Exploring Optimal Geometric Shapes for Martian Habitat Design: A Comparative Analysis and Structural Evaluation

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Abstract

Designing resilient and resource-efficient habitats is essential for ensuring the safety and well-being of astronauts in the harsh Martian environment. This paper investigates optimal habitat designs capable of withstanding extreme temperatures, high radiation, and the thin Martian atmosphere, while maximizing resource efficiency and sustainability. Previous studies have explored Earth-supplied or Martian soil-based materials, but both present significant challenges. Martian soil fails under tension while the high internal pressure of habitats places additional strain on building materials. To address this, polyethylene produced from Martian CO_2 is proposed as the primary construction material due to its superior tensile strength compared to soil or Martian concrete. However, material selection alone is insufficient; building geometry also plays a critical role. Finite element analysis (FEA) was used to compare various building shapes such as spheres, cylinders, ellipsoids, domes, tori, clusters of spheres, and rectangular forms, based on their compactness and structural integrity under Martian environmental loads. Results showed that spherical and dome-shaped habitats offer the best material efficiency and high compactness. By utilizing CO2 to produce polyethylene and optimizing structural shapes, this research highlights sustainability and reduced reliance on Earth-supplied materials. The study concludes that spherical and ellipsoidal habitats are the most optimal geometric shapes for Martian building designs in terms of structural performance and compactness, reducing material usage by 23% compared to the torus shape and by 480% compared to the rectangular shape. This study contributes to the literature by structurally evaluating the most suitable geometric forms for habitat construction on Mars.

Keywords: Mars, Construction on Mars, Mars habitation, Optimization, Mars building.

1 Introduction

As humanity prepares to extend its reach beyond Earth, the need for sustainable habitats on Mars has become a focal point of space exploration efforts. Establishing a human presence on Mars is not just a scientific endeavor but a step toward ensuring the long-term survival and expansion of our species. However, the Martian environment presents unique and severe challenges, necessitating architectural solutions that prioritize efficiency, resilience, and sustainability.

The Martian surface experiences extreme temperature variations ranging from -125°C during the night to 20°C during the day at the equator [1]. Mars's atmosphere primarily comprises 95.1% CO_2, followed by 2.59% N_2, 1.94% Ar, and 0.16% O_2. Its thin atmosphere, with a pressure of 6.52 millibars (0.65% of Earth's atmospheric pressure), is near-vacuum and makes human survival impossible without pressurized and ventilated spaces. Additionally, it offers little protection against cosmic rays and solar radiation. These factors pose significant health risks to astronauts. The thin atmosphere also means that traditional construction techniques used on Earth are not viable on Mars, necessitating innovative approaches that can utilize in-situ resources and autonomous construction techniques.

Previous research has explored the use of materials transported from Earth or derived from Martian soil [2-5]; however, all approaches face significant challenges and need further investigation in terms of structural analysis. Martian soil may have some compression capacity but cannot bear the tension. High internal pressure would inevitably create tension on the building materials by bending or direct tension. The logistics of transporting construction materials and life support systems from Earth further complicate habitat design, emphasizing the need for resource efficiency and sustainability.

