# Greenhouse for Partial Gravity Systems & Architecture

Mahsa Esfandabadi

American Institute of Aeronautics and Astronautics
Los Angeles - Las Vegas Section

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AIAA Los Angeles - Las Vegas
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## Education

- Master of Science in Aerospace Architecture, University of Houston, May 2020
- Master of Science in Architectural Engineering, Azad University, Feb. 2013
- Master of Architecture in Middle Eastern Architectural Studies, Isfahan, Aug. 2011
- Bachelor of Science in Architectural Engineering, Azad University, Sept. 2006

## Current Positions

- National Space Society, North Houston: Director/Secretary
- Mars Desert Research Station (MDRS), Mars Society: CapCom
- NASA Centennial Challenges (Deep Space Food Challenge) 2021: Juror

## Research Positions

- Sasakawa International Center for Space Architecture (SICSA), University of Houston: Research Assistant of Dr. Olga Bannova
- The Massachusetts Institute of Technology (MIT), Media Lab: Visiting Student Researcher for Dr. Valentina Sumini

Mars Desert Research Station
The Mars Society

National Space Society

Deep Space Food Challenge
NASA & CSA

## Greenhouse

**What to grow?**
Plant list

**How to grow?**
Cultivation process and systems

**Where to grow?**
The greenhouse architecture

## Crew

**What to eat?**
Daily menu

**How to eat?**
Post harvesting process and systems

**Where to eat?**
The greenhouse's human factors

| Greenhouse | Crew |
|---|---|
| What to grow? Plant list | What to eat? Daily menu with cultural diversity |
| How to grow? Cultivation process and systems | How to eat? Post harvesting process and systems |
| Where to grow? The greenhouse architecture | Where to eat? The greenhouse's human factors |

# Assumptions

↓

# Systems

↓

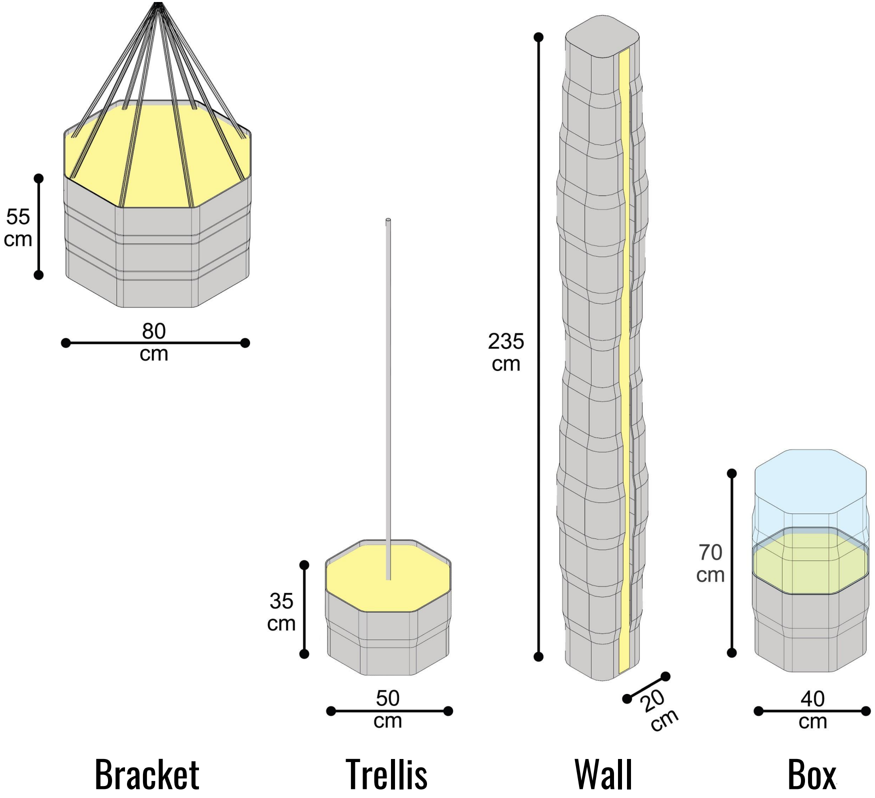
# Architecture

# Plant's Diversity in the Proposed Plant Lists

| | Russia | USA | ESA/Canada | USA | Japan | ESA/Canada | USA |
|---|---|---|---|---|---|---|---|
| Fruit | 0 | 0 | 0 | 1 | 0 | 0 | 4 |
| Grain | 1 | 4 | 2 | 4 | 1 | 2 | 6 |
| Herb and Spices | 1 | 0 | 0 | 0 | 4 | 4 | 6 |
| Leaf and Flower | 0 | 3 | 5 | 4 | 3 | 7 | 6 |
| Leguminous | 1 | 4 | 2 | 3 | 4 | 4 | 4 |
| Root and Tuber | 6 | 2 | 4 | 3 | 3 | 4 | 5 |
| Salad | 3 | 0 | 2 | 4 | 4 | 5 | 4 |
| Sugar | 0 | 0 | 0 | 1 | 1 | 0 | 1 |
| Total | 12 | 13 | 15 | 20 | 20 | 26 | 36 |

https://www.researchgate.net/publication/338499624_Designing_A_Martian_Greenhouse_as_A_Habitable_Space_Feasibility_Studies_and_Design_Approach

# Plants Diversity & Cultivation Area

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## Plants Diversity & Cultivation Area

| | Intake Calories Per Day (kcal) | Required Calories Per Day (kcal) | Ratio of Intake to Required Calories (%) | Cultivation Area ($m^2$) |
|---|---|---|---|---|
| NASA | 1130 | 2700 | 60 | 46.5 |
| Greenhouse | 3000 | 3000 | 100 | 123.5 |

**4 Crew Need 494 $m^2$ Cultivation Area**

| Example | Bracket | Box | Wall | Trellis | Total |
|---|---|---|---|---|---|
| Pots in Upper Level | 0 | 288 | 528 | 62 | 878 |
| Pots in Lower Level | 64 | 556 | 222 | 64 | 906 |
| Total Number of Pots | 64 | 844 | 750 | 126 | **1784** |
| Area of Each Pot ($m^2$) | 0.64 | 0.16 | 0.38 | 0.29 | |
| Total Cultivation Area ($m^2$) | 40.96 | 135.04 | 285 | 36.54 | **497.54** |

