the structural stability of the final form during printing, leading to the adoption of waving curves in place of straight horizontal lines.

This approach ensures a seamless continuation of the results obtained from energy analysis, resulting in a cactus-shaped structure. To achieve this, we implement curvature right from the initial steps of the process, rather than adding it after reaching the final result.

Consequently, the form undergoes a transformation towards a series of vertical pipes, each defining the domain for our sine line curvature. These pipes serve as the foundation for creating the planes that compose our puzzle-like pieces."





Form finding

Shading design with Cactus concept

The folds and grooves on a cactus body, such as its stem or pads, are adaptations that help increase surface area, allowing for better water storage and reducing water loss through evaporation. These structures also help protect the cactus from excessive sunlight and reduce heat absorption.

In hot and dry climates, both cactus forms and building forms exhibit certain adaptations to cope with the challenging environmental conditions. Cacti have a variety of specialized features, such as reduced leaf surface area to minimize water loss, spines for shade and defense against herbivores, and a compact, rounded shape that reduces exposure to intense sunlight. These adaptations allow cacti to store water, maximize water absorption, and minimize water loss through evaporation.

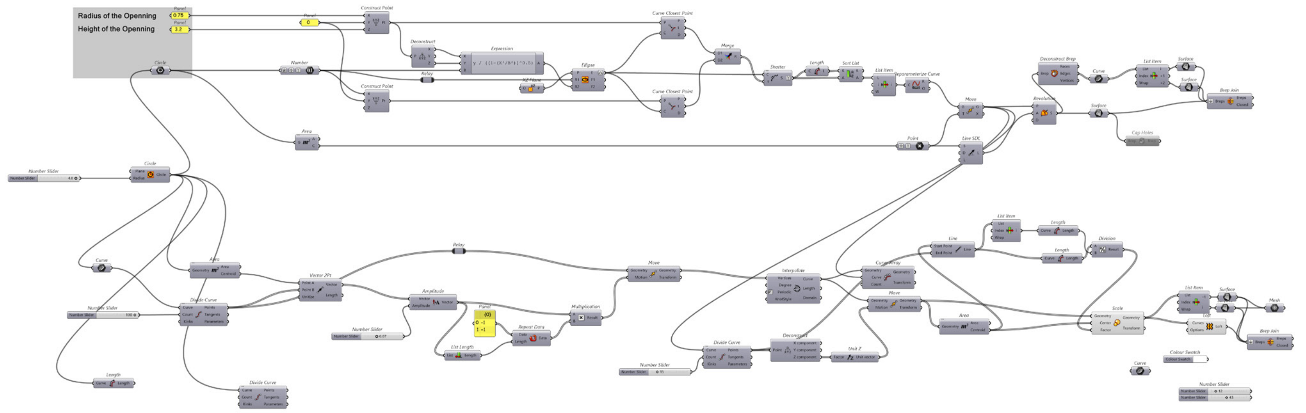
Similarly, buildings in hot and dry climates adopt design principles to enhance comfort and energy efficiency. Some common features include thick walls with high thermal mass to regulate indoor temperature, small windows or shaded openings to minimize heat gain, courtyards or central atriums for natural ventilation and cooling, and the use of materials with insulating properties. Additionally, buildings often incorporate water-saving strategies, such as rainwater harvesting and efficient plumbing fixtures, to address water scarcity.

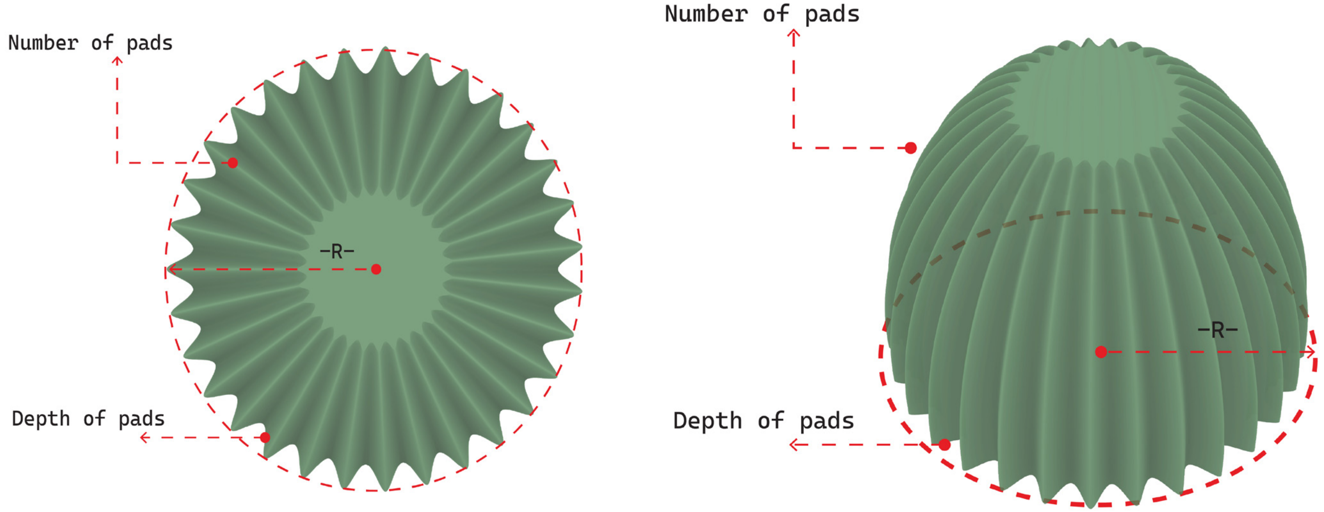
Both cactus forms and building forms in hot and dry climates reflect an understanding of the local environment and a need to adapt to extreme temperatures, limited water availability, and harsh solar radiation to ensure survival and comfort.

Form finding algorithm

To achieve a building form inspired by Cacti , we design an algorithm which generates alternatives and evaluates them by indoor adaptive .thermal comfort

.The independent variables of this process are the bottom radius of the unit, number of pads and depth of pads

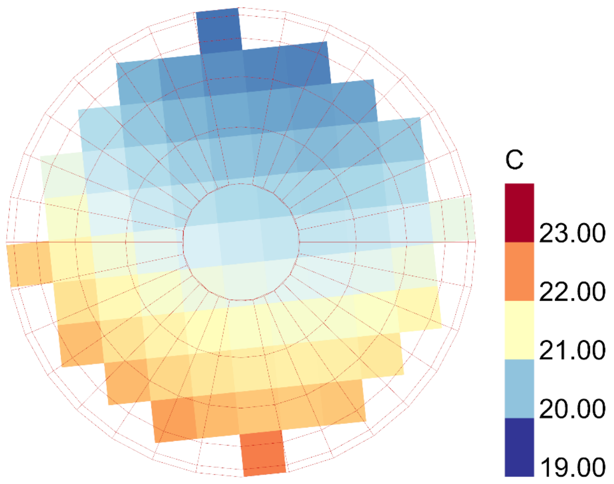




The dependent variable is the percentage of time which occupant is in thermal comfort. Adaptive model is chosen to calculate the thermal comfort.it calculated based on Ashrae 55.

Result

Without pads (with3m dimension)



Operative Temperature
1/1 to 12/31 between 0 and 23 @1

Spatial indoor temperature

Thermal condition average	TCP	HSP	CSP
-0.37	27.9	17.58	55.31

No shader geometry

Figure 2 - No shader geometry - Isometric

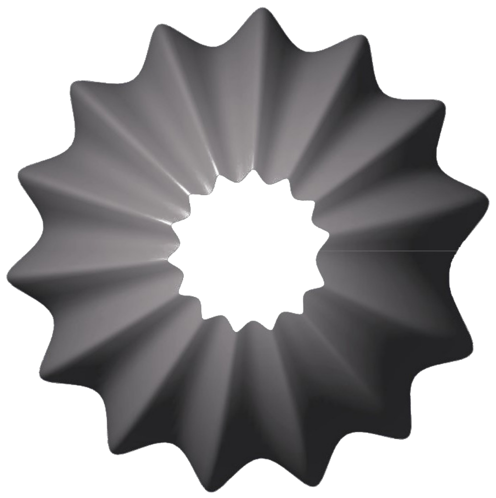
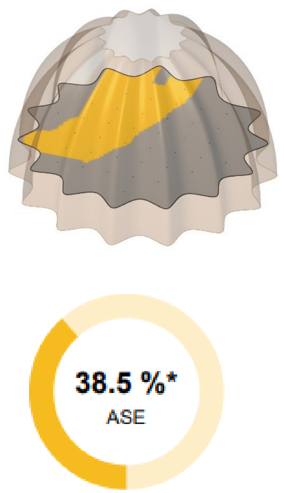


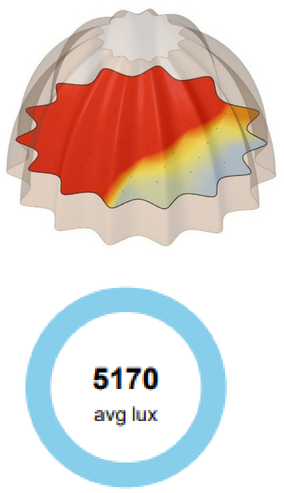
Figure 1- No shader geometry - Top view

1.sDA

2.ASE



3.Mean illuminance

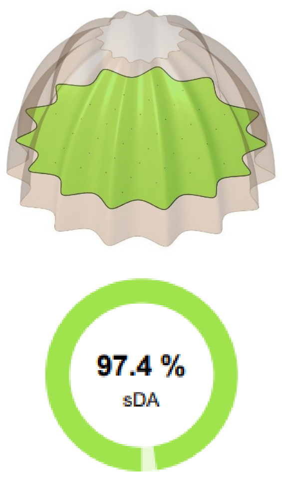


Geometry with shader

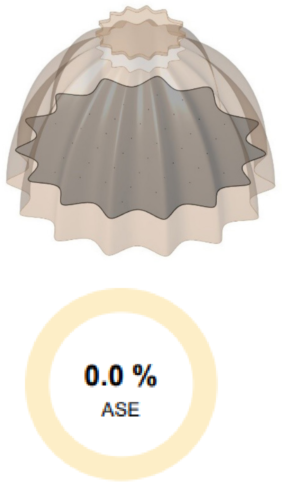
Figure 3 - LEED credits for geometry with shader

Daylight analysis

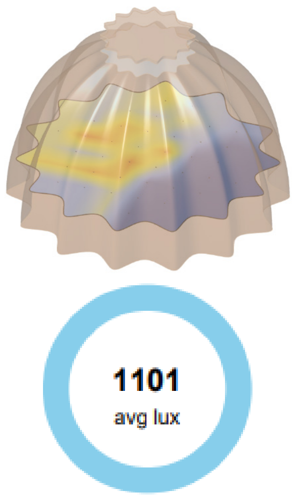
1.sDA



2.ASE



3.Mean illuminance



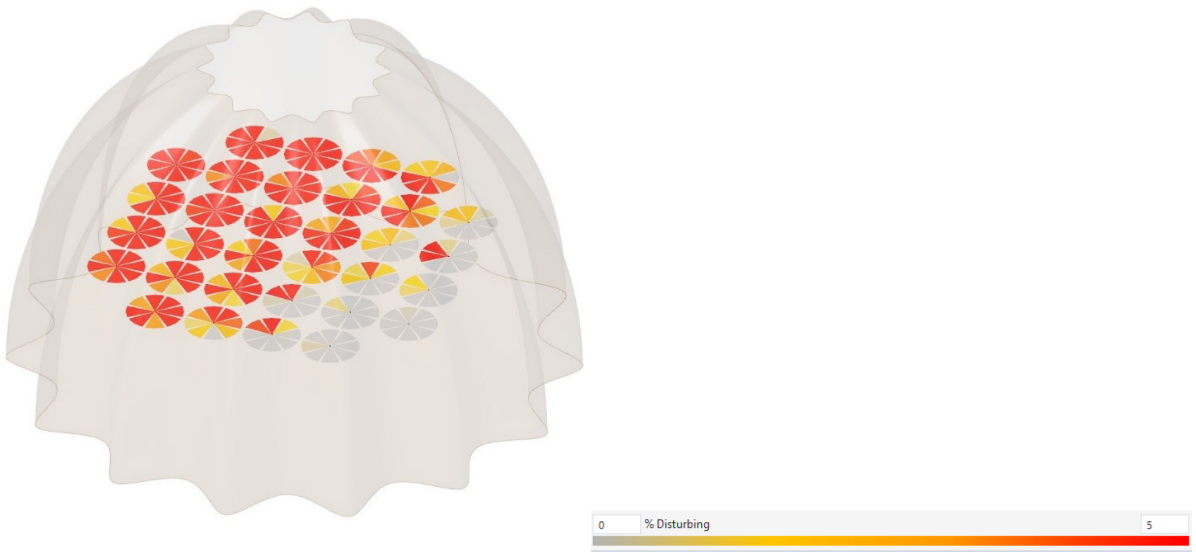
Glare Analaysis

A unique feature of ClimateStudio is its ability to calculate annual glare distributions across an occupied floor area. These glare calculations are based on the Daylight Glare Probability (DGP) metric, developed by Wienold and Christofferen. DGP predicts the likelihood that an observer at a given view position and orientation will experience discomfort glare. The metric is usually calculated using a fisheye rendering with an opening angle of 180 degrees. DGP can have values between 0% and 100%, which are divided into four bands:[2]

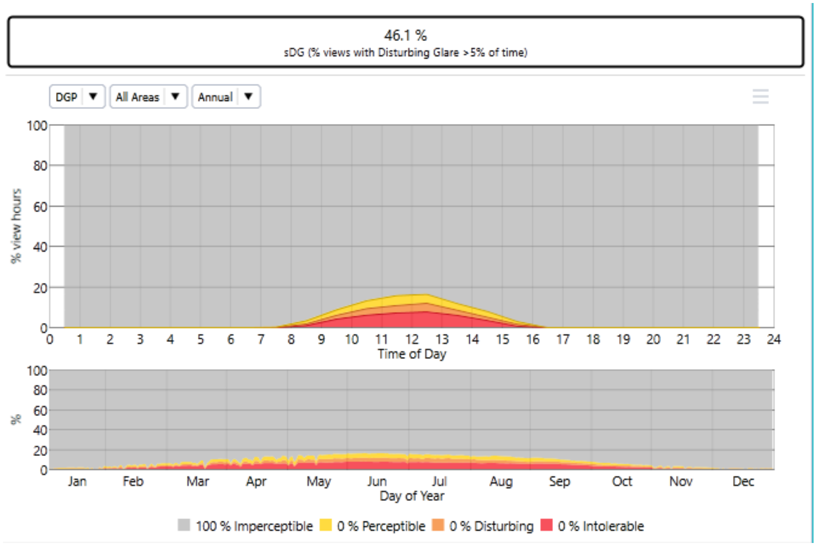
Imperceptible glare	Perceptible glare	Disturbing glare	Intolerable glare
DGP ≤ 34%	34% < DGP ≤ 38%	38% < DGP ≤ 45%	45% < DGP

Spatial Disturbing Glare (sDG): The percentage of views across the regularly occupied floor area that experience Disturbing or Intolerable Glare (DGP > 38%) for at least 5% of occupied hours. The calculation is based on hourly DGP values for eight different view directions at each position in the building. The default view height is 1.2 meters off the finish floor (eye height for a seated observer). The frequency of disturbing glare is visualized in the Rhino viewport using eight directional pie slices, with the color indicating frequency from 0 to 5%[2]

