Ministry of Tolerance and Coexistence

Tolerance Without Borders Initiative (TWB) in partnership with Sandooq Al Watan

Project Title:
Sahra Sphere - A sustainable agricultural practice in arid and semi-arid regions of the world

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Abstract

This research report underscores the significance of biomimicry and its potential to address critical global issues. The study focuses on the challenges of water and food scarcity in arid and semi-arid regions, and the lack of sustainable agricultural practices. Inhabitants of these regions often resort to high-energy consumption lifestyles, including importing food and resources, and using substantial amounts of electricity for crop production. Given the limited arable land, sustainable water supplies, and access to organic food, these communities endure substandard living conditions. This research proposes an alternative solution by employing the 'Biomimicry design spiral' to engineer a greenhouse aimed at providing a sustainable food production practice.

Objective

General Objective

- To investigate innovative and sustainable food production methods in arid and semi-arid regions, emphasizing minimal water usage.

Specific Objective

- To examine strategies to mitigate water wastage caused by elevated temperatures during food production
- To explore environmentally friendly alternatives to air conditioning systems in farmhouses to decrease carbon emissions.
- To identify efficient spatial utilization techniques in food production to minimize water, nutrient, and energy wastage.

Introduction

Arid regions are marked by a scarcity of water and food. The size of arable land is diminishing due to climate change, overuse, and nutrient depletion, leading to diminished living conditions for people in arid and semi-arid regions. Current solutions such as open field farming and low-tech greenhouses, while helpful, are often unsustainable, unsafe, and labor-intensive. Many countries, including the UAE (United Arab Emirates), are seeking alternative approaches, as indicated by initiatives such as Abu Dhabi's Masdar city and Masdar Farm, which serve as hubs for sustainable and reliable technologies and innovations.

Water Scarcity

The UN reports that the Middle East and North Africa (MENA) regions have the lowest freshwater availability per capita, at around 1200 cubic meters (about half the volume of an Olympic-size swimming pool) per person per year, which is below the scarcity threshold of 1700 cubic meters per person per year. Agriculture accounts for 85% of freshwater use in the MENA regions.

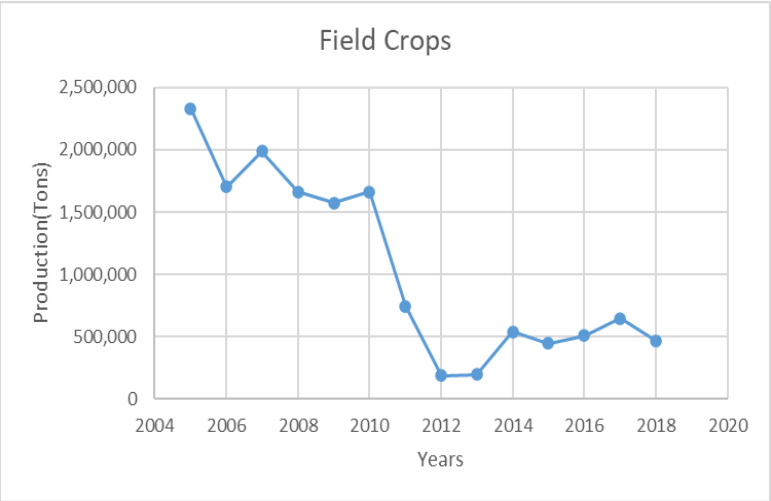
Food Scarcity

Desertification affects 70% of the Middle East's arable land, threatening agricultural production and food security. Additionally, extreme weather events due to global warming have impacted crop yield in these regions.

Water scarcity and food insecurity obliged the MENA regions to import substantial amounts of agricultural commodities and water from abroad. It is stated by the world bank that around 50% of grains consumed in these regions are imported. While globalization encouraged counties to completely rely on commodities produced in other countries, rarely are such commodities as essential as food. It cannot be assumed that the MENA regions can go on importing food and water forever, hence they must search for alternatives that could sustain them in the long run

