

ABSTRACT

Title of Thesis: FREE SPACE: ENVISIONING THE LOW
EARTH ORBIT METROPOLIS

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Master of Community Planning, 2021

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This thesis posits a permanent, free space settlement and a space-based regional plan as the first step in sustainable and ethical settlement beyond Earth. The settlement paradigm explores modular and redundant construction and planning techniques that could be scaled and replicated to achieve long-range missions of exploration and long-term space settlement.

A systems-based strategy within Low Earth Orbit provides the first architectural steppingstone for humans to realize themselves as a multi-planetary species. Space hosts a plethora of untapped and un-realized resources that have yet to be imagined for the betterment of life on Earth. As a result, it is imperative to plan and to think about what the consequences a permanent settlement in outer space could mean for life on Earth. In exploration, this thesis sets forth a strategy to ensure outer space and its resources are used fairly, responsibly, and justly, and access is promoted equitably, ethically, and morally to all who have a hand in a globally collaborative human agenda.

FREE SPACE: ENVISIONING THE LOW EARTH METROPOLIS

by

Andrew Joseph Mazer

Thesis submitted to the Faculty of the Graduate School of the
University of Maryland, College Park, in partial fulfillment
of the requirements for the degree of
Master of Architecture
2021

Advisory Committee:
Professor Lindsey May, Chair
Professor Casey Dawkins,
Professor Juan Burke,
Fred Scharmen

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Preface

"Make no little plans; they have no magic to stir men`s blood and probably themselves will not be realized. Make big plans; aim high in hope and work, remembering that a noble, logical diagram once recorded will never die, but long after we are gone will be a living thing, asserting itself with ever-growing insistency. Remember that our sons and grandsons are going to do things that would stagger us. Let your watchword be order and your beacon beauty."

- Daniel Burnham

Acknowledgements

Professor Lindsey M. May, Dr. Casey Dawkins, Professor James Tilghman, Dr Ariel Bierbaum, David Jefferis, Professor Michael Binder, Al Globus, Fred Scharmen, the National Space Society, The Planetary Society, Marc Cohen, Brittany Williams, Professor Madlen Simon, Professor Juan Burke, SpaceArchitect.org, American Institute of Aeronautics and Astronautics, Aerospace Research Central, NASA, ESA, and Abbey Luffey for her endless patience and support.

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List of Abbreviations

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1. The Inevitability of Space Exploration & the Architecture Continuum

Exploration and Survival

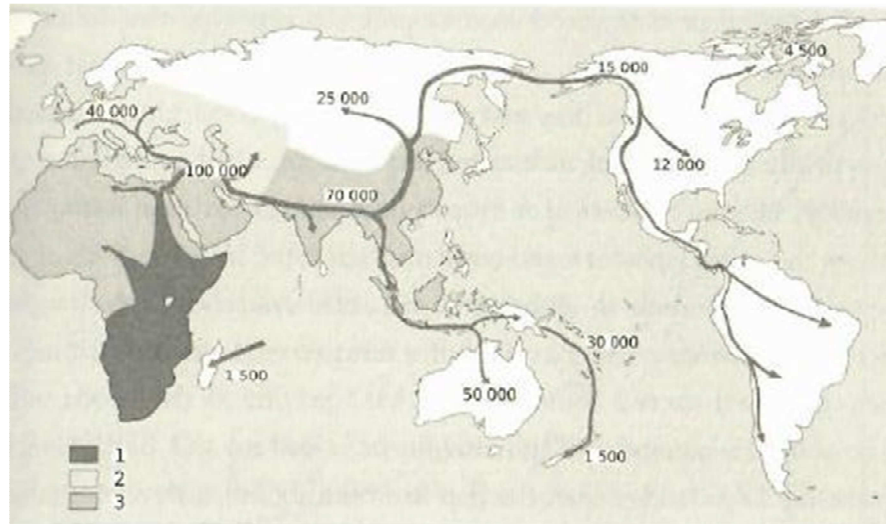


Figure 1. Map of early human migration patterns based on DNA. (Impey pp. 9)

Humans have constantly been exploring and migrating. Chris Impey posits that exploration is embedded in our genetic and anthropological composition. Animal migrations are driven by climate, food availability, and search for mates where humans systematically and intentionally move over great distances for less primordial reasons.¹ Humankind's physical and mental advantages such as long legs and large brains attributed and evolved genetic traits that favor adventurousness and are self-reinforcing which continues to enhance our mobility and dexterity over time. The most successful nomads have encountered new sources of food and new possibilities for tooling and enhancing their lifestyles which has ultimately led to survival. Space

¹ Impey, Chris. *Beyond: Our Future in Space*. 2015.

is inevitably our next frontier. "...as civilization becomes dispersed over multiple planets and solar systems, the risk of extinction declines."²

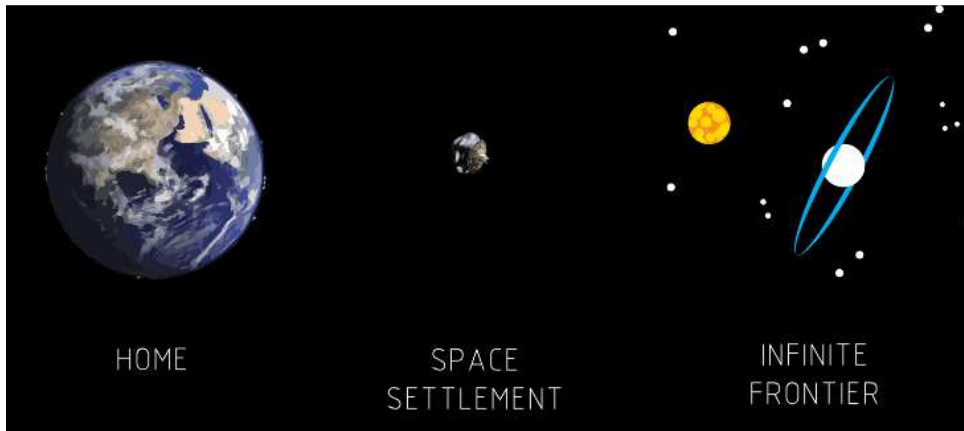


Figure 2. Space Settlement is the edge of the next frontier. (Source: by author)

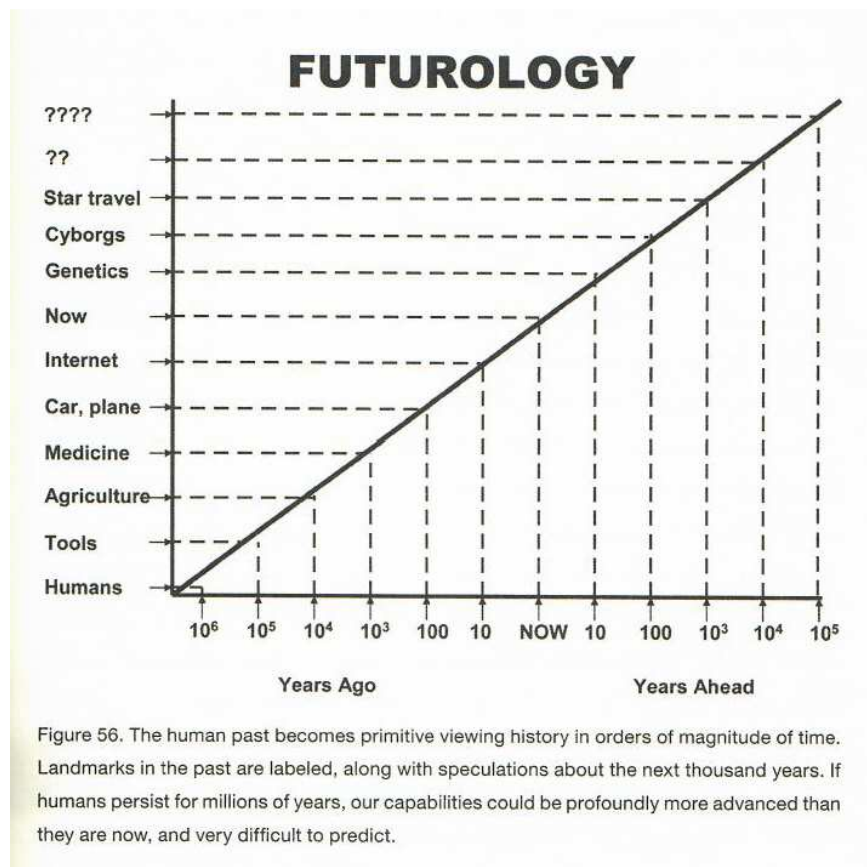


Fig. 3 Exponential Trajectory of Progress (Impey, Chris. Figure 56).

² Bostrom, Nick. The Future of Humanity. Future of Humanity Institute. 2009.

Impey also notes that the human trajectory of progress advances at an exponential rate.³ Insight on this trajectory presents reasons as to why we should be thinking about space exploration and its prolonged development. This trajectory is also important for considering long-term planning initiatives that will be outlined later. Exploration can lead to extrinsic visions of unrealized implications for the future of humans aiming to achieve multiplanetary settlement and to become a multiplanetary species.

Resources

Space hosts a plethora of untapped resources in the form of energy and material resources. This thesis exploration attempts to widen the avenue of opportunity for realizing the benefits of utilizing resources in space by proposing a permanent establishment on the space frontier. Materials such as water and oxygen as well as the ingredients of celestial soils on the Moon or Mars offer precious metals for mining and processing for use.

In addition to material resources, there is exponentially more energy available to harness in outer space than there is available from Earth. Sustainable energy rates can be imported from space for pennies on the dollar.⁴ The available renewable energy can be harnessed to not only support the efforts in outer space but also make essential infrastructure and utilities more available to people on Earth. Photovoltaic panels (PV) are 20% more efficient in space because there is no atmospheric

³ Impey, Chris. (pp. 249).

⁴ Garretson, Pete; Mankins, John. "A Case for Space-Based Solar Power." NSS Virtual Space Forum. National Space Society. August 20, 2020.

obstruction.⁵ In addition, utility accessibility, renewable energy can also help curb effects of global warming and support the current renewable energy industries.

Global Cooperation & Participation

The International Space Station (ISS) is about to reach its 20th year of constant human occupation – which should be noted as a feat of global cooperation.⁶ There have been astronauts using the ISS for research as representatives of countries from around the world (which ones?).

There is not one country can lay claim over space – it is far too expansive. Space needs to be a planetary agenda. As fears of a second space race allude to another single country's dominion over whatever it can lay claim to first, given the limited a. It would be impossible for one country to obtain military control over the entire Earth especially while other countries are occupying Earth orbit. Instead, goals like protecting civilization from detrimental collisions with asteroids or solving global warming would require all nations of one Earth to band together to achieve these goals because the Earth is so large and there are so many individuals at stake. The advancement of technology allows nations with younger space programs to be at the table while space development is still in its early pioneering stages. This thesis envisions what might be possible should all nations act in cooperation on their stake to use outer space.

⁵ Ibid.

⁶ Foust, Jeff. The Three Administrators. The Space Review. Accessed 10/12/2020. <https://www.thespacereview.com/article/4045/1>

Education & Research

STEM programs on Earth can be improved through long-term research establishments in outer space. Healthcare services and technology improvements. Vaccines, ultrasounds, optical surgery and technologies, breast cancer treatment, and growing high-quality proteins for biological sciences. Healthcare and wellness studies to support every-day livelihoods of the people on Earth.

The enhancement of observation – the “eagle eye” that has been pioneered by the airplane can be expanded upon with prolonged and permanent presences in outer space.⁷ 26 of the 50 of the tools we use to monitor and track changes in global warming occur via instruments that orbit the Earth⁸. Other advantages of global observation include monitoring natural disasters to provide advantages for people who lie in their paths, water quality monitoring for protecting the world’s drinking water, water recycling and purification technology, air quality monitoring and closed-loop systems that are capable of recycling, producing, and purifying air.⁹

Space Architecture

Space Architecture –

“Space Architecture is the theory and practice of designing and building inhabited environments in outer space.”¹⁰

⁷ Bunge, Eric. Jealousy: Modern Architecture and Flight. Flight, Issue 11: Summer 2003. Date Accessed: 9/11/2020. <http://www.cabinetmagemazine.org/issues/11/bunge.php>

⁸ Miraux, Lois. Why addressing the environmental crisis should be the space industry’s top priority. The Space Review. Monday, October 5, 2020. <https://www.thespacereview.com/article/4038/1>

⁹ Rainey, Kristine. 15 Ways the International Space Station is Benefiting Earth. NASA TV. NASA. October 30th, 2015. Accessed: <https://www.nasa.gov/specials/apollo50th/index.html>

¹⁰ Cohen, Marc M. (2012 July). The Continuum of Space Architecture: From Earth to Orbit (AIAA 2012-3575). 42nd International Conference on Environmental Systems (ICES), San Diego, California,

Habitat – “The degree to which an environment promotes the productivity, well-being, and situationally desirable behavior or if its occupants.”¹¹

Space Habitat –” Environments that enable people to live and work in space. May be considered both vehicular and stationary in nature. Pressure vessels that contain and protect the inhabitants from the hostile vacuum of space.^{12 13}

What is a space settlement? If a space station is to work, like a space hotel is to work and play, then a space settlement should support the life cycle of a person from birth through death.

