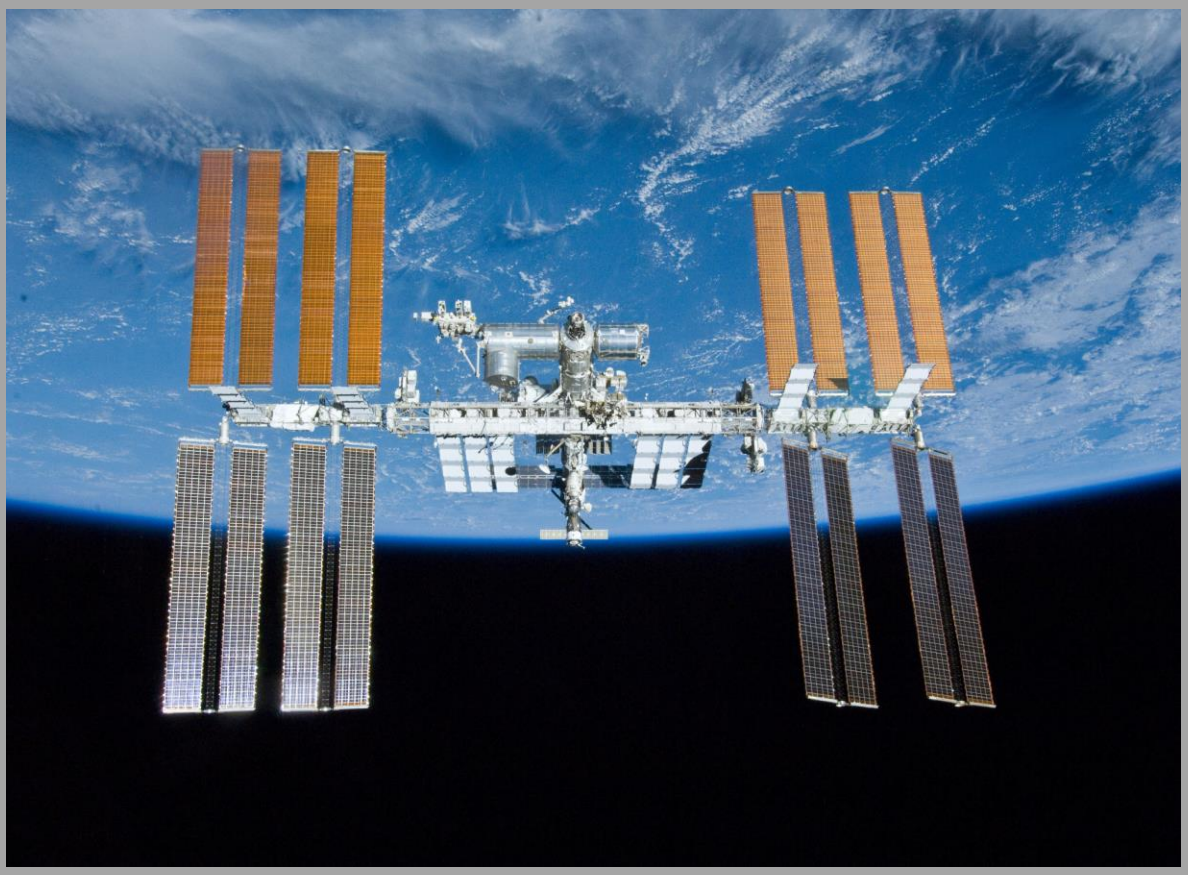
20 top space architecture designs every architect must see

8 Minutes Read



Space architecture, also known as space habitation design, is a branch of architecture and engineering that focuses on designing and planning habitats and structures for human space exploration, space tourism, and potential colonization of celestial bodies such as the Moon and Mars. This area blends architectural ideas with the specific challenges of planning for space.

20 Noteworthy Space Architecture Designs:

1] ISS(International Space Station)

The International Space Station (ISS), a collaboration between European countries (represented by ESA), the United States (NASA), Japan (JAXA), Canada (CSA), and Russia (Roscosmos), is the world's largest international cooperative scientific and technological venture. Between 1984 and 1993, the station's design was completed. Beginning in the late 1980s, elements of the station were being built in the United States, Canada, Japan, and Europe.
The International Space Station weighs about 400 tons and covers an area larger than a football field. It would have been impossible to build the orbit Station on Earth and then launch it into orbit at the same time because there is no rocket large enough or powerful enough. To avoid this problem, the Space Station was launched into space in sections and gradually built 400 kilometers above the Earth's surface.

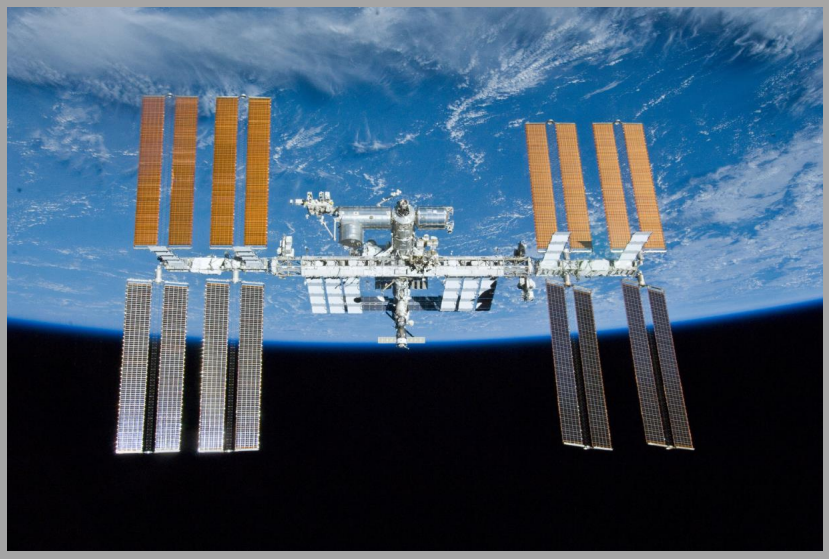


Figure 1_ISS_© https://www.esa.int/kids/en/learn/The_ISS

2] Skylab

Skylab was the first space station in the United States, operating from 1973 to 1974. It was a pioneering effort in human spaceflight, serving as a laboratory for scientific research as well as a platform for astronauts to live and work in space for extended periods. Skylab contributed significantly to our understanding of living and working in space, as well as conducting scientific research and preparing for future long-duration missions. It is still a major element of human spaceflight and exploration history.