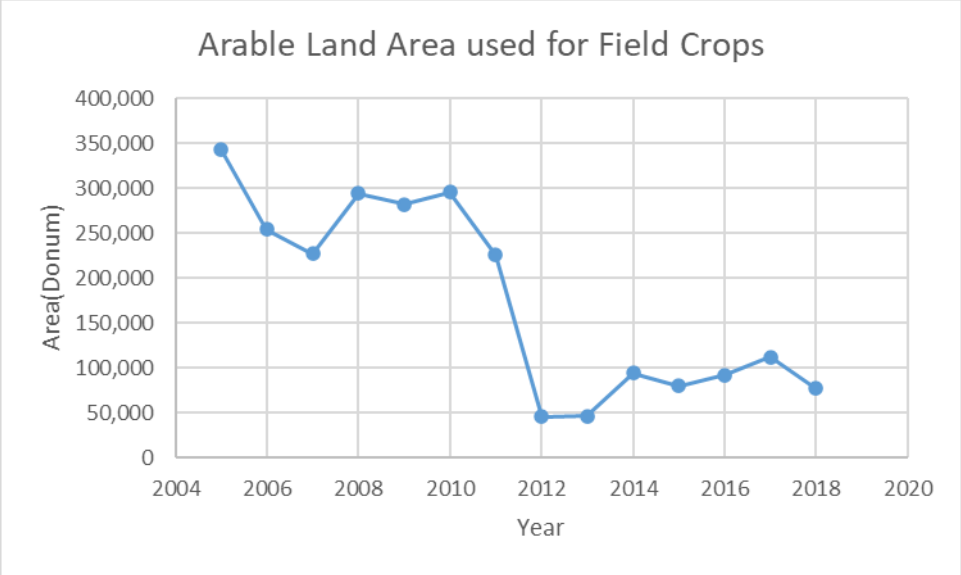
In our research findings, we identified three key areas to focus on for food production in these regions:

- Water conservation
- Adaptation to extreme temperatures
- Addressing the lack of arable land



This graph (1.1) here shows the rapid decrease in the field crops produced locally in UAE over 13 years (2005–2018). This tremendous decrease in the production capabilities of crops in UAE is primarily due to water scarcity and loss of Arable land due to global warming as shown in graph 1.2 below.

Graph 1.1 (Based on Data extracted from Bayanat.ae website for open data sources in UAE)



Graph 1.2 Arable land Area used for field crops per year shows a decrease by rate of 12.8% per year.

To address these points, the team decided to use the biomimicry design spiral, a concept coined by Janine Bayus, which refers to innovation inspired by nature.

Defining the problem

We narrowed down the problem into 2 statements that can accurately define the issue we are attempting to solve.

- “How might we improve living conditions in arid and semi-arid regions using a sustainable alternative to food production?”
- “How do we create a new sustainable agricultural practice to tackle issues of food and water scarcity in arid and semi-arid regions?”

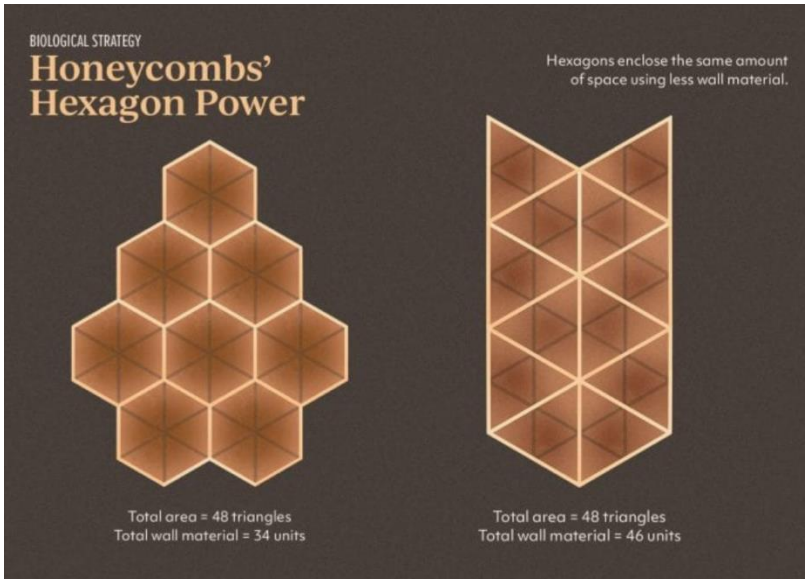
In the next step we biologized and investigated the nature around us and rewrote the 3 key points to investigate as the biological statements below:

1. How does nature adapt to extreme temperatures?
2. How does nature use and conserve space?
3. How does nature cycle water?

