Astrosociological Insights

Newsletter of the Astrosociology Research Institute

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Notes from the CEO

Astrosociology and Space Architecture: Convergence of Physical and Social Constructs

Jim Pass, PhD

Chief Executive Officer

Astrosociology Research Institute

Thank you for your attention to this important space architecture issue of *Astrosociological Insights*! With the preparations being made in the private and public sectors by SpaceX and NASA, as examples, the need to think carefully about the construction of spacecraft and space habitats is becoming increasingly vital for the success of travel to, and settlement of, other worlds. Space architecture is important because the future of humankind includes expansion into the rest of our solar system, and while the actual implementation remains somewhat stalled, the time will come when the pressures to migrate result in its ultimate reality. The missing element is a wide acknowledgment among those in both the traditional space and social science communities that both branches of science – the physical "not vs." the social – must work together to make space architecture work, not only in terms of the physical construction, but also in terms of the effects on people within the physical structures.

Before moving forward, a good definition of space architecture is necessary. "Space Architecture is the theory and practice of designing and building inhabited environments in outer space, responding to the deep human drive to explore and occupy new places" (Osburg, Adams, Sherwood, 2003).[1] Keeping with the Astrosociology Research Institute's mission and this definition, it is important to recognize that a universal architecture exists in which the benefits of architecture benefit both extraterrestrial *and* terrestrial locals. Thus, there is an inverse relationship between (1) the education of architectural practices, which involves theoretical issues, and (2) the implementation of architectural practices, which involves construction of the habitat or other structures. While the two may intertwine, the difference between education and practice remains important to ponder, as theoretical ideas can best be tested in space environments.

An important consideration involves the architecture of transportation systems to get people to other space environments. While traveling to the Moon is less complicated, migrating to other places such as Mars requires an ecosystem within the spacecraft that falls under the purview of the social sciences. Architecture can have a substantial impact on the quality of social life, either more positive or more negative, on isolated and crowded spacecraft.[2] The best-case scenario is that the inhabitants of such an ecosystem will be in good mental, social, psychological, and physical shape to continue on in another isolated ecosystem far away from the rest of humankind once their destination is reached. This is why astrosociology is so important. The physical and social sciences must begin working much more closely together in this area and others related to the relationship between humankind and outer space. Collaboration is extremely important, although a formal convergence represents the ultimate goal. Recognition of the importance of the social sciences in space education and research is not the same as actually taking advantage of it. Space architecture is not simply the construction of the physical structure, but also construction of the social structure.

When most people think about space architecture, the types of images that come to mind are probably the three most recognizable actual space stations (Figure 1), the orbiting habitats imagined by Gerard K.

1. Maria João Durão, "Embodied Space: a Sensorial Approach to Spatial Experience," SPESIF 2009, http://astrosociology.org/Library/PDF/Durao_SPESIF2009.pdf.

2. Osburg, J. Adams, C., and Sherwood, B., "A Mission Statement for Space Architecture," SAE Technical Paper 2003-01-2431, 2003, https://www.sae.org/publications/technical-papers/content/2003-01-2431/.

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O'Neill's O'Neill Cylinders (Figure 2),[3] space stations from science fiction (Figure 3), or perhaps the proposed space habitats on the surface of the Moon or Mars found in the social media. The important aspect of these structures for astrosociologists is the fact that most attention goes to physical construction and aesthetic shell while too little attention is paid to the sociocultural and psychological forces the humans face inside. Thus, space architecture is not simply based on the physical structures but also – and most importantly – on how these structures impact human beings. Ultimately, what it looks like on the inside is more important than what it looks like on the outside. Social life in spacecraft, space settlements, or orbiting space stations must always be a central consideration both outside and inside where the population must spend most of its time in isolation away from the bulk of humankind residing on Earth.

Skylab - NASA

Shuttle Atlantis Meets Mir - NASA

The International Space Station (ISS) - NASA

Figure 1: Real Space Stations

In summary, the physical constructs are extremely vital to provide for physical survival – that is, the life-science-based aspects of human settlers – although it is not sufficient for long-term sociocultural and psychological survival of the population in a space settlement ecosystem.

These are a few of my thoughts about space architecture. I trust that you will find the following articles in this issue perhaps even more thought provoking. Enjoy!

Cheers,

Jim

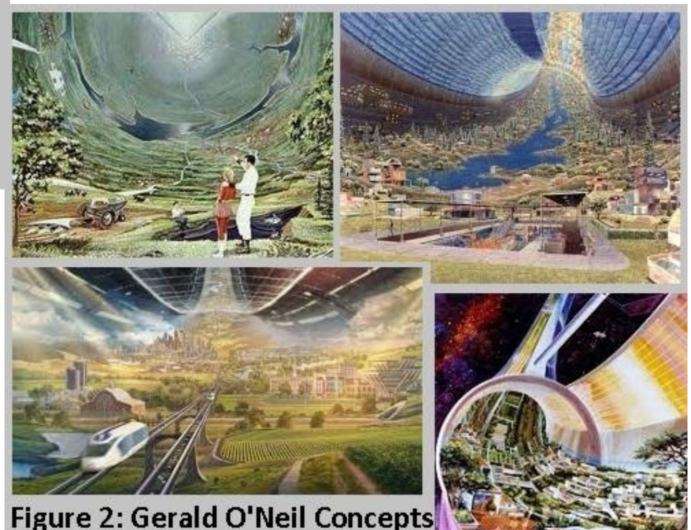

Figure 2: Gerald O'Neil Concepts

Star Trek Starbase

Atlantis (Stargate Atlantis) (It can fly!)

Deep Space Nine (Star Trek)

Deathstar (Star Wars)

Figure 3: Space Stations from Science Fiction

[3] O'Neill, G. K., "Frontier: Human Colonies in Space. William Morrow and Company, 1977.

Notes from the Editor

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Editor in Chief, Journal of Astrosociology & Astrosociological Insights

Assistant Professor, University of North Dakota

Department of Space Studies

This issue of Astrosociological Insights seeks to explore "Space Architecture" as a lens through which humanity sees its past, current, and future operations in the outer space environment. How we build our spacecraft and space stations says a lot about both priorities and capabilities of the people involved at every iteration, from planning to implementation. This is not a new concept, and artists, engineers, and scholars have debated the way things should look and operate in space since long before the first rockets succeeded at propelling human-made objects into orbit around the Earth. That said, the topic of architecture in space has become increasingly popular in recent years, in both media and academic circles. At the 2019 International Astronautical Congress in Washington, D.C., there were several sessions presented under this heading, where various individuals involved in the architectural processes of space contributed their thoughts on what has been done right or wrong (if such terms are valid on a topic that is as much about art as it is function), and how systems could be designed for the future. Due to other obligations, I was not able to attend each session on space architecture, but those that I did see were fascinating. I recall one panel where there was an astronaut speaking to experiences onboard spacecraft, a planner from NASA, and an architect engaged in planning for various space needs, all discussing together this most nuanced of topics.

Architecture tells us about human culture, and how we live our lives. It showcases creativity, materials science, labor and technological capabilities, and more. On Earth, we marvel to see the ornate grandeur of a building like the Hagia Sophia—a building so remarkable that it has served as a major house of worship for two of the world's most followed monotheistic religions. We can heap equal praise on the simplicity of Frank Llyod Wright's organic architecture, or the stark efficiency of brutalist design. If pressed, most people seem to have a preference for one style over another, whether the discussion concerns government buildings, a single-family home, or even a music hall. The variety of design is endless, and it always says something about the people who dreamed it up, built it, and showed it to the world. Likewise, the iconic designs of the Apollo capsule, the Soyuz craft, or the Space Transportation System (aka the Space Shuttle) still scintillate the public, and inspire modern engineers in their own visions for future space transportation.

In space, there are additional concerns beyond the efficient and the aesthetic. There, architects must ensure that engineers are kept in the loop, even in the early planning stage of a craft or station. Human factors considerations are paramount, for no matter what designs one can concoct, they must account for the needs of the human explorer in space, where things like oxygen, exercise, and defense against radiation are necessary in ways one might normally ignore for a building on Earth. Beyond this, an increasing focus on human-centric design means that building structures for space should not only keep people alive, but should help them *enjoy* the space around them, and use it more efficiently.

In the design of space suits, this is one of the major complaints received from astronauts—how difficult it can be to move their hands, or manipulate tools while in the suit. Designing around this can make their work better, and more effective. Similarly, space architects are thinking not only about beauty, but function.

In this edition, we have a spread of writings concerning any number of architectural themes. From a historical query about ancient architectural structures as applied to the future, to how capsules and transport devices are built and used, to what aspects of our culture follow us from Earth into space, and the future of humanity. This is, to my view, merely scratching the surface of this topic. I would enjoy revisiting this topic in the future with more voices, additional thoughts and permutations on early design, and proposals for the next generation of architectural design. For now, we at ARI would like to welcome you to this initial view on the topic of Space Architecture.

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Watch for the Next Issue of the *Astrosociological Insights* Newsletter

The topic: How can the social and behavioral sciences, humanities, and arts better contribute to the space exploration including its impact on terrestrial societies, settlement, and related issues in cooperation with the physical and natural sciences and the STEM disciplines? Also, why is the Astrosociology Research Institute important to achieving progress in these areas? The authors will provide us with their astute observations about these questions and others.

Note that a large number of submissions have come in from students, educators, space professionals, and, as a group, a great variety of contributors. It will be an amazing issue!

Dallas Beinhoff

Founder, Cislunar Space Development

A Reusable Cislunar Transportation Architecture

Merriam-Webster.com gives five definitions for architecture.[1] Two are pertinent to a transportation architecture. The first is, "the art or practice of designing and building structures…." The other is, "the manner in which the components of a computer or computer system is organized and integrated." We substitute "systems and elements" for "structures" and "components" to get the following: cislunar transportation systems and elements defined and integrated into a transportation network.

A transportation architecture is a network of vehicles, support services and routes for moving materiel (people, equipment, supplies, etc.) efficiently from one location to another. On Earth, it is highways, railroads, canals, ships, cars, trucks, airplanes, airports, gas stations and truck stops. Today there is a limited space transportation architecture serving the International Space Station, comprising three launch sites, four launch vehicles, three cargo carriers and two crew capsules. Soon, there will be a third crew capsule and cargo carrier.

NASA, Russia, ESA and China are all developing plans to return to the Moon. The Moon Village Association is promoting an open lunar community with integrated and shared services. The intent is to establish continuously inhabited permanent sites on the Moon for exploration, discovery and use. Routine, reliable and affordable transportation is a prerequisite for sustainable and thriving communities anywhere.

*Table 1. Earth to Orbit transportation architecture servicing ISS**

System	Purpose	Location	Reusable	Provider
Soyuz	Launch	Baikonur	No	Energia
Falcon 9	Launch	Cape Canaveral	First Stage & Shroud	SpaceX
Antares	Launch	Wallops MASP	No	Northrop Grumman
Atlas 5	Launch	Cape Canaveral	No	ULA
Progress	Cargo	Baikonur	No	Energia
Dragon	Cargo	Cape Canaveral	Yes	SpaceX
Cygnus	Cargo	Wallops MASP	No	Northrop Grumman
HTV	Cargo	Tanegashima, Japan	Yes	JAXA
Dream Chaser (coming)	Cargo	Cape Canaveral	Yes	Sierra Nevada
Soyuz	Crew	Baikonur	No	Energia
Dragon II	Crew	Cape Canaveral	Yes	SpaceX
Starliner (Coming)	Crew	Cape Canaveral	Yes	Boeing
Baikonur	Launch site	Baikonur	Yes	Russia
Wallops MASP	Launch Site	Virginia	Yes	NASA
Florida Space Port	Launch Site	Cape Canaveral	Yes	NASA

*Compiled by Dallas Bienhoff, CSDC

China and Russia are in the early development stages of their new personnel capsules capable of traveling roundtrip to the Moon's vicinity. China's concept, unnamed as of this writing, will carry 4 to 7 people (Figures 1 and 2).[1,2] Russia's Orel will have 4 to 6 seats (Figure 3 and 4).[4,5] These vehicles will get taikonauts and cosmonauts to lunar orbit but not to the surface. A lander is needed to get to the surface and back to orbit.

NASA is developing its Orion crew capsule for the Artemis Program to get personnel to lunar orbit; specifically, a Near Rectilinear Halo Orbit (NRHO). Orion is launched to the Moon by the Space Launch System. Once at NRHO Orion will dock with the Gateway so astronauts can transfer to a Human Landing System to access the surface. NASA recently selected three companies to initiate Human Landing System developments.[6] One concept includes a reusable Transfer Vehicle Element, an expendable Descent Element and a reusable Ascent Element plus Refueler Elements.

Another concept consists of a reusable Ascent Element with drop tanks to get from the Gateway to the surface plus Refueler Elements. The third solution is a fully reusable two-stage system that accesses the Moon from Earth with low Earth orbit refueling. Two of these three concepts will be selected for full development and implementation as a commercial lunar lander system. Space Launch System, Orion, the Gateway, selected Human Landing Systems and commercial launch vehicles make up NASA's transportation architecture to the Moon. It is a mix of expendable and reusable systems with different capabilities to the lunar surface using different propellant combinations across the various systems to move people and equipment from Earth to the Moon (Figures 5-10).[7]

Figure 1. The crew module (top) and service module of the new Chinese crewed spacecraft (Image credit: CAST).