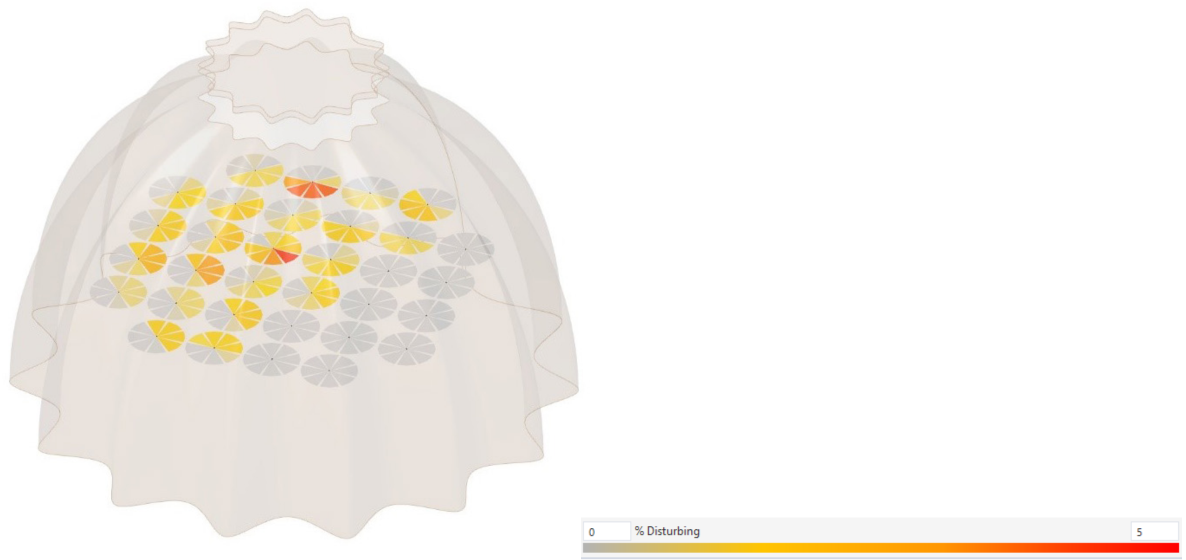
No shader geometry :

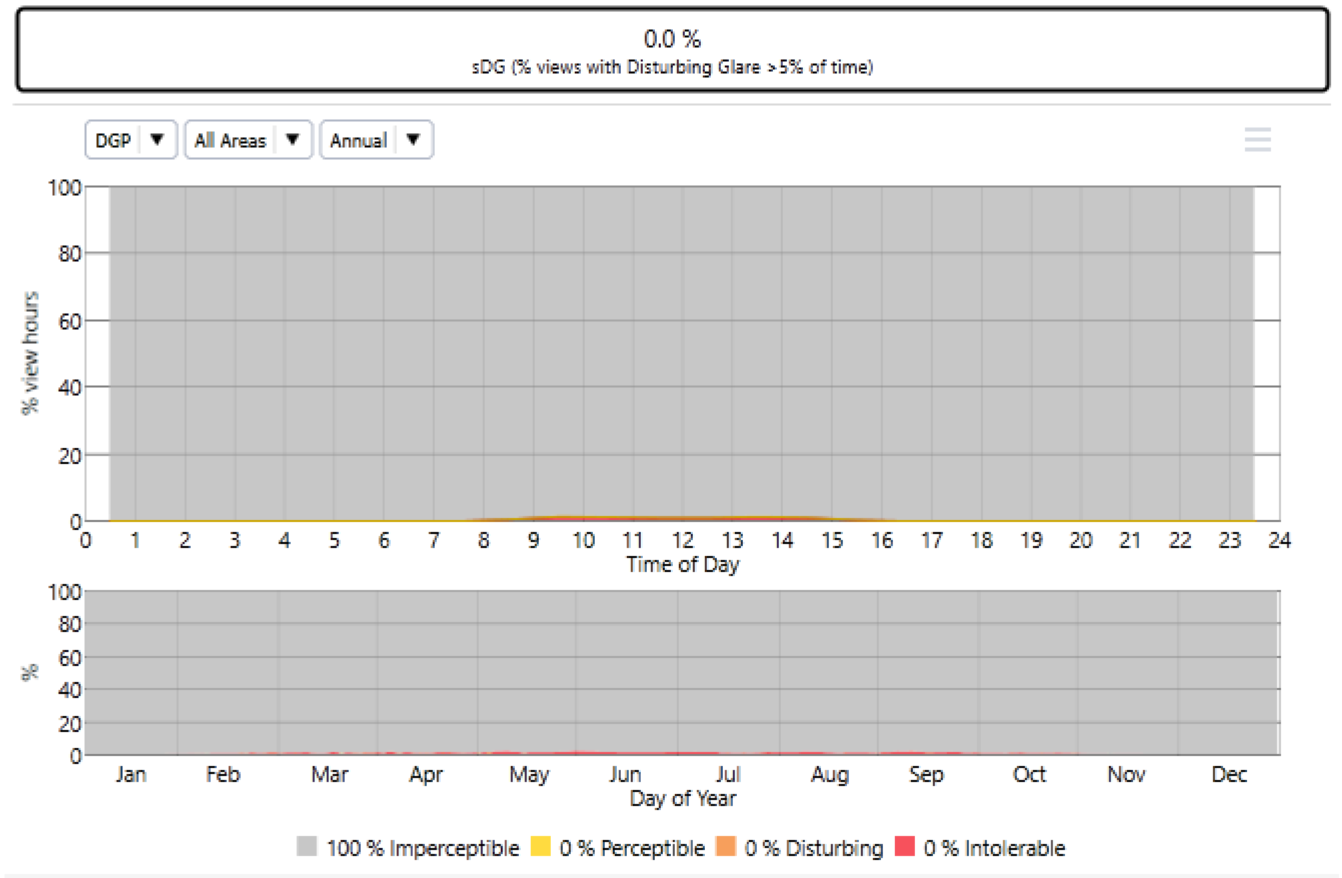


Glare Analaysis

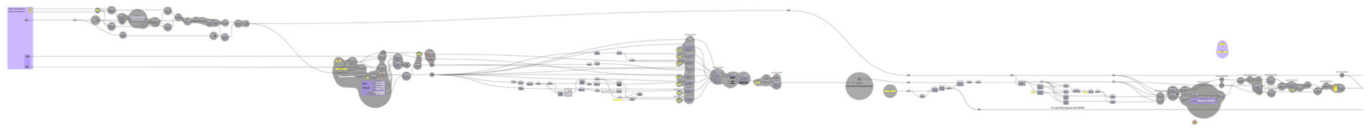


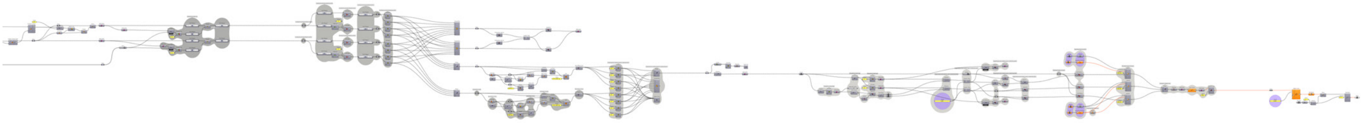
Geometry with shader: accepted





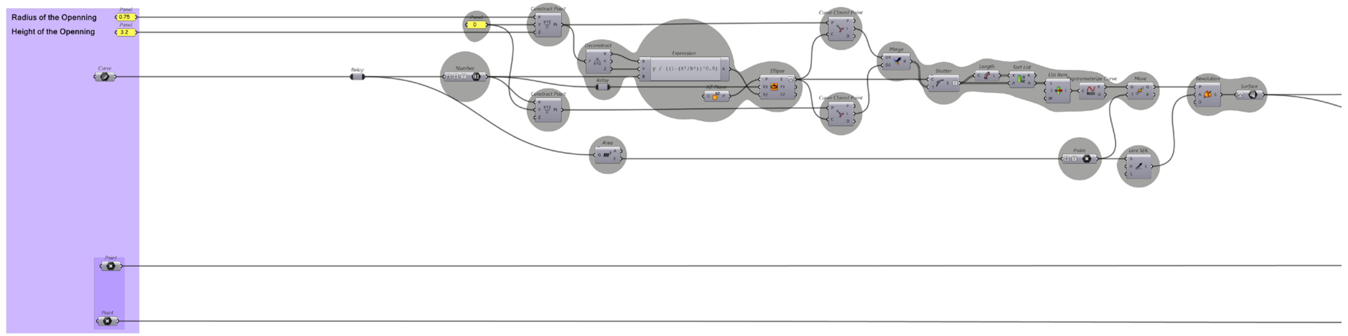
04 Toolpath



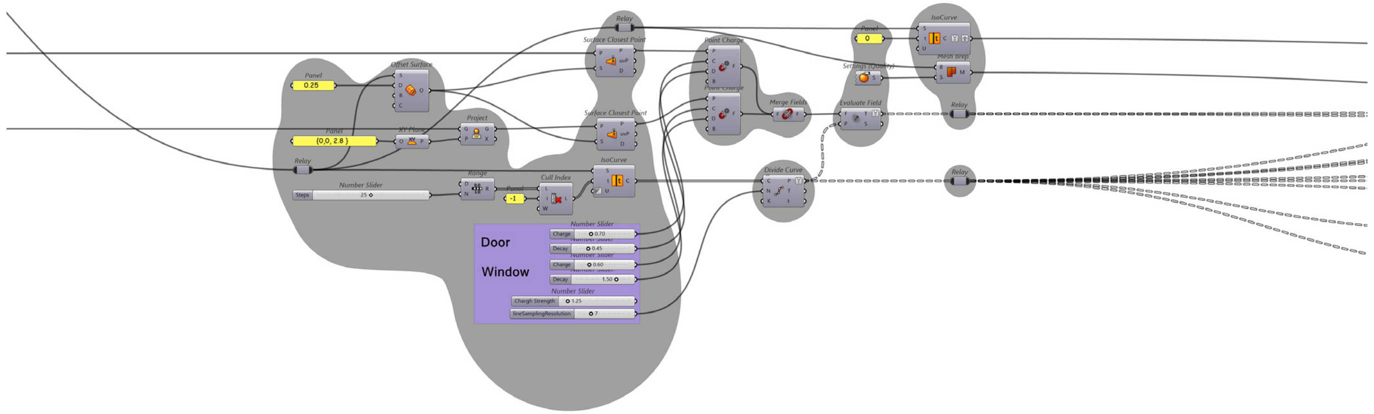


STEPS

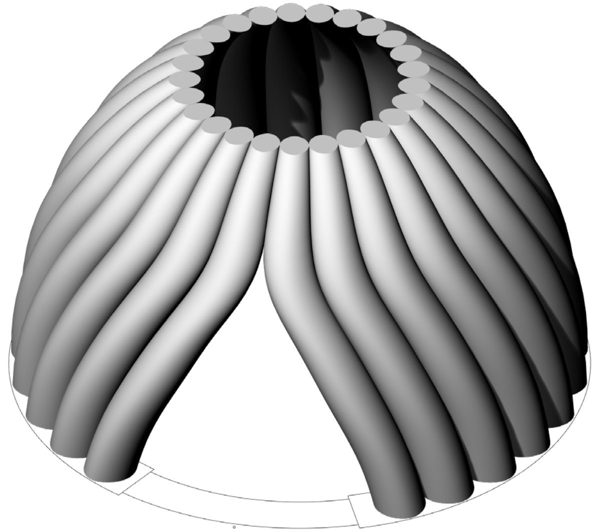
1. Grid developement
2. Kangroo Generate Openings
3. Grouping Points Near eachother
4. A troubleshooting code that allows more variables to grids angle
5. Extra modification

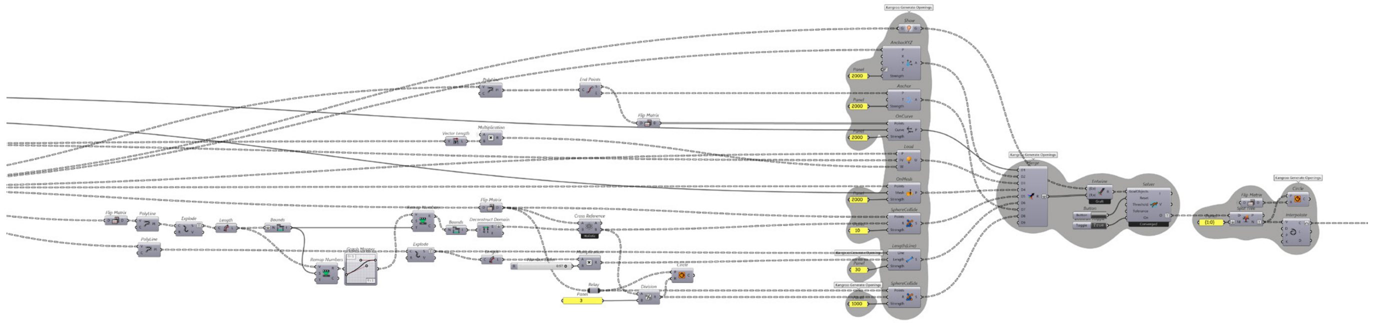


All shapes in this design is made of dome like forms with an opening at the top. first it's appropriate to create the domes based on the plan that the user inputs in the code, that is made of circles, constructing the project and points indicating the cavities. separation of doors and windows are required.



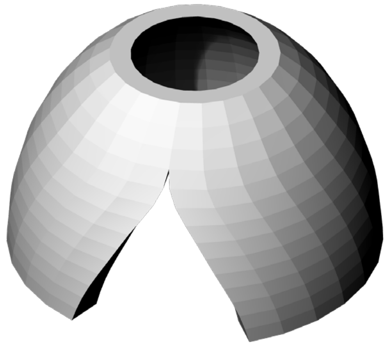
After creating the surface, a grid is constructed on it, that does not indicate final contoured geometry, but affects the smoothness of the openings creation. however, it should be kept in mind that the rows of points generated, will infact be final, and is the main data to make the final sine patterns on the model, so the rows count is a main input, placed at the start of the code.
The openings are then projected onto the surface and are used to make fields to repel the grid on the surface, in the upcominag steps.a

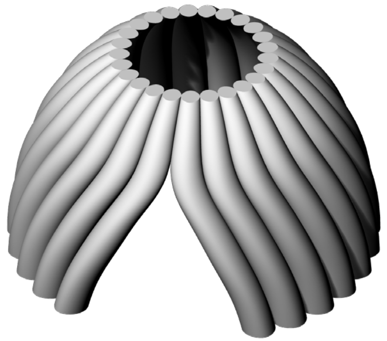


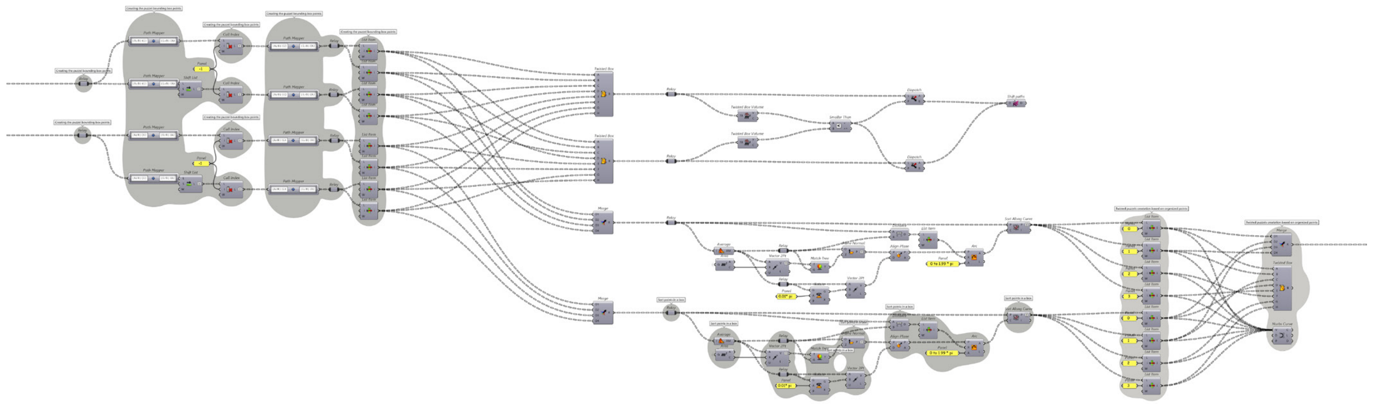


Kangaroo Physics®

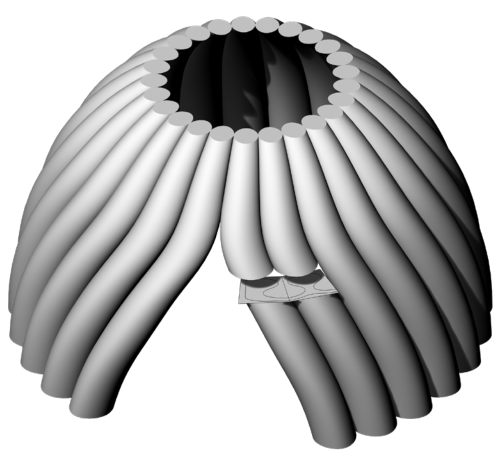
Kangaroo Physics® plugin is the main function to repel the grid, as it has the option to measure the distances of points while keeping them on the surface all the time.
The result output is a set of nurbs curves horizontally mapped on the surface with different distances, in regards to each other.