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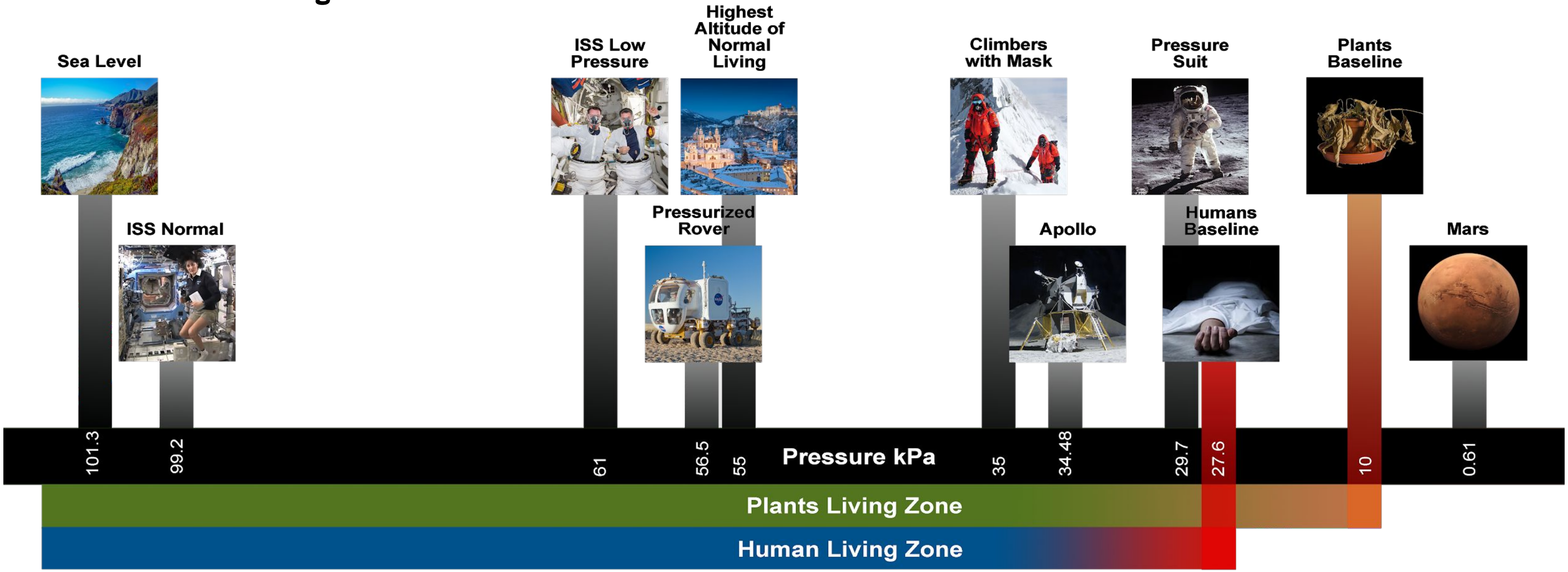
# Total Pressure in Living Zones

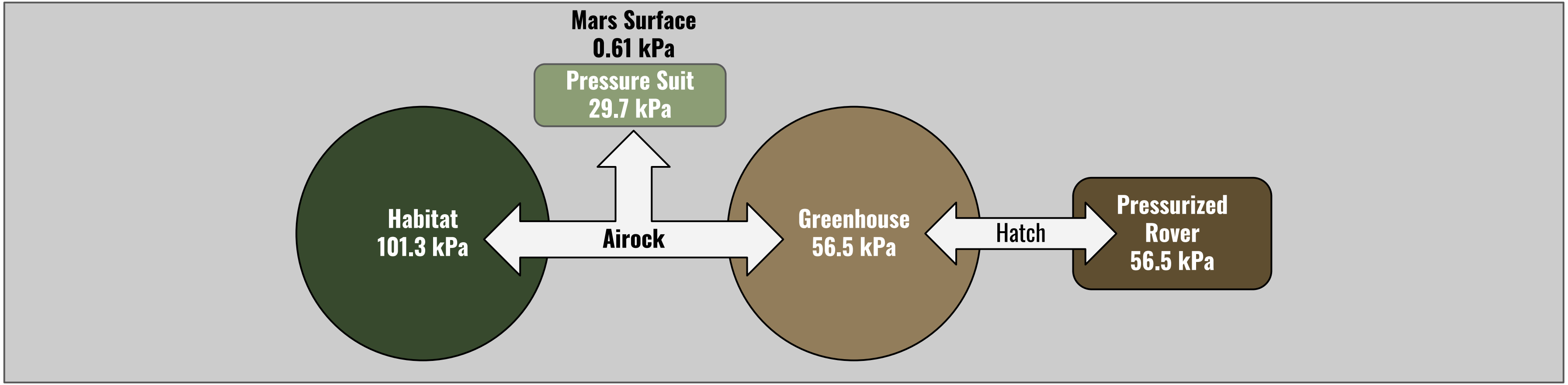



https://www.researchgate.net/publication/344754312_Pressurized_Greenhouse_A_Responsive_Environment_to_Partial_Gravity_Conditions

# EVA Scenarios

| Scenario | Total Pre-Breathe Time |
|---|---|
| Scenario 3x2h | 7:20 |
| Scenario 1x8h | 4:40 |