What is a space settlement and what makes it unique compared to other vessels humans have launched into space that support life? The Skylab and International Space Station (ISS) space station models have been proven to support life and function as viable space habitats but not as a permanent solution for human existence. Habitability is defined as “A measure of the degree to which an environment promotes the productivity, well-being, and situationally desirable behavior of its occupants.”¹⁴ The ISS and the idea of a space station most closely associates the program and functions taking place on board with the notion of work. Future space hotels as habitats are better at adequately supporting human life for

USA, 15-19 July 2012. Reston, Virginia, USA: American Institute of Aeronautics and Astronautics. <http://spacearchitect.org/pubs/AIAA-2012-3575.pdf>

¹¹ Cohen, Marc M. (1990). Designing Space Habitats for Human Productivity (SAE 901204). In, SAE Transactions, Journal of Aerospace (vol. 99, sec. 1, part 1, p. 352-364). Warrendale, Pennsylvania, USA: Society of Automotive Engineers. Revised and reprinted, 2011 July 26.

<http://spacearchitect.org/pubs/SAE-901204-rev.pdf>

¹² Howe, Sherwood. Out of This World: The New Field of Space Architecture. AIAA. September 30, 2009.

¹³ Cohen, Marc M. (1990). Designing Space Habitats for Human Productivity (SAE 901204). In, SAE Transactions, Journal of Aerospace (vol. 99, sec. 1, part 1, p. 352-364). Warrendale, Pennsylvania, USA: Society of Automotive Engineers. Revised and reprinted, 2011 July 26.

<http://spacearchitect.org/pubs/SAE-901204-rev.pdf>

¹⁴ Ibid.

longer durations of time with added comfort however, space hotels would be most closely associated with the notion of play and leisure and will most likely function as temporary destinations for Earthlings to spend their time. However, space hotels are largely disconnected from notions of productivity which is essential to achieve sustainability in order to support the long-term demands of a space settlement.

Space settlements will be designed to support life indefinitely so it will be important to marry ideas of habitability and productivity in order to serve the inhabitants well, provide human comfort, and to support the most important notion of reproducing and raising children¹⁵.

¹⁵ Globus, Al. Where Could the First Space Settlement Go: An Unexpected Option
NSS Virtual Town Hall. 7/23/2020.

2. Site Analysis

Potential sites can be categorized into two unique site types: celestial-bound sites and free-space sites. Settlements that situate themselves on Mars, the Moon, or any near Earth object (NEO) or asteroid would be celestially bound to these bodies. The Lagrangian Points and orbits around celestial bodies are situated in free space which implies developing a settlement unattached to any other larger body as a foundational host.

Each classification has merits; most specifically, resources and gravity. Both of these key considerations impact the decision-making process for choosing the right opportunity to develop the first settlement. These considerations are the basis for rationale for determining the most feasible location for a permanent space settlement. I will elaborate on the sites examined for the initial location for a permanent space settlement are on the Moon, Mars, an NEO or Asteroids, at one of the Lagrangian Points, or in Earth Orbit.

Celestial Sites

Celestial sites are located on celestial bodies that orbit the sun or larger celestial bodies that orbit the sun. Architectural construction upon them can take place very similar to how an architect would approach a site on Earth (also a celestial Body). While some programs will be better suited to celestial bound sites, other programs would be better suited for free-space sites. This classification can precursor space-based zoning that can govern future development projects similar to how planners on Earth will propose zoning and ordinance to suggest the best suited

program for said land. As an example, priorities of development on the Moon might be reserved for mining while permanent environments for housing humans might be best reserved for free-space orbit.

Earth is already developed. Earth is used as a control for comparison to give an additional sense of scale and human-scale relationship to variables that other sites are going to be compared against.



Figure 4. Ceres (Image by author)

Asteroids interact with the Earth in the form of highly elliptical orbits (HEO's).

Ceres, Juno, Pallas, Vesta are the largest asteroids to pass near Earth.

Mars is closely related to Earth in terms of size and its day-night cycles. Mars also offers in-situ resources that can be used for processing construction materials.

Free Space Sites

Free space refers to any location that is not situated on another celestial body. This thesis explores developing a replicable, free-space paradigm to be scaled to achieve long-term mission-successes in outer space such as reaching Mars or constructing a lunar colony or contributing to space mining networks. It should be noted that unlike celestially bound sites, free space sites have no natural resources

other than angular acceleration, microgravity, and vacuum. This thesis explores the primordial steps to settle our solar system beyond Earth by beginning in LEO.

Lagrange Points

[Explain what these are] Distance to Lagrange Point V (L5) is 382,000km and travel time takes about three days' time¹⁶.

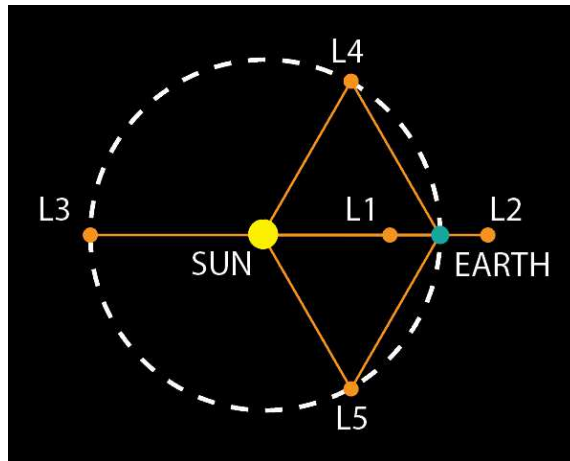


Fig. 5. Lagrangian Points. (Image by author)

Earth Orbit

Humans are currently a single planet species. Our “home” exists on Earth. Acknowledging this fact is helpful to comparatively understand measurable progress of development in outer space. Some key locations considered for a space settlement exist in Earth’s orbit. They are low-Earth orbit (LEO) and equatorial low-Earth orbit (ELEO).

¹⁶Globus, Al. Where Could the First Space Settlement Go: An Unexpected Option NSS Virtual Town Hall. 7/23/2020.

Distance at 550km-600km altitude above the Earth's surface and travel time currently takes about 2 days or less¹⁷. ELEO is currently the most convincing site for the first space colony. An outline of some key problems will explain why this is.

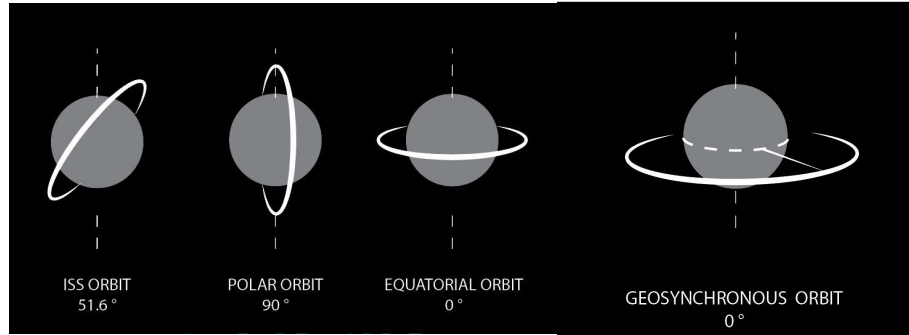


Fig. 6. Earth Orbits. An object in geosynchronous orbit will remain over the same point on the celestial body it is orbiting. (Image by author)

Key Site Considerations

Key considerations for site selection radiation, distance, travel time, gravity, sunlight availability, and the availability of in-situ resources. Interrelated considerations.

Available Sunlight



Figure 7. Orbital Path Solar Studies. (Source: By Author)

Sunlight is the most important consideration for the settlement proposal because it is essential to fueling everything people need to sustain life. A site that has

¹⁷ NASA. Planetary Fact Sheet – Metric. <https://nssdc.gsfc.nasa.gov/planetary/factsheet/>.

adequate sunlight will be required to provide settlers with vitamin D, plants with energy to perform photosynthesis, charge for solar panels to power the settlement. The free-space locations minus Lagrangian Point 2 (L2) will have constant sunlight. L2 does not have direct sunlight because the sun will always be eclipsed by the Earth. Mars will have sunlight conditions most similar to that of Earth because of its size and its rotational rate is roughly equivalent to that of an Earth-day (24.5 hours).¹⁸ Asteroids and NEO's will have variable sunlight depending on their size, orbital location, and how and if they rotate. The Moon will have 15 day da-night cycles. This would require an immense collection of power to be used during the periods without sunlight. This could also complicate growing plants and have psychological effects on the uses – similar to SAD experienced by people living in countries near the Earth's poles.

Access to solar energy will be restricted every 15 days for 15-day intervals (lunar cycle). During “night” solar energy will not be able to be harvested.

Distance & Travel Time

The distance of the settlement becomes important two-fold. Longer distances will cost more in fuel resources during construction but also life-support resources for humans over long trips. Generally, the closest the first initial settlement can be to Earth, the easier it could be to plan for its sustainable success over a long period of time.

¹⁸ Williams, Dr. David R. Planetary Fact Sheet. NASA. Updated 21 October, 2019. Accessed: <https://nssdc.gsfc.nasa.gov/planetary/factsheet/>

Sites being considered for selection lie within the boundaries of the inner-solar system for these reasons. It took Galileo six years to reach Jupiter.¹⁹ Furthermore, other Earth-like celestial bodies have been ruled out in this initial investigation because they are too far away from Earth to be practical options. It is still important to note these planets to help define the scope of the thesis proposal and because they may be viable options in the distant future.

Equatorial Low-Earth Orbit and Low-Earth Orbit are the closest locations to Earth that are also not on the Earth. Sites such as the moon, Mars, and the nearest asteroids are much further, require much more time to get there, and will require more resources. Distance to Mars is 54,600,000km²⁰ and travel time takes about three days' time²¹? Distance to [where?] at 3,474km and travel time currently takes about three days.²² Asteroids Ceres and Vesta are further away than Mars.

Radiation

Radiation poses a health concern for humans and space is full of it. The primary health concern is radiation induced cancers which, in the presence of large of amount of radiation, is likely to affect space farers. Earth is unique in that it has a magnetosphere protecting it from the most dangerous type of radiation galactic cosmic rays. Being unprotected by the Earth's magnetosphere and its atmosphere over long durations of time will have negative effects on the body.

¹⁹ NASA. <https://nssdc.gsfc.nasa.gov/>

²⁰ Williams, Dr. David R. Earth Fact Sheet. NASA. Updated 21 October, 2019. Accessed: <https://nssdc.gsfc.nasa.gov/planetary/factsheet/>

²¹ Globus, Al. Where Could the First Space Settlement Go: An Unexpected Option NSS Virtual Town Hall. 7/23/2020.

²² Ibid.

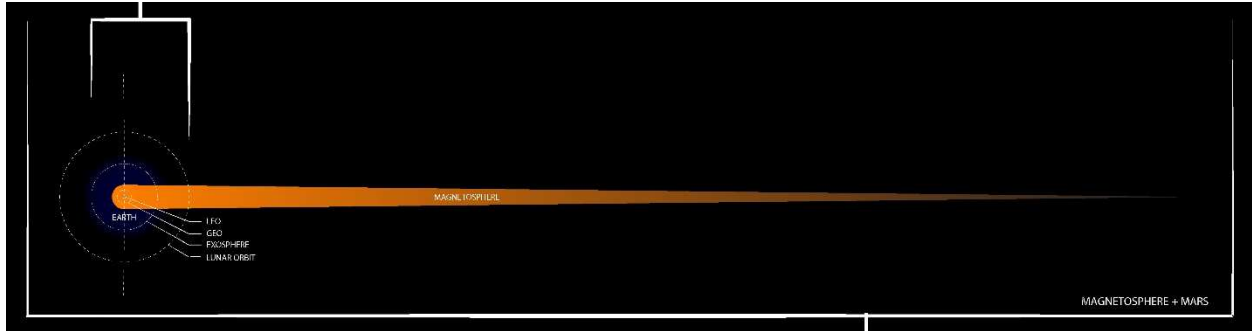


Fig. 8. Earth's magnetosphere. The long tail is leeward from the side of the Earth that faces the Sun. The tail is created from the electromagnetic particles being “blown” from the sun's emission.²³ Image by author

A free-space settlement located at 550km – 600km altitude orbiting Low Earth orbit LEO will be sufficiently protected by the Earth's magnetosphere as well as its atmosphere galactic cosmic rays.²⁴ Additionally, it is important the colony orbit the Earth at ELEO and not at LEO because an ELEO trajectory can most effectively avoid crossing the South Atlantic Anomaly.