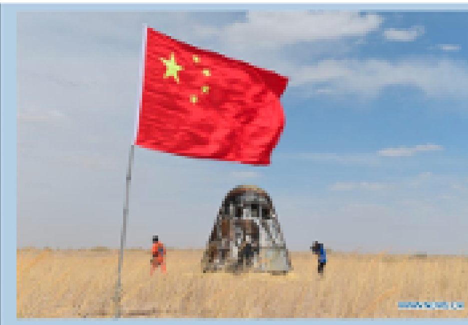

Figure 2. The Chinese crew capsule after landing Friday, concluding an unpiloted orbital test flight (Credit: Xinhua)

Figure 3. Mockup and test article of the Orel crew module, photographed at the Moscow Air and Space Show in August 2015 (credit: dunyanews.tv).

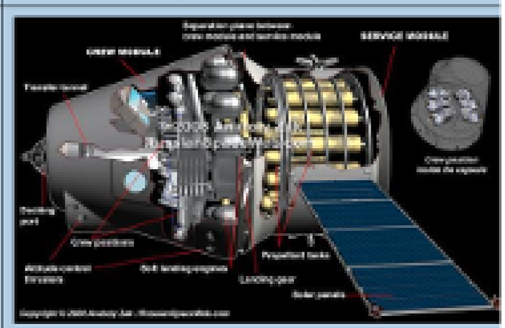

Figure 4. Internal layout for Russia's new Orel crew module (credit: RussianSpaceWeb.com).

Cislunar Space Development Company (CSDC) is taking a different approach for its commercial Reusable Cislunar Transportation Architecture. All systems have common interfaces, incorporate the same components and subsystem architectures for interoperability and minimum sparing. All systems are reusable with long operational lifetimes and high mission life. Liquid oxygen and liquid hydrogen, which is produced by low Earth orbit and Earth Moon L1 propellant depots from water shipped from Earth, is used by all propulsion systems. Once in space, systems stay in space, except for the Earth-to-orbit carriers. Space tugs are sized to move specific launch vehicle low Earth orbit payloads to geosynchronous transfer orbit, geosynchronous equatorial orbit and Earth Moon L1. The Moon shuttle capability to the lunar surface matches the Earth Moon L1 space tug capability, which matches the Delta IV Heavy low Earth orbit launch capability. Any space tug or Moon shuttle can be a demonstrator for other space tugs or Moon shuttle due to their similarity; three primary differences are propellant quantity, aeroshell or landing struts.

CSDC's Reusable Cislunar Transportation Architecture was conceived in 2008 in response to the question, "What does a common impedance (payload) architecture from Earth to the Moon look like?" At that time, the largest payload capability to low Earth orbit was 23,000 kg by the Delta IV Heavy. The largest single item being discussed for placement on the lunar surface was Bigelow Aerospace's B-330, at around 20,000 kg. Therefore, the Reusable Cislunar Transportation Architecture includes systems sized to move 25,000 kg from low Earth orbit to the Moon's surface via Earth Moon L1 to provide margin for growth (Figures 11 & 12).

Figure 5. NASA Orion crew module on its way to the Moon following launch by the Space Launch Systems (credit: NASA)

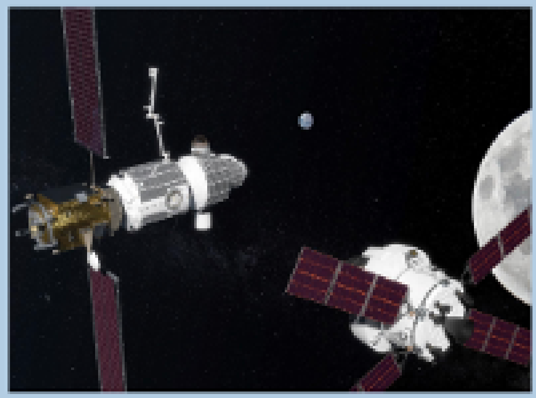

Figure 6. NASA Gateway in NRHO with approaching Orion (credit: NASA)

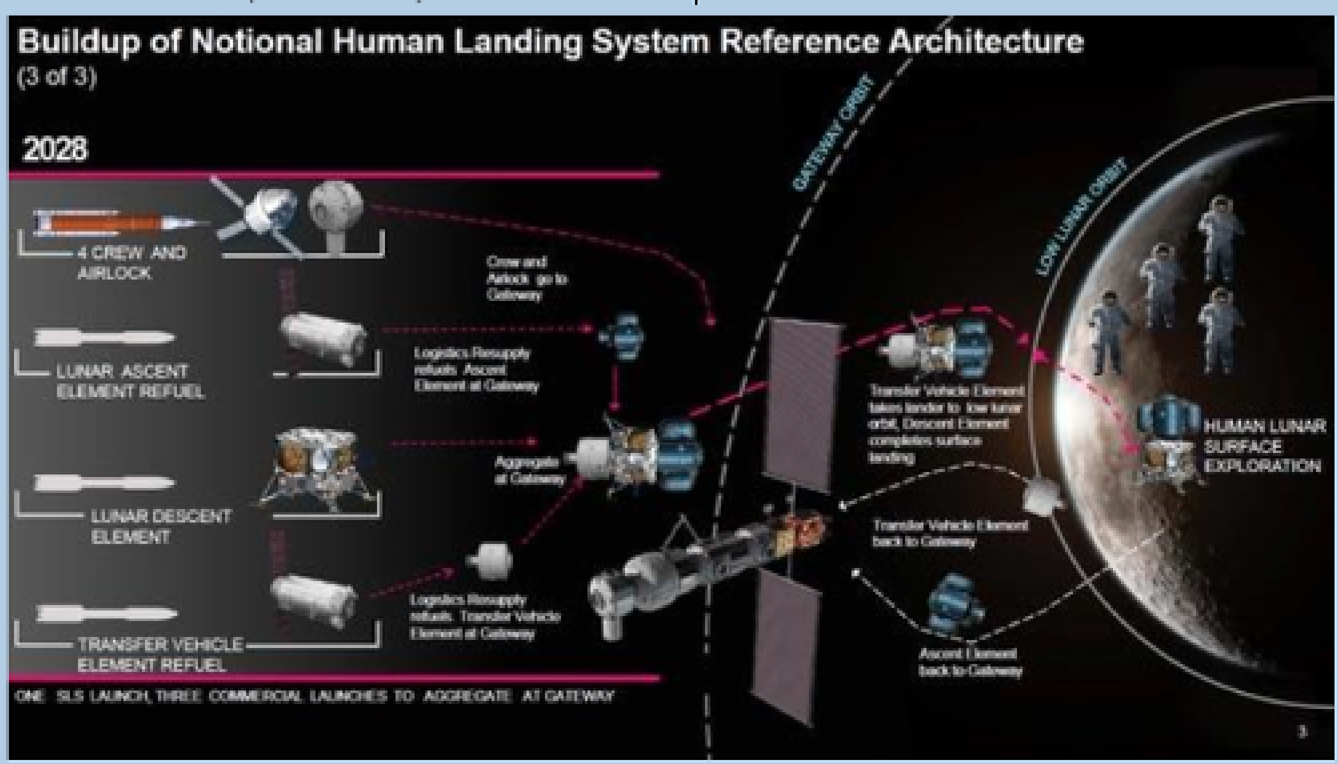

Figure 7. NASA's plans for landing humans on the Moon by 2028 using the Gateway and a three-stage lunar lander system (credit: NASA).

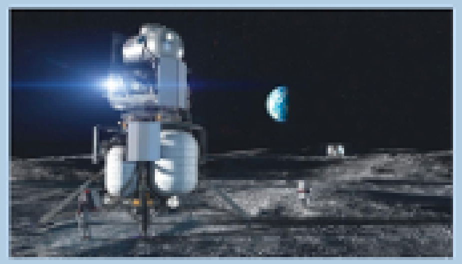

Figure 8. Blue Origin's Blue Moon Descent Element and Lockheed Martin Ascent Element. Credit: Blue Origin.

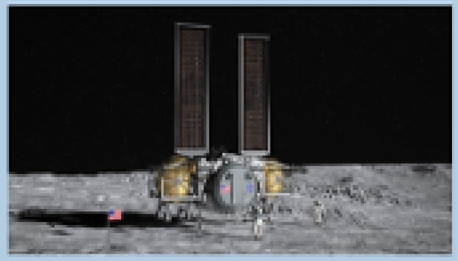

Figure 9. Dynetics Human Landing System on the Moon after expending its drop tanks. Credit: Dynetics.

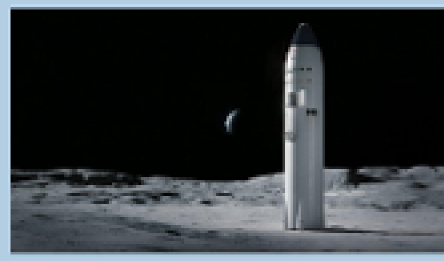

Figure 10. SpaceX Starship on the Moon with 100 mt capability. Credit: SpaceX

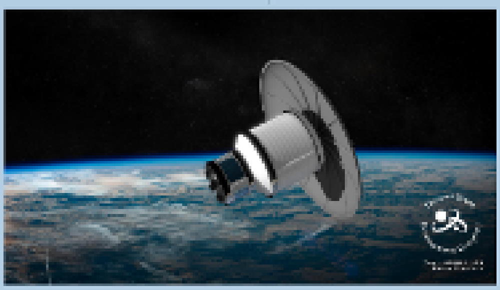

Figure 11. An aeroassisted space tug is sized to deliver 25 mt launched on a ULA Vulcan to Earth Moon L1 (credit: CSDC).

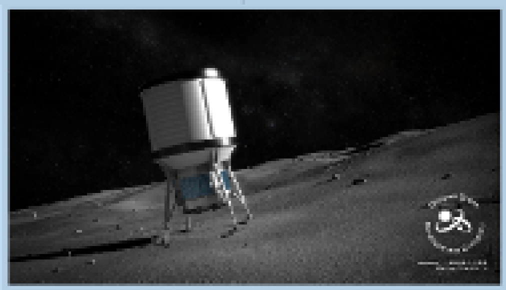

Figure 12. CSDC's Moon shuttle can land 25 mt on the Moon and return to Earth Moon L1 without refueling (credit: CSDC).

Six different space tugs are sized to deliver 1,360 and 4,000 kg to geosynchronous transfer orbit and geosynchronous equatorial orbit. Boeing's Phantom Express capability to low Earth orbit set the 1360 kg value while Firefly's Beta launch vehicle established the 4000 kg capability. Two are propulsive only while four use Earth's atmosphere to slow down when returning from higher orbits (Figures 13 & 14).

Space tugs are refueled by Earth-to-orbit propellant carriers until propellant depots are available. Once depots are operational, they are supplied by Earth-to-orbit water carriers (Figure 15 & 16). Depot water and propellant storage capacity is no less than twice that required for the largest operating space tug or Moon shuttle. Earth Moon L1 is used as a staging point to enable all-point access to the Moon for the same velocity change and anytime departure without concern for orbit alignment or staging point orbital position.

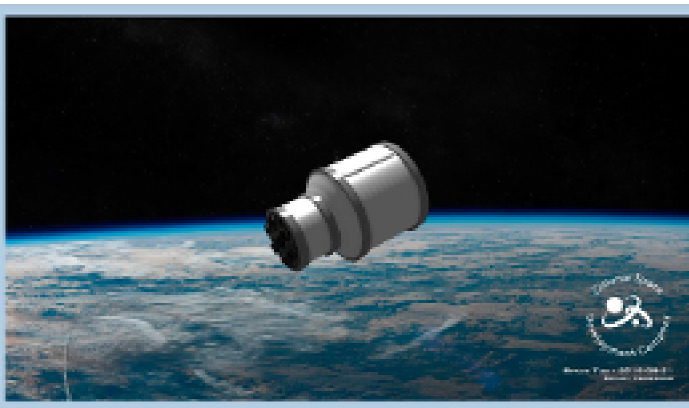

Figure 13. Two all-propulsive space tugs are sized to deliver 1360 kg and 4000 kg to geosynchronous transfer orbit and return to low Earth orbit (credit: CSDC).

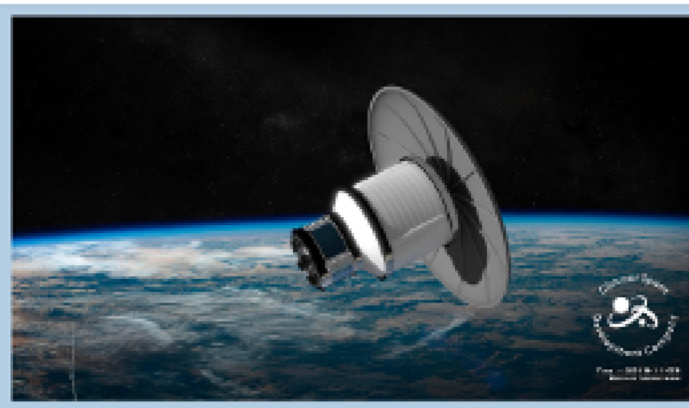

Figure 14. Four aero-assisted space tugs are sized to deliver 1360 kg and 4000 kg to geosynchronous transfer orbit or geosynchronous equatorial orbit and return to low Earth orbit. (credit: CSDC)

When water is available on the Moon from third party providers at an appropriate price, it will be used for returning to the Earth Moon L1 depot. If the cost of water is low enough, it can be exported to the Earth Moon L1 depot for lunar landings, return to low Earth orbit and missions to other destinations.