101.3 kPa    56.5 kPa    29.7 kPa    EVA    Each Unit is 20 Minutes

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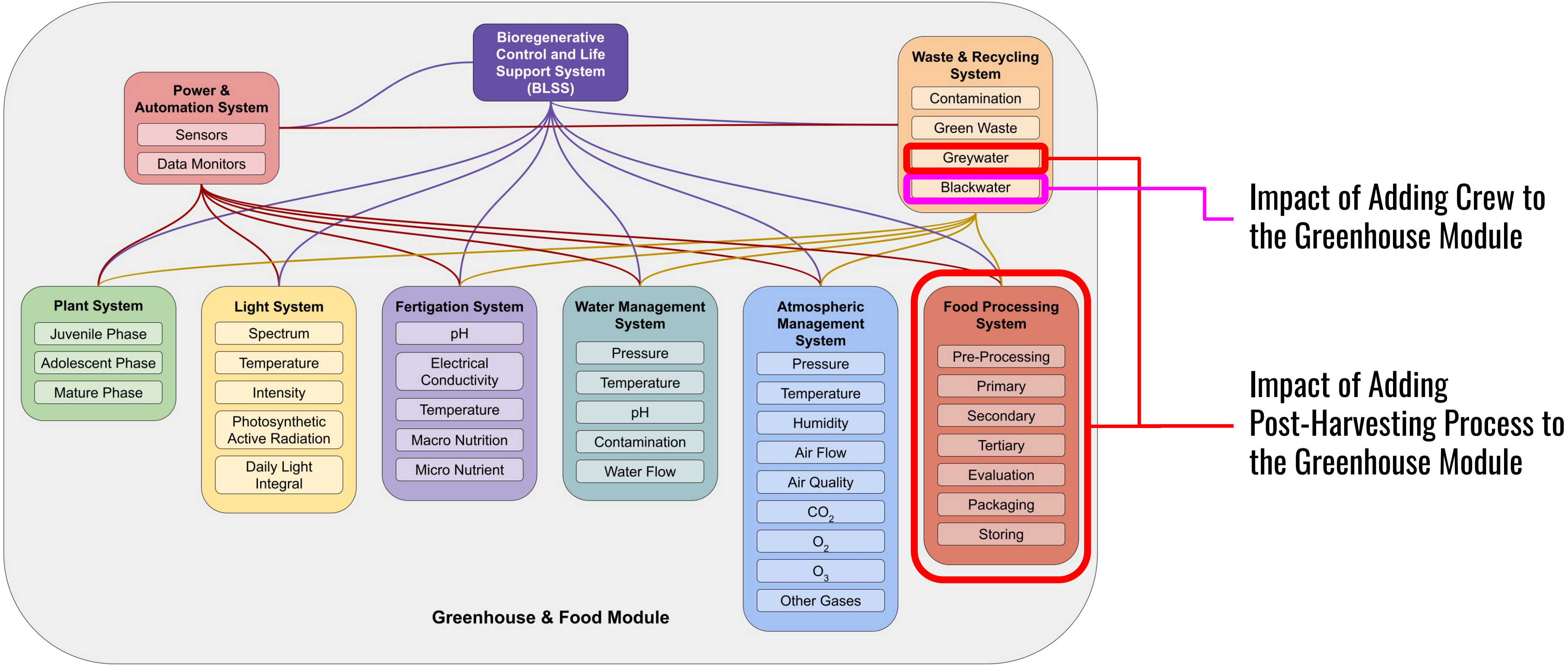
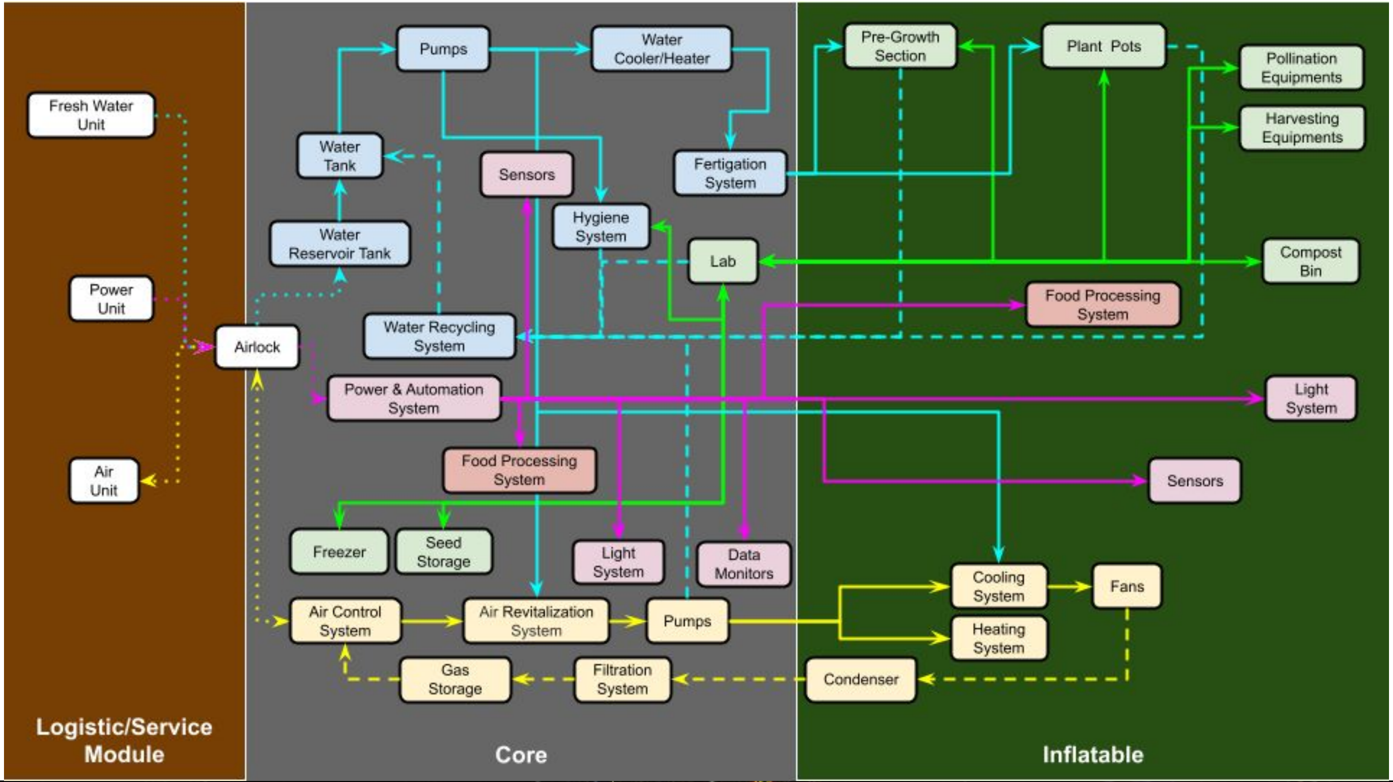
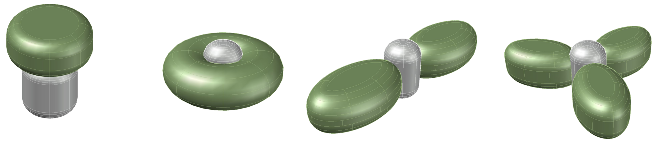
## Greenhouse & Food Module Systems



