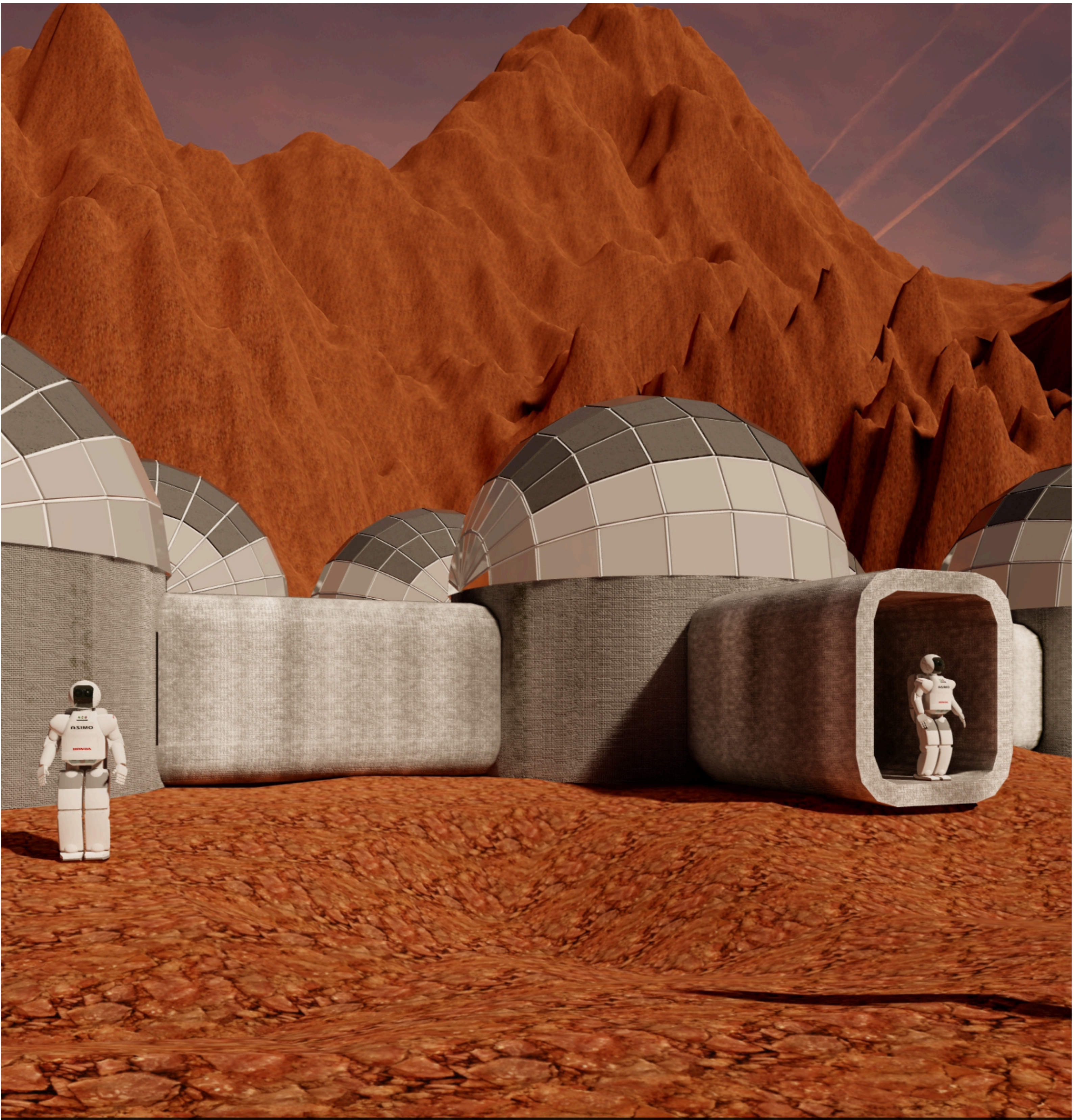

Space & Spaces
Your Home in Mars

AHURORA
TECHNOLOGY, HEALTH & COSMOS

EDEN TREE

AHURORA Team

Local Event: Guadalajara, Jalisco, México

Team:

1. **Team owner: Aurora Jocelin Chávez Palafox**
   4th-year Medical Student, Universidad de Guadalajara

2. **Erick Magnus De Dios Aceves**
   3rd-year Nanotechnology Student, Universidad de Guadalajara

3. **Axel Leonardo Álvarez Villegas**
   4th-year Architecture Student, Universidad de Guadalajara

4. **Luis Mariano Romo Medina**
   2nd-year Software Engineering Student, Universidad ITESO

5. **Nicol Guadalupe Hermosillo Mexia**
   5th-year Aerospace Engineering Student, Universidad Marista Guadalajara

6. **Pablo Enrique Ballinas Arroyo**
   4th-year Nanotechnology Engineering Student, Universidad Politécnica de Chiapas

Chosen Challenge:

- Your Home in Space: The Habitat Layout Creator

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1. Selected Challenge

The challenge selected was: **Your Home in Space: The Habitat Layout Creator.**

1.1 Challenge Summary

"Space habitats are 'homes in space' that keep crew members healthy and capable of executing their mission. Whether located on a planetary surface or in space, habitats must support critical functions such as waste management, thermal control, life support, communications, power, food storage and preparation, medical care, sleep, and exercise. Space habitat concepts can involve a diverse range of materials, geometries, and layouts. Your challenge is to create a visual tool that allows users to define the shape/volume of a space habitat and explore possible layout options."

1.2 Justification for Challenge Selection

The challenge "Your Home in Space: The Habitat Layout Creator" was selected by our team due to its comprehensive focus and its alignment with our strengths and objectives. This challenge offers us a unique opportunity to apply our knowledge in design, aerospace medicine, and technological innovation, while also contributing to one of the most crucial areas for the success of long-duration space missions: astronaut well-being and habitability.

Furthermore, the challenge aligns with our focus on optimizing astronaut well-being on long-duration space missions, such as those planned for Mars. This challenge gives us the opportunity to combine our strengths in design, health, and technology to create efficient and sustainable habitats in an extreme environment like Mars.

- **Focus on the Crew and their Well-being:** We focus on how to create habitats that are not only functional but also promote the physical and mental health of astronauts, which is crucial for prolonged missions on Mars.
- **Application of Interdisciplinary Knowledge:** This challenge allows us to integrate a variety of multidisciplinary knowledge:

    - **Architecture and Design:** To design habitats with an efficient and comfortable layout for the crew.
    - **Aerospace Engineering:** To ensure the habitat is functional and withstands the extreme conditions of space and Mars.
    - **Nanotechnology:** To select advanced materials that can withstand radiation, extreme temperatures, and the demands of a prolonged mission.
    - **Aerospace Medicine:** To ensure the habitat design promotes the physical and mental health of the astronauts.
    - **Web Development:** To develop an interactive app that allows simulation and optimization of the habitat design, improving the user experience.
- **Challenges of Mars and the Future of Exploration:** The challenge allows us to address real problems of Martian exploration, such as the management of limited resources, the design of a habitable and efficient habitat, and the optimization of spaces for the astronauts' needs.

1.3 Objectives to be Met by the Selected Challenge

Main Objective: <u>To create an easy-to-use and accessible visual tool for creating and evaluating space habitat designs.</u>

The goal of the tool is to allow users to:

1. Create a general habitat design with various options.
2. Determine which functional areas fit within the space and their location.
3. Quickly test different material options for the mission.

2. App Description

2.1 Storytelling

App Name:

Space & Spaces

Introduction:

"Space & Spaces" was created with the mission of designing the perfect home on Mars. After an extensive study of the planet's environmental conditions, the Martian atmosphere, and the available materials on the surface, the Space & Spaces team designed the ideal habitat for astronauts living there.

Inspiration and Concept:

Drawing from NASA's research and advancements, the team conceived a modular design inspired by the essence of life itself: Eden Tree. This habitat not only provides a functional space for the crew but also simulates a tree, a connected life system, where each module serves a specific purpose—from resource management to medical care, rest, and exercise.

User Interaction and Features:

Through Space & Spaces, users have the opportunity to be a part of this incredible project. The app allows users to not only edit and customize the habitat but also visualize it in 3D, choose building materials, and select the functional areas of the habitat, adapting them according to the crew’s needs.