Numerous architectural concepts and 3D models have been proposed to construct Mars habitats. Ciardullo et al. [2] developed the Mars Ice House design, which employs innovative spatial and scalable techniques for habitat assembly using solid water as the primary material. This design addresses radiation and insulation issues while gradually transitioning between a safe interior and a hazardous external environment. However, the need to transport the Ethylene Tetrafluoroethylene (ETFE) membrane from Earth, the significant time and effort required to gather ice on Mars, and the inability to withstand high internal pressure could be considered drawbacks of this design. Kading and Straub [3] suggested 3D-printed structures for a manned Mars mission using in-situ resources. Their design utilizes a 3D printing method to build a human habitat with basalt as structural material. The total mass transport from Earth is 83,200 kg, a considerable amount given the high transportation cost. Although the model employs basalt, an in-situ material, further research is needed to evaluate the energy requirements to melt basalt and the structure's resistance concerning indoor pressure requirements. This study effectively outlines the entire habitat construction process and highlights necessary future research. However, it still requires a footing design that addresses extreme bending under inner and outer pressure differences and other requirements, which are further discussed in the subsequent section. Tenorio et al. [4] designed a Super Pressure Balloon Habitat on the moon. In this paper, a deployable structure is designed which proposes to transport the whole material from Earth. The structure was designed and optimized for a deployable balloon under indoor pressure and appears suitable for lunar habitation. However, the cost of implementing this design may be prohibitive for habitation on Mars. Both basalt and balloon designs do not meet the requirements for visible sunlight transmittance. Cohen [5] presents a review of design concepts for Mars exploration habitats up to the year 2015. Selecting the most suitable geometric shape and utilizing in-situ materials are crucial for the success of Martian habitat design. The geometric shape directly impacts thermal management, radiation shielding effectiveness, and structural integrity, all essential for sustaining human life in Mars' harsh environment. Additionally, utilizing in-situ materials reduces reliance on Earth-bound resources, lowering costs and logistical complexities while enhancing sustainability and self-sufficiency of Martian missions. Together, these choices ensure habitats are resilient, cost-effective, and capable of supporting human habitation on Mars.

1.1 Objective

The objective of this research is to investigate and compare various architectural forms to identify the most efficient and resilient designs for Martian habitats constructed using in-situ materials. The analyzed shapes include spheres, cylinders, ellipsoids, clusters of spheres, domes, tori, and rectangular forms. Each design is assessed based on two primary criteria: compactness, measured as the surface area-to-volume ratio, and structural integrity under Martian environmental loads, as evaluated using the structural analysis software SAP2000 v.25.3.

This study seeks to identify optimal architectural solutions that maximize habitable volume while ensuring astronaut safety, comfort, and long-term sustainability in the Martian environment. A lower surface area-to-volume ratio typically reflects better compactness, which is advantageous for minimizing heat loss and shielding against radiation. By examining these factors, the research aims to support the development of adaptive and sustainable habitat designs tailored to the unique challenges of Mars.

1.2 Polyethylene as a Structural Material

Polyethylene (PE) is proposed as the in-situ structural material [6]. Production involves converting Martian CO_2 into methane via the Sabatier reaction, followed by cracking to form ethylene and polymerization [7-10]. PE offers high tensile strength, radiation shielding, and reduces dependence on Earth-supplied materials, lowering costs and logistical challenges. These advantages make PE a promising structural material for Martian habitats. Although capturing trace levels of H_2 and H_2O from the atmosphere is possible, using polar or underground ice [11] is planned to provide water and hydrogen by electrolysis. A total energy of 67.4 MJ/kg (18.7 kWh/kg) is needed as a minimum to produce one kg of PE from CO_2 in the absence of H_2. The chemical formula of polyethylene (PE), a polymer with a density of 920 kg/m^3, and tensile strength of 40 MPa, is $(C_2H4)n$ [12].

2 Methodology and Comparison Criteria

Each architectural form is analyzed and compared based on the following criteria:

Compactness: Evaluated using the surface area-to-volume ratio, which affects material efficiency and energy consumption.

Structural Integrity: Assessed through Finite Element Analysis (FEA) for load-bearing capacity under Martian loads.

Finite Element Analysis (FEA) is used to evaluate the structural integrity of the habitat designs under various load conditions in order to accurately assess the performance of each habitat design. FEA helps in identifying stress distribution, potential failure points, and overall stability of the structures. The shapes considered in this analysis, such as the sphere, cylinder, ellipsoid, cluster of spheres, dome, torus, and rectangle, are modeled in Sap2000 v.25.3 and analyzed under the loads mentioned above.