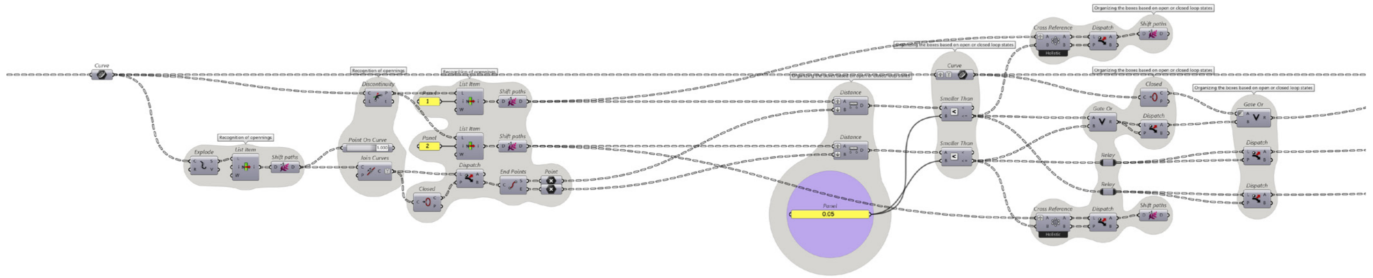




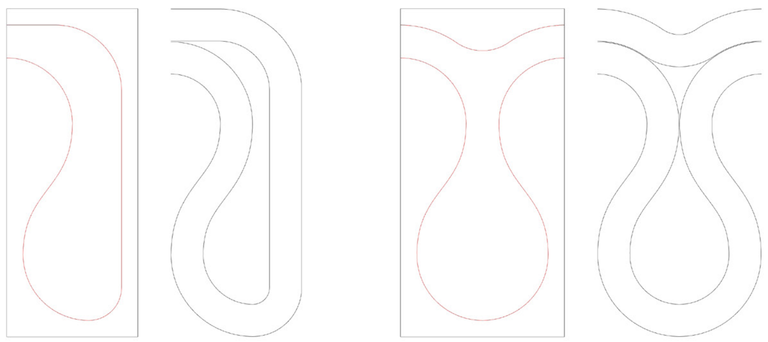


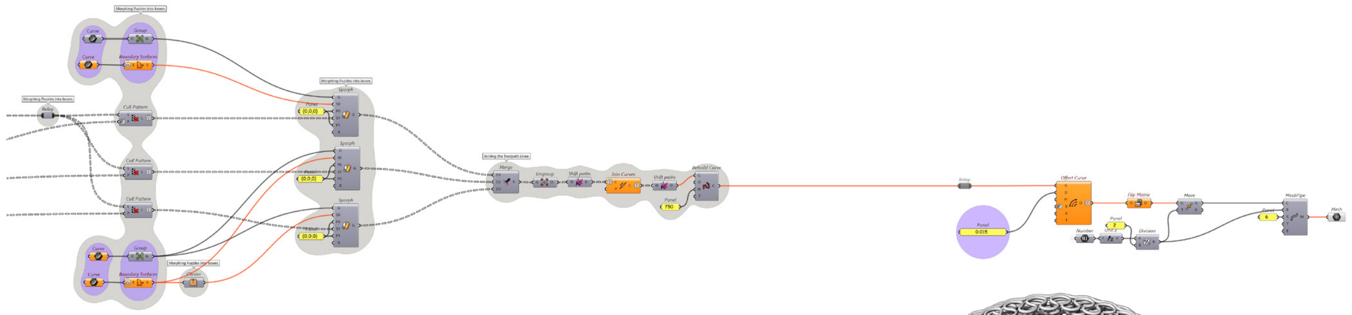
These curves are then evaluated at a horizontal distance, with regards to the XY plane, by the height measurement of the final 3D printed layers.
Then each point creates two of it's kind at an average distance, on both sides of it. these are used to indicated the length that the point affects and covers on it's specific plane on the surface.



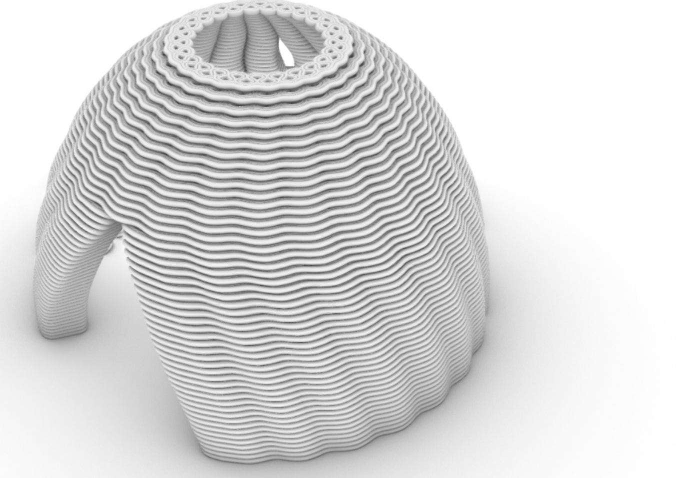


Next step is to group these points; the purpose is to match the position of consecutive points. for example if the left side point of line 4 is in reaching distance of right side point of line 5, then these two should be in the same position.
The reason being that, our lines should join each other at the end to construct a continuous loop around the surface, so a non porous surface can be achieved.
From the lines, that are now connected at the ends to each other, except for the openings, a set of boxes or boundaries will be created. This section requires an offset process, a data tree manipulation and a sorting process, using vectors from the geometrical center of dome to each point, to sort all 8 points that create the twisted box, in desired order.
To diagnose and separate the end of the line boxes from the boxes that are surrounded by two others at two sides, 5 logical gates are used. the reason for this, is the difference between the patterns that would be morphed into each set.





Output would be both the rebuild curve of these curves joint together and also the CNC basic code of these lines.



Challenges related to 3D printing toolpath generation:

1. Support Structures:
Support structures are auxiliary structures created during the 3D printing process to support overhanging or bridging sections of the model. addressing this challenge involves striking a balance between providing adequate support and minimizing its impact on the final print. Advanced slicing software uses algorithms to automatically generate support structures only where necessary, reducing material consumption and improving the overall print quality.

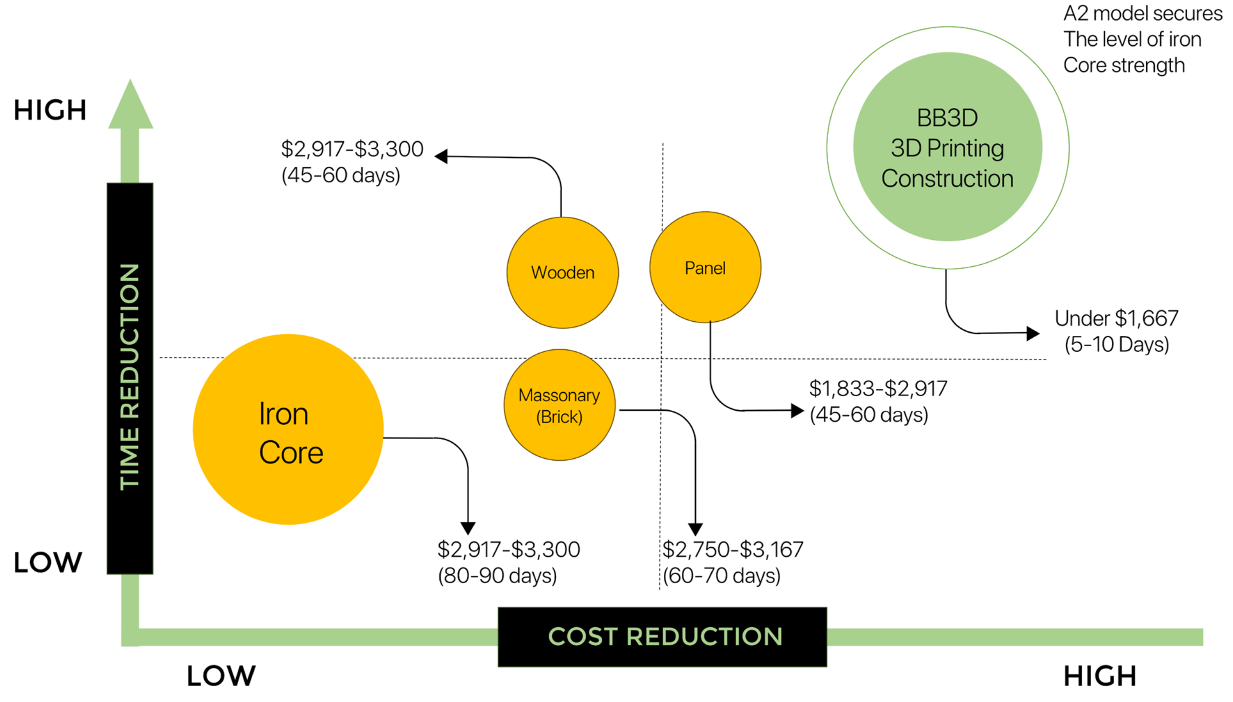
2. Print Time and Efficiency:
Print time can significantly impact the 3D printing process, especially for large and complex models. The toolpath needs to be optimized to minimize the total print time while maintaining the structural integrity and surface quality of the final part. one approach to improving print time efficiency is to optimize the travel moves of the 3D printer's nozzle. This can be achieved by reducing unnecessary movements between print features, using the shortest possible paths, and avoiding collisions with existing printed parts or support structures.

3. Layer-to-Layer Adhesion:
Ensuring strong adhesion between consecutive layers is essential to create robust and reliable 3D printed parts. Poor layer-to-layer adhesion can lead to delamination and weakened structural integrity. another crucial aspect is ensuring proper cooling between layers to prevent warping and improve adhesion. Some slicers include features that enable users to customize fan speed and layer cooling to achieve the best results for specific materials and models.

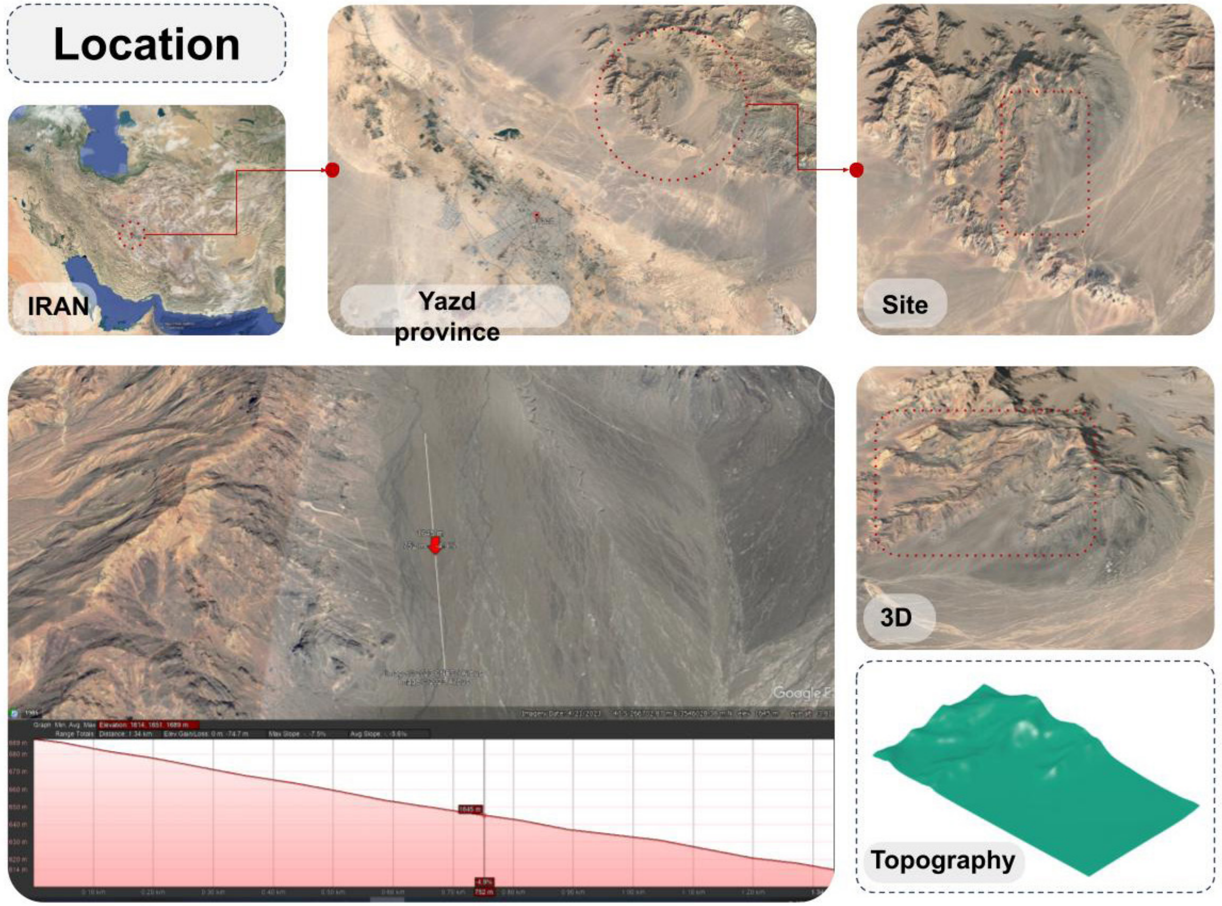
Overall, successful 3D printing toolpath generation involves considering various factors such as model complexity, material properties, support structures, print time efficiency, and layer-to-layer adhesion. Advancements in slicing algorithms and 3D printing software have been steadily addressing these challenges, making the process more accessible and efficient for users. However, the complexity of the models and the materials used will always require careful consideration to achieve the desired print quality and functionality.