Propellant depots also provide docking ports for space tugs between missions. In low Earth orbit, the docking ports are more like garages to protect space tugs from orbital debris. They may also serve as warehouses for on-orbit spare satellites.

The Reusable Cislunar Transportation Architecture also includes the ability to move water, propellants and people between low Earth orbit and the lunar surface. Full tanker mass, whether water or liquid oxygen and liquid hydrogen, is 25,000 kg, the same as the payload capability to the lunar surface. The maximum mass for a personnel module is defined by Moon shuttle and Earth Moon L1 space tug round trip capability.

To recap, the Reusable Cislunar Transportation Architecture is sized to move specific launch vehicle maximum payload mass from low Earth orbit to geosynchronous transfer orbit, geosynchronous equatorial orbit or the lunar surface. It uses liquid oxygen and liquid hydrogen to minimize propellant usage, enable water transfer to propellant depots and take advantage of lunar water, when it becomes available. Systems have long operational life and high mission life requirements. They have common interfaces and their components are interchangeable. Once CSDC's Reusable Cislunar Transportation Architecture is in place only people, cargo and propellant need to be launched to support lunar activities. These are necessary characteristics for a transportation architecture to support continuous, permanently inhabited facilities on the Moon.

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Proposal for the Deployment of a New Crewed Space Laboratory in GEO

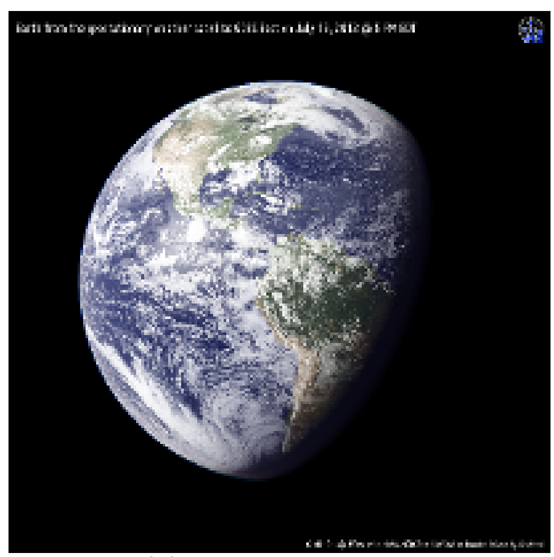
The idea of living in off-Earth habitats has been successfully proved with the experience and scientific data accumulated from the joined effort realized in the International Space Station (ISS) Program. Hence, based on this success and the lessons learned, several entities such as space agencies, non-profit organizations and private companies are scheduling new plans for the commercial development of Low Earth Orbit (LEO), Cis-Lunar space, Near Earth Asteroids (NEA) and are thinking about reaching Venus and Mars as well.

Although we have an extensive human spaceflight history, except the Apollo missions, all the millions of miles have been flown in LEO. We have not adventured enough through the marvels of our surroundings; hence we do not have enough experience inhabiting Deep Space. Even at present, the people living in the Concordia Research Station are logistically more isolated than the crew of the ISS. However, some things are changing, and with the retirement and decommission of the ISS scheduled by 2028, the designs and engineering work for the Lunar Orbital Platform-Gateway project is ramping up. Nevertheless, one piece of the puzzle seems to be absent so far.

The present article intends to highlight the importance of establishing an operational, intermediate step between the ISS and the Gateway. Specifically, it proposes the rapid deployment of a new human-rated space station to be located in a geostationary orbit.[1,2]

A New Orbital Platform

The always changing views through the cupola of the ISS is one the marvels that captivates the spare time of the crew living in the station, and also the general public that, being moved by curiosity, follow the astronaut's social media accounts. These changing images are due to the inclination of the ISS orbit.



Paradigmatic views. An always partial and dynamic view from the ISS on the left (1) versus a complete and static Earth view from geostationary orbit on the right image (2). Credits (1) From EOL @ JSC NASA, (2) From GOES East July 19, 2013 5PM EDT. Credit PHL @ Arecibo.

However, the proposed new GEO station presents an advantage over the diverse experiments done in the ISS that are conducted under the shield of the Earth's magnetosphere that protect us from the constant flow of charged particles of solar and cosmic radiation. A new space laboratory that is located in geostationary orbit, at an altitude of 35,786 kilometers / 22,236 miles, will stay orbiting at the final boundary of the outer Van Allen radiation belt where the radiation hazards are lower than the high energy protons of the inner belt and the radiation doses almost mimics the hazards of deep space.

This new scenario could be relevant in the fields of human spaceflight medicine and medical astrosociology to conduct research across the following areas:

- Rapid identification and evaluation of medical risks, including radiation, associated with deep space vehicles/habitats, and requirements associated with microgravity and hypogravity for Lunar and NEA operations.
- Identification, development, validation, and implementation of in-flight non-exercise countermeasures for Deep Space Exploration.
- Medical technologies and strategies to mitigate medical risks associated with spaceflight and management of optimal astronaut health.
- Evaluation of crew's psychological health due to isolation, distance, or monotony of the view.

We consider that providing a new destination outside the protective shield of the Earth's magnetosphere is a mandatory issue in order to test and validate the effectiveness of non-exercise countermeasures against ionizing radiation before sending humans to more distant places in outer space.[3]

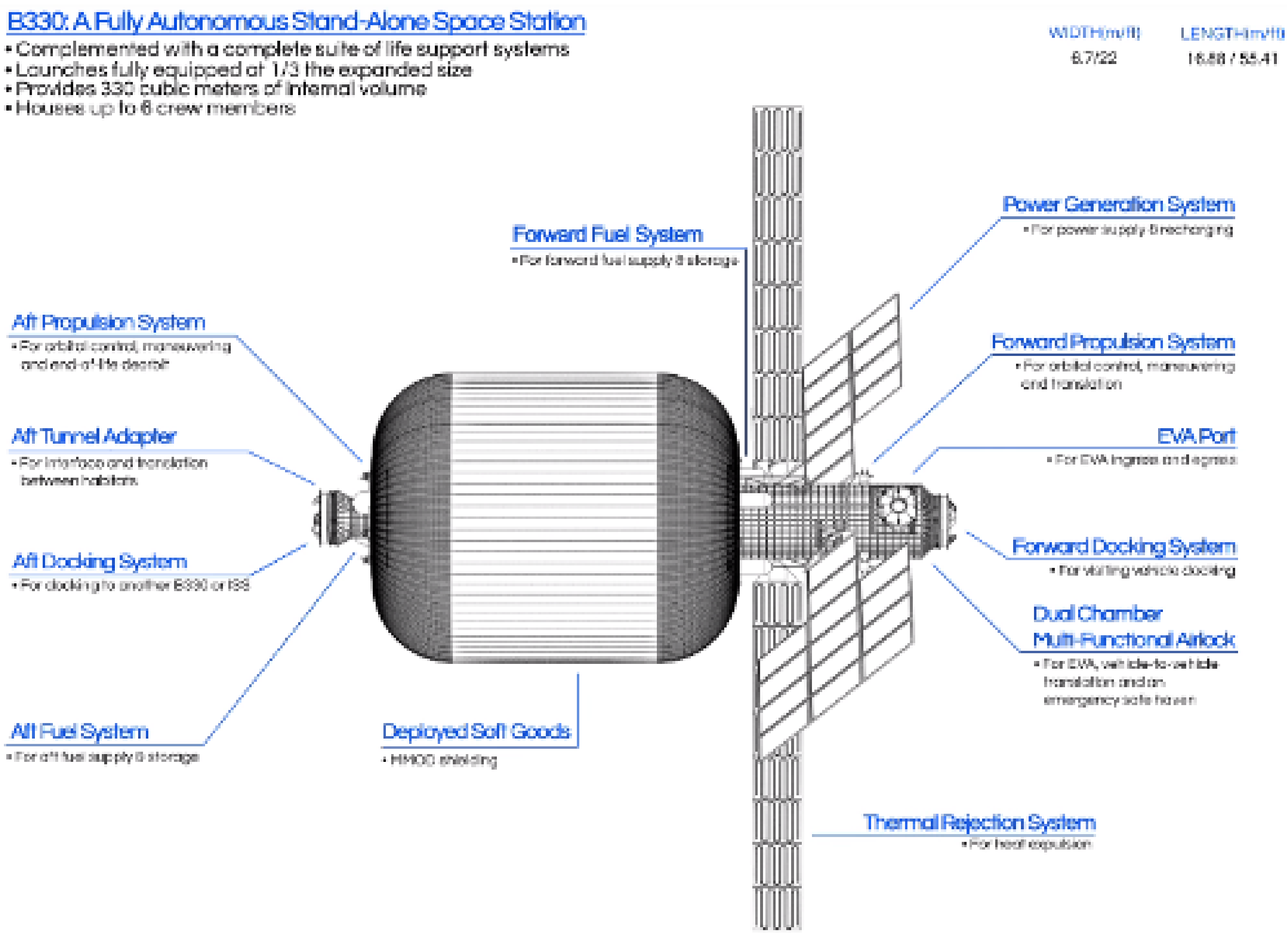
Hardware Characteristics of the First Milestone

This new GEO Station is intended to be a laboratory, observatory, and factory while providing a stepping point for transportation, maintenance, and recycling of decommissioned hardware from LEO, Medium Earth Orbit, and GEO. Also, this facility could serve as a staging base for future missions to deep space.

Following the precepts of the lean design, we propose to start small, and then while it is used, increasing the capabilities by adding more inflatable modules, connections and docking modules, and more dedicated technical modules.

For the first milestone, we identified from existing commercial companies, such as Bigelow Aerospace (BA), suitable hardware that can serve as the foundational module of the GEO Station. Since Bigelow's B330 has all the subsystems required for life support of six crews, power generation, fuel system, propulsion systems for orbital maneuvers, and fully equipped for the needs of the mission, the foundational module can be deployed as a fully autonomous stand-alone space station.[4]

According to the technical information from BA and considering its declared complete weight of 23 kg, this module can be easily launched in one stack and positioned in GEO by SpaceX's Falcon Heavy rocket. After arrival to it's GEO destination, and all the autonomous systems deployed and operational, the Station can then be occupied by an initial crew transported by a second launch service of SpaceX's human-rated certified Dragon V2 capsule.[5]



Rendering of the B330 module and its subsystems. Credit Bigelow Aerospace.

Commercial Development of Earth Orbit Transportation Systems

Despite a future vision of outer space inhabited by humans, the only destination for astronauts in Earth orbit at the moment is the ISS circling at LEO. There are several projects of different space stations that could dot the night sky and serve as in-space manufacturing facilities, orbiting fuel depots, space-based solar power plants, and even space hotels for wealthy space tourists, but most of them are still in the paper stage or searching for initial funding. One of the first spin-offs of the rapid deployment of a new inhabited facility in orbit is to provide a second destination for commercial development and validation of transportation systems that ferry astronauts and cargo from different points in Earth orbit or perhaps even the development of automated spacecraft systems that serves in the effort of cleaning and removal of space debris.

Conclusion

This brief article, while unable to cover every aspect and to be more developed in the future, is intended to explore the idea of "how and why" to rapidly increase the inhabited assets in Earth orbit as a stepping point before pursuing other missions to deep space. We consider that this effort could be accomplished rapidly in two ways: firstly, as a private endeavor to provide logistics and a real estate on the shore of outer space for space agencies and companies looking for a new space facility to develop or to test new technologies or to validate new processes.

Or secondly, the newly formed U.S. Space Force, having a more agile process of procurement and a bold vision and initiative, might be interested in setting up a dedicated inhabited space laboratory where advanced research could be conducted.[6]

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Will Our Cultural Baggage Permeate Our New Homes in Space?

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Humanity currently finds itself poised on the precipice of a new era, that of crewed interplanetary exploration and human settlement of our closest and most suitable celestial bodies, namely the Moon and Mars. International partners have resolved to work together to create the technologies needed to return our species to the Moon after nearly 50 years [1]. This is hugely significant for humanity, but one has to wonder - what 'cultural baggage' are we potentially bringing with us to our new home among the stars? What cultural bias informs the space architectural design process? How will this affect our social progress as an interplanetary species?

Architecture has served a vital role in not just housing but ultimately defining cultures all across the planet for thousands of years. These differing approaches to the utilization of space and the environment, serves today as a visible reminder of the cultural values of each particular society, both past and present. The spaces we inhabit in-turn inhabit us too, as architecture and design play a significant role in how we perceive, embody, and practice culture. J.C. McKnight writes, "…infrastructural systems are designed in accordance with existing cultural values…they then tend to reproduce those values in use…even given a desire to innovate or to reject an established order, they will bring it with them" [2]. In a similar vein, M. Foucault argues that we are bound by our old patterns and ways of thinking partly because so much of our history surrounds us everyday. Further, he wrote, "…it is necessary to notice that the space which today appears to form the horizon of our concerns, our theory, our systems, is not an innovation; space itself has a history in Western experience, and it is not possible to disregard the fatal intersection of time with space…" [3]. Simply put, how we imagine what 'could be' with respect to planetary settlement is inherently tied to what *is* now and how space has been used over time. Innovation in this respect is then extremely difficult, if not impossible, if we don't recognize bias from the outset in the design process. The intersection of place and time that Foucault spoke of is another important consideration. Social change and adaptations are complex and often multi-generational processes. This is perhaps due in some part to the fact that our embodied cultural practices are also where we dwell and these spaces continue to inform our behaviours. On a larger scale, Jane Jacobs too wrote of the effect that design and planning of cities had on a society, and indeed the potential impact on the stability of democracy and our very ability to maintain our chosen governance systems [4].