The architectural forms considered in this study are as follows: sphere, cylinder, ellipsoid, cluster of spheres, dome, torus, and rectangle. Each shape is modeled and analyzed under the Martian loads to meet the standardized living area of 250 m² and 2.5 m floor height [13]. The compactness and structural integrity parameters are calculated and compared to determine Mars' most efficient and resilient habitat design.

The following methodology outlines the standardized parameters, analysis criteria, and simulation techniques used to evaluate each shape.

Standardized living area and floor height: For a consistent basis of comparison, each habitat design is standardized to enclose a living area of 250 m^2 with with a deviation of less than 2%. This standardized area is chosen to ensure sufficient space for six astronauts to live and work comfortably, incorporating essential life support systems, communal areas, and private quarters. The dimensions of each shape are adjusted to meet this area requirement while maintaining their inherent geometric properties. If necessary, each habitat may be designed as a multi-story structure, and each floor is standardized to have a 2.5-meter height and a main column in the middle of the structure.

Compactness: It is evaluated using the surface area-to-volume ratio (SA/V). This ratio is crucial as it impacts the amount of material needed for construction, insulation, and the efficiency of internal climate control. A lower SA/V ratio is generally preferred as it indicates a more compact structure, requiring less material and energy.

Surface Area (SA): The total external area of the habitat, which affects the amount of material needed for construction and the exposure to external environmental factors.

Volume (V): The internal habitable volume determines the usable living space available for the crew.

Structural Integrity: The structural integrity of each habitat is analyzed under Martian loads, including dead, live, dust, wind, marsquake, micro-meteoroid, internal pressure, thermal insulation, and radiation shielding [6, 14]. The loads on Mars are discussed and calculated as follows:

Dead load: The permanent, static weight of the structure itself, including walls, floors and stairs. The gravitational acceleration of Mars (g_M) is 3.72 m/s^2; thus, the dead load on Mars would be less compared to terrestrial structures.

Live load: The dynamic or changing weight within the structure, such as the weight of astronauts, movable furniture, and other temporary items or equipment. A uniform live load of 2 kPa for a residential building is considered [15] and it is applied to the slabs of the building.

Internal pressure load: The need to maintain a pressurized environment inside the habitat against the thin Martian atmosphere. The ultra-low atmospheric pressure on Mars (0.6% of Earth) is not suitable for human life so a positive indoor pressure of 1 atm ≅ 101 kN/m^2 = 103 kPa is needed. Humans cannot tolerate pressures below 0.65 atm for extended periods; thus, an indoor pressure of 1 atm is targeted (with 0.35 atm as a safety margin). The internal pressure of 1 atm is uniformly applied outward from inside the building.

Dust load: The accumulation of Martian dust on the surface of the structure, which can add weight and impact the integrity and functionality of the habitat. Assuming a thickness of $75*10^{-6}$ m and a surface density of 2600 kg/m^3, the dust load will be 2 Pa [16]. The dust load due to dust accumulation is minimal and unlikely to impact the structural integrity of a well-designed Martian habitat. However, it is applied to the structure uniformly in the gravity direction. The primary concern with dust would be operational issues, such as clogging of mechanical systems, reduction in solar panel efficiency, and wear on moving parts, rather than structural failure.

Wind load: The force exerted by Martian winds on the structure, which can vary in intensity and direction, affecting the stability and design requirements. The wind storms on Mars can be intimidating, the thin atmosphere would barely create any force on the structures. The wind force is a function of wind speed and air density according to Eurocode EN 1991-1-4 (Eqn. 1) [17]. Martian air is about 0.02 kg/m³, only about 1.6% of Earth's air density (ρ = 1.25 kg/m³). A maximum wind speed of about 34 m/s is calculated at a height of 10 m at the Viking 2 site [18] which will be calculated less at lower heights.

$$q_b = 0.5*\rho_{air}*V_b^2 \qquad (1)$$

where q_b is design wind pressure, ρ_{air} is air density and V_b is basic wind velocity.

