The Destiny Plan: Colonization of Space

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

> This world's a treasure, Don; but it's been telling us to leave for a while now.
>
> –Cooper, Interstellar

Cooper: Don't you get it yet, TARS? I brought myself here! We're here to communicate with the three-dimensional world! We're the bridge! I thought they chose me. But they didn't choose me, they chose her!

TARS: For what, Cooper?

Cooper: To save the world! All of this, is one little girl's bedroom, every moment! It's infinitely complex! They have access, to infinite time and space, but they're not *bound* by anything! They can't find a specific place *in* time, they can't communicate. That's why I'm here. I'm gonna find a way to tell Murph, just like I found this moment.

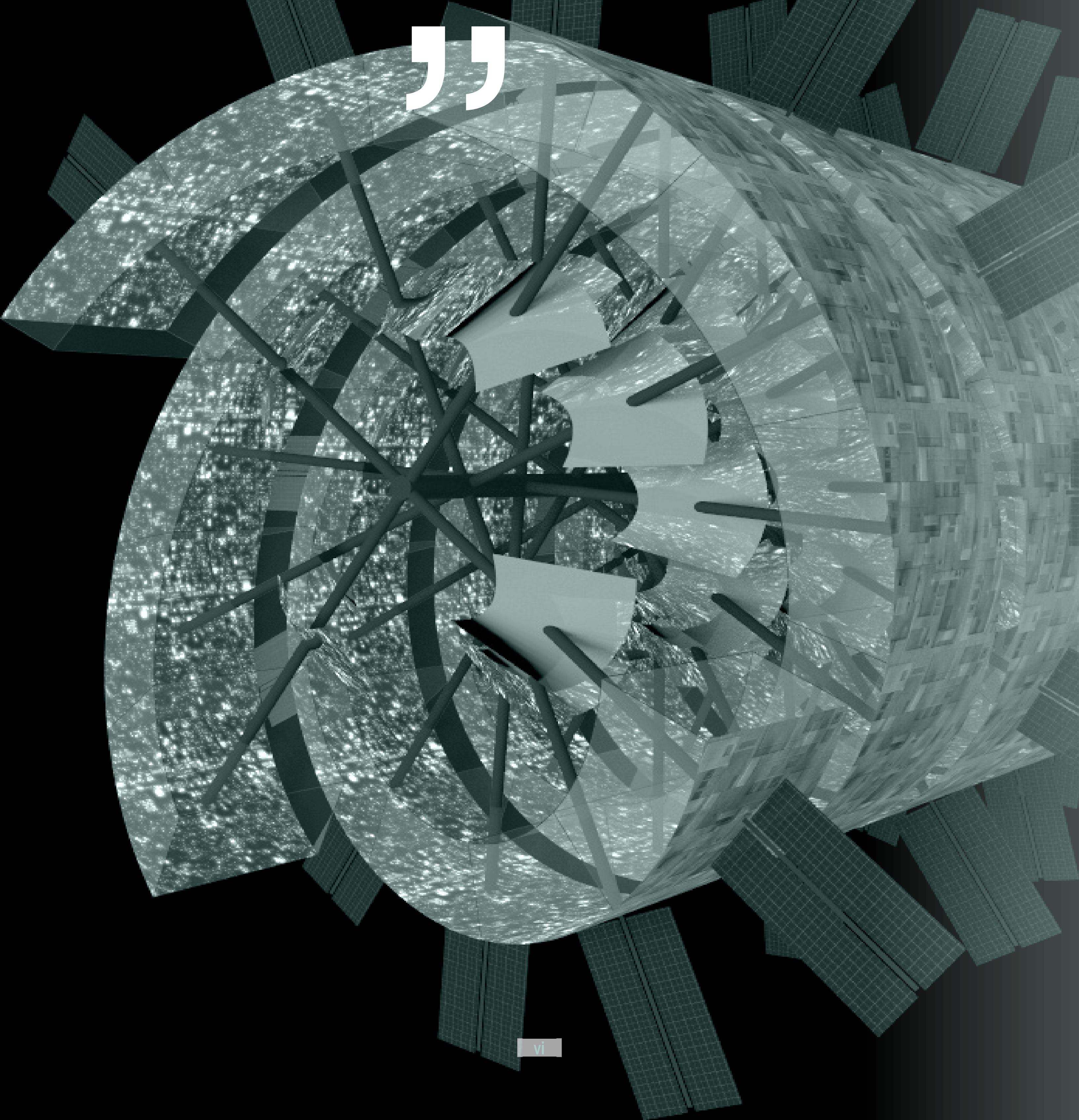
-Interstellar

ABSTRACT

This thesis explores a design of a colony in outer space able to comfortably sustain a dense growing population of 1 million inhabitants. This visionary colony, will exist in the Moon-Earth Lagrange Point 1 and aims to take advantage of the unique physical, phenomenological, and technological aspects of space while providing a level of comfort on par with that of a first world city. This paper engages the practice of architecture by exploring beyond our current ability to shape our habitation, examining a new frontier, one enabled by being surrounded in outer space. Ultimately the work seeks to answer the question of 'what sequence of events will allow for a self-sustaining and expanding city in space, and what type of life may we lead within?' The major studies in this thesis revolve primarily around four categories: the potential technology required, the abstract mechanics of how various systems would interact to support life, the timeline that would be required for a space colony to be built, and the urban design that a city of the sky should enjoy. The goal is to synthesize these areas and ultimately determine the schematic design approach for the creation of a space colony. To this end topics relating to energy production, mining, ecological footprint, modern scenes of fantasy, mechanical and structural engineering, alternative housing, linear cities and political governing will be explored topics of study. The overarching goal of all of this is to discover how we can to build a habitat in orbital space based on our current and projected technology, and to explore the emerging field of space urbanism.

“If I have seen further it is by standing on the shoulders of Giants

-Sir Isaac Newton”



ACKNOWLEDGMENTS

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I would specifically like to thank Anne Bordeleau for her vote of confidence, Elizabeth English for her guidance, as well as John McMinn and Vincent Hui for agreeing to commit to such a difficult schedule. Lastly I would like to express my gratitude to Val Rynnimeri for being endlessly excited about this thesis and bending over backwards to help me get it done.

"Love is the one thing that transcends time and space."

Brand, Interstellar

DEDICATION

In dedication to my family.

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“My thesis is on designing a city able to comfortably sustain a population of 1 million people, in space.