Biological Strategies

How do living organism in arid regions Survive elevated temperatures?
Living organisms in arid and semi-arid regions exhibit extreme resilience to elevated temperatures and unfavorable conditions by burrowing. Burrowing is a behavior where animals dig holes or excavate tunnels underground to escape extreme heat and cool down their bodies. Since the temperature underground is lower than outside, it acts as a cool refuge from the extreme weather. Examples of burrowing animals include moles, voles, weasels, rats etc.

How do Honeybees conserve space?
Honeybee comb is hexagonal in shape. It is used to store honey and larvae. Thomas Hales, a Mathematician who devoted his life to studying discrete geometry and space conservation in honeybee combs, tells us that the hexagonal shape of the comb is the most space conserving shape in nature. In fact, the structure can be up to 6 times more efficient than other shapes. In addition, hexagonal structures require less material to build while retaining a high strength to weight ratio.



How do organisms get water in arid regions?

a) In the Namib Desert, darkling beetles employ unique wing covers and body positions to condense water from humid air. Microscopic grooves or bumps on their forewings collect and direct water toward their mouths. These hydrophilic and hydrophobic features enhance their effectiveness in harvesting fog and dew.
b) In cloud forests, trees adapt to the dry season by directly absorbing water from clouds through their leaves. This condensed moisture is subsequently taken up by the tree's branches, stem, and roots.
c) Rosette succulents employ their smooth, waxy leaves to capture water droplets from fog. The combination of their leaf surface area and waxy coating effectively traps fog droplets, guiding them along the leaf's surface for absorption.
d) Geophytes show distinctive leaf shapes that help collect water from dew and fog. When cooler surfaces intersect with humid air, water vapor condenses into droplets. Geophytes cool during the night, releasing heat and promoting dew formation on their leaves. Their specialized features, such as curls and fine hairs, enhance heat dissipation, thereby aiding in water accumulation.

One common point that the three systems have is that they all require creation of temperature difference across a high surface area.

Biological Solutions

Closed loop Cooling

Using the concept of burrowing, we devised a mechanism to enhance greenhouse cooling. The closed-loop cooling system works by biomimicking the concept of burrowing in animals. Water compartments are buried deep underground (2 to 3 meters deep), and hot water from the building travels through tubes to the underground compartments. When the hot water flows to the loop underground, the heat is dissipated out of the tubes, cooling the water, which then flows back into the house. The now cool water loops around the greenhouse absorbing the heat and, in the process, cools down the greenhouse. The process then repeats. Existing systems that resemble our proposed ideas include geothermal cooling and heating that small scale houses use in cold regions of the world. The system used the same concept of burrowing. However, the borrowing is done a few meters away from the house but in our structure, we placed it directly below it. In addition, our system is made solely to keep the greenhouse at a cool stable temperature.

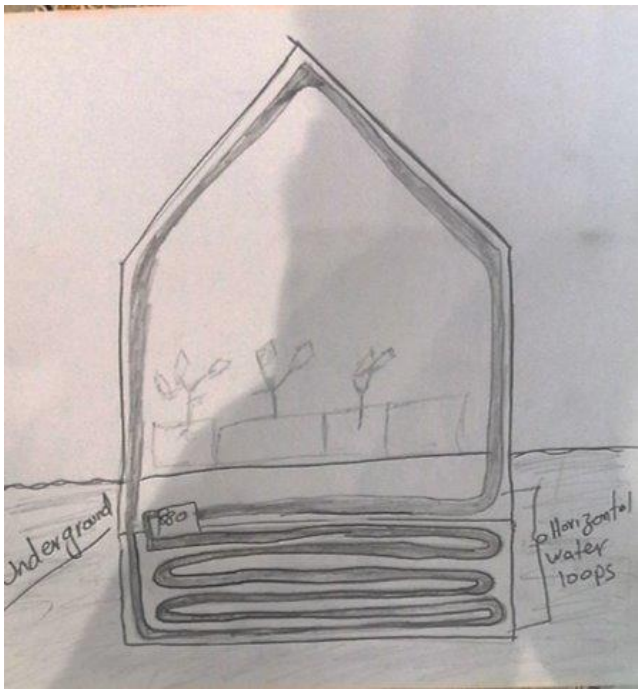
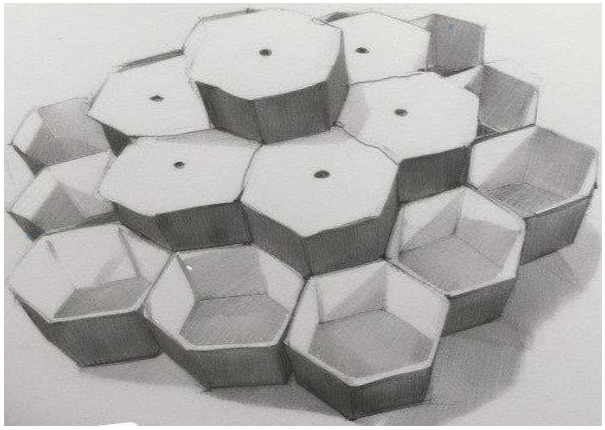