$$q_b = 0.5*0.02\ kg/m^3 * (34\ m/s)^2 = 11.8\ Pa.$$

Marsquake load: The seismic forces generated by tectonic activity on Mars, which can cause vibrations and stress on the structural components. Marsquakes, similar to Earth's earthquakes, occur as well, with the largest magnitude of 4.7 M_w recorded by NASA's InSight lander in 2022 [19]. InSight showed that the average depth of the crust of Mars is about 50 to 60 km, which is three times the depth of Earth's crust [20]. This means that marsquake waves should travel longer distances from the mantle to the surface, which would strongly dampen the quake components. Moreover, the weight of the buildings on Mars is 1/3 less than structures on Earth. A magnitude 4 Richter marsquake would be much less dangerous than a shallow 4 Richter earthquake which might not even be perceptible to humans. Therefore, in this study, marsquake loads are not applied to the building assuming the marsquake loads are negligibly small.

Thermal Insulation: Thermal insulation refers to materials and techniques used to reduce heat transfer between the interior and exterior of a building. Thermal insulation is essential for maintaining a stable temperature inside the building, ensuring a comfortable and safe environment for humans, plants, and equipment. Insulation is critical for protecting against low temperatures (annual average temperature is -63.0°C, ranging from -153°C to +20.0°C [1] and fluctuations (about 70°C daily temperature changes) on the planet. Heat loss for multiple layers of different materials can be calculated by considering the total thermal resistance $R_T=\Sigma(t_i/k_i)$, and the total energy loss is given by $W=A*\Delta T/R_T$, where W represents joules per second (Watt), k_i is the thermal conductivity coefficient of each layer, A is the surface area, ΔT is the temperature difference between the inner and outer surfaces, and t_i is the material layer thickness. Assessing the formulas in terms of geometric shape the total energy loss increases in direct proportion to the surface area. That is, for a fixed volume and wall thermal resistance, minimizing surface area reduces overall heat loss.

Radiation Shielding: The habitat's ability to protect inhabitants from cosmic and solar radiation. Radiation shielding is particularly crucial due to the thin atmosphere of Mars, unlike Earth, which benefits from a thick atmosphere and a magnetic field providing natural protection to its inhabitants. The material type and thickness of the layer affect the radiation shielding level. In the proposed model, PE is utilized as the primary structural material, serving as an effective shielding material against galactic cosmic rays (GCR) due to its high hydrogen content and low atomic number. Research [21] has demonstrated that PE demonstrates the best overall performance for radiation shielding compared to liquid hydrogen, aluminum, graphite, epoxy, water, and Mars regolith. This is due to its superior attenuation of high-energy ions and secondary particles, mass and volume efficiency, lightweight nature, reduced production of secondary particles, hydrogen-rich content, and high electron density per unit mass.

Micro-meteoroid load: The potential impacts of micrometeoroids are a concern for habitation on Mars. Micrometeoroids travel at extremely high speeds, up to 9 km/s [22]. Despite their lightweight masses ranging from 10^{-6} to 10^{-2} grams [23], their high velocities can generate up to 0.5 kJ of kinetic energy, posing a risk of puncturing small holes in MSBs. The required diameter of a micrometeoroid to penetrate a 100 mm thick layer of PE is calculated as 8.7 mm by Eqn. 4 using the energy method; assuming an average density of 3000 kg/m^3 for the micrometeoroid, an impact velocity of 9 km/s.

$$\tfrac{1}{2}\, m_{mm}v^2 = \sigma_{PE} * (2/3)\pi r_c^3 \qquad (2)$$

where m_{mm} is the mass of a micrometeoroid, v is the velocity of a micrometeoroid, σ_{PE} is the strength of PE, and r_c is the radius of the crater.