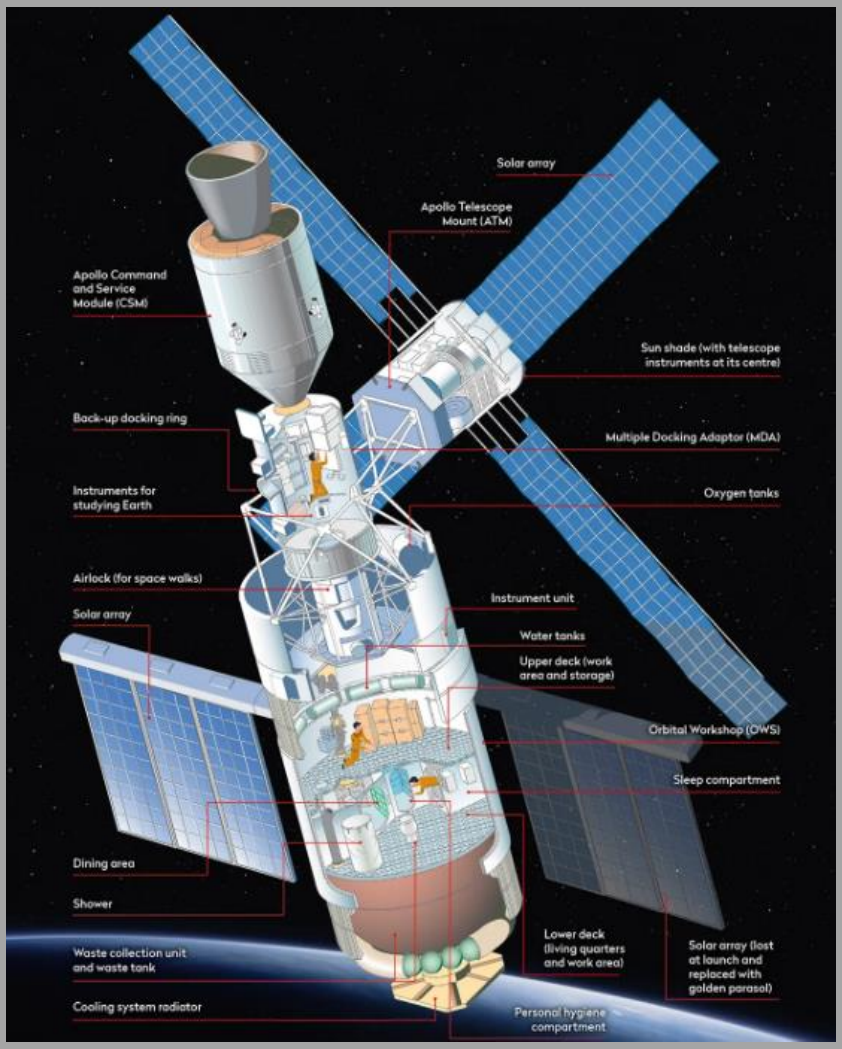


Figure 2_Skylab_© https://www.skyatnightmagazine.com/space-missions/skylab

3] Space Stations Salyut and Mir

The Soviet Union developed and later continued two important space station initiatives, Salyut and Mir. These space stations were important in human space exploration and provided crucial training for long-duration space missions. The Salyut and Mir space stations made substantial contributions to our understanding of living and working in space for lengthy periods, and they were critical milestones in space exploration. While these individual space stations are no longer in orbit, their legacy lives on in the form of the International Space Station and future space dwelling and exploration missions.

Figure 3_Salyut_© https://www.britannica.com/technology/Salyut

4] Tiangong Space Station

The Tiangong Space Station, often known as the Chinese Space Station, is a Chinese modular space station program. It represents China's long-term presence in space for scientific study, technology development, and international cooperation. The Tiangong Space Station highlights China's considerable advances in space technology as well as its long-term human spaceflight objectives. It also represents China's rising position in the international space community and opens the door to future collaboration in space exploration.

Figure 4_Tiangong Space Station_© https://cdn.mos.cms.futurecdn.net/RdV4BJCVXhYEgpT2vtRyUU.jpg

5] Mars Dune Alpha

Mars Dune Alpha is a pioneering space architecture concept designed for sustainable human habitation on Mars. This innovative structure aims to address the unique challenges posed by the Martian environment, offering a safe and comfortable living space for future Mars colonizers.

The Mars Dune Alpha draws inspiration from the natural landscape of Mars, specifically its iconic dunes. The structure is composed of modular units resembling interlocking sand dunes, creating a visually striking and functional habitat. These modules are constructed from advanced materials, providing durability and protection against the harsh Martian conditions, including extreme temperatures, radiation, and dust storms.

One of the key features of Mars Dune Alpha is its modular design, allowing for easy expansion as the Martian colony grows. Each module serves a specific purpose, such as living quarters, research labs, and communal spaces. The modularity enables efficient construction and adaptability to changing needs, promoting a sustainable and scalable approach to Martian architecture.

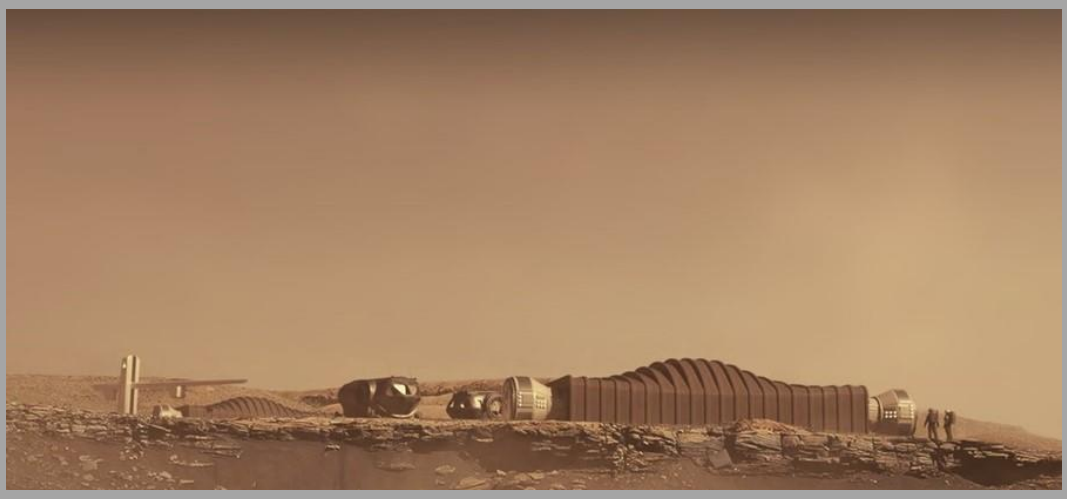


Figure 5 _Mars Dune Alpha_© https://www.dazeddigital.com/life-culture/article/59733/1/mars-dune-alpha-the-year-long-simulator-prepping-nasa-for-life-on-mars

6] Lunar gateway

The Lunar Gateway will be humanity's first space station around the Moon, built in collaboration with international and commercial partners, and will be an essential component of NASA's deep space exploration goals to the Moon, Mars, and beyond. Gateway is an important part of NASA's Artemis plans to return to the Moon and pave the way for the first human missions to Mars. The tiny space station will be a multi-purpose outpost circling the Moon, providing critical support for lunar surface missions, a scientific destination, and a staging site for future deep space travel. Gateway is being built in collaboration with commercial and international partners.