06 Statistic diagrams

Cost and time chart :

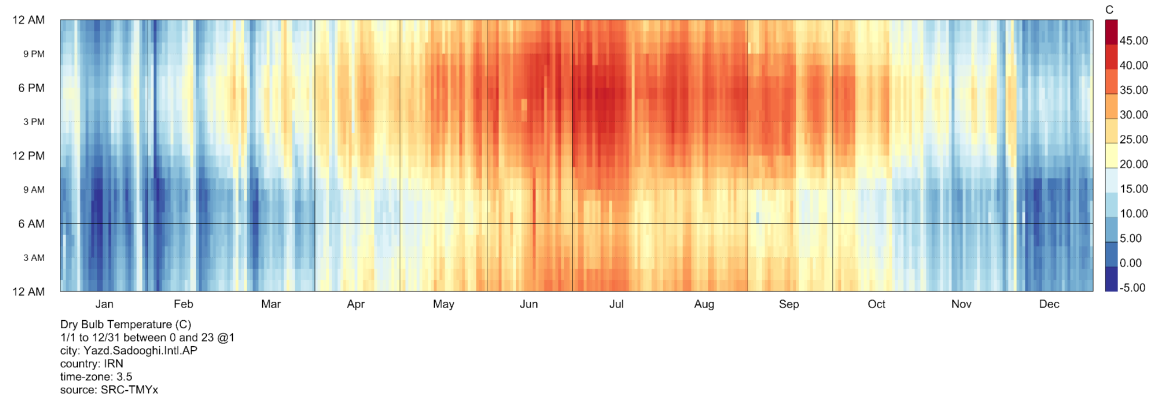


07 Sustainability analysis

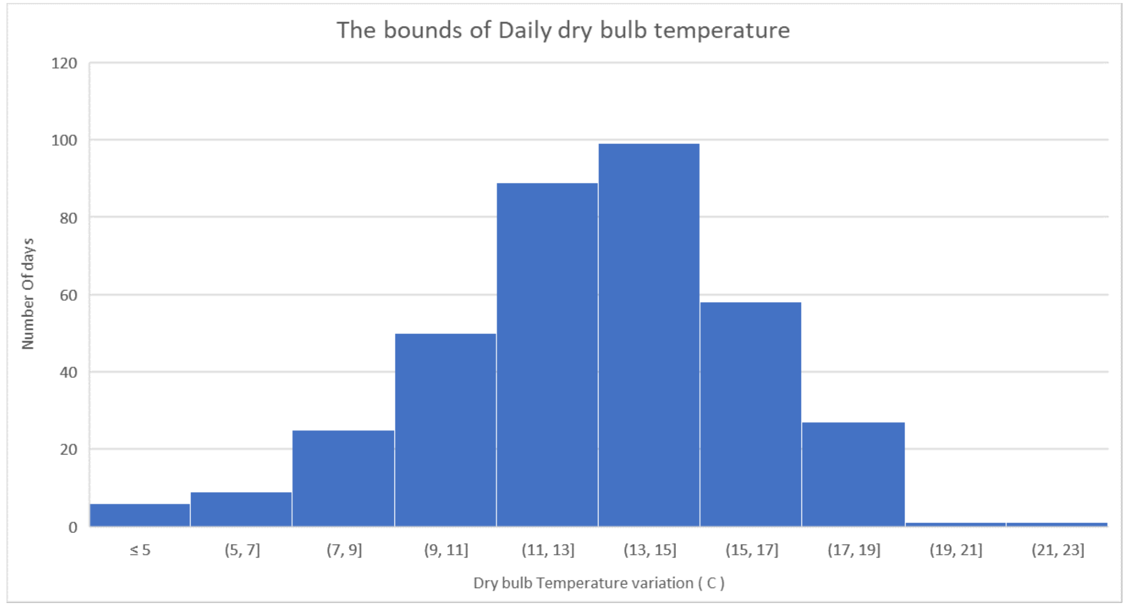


Climate analysis

DryBulb temperature

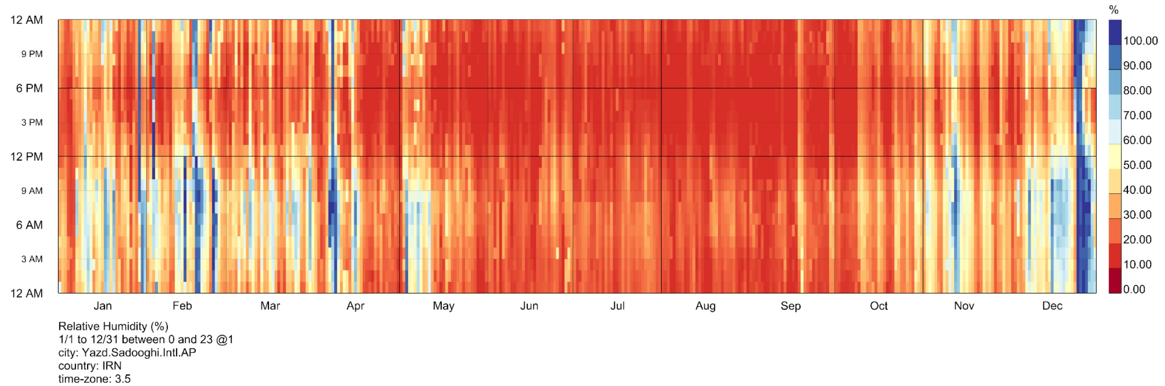


The annual average dry bulb temperature ranges from -5.8 C to 42 C, with an average of 19.74 C. 4 September is a summer day with a temperature range of 23 degrees Celsius (11 degrees Celsius to 33 degrees Celsius).

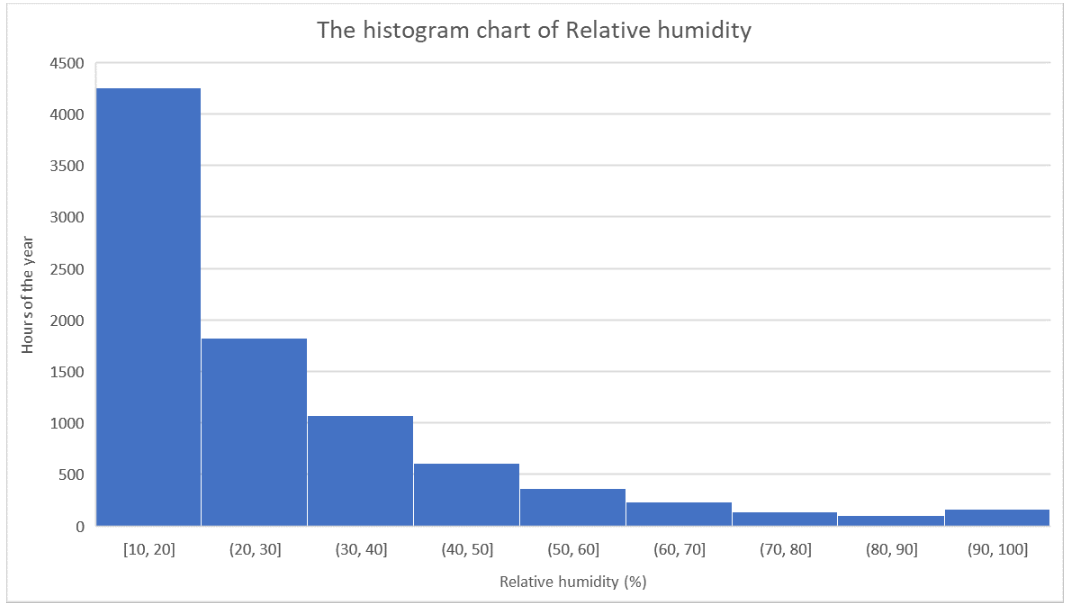


Therefore, a shift in temperature of 9 to 17 C over the course of a day is considered to be typical. In addition, although lower temperatures are more typical, higher temperatures are considered to be more extreme.

Relative Humidity

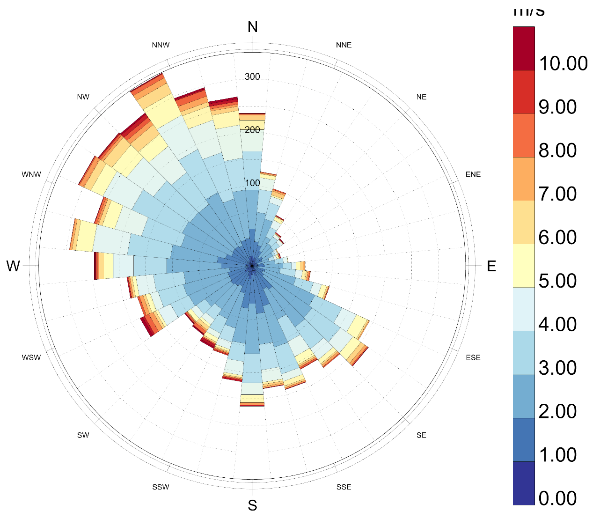


The graph represents a relative humidity that varies from ten to one hundred percent, with a mean value of twenty-seven percent. The air is extremely dry throughout the year, particularly in the summer and winter, which means that humidity is a significant influence for the overwhelming portion of the year.

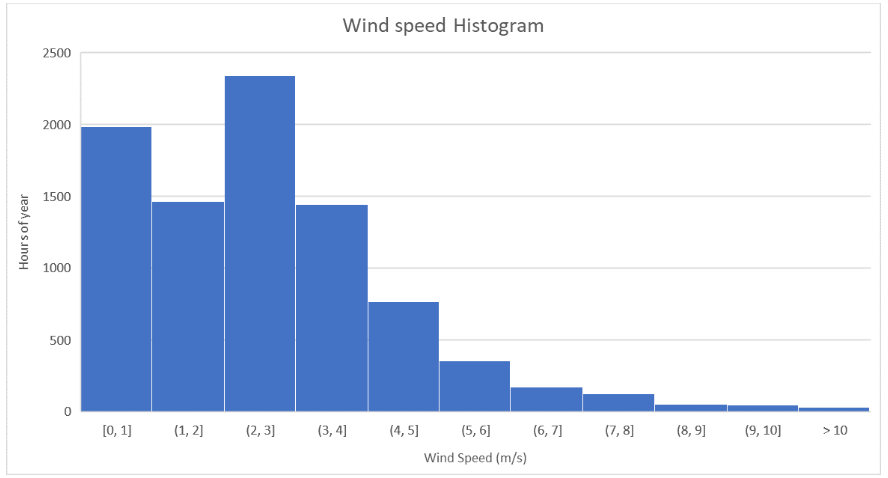


As was to be anticipated, the relative humidity in Yazd is lower than 30 percent for more than 6000 hours per year, which is equivalent to nearly 70 percent of the year.

Wind Rose

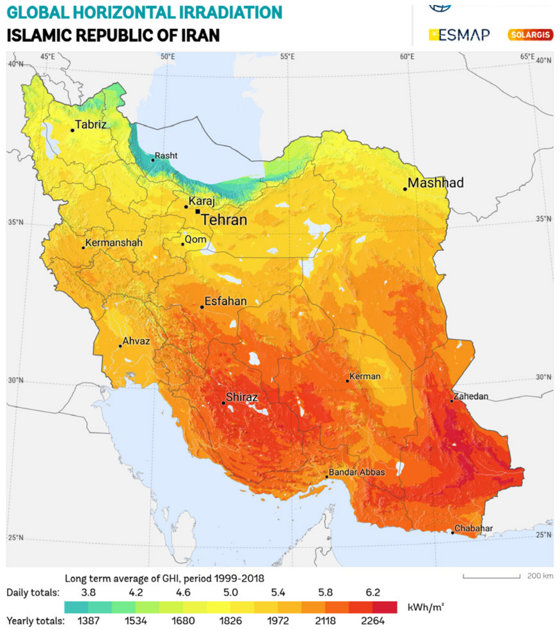


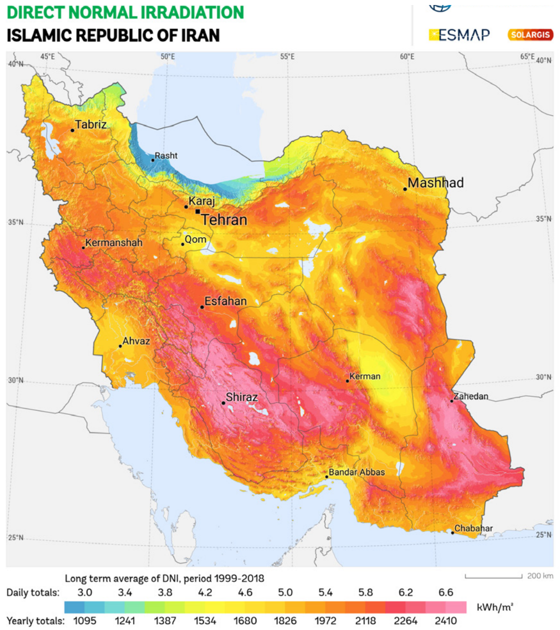
The speed of the wind can range anywhere from 0 to 18 meters per second, with a speed of approximately 2.8 meters per second acting as the average speed. The wind is coming from the southwest and shifting to the northeast at this time. Therefore, it is essential to construct a strong windbreak, whether it be natural or manmade, in order to combat the powerful and high-frequency winds that blow in the typical southwest-to-northeast axis.



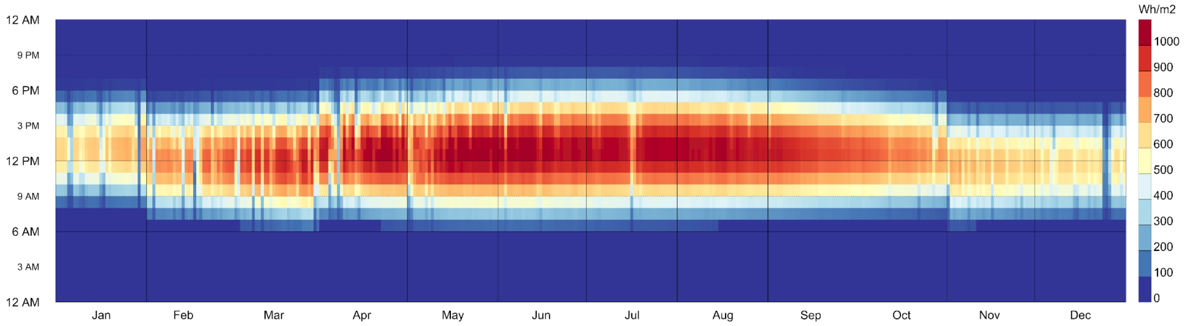
The speed that is most commonly observed is lower than 4 meters per second. Less than twenty percent of a year sees wind speeds more than four meters per second.

Radiation



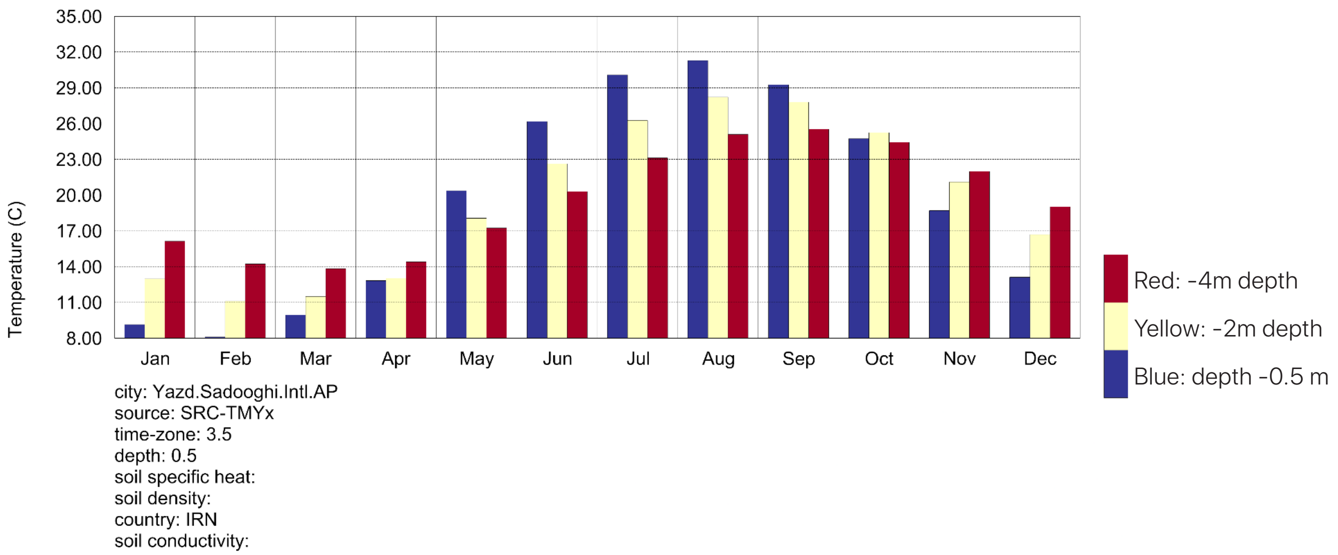


Iran has significant sun irradiation, suggesting solar energy potential. Iran can benefit from widespread solar energy adoption due to its tremendous solar potential. Solar power reduces greenhouse gas emissions and the country's dependence on non-renewable energy. Solar energy in Iran could increase energy independence, economic growth through renewable energy investments, and electrical access, especially in distant locations. Solar energy might also mitigate climate change and integrate Iran with global warming efforts. Yazd, Isfahan, Fars, and Kerman have the highest potential.