# Greenhouse & Food Module Systems Diagram



# Design Criteria

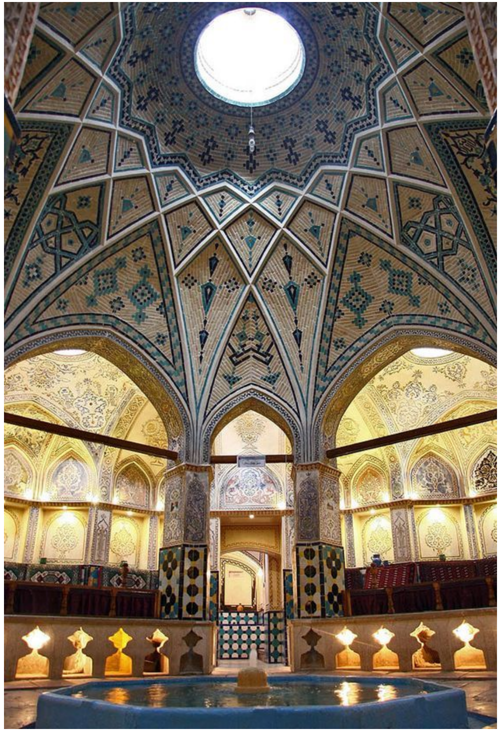


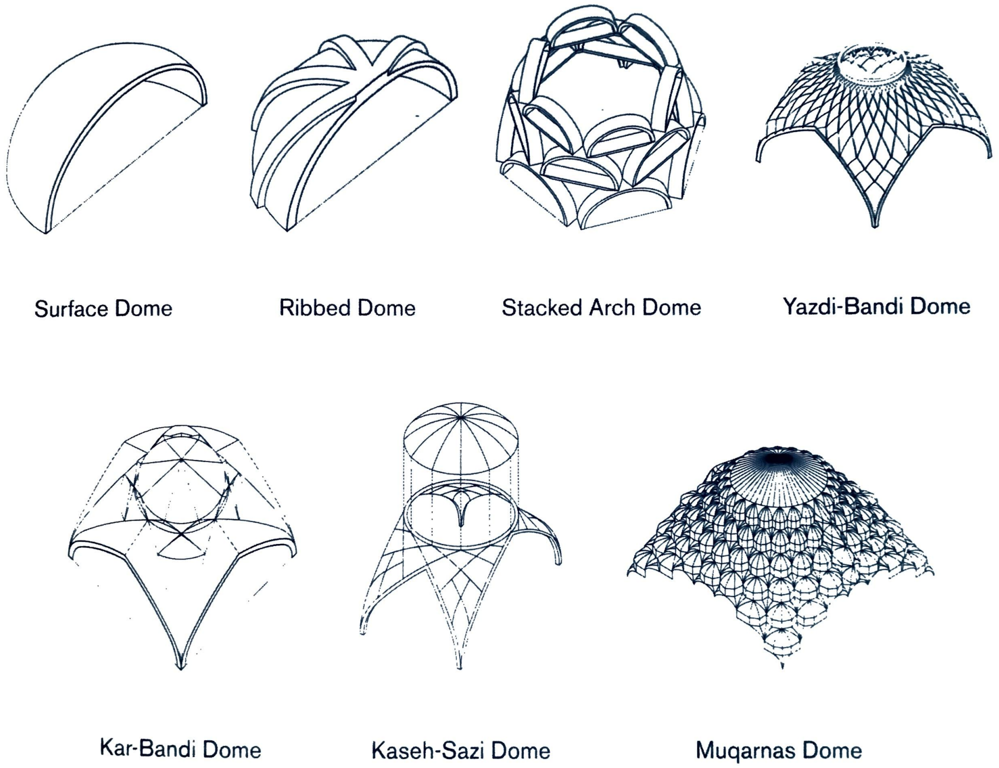
- Green: Most Preferable
- Yellow: Moderately Preferable
- Red: Least Preferable

| | | Mushroom | Torus | 2 Petals | 3 Petals |
|---|---|---|---|---|---|
| Operation | Space Efficiency | Red | Yellow | Green | Green |
| | Space Modification | Red | Red | Green | Green |
| Hibernation | Partial Operation | Red | Red | Green | Green |
| | Resource Consumption | Red | Red | Green | Green |
| Emergency | Crop Loss | Red | Red | Green | Green |
| | Functionality | Red | Red | Green | Green |
| Physical Properties | Mass | Red | Green | Green | Green |
| | Deployment | Green | Red | Yellow | Yellow |
| | Structure Assembly | Green | Yellow | Red | Red |
| | Systems Assembly | Green | Green | Red | Red |
| Human Factors | Accessibility | Red | Green | Green | Green |
| | Personal Area | Yellow | Yellow | Green | Green |

https://www.researchgate.net/publication/344754479_Greenhouse_Architecture_Analysis_in_the_Partial_Gravity_of_Mars_and_the_Moon

# Persian Domes



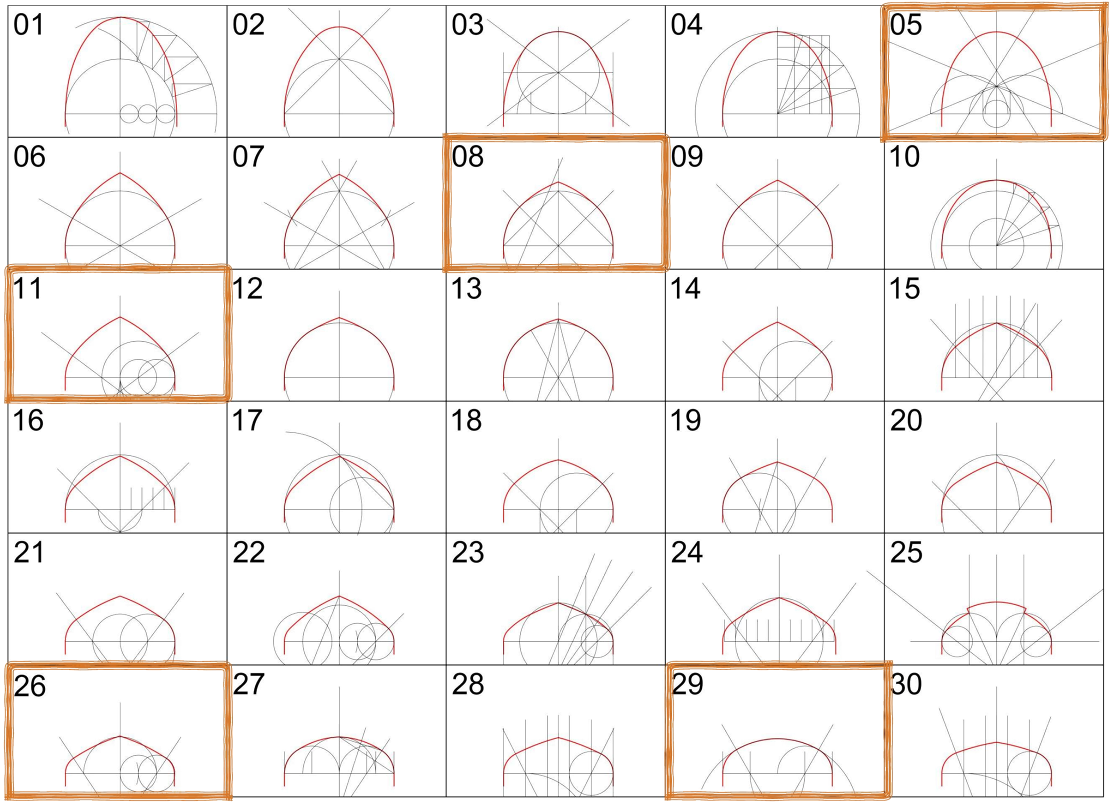


# Karbandi Construction Process



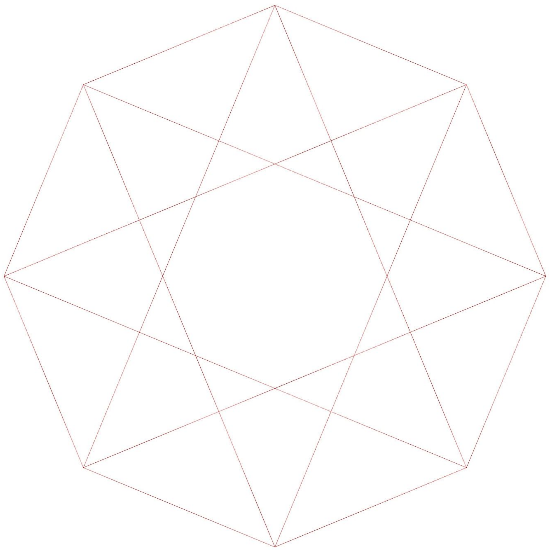



## Persian Arches

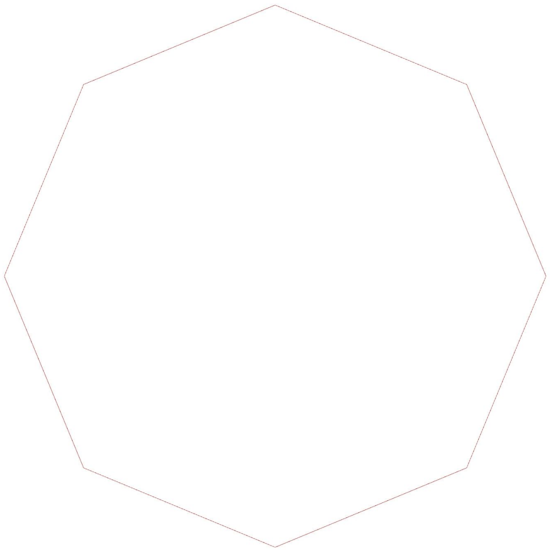



https://www.media.mit.edu/projects/persian-domes-for-human-space-exploration-on-mars/overview/