(Waits for the audience’s laugher to die down)

So this is how it will work...”

-Me at every presentation during my first semester. If I can do it, so can you.

PREFACE

I was born a month premature. As a result, I had small feet, a tiny head, flat ears, and disproportionately large eyes. Somehow, all of this was apparently enough of a rationale for my mom to nickname me ET (from the movie ET). Until this day, she still calls me by that, and I still respond with "mom stop calling me that." At the time of writing this, I have avoided telling her the topic of my thesis to escape the frenzy that would ensue after her learning that her "little ET" is doing a thesis on space. Nevertheless that dorky cute nickname probably 'is' my actual starting point for my thesis (thanks Ma).

I need to address the big elephant in the room. Why do a thesis revolving a around the development of a space colony? There are several reasons ranging from overpopulation, energy needs, and even the intrinsic human desire to explore what is out there. Although I do not aspire to be the champion of exploration, nor am I particularly interested in spending my life solving an energy crisis. My dreams and aspirations are much simpler than that. This thesis is potentially the last opportunity I have to design with limitless freedom in a forgiving academic setting, and the vastness of space provides an infinite sandbox where I can challenge myself. Creating a colony, setting the population at one million, and choosing space as the context, are all challenges set out, for more than any other reason, simply because I thought that a speculative challenge in such an outrageous, but still humanly desirable, exercise would be fun.

Do not go gentle into that good night;
Old age should burn and rave at close of day;
Rage, rage against the dying of the light.
-Dylan Thomas,

SCOPE

In this thesis the schematic design of a space colony that will grow to house a city of one million people is developed. This chapter introduces the reader to the broad array of challenges that mould the final design presented in the later chapters. Major axioms and fundamental assumptions in this thesis revolve around four categories: the potential technology required, the abstract mechanics of how various systems would interact to support life, the events that prelude its construction and the urban design that a city of the sky should enjoy. The goal is to synthesize a body of work in each of these areas and ultimately determine the schematic design approach for a space colony.

Timeline

This thesis sequences the events following our next major energy revolution into a narrative that will predict the beginning of human space colonization. The motives are established on real world issues that cannot be solved in their entirety on Earth; all are largely based on projected energy demand, population growth, and projected societal views on the environment.

The sequence of events follows the complete conversion to renewable technology as the Earth's main source of energy production. This move is often seen as the obvious next step, to both secure our future energy needs while lowering our environmental pollution. In doing so however, we lose the benefits of energy density embodied in fossil fuels and will be faced with the large amount of space that is required for renewables to produce the same yield. The increasing rate that humans will then start to accumulate land for survival cannot be sustained indefinitely and eventually we will need to search outside our globe to meet our increasing demands. This thesis proposes both a solution to that problem and a way to take the human species to its next state of being through the habitation of space.

Technology

On the technological side, information is presented on areas considered to be the structure of the enclosure and the overall layout of services that will make this giant machine for living logistically sustainable. One of the main ideas explored under the technology umbrella is how the dynamics of rotational artificial gravity will come into play. Manipulatable gravity will be fundamental in unlocking the new parameters of living and is both explored and designed around to provide a uniqueness to space. This, in turn, redefines the notion of what is 'sky' and what is 'ground.' For instance, if a force of gravity were to be simulated through the use of magnets, any kind of metallic surface could potentially be

[Figure 1] An example of an Earthship

the ground. Space planning could be turned completely on its head, literally, with these new parameters. Gerald K. O'Neill, an American physicist and past faculty member of Princeton University, takes advantage of this special freedom in his pioneering, 1970s book *The High Frontier: Human Colonies in Space*, where he first designed a cylindrical space station. This O'Neill Cylinder creates an interior of alternating strips of land and window, equally-dispersed array of narrow bands, inviting sunlight into the enclosure, and the landmasses for habitation. By rotating the cylinder, he is able to create enough centripetal force on its interior surface to mimic gravity. The result are upside down land masses that seem embedded in the sky. [1] This almost fantastical, but potentially feasible, view of space was so popular that it is consistently featured in various forms of entertainment media such as the Gundam franchise.

Life Support

Life support research is presented discussing the creation of a closed loop food system, generation of energy, facilitation

1 O'Neill, Gerard K. The High Frontier. London: Corgi, 1978.

of a water purification cycle, and accommodation of imports and exports. A design of a fundamental interdependent ecosystem is designed and modeled to determine the necessities of sustainable living. On the Earth, historically, we have settled in areas nearby vital resources such as water and farmable soil. Because we have lived within a wealth of supplies, land, and an already functioning ecosystem it has been easy for us to produce, without needing to reuse, and then throw away. A settlement in space, depending on where it is constructed, may be rich in resources and even water, [2] but will not have a functioning ecosystem without human intervention and materials extracted from Earth. If we continue to produce non-recyclable waste on the colony we will be dependant on Earth indefinitely, from a survival and political point of view. A cycle where the waste of one must be able feed another is paramount.

The history of Singapore, a city state in Southeast Asia bordering Malaysia, serves as an example of the importance of self reliance and design through closed systems. Singapore is a small nation and after its independence was reliant on other countries for water. The threat of increased export tariffs, or completely "turning off the tap," became a political tool used by the surrounding countries to influence Singapore's decisions. [3] I imagine the same situation could happen with oxygen, water, and food supplies if a hypothetical space colony relied too heavily on the resources of other countries.

Michael E. Reynolds, an architect currently based in New Mexico, wrote his Masters of Architecture thesis regarding buildings that facilitate a closed ecosystem and continued his research into construction with his firm producing these structures; what he dubbed Earthships. He called them Earthships because they were designed in respect to what a spaceship would need to be self reliant. Earthships are steps more advanced than passive eco-houses as they

2 Comets are comprised, in part, of ice that can be melted down used for survival.

3 Onn, LEE Poh. Water Management Issues in Singapore. Proceedings of Water In Mainland Southeast Asia, Center for Khmer Studies, Cambodia. Singapore: International Institute for Asian Studies, 2005. 3-5. doi:http://khmerstudies.org/download-files/events/Water/Lee%20Nov%202005.pdf?lbisphpreq=1.

not only provide the energy, but also the food for the user. [4] In respect to this thesis, his precedent is useful because it is essentially a grounded, low-technological, version of the International Space Station. Because of its low tech approach, it lessens the potential entropy of the whole system, thus lowering its risk of failure. Reynolds work presents a condition that is not futuristic; without high tech toys like 3D printed food and zero gravity suction propelled toilets, unlike the International Space Station. Instead we see that with fast growing fish and waste filtration plants, much of the same result could be achieved.