When these arguments are taken in aggregate, the implications to extant spacefaring societies are clear. L. Billings argued that true global cooperation and a fundamental de-colonial re-assessment of the values we wish to bring with us as a species as we begin to move off Earth are essential for success in these new spaces [5]. As such, we will be required to change our social habits and patterns in these completely novel, remote, and instantaneously lethal environments for which our terrestrial based knowledge of governance, design, social interaction, and indeed our implicit contemporary 'frontierism' intent for exploration may not be suitable in this wholly new environment. This adaptation may be especially difficult in some social respects as all of our implicit cultural knowledge is 'baked' into every structure we design as it is viewed from our terrestrial lens which may be incongruent in these new places.

Leaving Earth will require a re-evaluation of our societal values, cultural practices, and preferred governance systems. Though limited, these discussions are taking place and have done so for several decades [6]. However, this re-evaluation of how we might improve these practices should also include a robust discussion of how designed spaces steeped in our own cultural values may impact a future society's ability to adapt, progress, and flourish. While the biological requirements of habitation can be engineered down to the most minute detail and space architecture companies such as AI Space Factory have included inhabitant's mental health as a significant design consideration [7]; still largely absent from the research is how these spaces may bind us to a particular way of *thinking* on other worlds. Our ability to adapt culturally and quickly in these most remote of environments may require a radical shift in space architectural practice. Mitigation of these concerns in design could be accomplished by including more astrosociologists in the process to account for the significant socio-cultural requirements of off-world settlement and habitat design.

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Design as an Optimization Tool in Space Architecture

I. Abstract

This article works with ideas and examples regarding problem solving of complex space habitats and structures through minimalist design. Taking into account principles of design in space architecture like optimization, decoupling and commonality, this article presents ideas regarding current and future developments of habitats and structures in space. The article demonstrates examples on how to approach ideas of minimalism and complexity when dealing with safety systems.

II. Introduction

Think about a large museum atrium, where a three-story high ceiling encloses a simple rectangular floor plan and now imagine the same floor plan with a one-story ceiling and walls dividing the space into smaller rooms and directions. We can agree that the "open" feeling of the first space would generate in us a sense of awe, while the second scenario shows a dull and ordinary lobby in an office building. The main reason behind this is that it is easier for our minds to reconstruct the volume of a large rectangular prism than to think of a series of different volumes intersecting each other. The ease of mental reconstruction of a minimalist space or idea can be regarded as what we find "aesthetically" pleasing. When most people agree on the idea that a space that feels right or comfortable to them, what is happening is a subconscious consensus that their minds easily understand whatever they're experiencing.

The opposite to this minimalism in design is complexity, and complexity can be found in highly logical engineering and scientific fields like the space industry. Complexity in engineering is the solution that is used when having to solve difficult tasks like assembling the International Space Station (ISS) in low Earth orbit's microgravity environment; or when creating a complete mission for a settlement on the Moon or Mars. To solve these highly advanced technological problems, as a space engineer, scientist, and mission planner, you have to solve for hundreds of variables and requirements. It is essentially like dividing the museum atrium into hundreds of rooms, where all of those rooms have to be connected to each other and if one of those rooms fails you have to have more backup rooms to replace the bad ones. With all these rooms, the atrium is now so cluttered with rooms and hallways that the only minds capable of reconstructing that space are highly intelligent and trained ones like those of Astronauts.

In his transcendental book: *The Structure of Scientific Revolutions*, Thomas Kuhn, when mentioning the nature of normal sciences states:

> *"Today in the sciences, books are usually either texts or retrospective reflections upon one aspect or another of the scientific life… Both in mathematics and astronomy, research reports had ceased already in antiquity to be intelligible to a generally educated audience. In dynamics, research became similarly esoteric in the later Middle Ages, and it recaptured general intelligibility only briefly during the early seventeenth century when a new paradigm replaced the one that had guided medieval research."* (Kuhn, p. 20-21)

If space is eventually going to become a democratized reality to a larger population, the knowledge spoken in the scientific and astronaut-related community has to become more accessible. This has to start with the actual habitats and their different human-systems having understandable functionalities. Fortunately, this is why we have fields like space architecture and systems engineering in private companies and national agencies like NASA. Utilizing principles of optimization, ingenuity, reusability and commonality, space architects take the holistic view of a mission and functionally design the habitats of the future. There is a common misconception that architecture and design respond only to mere aesthetic principles. The reality behind design is that it is a necessary tool for optimizing and guiding projects in construction, engineering, and in the case of this article: space architecture and its subsystems.

Figure 1. Astronaut in Destiny Module. (NASA)

III. Optimization Examples in Space Projects

With the necessity of generating return on investments, private companies are focusing on reusability, optimization and commonality of architecture and systems to get to orbit. Commerce, efficiency and sustainability are proving to be the only way the space industry becomes a democratized reality. Looking to generate returns in sending satellites into orbit, launch companies like SpaceX are effectively solving the conventional and new methods to reaching LEO and GTO. We will now describe some examples where design decisions can optimize some of the already hyper-complex engineering endeavors in space.

The SpaceX Approach

In comparison to the museum atrium being subdivided, we find a current example in the resupply missions to the ISS by different government contractors. For resupply missions and complying with redundancy and risk mitigation requirements, the aerospace industry has been applying a "structure inside structure" strategy to spacecraft designs with the sizing of resupply modules to fit to the internal dimensions of payload fairings. Figure 2 shows the Northrop Grumman Cygnus resupply spacecraft on its way to the International Space Station, where the "aluminum can" is inside of a larger shroud. On the other hand, Figure 3, shows how the SpaceX Dragon resupply spacecraft is the external shape of the aerodynamic rocket shroud, hence eliminating the need for a complete internal aluminum structure. Not only is SpaceX's optimized approach saving mass to orbit and increasing internal volume for supplies, but also it does not have to worry about the shroud jettisoning mechanisms failing. These are decisions that have to be made during the design and architecture phases of the missions.

Figure 2. Cygnus Spacecraft.
(Orbital ATK – Northtrop Grumman)

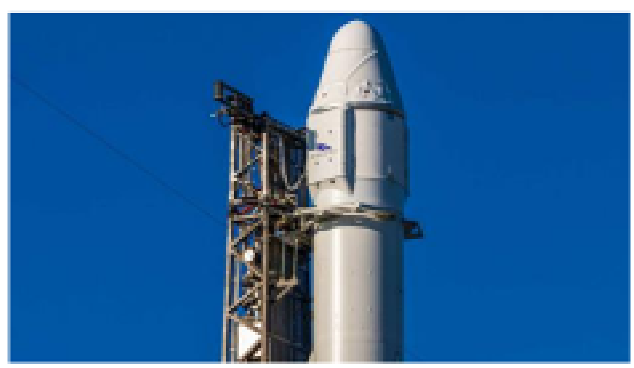

Figure 3. Dragon 1 Spacecraft.
(SpaceX)

Given the involvement of humans living in these extreme space environments, with thin walls separating them from the vacuum and harsh temperatures, it's essential and the primary goal of the mission to keep them safe. For this reason, there has to be a design for safety systems and sensors in all places possible around the habitats. One of the best solutions up to now can be found in the ISS, where modules are separated by hatches. In the case of an emergency where one module fails and begins to depressurize, the astronauts can quickly escape to the adjacent module and seal off the affected one. A design term for this is *decoupling*, that essentially states that the complete failure of one system would not affect the system as a whole and allow for a contingency plan.

But is there a point where adding too many safety systems can be counterproductive? When thinking of safety systems, it is important to note that these habitats are extremely complex machines that have to recreate the atmospheric conditions of Earth while responding to other scientific variables related to the mission. This is a case of a subdivided museum atrium that has multiple rooms with backup rooms in it. How then, do we optimize a space, while guaranteeing the safety of its astronauts? Can adding extra safety systems, that themselves have a probability of failure, overwhelm the capacity of even the bright minds of trained astronauts to solve multiple failures at once? Luckily, today's computing power and systems function as a technological optimization tool, where sensors can pick up on faults in real time and provide solutions to the user.

Can decreasing the number of safety systems maintain low-risk? Take for example the recently successful commercial Crew Transfer Vehicle (CTV), Dragon 2 spacecraft, and compare it to the manned Soyuz spacecraft. Both have their own designs to take astronauts from and to the ISS. The Soyuz has a pencil shaped launch abort system on top of the rocket (Figure 4), that was used during October 2018 during a malfunction of the Soyuz rocket. In dealing with its launch abort system, the SpaceX Crew Dragon utilizes it's Draco-Thrusters as the propulsion safety (Figure 5). In the case of the SpaceX vehicle, not adding an external launch abort system as in the Roscosmos case, decreases the weight and has one less mechanism of separation system failure to care for. Both function safely, but one is designed to be more optimized with fewer systems. The optimization through design by SpaceX can also be perceived in the final costs of sending an astronaut to the ISS: one seat in the Crew Dragon Capsule equates to $55m, compared to $90m per seat in the Soyuz.

Figure 4. Soyuz Launch Abort System
(Orbital ATK – Northtrop Grumman)

Figure 5. Soyuz Launch Abort System
(Orbital ATK – Northtrop Grumman)

IV. Conclusion

When dealing with space architecture and mission planning, it is of very high importance to understand the capacity of users to mentally reconstruct spaces and the function of the systems that they will be managing in space. Using design as an optimization tool will facilitate decision-making during trade-off scenarios. Having a minimalist approach in the space industry will also promote future stations, such as Axiom Station (Figure 6), that combine principles of advanced engineering as well as optimal design.

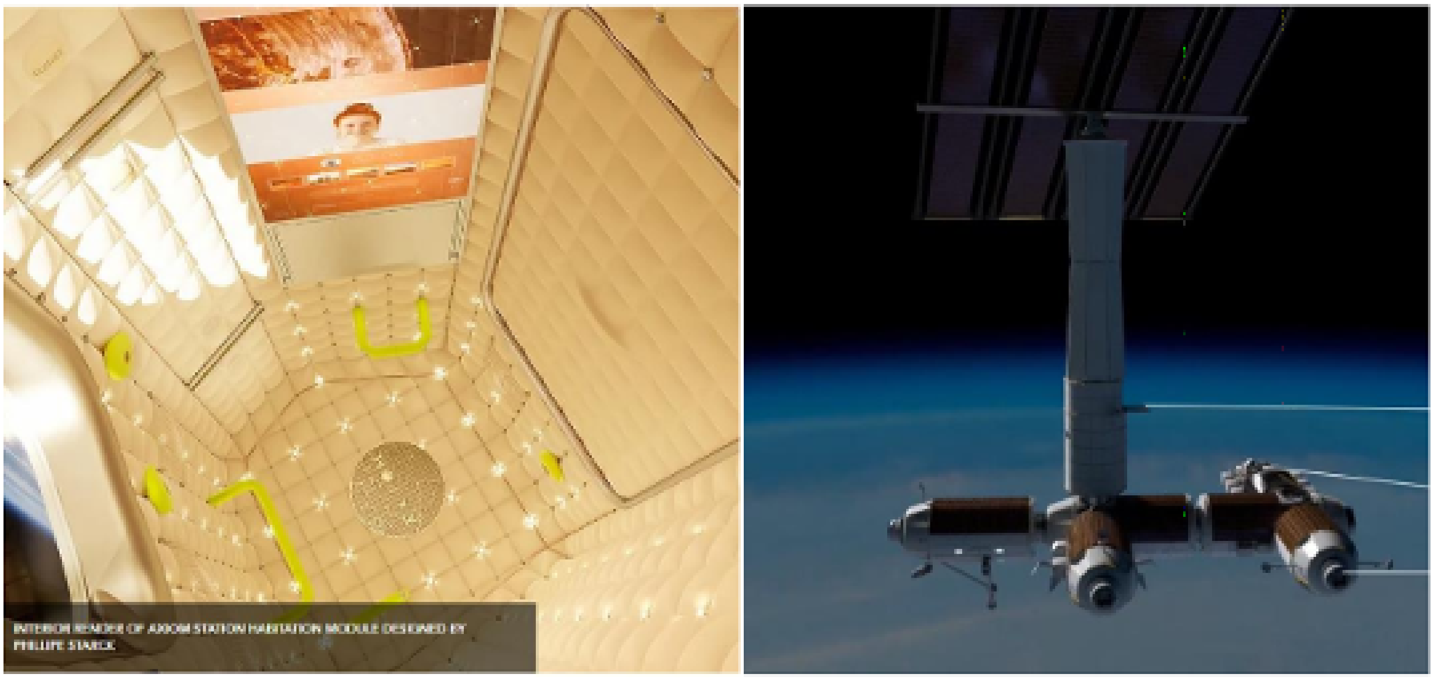

Figure 6. Axiom Station Renderings
(Axiom Space)

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Space Architecture

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Space architecture is closely related to astrosociology because social, cultural, and behavioural patterns in space habitats have a strong influence on design strategies.