Global Horizontal Radiation (Wh/m2)
1/1 to 12/31 between 0 and 23 @1
city: Yazd.Sadooghi.Intl.AP
country: IRN
time-zone: 3.5
source: SRC-TMYx

Ground temperature



Ground temperature is crucial for practical sustainable means uses in desert and hot, severe climates. Ground temperature is consistent year-round, making it useful for cooling and heating. In these hot climates, geothermal cooling systems can efficiently extract heat from buildings and discharge it into the colder earth. However, geothermal heating systems can use the ground's continual warmth to keep buildings warm on cold desert nights without using energy. Ground temperature can also be used for greenhouse heating and soil warming, helping farmers grow crops in harsh settings. In dry and hot settings, tapping ground temperature can sustainably counteract severe temperatures, conserve energy, and encourage environmental stewardship.

Red: -4m depth

Yellow: -2m depth

Blue: depth -0.5 m

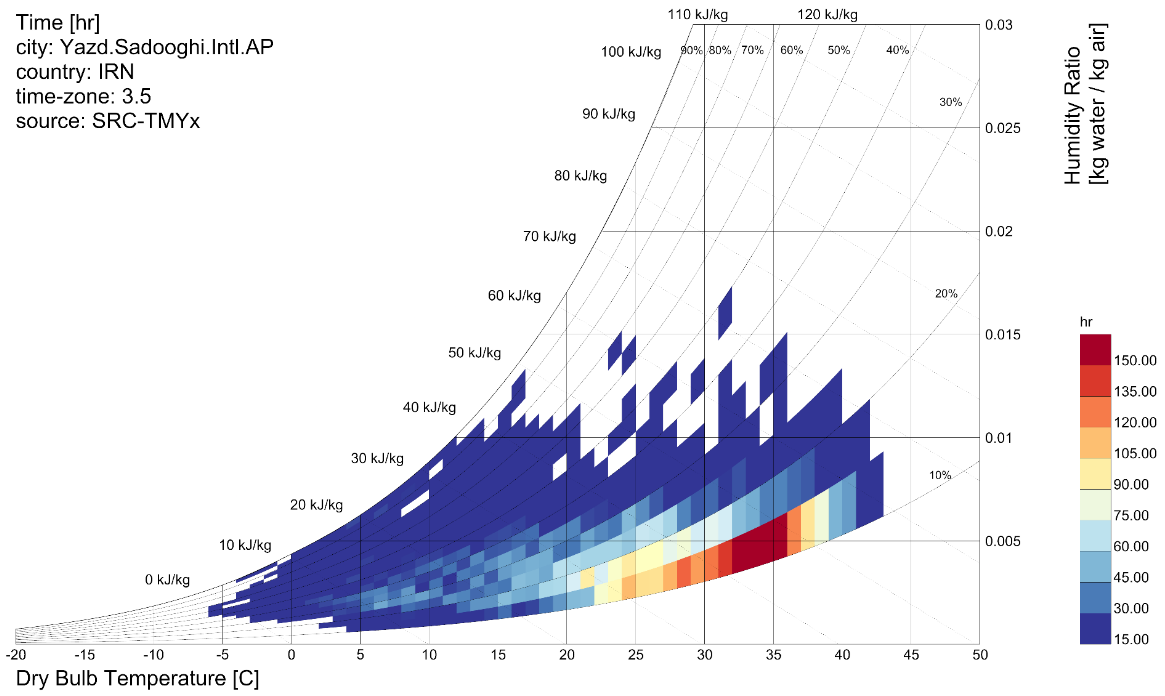
At a depth of 0.5 meters, the temperature of the ground varies from 8 C in February to 32 C in August.

At a depth of 2 meters, the ground temperature varies from 11 C in February to 28 C in August.

At a depth of 4 meters, the ground temperature varies from 14 C in March to 25 C in August.

It is evident that the temperature would change by 1.5 degrees Celsius for every meter of depth.

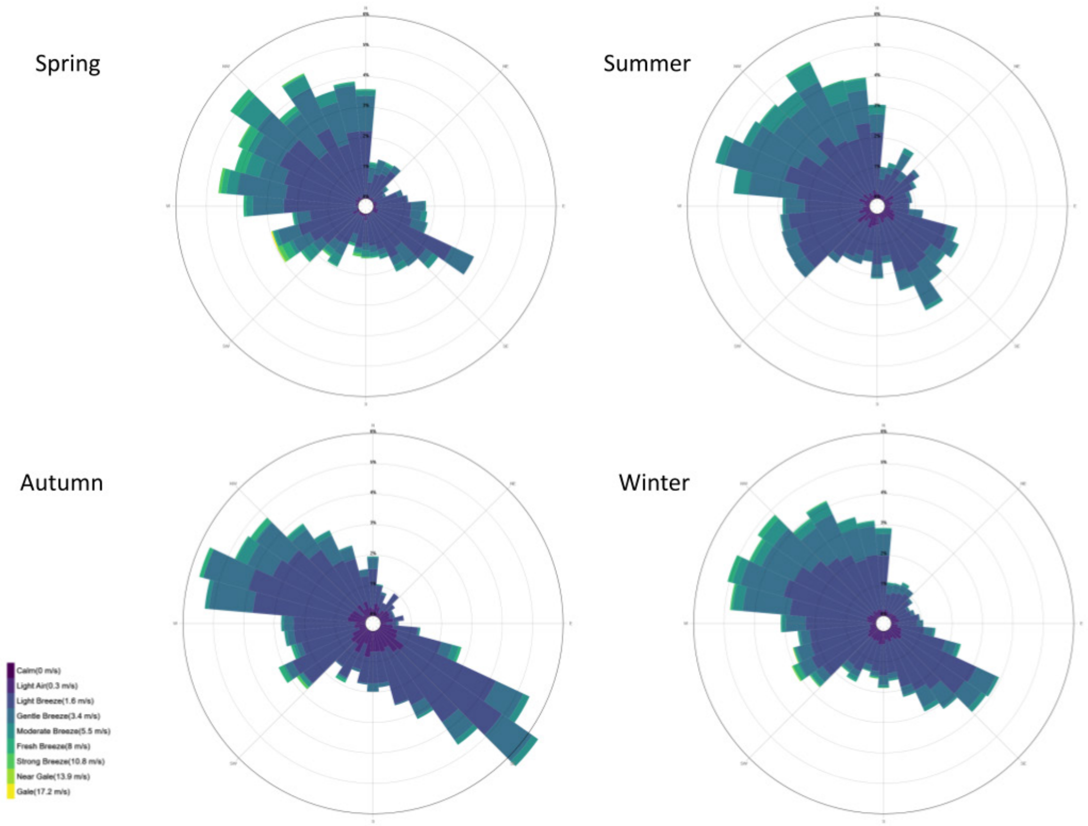
Psychrometric chart



Yazd's dry, hot climate requires the psychrometric chart. It emphasizes day-night temperature differences. The graphic can help architects and engineers create passive, low-carbon structures in such an environment. Designers can use passive techniques by considering air temperature, humidity, and evaporation cooling potential. Shading systems reduce direct solar heat gain, lowering building cooling loads on hot days. Passive evaporative cooling uses dry air to cool through evaporation, improving indoor comfort. Energy-efficient and sustainable building design can also use the steady ground temperature to cool during hot days and heat during cooler nights. Yazd structures can adapt to the harsh climate by incorporating these passive solutions from the psychrometric chart, reducing carbon emissions and providing comfort.

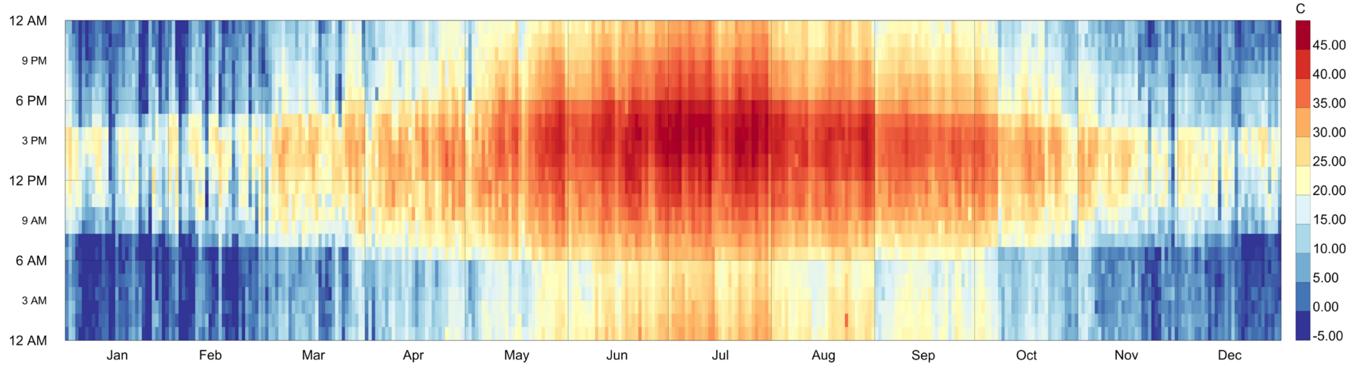
Yazd, Iran, known for its architecture, uses passive climatic solutions. During hot summers, historic windcatchers, or "badgirs," trap prevailing breezes to offer natural ventilation, while clever shading mechanisms keep buildings cool. Ancient buildings with thick earthen walls regulate temperature. The psychrometric chart helps design low-carbon buildings in Yazd's dry, hot climate with large day-to-night temperature fluctuations. Understanding the chart's insights allows passive tactics like evaporative cooling and steady ground temperature to create energy-efficient, sustainable building designs that respond to the city's demanding environment. Historical examples and psychrometric principles show how passive techniques might build resilient, climate-responsive structures for harsh regions.

Seasonal wind rose



Seasonal wind study in Yazd reveals various patterns that have a significant impact on the year-round climate of the city. Primarily originating from the west and northwest, springtime winds deliver a nice breeze and mild temperatures. As the temperature rises, hot, dry breezes from the west, north west, and occasionally the south east usher in summer. These summer winds exacerbate the dry conditions and contribute to the searing heat. As October approaches, the predominant winds will change from the north to the east and west, bringing relief from the heat and ushering in milder conditions. Winter sees a change in wind direction, with southeast and northeast winds predominating. These winter winds can bring milder temperatures, but they are still rather dry, keeping the city's environment arid even during the colder months. Understanding these seasonal wind patterns is essential for urban planning, architectural design, and energy-efficient measures in Yazd, allowing citizens to adapt and live in harmony with the city's year-round climate.

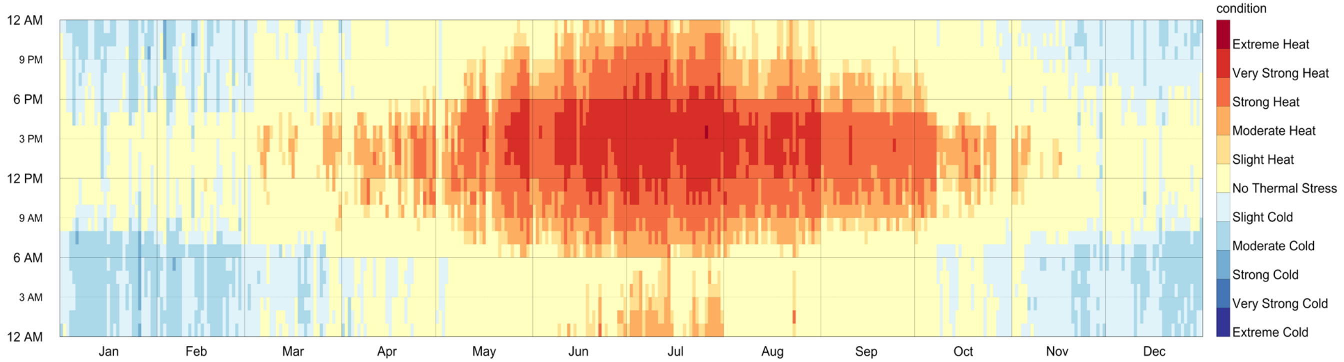
Sensible temperature



Universal Thermal Climate Index (C)
1/1 to 12/31 between 0 and 23 @1
city: Yazd.Sadooghi.Intl.AP
country: IRN
time-zone: 3.5
source: SRC-TMYx

The Universal Thermal Climate Index (UTCI) and sensible temperature are crucial for assessing the combined effects of temperature, humidity, wind, and radiation on the body. UTCI calculates the equivalent temperature people feel in specific environmental conditions. Air temperature, humidity, wind speed, and solar radiation determine thermal comfort or stress.
However, sensible temperature, also known as "feels-like" temperature, describes how the body perceives temperature when wind speed and humidity are considered. When air temperature doesn't match people's discomfort, sensible temperature is important. In windy conditions, body heat loss increases, making the air feel colder than measured. In humid conditions, the body's sweating ability is hindered, raising the perceived temperature.
UTCI and sensible temperature help assess extreme weather health risks. They help authorities issue heat advisories and warnings during hot and humid periods, helping the public avoid heat-related illnesses. These metrics help improve public health and safety in various climates by understanding the body's complex response to weather elements.
Radiation and dryness are crucial in Yazd, where the dry bulb temperature ranges from -3 to 43.5 C and the sensible heat from -23 to 46.

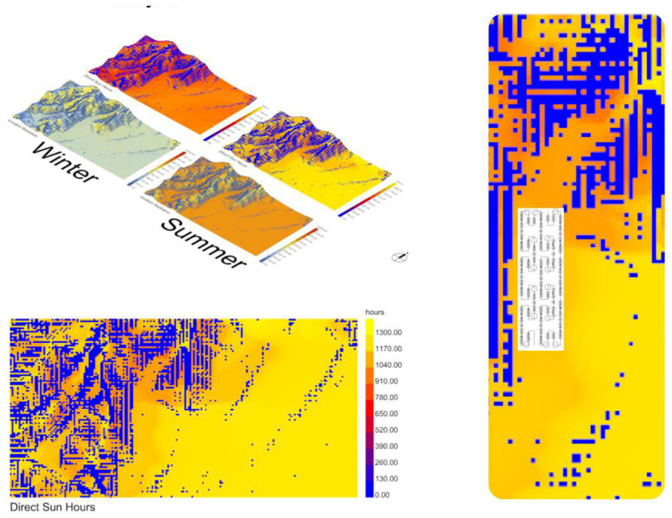
UTCI category



Thermal Condition Eleven Point (condition)
1/1 to 12/31 between 0 and 23 @1
city: Yazd.Sadooghi.Intl.AP
country: IRN
time-zone: 3.5
source: SRC-TMYx

The Universal Thermal Climate Index (UTCI) categories are useful for weather-based thermal stress assessment. Each UTCI category represents different degrees of thermal discomfort or stress on the body, from extreme cold to extreme heat. Protecting against hypothermia and frostbite is necessary in extreme cold. Cold and mild cold conditions indicate discomfort without adequate insulation or heating. Comfortable and slightly warm temperatures are ideal for most people. In warm and hot temperatures, heat stress can be moderate to severe, requiring cooling and hydration. Heat-related illnesses are common in very hot and extreme heat, necessitating immediate action. Public health authorities, urban planners, and disaster management agencies use the UTCI categories to understand and mitigate the effects of weather on human health and well-being. They also help people adapt to different thermal stress levels in different environments.