²³ Kaase, Aaron. Earth's Magnetosphere. Solar System and Beyond. NASA. March 21,2011. Accessed Date: 10/15/2020. Accessed: <https://www.nasa.gov/specials/apollo50th/index.html>

²⁴ Globus, Al; Covey, Stephen; Faber, Daniel. Space Settlement: An Easier Way. Copyright 2015, 2016, 2017 Al Globus. July 2017.

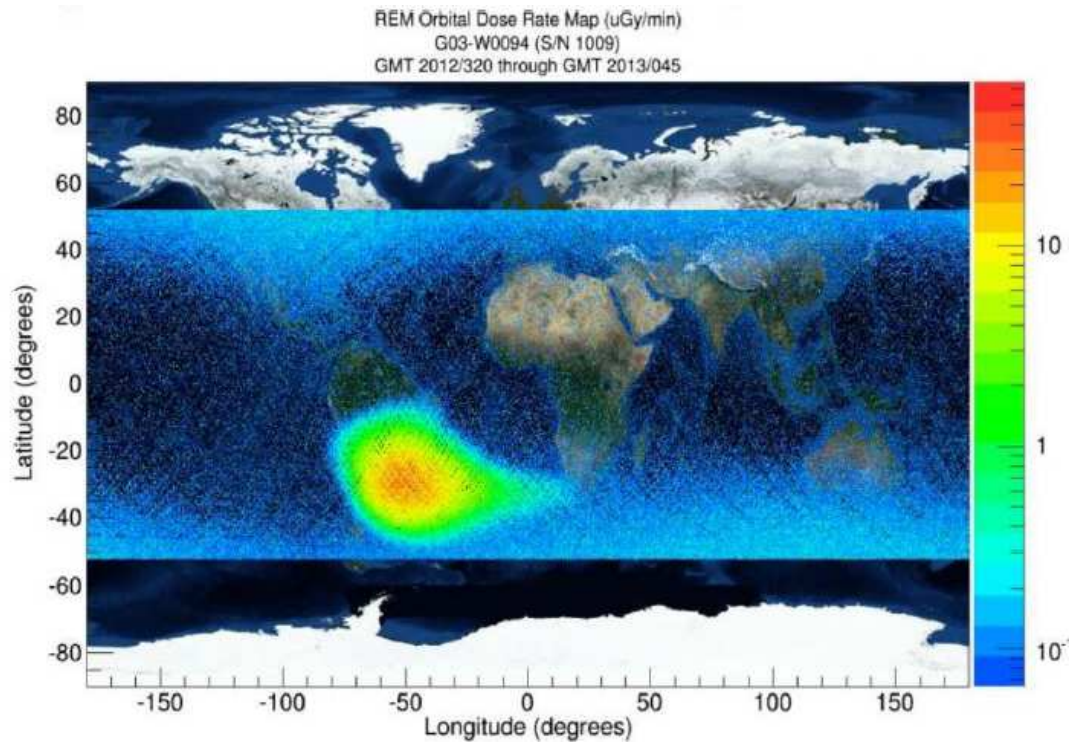


Figure 9. South Atlantic Anomaly. (source: Globus, et. al, Space Settlement: An Easier Way)

Gravity

Gravity will be classified into two types: gravity as we know it on Earth or “natural” gravity, and “artificial” or “pseudo-gravity”. Natural gravity is present when there is a sizable mass pulling in on itself. This will be experienced on celestial sites in varying degrees depending on the mass of the celestial body. In free space, gravity will not exist unless it is created.



Figure 10. Two different classifications of gravity. “natural gravity” and “artificial gravity”.

Artificial gravity or “pseudo-gravity” is generated by centrifugal force. (Source: by author)

If the colony located at a free space site were to rotate around an axis at a rate correlative to its size and mass, centrifugal force can create an artificial gravity for the inhabitants.²⁵ This pseudo gravity will allow inhabitants to experience the same gravitational sensation as if they were standing on the surface of a body of considerable mass. This concept also gives the architect the ability to design and control the rate of gravity at the settlement.

All of the free-space sites will be absent of gravity. The unique advantage to constructing in the absence of gravity is consideration for the loads of the settlement on itself. There are no external gravitational forces action on the settlement.

However, there will need to be consideration for live loads and mechanical equipment to allow the settlement to calibrate and course correct as live loads move about the settlement.

Gravity as a key metric to ranking site selection is biased. The presence of gravity or not could be advantageous to different configurations and designs of space architecture. LEO is chosen as the site because gravity can be controlled here rather than if the settlement were sited on say the Moon or Mars where gravity is a constant that cannot be manipulated like it could in free space.

In-Situ Resources

Celestially bound sites have the advantage of offering resources to settlements that free-space sites do not have. These resources could take the form of ice, metals,

²⁵ Globus, et. al, Space Settlement: An Easier Way

and regolith which can be used for water, and building materials. To this regard, there would be a small advantage to an Earth orbit site to recycle abandoned and broken satellites. This would double as a responsible sustainability initiative. While celestially bound sites have the potential access to resources, they are subject to the gravitational pull of that body.

Size & Mass

The size and mass of the colony is important to consider during site selection. The location and the availability of in-situ resources will determine how radiation shielding can be designed and applied to the settlement. The less mass that needs to be launched into space, the cheaper and quicker the space settlement can be developed. Settlements located in areas that are unprotected from cosmic galactic rays are going to require more mass to protect the users from harm.²⁶ Additionally, moving in-situ resources from celestial bodies on which gravity is less restrictive than on Earth is more energy and cost efficient.²⁷

This not only adds to the amount of materials that must be located to the site of the settlement, but factors of time and the distance also contribute to added construction time.

The size of the initial colony that would be comfortable for humans has been surveyed to be something similar to the Kalpana II model²⁸ More investigation on

²⁶ Globus, et. al, Space Settlement: An Easier Way

²⁷ Ibid.

²⁸ Ibid.

size is going to be conducted to better understand what programs would be adequate to serve the largest possible population with the greatest economy.

3. Precedence: Typological & Programmatic Models

Two types of project precedents are consulted to develop the design of the space settlement. While the typological precedents support decisions being made about the physical space and the settlement's layout, the programmatic models help address the experiences and sensations of being on board from the user's personal perspective.

Typological Precedents

History would suggest that it was only a matter of time before humans could exist off Earth. Modern Architecture has had its eye on the sky prior to the first space age.²⁹ Even before this, Konstantin Tsiolkovsky envisioned humans living in free-fall in free space environments (see Figure ##) and H.G. Wells first wrote about characters in his novel *The First Men in the Moon* inhabiting a similar spherical environment that was launched into space.³⁰ These depictions of fictitious and non-fictitious architecture alike were devised with a level of detail to conjure up feasible ideas about space settlement and perhaps unknowingly progressed the world's trajectory of space exploration.

²⁹ Bunge, Eric. *Jealousy: Modern Architecture and Flight*. The airplane and the modern conscience of urbanism. *Cabinet*. Summer 2003.

³⁰ Wells, H.G.. *The First Men In The Moon*. 1901.

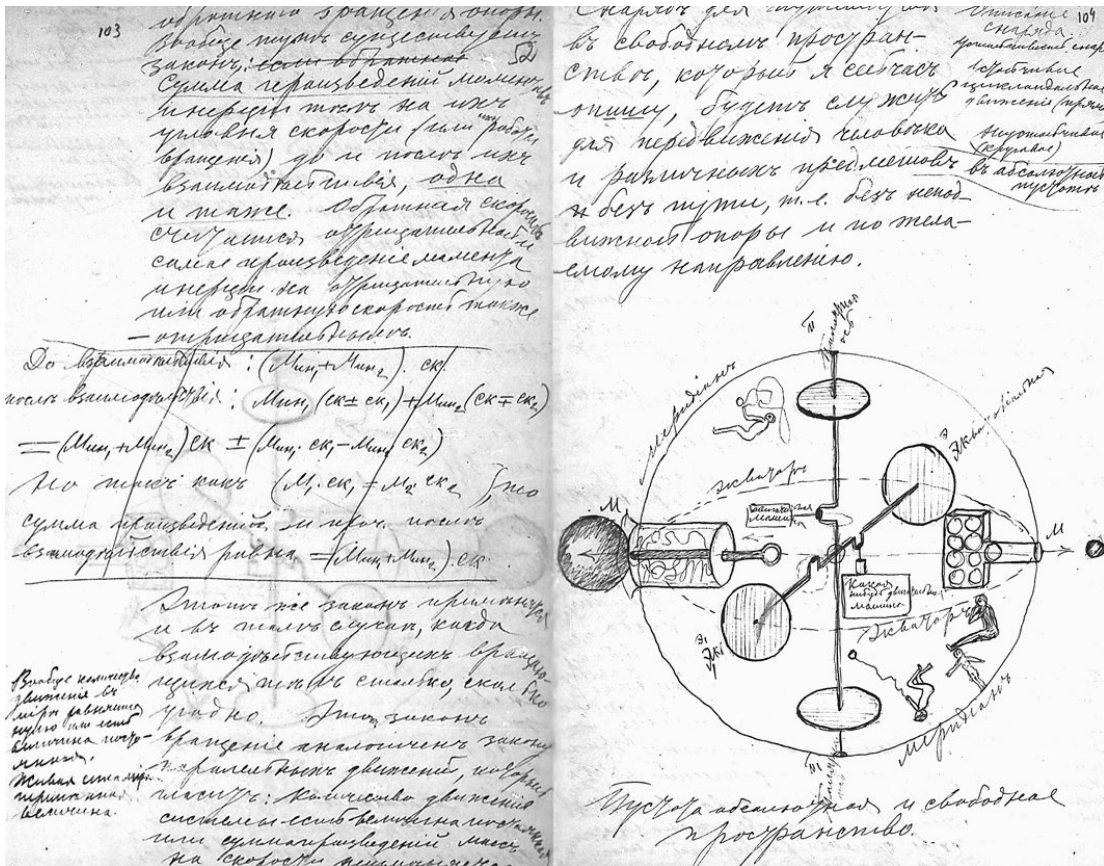


Figure 11. Image of Konstantin Tsiolkovsky’s notebook depicting an environment adept to support humans living in free space.³¹

From an architectural perspective, it is most important to present Buckminster Fuller’s proposal for floating cloud structures (see Figure ##) and his concept of “spaceship Earth”.³² It is important to note the parallel progress that architecture made in terms of hyper-efficient construction methods and the consciousness and awareness of material resources. These foci are important because they impact the health and well-being of architecture’s users and occupants. These concepts become imperative to the feasibility of the typological precedents that are going to be

³¹ Scharmen, Fred. Space Settlements. Columbia University Press. 2019.
³² Conrads, Ulrich. Programs and manifestos on 20th-century architecture. Buckminster Fuller: The Architect as World Planner.

considered and identifying why they are helpful. It is also important to note that these key elements that have been developed to support the ideas of humans living off Earth came before the launch of Sputnik in 1957 which prompted the global race for space and officially declaring the start of the Space Age.



Figure 12. Floating Cloud Structures developed by Buckminster Fuller in 1962. ³³

³³ Bunge, *Jealousy: Modern Architecture and Flight*. 2003.

Early Space Age Typological Settlement Models Von Braun Space Station



Figure 13. A depiction of Von Braun's space station.

Von Braun is most well-known for his attributions to Nazi regime designing rockets. He escaped wartime persecution and immigrated to the United States where he worked for NASA and contributed to their running in the global space race. Von Braun is credited for developing a ring settlement in 1952. Von Braun's ring-shaped concept has been riffed on in the NASA 1975 Summer Study and has since been revised into a more robust and modern adaptation designed by the Gateway Foundation.

Space Architecture Vernacular

Space architecture vernacular is organized into three separate typologies: launch vehicles, pressure vessels, and support infrastructure.³⁴ Pressure vessels are divided into three different classifications based on their constructability process: pre-integrated, pre-fabricated, and in-situ.³⁵

1975 NASA Summer Study

The earliest models developed in the 1975 NASA Summer Study were simple and pure in their form. The most important feature these models demonstrate is their ability to recreate gravity. These models were designed with the ability to rotate around an axis to produce pseudo-gravity as mentioned before in order to create an environment that mimics the environment we know on Earth. The ability to create gravity is important to ensure a high level of human comfort is met.