Fig) Hand Drawn concept of a closed loop cooling system

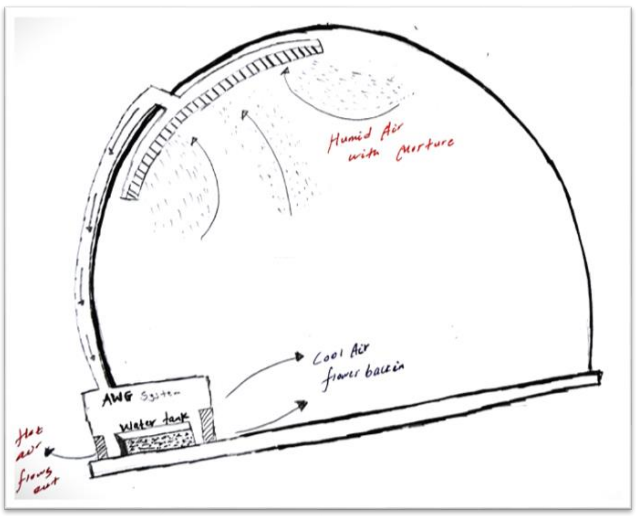
Honeycomb Pod

The efficient space and material usage of the honeycomb can be introduced to the working of hydroponics. This can be achieved by creating a hexagonal cylinder, arranging them from top to bottom in a triangular pyramid for water and nutrient movement, and leaving the middle empty for a water tank. There are lots of structures that are made to mimic the honeycomb but unlike our design, these structures do not utilize a pyramidal shape for maximum horizontal and vertical space. (Below is a hand sketch of the pods)



Atmospheric water generation

To generate water from air, we can use cooling condensation of vapor that is in the air and by mimicking the Namib desert beetle. We can achieve this by creating a temperature difference, setting a high surface area for absorption, and supplying and circulating humid air through our device. Usually, these devices are used to collect humidity from the outside surrounding and form water from thin air, but the amount of energy they use, the installation is too expensive and requires huge land which is scarce in arid areas. Hence, our design proposes to convert the humidity released from the plants inside the greenhouse and recycle it.(Below is a hand sketch of the concept)



→ **AWG Building Process Highlights**

We are proposing a work around the problems we face and tried to come up with efficient design that works.

- Use of air vents that are placed in accordingly matter so that they supply enough air to AWG (atmospheric water generation) device. This can be done using a system of fans.
- Applying the new and improved concepts of vapor condensation.
- Energy Efficiency- Use of sustainable power source for the working of AWGS. Using power sources like solar energy is crucial. Consider the most efficient way of creating temperature difference needed.
- Cost Reduction – reducing the cost of production by using recycled materials such as recycled metal, recycled plastic and recycled electronic components.
- Optimization – optimizing the AWGS for the environment intended to work.
- Scalability and future implementation – applying the concept from small scale individual household to large scale farming.
- Maintenance and Durability – device that is robust and has a longer lifespan.
- Zero Environmental Impact – minimum waste and emissions.