# Arch Modification



Pattern: 4
Node: 8 to 28



Pattern: 8
Node: 8 to 28

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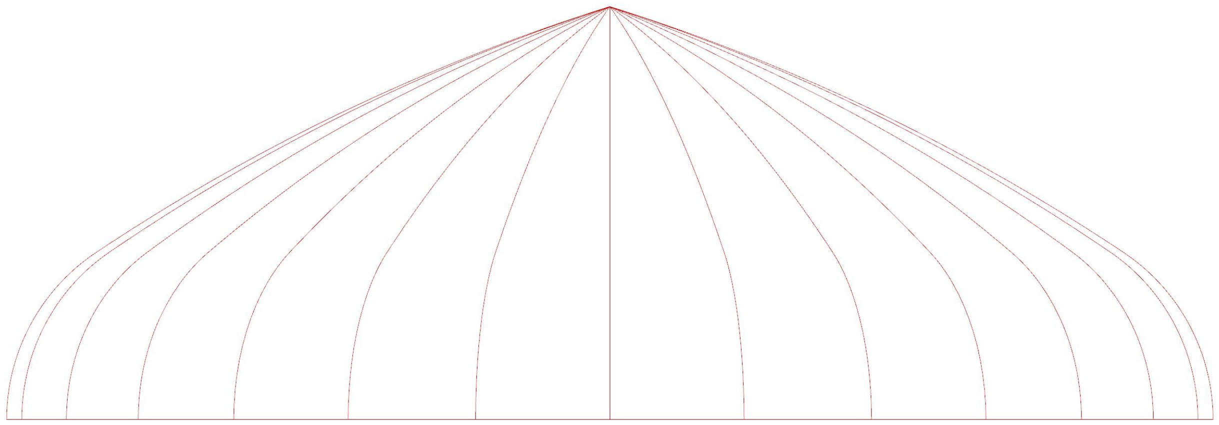
# Arch Modification



Node: 28
Pattern: 2 to 28

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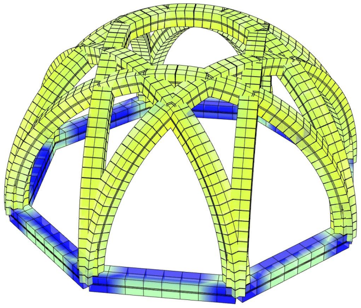
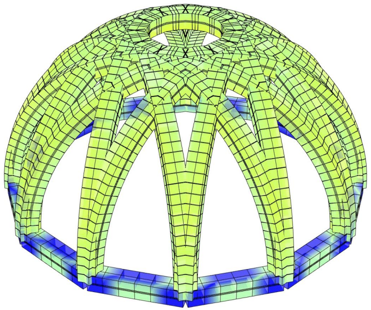
# Structural Analysis Results: Hemisphere Pattern 4

Arch: H Node: 08



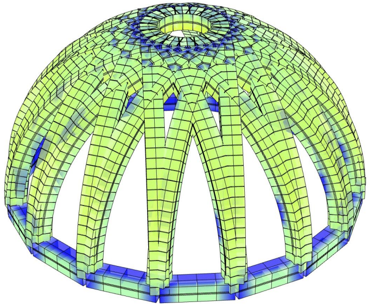
Pressure: 27.6 kPa

Arch: H Node: 12



Pressure: 27.6 kPa

Arch: H Node: 16



Pressure: 27.6 kPa

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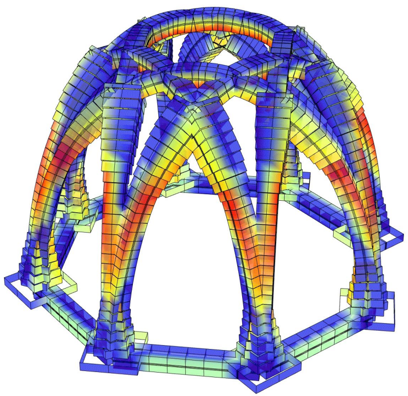
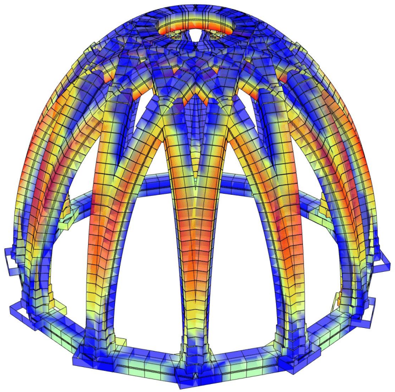
# Structural Analysis Results: Arch 05 Pattern 4

Arch: 05 Node: 08



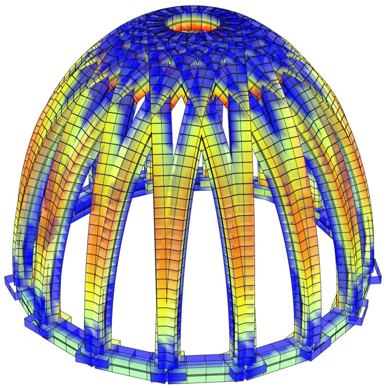
Pressure: 27.6 kPa

Arch: 05 Node: 12



Pressure: 27.6 kPa

Arch: 05 Node: 16



Pressure: 27.6 kPa

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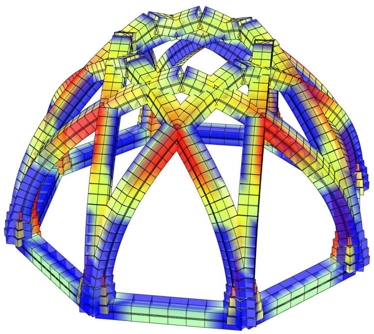
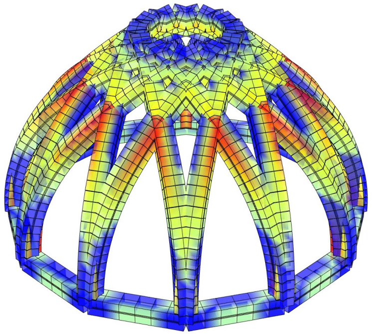
# Structural Analysis Results: Arch 08 Pattern 4