"I want to become a space architect", this is something we are hearing more and more often. Why do young architects want to work in this field? It might be about breaking down frontiers designing for extreme environments. Practising space architects often describe their work as a way of finding answers to society's urgent problems such as climate change and population growth. A spaceship in its concept is self-sustainable, recovers valuable resources, and has limited habitable volume, aspects imperative to a sustainable future living on Earth.

Designing as an architect for real space projects seems the ultimate goal for many, but it is less exotic than it may sound. In-depth knowledge regarding space systems engineering and good social skills to work beyond traditional architecture-related disciplines are required. Engineering requirements prevail over architectural work since designing and building for space needs to create a safe and secure human habitat within a harsh and unforgiving environment. Further, classical space business has been dominated by engineers and the field is permeated by this particular mindset. The classical notion of the architect as lead designer is definitely out of place. The work of a space architect is one small gear in a huge machinery.

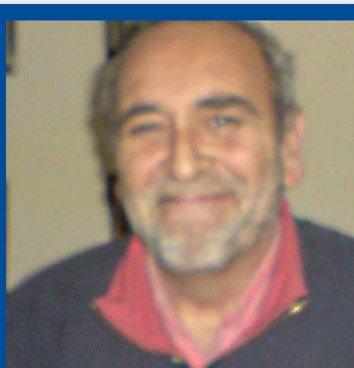
A human space exploration project is an international, intercultural and interdisciplinary enterprise, an exciting work situation that requires sensitivity and versatile curiosity beyond architecture. To imagine, conceive, design and contribute to building human habitats in orbit or on planetary surfaces is for sure, even within the most stringent constraints, an exciting architectural remit.

The first challenge we are often faced with is the scarce availability of room because it is limited by rocket fairing capabilities. A strategy to solve this is folding of furniture, room segments or even whole habitat envelope structures. One example is an EU-funded project we developed together with international European partners called Self-deployable Habitat for Extreme Environments (SHEE). SHEE is a mobile simulation habitat, shaped and sized to fit a shipping container that can be transported with conventional terrestrial means in its packed mode. Two such units would fit into a rocket fairing. Deploying the module by radial movement of hard-shell segments which then are sealed by inflatable tubes, the module can double its size from 25 to about 50m^3, offering sufficient space for a crew of two for two weeks. Since the interior is fully functional and outfitted with HVAC technology and furniture, everything inside has to be foldable as well, so that in its packed state there is hardly any interior space left. The necessary room for humans to live is provided only when needed and folded away during transport.

We consider this a promising strategy for future habitats on remote planetary surfaces, not only to make larger volumes transportable, but also foldable structures are helpful when reorganizing interior configurations appropriate to the daily routines aboard inhabited structures with limited amounts of room, as in space stations or lunar habitats. A private crew quarter for example, only needed during personal retreat such as sleep periods, can be folded away when not in use, to free up room for other activities like exercising. Something we are also pursuing in our current work is the interior organization of the European habitation module I-HAB for the next space station GATEWAY orbiting the Moon, that is under development and led by Thales Alenia – Italy. The international space station (ISS) offers a rich pool of experience we can learn from; however, building a station for lunar orbit is much more challenging, since rocket transport capabilities decrease with increasing travel distances, resulting in a dramatic reduction of spaciousness.

Given the difficulties regarding transportation, as human space exploration advances further to planetary surfaces, it seems obvious to consider utilizing local resources as building material. Furthermore, other environmental conditions also have to be considered such as differing gravity or cosmic and solar particle radiation. A permanent lunar settlement, for example, will need to have some kind of shielding structure to make longer durations possible without harming the human body. At present, the only solution is to cover the habitats with soil. RegoLight was a project led by the German Aerospace Center (DLR) – Cologne in which we partnered conceiving a lunar base and developing geometries for interlocking building elements that are 3d-printed. Three different 3d-printers were developed by a European consortium, and experiments under vacuum conditions were conducted to raise the technology readiness level from three to five.

At this early stage of space exploration, architects are fighting at the forefront to conquer the most hostile of all extreme environments that we know. Space architecture in practice has less to do with making a place cosy than making its habitation bearable at all. Scientists and engineers have their hands full, designing and constructing machines that provide the necessary basic environmental conditions for humans to survive. Apart from that, it needs someone trained to deal with at least basic ergonomic and psychological requirements of humans under those boundary conditions. We may shrug off a lot in turn for experiencing microgravity, or the amazing view awaiting us as we escape the atmosphere. Nevertheless, our basic needs remain the same. We not only need food, sleep and daily body care, but also appropriate space for these activities, as we want to stay permanently. For long duration space missions, astronauts will need more elaborate spaces, well designed to live healthily and to thrive to accomplish the set mission goals. The challenge is to provide this living environment in an area that is dominated, and thus strongly restricted, by the most challenging boundary conditions we have ever been faced with. Lessons learned in this unforgiving environment can help us master the challenges of living on our home planet.



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Space Architecture

Sci-Fi space media has 'Imagineered' ships and habitats of every conceivable type, but more for visual impact than functionality. Here we look at the near future, priorities, constraints and influence on sociological development. What problems do we face *now*? What habitat options do we have?

Humans evolved to best suit the conditions of our own planet. Leave it and we have big problems to overcome to ensure survival. Stays at the International Space Station (ISS) have gradually lengthened as we have learned about the effects of zero and micro gravity, and of cosmic radiation beyond our ionosphere. The most professional astronauts can also have sociological issues, disagreements and dislikes. One crew of the ISS's predecessor, SkyLab, in its fourth mission even mutinied over mission control work demands! Valeri Polyakov spent 438 days on MIR, a Soviet/Russian space station, and 2 others a combined 878 days. However, most stays still last less than a year and crews still experience physiological, if not psychological, problems. Scott Kelly spent a total of 340 days in space and suffered a number of physical and genetic changes.

> ***Scott's chromosomes also went through many structural changes, another team found. Chromosome parts were swapped, flipped upside down or even merged. Such changes can lead to infertility or certain types of cancer… He was slower and less accurate on short-term memory and logic tests.***[1]

Most of the effects reverted after a while back in normal Earth gravity, including on his mental abilities, but trips to other planets could take many years. Even Mars is seven months away.

Given the raw materials, mainly water, oxygen can be manufactured. Even water itself can be a problem. We are efficient at recycling, even from the ISS atmosphere and lab animal urine! But recycling is only a partial solution. Water is heavy, so finding it on other planets is essential to reduce the amount we need to take with us at launch. Radiation can be screened but screening is invariably also heavy. So our first main requirements for habitats are the obvious ones; keep the air in and radiation out. They will likely equally apply to planet-based habitats, as finding one with a suitable atmosphere seems to be many generations away.

Gravity, or lack thereof, is the biggest problem for the human body in space. There is gravity at ISS orbit height, but orbital speed is what keeps it up, so the centripetal (more familiar as 'centrifugal') force has to balance it, so no gravity is felt. In deep space, any gravity is insignificant anyway. Large planets will have the opposite problem. Humans can withstand high gravitational forces to some extent, but only for a limited time. Much more mass than Earth becomes a problem.

First, let us review more long-term effects of lack of a gravity, and how Elon Musk may change the details of his planned trip to Mars! Multiple studies by NASA and others have demonstrated that muscle and bone degradation occur over a long period; and more recently, it was discovered that eyesight problems occur in astronauts. Many changes are measurable after even quite a short time. Humans in zero G would not need much use for bones and muscles over an extensively long period of time, so they may acquire some jellyfish-like attributes, as water pressure counteracts the effects of gravity. They may need to exercise in order to search for food, construct shelters, avoid predators, and engage in other physically demanding activities. Possibly a more worrying effect that seems to take only a little longer is that a human blood flow can halt or even reverse (particularly in the upper body).[2] This has been observed after a number of months in astronauts, but its implications are far from understood.

The prime requirement of a space habitat will then be to create the effects of gravity the only way we know how by either using a counterweight or by using the same centripetal force that can counteract the effects of gravity in orbit or in open space. That requirement then imposes severe constraints on spacecraft architecture, as it requires rotational motion of the habitat zone, which would be in a "ring" or the "walls" of a cylinder. A number of such craft or habitats have been envisioned. Even toy manufacturer LEGO has a ring-shaped space station (see Figure 1) and the same configuration was highlighted in the film *2001: A Space Odyssey* (see Figure 2). The "Coriolis effect" would make living on the spacecraft a bit strange as, for instance, poured water would not fall directly down. Contra-rotating section would aid overall stabilities although it would be difficult to move from section to section, potentially creating a social division.

Architecture on planets is a different matter and forms would greatly depend on local materials and particular environments. We can only carry a very limited amount of building material into space. Indigenous architecture would develop. All the sociological considerations applicable on Earth would also be valid. Architectural design can have a major influence on well being, and we all need the right degrees of privacy and intercourse.

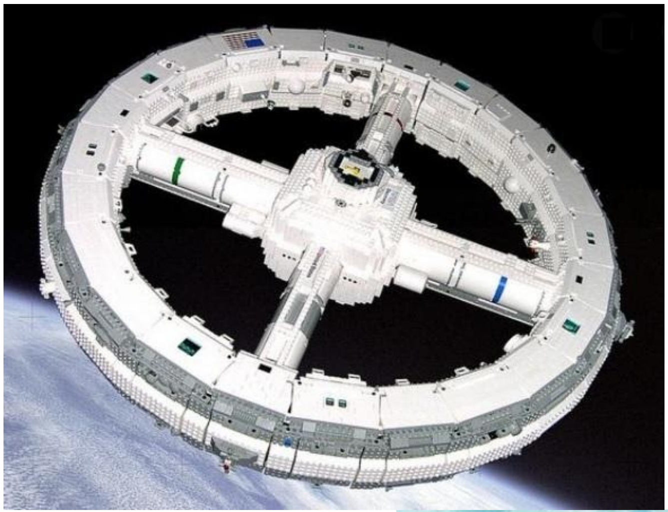

Figure 1: LEGO Ring Space Station Kit

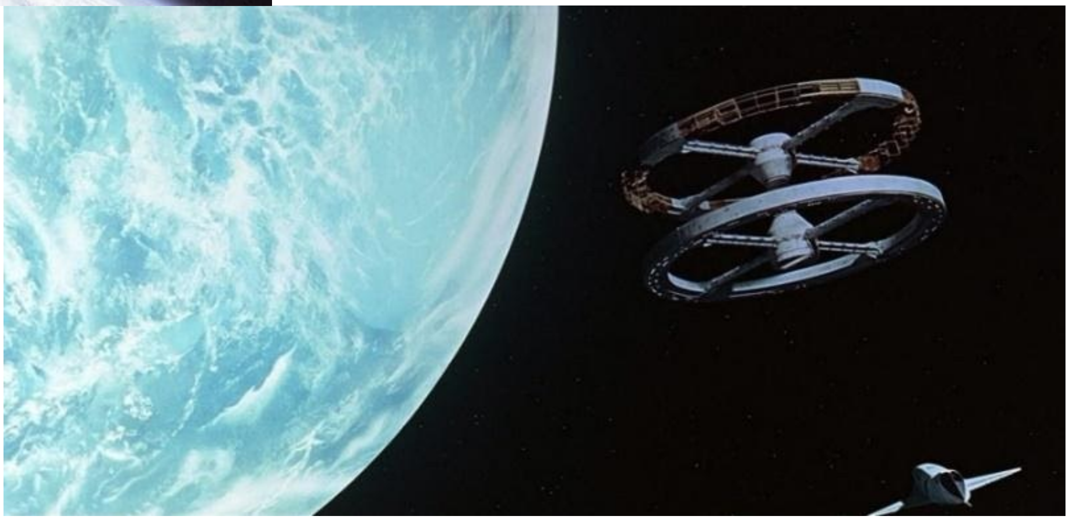

Figure 2: Space Station Depicted in 2001: A Space Odyssey

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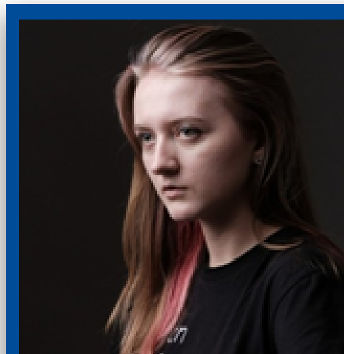
New Space Architecture Paradigm



Anastasia Prosina

Co-founder & CEO at Stellar Amenities

What is Space Architecture?

First, let us define what architecture is. Architecture is the art and science of designing buildings and other physical structures. Space Architecture is a subset of architecture, sharing the niche of small architecture among tiny housing, small living apartments/houses, vehicle design, capsule hotels, and more (Fig. 1). The principles of a successful design for a small space habitat do not differ from other design principles applied to the variety of small living areas on Earth: all aim to be multifunctional and mitigate the sensory deprivation of existing in a small space.