Mission Success and Well-being:

Astronauts will be able to enjoy an environment designed for survival and well-being, with areas dedicated to work, recreation, hygiene, and rest. Every decision made within the app will play a critical role in ensuring that the Mars habitat is not only livable but also a sanctuary where astronauts can thrive in such a challenging environment.

Final Vision:

With Space & Spaces, every user has the power to design the future of life in space, building a home on the Red Planet for humanity.

2.2 Core Functionality

Space & Spaces is a visual tool designed to define and explore the design of a habitat on the surface of Mars. The app allows users to customize and optimize a pre-established habitat, material selection and strategic distribution of spaces, all designed to guarantee a successful mission on the Red Planet.

- **Target Audience:** The tool is designed to serve as a professional and critical resource primarily intended for crew members and mission specialists (including researchers and engineers), as well as aerospace architecture and engineering professionals involved in the planning and execution of long-duration space habitats.

2.3 Key Features

- **Interactivity:** Users should be able to:
    - The system uses a modular TRUNK + 5 ROOT structure, representing a central hub connected to five customizable habitat zones. Users can

assign unique functional areas to each ROOT for maximum adaptability.

- Optimized for a four-astronaut crew and Mars-specific mission parameters, particularly targeting the Gale Crater region due to its stable terrain and scientific potential.
- Each ROOT can be assigned to one of five functional categories:
  - **Research** – Laboratory, experimental cultivation, and scientific operations.
  - **Health & Fitness** – Medical care and physical well-being.
  - **Rest** – Private quarters, recovery zones, and personal storage.
  - **Food & Resources** – Nutrition, storage, and resource management.
  - **Social** – Communal and recreational spaces to enhance crew morale.
- The TRUNK acts as the main operational hub, connecting all ROOT modules and optimizing circulation flow between functional areas.
- Fully interactive 3D visualization with orbital camera controls, zoom, and pan for real-time spatial exploration of the habitat.

- **Quantitative Outputs:**
  - **Green indicators** – Valid configurations (no duplicated assignments).
  - **Red indicators** – Invalid configurations (duplicate area assignments).
  - **Toast notifications** – Instant feedback for area changes and material selections
  - **PDF generation** – Enabled only when the configuration passes all validation checks.

2.4 Relationship with Space Exploration and NASA's Vision

Space & Spaces allows users to simulate what it would be like to live on Mars under extreme conditions — a crucial challenge for the success of future space missions. The app aligns with NASA's vision for creating sustainable space habitats, optimizing the use of available resources and ensuring astronauts have a safe and efficient environment on the Red Planet. This contributes to the advancement of space exploration, adapting to the needs of future missions and the vision of autonomy and self-sufficiency on Mars.

3. Web Development

3.1 Development Tools & AI Integration

We leveraged several AI-powered development tools to accelerate our workflow while maintaining full creative control and originality.

3.2 AI Development Environments

- **Lovable (formerly GPT Engineer):**
  Our primary tool for rapid UI component scaffolding, design system implementation, and boilerplate code generation. During the development of the interactive 3D editor and multilingual tutorial system, approximately 70–80% of the initial codebase was AI-assisted, including:
    - Zone detection logic in GLB models
    - Validation system for duplicate configurations
    - Dynamic PDF generation with jsPDF
    - Interactive material carousels

- **Cursor AI Editor:**
  Used for code generation assistance, debugging complex 3D rendering issues, and rapid prototyping of core features.

- **VSCode with GitHub Copilot:**
  Employed for code completion and technical documentation generation.

Disclosure: All AI-generated code was thoroughly reviewed, modified, and tested by the team. System architecture, business logic decisions, and UX design were 100% human-driven.

3.3 AI Usage Disclosure

- All AI-assisted code includes comments indicating AI involvement.
- Final implementation, architecture, and business logic decisions were made exclusively by humans.
- **The team maintained full oversight over:**
  - Component architecture
  - State management system
  - Three.js integration and 3D rendering
  - Habitat configuration validation logic
  - Multilingual system (EN, ES, FR, DE)

3.4 Development Approach

Our development process emphasized human oversight of AI-assisted code. Over two days of intensive work, we implemented the following systems:

1. **Full Interactive 3D Editor**
   - GLB model rendering with Three.js
   - Zone selection system (1 TRUNK + 5 ROOTs)
   - Two visualization modes: Normal (materials) and Render (configurations)
   - Accurate click/hover detection on 3D geometries
   - Highlighting system with emissive colors (green = selection, red = duplicate, white = hover)

2. **Advanced Materials System**

- 3 Martian construction materials: Sulfur-Regolith, Martian Geopolymer, Kevlar Membrane
- Interactive carousel with 4 images per material (12 assets total)
- Dynamic image imports from src/assets/
- Smooth navigation with indicators and animations

3. **Enhanced Interactive Tutorial System**
   - 5 guided steps with automatic spotlight on target elements
   - Modern glassmorphism design with gradients and shadows
   - Animated progress bar with step indicators
   - Emoji icons per step (🚀 🎨 🖼️ ⚙️ 📤)
   - Automatic mode switch (Normal → Render) during tutorial
   - Always-on tutorial on editor entry (no localStorage dependency)
   - Robust DOM element validation before spotlight activation

4. **Comprehensive Internationalization (i18n)**
   - Support for 4 languages: English, Spanish, French, German
   - Context API with custom useLanguage() hook
   - Over 1,461 translation strings in src/translations/index.ts
   - LocalStorage persistence
   - Real-time language switching without reloads

5. **Dynamic PDF Generation**
   - Export of habitat configurations
   - Duplicate validation before export
   - Formatted tables with autoTable
   - Custom headers with Eden Tree branding
   - Dynamic file naming with ISO timestamp

6. **Social Media Sharing System**
   - Integration with WhatsApp, Twitter, Facebook, LinkedIn
   - Dynamic shareable text generation
   - Toast notifications with instant feedback

While AI tools significantly accelerated our initial development, all core functionality, integration of habitat technical data, and UX design were conceptualized and implemented by the team. AI tools acted as productivity enhancers, not solution designers.

4. App Graphic Design

4.1 The name: Space & Spaces

The name Space & Spaces reflects the essential duality of the mission: outer space and the spaces within the habitat. The app is designed to manage both the environment of the planet and the physical space inside the habitat, ensuring that both aspects are safe, functional, and optimized for human life on Mars.

4.2 Logo: Space & Spaces

Logo Space & Spaces. Original Autorship.

The **Space & Spaces** logo features a house inside Mars' orbit, symbolizing the creation of a habitat on Mars. The house is surrounded by Mars' orbit, highlighting the safety and sustainability of the habitable space on the Red Planet. Mars' moons, Phobos and Deimos, situated within the orbit, reinforce the habitat's connection to Mars' natural environment and its lunar system. The house's location on Mars, inside the orbit and surrounded by the moons, underscores the idea that astronauts will live on Mars while interacting with its natural environment, including the Martian moons.

4.3 Space & Spaces: Slogan

"Your Home in Mars" This slogan reflects the app's purpose: that beyond being a functional habitat, it must be a home on Mars for the astronauts, providing comfort and security during their stay on the Red Planet. The app aims to ensure that astronauts not only have a space to live but a place where they can feel at home, even in an environment as extreme as Mars.

4.4 Space & Spaces: Color Palette

The selected color palette is inspired by the tones that evoke the planet Mars and its environment, combining warm and neutral colors to convey modernity, sustainability, and trust:

- **White (#ffffff):** Represents the purity, safety, and clarity of the design.
- **Orange (#af4c0f):** Evokes the characteristic color of Mars, associated with energy and enthusiasm.
- **Beige (#d49f85):** A warm tone that reflects the adaptability and harmony of the habitat in extreme conditions.
- **Black (000000):** Provides a touch of elegance and sophistication, symbolizing the darkness of space.

4.5 The Name: Eden Tree

The name Eden Tree refers to the Garden of Eden, symbolizing the origin of life. This name evokes the idea of creating a new "Eden" on Mars, a home where humanity can thrive and adapt, starting with the essentials for survival. The tree represents growth, connection, and balance, reflecting how the habitat’s modules interact to ensure stability and sustainability on Mars.