Arch: 08 Node: 08



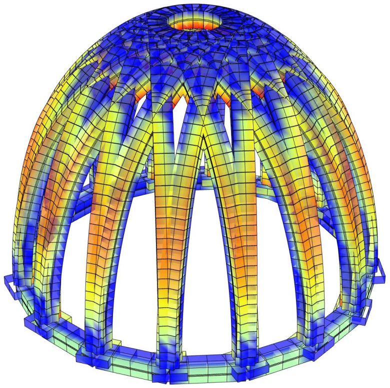
Pressure: 27.6 kPa

Arch: 08 Node: 12



Pressure: 27.6 kPa

Arch: 05 Node: 16



Pressure: 27.6 kPa

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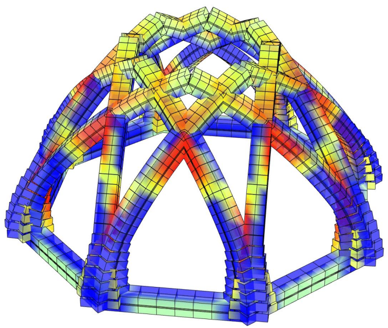
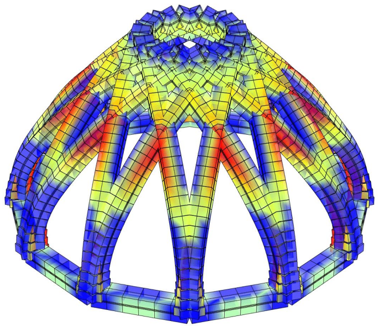
# Structural Analysis Results: Arch 11 Pattern 4

Arch: 11 Node: 08



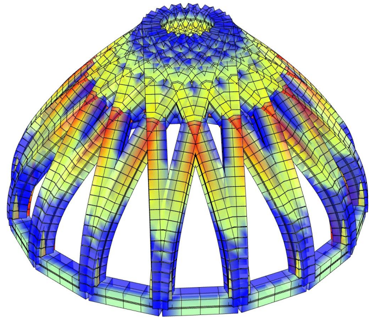
Pressure: 27.6 kPa

Arch: 11 Node: 12



Pressure: 27.6 kPa

Arch: 11 Node: 16



Pressure: 27.6 kPa

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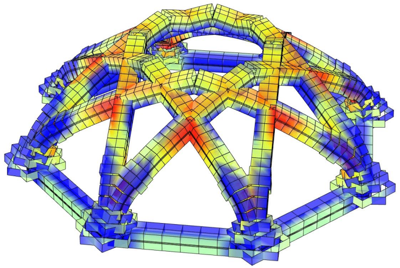
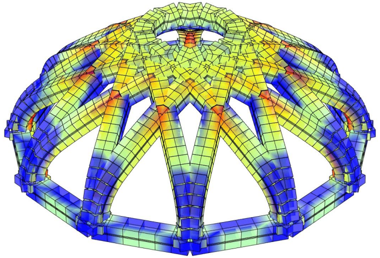
# Structural Analysis Results: Arch 26 Pattern 4

Arch: 26 Node: 08



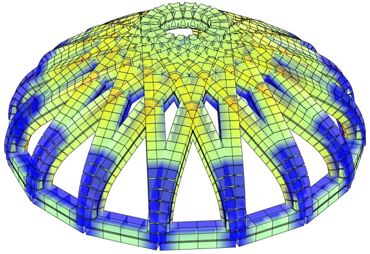
Pressure: 27.6 kPa

Arch: 26 Node: 12



Pressure: 27.6 kPa

Arch: 26 Node: 16



Pressure: 27.6 kPa

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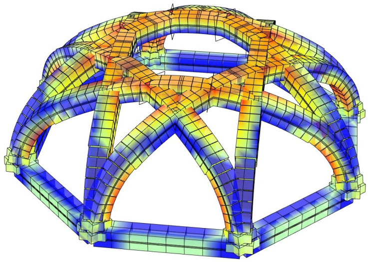
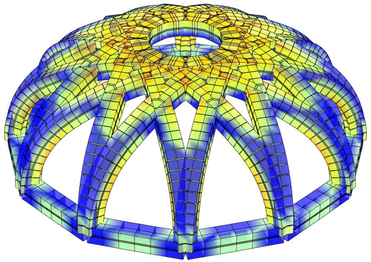
# Structural Analysis Results: Arch 29 Pattern 4

Arch: 29 Node: 08



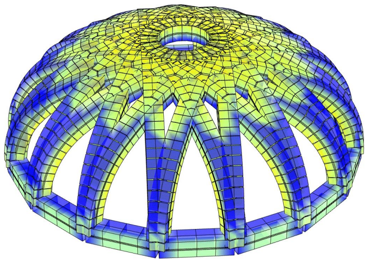
Pressure: 27.6 kPa

Arch: 29 Node: 12



Pressure: 27.6 kPa

Arch: 29 Node: 16



Pressure: 27.6 kPa

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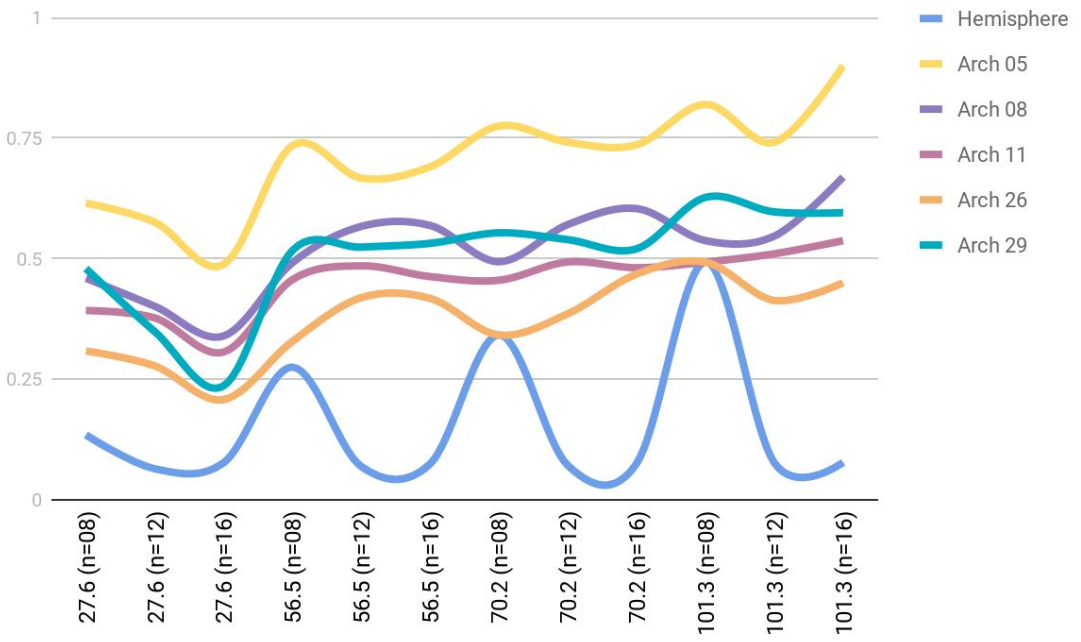
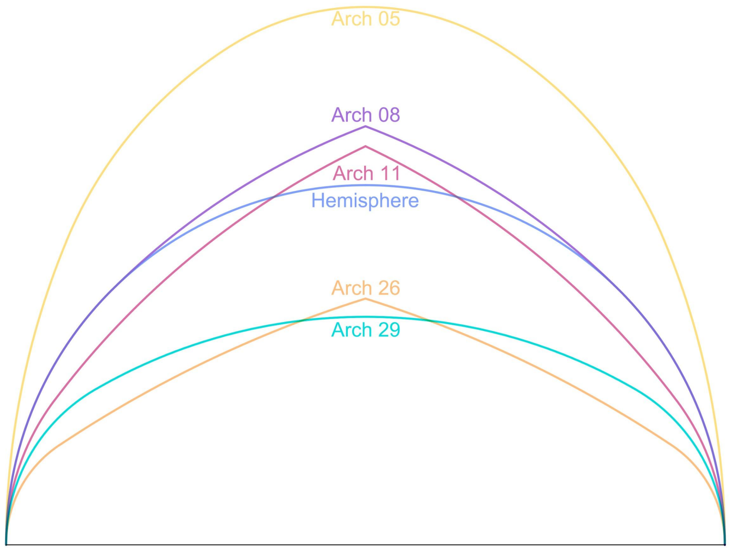
# Comparing Results: Maximum Deformation