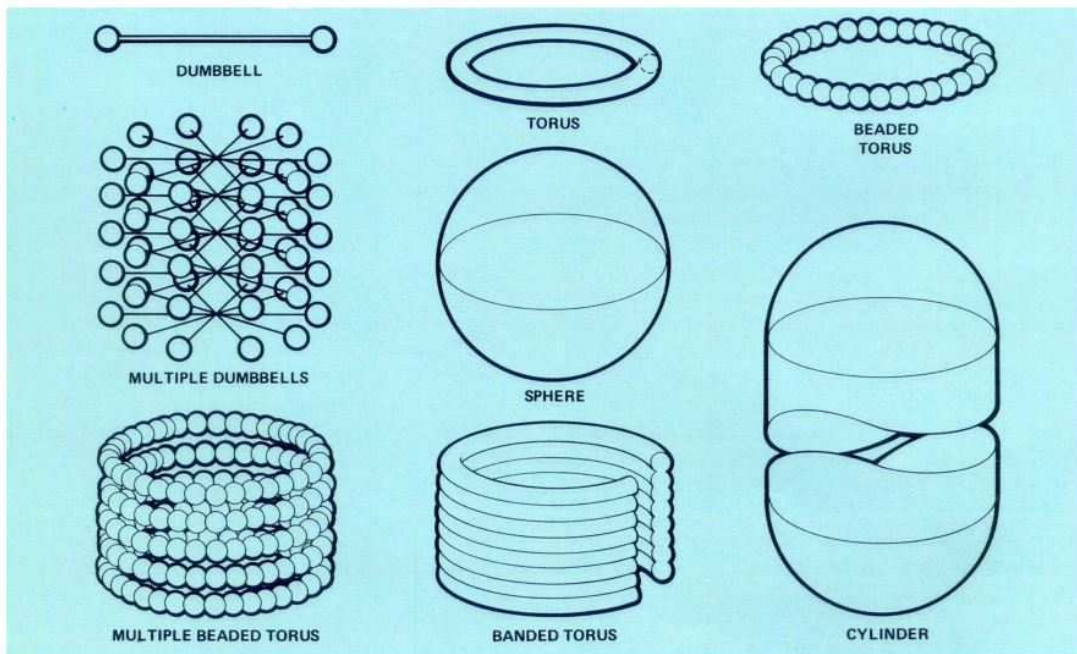


Figure 14. Model Typologies developed during the 1975 NASA Summer Study.³⁶

³⁴ Howe, Sherwood. *Out of This World: The New Field of Space Architecture*. AIAA. September 30, 2009.

³⁵ *Ibid.*

³⁶ Johnson, Richard D; Holbrow, Charles. *NASA SP-413 Space Settlements: A Design Study*. Scientific and Technical Information Office, NASA. 1977.

Again, it is important to note the similarities of form in the designs of the different space settlements being investigated during the summer study. This form will have social, subliminal, and psychological impacts on the people living on board.

Bernal Sphere

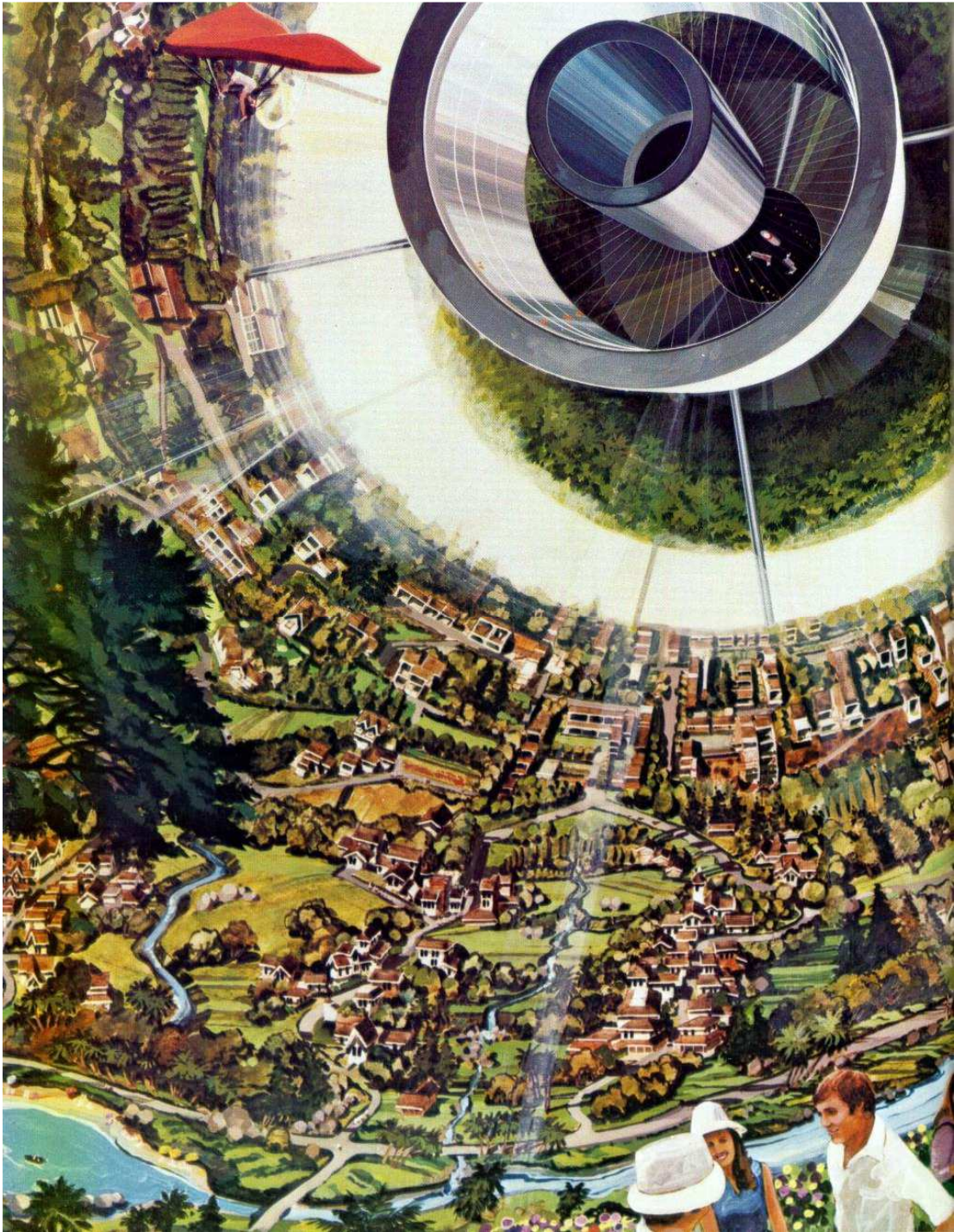


Figure 15. Depiction of the interior of a Bernal Sphere settlement model.³⁷

³⁷ Ibid.

Stanford Torus



Figure 16. Depiction of the Stanford Torus settlement model.³⁸

³⁸ Ibid.

The Stanford Torus is slightly unique in the form of its environment. The design of the torus organizes the contained environment in a ring rather than providing a vast void in a large container like the cylinder and the sphere models. The torus is an important model to consider because its environment contained in a

O'Neill Cylinder

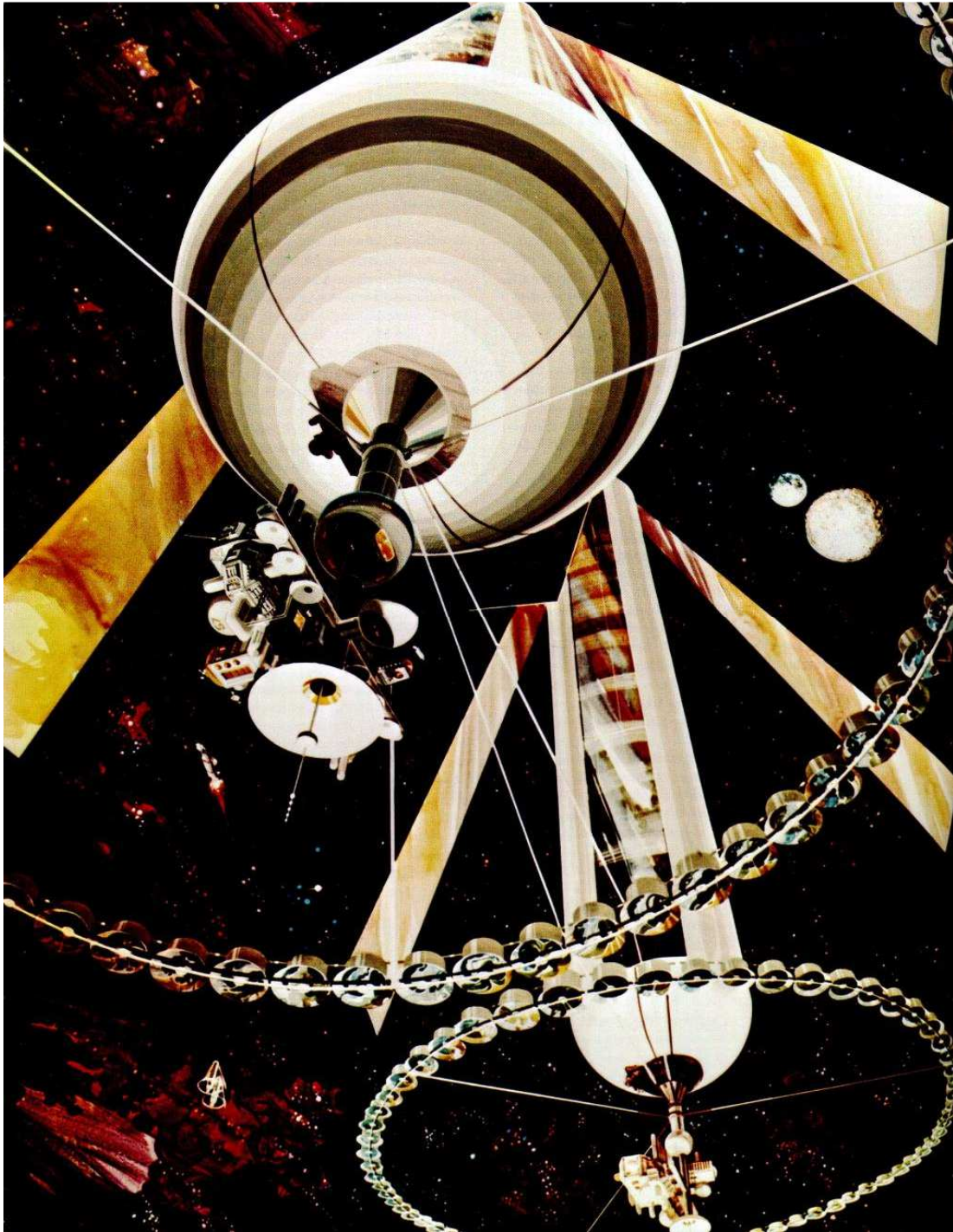


Figure 17. Painting of O'Neill Cylinder. The O'Neill Cylinder is large - Gerard O'Neill anticipated this model supporting a population of 10,000 people.³⁹

³⁹ Ibid.

Existing Typological Precedents

It is important to note that there are only two examples of realized projects that have been successful at sustaining humans in outer space in zero-gravity, free-space environments. Skylab and the ISS both initially conceived of by NASA, are the only two realized structures that can support long-term habitat for humans in space. Skylab was the first constructed by NASA and launched into orbit in 1973. It was continuously occupied while in Earth orbit before being decommissioned in 1979. The ISS was launched into orbit in 1991 and has consistently supported astronauts since this date.

Currently, the only locations that humans have been able to support life off Earth have been in LEO. Because successful structures have not been realized in any other location, the aforementioned challenges justify the reasons for why a space settlement in ELEO is the place to start.

The international space station is getting crowded to accommodate all of the research that scientists are looking to conduct. There is an industrial demand for more accessible options to begin new research development for things that are going to further progress of space exploration.

Modern Space Settlement Models

Von Braun Class Space Station

The modern model of the Von Braun Class Station is proposed by the Gateway Foundation. This model exploits the advantages of a Stanford Torus-type model at a more manageable scale. The torus form can begin to be considered as a modular component to begin constructing a larger cylindrically shaped settlement.

It is important to highlight this model comes with an issue of historical symbology and branding. The relevance of this point will be highlighted as the reasons for selecting some of the programmatic precedents are explained. The argument I will make here is that no new settlement built on the basis of global cooperation, a is intended to support world-wide equity and diversity should be named after an individual responsible for religious genocide – no matter how great the scientific achievement.

Kalpana

The Kalpana model was developed by Al Globus, curator of NASA’s archive on space settlement publications.⁴⁰ Al posits the Kalpana II model is the smallest, and most economically viable design for constructing the first space settlement. This thesis will use the Kalpana II model as a template to initiate the design process as well as a standard of which to design to. The size and mass of materials that would be required to construct the other aforementioned free-space settlement models developed during the Summer Study would be much less feasible.

Technological and Social Programmatic Precedents

Social programmatic precedents are consulted to better understand the experience of the individual living in a space settlement. The social program precedents attempt to break homogeneity to ensure inclusive, equitable, and diverse populations of space settlers. The technological programmatic precedents are mapped to space habitat applications in order to reach design decisions that respond

⁴⁰ Globus. Space Settlement: An Easier Way. 2017.

to understanding how physical spaces can support the social integrity of the settlement. Settlement layouts drawn from the programmatic precedents can then be compared to the typological precedent foundations to understand the experiential components to the space architecture components. The typological precedents mentioned prior are used as physical and spatial foundations with which to test the programmatic concepts highlighted below.