Daylight analysis



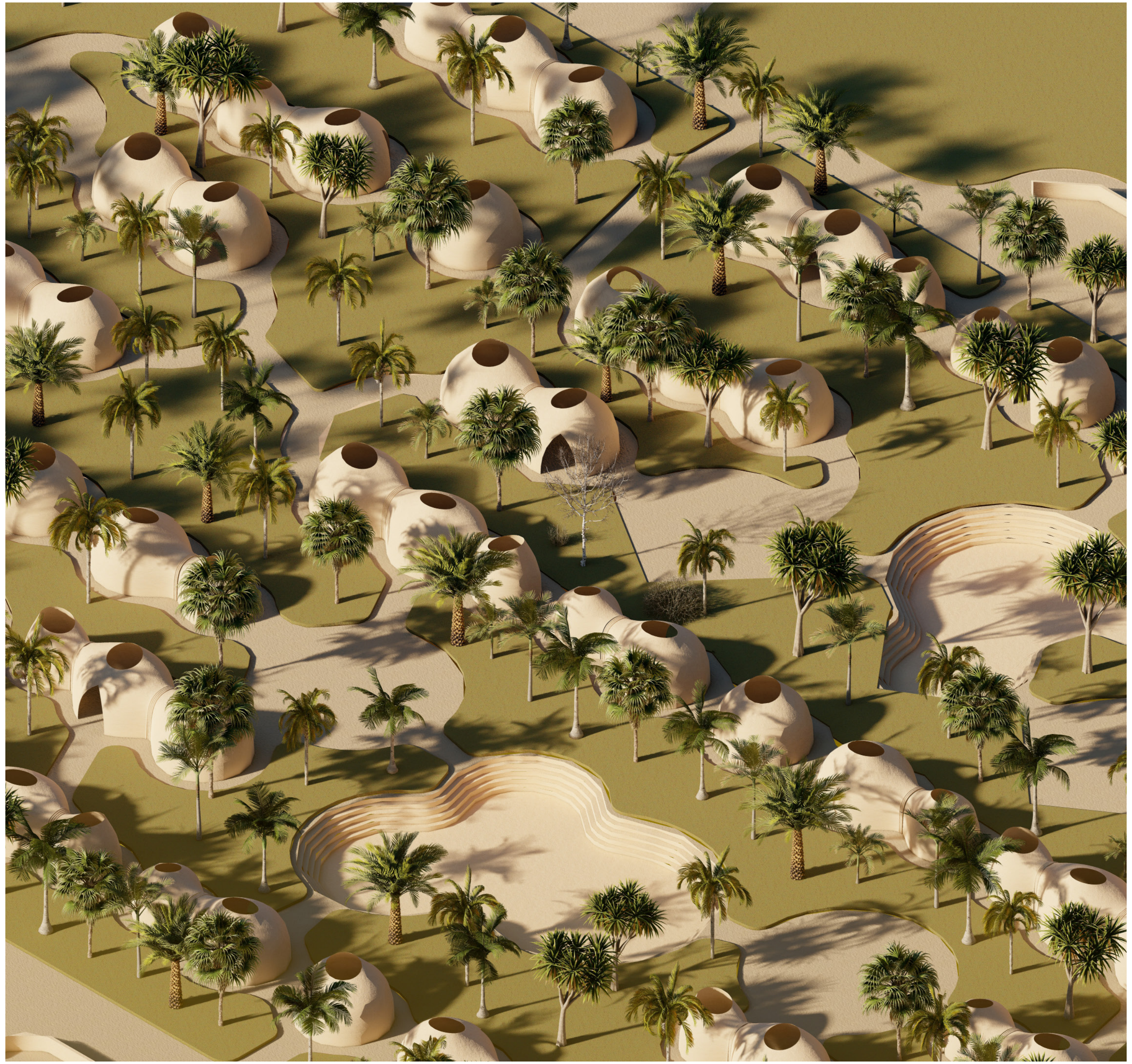
LEED merics and thresholds

1.Spatial Daylight Autonomy (sDA): The percentage of the regularly occupied floor area that is "daylit." In this context, "daylit" locations are those meeting target illuminance levels (300 lux) using daylight alone for at least 50% of occupied hours. Such locations are said to be 50% daylight autonomous. sDA calculations are based on annual, climate-based simulations of thousands of different sky conditions throughout the year. Per LM-83 guidelines, dynamic shading devices such as blinds or electrochromic glazings must be specified for all exterior window units.[1]

2.Annual Sunlight Exposure (ASE): The percentage of the regularly occupied floor area that is "overlit." In this context, "overlit" locations are those receiving direct sunlight (>1000 lux directly from the solar disc) for more than 250 occupied hours. LEED versions 4.0 and 4.1 differ in how strictly ASE limits are enforced. It is worth pointing out that ASE is calculated for the dynamic shading system fully opened all year, whereas sDA takes the operation of dynamic shading into account. This distinction can cause confusion, but is meant to encourage passive design strategies that minimize visual and thermal discomfort without relying on manual shade operation. In the displayed model, the static brise soleil were augmented to reduce ASE to acceptable levels. Another strategy might involve specifying automated blinds or electrochromic glazing systems, which trigger ASE exemptions for adjoining rooms. ASE values above 10% is not acceptable[1]

	Version 4.0	Version 4.1
sDA ≥ 40%	-	1 point
sDA ≥ 55%	2 points	2 points
sDA ≥ 75%	3 points	3 points

05 Landscape design



Landscape design design process :

The site of 3D printed eco-camp Locates in the middle of yazd province, in general the city has a hot and dry weather, but specificly on the site of design, we have some drastic winds from the east and forcible solarization from south. Before any design solution, we made sure that the site is covered by the hills on the west and north. Beside that we use the walls as wind breaker on the east edge of site plan. In addition, the plant pattern considered as a barrier in front of wind and sun, so the plants that are choosed for this project are tamarix aphylla and seidlitzia rosmarinus, wich are eco friendly and syntonic. The plants transplanted on the south edge and some area in the east side of the site. And last but not the least, the composition of the modules are done in four vicinage columns that make shades on each other.

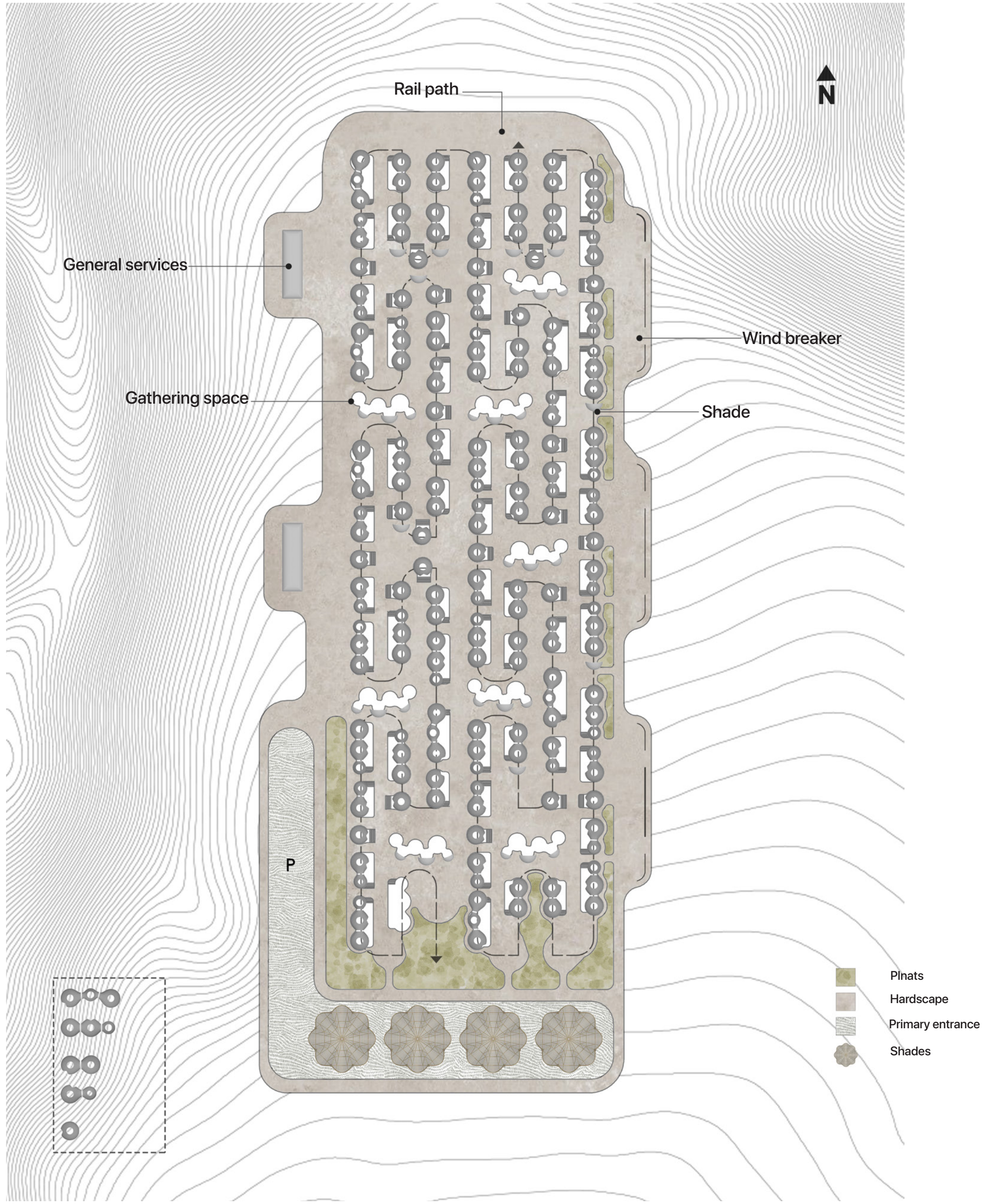
Plant pattern

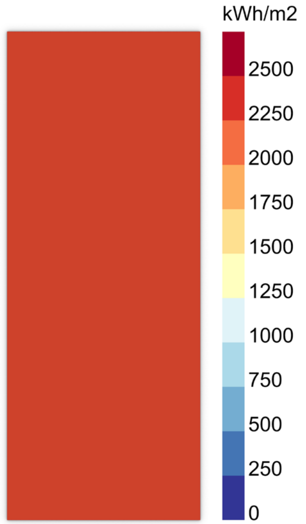
With an eye on the dryness of the central desert of the country, we decided to transplant two species of native plants of that area. The first plant is named tamarix aphylla and is indigene. There are researchs that show planting this species in a row with an optimum gap (7.5m) would takes a roll of a wind breaker.
It attains a height of 10-15m and may attain a diameter of 0.8m.
The second species is named seidlitzia rosmarinus and also is a native plant for the rigion. This plant grow up to 2m tall at maximum height and attains a diameter of 1.5m.

tamarix aphylla

seidlitzia rosmarinus

seidlitzia rosmarinus



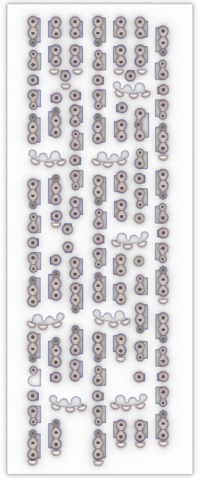


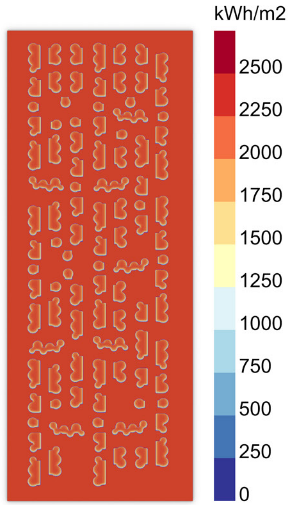
Incident Radiation

It can be concluded that the site receives about 2500 kWh/m2 in cumulative radiation. The psychrometric chart indicates that shading strategies are one of the most effective and impactful passive strategies in this climate zone.

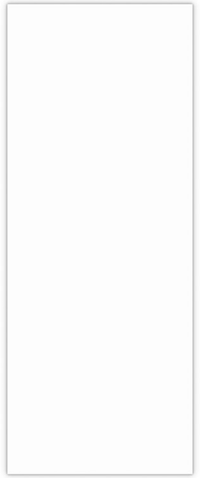
With excavation

It appears that the soil temperature will decrease by 1.5 C per metre when considering the temperature at various depths. Excavation is advantageous for both increasing the ground boundary condition and heat transfer with the ground, as well as creating shadows on site and outdoor gathering spaces. With attention to the limitations of the robot, the below concept was designed and evaluated.



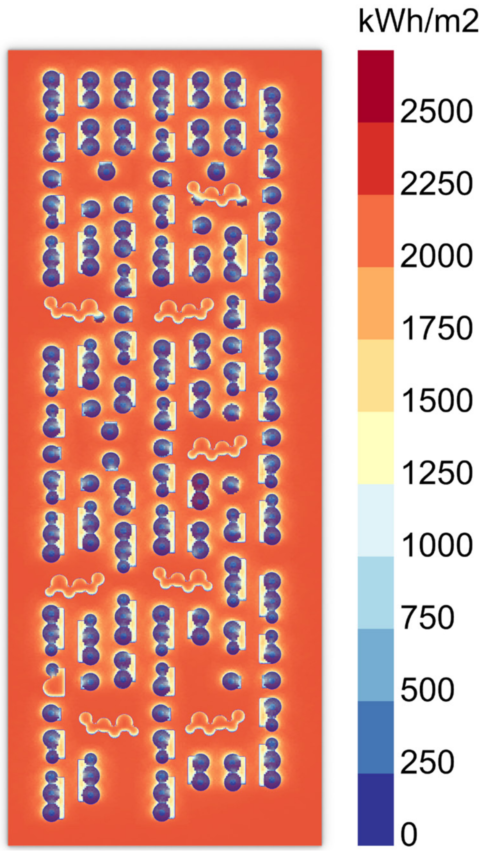


Incident Radiation

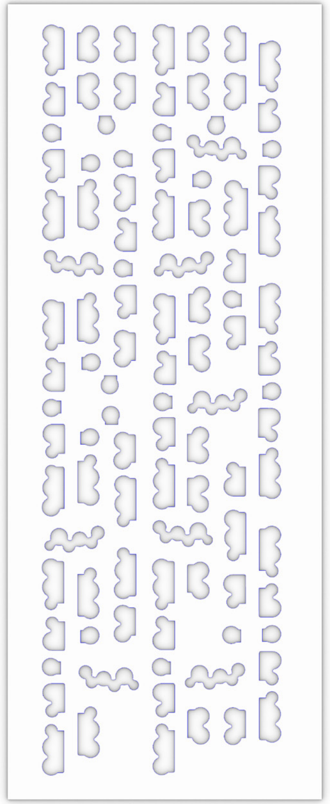


As shown in the top heatmap, excavation creates an opportunity to design and place modular and open spaces in the boundary of excavations that have lower radiation.
At the excavation boundary, the radiation amount was reduced from 2500 kWh/m2 to 1500kWh/m2.