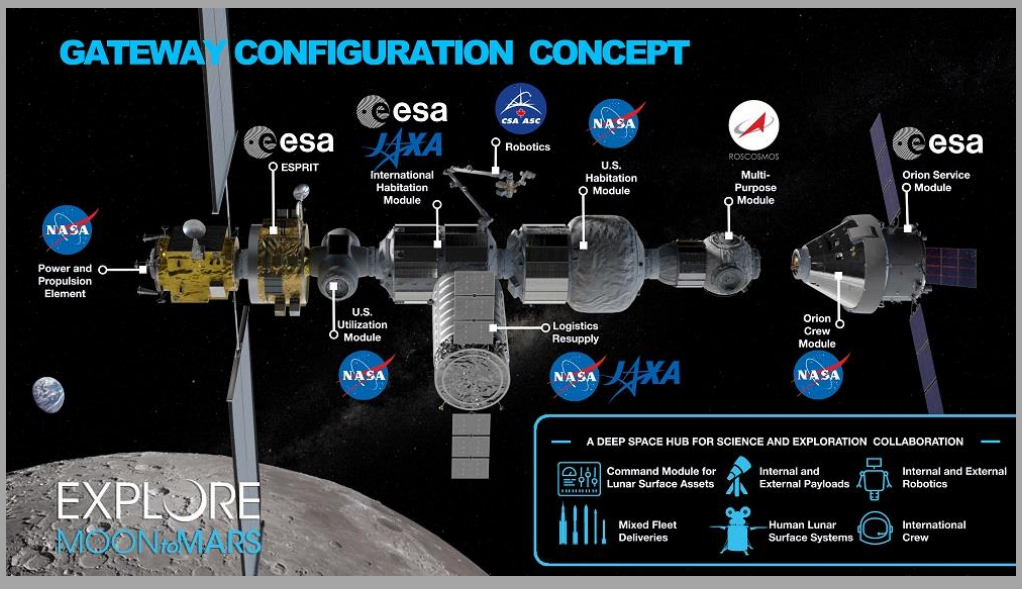


Figure 6_Lunar Gateway_© https://spacenews.com/op-ed-lunar-gateway-or-moon-direct/

7] Bigelow Expandable Activity Module (BEAM)

The Bigelow Inflatable Activity Module (BEAM) is a NASA-contracted experimental inflatable space station module created by Bigelow Aerospace. The Bigelow Extendable Activity Module (BEAM) is an International Space Station extendable habitat technology demonstration. Expandable habitats significantly reduce the amount of transport volume required for future space trips. The BEAM weighs around 3,000 pounds (1,360 kg). The BEAM is made up of two metal bulkheads, an aluminum structure, and various layers of soft fabric spaced apart to cover an internal restraining layer and bladder system. Three to four times each year, space station crew members will enter the BEAM for a few hours at a time. They will take measurements and analyze its effectiveness to help advise future habitat system designs. Learning how an expandable habitat performs in an orbital environment and how it reacts to temperature changes, radiation, micrometeoroids, and other forms of orbital debris will provide answers to key questions about living and working in an expandable module in the harsh environment of space.

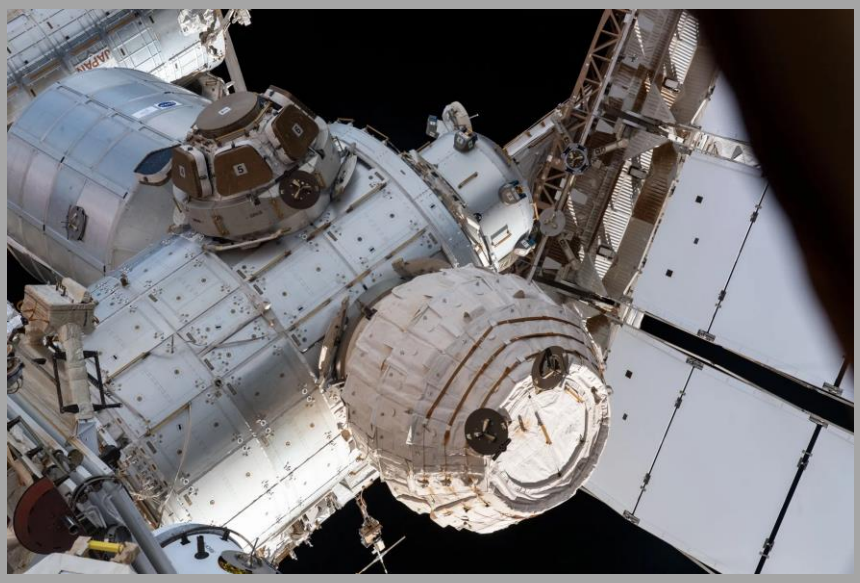


Figure 7_BEAM_© https://www.nasa.gov/wp-content/uploads/2023/03/beam-iss067e214089.jpg?w=2048

8] Mars Ice House

On long-duration Mars surface missions, galactic cosmic radiation poses a major risk to human health. Mars Ice Home is a transportable Mars housing idea that utilizes in situ resource usage produced from ice as radiation shielding and as a structural component. The water ice fills and freezes within the precision-manufactured inflatable membrane's cellular pockets. The interior of the habitat will be insulated from the ice by a cellular layer of carbon dioxide taken from the Martian atmosphere.