This means that micrometeoroids with a diameter smaller than 8.7 mm will not be able to penetrate a 100 mm thick PE layer, which constitutes most of the micrometeoroids. The frequency of impact is calculated using a curve fit to available data [24] as 1.93E10^{-6} particles/m^2/year for micrometeoroids larger than 8.7 mm in diameter. Assuming a service life of 50 years for an MSB, the probability of a 500 m^2 area being hit by a micrometeoroid (d>7.9mm) is calculated to be $1 - [1 - (3.42^{-6}*500)]^{50}$, meaning that the total probability of at least one damaging impact over the 50-year lifespan is only about 4.7%. If the inner 100 mm thick PE would also be punctured, the meteoroid diameter 10.96 mm, reducing the probability to 1.17%, which is lower than the probability associated with a 2475-year return-period earthquake on Earth. A hole plugger tube with an extending arm may need to be installed inside the MSB to be quickly used to repair a hole in the 1.17 % rare event of a micrometeoroid hit. The frequency of impact versus micrometeoroid size according to [24] is curve fitted and extrapolated data is displayed in Figure 1.

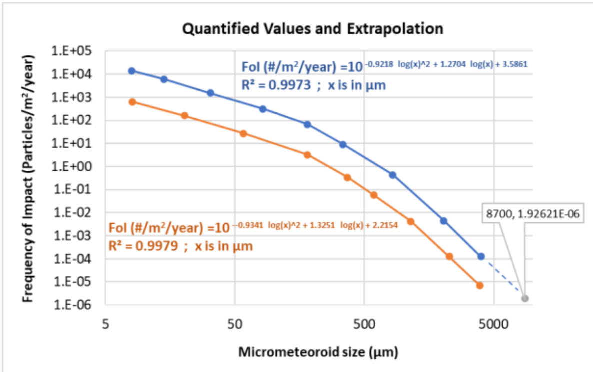

Figure 1 Micrometeoroid size versus frequency of impact (FoI) curve fitted and extrapolated data

3 Analysis Results

The analysis section incorporates various demands described in Section 2 which are used to analyze the Martian buildings considering the methodology and semantic correlation. Each subsection below discusses the analytical requirements and then relevant comparisons.

3.1 Compactness Analysis Results

Each geometric shape is assumed to have a standardized living area of 250 m² and a 2.5 m floor height. The 3D geometries of models are initially prepared using the Rhino 8 software. The surface area-to-volume ratios (compactness) for each architectural form were calculated both analytically and numerically, and the results are summarized in Table 1. Lower ratios indicate more compact structures, which are advantageous for minimizing material use, enhancing thermal efficiency, and radiation shielding.

Table 1: Compactness calculations for each shape

Shape	V (m^3)	SA (m^2)	Compactness (SA/V)
Sphere	700.7	381.5	**0.544**
Cylinder	683.2	432.0	0.632
Ellipsoid	630.7	363.1	0.576
Cluster	1111.5	733.3	0.660
Dome	575.2	398.2	0.692
Torus	987.0	789.6	0.800
Rectangle	812.7	522.8	0.643

The sphere and secondly the ellipsoid shapes are the most efficient shapes in terms of surface area to volume ratio, making them suitable for designs prioritizing material efficiency. The dome also shows good structural efficiency. In contrast, the torus and cluster of spheres are less efficient, with higher compactness ratios. These insights can guide the selection of shapes for habitat design on Mars, balancing material use, structural integrity, and habitable volume.
The sphere demonstrates excellent material efficiency with a compactness ratio (surface area-to-volume ratio, SA/V) of 0.544. Its minimal surface area relative to its volume indicates reduced heat transfer through the walls, optimizing thermal insulation and energy efficiency, which is crucial for maintaining stable internal temperatures on Mars. In terms of compactness, both the sphere and ellipsoid shapes are highly feasible for habitation design on Mars. However, further structural integrity analyses are necessary to provide a more comprehensive evaluation of their suitability for Martian habitats.