Review of related projects

The geodesic domes of the Eden Project, inspired by James T. Baldwin's Pillow Dome, stand as architectural marvels blending innovation and biomimicry. Mimicking the efficiency of natural structures, these domes create self-supporting, spacious enclosures that emulate diverse biomes. Constructed with steel frames and thermoplastic, they house thousands of plant species within ethylene tetrafluoroethylene (ETFE) inflated cells. Through biomimicry, the Eden Project's design harnesses nature's principles to create sustainable habitats, fostering biodiversity while showcasing the intricate beauty of ecosystems. (Eden project 2024)

The ascent of geothermal heating and cooling systems in the United Arab Emirates underscores a pivotal transition towards sustainable HVAC solutions, with a legacy spanning over five decades. Witnessing a surge in demand for geothermal HVAC components in 2022, this trend signifies a profound embrace of eco-friendly alternatives. Unlike conventional systems, geothermal HVAC systems seamlessly integrate with nature, offering unparalleled heating and cooling capacities devoid of fossil fuel reliance or greenhouse gas emissions. Notably, during scorching summers, these systems excel in extracting heat from indoor air. By utilizing internal heat pumps, they efficiently remove heat from homes, leaving behind refreshing coolness circulated through vents. Furthermore, the extracted heat is effectively dissipated into the Earth through the ground loop, ensuring a sustainable and efficient cooling process. The UAE's embrace of geothermal technology epitomizes a steadfast commitment to cost-effectiveness, ecological stewardship, and energy efficiency in space conditioning systems. (Al Imraan UAE, .n.d)

Final Design (Prototypes)

In the final prototype model for the greenhouse, we used:

- Cardboard base
- 3D printed hexagonal pods
- Plastic Dome
- Water pipes
- ESP 32 controller
- Humidity sensor
- Temperature sensor
- Arduino uno
- LED
- Water pump
- Batteries
- Small Solar panels

Building Procedure of the Prototype

- ✓ The base
  - Cylinder is made of Cardboard with radius of 48 cm
  - Height of 10cm
- ✓ Upper dome – plastic dome of radius 43 cm
- ✓ Closed loop system –tubes, pumps, and batteries
- ✓ Hydroponic pods - Cardboard with 6 sides of dimensions (Side x Height):
  - Smaller pod (19 pcs) - 3.5 x 5 cm
  - bigger pod - (18 pcs) - 3.5 x 7.5 cm -
  - The combined structure has dimensions – 45 cm width and 20 cm height
- ✓ Solar panels that are mounted to the top side of the dome

Below you will find the images of the components.

Atmospheric Water Generation System Prototype

A design that is well built around the Sahara Sphere. Adopts the design strategy that is mentioned in biological solution stages.
The system is modular and can be fitted anywhere. The dimension of the AWGS prototype is **26cm length, 8cm width, 15cm height**
The prototype contains the following components:

- A thermoelectric Peltier (X1)
- Heat sink (X2)– large and Small
- Fan Module (X2) - large and small