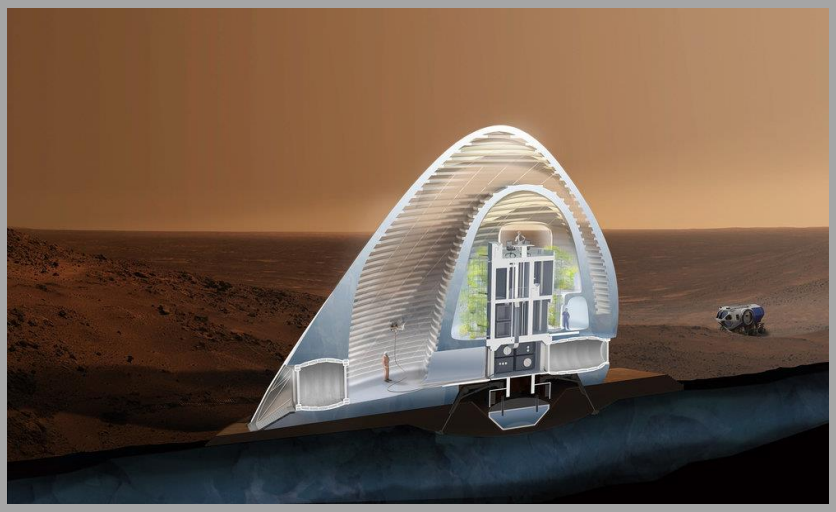


Figure 8_Mars ice house_© https://images.squarespace-cdn.com/content/v1/56a6579ab204d52e0646b187/1483628975137-SJKSE9UV8IFSK6M51SMC/Mars-Ice-House_section_lr_2000.jpg?format=1000w

9] Skylon Spaceplane

Reaction Engines Limited, a British aerospace company, built the Skylon spaceplane as a hypothetical single-stage-to-orbit (SSTO) spaceplane. While the Skylon is an ambitious and unique design, it's worth noting that, in September 2021, the Skylon was still in the idea and development phase, with no operating Skylon spaceplanes. By integrating air-breathing and rocket propulsion technology, the Skylon spaceplane concept proposes a novel method for space access. If created and operationalized successfully, it might have a substantial impact on the economics of space transportation.

Figure 9_Skylon Spaceplane_©https://www.aerospace-technology.com/wp-content/uploads/sites/15/2017/10/5-skylon-vehicle.jpg

10] Stanford Torus

The Stanford Torus is a suggested space habitat or space station concept for human colonization of space. It was invented in the 1970s by a group of Stanford University scientists and engineers, hence the name. The idea is for a massive, donut-shaped structure to offer a self-sustaining habitat for a permanent human presence in space. While the Stanford Torus is a well-known design that has piqued the interest of space enthusiasts, it has yet to be built or launched into space. The concept of large-scale space homes and colonization remains a vision for the future, and several alternative designs and concepts for space habitats and space exploration are being studied by space organizations and private businesses.

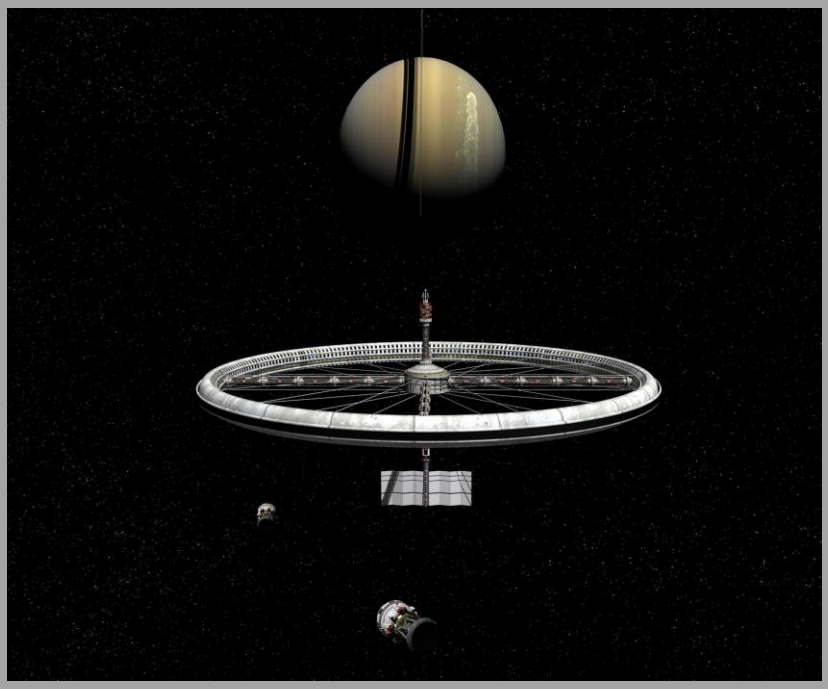


Figure 10_Stanford Torus_© https://www.deviantart.com/william-black/art/Stanford-Torus-Space-Colony-397486448

11] O'Neill's Space Xanadu

The concept of "O'Neill's Space Xanadu" most likely relates to Gerard K. O'Neill's vision for the establishment of massive, self-sustaining space homes in the form of rotating space colonies. O'Neill's vision was not dubbed "Space Xanadu," but it shared the idea of establishing enormous space colonies where people might live and work in a comfortable and self-sufficient environment, similar to a paradise. While O'Neill's vision was not realized during his lifetime, and the concept of space colonies remains in the realm of science fiction and fantasy, his ideas have had a significant impact on the field of space exploration, inspiring further discussions and designs related to space habitats and long-term human presence in space.

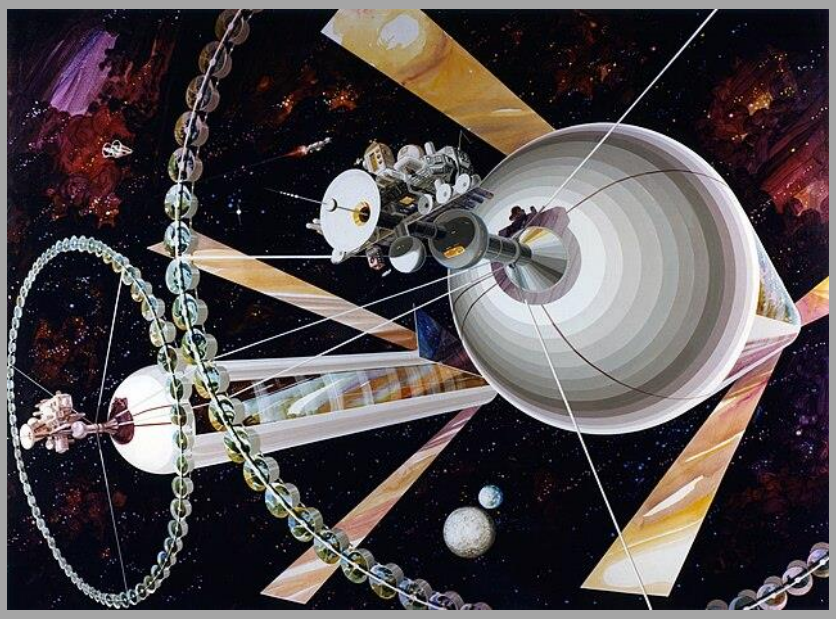


Figure 11_O'Neill's Space Xanadu
_©https://upload.wikimedia.org/wikipedia/commons/thumb/1/16/Spacecolony1.jpg/640px-Spacecolony1.jpg