Etienne-Louis Boullée's Cenotaph Design for Sir Isaac Newton

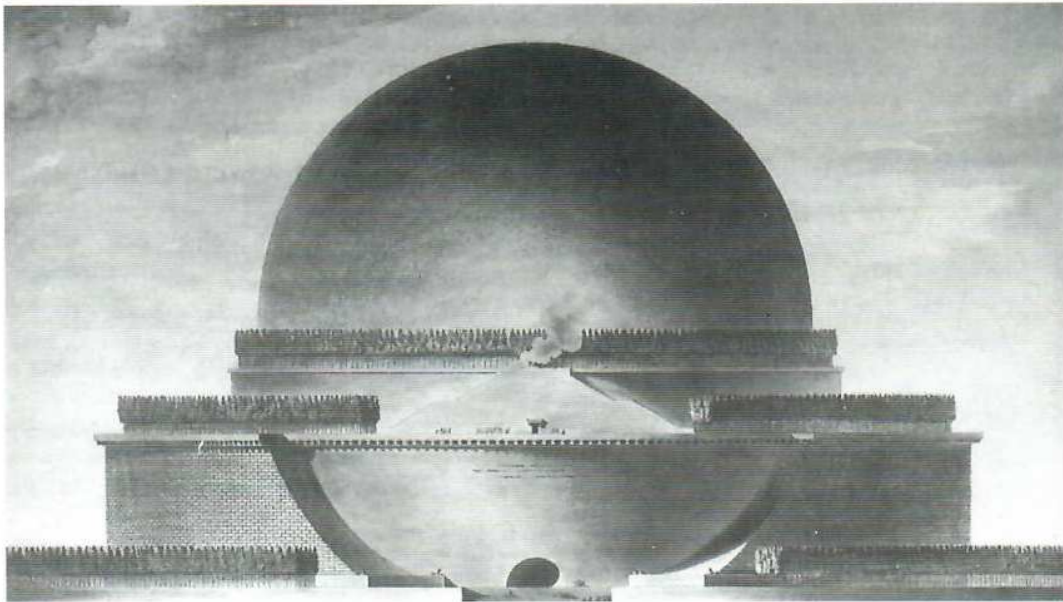


Figure 18. The cenotaph designed for Sir Isaac Newton.⁴¹

The Cenotaph for Newton designed by Etienne-Louis Boullée in 1784 serves as programmatic formal and functional precedents for the design of the space settlement. This project serves as spatial precedent for the organization of a space settlement. It is no coincidence that the formal purity of Newton's Cenotaph is similar to the pure geometries of the space settlements of the 1975 Summer Study and

⁴¹ Sadler, Simon. *The Situationalist City*. MIT Press. Cambridge, MA. 1999.

Al's Kalpana model. This formal layout organizes the inhabitants at the center of the architecture. The human in this space is framed within the thing that supports their survival opposite of how humans' survival is support on Earth.⁴² Emphasis is placed on the individual's relationship to the thing that supports its life. The imagined experience of the individual within Newton's cenotaph with internally focused spatial program could be similar to that as if they were on board a settlement such as Kalpana.

Another coincidental observation is the similarity in size in the cenotaph has to the Kalpana settlement model. Newton's cenotaph was designed with a diameter of 150 meters. Al Globus suggests a Kalpana model sized at a diameter of 112 meters.

Transit Oriented Development Model

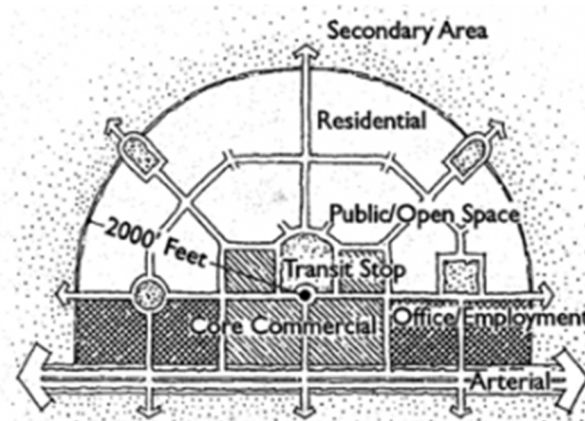


Figure 19. General layout of a TOD node. ⁴³

The spatial principles of a generalized TOD node will be explored while designing the space settlement. Because the requirements of a sustainable settlement

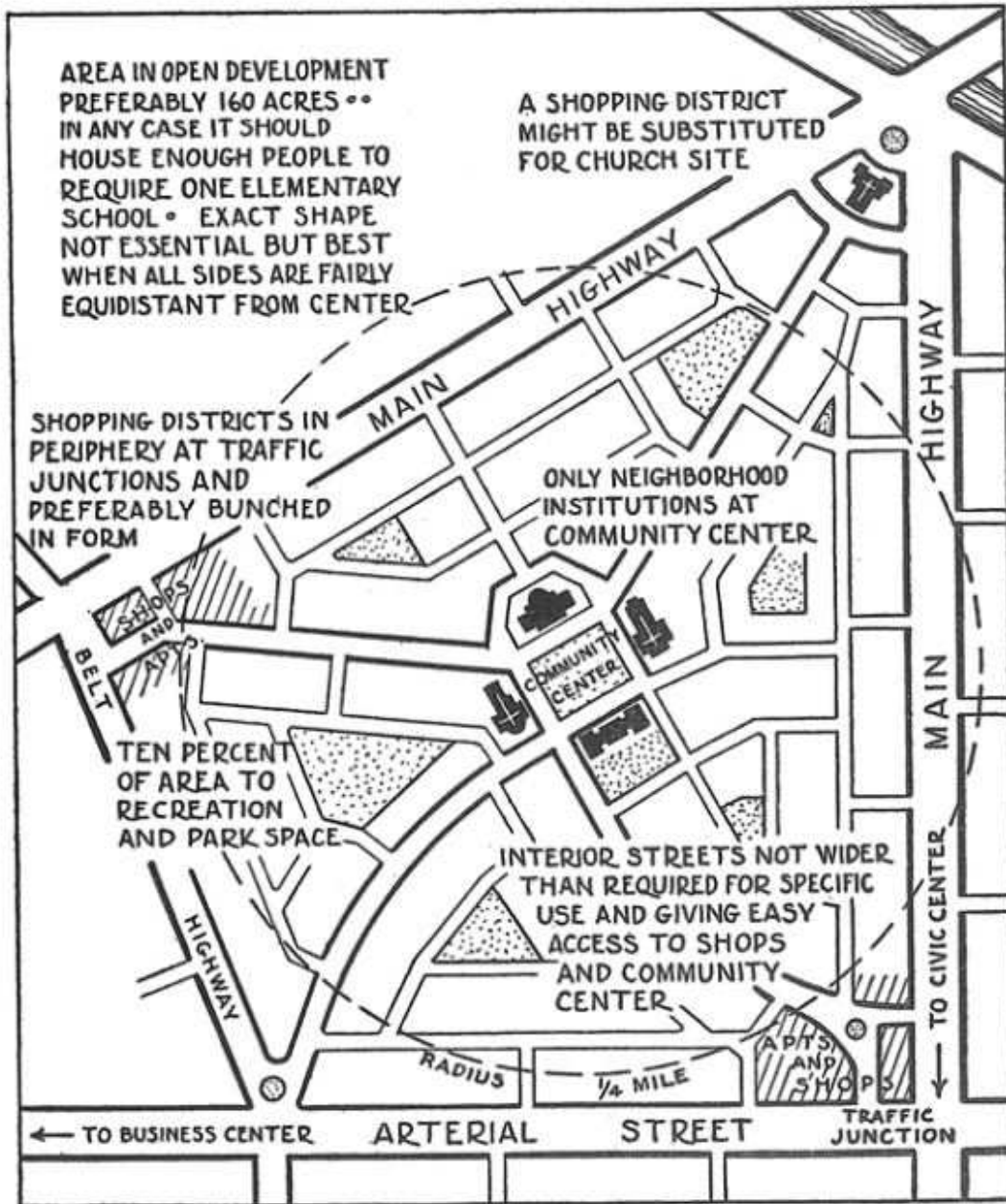
⁴² Scharmen. Space Settlements. 2019

⁴³ Calthorpe, P. (1993) The Next American Metropolis: Ecology, Community, and the American Dream. Princeton Architectural Press, New York. (Page 56).

require a neighborhood-sized population, considering the organization of movement of people and goods especially in emergency situations is important to protecting their safety and supporting walkability. Attempting to construct a settlement greater than an uncomfortable walking distance would require additional transportation. The movement of large things around a free space-type settlement would require more efforts to keep it calibrated to its trajectory.⁴⁴

⁴⁴ Globus. *Space Settlement: An Easier Way*. 2017.

The Neighborhood Unit



The basic components of Clarence Perry's neighborhood unit. Source: (Perry, 1929)

Figure 20. Perry's Neighborhood Unit layout.⁴⁵

⁴⁵ Perry, C. A. (1929). "The Neighborhood Unit, a Scheme of Arrangement for the Family-Life Community." Monograph one, Neighborhood and Community Planning, Regional Plan of New York and Its Environs (New York: Committee on Regional Plan of New York and Its Environs, 1929). Page 88.

Perry's neighborhood unit is clearly utopian in its vision, but its usefulness to this thesis is the idea of a sustainable population to support the productivity of the settlement to function independently of Earth. Perry's Neighborhood Unit model supports an elementary school with a population of an estimated neighborhood size between 5,000 and 9,000 people. Perry's neighborhood model has a density of 10 units per acre. Perry's neighborhood unit draws similar consideration around the idea of walkability as a TOD. This programmatic reference can be applied to the settlement's layout in order to understand population densities and program, and number of inhabitants would be required to indefinitely support human life.

Biosphere II

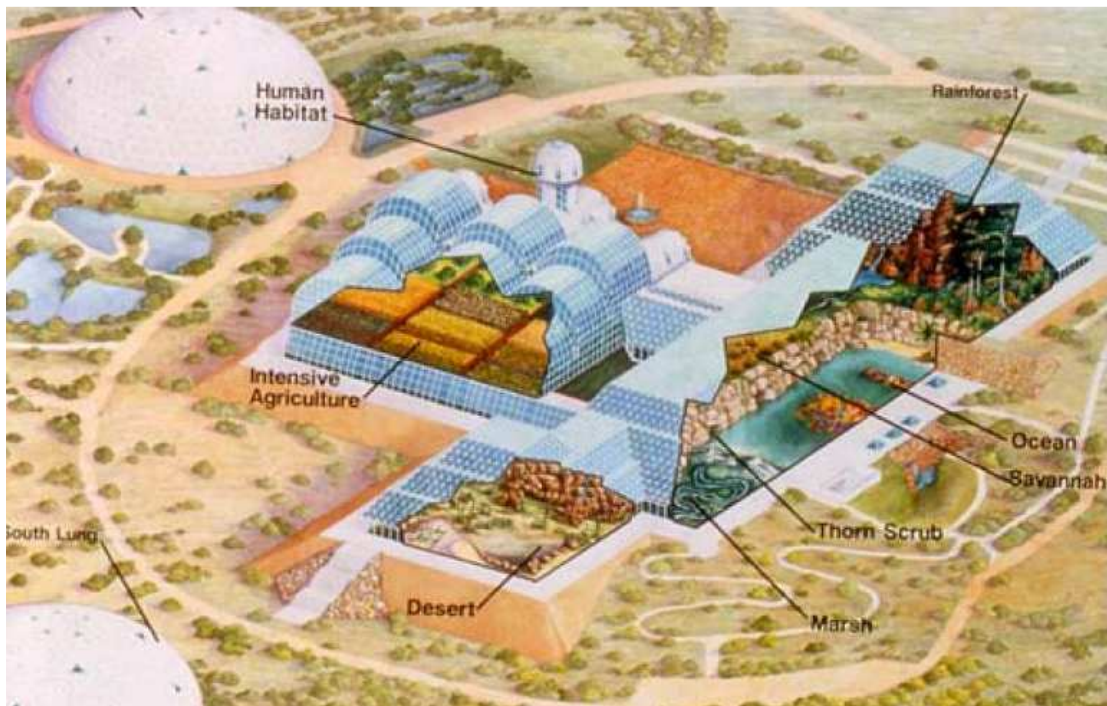


Figure 21. Cut Away plan of Biosphere II in Arizona. ⁴⁶

Biosphere 2 serves as a scenario plan model for a bioregenerative space mission. Eight crew members were supported with food, water, and air on three acres of land in a sunlight-driven bioregenerative system for two years⁴⁷. The test mission ended on 26th of September 1993. The lessons worth noting are those regarding the health of the crew, and unforeseen problems that arose in their contained environment.

Cruise Ships & Pleasure Wheels

Cruise ships are like floating islands. The largest support up to 8,800 passengers plus crew.⁴⁸ According to this population, this is adequate for supporting one of Perry's neighborhood units.

Crew Makeup and Organization

In order to protect settlement inhabitants from the hard realities of outer space, their social dynamic must support the greater good of the group in order to maintain true settlement sustainability through cooperation. It is important to consider investigations in crew makeup and organization factors before beginning to consider the socio- and cultural imaginaries on board a space settlement. Crew selection, training, rotation, and scheduling strategies are accounted for while preparing for space missions.⁴⁹ It is important to highlight that crew diversity is important in a

⁴⁶ MacCallum, Taber; pointer, Jane; Bearden, David. *Lessons Learned From Biosphere 2: When Viewed as a Ground Simulation/Analog for Long Duration Human Space Exploration and Settlement*. Paragon Space Development Corp.. 2004.