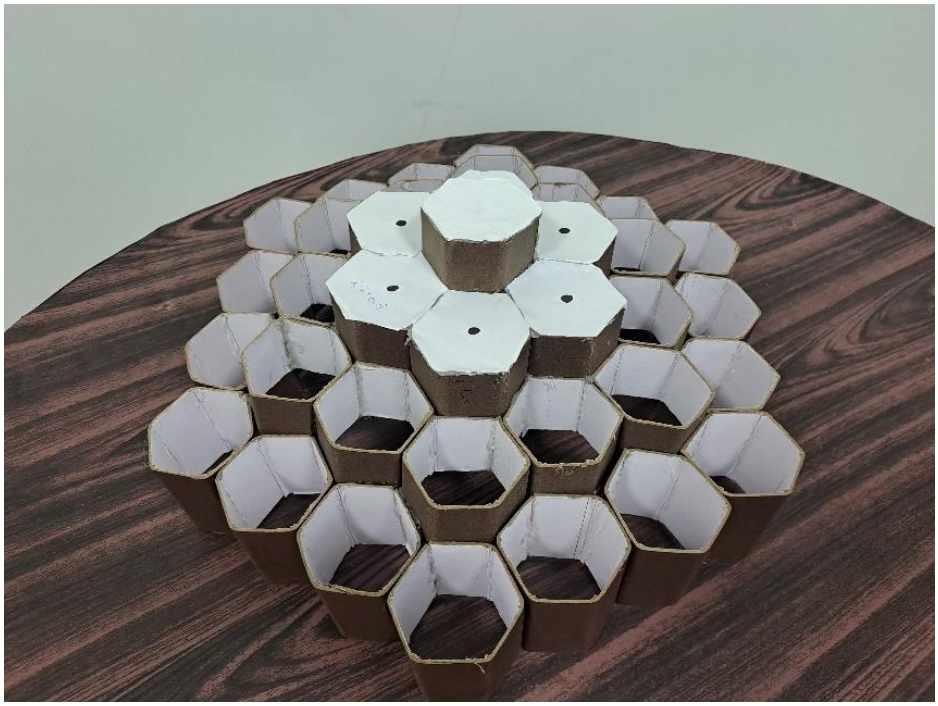




Closed Loop cooling system



Honeycomb Pod



Final Look



Final Design (Actual architecture)

- The final design is a large geodesic dome made of preferably 8mm thick Poly carbonate Panels due to their high R and low L values (measures of energy performance of a window) but these materials can be substituted by any other sustainable material. Spraying this with a coating made of bicarbonate material will help block 70% of the sunlight from getting in. The outer design utilizes geodesic dome architecture, which has several real-world proven advantages: high structural to weight ratio, aerodynamic resilience to high winds, lightweight, uses less material to build, and can provide passive ventilation due to its shape promoting natural airflow.

- The inside is covered with water tubes made of copper looping the dome. The tubes are part of the closed loop cooling system that ensures the internal of the dome is always at optimal temperature for the crops to grow. The closed-loop cooling system is buried at a depth of at least 2 to 3 meters. This system provides the primary cooling system for the greenhouse. This system can last decades without facing any significant issues. To make it even more sustainable, the system can run purely on solar energy.

- Inspired by the honeycomb structure, inside the massive dome resides a unique architectural structure (referred to as “Hydroponic pods”) made from ferrocement or other sustainable materials. The structure is built in a pyramidal shape with a single comb structure at the top and stairs to allow access to the pods. This design has several advantages: the comb (hexagonal structure) alone has huge space optimization benefits but combining it with a pyramidal design can produce maximal vertical space with a minimal footprint on the ground, help produce more plants in less space, material usage efficiency, high strength to weight ratio, and constructional efficiency.

- At the bottom of the dome structure, there are open slots where humid air escapes into and then captured by a thermoelectric dehumidification system. This system takes the humid air, cools it down, and collects the moisture which acts as a secondary water source for the plants.

Project's Sustainability

Being part of a country that is working to achieve the United Nations sustainability development goals, we wanted to contribute a small share to the cause. We were motivated to think of ways to utilize sustainable building materials like recyclable plastic and waste. The materials include:

- Ferrocement
- Polycarbonate panels
- Bicarbonate sprays
- Aluminum foil tapes

In addition to using sustainable materials, we plan to harness renewable energy sources to reduce the carbon footprint in our surroundings.
Using renewable source of energy for Sahras sphere will have a positive impact on environment. Solar panels can be placed on the exterior to harvest enough energy for the green house.

Commercial Aspect of the solution

The commercial aspect of our solution is crucial to ensure its sustainability and viability. While our primary aim is to establish a sustainable agricultural practice, we recognize the importance of considering the three pillars of sustainability: "Equality" to ensure fair treatment for all, "Environment" to protect the planet, and "Economy" to assess the economic impact.

To address this, we have developed a strategy to commercialize each hydroponic pod. These pods can be leased to farmers or families, providing them with access to sustainable agricultural resources. This approach not only promotes economic viability but also facilitates equal opportunity and contributes to environmental preservation.

The income generated from renting out the greenhouse can cover its operational expenses, repair costs for any damages, and wages for workers. This arrangement benefits both parties: it provides food for families (profit for the farmer) while also ensuring that the greenhouse remains operational and functional.

Conclusion

The combination of all these systems complements each other in a way that biomimics the real-world ecosystem. Water is recycled and reused constantly, tackling the water scarcity problem. Building this requires less space but it can provide more food, unlike other alternatives. The system is also resilient to extreme temperatures that characterize the arid and semi-arid regions. Additionally, the system is sustainable with a decades-long lifespan.

Sustainability Goals

Our solution aligns with various UN sustainability goals including

- Achieving Zero hunger,
- Affordable and clean energy and,
- Sustainable cities and communities.

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