12] Blue Origin and Sierra Space's Orbital Reef

Embarking into uncharted frontiers, Orbital Reef pioneers revolutionary space architecture, unlocking Low Earth Orbit (LEO) for groundbreaking use cases. Developed, owned, and commercially operated, this innovative habitat simplifies space access complexities, opening doors for diverse customers. Orbital Reef's design centers on a novel approach to space living with expansive modules featuring Earth-facing windows, offering breathtaking views and weightless comfort. Thoughtfully crafted living and working quarters ensure a safe, practical, and inspiring environment.

Cutting-edge research facilities accelerate scientific discoveries, supported by seamless logistics, advanced robotics, and the Single Person Spacecraft for routine operations. Cost-effective transportation, including the Dream Chaser spaceplane, Starliner spacecraft, and New Glenn launch system, anchors the habitat's accessibility.

Orbital Reef becomes a haven for researchers, providing all necessities for fundamental science and applications development. From experiment accommodations to spacious laboratories with next-gen facilities, our habitat simplifies complexities, making orbital work easier than ever.

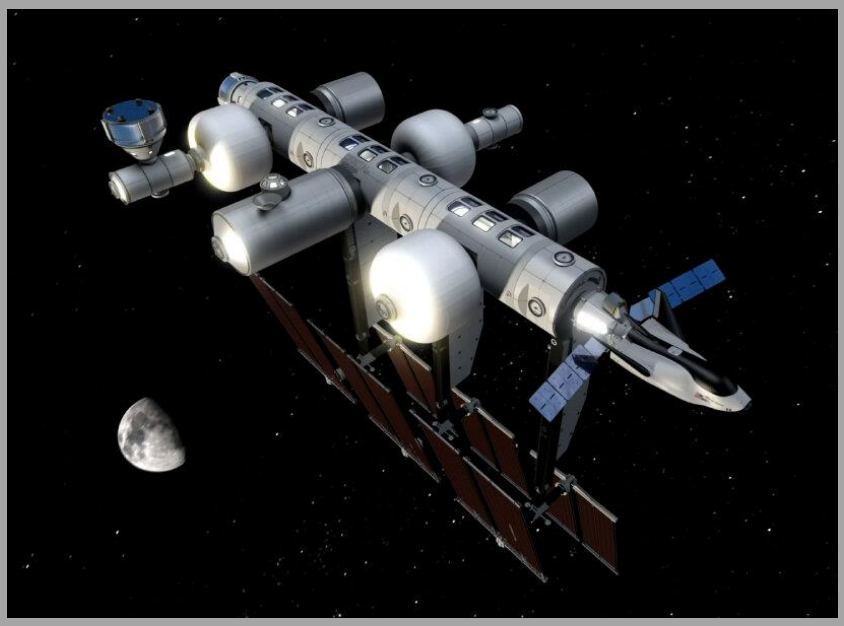


Figure 12_Blue Origin and Sierra Space's Orbital Reef_©https://www.designboom.com/wp-content/uploads/2023/01/sierra-space-orbital-reef-dream-chaser-designboom-01.jpg

13] Von Braun Station

The Von Braun Rotating Wheel Space Station is an iconic example of forward-thinking space architecture, flawlessly combining functionality, sustainability, and the pursuit of human exploration beyond Earth. This space station, named after the famous aerospace engineer Wernher von Braun, is intended to create a comfortable and habitable environment for long-term human presence in space.

The Von Braun revolving Wheel Space Station is defined by its unusual revolving wheel structure, which simulates artificial gravity using centripetal force. The revolution of the wheel produces a gravitational influence on the inner surface, giving residents a sense of weight similar to that of Earth. This ground-breaking design solves the physiological concerns of prolonged microgravity exposure.

The Von Braun Station is made up of twenty-four cylinder modules, each measuring twenty meters in length and twelve meters in diameter. There is a total of 12,000m2 available for the 24 modules, with each module providing 500m2 of usable space over 3 levels. These 24 modules will have a combined volume of 2130 m3. That is 2,3 times the 915 m3 pressurized volume of the International Space Station, which is 51 m long and 109 m broad. The Von Braun Station is expected to be built in two years, according to the researchers (the ISS took twelve years to assemble).

The station is made up of connected modules that are positioned around the revolving wheel's rim. Living quarters, command headquarters, and research facilities are all housed in these modules. Each module's wide windows provide incredible panoramic views of the universe, encouraging a sense of connectedness to the expanse of space. The interior's layouts, lighting,

and air circulation have all been thoroughly considered in order to maximize living circumstances.
The Von Braun Rotating Wheel Space Station incorporates closed-loop environmental control systems, recycling technologies, and sophisticated life support systems. By minimizing the need for resupply missions from Earth, these elements help the station become more self-sufficient and less environmentally impactful. The wheel's movement also helps control radiation exposure, improving the residents' general safety and wellbeing.

Figure 13 _Von braun station_© https://www.kidsnews.com.au/space/designs-revealed-for-the-von-braun-rotating-space-station-hotel/news-story/defa75603b25c48cfc9877e5e44b3e6f

14] Orion Span's Aurora Space Station

The Aurora Space Station was a low-Earth orbital private commercial space station proposal. Orion Span, a Houston-based commercial space agency, announced it in March 2018. The station was built to accommodate six passengers at a time, including two crew members, for 12-day space travel tours. The station was supposed to be around the size of a large private jet's cabin (4312 feet long and 14 feet broad). It was expected to circle Earth at a height of roughly 200 miles, somewhat lower than the International Space Station's altitude of 250 miles. Orion Span declared its intention to cease operations in 2022. A 12-day stay would have cost tourists $9.5 million.