Urban Design

The urban structure of the space colony takes less of an engineering approach, and places focus on the unique opportunities available in space. These are used to form a view of how I believe the new city of the sky should function.

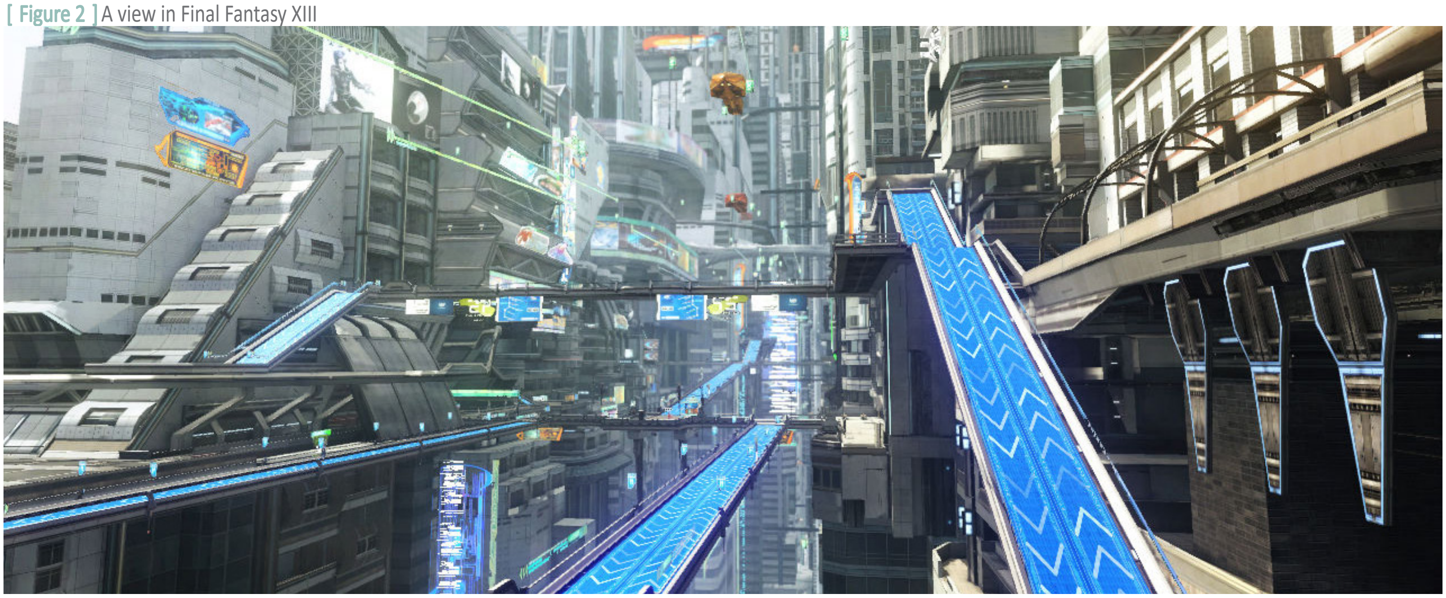
Looking at all of the complex aspects of urban life, an efficient transportation system is necessary for financial and physical growth of the space colony. The citizens will primarily rely on a public transportation system that is built alongside the expansion of the city. A low dependence on cars often the main advantage to living in highly dense cities. High usage of public transportation also defines and centralizes urban nodes and veins of circulation, helping urban planners predict where to locate various amenities along transportation routes. Singapore is an excellent example of this principle and practice; 70% of the county's population use public transit on a daily basis. [5] This is achieved by reserving automobiles for the most affluent in the community due to the government's view on cars as a luxury, not a necessity. [6] Roads are freed up for emergency vehicles and the citizens are encouraged to live a shorter distance from their workplace. This results in residents spending less time traveling to and from work each day.

4 Reynolds, Michael E. Earthship. Solar Survival Architecture, 1991. v. 1. How to build your own--v. 2. Systems and components.

5 Onn Chiu Chuen, Mohamed Rehan Karim, and Sumiani Yusoff, "Mode Choice between Private and Public Transport in Klang Valley, Malaysia," The Scientific World Journal, vol. 2014, Article ID 394587, 14 pages, 2014. doi:10.1155/2014/394587

6 In order to own a car in Singapore, you must purchase an ownership certificate of entitlement that costs $70,000 based on the model of your car. This is on top of a driver's license, which is also particularly difficult and expensive to obtain in the country.

[Figure 2] A view in Final Fantasy XIII



Any city today must respond to a population of people who are diverse and ever advancing. The ability of a space city to grow in both population and size, is what could potentially set it apart from other space colonization designs. Just as importantly, the city also needs to be designed in such a way so that it can decay, become obsolete, decommissioned and then recycled.

The space colony will have a dense population, as demanded by the cost of land in the colony in comparison to the Earth. A new methodology of urban design will have to be explored, one that allows for a dense city to function efficiently and healthily. "Arcology" is an idea referring to the planning approach of such a dense cites by Paolo Soleri, an Italian architect and past lecturer at Arizona State University, [7] It was brought forward in Soleri's 1969 book, *City in the Image of Man*, where he describes future hyper-dense cities that strive to be self reliant. Soleri envisioned that the population could gain a more efficient and more cultural existence through density. New York, Hong Kong, and Paris, have all historically managed to become cultural hubs of their

7 "BIOGRAPHY." Biography | Arcosanti. Accessed June 27, 2016. https://arcosanti.org/index.php?q=node/7379.

respective countries and are some of the most sought after places to live and travel. Density, when it is planned and zoned appropriately, can lead to a more desirable place to live and could be key to drawing a new population to a space colony.

The space city will need to be the very best, like no city ever was since its people are being asked to abandon the Earth as its home and travel an unimaginable distance. There will need to be perks to living there to offset that terrestrial loss. Throughout my architectural education, I have been increasingly interested in the those who strive to invoke wonder and whimsy through imaginative and brilliant architecture. The *Final Fantasy* franchise by Square Enix for instance has been famous for projecting fantastic environments that have elements grounded in realism. [8] Various cities in the game franchise such as Cocoon [9] and Midgar [10] have even been formed based on principles of arcology. The space city will have a design guideline that strives to provide that stimulation, and a design manual will emerge.