⁴⁷ Ibid.

⁴⁹ Cohen, Marc M. (1985 October). *Human Factors in Space Station Architecture I: Space Station Program Implications for Human Factors Research* (NASA TM-86702). Washington, DC,

more complex environment such as space than on Earth. Programmatic examples will be analyzed in this thesis to begin shaping architectural considerations for supporting a productive social sphere.

The primary duties of the space inhabitants will be ensuring the supporting space architecture remains operable, monitoring its status, and taking necessary actions to maintain settlement safety and integrity. Training considerations will require consideration for personnel that cannot operate command consoles and mission controls.

There is a survivalist state of mind that must be reconciled with amongst the crew that the good of the group supersedes the individual. Because the environments that support the crew in space are temperamental and issues can arise and escalate quickly, the crew needs to ensure that they can rely on one another to make judgements under pressure quickly without compromising health, safety, and well-being.

In this case, the crew will be made up mostly of new space farers looking to live, work, and procreate in outer space and among them, a ratio of crew who are to be formally trained in as astronaut-pilots and mission specialists in order to resolve technical challenges, and maintain orbital path.

Crew Culture

The mission-first mindset is sometimes coded into the culture of the team working together in order to survive. Expeditions that jeopardize survival require

USA: National Aeronautics and Space Administration. <http://spacearchitect.org/pubs/NASA-TM-86702.pdf>

teamwork and strong social relationships among those who decide to make the endeavor.

The promotion of the collective and the autonomy of the architectural agency could be integrated to promote the individual's ability to coexist in an organic and naturally expressive and humane way with and among the habitats.

Alternative Economies

New Babylon & Situationism

Situationism: the freeing of the individual⁵⁰. The socialization of the necessary resources and the promotion of play. A new disposable surplus of value is supported by the close integration of automation, and the environments hosting the inhabitants.



⁵⁰ Conrads. Programs and manifestos on 20th-century architecture. "Situationists": International Manifesto. 1975.

Figure 22. Collage of Constant's New Babylon.⁵¹

The utopian vision of New Babylon explores an architecture that exhibits a culture of play and experimentation through a new architecture.⁵² Space architecture strives to the same to support a new space culture of spontaneity and support organic social environments. Constant proposes material to realize the notion of Unitary town planning⁵³. This object which supports an individual's participation in the movement of mass creativity. The automation of the necessities free up space and time for the individual to better collaborate and participate in a constant transformation and shaping of the physical and social environments. The only way the playful notion of space will be realized is if it is fueled by the participation of the user. A free space settlement can support these notions of anticipated spontaneity. New Babylon's stance on preserving the natural environment and being situated on armatures that allow the mass of the structure to hover of the Earth. By moving the settlement off Earth, the same sentiment of Earth and natural preservation remain.

Yolanda Friedman's ten principles of space town planning validates Constant's vision for total functionalism and organicism.⁵⁴ Friedman posits architecture should be shells that are constructed to support the personal initiatives of the individual. The physicality of the architecture is supporting of the individual's collective good.

⁵¹ Conrads. Programs and Manifestos on 20th-Century Architecture: Yona Friedman: The Ten Principles of space town planning. 1962.

⁵² Conrads. Programs and manifestos on 20th-century architecture. Constant: New Babylon. 1962.

⁵³ Ibid.

⁵⁴ Conrads. Programs and manifestos on 20th-century architecture. Yona Friedman: The ten principles of space town planning. 1962.

In a space settlement there is an acute awareness of the relationships between technology and the individual. Situationist theory helps to address this dichotomy. As posed in Constant's New Babylon, automation becomes essential to free the individual from their daily work strife to allow them the opportunity of unlimited play. The space settlement seeks to use the economy of the state of architecture as a way of supporting the individual by promoting their abilities to exploit creativity and nature inhibitions since they will be disconnected from Earth. With today's technology capable of realizing the idea of total automation, the relationship between technology and the individual is imperative to support survival. With technology completely supporting the lives of those living on board a space settlement, the inhabitants will be in constant dialogue with their environment. This will be important to understand how their interactions can promote the wellbeing of those living on board. Human choice needs to be inserted into the architectural autonomy.

Farmer's Improvement Society & the Women's Barnyard Auxiliary

Cooperative social models are essential for supporting the livelihood of the inhabitants of a space colony. The Farmers Improvement Society was a farming cooperative in Sunflower county, MI that promoted the insistence of economic opportunity for Black people in agrarian landscapes. Utopian in its vision. In this case the farm. Not operating in isolation. This farm operates in parallel with other social justice work through agrarian movements. The cooperative spirit conceived the concept of total individual ownership. This system operated outside of the racist federal models that otherwise assisted white agrarian workers participating in the agrarian economy. A cooperative model of this scale proved to be successful for

promoting power and social capital among individuals being systemically discriminated.

These cooperative models can be linked to architecture movements promoting the individual's power over their own space.

Black Panther Party Programs

The Black Panther Party created a transnational legacy that promoted community among black people in the wake of racist oppression. The Black Panther Party supported an important social movement that promotes community and well-being for the systemically underserved populations of black people. The Black Panther Party played an important role as a social organization because it empowered black people to enact positive change for their communities that have been historically marginalized. Like the farmers improvement societies, the Black Panther Party was able to afford outreach programs to the same capacity as some of the other efforts being made that otherwise excluded black people. As an example, the Free Breakfast for Children Program implemented by the Black Panther Party performed so well that the federal government installed their own program across the nation because it was so successful.

These radical programs proved to be better equipped to handle their tasks than the federal government at their times. These social models provide fodder for planning and designing spaces that enable the social sphere to advocate and develop power and agency to organize and ensure that adequate provisions are being met.

Space Ethics

These social precedents present models that make ethical considerations towards the use and well-being of those who are going to be using space resources and living in outer space. Joel Sercel highlights the importance of utilizing space not beyond its physical means like we have done in the past on Earth.⁵⁵

Bioethics lays a framework for how ethics could be mapped into space applications⁵⁶. If we are going to endeavor to be multi-planetary species, we need to be responsible stewards of the space environments we are going to be impacting. We also need to be aware of what we do not know in order to protect large populations from negative physical and psychological externalities of space.

To anticipate the deficits that have been present throughout history amongst systemically marginalized people, I am implementing design to address and fill these societal shortcomings before they have a chance to entrench themselves in space communities.

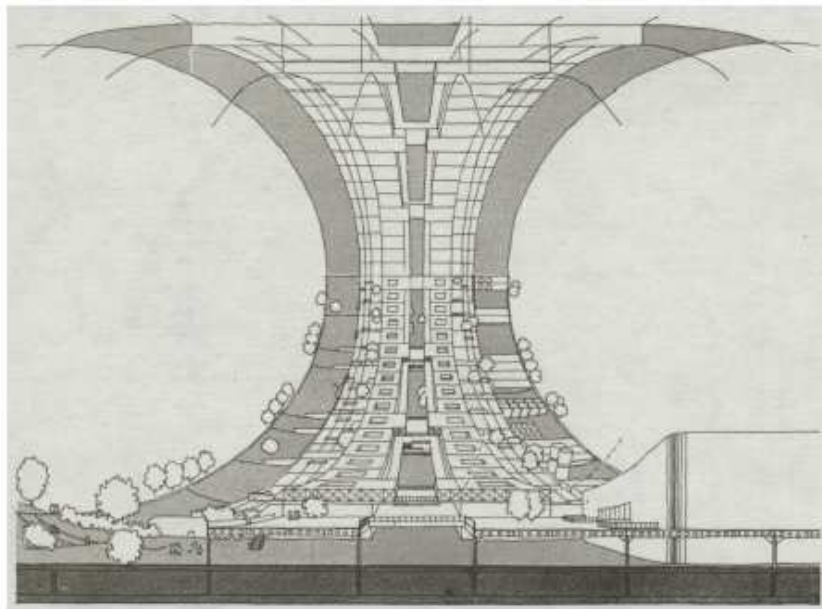
⁵⁵ Kaplan, Mat; Sercel, Joel; BettTs, Bruce. A return to Asteroid Mining, and Digging Into Space Ethics with Joel Sercel. Planetary Radio. November 4, 2020.

⁵⁶ Ibid.

4. Planning and Programming

Now that the table has been set to design the architecture of the space settlement and the parameters have been defined and the necessities identified. The goal is to minimize the adverse and maximize positivity. As it has been noted previously, a space settlement operates somewhat like an island. The mentality of the users of a space settlement may need to resemble that of a crew aboard a spaceship. No one person is left out of upholding collective responsibility to promote the well-being of their fellow crew.⁵⁷

It is important to consider that the planner as well as the inhabitants of a space settlement will have a preconditioned notion to think that this new environment will resemble only what they know on Earth.



⁵⁷ Explore Mars. Lessons Learned from COVID-19: And how to apply them to Mars Exploration. 2020.

Figure 23. Perspective Drawing of the interior of a prototype colony.⁵⁸

With the principles of situationism in mind, what are the limits between public, private, and semi-public/private and how can these relationships be defined as a whole or for the individual?⁵⁹ The architect is responsible for designing an environment that is psychologically palatable, it needs to be culturally and philosophically oriented to provide fundamental humanities. Can claustrophobia and agoraphobia be addressed ethically through design? What factors will define the quality of light? What are the scientific consequences of living in a variety of gravitational environments?

Phasing

This thesis breaks down human settlement in free-space developments in three major categories: the Near Future (10 - 20 years), the Close Future (20 - 50 Years), and the Distant Future (50 – 500 Years) or by this period of time, native-born free-space citizens. The scheduled phasing of construction is intended to compensate for the limitations of transporting construction materials into space. Furthermore, habitat modules correspond are defined to correspond with the phases of the progression of construction.

The need for *scenario planning* and *scenario modeling* to equip designers as well as inhabitants to be capable of responding to slow-developing issues; an example of occurrences in the Biosphere 2 Project (MacCallum, Poynter, Bearden).

Amalgamation of scenarios to provide feasible insight to a most rational proposal.

⁵⁸ Crowell, Robert. "Environmental Design of a Prototype Space Colony." *Ekistics* 50, no. 302 (1983): 329-36. Accessed July 16, 2020. www.jstor.org/stable/43621834.

⁵⁹ *Ibid.*

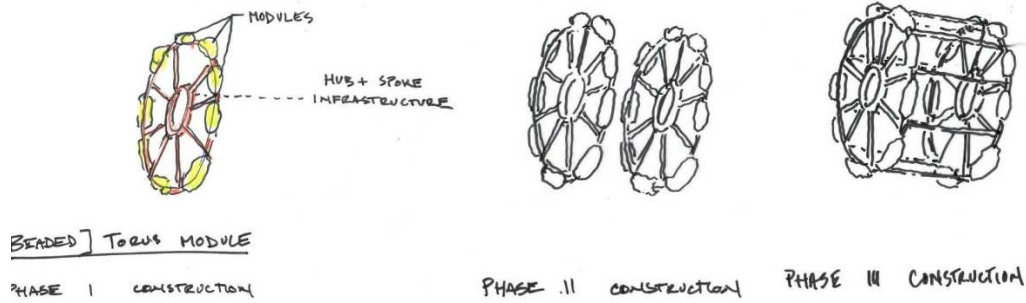


Figure 24. Breakdown of Parts to Whole and the incremental modules to be used to achieve a full space settlement build-out. (Source: By Author.)

Planning a space settlement is important to consider phasing. Phasing a modular growth sequence will ensure the challenging feat of constructing an architecture at such a large scale. To do so, these pure forms can be broken down into modules and then incrementally assembled until the adequate size and scale is achieved.