Figure 14 _Orion span’s aurora space station_© https://cdn.mos.cms.futurecdn.net/FQFjVGVBh9kGSXXVjoh4Hk.jpg

15] SpaceX Starship

It's the world's largest and most powerful rocket, with much more thrust at liftoff than NASA's famed Saturn V moon rocket. Both aspects of Starship are intended to be fully and quickly reusable. Starship is the world's most powerful launch vehicle, capable of delivering up to 150 metric tons entirely reusable and 250 metric tons disposable.
Starship, with the Super Heavy launch vehicle, is the successor of SpaceX's earlier rockets: the Falcon 1, Falcon 9, and Falcon Heavy. The Super Heavy's first stage would be capable of lifting 100,000 kg (220,000 pounds) to low Earth orbit, making it the most powerful rocket ever built. The payload would be Starship, a massive spacecraft planned for a variety of uses, including quick transportation between cities on Earth and the establishment of outposts on the Moon and Mars. Both the Starship and the Super Heavy would be reusable, making it the first such system. The combined Super Heavy-Starship system would be the biggest rocket ever, reaching 120 meters (394 feet) tall.

Figure 15_Starship_© https://cdn.britannica.com/51/238251-050-EF7A9C22/SpaceX-Starship-Super-Heavy-Rocket-Boca-Chica-Texas-February-2022.jpg

16] Japanese Kibo Module

The Japanese Experiment Module (JEM), popularly known as Kibo on the International Space Station (ISS), is a science module. The Japan Aerospace Exploration Agency (JAXA) created it. Kibo is the ISS's largest single module and is connected to the Harmony module. Kibo is Japan's first man-rated space station. It is intended to house up to four astronauts for experimental purposes.

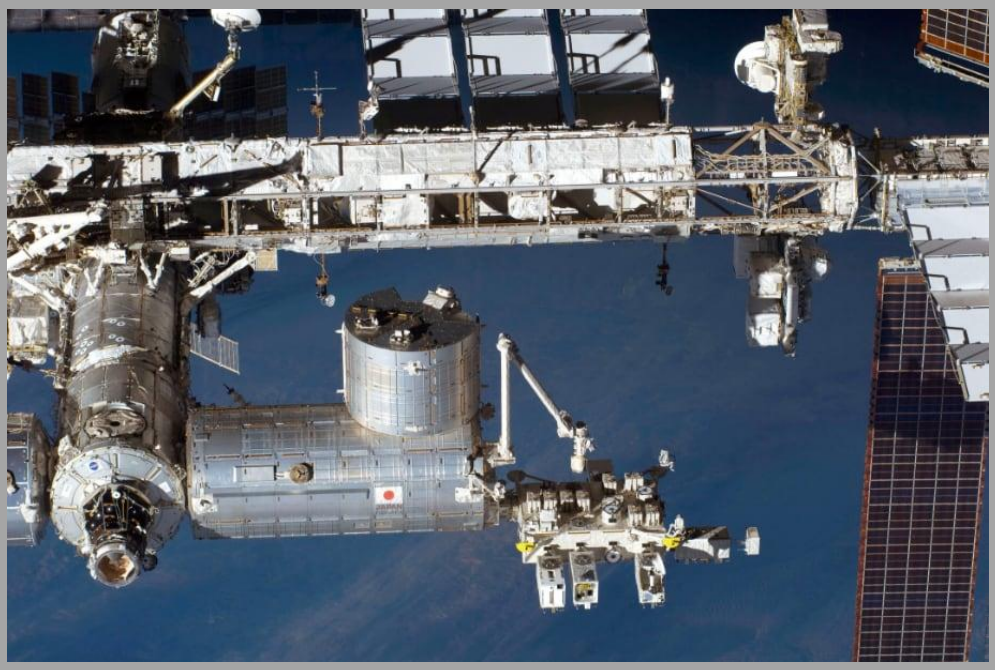


Figure 16 _Kibo_© https://humans-in-space.jaxa.jp/en/assets/images/kibo/top/img02.jpg

17] TESSERAE

Structures with self-assembling, adaptive, and reconfigurable capabilities are crucial for the future of human living in space. By leveraging reconfigurable self-assembly, we can reduce payload weight, simplify assembly processes, and revolutionize space structure modularity. This approach contrasts with the traditional method of transporting fixed, inflexible habitation modules, which can pose risks to astronaut Extravehicular Activities (EVAs) during construction. TESSERAE (Tessellated Electromagnetic Space Structures for the Investigation of Adaptive and Reconfigurable Environments), is constructed using a set of tiles, with the initial prototypes focusing on the Buckminster fuller structure (20 hexagonal tiles, 12 pentagonal tiles). These tiles autonomously self-assemble into a specific geometry. Each tile includes essential features such as a rigid exterior shell, electro-permanent magnets for dynamic controllable bonding actuation, responsive sensing, control code for bonding diagnosis, and an on-board power harvesting and management system. For habitat-level pressurization, TESSERAE tiles will also incorporate clamping and sealing mechanisms. In microgravity test conditions, the tiles autonomously self-assemble in a quasi-stochastic manner.
This project aims to develop low-cost, multi-purpose orbiting modules for zero-gravity settlements.