To supplement and help execute the goals of the city plan, various atypical legislation will probably need to be explored. Due to the expense and time required of the construction and growth of the physical enclosure of the colony, sudden changes in population growth are undesirable. The state will need to intrude in various aspects of life in order to maintain the longevity of the population. An appropriation of China's one child policy, for example, or significant financial incentives for having multiple children may be necessary. An analysis of Singapore's governing laws is presented in this thesis and used as a model that the colony may need to follow.

Will military service be required? *Gundam* is a popular animated television and movie franchise from Japan, produced by Sunrise Inc. and centers around wars in space. [11] The series displays the importance of minimizing the potentials for intranational and international conflict through design. This space society must be

8 Square Enix is a Japanese video game developer, publisher, and distribution company, that is best known for its role-playing video game franchises Final Fantasy, Dragon Quest, Kingdom Hearts. It has been acclaimed for its leading edge video game graphic styles.

9 Cocoon is an arcology from Final Fantasy XIII set in a futuristic world. The world exists in a fantasy setting but is of interest due to the dense urban environments that the city enjoys. Within it, the citizens experience a world that takes advantage of all 3 dimensions to create an urban fabric that is both dense and functional.

10 Midgar is an arcology from Final Fantasy VII a hyper dense city based on modern day currently available technology. It is a large circular plate structure supported above the ground by eight reactors and a central pillar.

11 Morosawa, Chiaki, writer. Mobile Suit Gundam SEED. Directed by Mitsuo Fukuda. Produced by Sunrise. YTV.

tightly controlled to reduce the potential for anarchy, war, and terrorism. In the television series *Mobile Suit Gundam SEED* for instance, a war breaks out after a nuclear bomb strikes a space colony, causing the colonies to start a war against the people of Earth. Originally, in the scenario, the construction of the colonies were funded by the people of Earth for the mining of asteroids. As the colonies grew in population, they sought increased independence and freedom from mining quotas. This caused the nations of the Earth to fear that they were losing control on an investment that had become integral to an interplanetary economy. Tensions rose, resulting in a nuclear strike on the space colonies. Immediately, due to the colony's fragility in the face of a nuclear bomb, the enclosure fell apart, causing depressurization, and killing all 2 million inhabitants. Although the scenario is completely fictional, one can draw many parallels to our world, such as the events of the American Revolution. There is no doubt that a series of events could actually unfold in this manner. In Japan, after the Second World War, the nuclear warheads used there poisoned the ground radiation, yet the following year new buds sprouted from the ashes. [12] A foreseeable space colony would enjoy no such luxury and the resilience of Mother Nature's complex self repair mechanism cannot be depended on. In space, a bomb, even of a relatively small magnitude, could mean complete and utter destruction.

12 Morosawa, Chiaki, writer. Mobile Suit Gundam SEED. Directed by Mitsuo Fukuda. Produced by Sunrise. YTV.

[Figure 3] Interior view of the space habitat Elysium

Big Picture

When I began my research, I started primarily looking into what has been described in this chapter. This section was designed to peak the reader's interest in the thesis while providing a rough background and framing the direction this particular space thesis will take. The later chapters will discuss the thesis in greater detail.

This thesis is not taken from a utopian point of view, and is framed within the realm of reality. Although theoretical in nature and unachievable for perhaps centuries to come, this thesis will present a condition that is both achievable and in line with our current progression. This design will not aim to describe a perfect world, rather just a world we ought to live in.

“

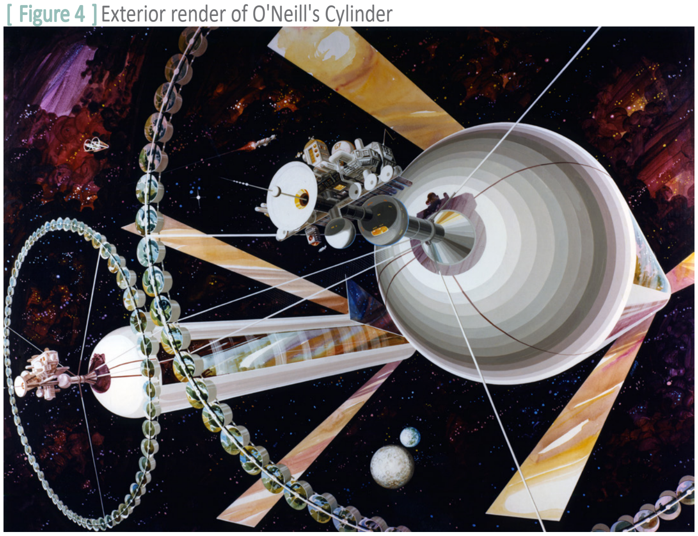
We’ve always defined ourselves by the ability to overcome the impossible. And we count these moments. These moments when we dare to aim higher, to break barriers, to reach for the stars, to make the unknown known. We count these moments as our proudest achievements. But we lost all that. Or perhaps we’ve just forgotten that we are still pioneers. And we’ve barely begun. And that our greatest accomplishments cannot be behind us, because our destiny lies above us.
-Cooper, Interstellar

”

PRECEDENTS

Throughout this thesis many precedents are used to explain the different rationales behind design moves. However, we have yet to see an actual space colony come into existence, and there is very little solid evidence already built to back up a lot of what will be proposed in this work. Most of the suggestions will be result of crossing different areas within the realm of technology, design, and life preservation systems. In addition, many of these 'precedents' will not be true precedents in the sense that they are forms that have preceded the design, hence much of the material in the thesis design will take the form of a design manual for a projected future design.