4.6 Logo: Eden Tree

Eden Tree Logo. Original Autorship.

The logo of Eden Tree represents an interconnected modular habitat, inspired by a tree, symbolizing life, connection, and balance. The modular habitat icon reflects the flexibility and adaptability of the design, crucial for expansion and sustainability on Mars.

The Source Sans Pro typeface was chosen for its clarity and modernity, reflecting the functional and futuristic approach of the project.

5. Theoretical Framework: Mars

5.1 Planet Overview

Mars is the fourth planet in the solar system and the seventh largest. It is known as the "Red Planet" due to the iron oxide that covers its surface, giving it a characteristic reddish color. Mars has two moons, Phobos and Deimos, and a very thin atmosphere composed mainly of carbon dioxide, with traces of nitrogen and argon. The atmosphere has an atmospheric pressure of only 1% of Earth's, which means it cannot sustain liquid water on the surface without it rapidly evaporating or freezing.

5.2 Martian Environmental Conditions

- **Temperature:** The average temperature on Mars is approximately $-60^\circ C$, although it can range between $-125^\circ C$ at the poles and $20^\circ C$ at the equator during the day.
- **Atmosphere:** The Martian atmosphere is mainly composed of carbon dioxide (95%), with traces of nitrogen (2.7%) and argon (1.6%). The atmosphere is too thin to breathe and lacks oxygen.
- **Radiation:** Mars lacks a global magnetic field and has a very thin atmosphere, which allows high levels of cosmic radiation to reach the surface, posing a risk to astronaut health.

5.3 Extreme Martian Conditions and Their Impact on Astronaut Health

Variable	Research	Problematic
Cosmic Radiation and Solar Storms	Mars lacks a global magnetic field, leaving the surface exposed to high levels of cosmic and solar radiation.	Prolonged exposure to radiation can cause cancer, nervous system damage, and cardiovascular problems, among other health risks.
Extreme Temperatures	Mars experiences extremely cold temperatures, averaging around -60°C and ranging between -125°C and 20°C.	Low temperatures can cause hypothermia, cardiovascular stress, and impaired muscle function.

Low Gravity	Martian gravity is only 38% of Earth’s gravity.	Reduced gravity can lead to bone and muscle mass loss, impaired blood circulation, and metabolic disorders.
Psychological Isolation	Isolation in such a hostile and distant environment from Earth can severely impact astronauts’ mental health.	Prolonged stress, anxiety, and depression can reduce mission performance and may lead to serious psychological disorders.

5.4 Extreme Martian Conditions and their Impact on the Habitat and Mission

- **Dust Storms:** Mars experiences global dust storms that can last for days or weeks, reducing visibility and affecting habitat operations.
- **Extreme Temperatures:** Extreme temperature fluctuations require advanced thermal control systems to maintain habitable conditions inside the habitat.
- **Cosmic Radiation:** Constant exposure to high levels of cosmic radiation can damage electronic equipment and pose risks to human health.
- **Reduced Gravity:** Gravity on Mars is approximately 38% of Earth's, which can affect astronauts' bone and muscle health long-term.

5.5 Extreme Martian Conditions and their Impact on Astronaut Health

- **Radiation:** Exposure to high levels of cosmic radiation can increase the risk of cancer and other long-term health issues.
- **Reduced Gravity:** Reduced gravity can lead to bone mass loss and muscle atrophy. It is essential to implement physical exercise programs to mitigate these effects.
- **Extreme Thermal Conditions:** Extreme temperatures can cause hypothermia or overheating. Thermal control systems must be efficient and reliable.
- **Psychological Effects:** Isolation and extreme conditions can affect astronauts' mental health. It is crucial to provide psychological support and maintain high morale.

5.6 Why Mars? Reasons for Habiting the Red Planet

Mars has been considered one of the most promising destinations for human exploration for the following reasons:

- **Possibility of Past Life:** Mars shows evidence of having had liquid water on its surface in the past, suggesting it could have harbored microbial life at some point in its history.
- **Available Resources:** The presence of water in the form of ice, carbon dioxide in the atmosphere, and useful minerals for construction and energy production make Mars a viable candidate for human colonization.
- **Relative Proximity:** Mars is the closest planet to Earth that could potentially host life, which facilitates round-trip missions with current technology.

5.7 App's Relationship with ARTEMIS II and Future Missions

The ARTEMIS II mission aims to test the necessary technologies for future Mars missions, including a crew of four astronauts. These astronauts have key roles in the mission, which include:

- **Reid Wiseman – Commander:** Responsible for the overall safety and success of the mission, overseeing all critical operations.
- **Victor Glover – Pilot:** Responsible for operating the Orion spacecraft, performing orbital maneuvers, and ensuring proper system functioning during the flight.
- **Christina Koch – Mission Specialist 1:** Manages scientific experiments and technical operations on board, in addition to monitoring crew health.
- **Jeremy Hansen – Mission Specialist 2:** Collaborates on scientific and technical tasks, providing support in operating the spacecraft systems.

The app proposed in this project seeks to simulate the habitat for a Mars mission, using these roles as a model for planning and monitoring resources and crew well-being in extreme conditions.

5.8 How does the App relate to ARTEMIS II?

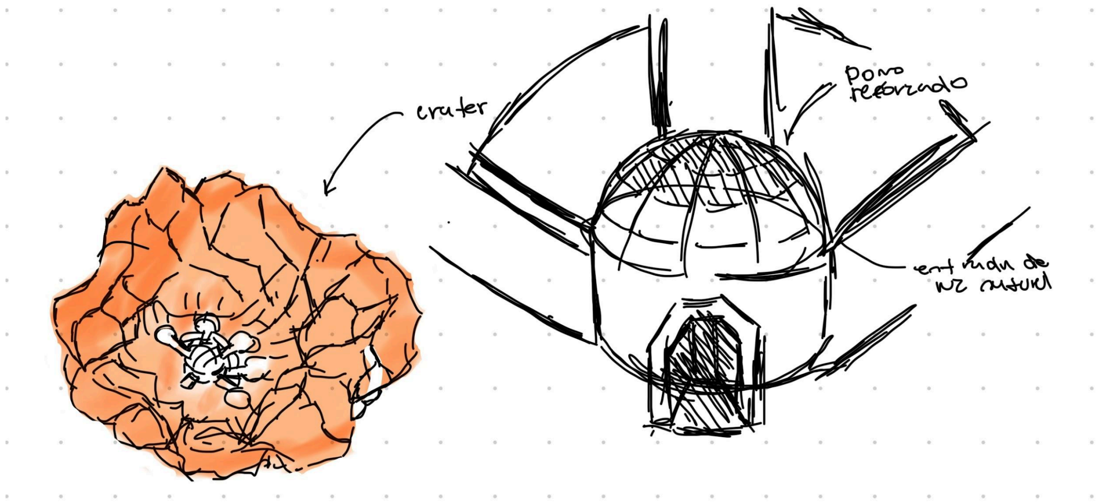
- **Habitat Simulation:** The app is designed to manage the space and resources of a Mars habitat, drawing inspiration from the functions that the ARTEMIS II astronauts will perform during their mission. This includes space distribution, resource allocation, and the optimization of key areas to ensure mission efficiency.
- **Limited Resource Management:** The app will focus on the efficient management of water, food, energy, and oxygen—essential resources for the mission.
- **Habitat Optimization:** The app will help efficiently distribute space within the habitat, covering rest, work, exercise, and recreation areas.

The app uses the ARTEMIS II experience as a basis for designing a comprehensive system that supports Mars missions, guaranteeing the crew's health and safety, and operational efficiency in an extreme environment.