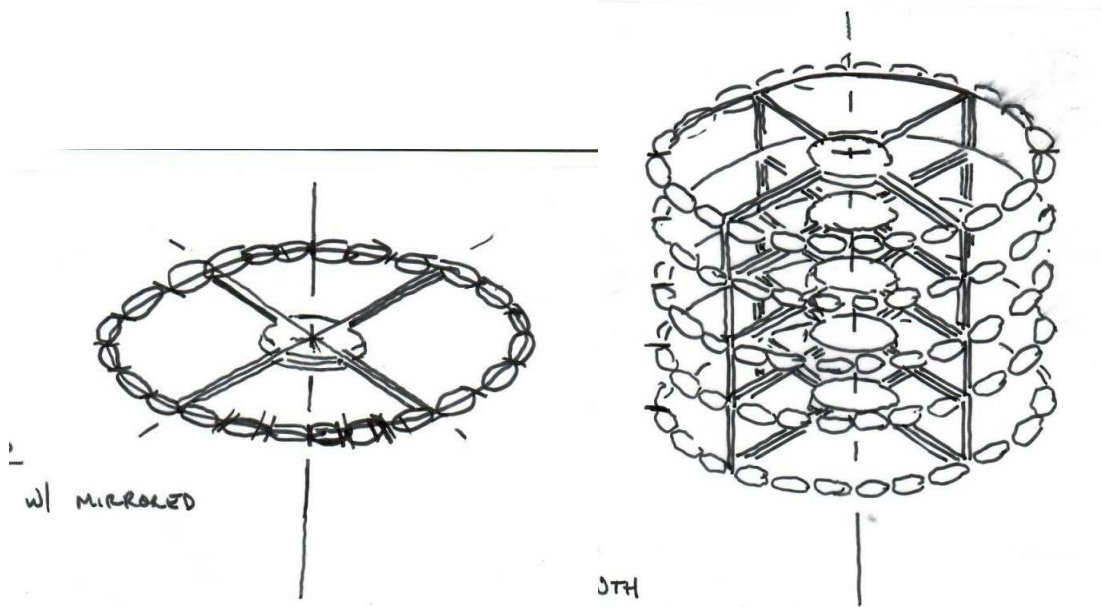


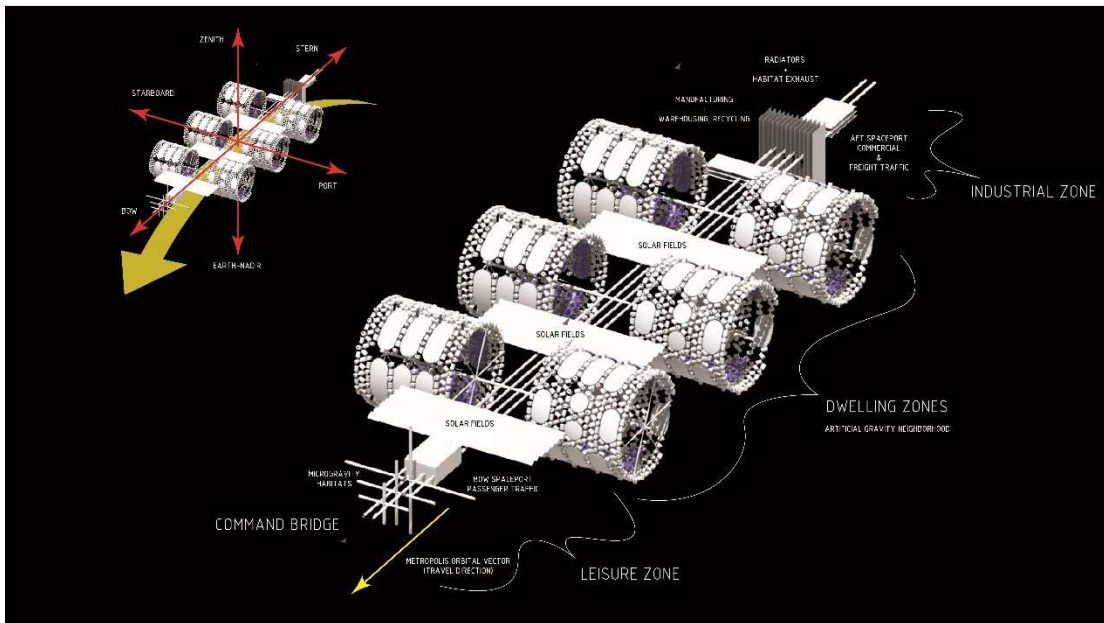
Figure 25. Diagram showing an aggregated torus of modules and an aggregated series of tori to form a cylindrical habitat. (Source: By Author)

As an example, a cylindrical model can be broken down into a series of tori and then assembled until a cylinder is made. The modern rendition of the Von Braun

Class Space Station can be posed as one of these torus modules. By attaching multiple tori modules together, adequate structural armature can serve as the scaffold or the foundation for outfitting a Kalpana-sized settlement model.

Growth

As more modules are constructed and colonies continue to grow, a network of redundancies is formed. This ensure that the safety and well-being of the occupants is protected, and the integrity of the technical infrastructure is resilient to errors. In addition, the growth of the settlement will be in coordination with the growth of the population of the space inhabitants. In order to maintain sustainable population, they will likely grow and contract as they naturally do on Earth.



(Figure ##) LEO Metropolis. (Sources: Drawing by author, Concept Adapted from Howe, Sherwood.

Out of this World: The New Field of Space Architecture. 2009)

Systems Redundancy

The design of the programs and their layout are intended to maximize human safety on board the free space habitat.

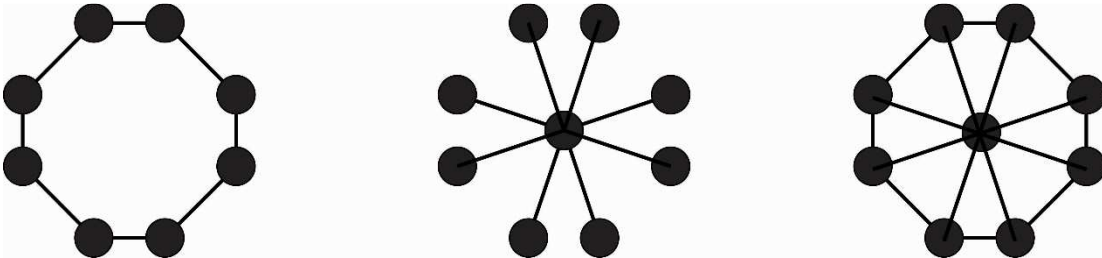


Figure 26. Space settlement design concept that allows for redundancy among different space architectural systems to ensure inhabitant safety. The combination of a linearly connected system and a hub-and-spoke system could provide a system with adequate redundancy. (Source: By Author)

By providing redundancy to the habitats as well as multiple means of egress and areas of refuge or safe havens, the design of the space architecture can ensure the safety of the inhabitants living on board. This feature offers psychological connections to Earth.

Wayfinding

Wayfinding and user orientation are important considerations for accessibility and safety accommodations. “space is a place but to be anywhere [in space]is to be in motion.”⁶⁰

⁶⁰ Scharmen. Space Settlements. 2019.

Gyroscope technology would be implemented to keep the space station on orbit and nautical terms would be used to locate place on board the settlement in relation to its orientation towards Earth similar to the ISS.⁶¹

Safe Havens Philosophy & Egress

Safe havens are to space habitats as areas of refuge are to architectural designs.⁶² To ensure architectural stability at a modular level, each habitable module will need to encompass a command feature to connect with system command. Egress in space is the ability to use an escape or an emergency vehicle like the nautical equivalent of a lifeboat. Safe havens will be equipped with the capability to have emergency vehicles docked in immediate proximity in the event of an emergency.

⁶¹ Scharmen, Fred. "The Shape of Space," *Places Journal*, August 2018. Accessed on 09 June 2020. <https://doi.org/10.22269/180814>

⁶² Cohen. *Designing Space Habitats for Human Productivity*. 1990.

5. Settlement Design & Construction

Participatory Design

The space architecture will be designed to encourage cooperation to support human productivity. Marc Cohen discusses the importance of the how decisions are made as they may incur impacts on the collective group during a NASA mission. It is for this reasons that individuals are strongly encouraged to constantly and actively participate within the community. An enhanced level of public participation will better enable the group to democratically make better decisions to change the architecture to fit to more nuanced levels of comfort. Community participants will feel safe and comfortable speaking up for ideas and out against ideas they feel need to be changed. Through this public participation, individuals can develop agency to support spaces that are adequate for them to fulfill productivity levels as well as support living in a comfortable space habitat.

Participatory planning models give rise to more diverse perspectives. Added diversity gives the group the potential to garner new professional perspectives which add strength to their cooperative dynamics in emergency or stressful situations. Participatory planning gives the potential for international partners to contribute to achieve diversity of owner agency and diversity of architectural design.

Efficiency of Form

The space settlement design will be explored through the aggregation of a series of habitable modules. The current reality constrains us to what the largest rocket is able to carry into Earth orbit. As rocket travel becomes more efficient and

cheaper, and the rocket payloads grow larger, what is able to be prefabricated on Earth to be deployed in space with less assembly can also increase in scale.

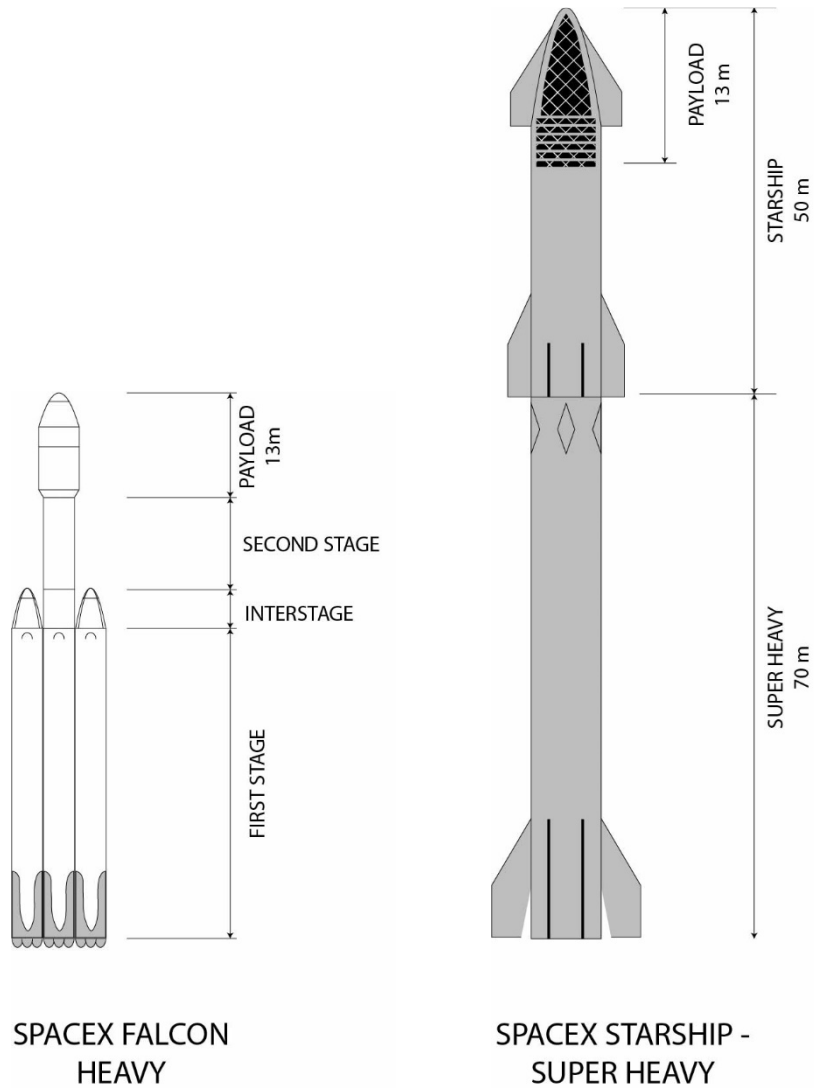


Figure 27. Schematics of the SpaceX Falcon Heavy and the Starship-SuperHeavy. (Source: By Author)

The first scheme explores the layout of the modules around a torus armature and each module is programed to incorporate redundancies in program, infrastructure,

and life support in order to actually ensure safety but to also ensure inhabitants of a sufficient psychological sense of safety.

Buckminster Fuller draws on an ethical approach to the progress of societal development and an awareness of our finite resources.⁶³ Buckminster Fuller supports the notion that planning needs to consider the totality of the world and understanding the fluctuations and complex intricacies of the many systems at work. A space settlement where the whole of its entirety is being constructed, one can prototype these whole and inclusive ideas not out of desire but out of necessity in order to accommodate ethical designs to support the populations living on board. The planner needs to be acting at the global level because Fuller posits one nation will never satisfy the comprehensive planning for the entire world. In order for global cooperation to exist, everyone must be involved.

Nature of the Design Process & Drawing Typology

The space efficient forms and natural qualities of them present unique circumstances for which one must consider design. For example, cutting a section through the vertical of a cylinder will display features of the cylinder's wall section as well as the plan of the interior face of the drum. Additionally, and most applicably to this design study, the plan of the interior face of the drum can be flattened to show a familiar and conventional way of looking at the plan of the space settlement by abstracting it from its cylindrical form.

⁶³ Conrads, Ulrich. Programs and manifestos on 20th-century architecture. Buckminster Fuller: The Architect as World Planner. 1975.