Fig. 1. Space Architecture within Architecture

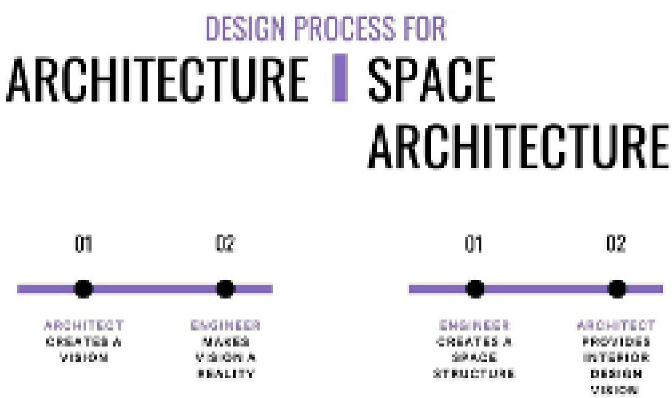


Fig. 2. Design process in Architecture and Space Architecture

The processes of creating architecture and space architecture are different (Fig. 2). In architecture, the vision of an architect comes first, and then an engineer helps this vision become a reality. In space architecture, the process starts with a group of engineers who design and assemble the spacecraft, outfitted with the necessary systems. A space architect comes afterwards to help design for the human needs in the confined environment.

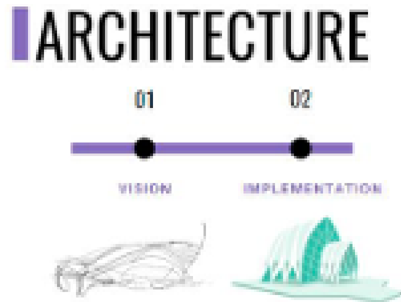
Although architects are creative and visionary, they are rarely so radical that they design structures that cannot be built with modern engineering. Certainly, they always sacrifice some of their vision to the necessities of engineering, yet architects have an intuition about what is physically feasible.

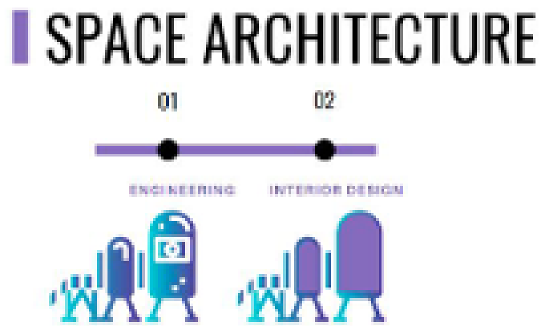
In contrast, the spaceflight industry has strict requirements because a spacecraft is such an extensive system of interdependencies that cannot be changed. Seeing the engineering constraints first is much more efficient for a space architect. He or she can then work within those constraints rather than implement the vision and then work with an aerospace engineer to see if this vision can be made practical. Creating space architecture that way would be inefficient because each architect's vision would require the design of a new spacecraft. Analogous to aircraft design, architects design the interior of an aircraft, yet none are designers of the plane itself. To implement the vision and then create the aircraft is not practical. For highly constrained regimes such as aircraft and spacecraft, doing the engineering first and then implementing the architecture vision makes sense.

Who is a Space Architect?

Traditionally, a space architect was a systems engineer, because systems engineers were the only ones on a design team who had enough knowledge about a spacecraft to design an interior. Now, people can be trained to be actual space architects, whose duties are to create interiors within constraints. System engineers no longer have to do this job; instead, they can advise space architects on the constraints.

In space architecture, it is not practical to design first and then to see what can be implemented through engineering. It is because the diversity of structures that are valuable for space travel and cost are minimal—that is why everything should be domes, spheres, toruses, cylinders, and pill shapes. With the increasing demand for designing valuable interiors for spacecraft and space habitats, it makes more sense to have real space architects rather than having systems engineers do space architecture.





Why should Systems Engineers Decide the Spacecraft Structure?

The reason system engineers should design the structures is that the costs involved for introducing additional mass and volume are huge. Thus, deviating from a mathematically ideal structure dramatically decreases the amount of funding available for the interior design. Doing so is very rarely, if at all, worthwhile. In other words, the added value that a structure has when an architect designs it is not great enough to offset the dramatic increased cost of introducing additional mass, additional volume, and nonideal sizes and forms into rockets.

Deviating from things that are not efficiently packed into cylinders dramatically decreases the amount of volume architects have to work with. Rather than trying to guess what structure is valuable, engineers should continue to provide the constraints, such as the rockets available, their payload masses, fairing sizes, and what spacecraft restrictions are in terms of the spacecraft's available volumes, forms, inputs, and outputs.

In the far off future, this fact could change when the cost of space travel comes down dramatically, possibly as people live in larger numbers on other worlds, rather than only in orbit. For the foreseeable future, such as this century, however, space architecture should focus on designing within the engineering constraints and begin after the engineers' work is done.

CubeSats, for example, have a well-defined size, and anyone can fill a CubeSat with whatever they want as long as it meets the constraints of the CubeSat. People do this type of designing already, greatly expanding the diversity of things that are implemented in CubeSats. The same scenario could exist for other spacecraft interiors. Engineers can design the rockets, rocket cabins, space stations, and habitats, and then space architects can fill that structure.

Why do Systems Engineers get to Decide the Shapes of a Space Habitat?

The most significant determinant of the shape best suited for a habitat from an engineering perspective is whatever best accommodates the internal pressure of the living volume and fits adequately into rockets. The cost is smaller to proceed with a minimum amount of mass and volume of the habitat structure.

If you deviate from the ideal structures for space travel, the cost of doing so is so high that it dramatically decreases the funding available for the interiors. By supporting the optimal exterior arrangement for space travel, you significantly reduce the baseline structural cost and preserve funding available for internal design.

During long-duration missions, astronauts/space tourists will struggle with seeing the same people, performing routine tasks, isolation, and the small volume of a space habitat. It will cause rising conflicts as well as affect the overall wellbeing of each person. Not everyone can tolerate the isolation and loneliness encountered on long space flights, but a well-thought-out human-centered design can significantly relieve these issues, thus helping humanity to explore space without causing harm.

Notes About Human Habitats Design Approach

Alon Shikar

Co-founder and Designer of D-MARS, Desert Mars

The engineer aesthetics, and Architecture, are two things that march together and follow one from the other.

Le Corbusier 1931

Abstract

This article presents ideas for the design of Space Habitats through planning and building analog Habitat structure prototypes. The ideas are presented over a series of diagrams and drawings of HAB-02, the second prototype of a Mars analog base site made by the D-MARS Analog Missions Organization.[1] The diagrams present and analyze basic architectural features such us movement, spatial volume, vision, rhythm, mix uses, and other important metrics. By doing so, we hope to engage and enrich the bodies of knowledge of space architecture and conventional Earth architecture, while keeping the sustainable approach in mind in both cases. In recent years, more groups of researchers have been developing habitats and analog habitat concepts,[2] making this difficult field a globally collaborative task. In this paper, we propose the use of urban design analysis methods to tackle the complexity level required for designing a professional habitat. By doing so, we could design the space in a more perceptual and prosaic manner.

Habitats

In space exploration, "habitat" is a general term for home or shelter. It can be used for humans, other natural organisms or for machinery/robotic objects. In ecology, habitat refers to the overall conditions required for an organism to not only exist, but also to flourish.[3] The main role of the habitat is to provide the full needs of a human research mission in extreme isolation conditions, and it must include all the elements needed for scientific practice. These strict demands require the consideration of a wide range of features, operations, and possibilities not merely in the physical, technical, and climatic aspects, but also the cultural, financial, social, behavioral, and psychological ones.

Space habitats is a challenging field of study. Imagine simulating a home located on Mars, 200 million kilometers away from here. It is an architectural adventure, combining prehistorical construction methods with the most advanced and sophisticated technology. The design could draw inspiration from the first ancient human settlements, which were constrained by limited resources. We, just like our ancestors, will have to deal with a lack of materials, lack of communication, limited mobility, and many other difficulties. To overcome this, we need to have simple, smart, and modest design concepts.

This article is based on the discussions and brainstorming sessions that we are performing at the D-MARS organization as we develop a second prototype for an international Mars analog Habitat base (Figure 1) located at the Makhtesh Ramon Crater, in the Negev Desert in Israel.[4,5]

Any human mission and habitat design will face many challenges, including:

(1) keeping the crew of researchers or dwellers safe and comfortable; (2) using in-situ resource utilization (ISRU) techniques to reduce the dependency on shipments from Earth; (3) reducing mission costs; (4) supporting the scientific program; (5) communicating with Earth, satellites, or other habitats; (6) creating international standardization for habitat units; and (7) developing space activities and business opportunities.[6]

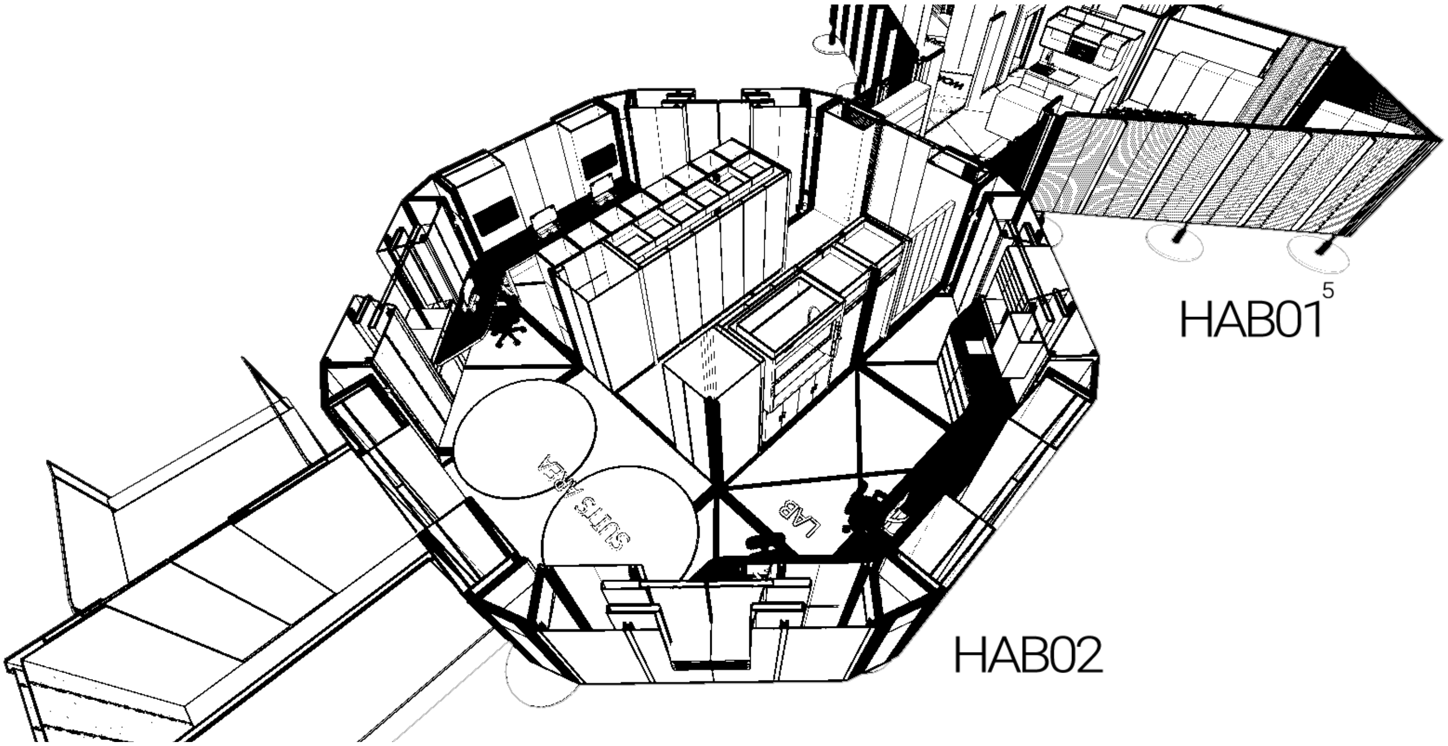


Figure 1: ARABIC 1-D-MARS new module habitat connected to the first module. The Habitat must be very efficient in sense of movement and uses.

Since the 1960s when space architecture emerged as a genuine field of study outside the science fiction realm, only a handful of habitat concepts have been fully developed. Each concept reflects the contemporary technology and the conditions/climates of the habitat's destination. In Haym Benaroya's book *Building Habitats on the Moon,*[7] he describes a framework for a three-stage approach to habitat construction. The first stage is the rigid structure, a preliminary "closed box" shipped from Earth and perfectly sealed and protected from radiation, various flying particles, and thermal differences. Due to the limitations on the weight and size of the space vehicle, the habitat will have to be made from light materials and will have to carry as many life support systems as possible within in order to support the crew. To increase the duration of the mission, the second stage is to achieve a larger volume and the habitat will need to have an expendable capability. This could be achieved by deploying inflatable mechanisms, 3D printing methods on-site, or futuristic biological structure fabrication concepts.

Machine for Living

The final ISRU stage also involves the cultural aspect. Humans using resources on another planet to sustain life is a cultural phenomenon and will probably lead to a new type of infrastructure. In a paper from the late 1920s, and in a later book called *Towards a New Architecture,* the renowned architect Le Corbusier labels five architectural principles which later became the foundation of the modern architecture movement.[8,9] This was a period when construction methods were changing dramatically, including the use of concrete and air conditioning solutions. Le Corbusier understood that these new technology improvements could liberate architecture from conservative constraints. He referred to the house as a "machine for living" and suggested a greater correlation between using new construction methods to achieve a greater natural light and a better use of the local climate and surroundings. In order to achieve it, the design approach for habitats in space needs to be defined by (1) contemporary and future construction technology; (2) using the advantages of local climate and surroundings; (3) multi-use/multi-functional spatial capabilities design; (4) exploring and promoting the use of cyberspace to enrich or complete the user experience of the dwellers;[10] (5) rethinking standard architectural terms like "Wall, Floor, Ceiling";[11] (6) promoting a User Experience/Interface design orientation; and (7) using data collection with spatial sensors to analyze movement, social behavior and more.