6. Space Architecture and Design

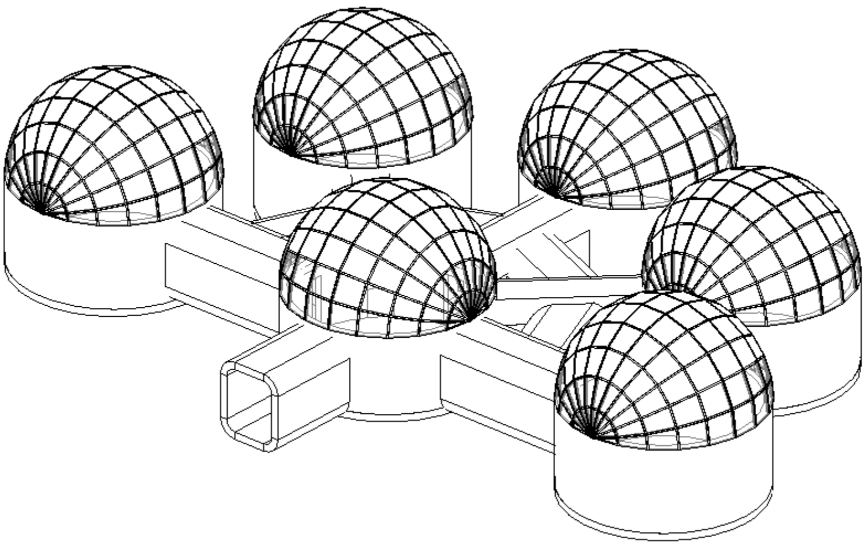
6.1 Concept and Symbolism

The *"Árbol del Edén"* (Eden Tree) concept arises from a symbolic and structural reinterpretation of the tree of life, an archetype representing growth, connection, and vitality. Its organic morphology serves as both an aesthetic and functional foundation for developing a self-sufficient, adaptable, and emotionally supportive habitat for human life on Mars.



Habitat Sketches. Original Authorship.

This architectural vision seeks to replicate the sense of belonging and familiarity that astronauts associate with Earth, mitigating the psychological challenges of long-duration missions. The design aims to harmonize biological inspiration with advanced engineering, reflecting the unity between life and structure as fundamental principles for extraterrestrial survival.



Eden Tree. Revit Design.

6.2 Spatial Organization and Functional Distribution

LOCATION	Functional Category	Areas	Sub-areas	ID
TRUNK	Central Core	Airlock		1.1
		EVA Support		1.2
			Control and visualization computer interface	1.2.1
			Suit component testing and repair	1.2.2
			Temporary storage for EVA equipment	1.2.3
		Operations Center		1.3
			Computer interface for teleoperation and communication	1.3.1
			Command and control interface for monitoring vital systems	1.3.2
			Maintenance, diagnostics, and repair station for system components and electronics	1.3.3
ROOTS	Branches / Modules			2
	ROOT 1			
		Social Root		2.1
			Common room for	2.1.1

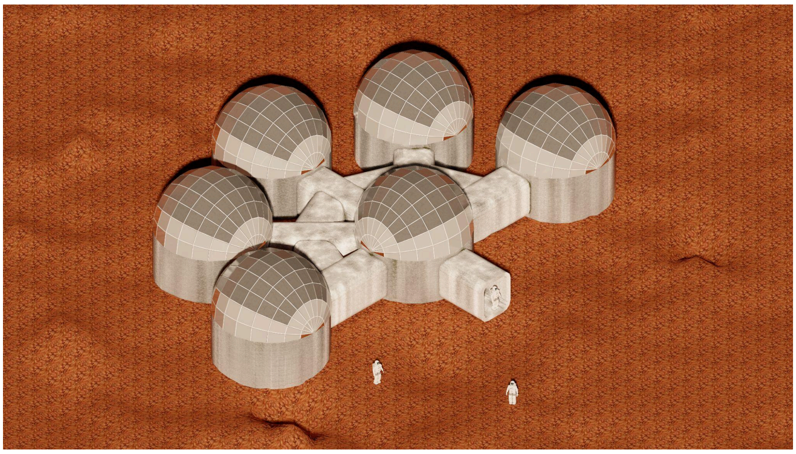
			meetings and mission planning		
			Recreation area		2.1.2
			Sensory / Interfaith Cabin		2.1.3
			Multisensory Room		2.1.4
	ROOT 2				
		Health Root			2.2
			Physical exercise		2.2.1
				Strength training	2.2.1.1
				Endurance training	2.2.1.2
			Personal hygiene		2.2.2.
				Toilet area	2.2.2.1
				Shower and drying area	2.2.2.2
				Vanity area – facial and hand cleaning	2.2.2.3
			Human Waste Collection (liquid and solid)		2.2.3
			Medical room		2.2.4
				Autonomous outpatient care	2.2.4.1
				First aid	2.2.4.2
				Individual Telemedicine and Mental Health Space	2.2.4.3
	ROOT 3				
		Rest Root			2.3

			Individual bedroom	2.3.1
			Dressing room	2.3.2
			Personal storage	2.3.3
			Stretching area	2.3.4
	ROOT 4			
		Food and Resources Root		2.4
			Kitchen (food preparation)	2.4.1
			Dining area	2.4.2
			Food storage and classification	2.4.3
			Water storage	2.4.4
			Waste and recycling	2.4.5
			Supply and material management and storage	2.4.6
	ROOT 5			
		Research and Greenhouse Root		2.5
			Laboratory	2.5.1
			Research room	2.5.2
			Greenhouse and crop area	2.5.3

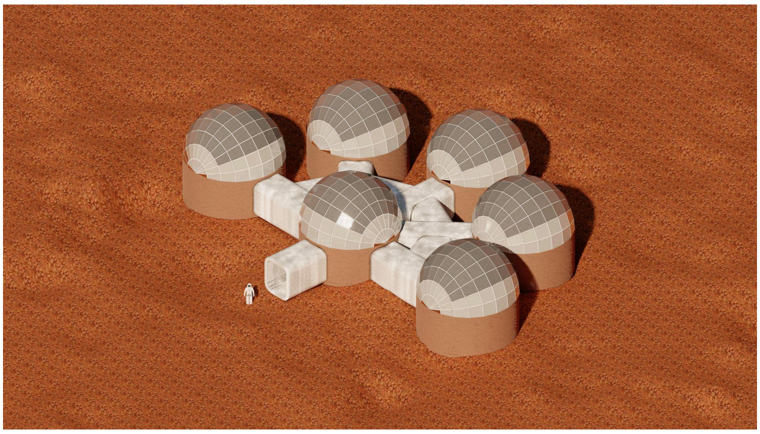
Table of EdenTree Areas Based on 'Defining the Net Habitable Volume for Long Duration Exploration Missions,' C. Stromgren, C. Burke, J. Cho, R. Calderon, M. Rucker: Information on Understanding Volumetric Requirements for Crews in Space Habitats.

6.3 Structural System and Materials

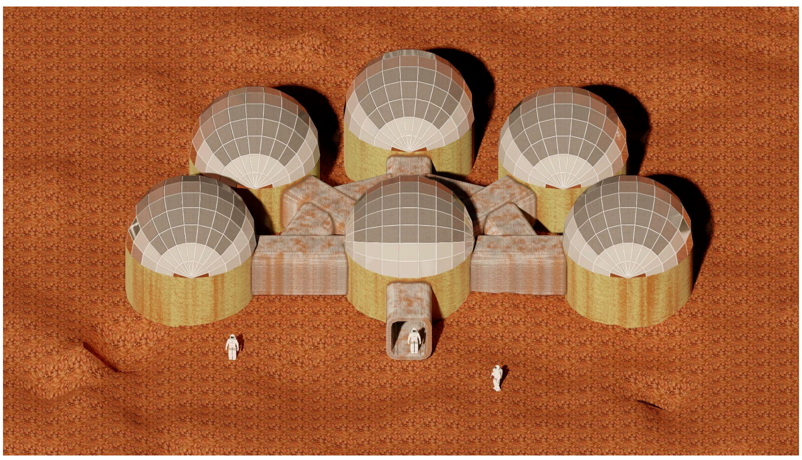
Technically, the habitat's structure is conceived from sulfur-based composites, Kevlar, and Martian regolith, materials chosen for their durability, availability, and potential for in-situ production (ISRU). The Kevlar tunnels connecting each module provide lightweight flexibility and resistance to Martian atmospheric pressure, ensuring airtight interconnections.



Kevlar. Lumion Render.



Geopolymer. Lumion Render



Sulfur-Regolith. Lumion Render

The upper dome consists of steel frames and Alumina Glass (synthetic sapphire / aluminum oxide) panels, which enable controlled sunlight transmission while maintaining thermal insulation. Additionally, a Titanium (Ti-6Al-4V) protective shell surrounds the entire structure, acting as a shield against micrometeorite impacts and dust storms. These materials were validated through the project's CFD analysis, which confirmed their capacity to withstand the predicted aerodynamic loads under Martian wind conditions.