3.2 Structural Integrity Analysis Results

FEA was performed on each habitat design to assess their structural integrity under Martian loads. The shapes are modeled in Sap2000 v25 and analyzed under dead, live, dust, wind, and internal pressure loads. The principal stress distribution and potential failure points were identified, and the structural integrity is discussed.
To define and model the candidate geometries in the structural analysis software, the following inputs were specified in SAP2000 v25. Polyethylene was modelled with a density of 920 kg/m³, an elastic modulus of 1000 MPa, a Poisson's ratio of 0.30, and a coefficient of thermal expansion of 1.17×10^{-5} /°C. The load cases considered in the analyses are simply modified with a scale of 0.38 for dead load related load cases.
A certain amount of damage is allowed in the design of terrestrial structures. Inter-story drift ratio higher than 1 % usually causes damage and plastic behavior in structures. However, an inter-story drift ratio of up to 2 % is usually allowed by design codes for residential buildings [25, 26]. This is because damage in terrestrial structures does not always lead to disaster. The environmental condition on Mars is completely different from terrestrial approach and requires a new perspective. As Mars has a harsh environment, Martian structures would experience different conditions compared to terrestrial structures. Slight structural damage in Martian structures would lead to disaster. For example, On Mars, a small crack that allows air leakage can cause freezing, expansion, crack propagation, and finally, collapse. Thus, unlike terrestrial structures, structural damage is not allowed for Martian structures and probable structural loads and combinations should be calculated in accordance with the worst-case scenario.
The structures are designed according to Allowable Stress Design (ASD) and a factor of safety of 2 is applied to the design. The member's stress limit is set to 40/2=20 MPa in an elastic range.
Probable Martian structural loads were studied, calculated and investigated using the results of previous studies and valid data from Martian landers, rovers and orbiters (Table 2). Although it is seen from the table that dust and wind loads are negligibly small, still the loads are loaded to the shapes analyzed. Due to lack of complete knowledge, short span of data recorded, Martian environment and hazardous environment that were mentioned and expressed before, all Martian structural loads were calculated in accordance with the worst-case scenario.

Table 2: Applied Martian loads and their specifications.

Load Type	Quantity	Specification
Dead	Self-weight on Mars	Gravity on Mars (g_M) is 3.72 m/s^2; thus, the dead load on Mars would be less compared to terrestrial structures.
Live	2 kPa	The weight of astronauts, movable furniture, and other temporary items or equipment.
Dust	2 Pa	Martian dust load on the surface of the structures.
Wind	11.8 Pa	The force exerted by Martian winds on the structure.
Internal Pressure	103 kPa	Pressurized environment inside the habitat against the thin Martian atmosphere for human life (1 atm).

3.3 FEA Results

The structural shapes are modeled as explained in the previous sections and the load assignments are applied. The structures are analyzed for two cases. First case is considered to construct the whole structure in a staged construction as follows:

Stage 1: Outer layer of the sphere and dead load
Stage 2: Stage 1 + Internal Pressure
Stage 3: Stage 2 + Slabs + Column
Stage 4: Stage 3 – Internal Pressure
Stage 5: Stage 4 + Internal Pressure + Other Loads

The second case is to construct the whole building which is called non-staged construction.

Non-Staged: The building is printed once with all members including shell, slabs and columns and loaded in terms of load combinations.

Uniform tensile stress distribution is considered, and local high stress concentration is neglected. The maximum principal stress results for various shapes under the dominant load combination are presented for the sphere in Figure 2. Figure 2a shows Stage 1, which consists of only the outer layer of the structure and the dead load. Stage 2 (Figure 2b) includes Stage 1 along with the internal pressure load. Stage 3 (Figure 2c) represents the addition of the structural slabs and column members to Stage 2. Stage 4 (Figure 2d) illustrates the stress results when the internal pressure is temporarily removed after the slabs are in place. Finally, Stage 5 (Figure 2e) shows the stress results with internal pressure reapplied and all remaining loads added to the structure. For staged construction, Stage 5 was observed to be the most critical stage in terms of stress analyses.