[Figure 4] Exterior render of O'Neill's Cylinder



[Figure 5] Gerald K. O'Neill

O'Neill's Cylinder

O'Neill's Cylinder resulted from a space colony design experiment authored by Gerald K. O'Neill, an American physicist and space activist who served as a faculty member of Princeton University. O'Neill assigned his students a project to develop a feasible space station. This in turn inspired him to pursue his own theoretical design of a space colony that he later published in his 1978 book, "The High Frontier: Human Colonies in Space."[1] Even today, it is still being featured in various science fiction media such as television franchise Gundam[2], and games like Mass Effect.[3]

The rationale for the urgency of this space colony was based on the increasing population growth rate. At the time the book was written, we struggled to feed 70% of the world population. O'Neill believed our Earth could not sustain our population boom, fearing for a world that would reach a population of 8.5 billion by the year 2020 (which will occur). The goals that

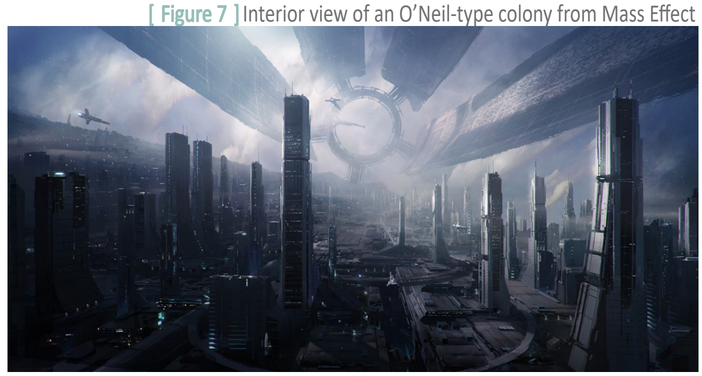
1 O'Neill, Gerard K. The High Frontier. London: Corgi, 1978.

2 In Gundam Seed the Heliopolis is a nation part of the Orb Union that is destroyed in a battle. It is designed based on principles from O'Neill's Cylinder

3 In Mass Effect the Citadel is designed based on principles from O'Neill's Cylinder

[Figure 6] Interior view of O'Neil's Cylinder from the High Frontier

[Figure 7] Interior view of an O'Neil-type colony from Mass Effect

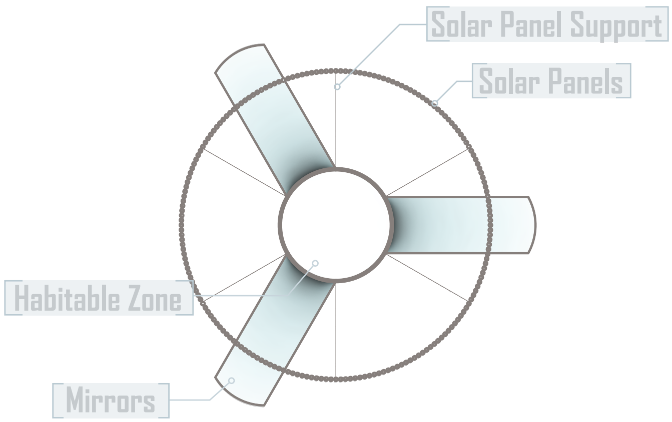


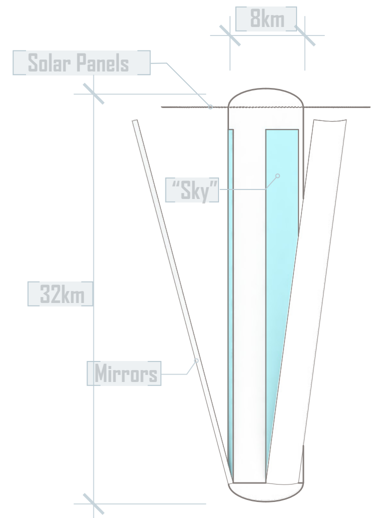
he set out for in his design were to end global hunger, provide a quality home for all, increase individual freedoms, and achieve population control without war, famine, or dictatorship. O'Neill also put forth a set of laws that he insisted future population growth must operate in being potentially unlimited: universally available low cost energy, new land, and new materials that could be sourced without stealing, killing, or polluting. We have yet to find a way to grow our population without violating one of these laws, and in each instance that we do not adhere to them there appears to be a future price to be paid. O'Neill then looked towards the stars, viewing space as the only site that can allow a means of growing in a sustainable manner, with limitless solar energy, asteroids to mine from, and an infinite area for waste disposal.

Perhaps the most unique and successful part of O'Neill's Cylinder space colony is its interior view, a perspective completely unachievable on Earth. As an

[Figure 9] Top view of O'Neil's Cylinder

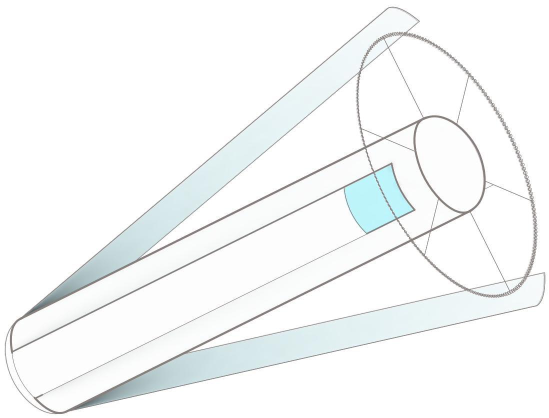
[Figure 8] Front view of O'Neil's Cylinder



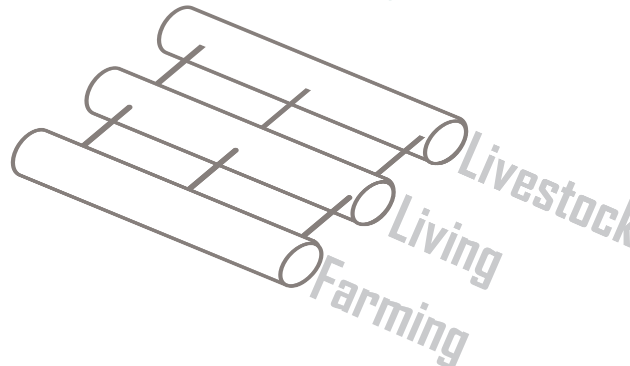


inhabitant inside the colony the inhabitant presented with two valleys in the sky that appear to be floating and upside down but are in fact two other habitable zones that are much like the one in which you are standing. This creates the illusion of inverted cities in the sky and is achieved by using a cylindrical massing which houses its citizens on the inside of the cylinder along the curved surface. The mass is then divided along that curved surface into two alternating zones running lengthwise. One of the two zones is inhabited by people, the other is representative of the sky, and is made of a translucent material that allows light to enter into the colony. O'Neill theorized that a day and night cycle could be provided by reflective mirrors that redirect sunlight through translucent material into the colony. The habitat itself spins about its central axis at a velocity significant enough to create rotational centrifugal force equivalent to the Earth's force of gravity to allow for a habitation on the cylinder's inside surface as that surface pushes back with a matching centripetal force. Such a solution will be the foundation of the artificial gravity of this thesis colony.