6.4 Modularity and Adaptability

The geometric proportions of the trunk and roots maintain a uniform modular scale, allowing flexibility in furniture arrangement, spatial organization, and potential expansion. This modularity ensures that the habitat can evolve as mission requirements change or additional crew arrive.

Furthermore, the design supports personalization by users, enabling astronauts to adapt living areas according to individual preferences or operational needs. The modular logic integrates seamlessly with the digital control system developed by the engineering team, providing real-time monitoring and adaptive environmental management.

6.5 Interdisciplinary Development and Digital Modeling

The design process was supported by interdisciplinary collaboration between architects, aerospace engineers, nanotechnology specialists, and software developers, ensuring both aesthetic coherence and structural feasibility.

The digital representation was modeled using Revit, AutoCAD, and Lumion, which allowed for precise visualization of the habitat's morphology, structure, lighting, and environmental simulation. This integration of architecture and engineering reinforces the project’s core mission: creating a habitat that is not only structurally resilient but also emotionally and functionally habitable for future Mars explorers.

7. The Habitat: Eden Tree

The concept of Eden Tree is a modular habitat designed for life on Mars, with a focus on the well-being of the crew and stress management. Every aspect of the habitat was carefully designed to optimize distribution and functionality, ensuring that each module serves a specific purpose to guarantee the comfort, efficiency, and mental health of the astronauts. Inspired by the structure and function of a tree, this habitat is divided into key areas that provide comprehensive support for the crew, from resource management to physical and psychological well-being. The "Eden Tree" simulates an interconnected environment, with modules working synergistically to ensure a functional, efficient, and healthy living experience on the Red Planet.

The design of the habitat was based on the best practices and standards outlined in the Human Integration Design Handbook (HIDH), a reference from NASA, which provided valuable insights into creating a safe and efficient habitat. This research helped guide decisions on optimizing crew performance, system integration, and habitat functionality, ensuring a well-designed space for long-duration missions.

Table 8.2-5 Habitat Design Guidance for Various Psychological Stressors

Psychological Stressor Category	Habitat Design Guidance
Lack of Personal Space / Lack of Private Space	Provide individual, separate sleeping/personal quarters w/auditory isolation (mandatory) and physical separation (if possible) for each crew member
	Isolated locations throughout the vehicle
	Separation of private spaces from spaces allocated for common, social areas and congested translation paths is preferred
	Visual separation of private spaces from each other to allow for perception of increased privacy
	Rotating shifts
Feeling of "Crowdedness"	Separation of high traffic function
	Appropriate task scheduling/ task location
	Dedicated translation paths in integrated environment
	Increased volume or other dimensions to increased actual/perceived space
	Rotating shifts
Lack of Privacy of Waste & Hygiene Compartment	Dedicated, private area for waste and hygiene with hygiene areas away from dining area and medical station
	Separation of Waste & Hygiene Compartment area from translation areas
Lack of Meaningful Work/Activity	Provide individual development plans for each person's work goals, progress, and achievements
	Allocation of space and resources to accommodate each individual's work and activities (i.e., science, laboratory equipment, electronic curriculum, etc.). Each individual should have his or her own workspace and materials should be appropriately placed for ease of use and improved functionality
	Volume will be needed to hold samples and toolkits for in-flight experiments. Other features to impact volume may include electronic equipment to store data (workstations and hard drives) and a telescope. Equipment needed for analysis of collected samples during inbound flight.
Sense of Poorly Placed Stowage	Ensure stowage types are near designated areas (i.e., food near dining)

Human Integration Design Handbook (HIDH), NASA.

7.1 TRUNK (Central Core)

The Trunk represents the central core of the habitat, where critical systems and communal areas essential for daily astronaut life are located. This core acts as the heart of the habitat, housing the airlock and key operational and monitoring systems. It serves as the command center for the habitat, where primary functions, such as life support, resource management, and system monitoring, are controlled.

The airlock allows for safe entry and exit from the habitat, ensuring that astronauts can travel to and from the Martian surface or other modules without compromising the integrity of the habitable space. The Central Core coordinates essential systems, ensuring that life support, environmental controls, and communication systems function smoothly.

The connection to the tree structure reflects the central role of the Trunk in distributing vital resources to other modules, ensuring the survival and well-being of the crew.

7.2 ROOTS

The Roots represent the foundation of the habitat, providing stability and a connection to the Martian environment. In design terms, the roots are the functional modules directly involved with the crew's daily life. These modules include areas such as sleeping quarters, storage spaces, exercise facilities, and health areas.

The concept of the roots emphasizes the importance of maintaining functional balance, so that each module in this section is optimized to provide comfort, efficiency, and security. The Roots are essential for the growth and stability of the habitat, providing the foundation upon which the more specialized and advanced areas of the Eden Tree will develop.

7.3 Translation Paths (Tunnels)

The Translation Paths are the physical connections between modules, enabling efficient and safe movement throughout the habitat. These pathways are essential to ensure that astronauts can easily move between the Trunk and the Roots, as well as between other specialized modules, without compromising the habitat’s functionality.

According to the Human Integration Design Handbook (HIDH) from NASA, Translation Paths should be carefully designed to optimize circulation and facilitate daily tasks. These tunnels connect the modules and ensure communication between areas, allowing astronauts to perform their tasks without restrictions or complications.

Benefits of Translation Paths:

- Increased crew performance: Allows astronauts to move quickly and efficiently between areas of the habitat, enhancing their productivity and coordination.
- Optimization of logistics and movement: Well-designed paths ensure that the transport of supplies and resources is quick and efficient.
- Avoidance of traffic congestion: Minimizes the risk of bottlenecks or crowded areas within the habitat.
- Optimization of emergency procedures: Well-planned pathways allow for fast and effective evacuation in case of an emergency, which is crucial for crew safety.

The Eden Tree habitat is designed so that each module and its interconnections are essential for the success of the mission. From the Central Core, which coordinates vital functions, to the Roots that provide stability, and the Translation Paths that facilitate circulation, the entire design aims to create an environment that optimizes efficiency and crew well-being. This modular design is not only functional but also addresses the complex needs of living on Mars, ensuring that the crew can thrive in such a challenging environment.

7.4 Location Information

Planet: Mars
Crater: Gale Crater
Location: 5.22° S, 137.49°
Size:

- **Diameter:** 154 kilometers (96 miles)
- **Depth:** 3.5 to 5.5 km
  The central peak of the crater, the mound, rises about 5.5 kilometers (3.4 miles) above the northern crater floor and about 4.5 kilometers (2.8 miles) above the southern floor.

Advantages of the location:

Structure:

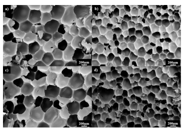
- The terrain offers a physically stable environment for a space habitat.
- The high walls provide natural protection against cosmic and solar radiation. In addition, they offer shelter from dust storms and strong Martian winds.
- Compared to the surface, temperatures are less extreme and the environment is more stable within the crater.
- There is potential to utilize in situ resources for construction, protection, and structural support, as well as to exploit local minerals and possible subsurface ice.

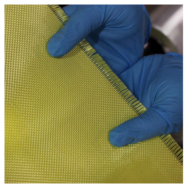
Research:

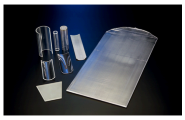
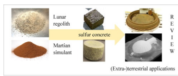
- The location facilitates continuous scientific exploration and geological study of Mars.
- It holds great scientific value due to evidence of ancient habitable environments.
- The presence of sediments and minerals indicates that liquid water once existed in the past.
- It has strong potential for developing a sustainable base for extended operations on Mars.