The staged construction analyses (Stage 5) stress results are compared with the analysis results of the building printed once (non-staged) with all members under exposed loads. In this comparison the more optimized construction method is selected. In FEA, 17 mm shell thickness for sphere model resulted from the numerical model in order to provide 20 MPa limit stress. It is obvious that staged construction is more optimized for sphere shape comparing Figure 2e and 2f for sphere.

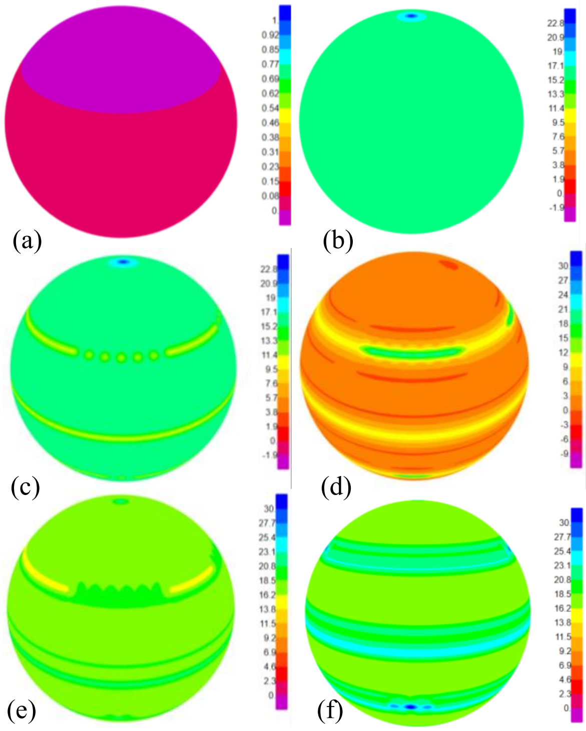

Figure 2 a) Stage 1 b) Stage 2 c) Stage 3 d) Stage 4 e) Stage 5 f) Non-Staged Construction

The same procedure is conducted for the rest of the geometrical shapes studied and the numerical stress results for the most optimized cases (either stage-5 or non-staged) are shown in Figure 3.

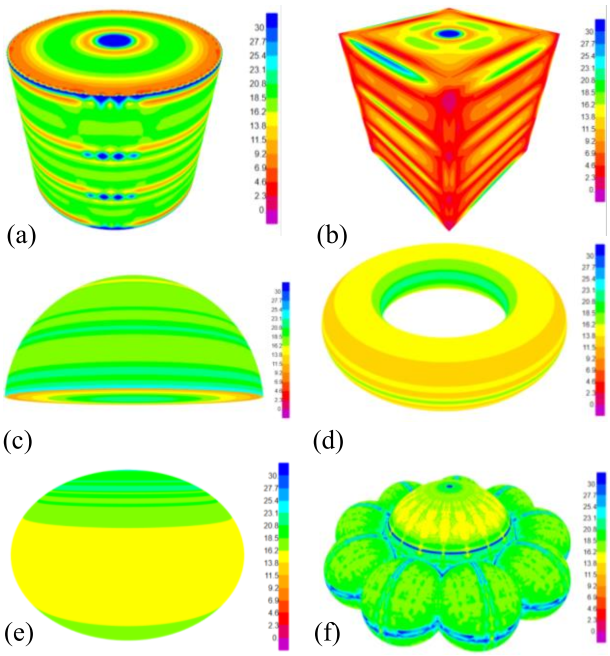

Figure 3 a) Cylinder b) Rectangular c) Dome d) Torus e) Ellipsoid f) Cluster of spheres

The thicknesses are arranged for the stress limitation, and the total weight of the structures are tabulated in Figure 4.