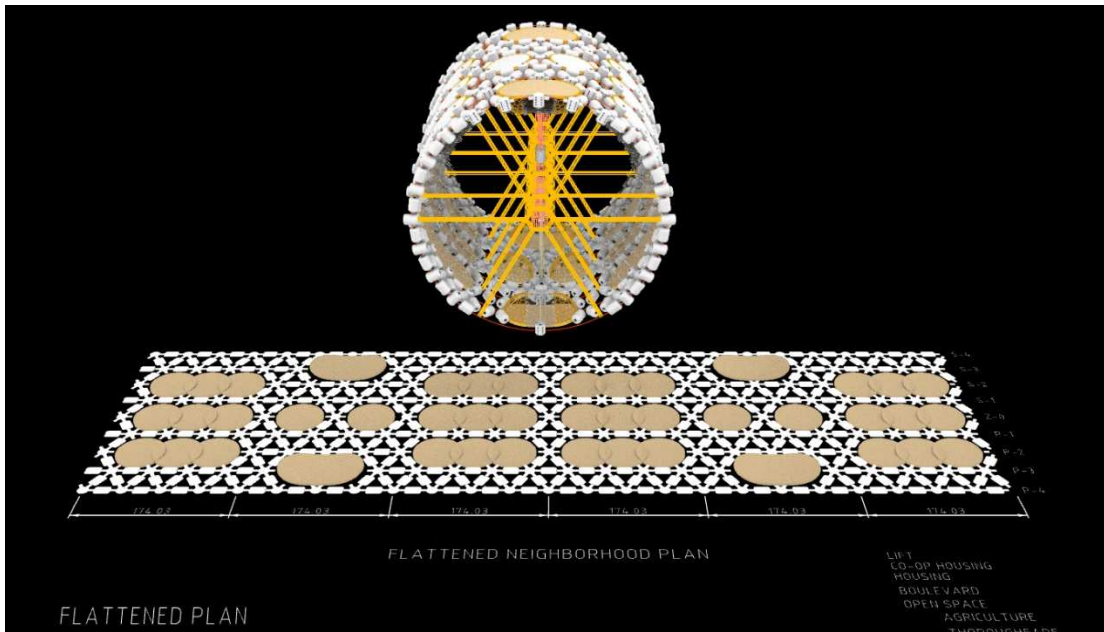


Figure 28. Flattened Neighborhood Plan. (source: By Author)

Modularity

All of the precedented free-space models share their plans and sections views through one drawing. Thus, a typology of drawing and designing enabled by the formal nature of the architecture.

An overriding design factor of the overall layout of the modules of the settlement will be constrained by their size due to the ability they will need to be transported to LEO for assembly and or deployment.

The size of the modules investigated here are based on the payload capacity of SpaceX's Starship and Super Heavy Rockets overlaid with the conceptual design criteria for Bigelow's 2100 Olympus Module.

Rack Module

Modules known as Racks are functional modular units that are integrated into the architecture of the habitable modules of the ISS and operate as independent task

stations that support astronauts' programmatic objectives.⁶⁴ The Rack concept will be explored as a means of supporting programs and functional activities within the space as well as organize and deliver infrastructure and life support systems to the designed spaces. Rack modules are capable of being repositioned and changed to respond to demands of the crew. Modularity is important to ensure up-most efficiency of space architecture to adapt to organic applications of human needs.

Pseudo-Gravity

Another driving design challenge is the fabrication of pseudo gravity among the modules of the space settlement. The perceived vertical organization of the programmed habitat levels will be prioritized based on where the inhabitants will be spending the majority of their time in order to protect them from unknown consequences of living in foreign gravitational environments.

⁶⁴ Scharmen. Space Settlements. 2019.

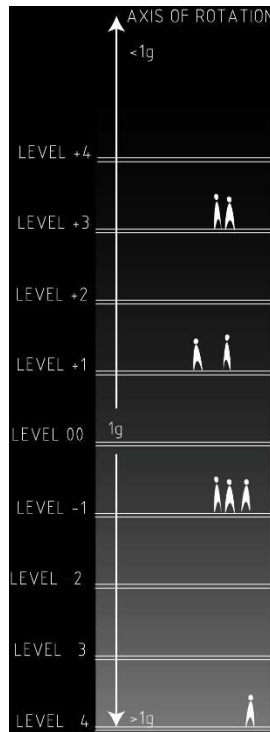


Figure 29. Pseudo-Gravity as it enacts force upon the different vertical levels of the habitat. (Source: by author)

Materiality

The construction materials can be made from aluminum and light gauge steel. The materials of any components that need to be assembled in space will explore the idea that they might be able to be fabricated from materials found in outer space and extracted and fabricated through space mining programs and space manufacturing processes. The considerations for construction materials would ensure the space architecture paradigm could progress based on resources that are available in space. These considerations would have implications on lower costs and lower embodied energies of construction.

Structural Systems

Building in environments with less gravity than on Earth offer opportunities to explore construction through different constraints; spans could be lengthened and bearing loads could be increased. An advantage to designing a habitat in free space is the opportunity to create artificial gravity or pseudo-gravity by rotating the habitat around a central axis. The rotational speed can be calibrated to create centrifugal forces that mimic the gravitational conditions on Earth.⁶⁵ Rotational speed and the distance from the rotational axis act as variables that may be adjusted to accommodate unique gravitational environments within the settlement that differ from Earth's for a multitude of reasons.

Structural considerations will be made to address the integrity of the space architecture's assurance to overcome shear forces acting upon itself as it rotates.⁶⁶ As an example, lower gravity environments can be used for science experimentation and hospice for elderly folks while high-gravity environments can be programmed for sports, weight training, and recreation.

On Earth, gravity accelerates at 9.8 m/s or 1g. On the Moon and Mars, gravity accelerates at 1.62m/s and 3.77 m/s respectively. The same general structural principles that are considered on Earth will also apply to these locations. The difference, however, will be the size of the structural members and the capabilities of their spans. Because less force is acting these structures, they will be capable of

⁶⁵ Globus. Settlement, an Easier Way. 2017.

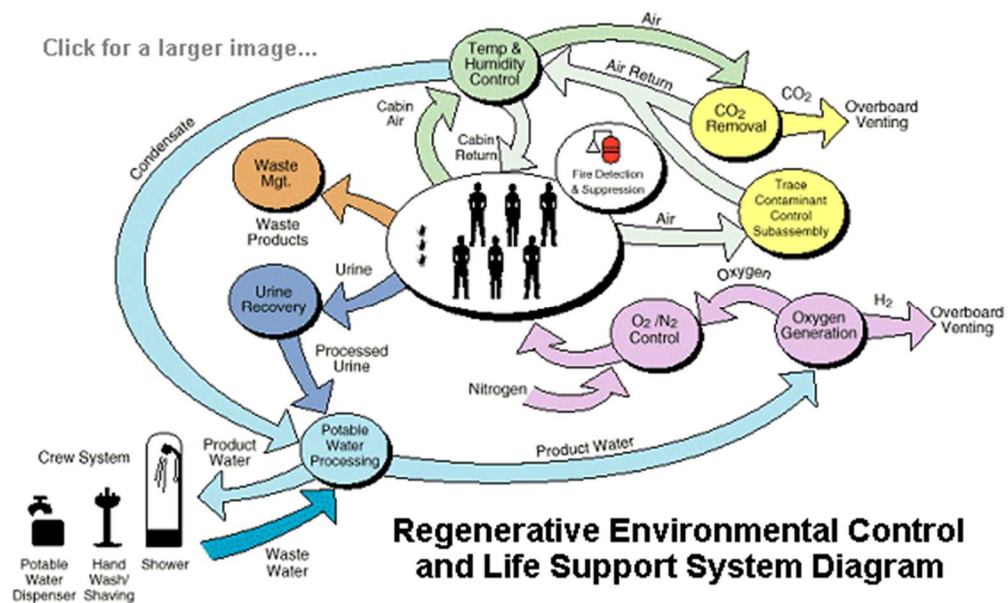
⁶⁶ Ibid.

being more efficient in terms of structuring an amount enclosed area per the material used.

Life Support

Biosphere II has demonstrated viability for “fully regenerative agricultural systems” to support a permanent population in a man-made environment.⁶⁷ A lesson learned from the Biosphere 2 projects highlights the need for redundant dietary staples allow for adaptation to unforeseen circumstances when developing sustained agriculture.⁶⁸

Plants can be used to aid oxygen production as well as air purifying through natural means. Racks can be outfit with Environmental Control and Life Support System (ECLSS) that can recycle water and create oxygen for the inhabitants on board.⁶⁹



⁶⁷ MacCallum, et. al. Lessons Learned From Biosphere 2. 2004.

⁶⁸ Ibid.

⁶⁹ NASA. International Space Station: Environmental Control and Life Support System.

Figure 30. Flow diagram illustrating how the ECLSS supports aspects of typical habitable environments in a space habitat.⁷⁰

Agriculture

Food production in situ is an important design driver to explore permanent sustainable habitats. Using Perry’s Neighborhood Unit population of 5,000 to 9,000 inhabitants, the design of the space settlement explores the extent of what level of agricultural production would be required to support a population of this scale. Precedents show that it is possible to create food forests in the most inhospitable locations on Earth.⁷¹ Additionally, highly productive agricultural models such as food forests can optimize land use and capitalize on output. One such case has been able to produce 7000lbs of food in a year on a tenth of an acre.⁷² Based on an annual consumption of 2000lbs of food person,⁷³ this the design will be calibrated to understand how much space would need to be required to support an adequate population to permanently sustain a space settlement. Additionally, minerals and soils can be imported from other celestial locations in space easing transportation and fuel cost burdens and without the need for disturbing and moving soil from Earth.

Agriculture produced in space can be grown from methods using both natural and artificial daylighting sources.

⁷⁰ Ibid.

⁷¹ “Desert Food Forest and Organic Commercial Production in Three Years – Update on Wadi Rum Consultancy (Jordan).” 2013. The Permaculture Research Institute. December 10, 2013. <https://www.permaculturenews.org/2013/12/10/desert-food-forest-organic-commercial-production-three-years-update-wadi-rum-consultancy/>.Dietzler

⁷² Ibid.

⁷³ “Crop Yield Verification.” n.d. Accessed November 6, 2020. <https://www.gardensofeden.org/04%20Crop%20Yield%20Verification.htm>.

Daylighting

The settlement will need to harvest light for two main reasons: Solar power generation and absorption for living things like plants and animals.

Space Frame & Expansive Glazing Details

The space frame like the can be used to create sealed volumes over large areas with structural concepts derived from Buckminster Fuller's tensegrity models. With help from Biosphere II's architectural detailing, these glazing details will be incorporated similarly in outer space.

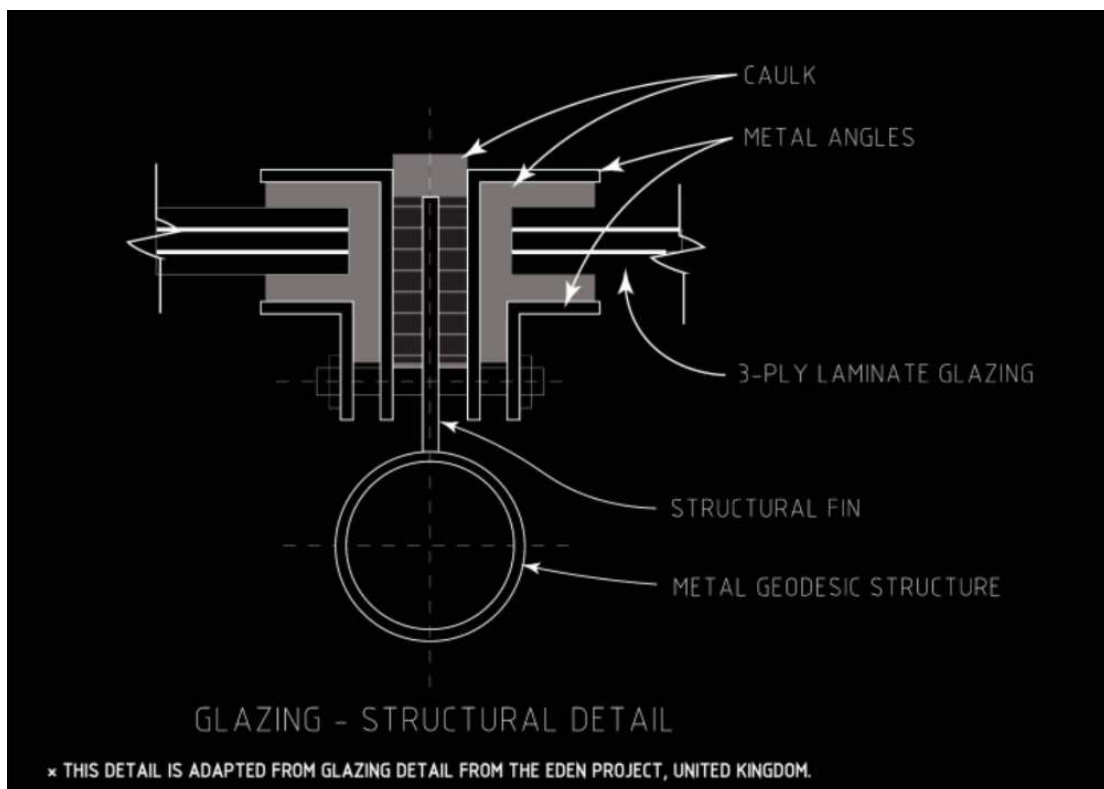


Figure 31. Glazing Detail at space frame.

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