8. Nanotechnology and Materials

8.1 Chosen materials

Material	Key properties	Why this material was chosen	Benefits	Drawbacks	References	Image
Polyurethane reinforced with carbon nanotubes (CNT-PU)	Enhanced stiffness, tensile strength, and limited thermal conductivity increase with small CNT	Serves as an insulating and structural layer combining flexibility with mechanical	Excellent thermal insulation, improved strength and toughness, lightweight, adaptable	Difficult CNT dispersion, potential radiation degradation, relatively high manufacturing cost.	Recent Advances in Structural Carbon Nanotube Composites” — Emilie J. Siochi, NASA Langley Research	

	loadings (Wiley Polym. Compos., 2020.	reinforcement.	for interior panels or protective shells		Center (2024)	
Kevlar sacrificial layer (external membrane)	Very high tensile strength, low density, strong impact resistance, high energy absorption capability	Acts as an external “sacrificial membrane” to absorb impacts from micrometeoroids and dust abrasion.	Lightweight, high strength-to-weight ratio, used successfully in space structures and suits (NASA Tech Report 1993-00888)	Sensitive to UV and radiation degradation over time, poor compression resistance, limited lifespan under harsh exposure.	“The Next Generation of Kevlar® Fiber for Improved Micrometeoroid and Orbital Debris Protection” — DuPont / NASA colaboración (2023)	
Injected Martian geopolymer (in-situ produced)	Cement-like material made from Martian regolith activated by alkali solutions; high compressive strength, thermal and chemical resistance (Geopolymer Institute, 2023).	Enables construction using in-situ resources (ISRU) to reduce launch mass and cost.	Locally produced, strong, fire-resistant, good thermal and radiation shielding; reduces Earth-supplied material.	Complex processing, curing under Martian pressure/temperature is difficult, brittleness, variable regolith composition.	“Shield Development — Shielding Materials” en NASA / JSC	
Titanium (Ti or Ti-6Al-4V alloy)	High strength, low density, excellent corrosion	Ideal for structural frames, load-bearing supports,	Strong, durable, corrosion-resistant, widely used in	High cost, challenging to machine or weld on Mars, may	“Advantages and challenges of novel materials for	

	and fatigue resistance; performs well in extreme environments (NASA NTRS 2016-0013391)	and pressure vessel components.	aerospace; provides reliable mechanical stability.	require surface coatings for radiation and wear.	future space applications” — L. Pernigoni et al. (2023)	
Alumina glass (synthetic sapphire / aluminum oxide)	Extremely hard, high melting point, transparent (single-crystal form), resistant to radiation and abrasion (C&EN NASA materials, 2023)	Used for windows, domes, and shielding elements where light transmission and protection are both needed.	Transparent but tough; resists micrometeoroid impacts and radiation; suitable for pressure-resistant windows.	Brittle under tensile stress, heavy when thick, expensive to manufacture or replace.	“Carbon Nanotube Reinforced Lunar-Based Geopolymer” — J. Prater, Young Hoon Kim (2024)	
Regolith + sulfur (sulfur concrete/ sulfur-regolith composite)	Composed of molten sulfur (40-60%) mixed with martian regolith simulant (MMS- or JSC Mars-1). -Hight compressive strength:40-60 MPa under optimal conditions, can be melted and re-cast	Selected as an in-situ resource utilization (ISRU) material for constructing outer layers or radiation shilds using locally available sulfur and regolith	Can be manufactured directly on mars from surface materials, stronger under compression, suitable for domes, shielding walls, or foundation layers, recyclable and repairable (sulfur can be remelted) provides	Thermal cycling can cause creaking due to expansion /contraction of sulfur, brittle under tensile stress, sulfur sublimate or soften under high temperatures (120 C), requires controlled melting and cooling	- Grugel, R. N. (2008). “Sulfur Concrete for Lunar Applications – Environmental Considerations.” NASA TM-2008-214543. ntrs.nasa.gov - Wan, L., Wendner, R., & Cusatis, G. (2015). “A Novel Material for In-Situ Construction on Mars:	

	(thermoplastic binder) no need for water (advantageous in martian environment). Resistant to radiation and corrosion.		significant radiation protection and dust abrasion resistance, Eliminates need for imported water or cement.	processes under	Experiments and Numerical Simulations." arXiv:1512.05461 - Mars In Situ Resource Utilization and Sulfur Concrete (ASCE, 2020). figshare.com - McAdam, A. C. et al. (2014). "Sulfur-bearing phases detected by evolved gas analysis of the Rocknest deposit, Gale Crater, Mars." Journal of Geophysical Research: Planets. AGU - NASA (2017). "ISRU-Based Robotic Construction Technologies for Lunar and Martian Missions." NASA TM-2017-004640. ntrs.nasa.gov	

8.2 Material analysis

The material selection for the Martian habitat is grounded in the principle of structural redundancy and logistical feasibility, balancing the need for high-performance materials with the imperative of In-Situ Resource Utilization (ISRU). The design focuses on a confinement of forces: inner layers manage tension, while outer layers handle shielding and compression.

8.3 Qualities and optimization

The choice of Multi-Layer Kevlar (Layers 2 & 3) is indispensable for the inflatable structure, offering the highest tensile strength-to-mass ratio, which is fundamental for supporting the internal atmospheric pressure 10,330 kg/m^2 and minimizing launch costs. Polyurethane with Carbon Nanotubes (CNTs) (Layer 1) complements the Kevlar by providing the flexible airtight seal and turning the liner into a "smart skin" for active monitoring of leaks.

Shielding is addressed via two strategies:

- Massive Passive Shielding (Lower Section): Martian Geopolymer (Layer 4) is the most efficient ISRU solution, fabricated from local regolith. Its high density provides the crucial passive shielding against cosmic radiation. The structure functions because the geopolymer creates a rigid outer shell that contains the Kevlar's tensile forces, operating optimally in compression.
- Low-Mass Active Shielding (Roof Dome): The selection of Ultra-High Molecular Weight Polyethylene (UHMWPE) encapsulated in a Titanium structure is derived directly from aerospace science. UHMWPE, being rich in hydrogen, is the most effective low-density shielding material favored by NASA for mitigating dangerous Galactic Cosmic Rays (GCRs), making it the optimal choice for the habitat's most vulnerable point.

8.4 Scientific foundation

This material selection is strongly supported by research from NASA and ESA. The use of Aramid inflatable structures is the standard for next-generation modules due to their logistical efficiency (e.g., BEAM module). The reliance on regolith for construction (ISRU) is a pillar of long-term exploration strategies. Finally, the preference for hydrogen-rich materials like UHMWPE for shielding is based on decades of studies demonstrating their superiority over metals or basalt at scattering high-energy radiation. The confinement of materials ensures each component operates within its optimal stress or compression limit, guaranteeing redundancy and safety.

9. Aerospace Engineering

Designing sustainable habitats on Mars represents one of the greatest engineering challenges for future space missions. The thin Martian atmosphere, composed of over 95% carbon dioxide, presents extreme environmental conditions such as low pressure, high temperature variations, and frequent dust storms. These storms, though less forceful than those on Earth due to the low air density, can still cause significant mechanical stress and reduce visibility and energy efficiency for surface structures.

Understanding how Martian winds interact with a surface habitat is critical for mission safety and structural integrity. Computational Fluid Dynamics (CFD) analysis provides valuable insights into aerodynamic behavior, allowing engineers to evaluate the impact of wind loads on domes, modules, and connection structures. In this study, an ANSYS Fluent simulation was performed to assess the aerodynamic performance of a modular geodesic habitat located within a protective crater on Mars.