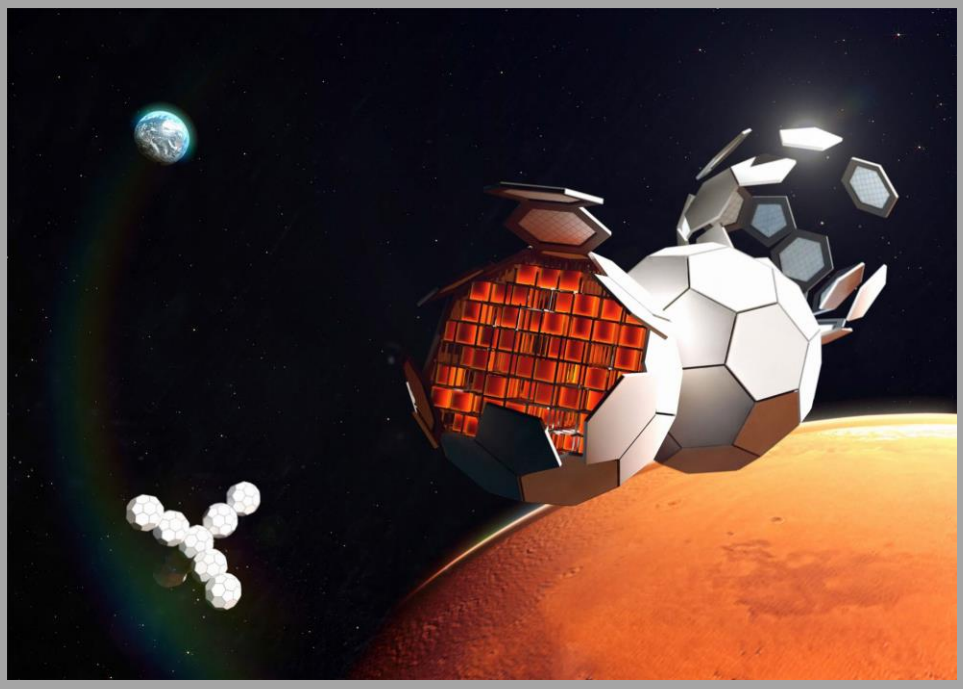


Figure 17_TESSERAE_©https://parametric-architecture.com/wp-content/uploads/2022/06/The-TESERREA-Project_-5-1999x1413.jpg

18] Lunar Lantern

In October 2024, NASA's Artemis Program is set to mark a historic return of astronauts to the Moon's surface, a momentous event since the Apollo Era. As we look ahead to the years and decades following this mission, various space agencies and commercial partners are actively planning to establish the necessary infrastructure for a sustained human presence on the Moon. Among these initiatives is the Lunar Lantern, a conceptual lunar base devised by ICON. This undertaking is part of a NASA-supported project dedicated to creating a sustainable outpost on our celestial neighbor.

The Lunar Lantern, aptly named for its innovative double-protective outer shield structure, signifies a paradigm shift in habitat design. Fueled by human factors principles, the primary goal is to prioritize the safety and security of future lunar crews. Under the overarching initiative known as Project Olympus, the vision is to develop robust, self-sustaining, and resilient surface structures through the application of cutting-edge 3D-printing technologies.

The Lunar Lantern represents a holistic lunar outpost concept that can be autonomously constructed on the Moon using state-of-the-art robotic 3D printers. Aligned with the ethos of both private companies and NASA's Artemis Program, the construction methodology relies on emerging technologies and In-Situ Resource Utilization (ISRU) to minimize reliance on Earth-bound resources. The Lunar Lantern outpost encompasses habitats, sheds, landing pads, blast walls, and roadways. SEArch+'s design introduces multiple strategies for dust mitigation and dust collection, integrating seamlessly with considerations of printability, form, and function."

This comprehensive approach ensures the Lunar Lantern's capability to thrive in the lunar environment while pushing the boundaries of lunar construction and habitation.

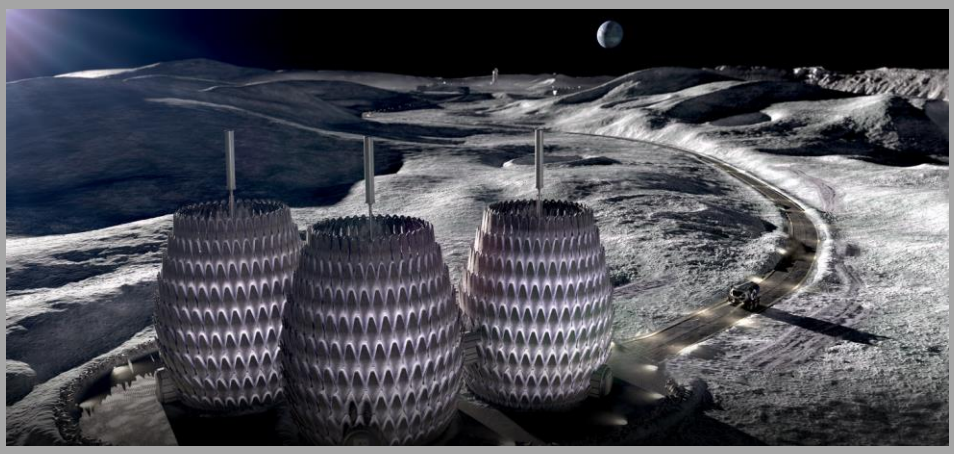


Figure 18 _Lunar Lantern 3D Printed Lunar Base_© https://www.spacexarch.com/lunar-lantern

19] The Mars Desert Research Station of the Mars Society

The Mars Desert Research Station (MDRS) is a facility run by The Mars Society, a non-profit dedicated to Mars exploration and habitation. The MDRS is a one-of-a-kind analog habitat constructed in the Utah desert, designed to recreate conditions comparable to what humans could encounter on Mars' surface. It is a research center as well as a training ground for anyone interested in Mars exploration and habitation. The Mars Society established the Mars Analog Research Station Project with the declared purpose of gathering information required for human exploration of Mars.

Figure 19_The Mars Desert Research Station of the Mars Society _© https://mdrs.marssociety.org/wp-content/uploads/2017/10/MDRS-2017.jpg

20] SHEE

Under the European Commission Framework 7 Program, a three-year research and development project known as Self-Deployable Habitat for Extreme Environments (SHEE) was carried out.
SHEE aimed to combine design ideas from space habitats and robotics to create a self-sufficient home for harsh environments on Earth and beyond. It has a central framework and six outward-deploying "petals." The framework and petal shells are made of aluminum, with self-supporting fiberglass shells encasing a foam core. Each petal spins outward, all made of fiberglass foam core shells. Inflatable rubber seals ensure a tight seal between the petals.
The SHEE prototype's configuration consists of six fully functional modular "zones": two staterooms, a kitchen, a restroom with hygienic facilities, an office, and a workshop/laboratory. The furniture and subsystems of these modules are all designed to fit inside a shipping container with the maximum amount of usable volume. Because the SHEE's furnishings and equipment are modular in design, they may be quickly adapted to match the unique requirements of each analog mission. In addition to the prototype being modular, the SHEE designers envision more modules being developed in the future as research labs, first aid stations, or even greenhouses.