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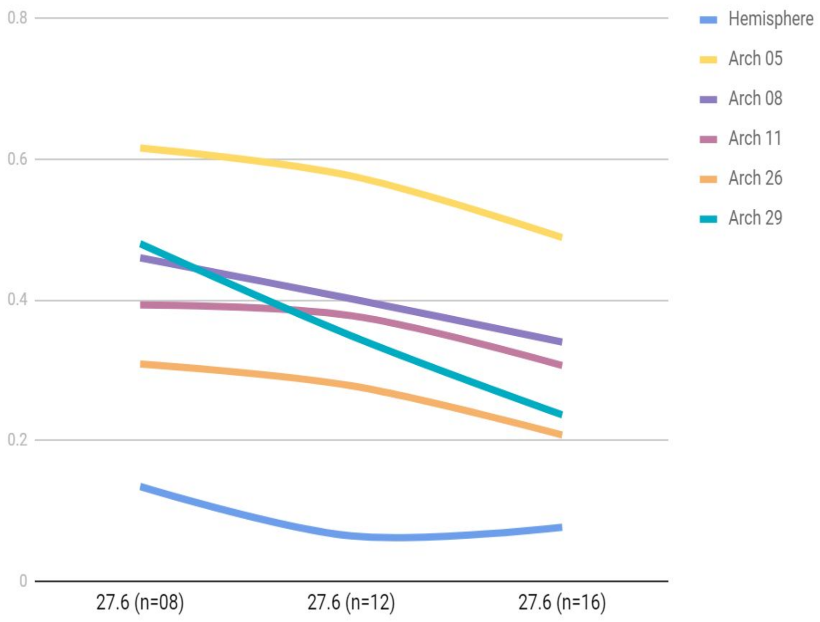


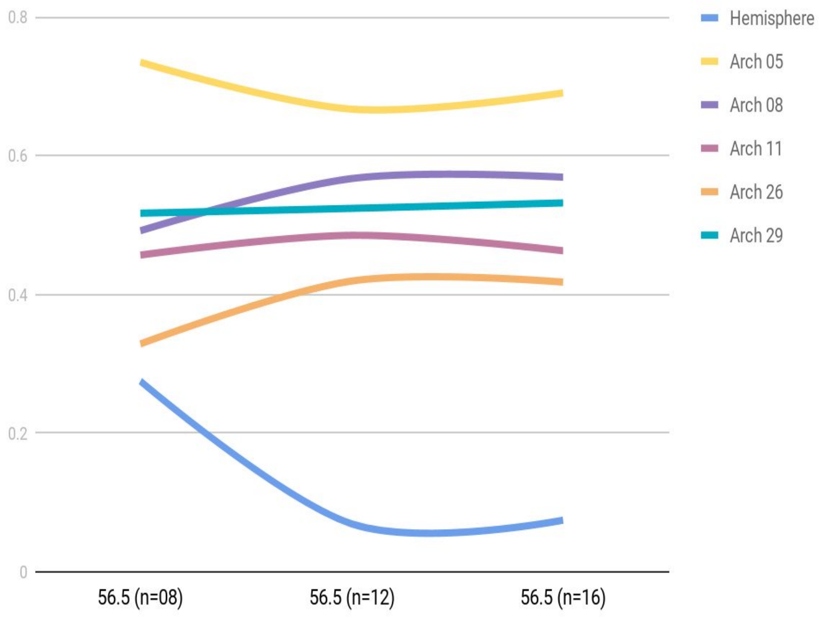


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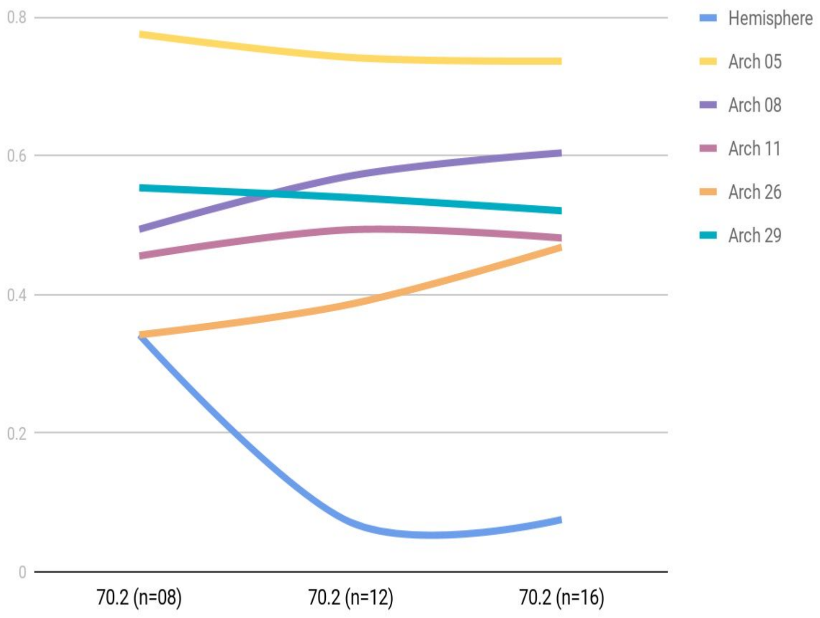