9.1 Design Parameters

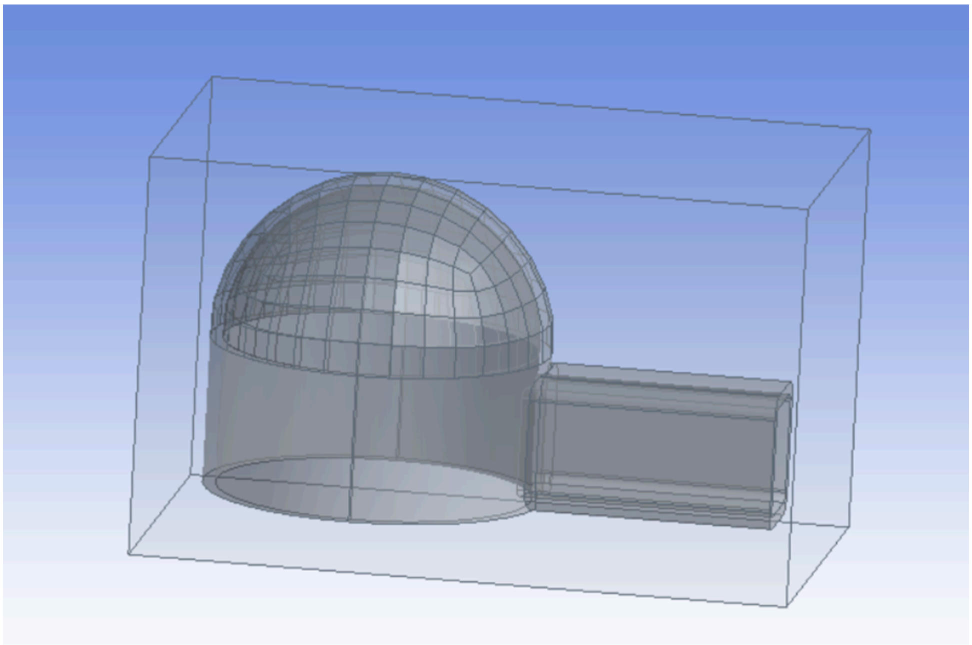
The simulation considered a single habitat module exposed to Martian wind conditions, using simplified but realistic physical parameters derived from NASA's atmospheric data. The model assumed the structure is enclosed within a cubic domain (*enclosure*) to replicate a wind tunnel environment. The objective was to visualize the flow distribution, pressure zones, and turbulence patterns around the dome and its lateral module.

Parameter	Value	Description
Ambient pressure	610 Pa	Mean surface pressure on Mars
Density (ρ)	0.0154 kg/m³	Derived from ideal gas law at 610 Pa, 210 K
Dynamic viscosity (μ)	1.0×10^{-5} kg/(m·s)	Approximate viscosity of CO_2 at 200–210 K
Wind velocity (V)	25 m/s	Typical strong Martian dust storm velocity (NASA JPL, 2023)
Gravity (g)	3.71 m/s²	Martian surface gravity

9.2 CFD Methodology

The Computational Fluid Dynamics (CFD) analysis was carried out using ANSYS Fluent, focusing on the aerodynamic behavior of a single habitat module. The complete structure was not imported due to computational limitations inherent to the student version of ANSYS Structural, which restricts the total number of mesh elements. Therefore, the model was idealized to represent only one module of the habitat, which is sufficient to capture the local flow interactions and pressure distribution around the geodesic structure.

A rectangular enclosure was created around the module to simulate a wind tunnel environment, representing the flow conditions of a Martian dust storm. This enclosure allowed the control of inlet and outlet boundaries and ensured that the airflow could develop naturally around the dome.



A Boolean subtraction operation was performed in the Design Modeler stage to subtract the module's volume from the enclosure. In this process, the enclosure was selected as the target body, and the module as the tool body. The subtraction effectively removed the module's shape from the fluid domain, leaving an empty region where the fluid can flow and interact with the structure's surfaces. This method ensures that the CFD simulation calculates the flow only in the surrounding air domain rather than through the solid geometry.

Solver and General Settings

The simulation used a pressure-based, steady-state, three-dimensional solver in an absolute frame of reference, with double precision enabled for higher numerical accuracy. Gravity was activated and later defined as $g =- 3.71\ [m/s]^2$, corresponding to the surface gravity on Mars.

Models

The energy equation was deactivated to perform an isothermal simulation, as temperature variations have a negligible effect on low-density, subsonic Martian flows. The viscous model selected was the k–ω SST (Shear Stress Transport) turbulence model, which provides accurate predictions for flow separation around curved surfaces such as domes. Other advanced models, including species transport, multiphase, and discrete phase, were disabled since the objective was to analyze aerodynamic loads rather than particle trajectories or thermal interactions.

Material Definition

Since the Fluent database does not include Martian atmospheric gases by default, the predefined "air" material was modified to represent the physical properties of Martian CO_2.

- The material was renamed mars_CO_2.

- Density was set to a constant value of 0.0154 [kg/m³], corresponding to the average density of the Martian atmosphere at approximately 610 [Pa] and 210 [K].

- Dynamic viscosity was defined as 1.0×10^{-5} [kg/(m·s)], consistent with CO_2 viscosity under low-temperature conditions.

The newly defined material was then assigned to the fluid region in the Cell Zone Conditions to ensure the entire enclosure was filled with the simulated Martian atmosphere.

Boundary Conditions

Boundary conditions were applied to reproduce a high-intensity Martian dust storm scenario:

- Velocity Inlet (upwind face): The incoming flow velocity was set to 25 m/s, representing a strong but realistic Martian wind event. Turbulence intensity was defined as 10%, and the flow direction was oriented normal to the inlet face.

- Pressure Outlet (downwind face): The outlet was assigned a pressure-outlet condition with a gauge pressure of 0 Pa, consistent with the operating pressure of 610 Pa.

- Walls and Habitat Surface: All walls, including the habitat module, were treated as no-slip boundaries, ensuring that viscous effects were captured near the surface.

Solution and Numerical Methods

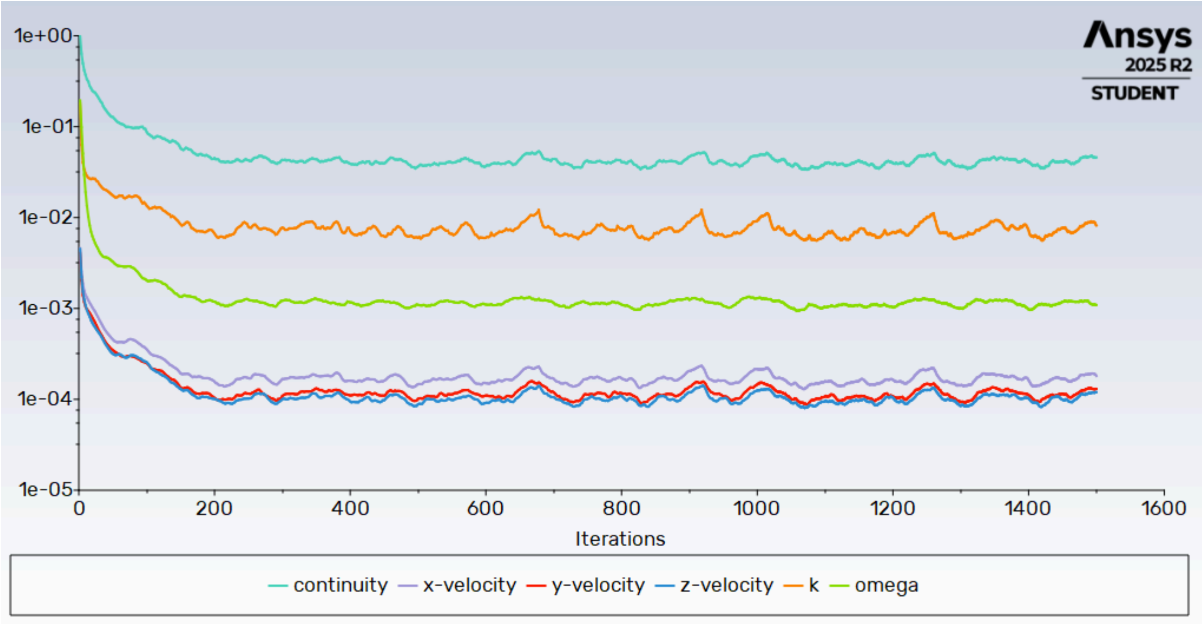
The SIMPLE pressure–velocity coupling scheme was used to maintain stability and convergence.

- **Gradient formulation:** Least Squares Cell-Based

- **Pressure discretization:** Standard

- **Momentum and turbulence equations:** Second-Order Upwind for higher accuracy in velocity gradients.

Hybrid initialization was used to establish initial flow conditions, followed by 500 steady iterations until convergence was achieved. The simulation results were monitored through residuals and flow field behavior, confirming the stability and accuracy of the solution.