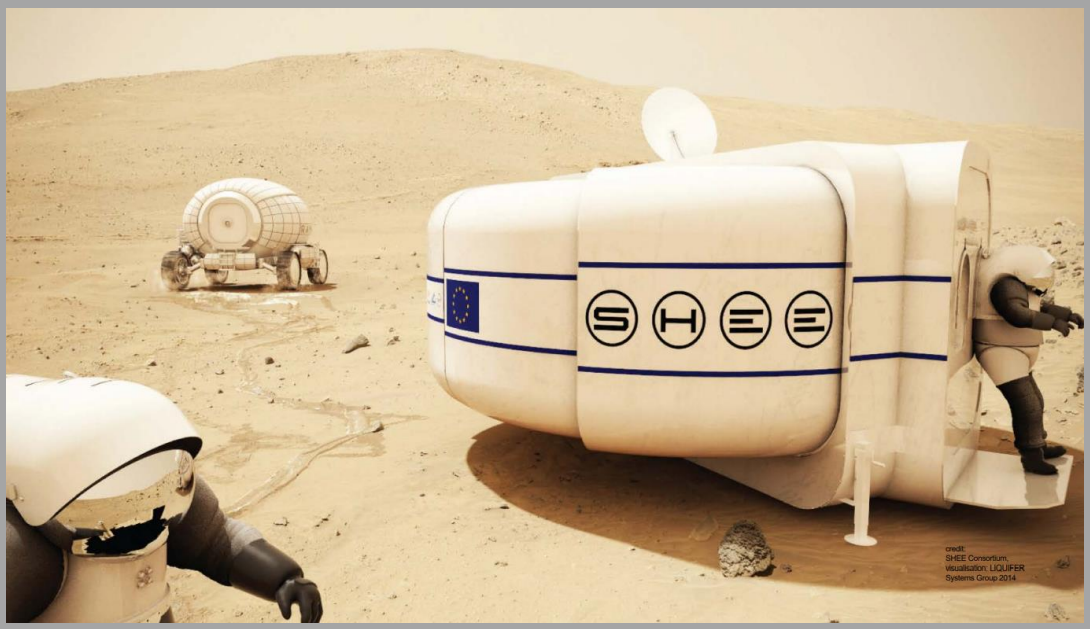


Figure 20_SHEE Deployable Habitat_https://liquifer.com/wp-content/uploads/2021/05/SHEEbrochure_2015.pdf

Reference:

1. International Space Station (2023) NASA. https://www.nasa.gov/international-space-station/ (Accessed: 18 October 2023).
2. The ISS (no date) ESA. https://www.esa.int/kids/en/learn/The_ISS (Accessed: 18 October 2023).
3. Harland, D. (n.d.). Skylab | History, Discoveries, & Facts. skylab
4. airandspace.si.edu. (n.d.). The First Space Stations. Mir space station [Accessed 20 Oct. 2023].
5. Andrew Jones 24 August 2021 (2021). China's Tiangong space station Space.com. Tiangong space station
6. Anon, (n.d.). Gateway - NASA. lunar way
7. Expandable, B. (n.d.). National Aeronautics and Space Administration NASAfacts Demonstrating Technologies For Deep Space Habitation. BEAM
8. Bigelow Aerospace. (2018). Bigelow Aerospace - BEAM. Bigelow
9. Starship (no date) SpaceX. https://www.spacex.com/vehicles/starship/ (Accessed: 18 October 2023).
10. English, V.L. (2023) NASA shows Mars Habitat where four people will live for one year, VOA. Mars Habitat (Accessed: 19 October 2023).
11. Space Exploration Architecture. (n.d.). Mars Ice Home.
12. cloudsao.com. (n.d.). MARS ICE HOME — Clouds Architecture Office. MIH
13. www.aerospace-technology.com. (n.d.). Skylon - Aerospace Technology. skylon spaceplane
14. Anon, (2017). Colonies in Space: Chapter 12 – The Shell of the Torus - National Space Society. shell of the torus
15. science.nasa.gov. (n.d.). The 'Xanadu Annex' on Titan - NASA Science. Xanadu annex[Accessed 20 Oct. 2023].
16. Orbital Reef will be the premier mixed-use space station in low Earth orbit for commerce, research, and tourism by the end of this decade. (no date) Orbital Reef. Available at: https://www.orbitalreef.com/ (Accessed: 19 November 2023).
17. https://www.spacetechasia.com/meet-the-von-braun-station-the-most-advanced-rotating-space-hotel-design-to-date/
18. Shen, D., Yue, Y. and Wang, X. (2022). Manned Mars Mission Analysis Using Mission Architecture Matrix Method. Aerospace, 9(10), p.604. mars mission analysis
19. Blachowicz, T. and Ehrmann, A. (2021). Shielding of Cosmic Radiation by Fibrous Materials. Fibers, 9(10), p.60.Cosmic radiation shielding
20. Starship (2023) https://www.britannica.com/topic/Starship (Accessed: 19 October 2023).
21. iss.jaxa.jp. (n.d.). Japanese Experiment Module (KIBO) - International Space Station - JAXA. KIBO
22. Project Overview ' tesserae: Self-assembling space architecture (no date) MIT Media Lab. Available at: https://www.media.mit.edu/projects/tesserae-self-assembling-space-architecture/overview/ (Accessed: 19 November 2023). Lunar Lantern (no date) Melodie Yashar. Available at: https://www.melodieyashar.com/lunar-lantern (Accessed: 19 November 2023).
23. Williams, M. (2021) The lunar lantern could be a beacon for humanity on the Moon, Universe Today. Available at: https://www.universetoday.com/151459/the-lunar-lantern-could-be-a-beacon-for-humanity-on-the-moon/#google_vignette (Accessed: 19 November 2023).
24. Mars Desert Research Station. (2017). Home. Mars Desert research station[Accessed 21 Oct. 2023].

25. Executive study self-deployable habitat for extreme ... - liquifer. Available at: https://liquifer.com/wp-content/uploads/2021/05/SHEEbrochure_2015.pdf (Accessed: 19 November 2023).

Author: Siddhi Amar Salokhe

Siddhi is a B.Tech student and a dedicated aerospace enthusiast aspiring to specialize in aerodynamics, propulsion, space science, satellites, and launch vehicles. Having recently completed an internship at the National Aerospace Laboratory, she has co-authored two international conference papers [IAC 2023, Baku]. Siddhi has also served as an ambassador for the International Astronomy and Astrophysics Competition 2023 and the National Students' Space Challenge 2023, in addition to holding the position of joint secretary at the Alatus Space Club in her college.

Currently involved in the student satellite project at the Centre of Space and Technology, Siddhi's daily commitment to design, writing, and knowledge reflects her unwavering dedication to achieving her career goals in the aerospace field.

Editor: Vedika Adukia

INSPACEDESIGNERS
Beyond the realms of Earth

InSpaceDesigners is an online publication that disseminates newsletters, articles, and reports on space architecture, engineering, and related subjects, along with the most recent space news updates with the intention of advancing the discipline of space architecture in India.