[Figure 10]Perspective view of O'Neil's Cylinder



[Figure 11]Separation of food and living

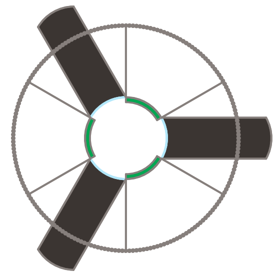


Energy to operate the colony is provided for through the use of solar energy which, in space without the nitrogen light resistance in the atmosphere, can be harvested at a rate 10 times that of that on Earth. The incoming energy is also not limited to day or hampered due to weather.[4]

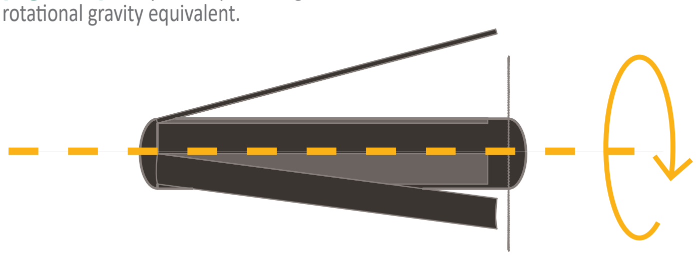
O'Neill further proposed the separation of various different systems to create a greater efficiency of food production and living. To this end, the colony is not just comprised of one enclosure, rather it would require many cylinders to divide the various systems into their most environmentally conducive setting. For instance, one cylinder could be for human living, another for raising animals, and a third for food farming. In each instance, the interior environment created would be altered to suit the specific activity, which in turn would aid overall to supporting human life. A farming environment, for example, could have higher carbon dioxide concentration, and 24 hour sunlight. Rather, than fit the process to the

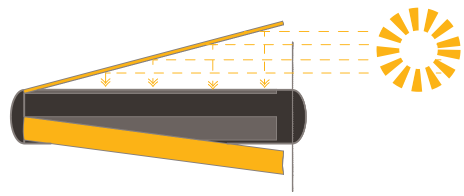
4 O'Neill, Gerard K. The High Frontier. London: Corgi, 1978.

[Figure 13]Sunlight is permitted into the colony through a series of mirrors.



[Figure 12]The cylinder spins along it's axis to create a rotational gravity equivalent.



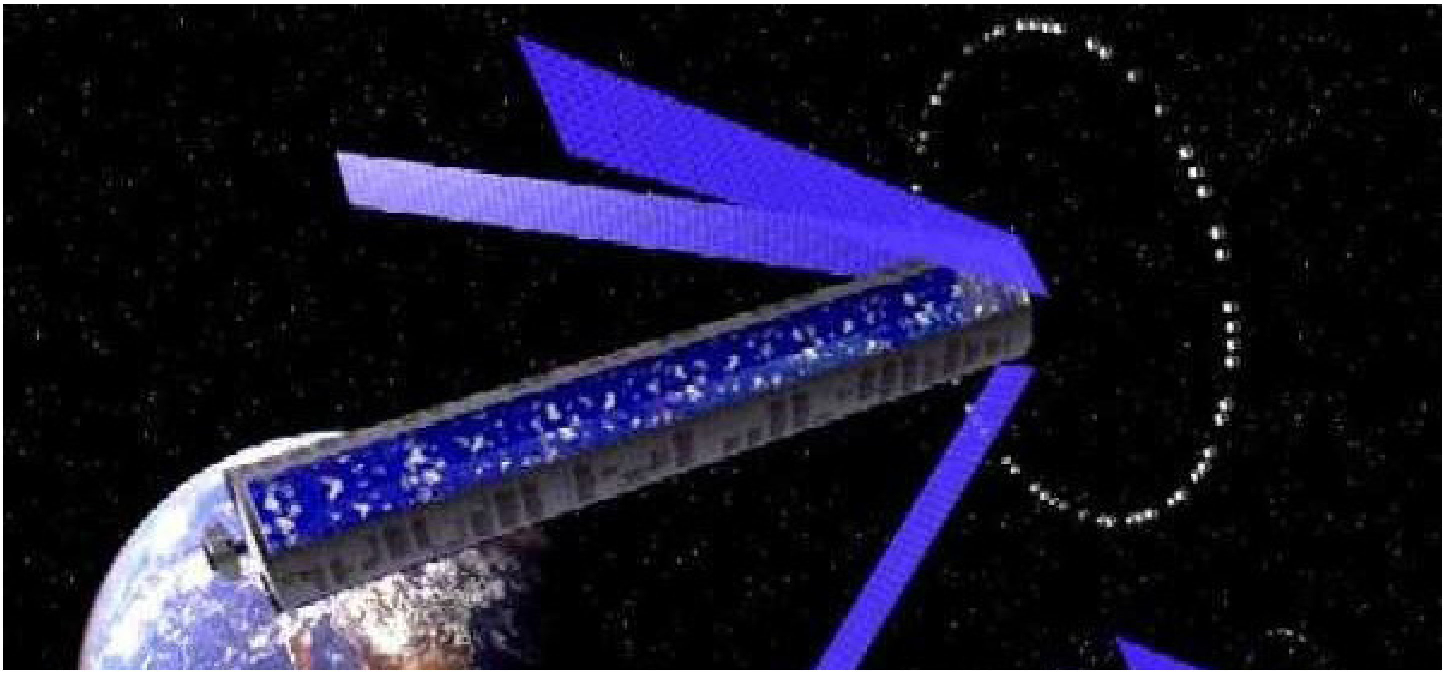


environment, engineers would fit the environment to the process.

Another system that O'Neill doesn't go into detail on is the importance of food production. He mentions that it should be incorporated but does not highlight as to why or how. Because of the cylinder has a manipulable atmosphere, allowing for higher yields to be achieved, one could assume that his colony would be constantly serviced or visited by Earth (how would someone construct that gigantic enclosure to begin with). There would have to be an import-export relationship with the mother planet. The importance of self-sustainability as an issue could be understood in the next section by looking at the brief history of the city of Singapore which due to its limited size, was highly dependent on neighboring counties such as Indonesia and Malaysia for various resources, principally water.