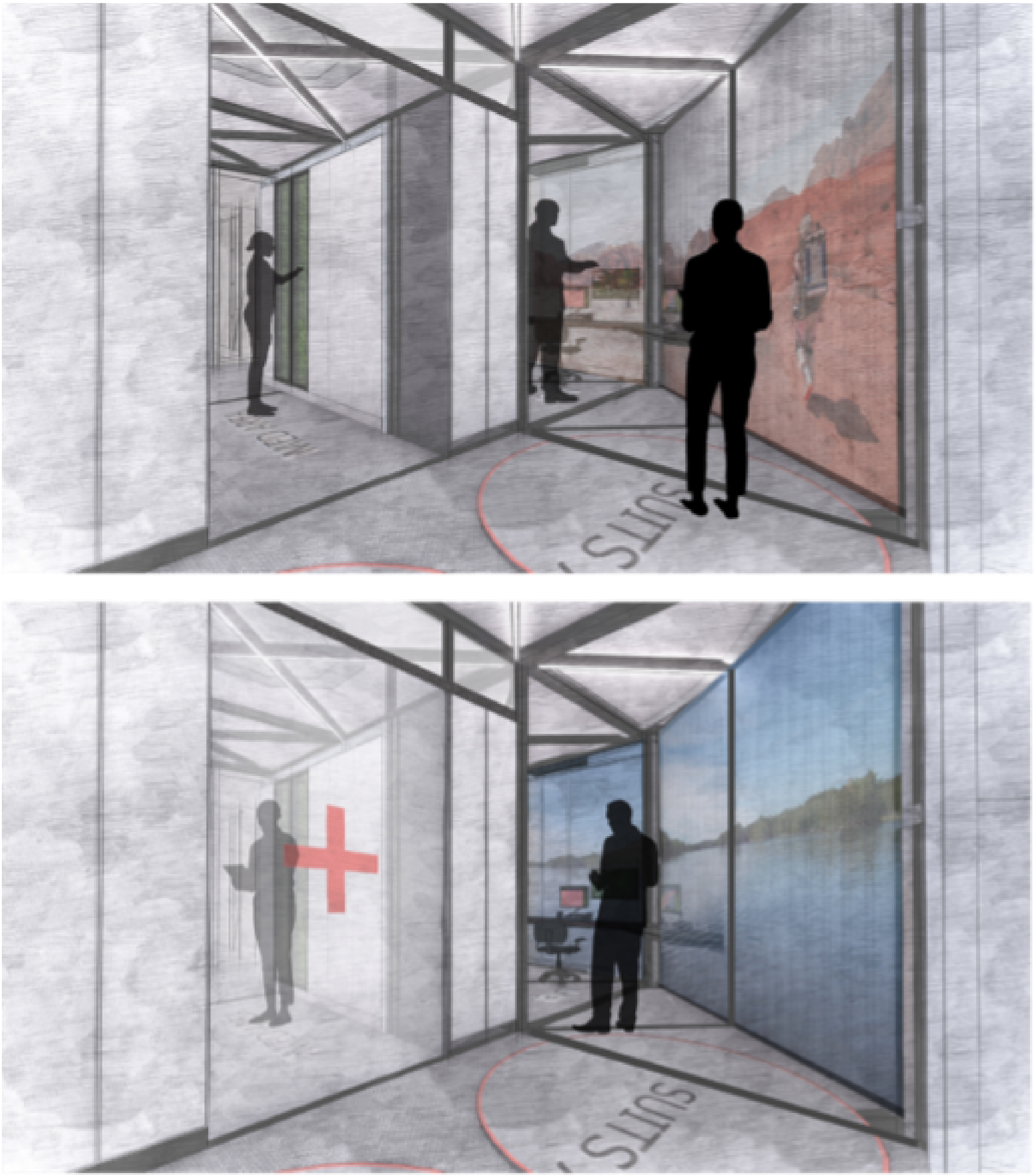


Figure 2: ARABIC 2 - Habitats - liberate architecture from conservative constraints. Multi use space with and addition of cyberspace features. View facing the command CMD area and the main operational passage. During emergencies, it could turn in on medical room, the cabinets could move from side to side. Allowing for more flexibility for users.

Habitat 02 - DMARS, Design by SHIKA design collective.

Movement Based Layout

Habitats are compact, similar in size to the area of a student's apartment. Each square meter should be allocated for several functions, making the habitat a limber multi-purpose spatial volume (Figure 03). To analyze walking paths and visual perspective possibilities inside the habitat, we use Space Syntax methodology,[12] a set of rules that analyzes cities by movements, diversity of path choices, field of view, sight perspectives, connectivity, and similar metrics. By doing so, we have tested several different indoor configuration layouts (Figure 4) and chose option B as an example of a good balance between the use of space and the paths it allows. By allowing the cabinet to move we could create another space (Option D). Although further study needs to be conducted, the diversified paths and multi-use spaces will increase physical activity.

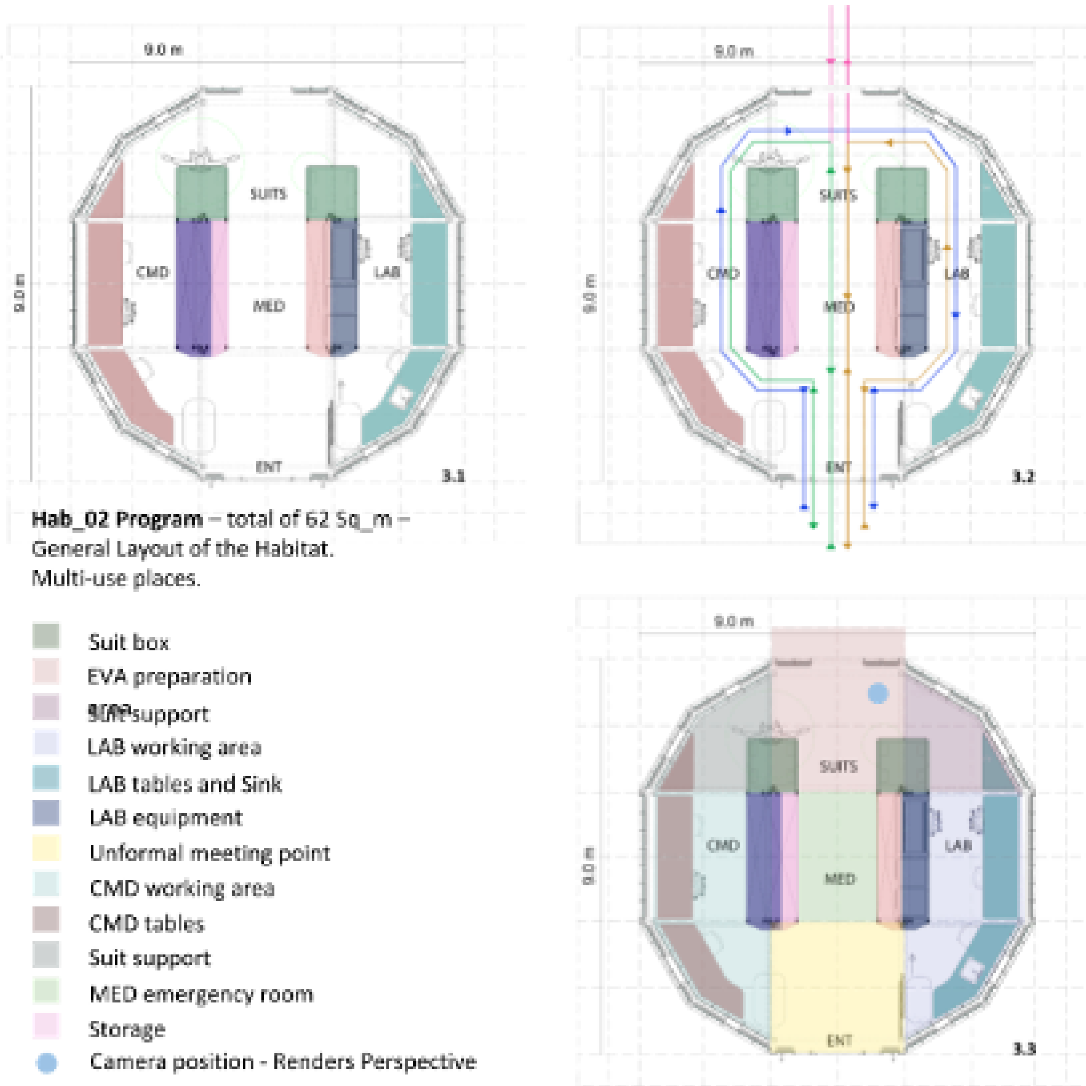


Figure 3.1: Main 4 functions - Laboratory, command, suits (donning and doffing), medical emergency unit. Figure 3.2: Movement path choices. Figure 3.3: Area use. See able above.

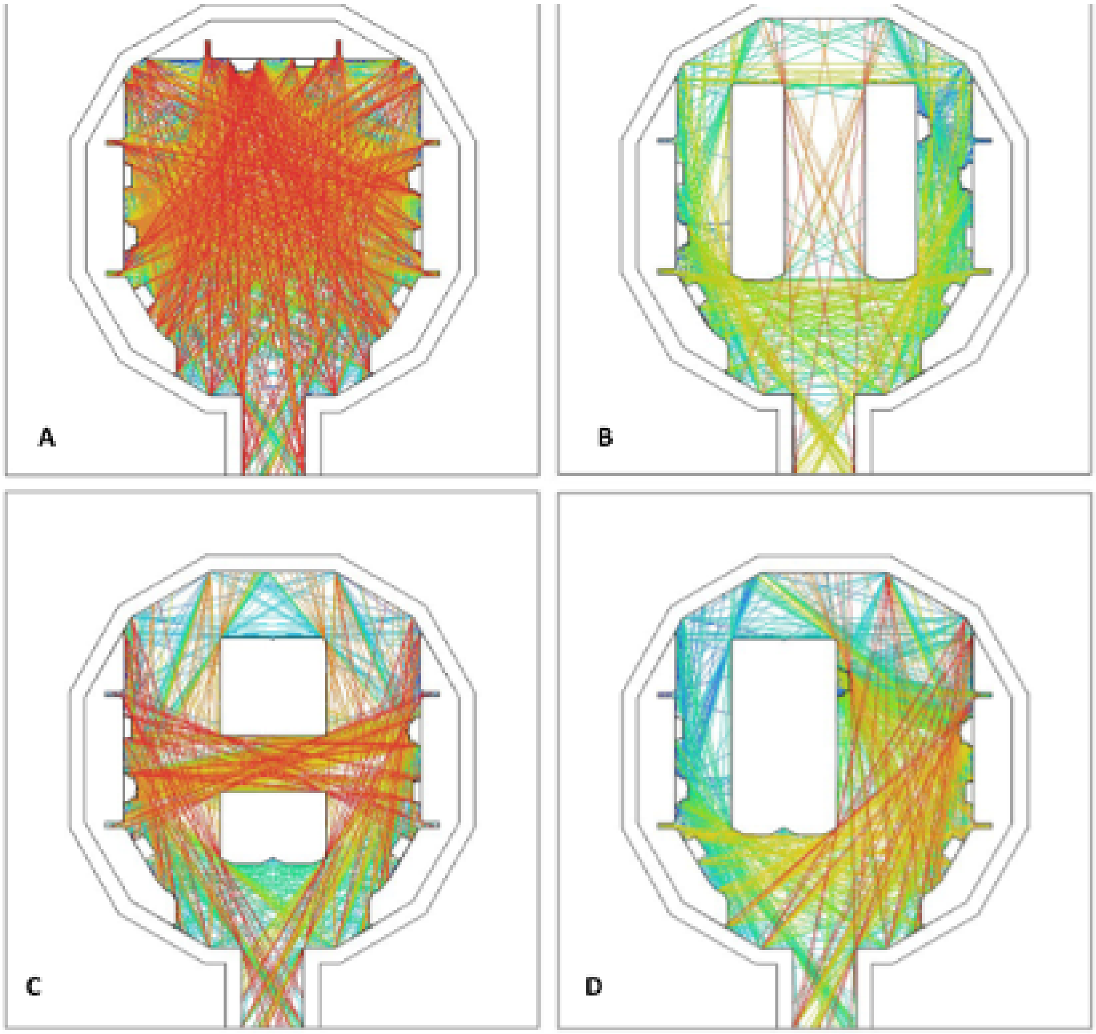


Figure 4: ARABIC 3 - Habitat 02 functions layout based upon Space syntax analysis outcomes. The design allows many walking experiences of the space. D-MARS Analog Base Station, Israel, 2020

Maps made with Depthmapx

Conclusion

The difficulties of building habitats are plentiful and come from a wide range of directions and perspectives. To resolve the space "settlement" problem, we must design and build hundreds of diversified examples and prototypes of habitat structures. These will enrich the body of knowledge both for the space sector as well as the construction industry and sustainability movement. This article presented the second prototype of the D-MARS habitat through a principle layout plan. This included the division of functions inside the habitat and an analysis of the space syntax methodology. In order to test these diagrams, a further study tracking the mobility of the residence must be conducted.[13]

Many Thanks for all the DMARS team, our FAB-SHIKA studio and all our partners and collaborators.