With excavation and domes
The excavation was created based on the robot limitation and the dome placed on the boundary of excavation.



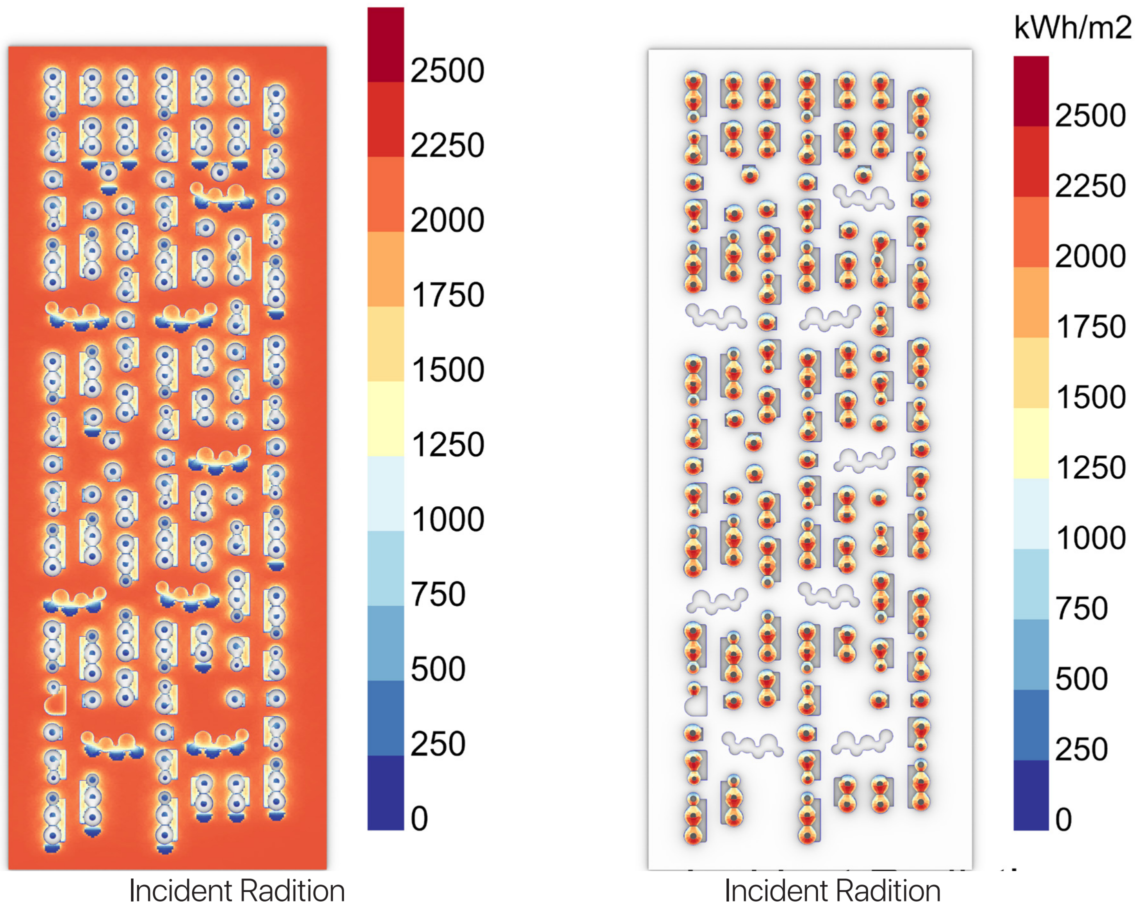
Incident Radition

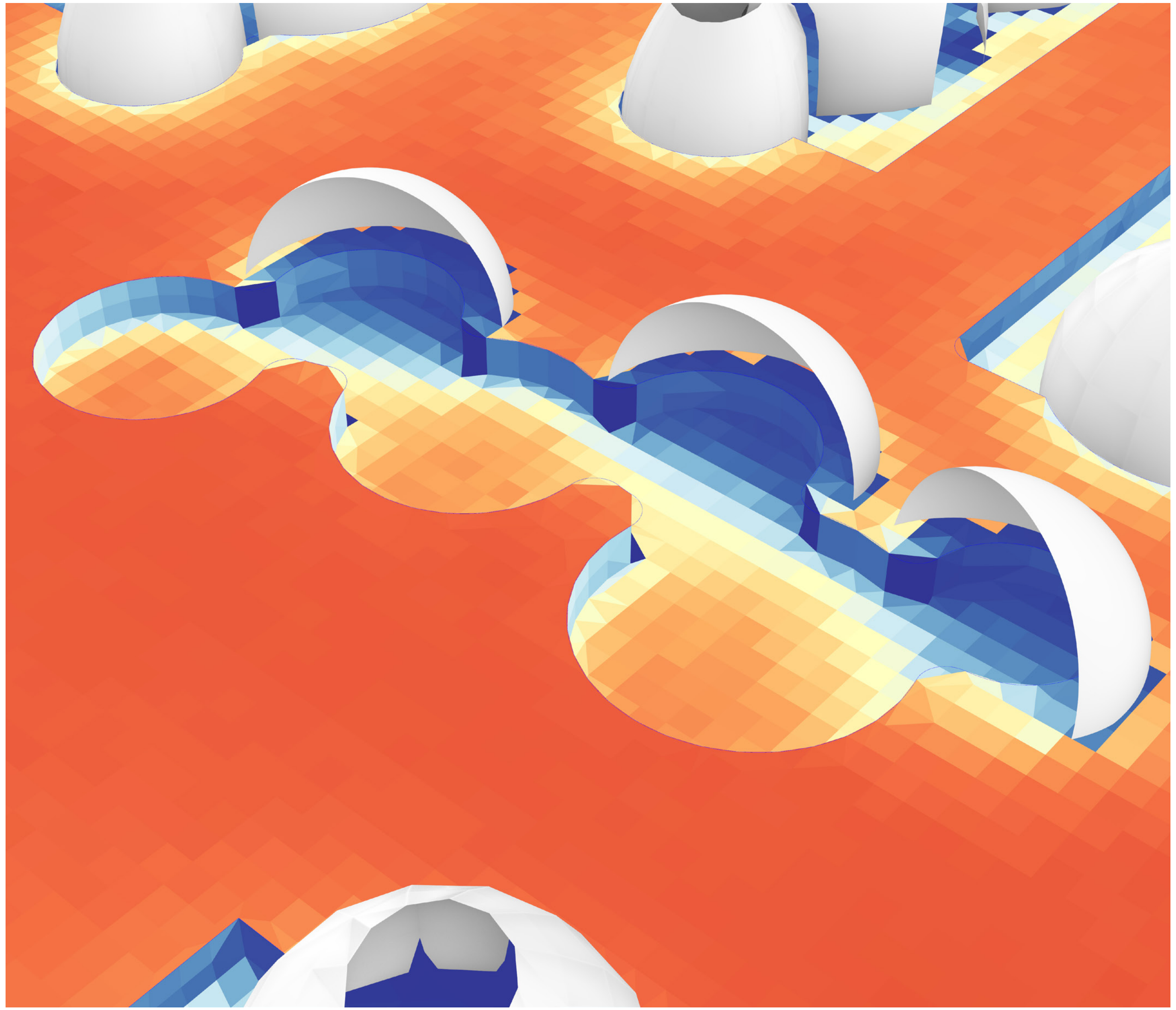


The radiation amount was reduced from 2500 kWh/m2 to 1500kWh/m2 at the excavation boundary.

Add semi domes

As the last step, to improve the shadow quality and shading device expansion, some semi domes were added as site objects. These objects improve the outdoor comfort for gathering open spaces and also can create shadow on the domes.

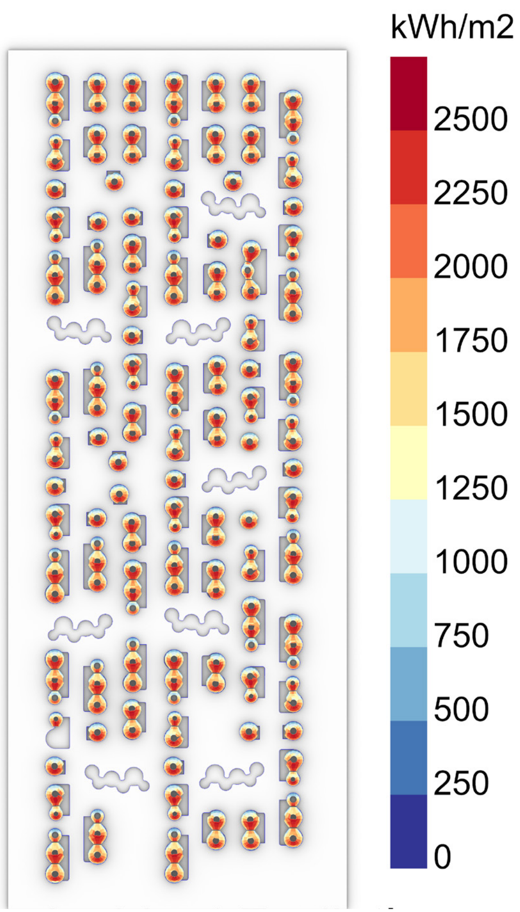




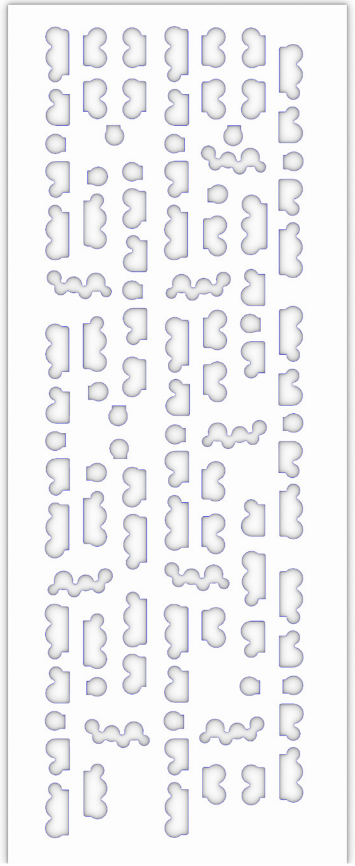
The semi domes can improve the shading of areas on excavation.

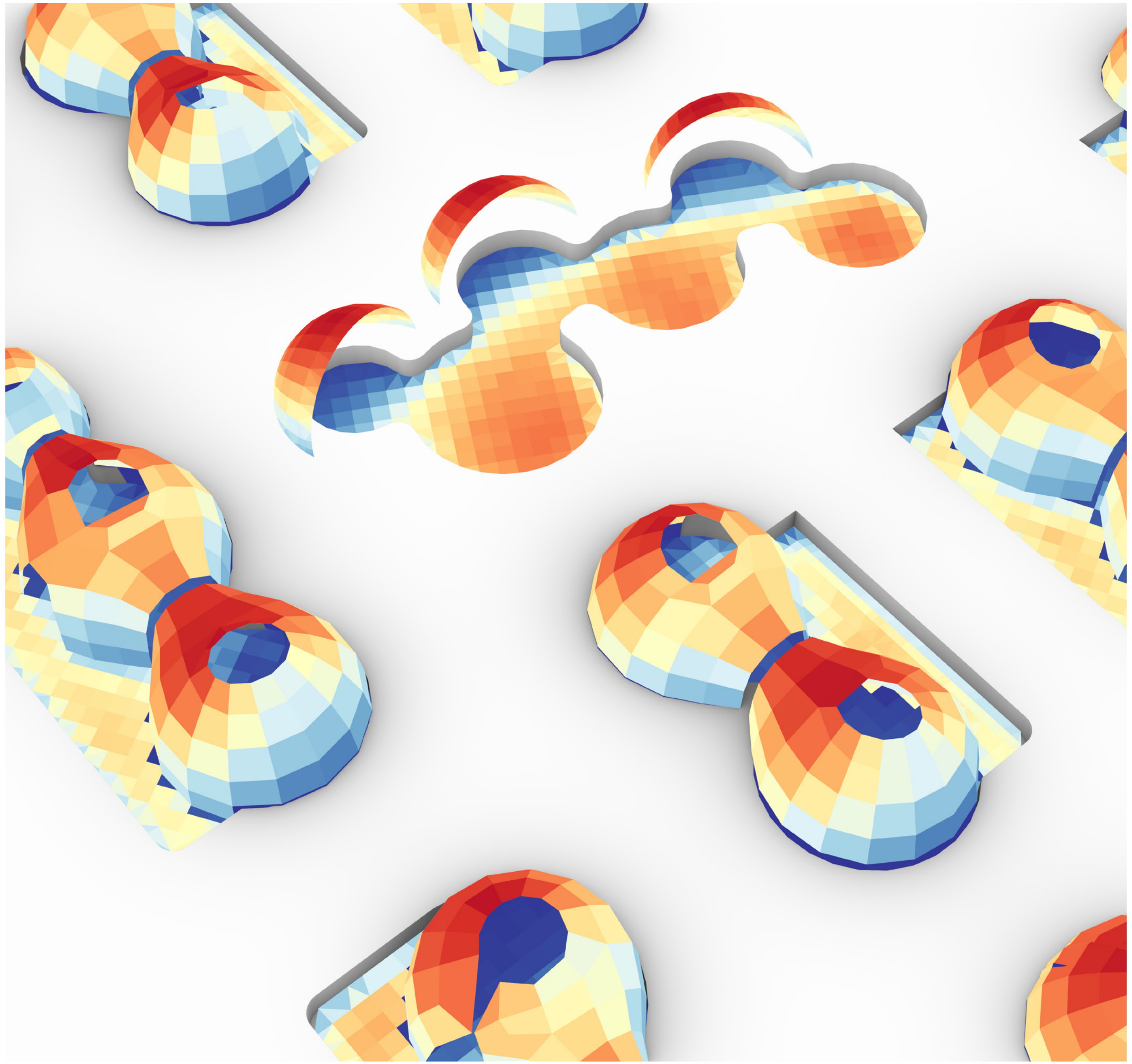
Radiation on domes

The form of domes is really useful in hot harsh climates. In the other hand, caly as a accessible material has no embodied carbon. So with modeling the domes and analysis radiation, these claims could be approved