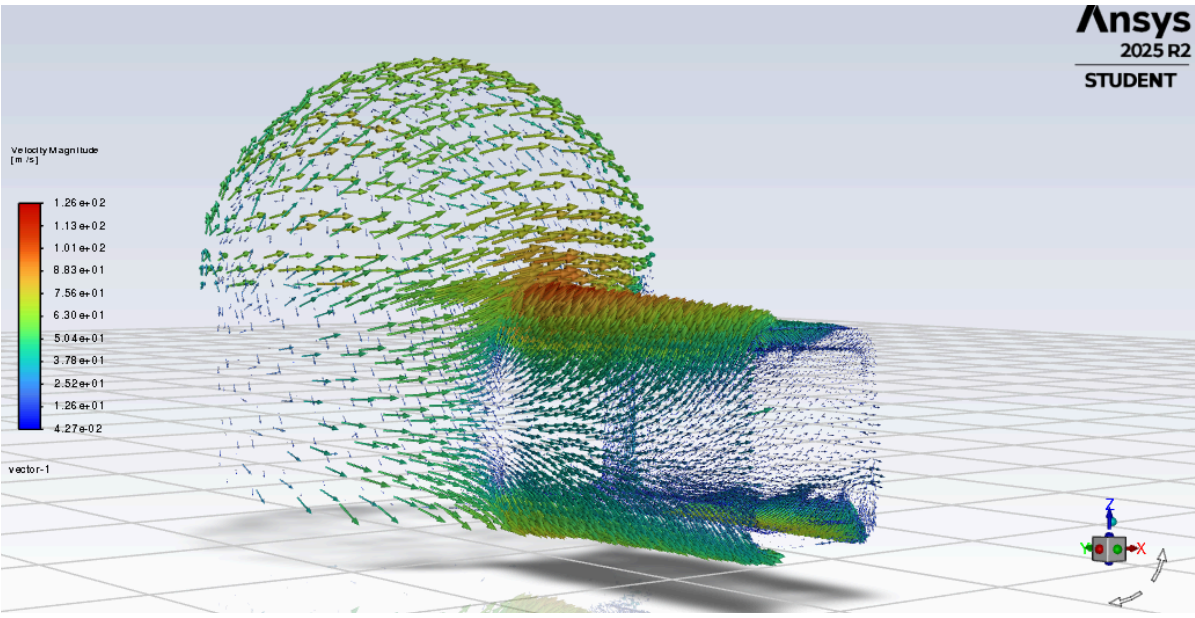


The solution reached steady behavior after 300-500 iterations. Velocity and turbulence residuals decreased to $O(10^{-4})$, while continuity stabilized around $O(10^{-2})$, which is acceptable for external flow provided force monitors and mass balance are stable.

9.3 CFD Results

Velocity Field and Flow Behavior

The velocity vector plot (Figure below) reveals the wind interaction with the habitat's dome and the attached rectangular corridor. As the CO_2 flow encounters the curved surface, it accelerates over the dome, reaching a local maximum of approximately 120 m/s due to the pressure drop caused by curvature-induced flow constriction. Downstream of the dome, a large recirculation region develops, characterized by a significant velocity reduction (values approaching 0–10 m/s).

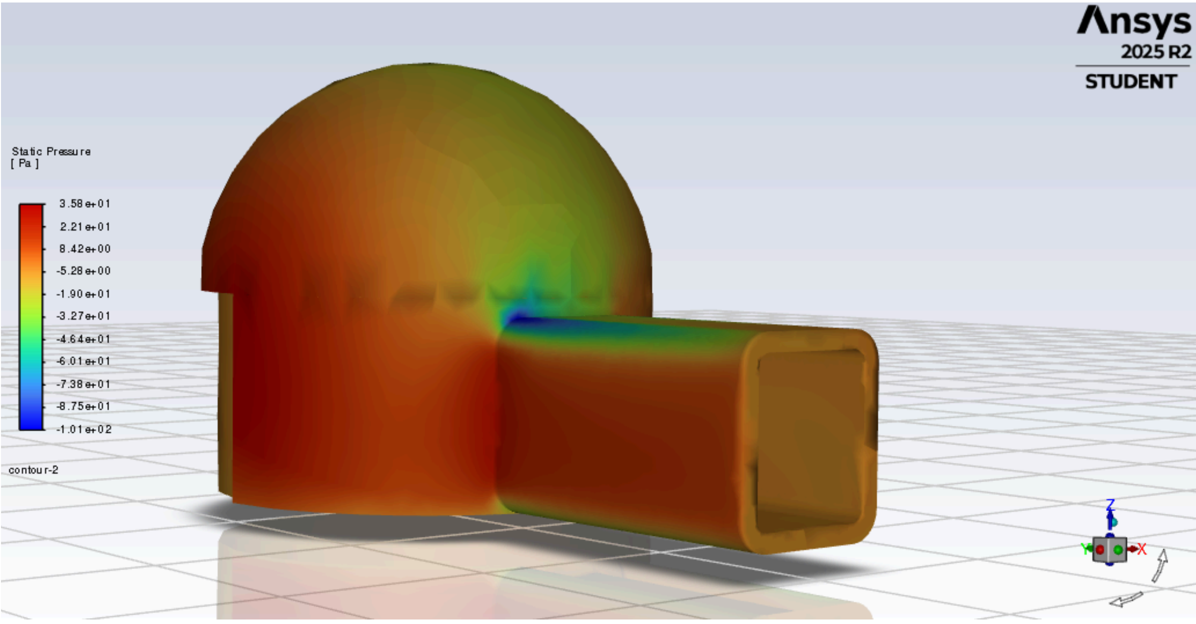


Velocity Magnitude. ANSYS Fluent Analysis.

This wake formation indicates the separation of the boundary layer behind the structure, a typical phenomenon in blunt-body aerodynamics. The attached corridor intensifies this separation, producing asymmetric turbulence zones. This pattern suggests that the habitat's placement inside a protective crater, as proposed in the project concept, would help reduce these effects by shielding the structure from the full force of the wind and mitigating the intensity of flow separation.

Static Pressure Distribution

The static pressure contour (Figure below) shows the pressure load distribution on the habitat's surface. The highest pressure values (around +35 Pa) appear on the frontal area of the dome where the flow stagnates, while the lowest values (approximately −100 Pa) occur in the wake region behind the module. This pressure differential defines the aerodynamic load that the structure would experience during a dust storm with a nominal wind speed of 25 m/s.



Static Pressure. ANSYS Fluent Analysis.

Although the color map visually amplifies the gradient, the absolute magnitude of these pressures is relatively small when compared to Earth-like atmospheric conditions. This observation aligns with NASA's findings that Martian dust storms, while visually intense, exert limited mechanical stress due to the planet's low air density.

9.4 Correlation Between CFD Results and Material Performance

The CFD analysis confirmed that the geodesic habitat design efficiently withstands Martian wind loads. The maximum pressure differential (135 Pa) remains within safe limits for the selected structural materials. Titanium alloy (Ti-6Al-4V) was identified as the main structural component due to its high strength and low weight, while Alumina Glass (Al_2O_3) was chosen as a dome coating for dust and radiation protection. The results validate that the simulated aerodynamic loads are consistent with the expected mechanical resistance of these materials, supporting the habitat's safety and mission feasibility on Mars.

9.5 Limitations

While the CFD analysis provided valuable insights into the habitat's aerodynamic behavior, several simplifications were required due to computational constraints. The simulation was steady-state, isothermal, and assumed a constant atmospheric density (ρ = 0.0154 kg/m³), omitting transient effects, temperature gradients, and compressibility variations. Dust particle transport and terrain roughness were not modeled, and only one habitat module was analyzed, excluding aerodynamic interference between connected structures. Despite these limitations, the model effectively captured the key pressure and velocity gradients representative of strong Martian wind conditions, making it suitable for preliminary structural design.

10. Conclusions

User Journey

Our project aims to ensure that, during its use and implementation, the target user —in this case, astronauts with prior experience in space exploration missions— has the ability to personalize and adapt their habitat according to their specific needs. The option to modify the environment at will, organize the arrangement of modules, select construction materials, and access all integrated information, recommendations, and safety alerts within the system provides greater control and ensures optimal safety conditions during expeditions.

Improvements and Projection

- **Collaboration and shared editing:** Enable multiple users to participate simultaneously in modifying and customizing the base.
- **User management:** Develop an access control and role-based system to improve team coordination and task organization.
- **Enhanced personalization:** Incorporate advanced options for modifying objects, structures, and habitat modules.

- **Habitat management:** Once installed, the application will provide astronauts with real-time information about each habitat area, improving mission control and overall safety.

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