Special Thanks to Dr. Hilel Rubinstein CEO of D-MARS and Mikhail Raizanski for their enormous contribution to the design process.

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1. Human – home 2. Scientific. 3. Volume and size. 4.Mars condition: Radiation, Thermal. 5.Earth-Mars time delay. 6.Education. 7.Public engagement. 8. Costs. 9.ISRU. 10. Recycling and Reuse.

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12. Bill Hillier (1996) *Space Is the Machine*, 2007 edn., 4 Huguenot Place, Heneage Street London E1 5LN United Kingdom: Space Syntax.

13. For more information about near future experiments in the Habitat, please visit the Austrian Space Forum website – under the International Experiment AMADEE-20. https://oewf.org/en/portfolio/amadee-20/

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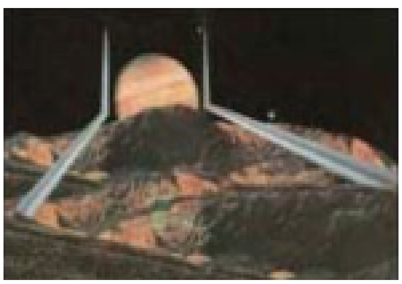
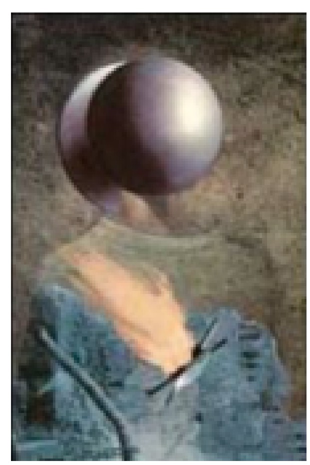
San Antonio, Texas

Ancient Space Architecture

The lunar science community was asked to answer the question, "Why Explore the Moon?" It was an intriguing exercise played out on their list-server with a tremendous outpouring of responses from community members. After all the science rationale, after the exploration and economic arguments, after the policy and security considerations, and even after the habitation and settlement reasons, I thought there still remained an additional aspect to consider, the facet of legacy. The legacy of the human race as expressed through lunar exploration and space exploration in general. If we sing the mantra that the Moon is a proving ground for getting to Mars, then Mars becomes validation of a multi-planet species venturing to other worlds and beyond. As we blaze our trail of human exploration and settlement throughout the solar system and cosmos over the millennia, what do we use to tie it all back to the legacy of where we came from and who we are? As a space architect, I approach this question from a perspective of building.

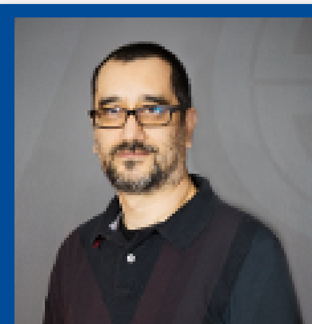


The ancients used architecture to orient their place in the cosmos and built their monumental structures to the cardinal directions. The pyramids of Egypt, the Chaco Canyon civilization, Globeki Tepi built 12,000 years ago are only a few examples that attest to this. Will a lunar base and future planetary bases or settlements do the same, orient its site development for a human experience of understanding where we came from, where we are going, where we are? Positioning and navigation technologies are with us, but we can also use the ancient ways of building monuments to our legacy aligned to astronomical markers, planet azimuths, or structures aligned to a planet's coordinate system. What if we devised for future architectural monuments or site planning on the Moon and then Mars an employment of astronomical alignments, site orientations for the structures we create that periodically or seasonally connects us back to Earth by nature of position at a particular point in time in the solar system. We can use astronomical alignments in our site planning to extend a network of monumental architecture we create on the Moon, Mars, and future new worlds that are astronomically aligned structures between planets connecting to some starting point on Earth, such as to the Great Pyramid of Giza that stands purportedly at the geographical center of Earth. In this way the legacy of where we come from is archived as we reach further into the cosmos.



What will be the iconic architectures we leave behind on these new worlds, the lasting monuments built along the way, encoding the knowledge of who we are with our accomplishments gained in science, engineering, and the arts? The legacy left behind for future generations and civilizations to discover and understand who we are, where we came from. Using space architecture to tie our ancient architectural heritage to these new worlds requires a bold vision of expression of our species for our civilization as we step into the cosmos to settle distant planets. Merely designing habitats for lunar bases, or architectural ecosystems for dwelling in planetary caves, or for Mars settlements, falls short of the promise of space architecture. As we become proficient in building off-world with future technologies and new materials that advance our craft, and we get to a point where we are not just trying to survive in a harsh environment but have the luxury to actually build monumental structures, space architecture should strive to encode our human presence in the solar system. Such architectural statements of who we are also act to insure our legacy against cataclysmic events. Just like the pyramids and megalithic ruins found on all continents of the globe, ancient cultures are left with the architectural remnants of their civilization for new explorers to ponder their purpose. Space Architecture should have within its domain the building of planetary structures that withstand the test of time, ancient time.

In Search of an Anthropology of the Cosmos



Marcos De Colsa Ll.

Master's Degree in Anthropology

Bachelor's Degree in Social Anthropology

Fifty years after the arrival of man on the Moon, one of the great narratives that shaped the twentieth century has been revived: space exploration as one of the most important scientific and technological achievements of humanity.

Although in 1969 the Apollo 11 Moon landing was an act that had meanings closely linked to American identity, today, space exploration has more global connotations and does not only cover government sectors, but also the private sector.

The monumental achievement of NASA in the days of the Apollo mission has different angles of analysis and edges that had an impact on modern history, but what interests us here is to approach the space exploration that begins in the second half of the twentieth century as the continuation of a narrative that has its roots in our ancestors, and also which is the construction and cultural appropriation of space as a universal quality of the human being.

In establishing this, we also advocate an anthropology of the cosmos, in the sense of treating the cosmos as a cultural object, which has had different representations throughout history. Of course, it is currently a cultural construction that goes hand in hand with advances scientific and technological, but there is also a popular cultural imaginary that weaves and enriches this narrative or modern myth.

Some myths and narratives of modernity are closely linked to technological and scientific development, which does not mean that progress is a myth. What is structured as a myth is the narrative that is built towards the collective imaginary, sometimes from the popular culture preceding technological advances, such is the case of Jules Verne and his novel *From the Earth to the Moon*, 1865.

The modern narrative of space exploration literally took off in 1969 with the launch of Apollo 11 and the Moon landing on July 21, 1969, when a human being walked for the first time on the surface of an object of the solar system that did not is the Earth.

Beyond the technological challenge that the Moon landing represented, in anthropological terms, a narrative was established in which the cultural construction of space entailed a concrete form of appropriation and the possibility of migrating Culture (capitalized) to outer space.

Paradoxically, a year earlier, the Stanley Kubrick film, *2001: A Space Odyssey*, anticipated space mythos, already rooted in popular culture, with a film that marked a before and after both in the way of representing the cultural link of the human being with space, as in the cinematographic perspective by taking the science fiction genre on the big screen to a quasi-intellectual level.

So that popular culture and science worked hand in hand to establish a cultural landscape around space in two senses, in a "real" sense, where science and technology pushed astronomy towards a golden age with a new generation of powerful telescopes that gave us images of previously invisible stars and galaxies, and another "fantastic" vision of the cultural possibilities of outer space, where the collective imaginary interwove a narrative that put on the discussion table the archetype of life in the cosmos, or to be precise, of intelligent life.

In the years that followed the Moon landing of 1969, the encounter between the two narratives lived its best life. Incredibly, the initiative would be taken by a group of scientists whose most visible face was the cosmologist Carl Sagan and the most important space agency in the world, NASA.

In collaboration, they sent a series of "messages" to the cosmos about the existence of intelligent life on Earth, as a form of testimony of the existence of humans, first in the Pioneer 10 and Pioneer 11 space probes between 1972 and 1973, and later in 1977 in the Voyager 1 and Voyager 2 probes.

A turning point in the narrative of the twentieth century on the cultural construction of space was undoubtedly the 1980's television series *Cosmos: A Personal Voyage* Through which Carl Sagan became a central figure by embodying the great diffuser of science on a massive level. The cultural impact of *Cosmos* has been to bring interest in science and astronomy to an audience that covered all educational levels and ages. For the new millennium, the series has been seen in 60 countries with an audience estimated at 500 million people.

The series gave a new perspective to the general public on issues such as the size of the universe, the number of galaxies there are, life on Earth, the evolution of the human being versus the age of the universe, the Big Bang, and black holes. A whole new language, previously contained in the academic and scientific community, exploded in the imagination of the rest of the world.

From my perspective, *Cosmos* not only marked a watershed by introducing a new lexicon and a new way of understanding the universe, but drew a bridge for the discussion between popular narrative and science about the possibility of life beyond the Earth.Until the arrival of the series, it is very likely that the general public had never seen a scientist talk about extraterrestrial life; that only happened in the movies.

Today, 40 years after the premiere of *Cosmos*, there are groups of scientists and astronomers who form their professional lives around the search for life in the universe, and disciplines such as astrobiology have taken the discussion to a high scientific level. In fact, scientists have put a change of focus on the discussion table: The fundamental question is no longer if there is life in the universe, but how long it will take for human beings to have solid evidence.

But what about the implications of space exploration for anthropology? And how can an anthropology of the cosmos be built?

The first step is to try to establish the possible scenarios. NASA currently has a very ambitious project called Artemis, alluding to the Greek deity and sister of Apollo, with which they plan to return man to the Moon by 2024. The phrase used by the project is "humanity´s return to the Moon" and thus establishes a sustainable platform that allows astronauts to be sent to Mars.

For any scientist, it is an extremely seductive scenario, and nearly anyone can identify with the excitement of such a possibility. However, for an anthropologist there are implications that force us to rethink the human experience, how our beliefs will be modified, how it will impact the great religions, what impact will it have on the idea of life that we have so far, what impact it will have on the different cultural identities, and so we can continue.

Obviously, what we have at the moment are questions. Explorations of Mars have been indirect, that is, by means of artifacts that man has sent, but has not yet been explored directly by putting feet on its surface.

Achieving a sustainable life outside the planet Earth is the most imminent implication for anthropology, and if that sustainability extends to other generations we will have to ask ourselves what are the consequences of a new generation that will have to redefine its identity, its idea of family, its relationship with its habitat, its beliefs, and so on.

What astronomy has taught us is that the planet Earth does not have a privileged place in the universe. We live in a typical galaxy, of which there are billions, and we orbit around a typical star, of which there are also billions. The basic elements for the presence of life (hydrogen, oxygen, carbon, and nitrogen) are all over the universe.

Which brings us to the other great implication for anthropology: a scenario where life is discovered on another planet. Astrobiology experts talk about the possibility of areas in the solar system where microbial life is possible. So we may not have to go far to find it. The impact of finding it will be a milestone in the history of mankind. Beyond being the most important scientific discovery, in anthropological terms it could be what forces us to redefine ourselves as a species.

So the search for an anthropology of the cosmos has to do with looking back and learning how our ancestors built their cultures and identities from their relationship with the cosmos, how they made the cosmos a cultural object, and looking to the future to see how we are doing.

Two Architects are Building and Testing a Moon Home on an Extreme Mission

Anthon Shrader

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SAGA Space Architects

Sebastian Aristotelis, 27, and Karl-Johan Sorensen, 23, the founders of SAGA Space Architects, have spent a year researching, designing and now building the LUNARK Habitat. It is an origami-inspired building that will expand by 560% upon landing, and can thereby function as a home for future space travelers while not taking up a lot of space on the spacecraft.

Well-being and indoor climate play a crucial role in our habitat architecture. While the duration of space missions are increasing, it only becomes more important for the astronaut's health and performance. Our generation spends 90% of our time indoors. The expedition will help to discover solutions in well-being and indoor climate on Earth as well as in space. The mission is a completely closed and confined living-space, perfect for behavioral studies. Humanity does not have to go far away to find relevance for these studies. Most people work indoors and will spend a huge majority of their lives inside. Thus, people must strive to find healthy countermeasures for space and Earth.

The interior of the LUNARK Habitat is designed to combat the psychological challenges astronauts face in space such as losing a sense of time because of the lack of changes in the surroundings, depression from being isolated, and a general longing for stimuli such as nature.

The LUNARK Habitat is controlled by ODIN, the brain of the building. Through the Circadian Light System, changing weather conditions will be simulated, and by integrating a vertical garden and a speaker playing sounds from nature, ODIN will provide the LUNARK Habitat with a stimulating environment for the people who live in it.

"The LUNARK mission is an admirably ambitious project and a refreshing technology demonstrator of what the future Lunar Habitat might look like. The project promotes important innovation and research for aerospace."- Kristian Pedersen, Director of DTU Space

Last fall, the two co-founders and best friends took the LUNARK Habitat to Northern Greenland and test their creation in one of the most extreme environments on Earth, with temperatures dropping to -30 degrees Celsius, hurricane winds and polar bears.

Figure 1: LUNARK Model

Learn more about the LUNARK Habitat in this 3-minute video:

https://www.youtube.com/watch?v=QEEQR95Pl68