O'Neill also does not mention how the colony would be constructed and, more importantly, how it would be decommissioned. Since the colony itself is essentially a cylindrical

[Figure 14]O'Neil's Cylinder From Gundam Seed Destiny



capsule, it cannot be inhabited at all until the entire enclosure is built. This is similar to how we build our terrestrial buildings, which are not able to reach occupancy till completion. Also, as with buildings, there is a capital cost associated with a the construction of a space colony, and some sort of expected return on the investment. Unlike buildings however, which are completed in a span of a few years, such a massive feat of space construction would take decades to reach completion. This extended timeline is not economically or logistically feasible by the standards of today's economics. A more feasible version of any space colony should see it built and inhabited in stages, and each stage be fully functional.

Another major issue, having no decommissioning plan for the colony, is also potentially lethally hazardous. Since its enclosure is physical and mechanical in nature, it is doomed through wear and tear of parts to eventually fail, or at least become obsolete. When it does, the population will have to immediately leave the colony. Following its eventual abandonment, the colony, one assumes, would be slowly dismantled with each of its parts recycled to build a new colony. This imposes two problems: when the colony station fails, it fails a population the size of a city which is then forced to leave their home. Secondly the population would most likely not be able to settle all in the same place. They would hopefully disperse across other colonies (if built) and nations back on the Earth effectively destroying any sense of culture that would have developed during the lifespan of the colony.

One of the major ironic drawbacks of the O'Neill's Cylinder proposal is that although the vista it would provide is breathtaking and it would produce food at higher rates, the visualisations depicting the interior of the colony resembled suburban American life, the ideal life of the 1970s. The colony tried to be too similar to life on Earth and did not take into account how the physics of the enclosure could and should inform an entirely new method of living. Those 1970s images are the only real descriptions of the interior and they contained what seems to be happy valleys of endless greenery. O'Neill was not an architect or planner, he was a physics professor and throughout the book did little to concern himself with the life of the individual. Rather, he saw the population of the people who would inhabit this place as a collective to be determined. In doing so he missed out on what could potentially take this colony to the next level in terms of the visionary proposals that it created. Although the O'Neill's Cylinder design proposal was visionary in nature, O'Neill himself most likely believed that he would never live to see it built. This first attempt at designing a space colony, however still creates awareness of the issues and constraints that one must operate in before ever embarking on such a work. People tend to resist things

[Figure 15] A view of the Marina Bay Sands in Singapore

that are new and foreign, in each case a risk is always involved, but through an iterative process of designing one space colony after another, problems continue to be highlighted and the reality of living in space is constantly inched forward.

Singapore

The city state Singapore, a located in Southeast Asia bordering Malaysia, provides an interesting precedent of an economic and self-reliant mode of civic life. Singapore was born from its independence from the British in 1965[5] but had self governance since 1959.[6] Malaysia, which surrounds Singapore, in 1957, was also declared independent.[7] This is important to note because the two countries while sharing the same starting point, geographical location, ecology, natural resources, and demographics ended up in two completely different categories of wealth and stability. Singapore today ranks 9th on the United Nation's Human Development Index[8] and contains one of the highest amount of millionaires per capita[9] than any other country in the world despite having little natural resources.

5 Singapore. Towards Independence. Accessed November 9, 2015. http://app.singapore.sg/about-singapore/history/towards-independence.

6 Singapore. Towards Self Government. Accessed November 9, 2015. http://app.singapore.sg/about-singapore/history/towards-self-government.

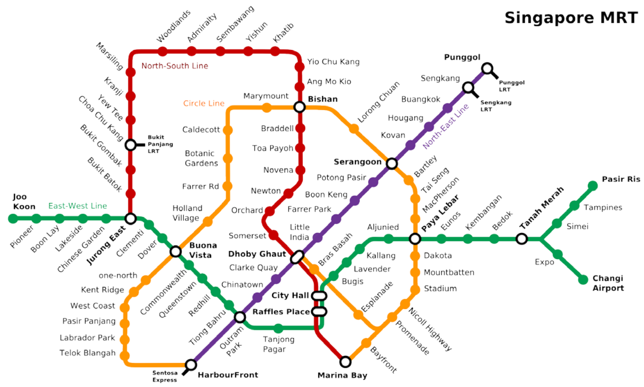
7 H.M.S.O. (1957) (enacted).

8 United Nations Development Program. Table 1: Human Development Index and Its Components. Report. 2014. Accessed November 9, 2015. http://hdr.undp.org/en/content/table-1-human-development-index-and-its-components.

9 Linton, Eric. "Millionaires Per Capita: Qatar Leads With 17.5%, Followed By Switzerland, Singapore." International Business Times. June 10, 2014. Accessed November 09, 2015. http://www.ibtimes.com/millionaires-capita-qatar-leads-175-followed-switzerland-singapore-1597644.

[Figure 16]The interior of a Singaporean MRT Train Car

[Figure 17]Subway Map of Singapore



Malaysia on the other hand, has a struggling economy and has been plagued through its history with corrupt governments. The infrastructure in Singapore is also vastly superior to that of Malaysia's capital city, Kuala Lumpur. An excess of 70% of the Singaporean population use efficient public transit[10] whereas Kuala Lumpur is in a constant state of traffic gridlock. The divorce rate in Singapore is also significantly lower than in both Malaysia and most developed countries such as Canada and the United States of America.[11] When Singapore's society and urban system are broken down however, it becomes quite simple to understand the reasons and planned social dynamics that explain the city state's success.

Starting with Singapore's low divorce rate, in order to get a government subsidized house you need to be either 35 or married,[12] and because the vast majority of the population cannot afford anything other than a subsidized house[13] people are hurried into buying a home as soon as possible. Afterwards, the people who find themselves in unhappy marriages either

10 Onn Chiu Chuen, Mohamed Rehan Karim, and Sumiani Yusoff, "Mode Choice between Private and Public Transport in Klang Valley, Malaysia," The Scientific World Journal, vol. 2014, Article ID 394587, 14 pages, 2014. doi:10.1155/2014/394587

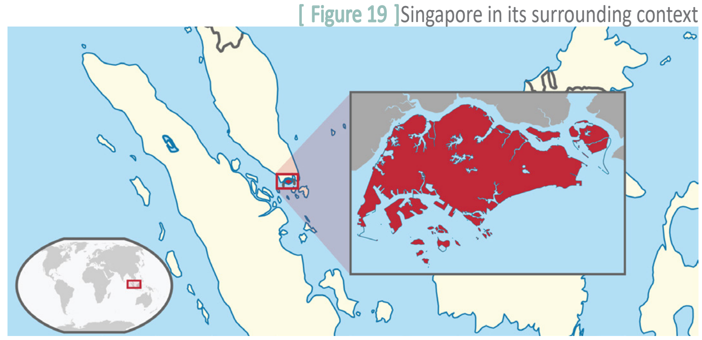
11 United Nations. Divorces and Crude Divorce Rates by Urban/rural Residence: 2007 - 2011. Accessed November 9, 2015. http://unstats.un.org/unsd/demographic/products/dyb/dyb2011/Table25.pdf.