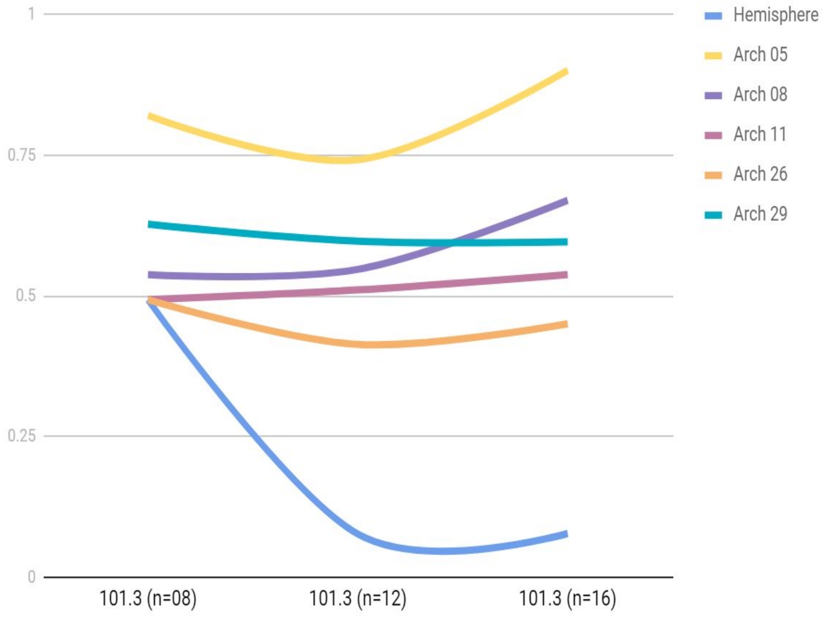


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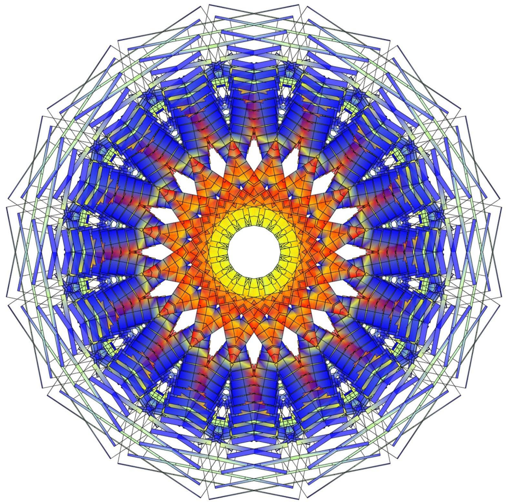
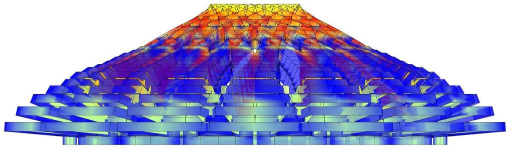
## Structural Analysis Results: Hemisphere Pattern 4

- The computational model was required to analyze the performance of Persian bathhouse dome structures for Mars, adapting to different internal pressurization loads
- The optimized Arch 26 resulted in having similar performance to the perfect hemispherical dome with the 1 atm - max pressurization level
- Future works could consider other Persian arch types, that are in literature
- Exploring the combination and aggregation of different dome structures, with different pressurization loads on Mars that host different functions (housing, office,...)
- The construction method Karbandi is the closest reference to 3D printing technology with Martian regolith for Mars, building arch first and filling
- More freedom in choosing the material for radiation shielding: opaque/translucent, regolith/ice



26-12-101.3



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# Thank you for your attention

Mahsa Esfandabadi

mesfand@uh.edu

mahsa.esfand@gmail.com

# Greenhouse for Partial Gravity : Systems & Architecture

## Plant List

| | Russian Academy of Sciences | NASA | ESA/Canada | University of Utah | NASA | Institute for Environmental Sciences in Japan | ESA/Canada | NASA | University of Utah |
|---|---|---|---|---|---|---|---|---|---|
| | Beets | Beans | Beans | Broccoli | Beets | Beans | Alfalfa | Banana | Beans |
| | Carrots | Broccoli | Beets | Canola | Broccoli | Cabbages | Beans | Barley | Beets |
| | Cucumber | Corn | Broccoli | Carrots | Corn | Carrots | Beets | Beans | Broccoli |
| | Dill | Kale | Cabbages | Chilies | Cucumber | Cucumber | Broccoli | Beets | Cabbages |
| | Earth Almond | Mustard Greens | Carrots | Kale | Kale | Komatsuna | Cabbages | Broccoli | Canola |
| | Kohlrabi | Oats | Cauliflower | Lentil | Lettuce | Lettuce | Carrots | Cabbages | Carrots |
| | Onions | Peanuts | Kale | Lettuce | Mustard Greens | Mitsuba | Cauliflower | Cantaloupe | Chard |
| | Peas | Peas | Lettuce | Onions | Oats | Onions | Chard | Carrots | Chilies |
| | Potato | Potato | Onions | Peas | Onions | Peanuts | Chilies | Cauliflower | Chives |
| | Radishes | Rice | Potato | Peanuts | Peanuts | Peas | Cucumber | Celery | Fennel |
| | Tomato | Soybeans | Rice | Rice | Peas | Peppers | Herbs | Chard | Flax |
| | Wheat | Turnip | Soybeans | Soybeans | Potato | Radishes | Kale | Chives | Garlic |
| | | Wheat | Spinach | Sweet Potato | Rice | Rice | Lettuce | Corn | Ginger |
| | | | Sweet Potato | Tomato | Soybeans | Shiso | Mushrooms | Garlic | Kale |
| | | | Wheat | Wheat | Spinach | Shungiku | Onions | Grape | Lentil |
| | | | | | Strawberries | Soybeans | Peanuts | Kale | Lettuce |
| | | | | | Sugar Beets | Spinach | Peas | Lettuce | Melons |
| | | | | | Sweet Potato | Sugar Beets | Peppers | Mint | Millets |
| | | | | | Tomato | Tomato | Potato | Oats | Mushrooms |
| | | | | | Wheat | Turnip | Rice | Onions | Oats |
| | | | | | | | Soybeans | Parsley | Onions |
| | | | | | | | Spinach | Peanuts | Oregano |
| | | | | | | | Squash | Peas | Parsley |
| | | | | | | | Sweet Potato | Peppers | Peanuts |
| | | | | | | | Tomato | Potato | Peas |
| | | | | | | | Wheat | Rice | Potato |
| | | | | | | | | Rye | Pumpkin |
| | | | | | | | | Soybeans | Quinoa |
| | | | | | | | | Spinach | Radishes |
| | | | | | | | | Strawberries | Rice |
| | | | | | | | | Sugar Cane | Sage |
| | | | | | | | | Sweet Potato | Sorghum |
| | | | | | | | | Taro | Soybeans |
| | | | | | | | | Tea | Squash |
| | | | | | | | | Tomato | Strawberries |
| | | | | | | | | Wheat | Sunflower |
| | | | | | | | | | Sweet Potato |
| | | | | | | | | | Thyme |
| | | | | | | | | | Tomatillo |
| | | | | | | | | | Tomato |
| | | | | | | | | | Wheat |
| Fruit | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 4 | 3 |
| Grain | 1 | 4 | 2 | 3 | 4 | 1 | 2 | 6 | 6 |
| Herb and Spices | 1 | 0 | 0 | 1 | 0 | 4 | 4 | 6 | 9 |
| Leaf and Flower | 0 | 3 | 5 | 2 | 4 | 3 | 7 | 6 | 6 |
| Leguminous | 1 | 4 | 2 | 4 | 3 | 4 | 4 | 4 | 6 |
| Root and Tuber | 6 | 2 | 4 | 2 | 3 | 3 | 4 | 5 | 5 |
| Salad | 3 | 0 | 2 | 3 | 4 | 4 | 5 | 4 | 5 |
| Sugar | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 |
| **Total** | **12** | **13** | **15** | **15** | **20** | **20** | **26** | **36** | **41** |

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