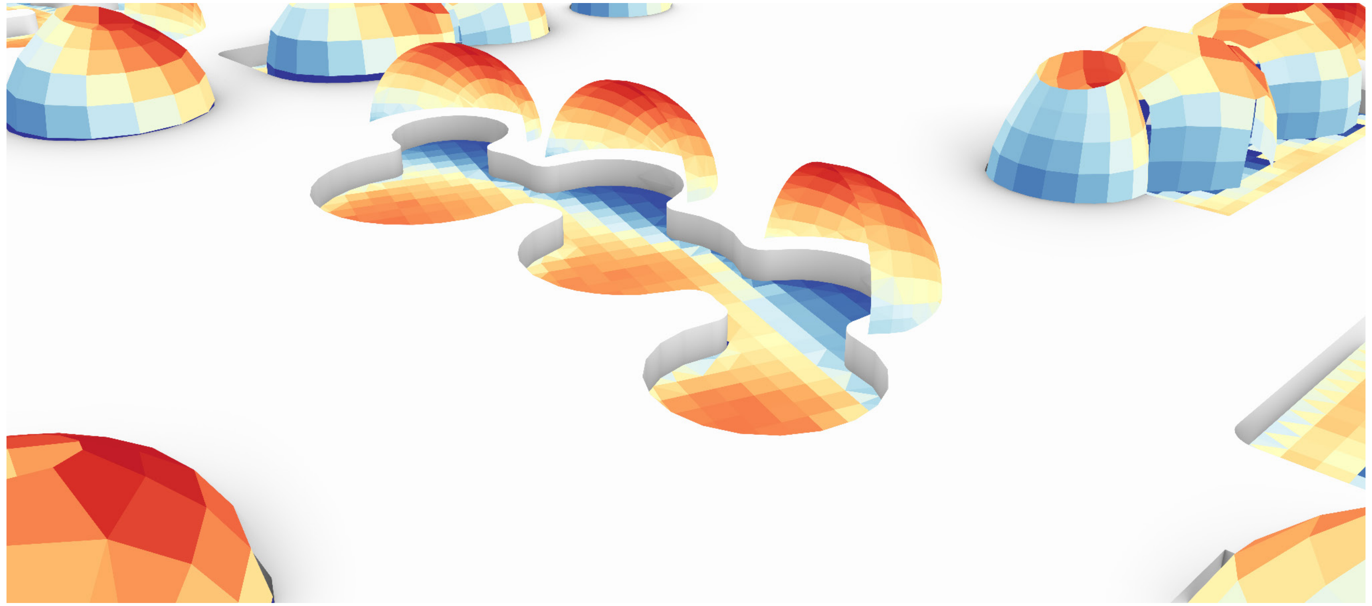


Incident Radition

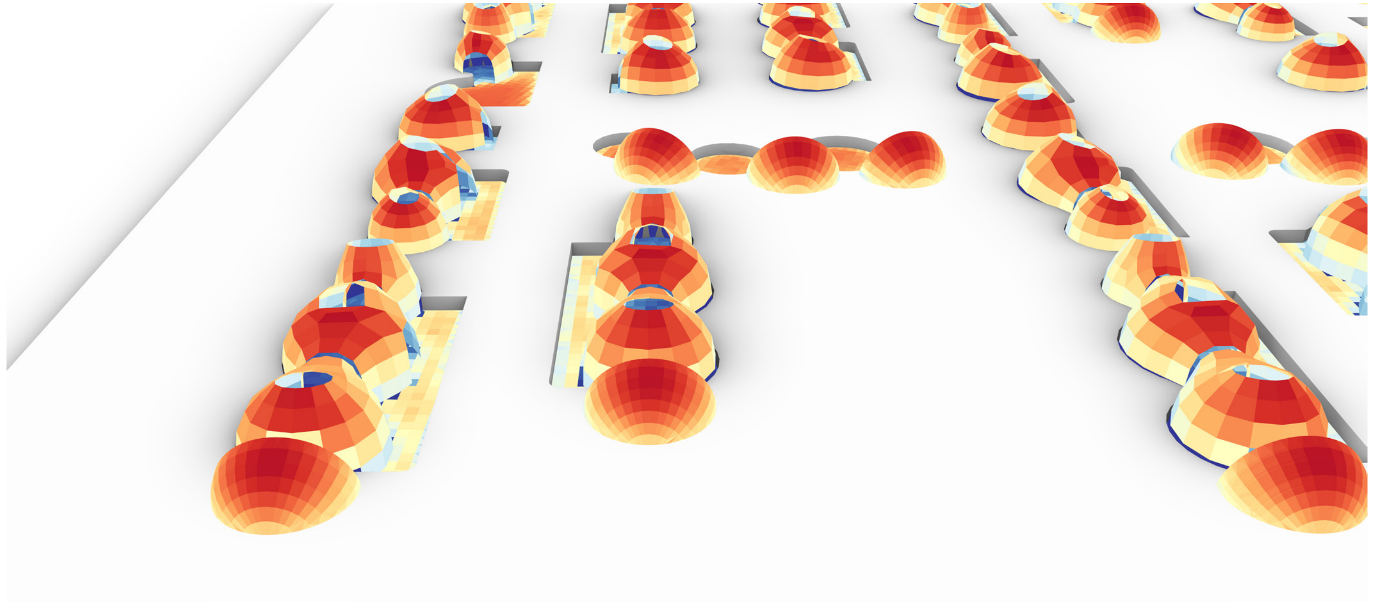




Placing units at the edge of the excavation



Impact of semi-domes on excavation and outdoor gathering spaces



South radiation on domes and semi-domes

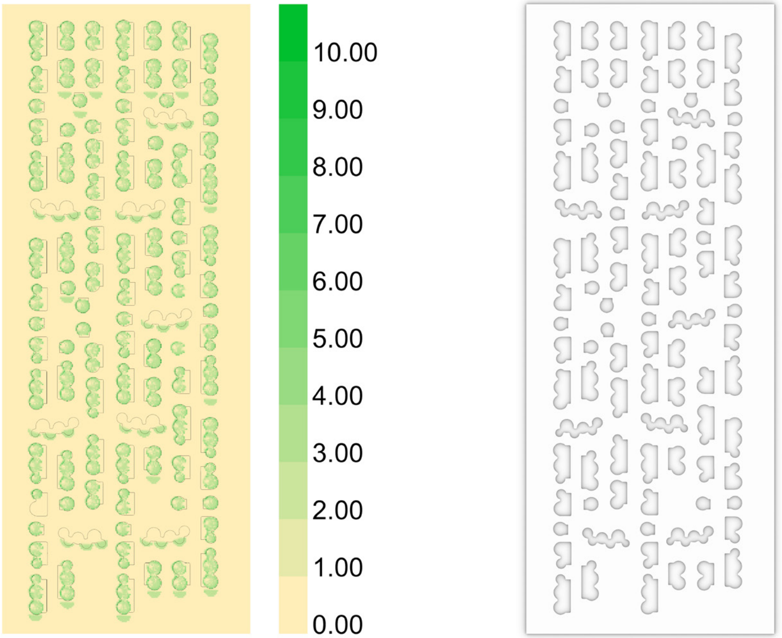
Outdoor comfort

The Universal Thermal Climate Index (UTCI) is a thermal comfort index used for evaluating outdoor thermal comfort. The equivalent temperature (°C) measures the human physiological response to meteorological conditions such as atmospheric temperature, humidity, wind speed, and solar radiation. UTCI takes into account the population's clothing adjustments in response to the outdoor climate.
For determining the likelihood of heat stress and cold stress in outdoor environments, the UTCI is a useful tool. It can also be used to plan outdoor activities and design comfortable outdoor spaces for individuals of all ages and activity levels.

The UTCI is a relatively new thermal comfort index, but it has been shown to accurately predict the thermal comfort of humans in a variety of outdoor environments. Researchers and practitioners around the world are currently employing it to increase knowledge of outdoor thermal comfort and promote human health and well-being.

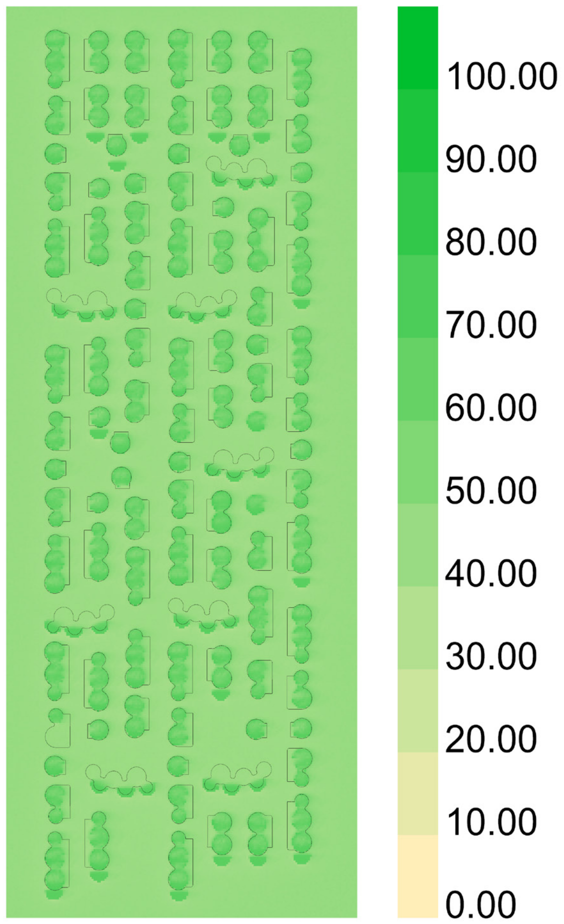
The UTCI is a more precise predictor of human thermal comfort than indices like the PMV and PPD The UTCI can be used to evaluate the thermal comfort of individuals of any age or level of activity. The UTCI can be used to plan outdoor activities and design comfortable outdoor spaces for people of all ages and levels of activity. The UTCI is a valuable instrument for evaluating the potential for heat and cold stress in outdoor environments.

The outdoor comfort is evaluated in the winter for 3 months, the summer for 3 months, and the moderates.

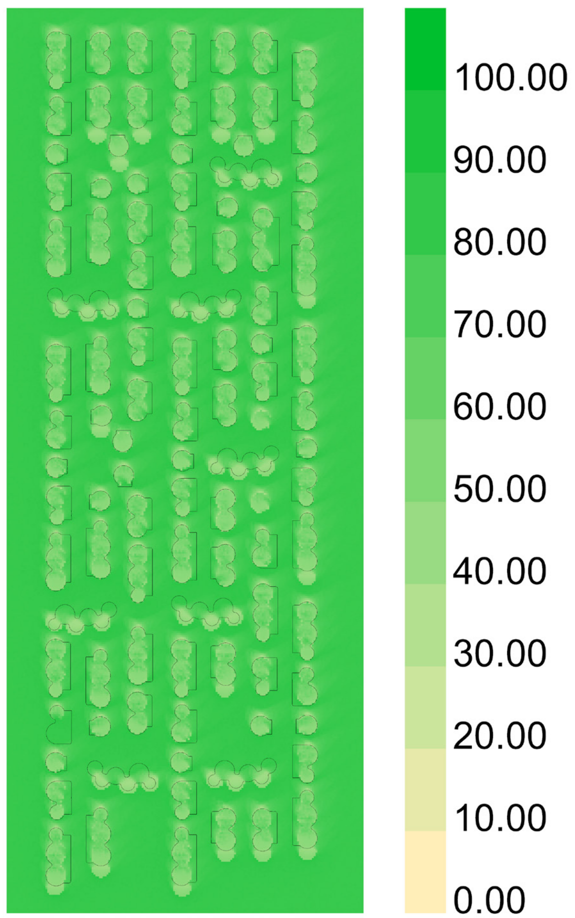


UTCI in summer

As could be predicted, in the summer this climate is too harsh, and using these strategies could improve the situation. So staying in units or designated semi-open spaces could improve outdoor thermal comfort.

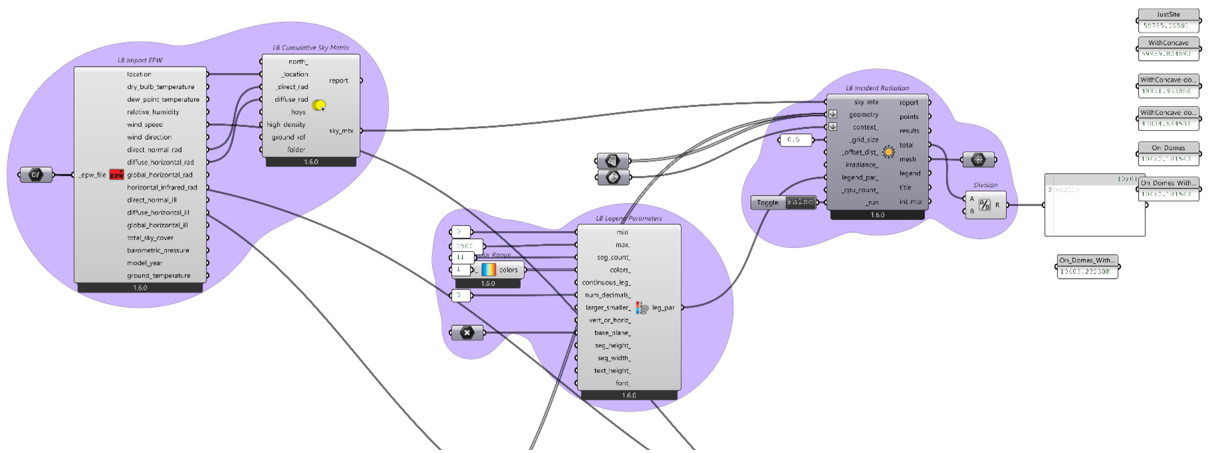


UTCI in winter

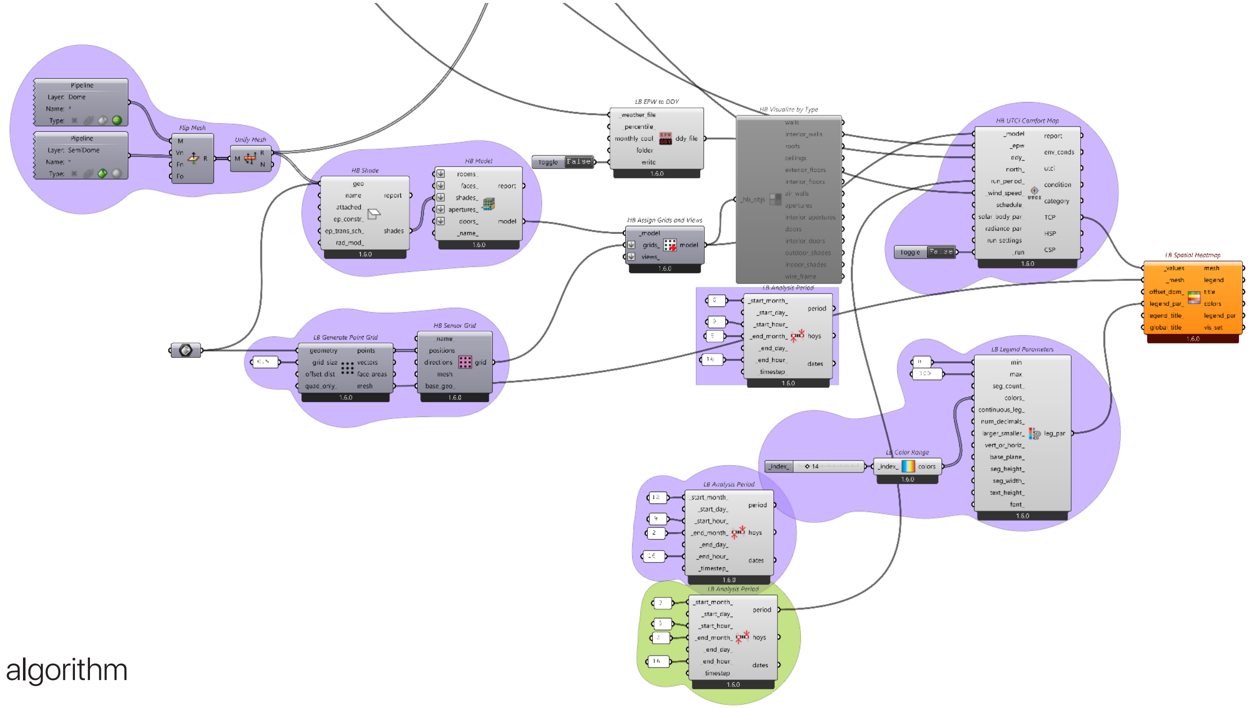


UTCI in moderates

In the winter, these semi-open spaces could conserve heat during the day and give it back to the environment at night. So these ideas also work in the winter.
In the moderates (spring and autumn), the UTCI is provided and no critical issues exist in these times.



Radiation Algorithm



UTCI algorithm