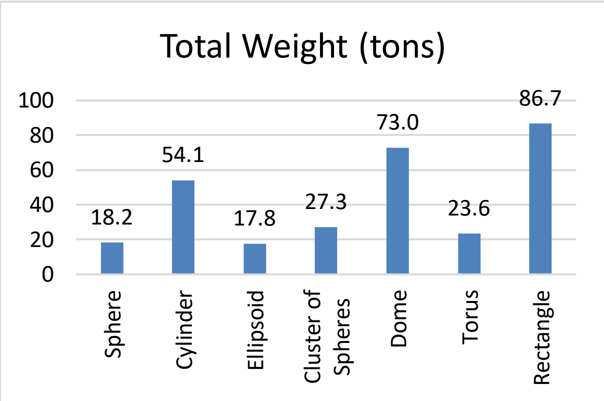

Figure 4 Total weights of PE in terms of shape of the building.

Showing the most, with results indicating that spherical and dome-shaped habitats exhibit superior load distribution and stability. Considering a building for six astronauts with a total living area of 250 m^2 and a floor height of 2.5 meters, 18.17 tons of PE material will be used to construct the building which is less compared to the rest of shapes. Cylindrical and ellipsoid structures also performed well, with manageable stress levels and robust structural properties. Clusters of spheres and toroidal designs presented unique challenges in terms of connection points but offered redundancy and flexibility. The rectangle, while simpler in construction, required additional reinforcement to withstand internal pressure and thermal stresses.
To validate the numerical analyses, analytical calculations were performed for each shape. For cylindrical geometries, hoop stress is determined using the formula p*r/t, and the longitudinal (axial) stress is calculated as p*r/2*t, where p represents the internal pressure, r is the radius of the cylinder, and t denotes the shell thickness.
A similar approach was applied to the other geometric shapes, ensuring comprehensive verification of the numerical results.

4 Conclusion

This study provides a comprehensive comparative analysis of various geometric shapes for Martian habitat design, highlighting the significance of compactness, structural integrity, and material efficiency. Among the shapes analyzed, spherical and dome-shaped habitats emerged as the most efficient in terms of compactness, offering superior protection against radiation and minimizing material use due to their low surface area-to-volume ratios. These qualities make them ideal candidates for maintaining thermal stability and enhancing radiation shielding, both of which are critical for long-term human habitation on Mars. The spherical shape, with a compactness ratio of 0.544 and a material requirement of 18.17 tons, was identified as the most suitable and optimized option for habitat design on Mars. Cylindrical and ellipsoidal shapes, while slightly less compact, demonstrated strong potential for modular expansion and practical internal space utilization. Their more linear configurations allow for easier division into functional spaces, which can enhance crew productivity and comfort in extended missions. Clusters of spheres and toroidal shapes presented innovative designs that promote flexibility and adaptability to varying Martian terrains, although their higher material requirements and complex connection points may pose construction challenges.
The use of in-situ polyethylene, derived from Martian CO_2, plays a crucial role in reducing dependency on Earth-supplied materials and ensuring the sustainability of these designs. Polyethylene's superior tensile strength, combined with the optimized geometric shapes, creates a robust architectural solution that can withstand the harsh Martian environment, including high internal pressures, dust accumulation, and potential micrometeoroid impacts.
This research underscores the importance of integrating local resource utilization with advanced architectural design to create habitats that are not only functional and resilient but also sustainable. By leveraging the Martian atmosphere's CO_2 to produce building materials, the feasibility of long-term human exploration and settlement is significantly enhanced. The insights gained from this study contribute to the growing body of knowledge required to support sustainable human presence on Mars, paving the way for future colonization efforts.
Further research should focus on the practical implementation of these designs, including large-scale testing of polyethylene production processes on Earth and the development of construction techniques that could be used by autonomous systems or astronauts on Mars. Additionally, more detailed studies on construction methodology and energy supply analyses will be necessary to refine and optimize these habitat designs for real-world use.

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