12 Singapore. Housing Development Board. HDB Flat. Accessed November 9, 2015. http://www.hdb.gov.sg/cs/infoweb/residential/buying-a-flat/new/hdb-flat.

13 Kendall, Jon D., and Donghyun Park. "Factors Affecting Housing Prices In Singapore." In East Asian Economic Issues, 74-82. Vol. 5. Singapore: World Scientific, 1998. Accessed November 9, 2015.

[Figure 18] Singaporean MRT car on the North-East Line

[Figure 19] Singapore in its surrounding context

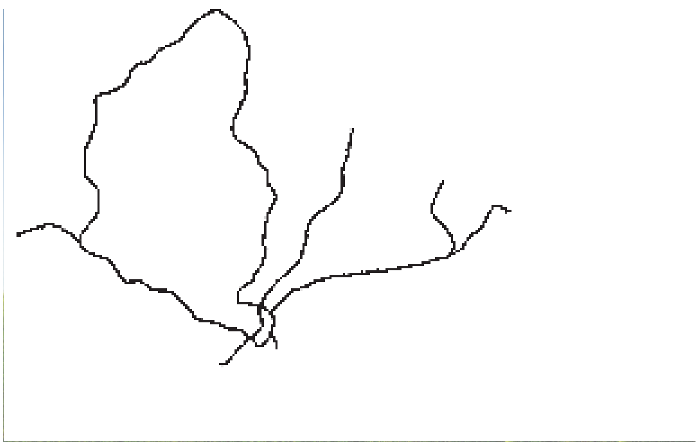


work on their marriages, or live together bitterly instead of divorcing. Divorce, however, would effectively condemn the one party to rent at a high cost till they reached the age of 35 or remarried. This is important to the economy because, similar to many first world countries with an educated population, Singapore has a fertility rate of 1.3 children to every women.[14] In a hypothetical space colony as a parallel example, work visas would initially only be offered to people who are highly skilled; people who also tend to have fewer children and a higher divorce rate. Efforts like Singapore's to increase the colony's marriage rate may be necessary.

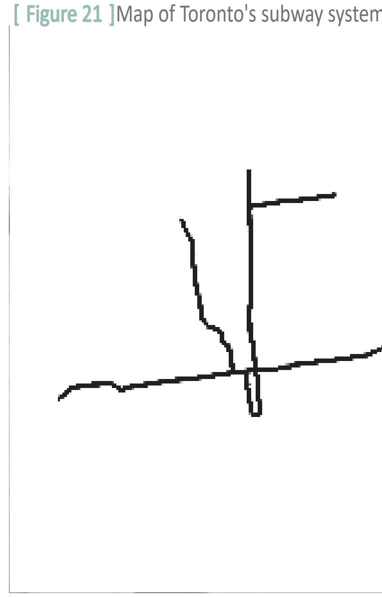
The majority of Singapore's population use public transit because in order to own a car you must purchase an ownership certificate that costs a minimum of 70,000SGD based on the model of your car. This is on top of a driver's license, which is also particularly difficult to obtain in the country. The certificate, which only lasts for 10 years before requiring a renewal (and another 70,000SGD), is used to

14 Fertility Rate, Total (births per Woman). Report. World Bank, 2015. Accessed May 22, 2016. http://data.worldbank.org/indicator/SP.DYN.TFRT.IN?

[Figure 20]Map of Singapore's subway system



[Figure 21]Map of Toronto's subway system



control vehicular congestion of the type that is particularly bad in Singapore's surrounding countries, and it is also used to help fund the public transit system itself.[15]

Economically, Singapore is a service dominated country, thriving on international banking and electronics. Ultimately its wealth, compared to Malaysia, is derived from the education quality and work culture of its citizens. This is due to Singapore's lack of a minimum wage and a competitive cultural mentality. Citizens who are willing to take on jobs that require little to no education or special skills are paid very low wages (some bringing in less than $500 a month).[16] This results in a nation wide pursuit to develop some sort of special skill, usually obtained through enrollment in a university or a polytechnic. Such an employment skill is often necessary in order to maintain a baseline living standard. Singapore thus holds higher service capabilities based on its intellectual capital in comparison to the rest of the surrounding counties.

To sustain this work ethic, the government of Singapore

15 Singapore. Land Transport Authority. CERTIFICATE OF ENTITLEMENT (COE). Accessed November 9, 2015. http://www.lta.gov.sg/content/ltaweb/en/roads-and-motoring/owning-a-vehicle/vehicle-quota-system/certificate-of-entitlement-coe.html.

16 Singapore. Ministry of Manpower. Salary. Accessed November 9, 2015. http://www.mom.gov.sg/employment-practices/salary.a

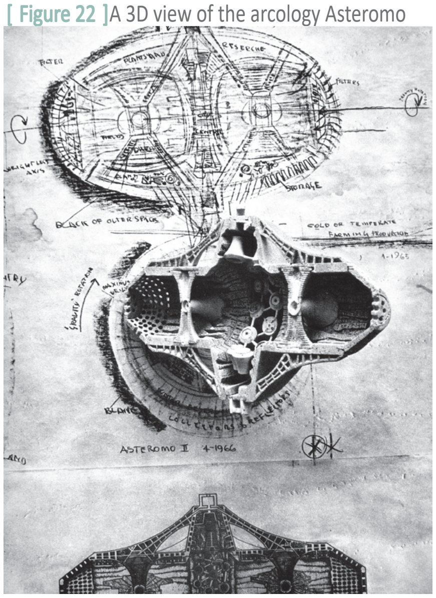
imposes an unofficial curfew to maintain the orderly and work-ready lifestyle of its citizens. All public transportation, aside from taxi's (which are government run), are heavily subsidized, with a cross country trip costing less than $2.[17] At midnight, all public transportation shutdown with the exception of taxis, whose fares are multiplied by 1.5x. Most people who are not rich cannot afford a car. As a result, a $2 cross country trip could easily turn into $50 in cab fare. Effectively the government indirectly tells its citizens; 'unless you have the money to burn, stay home and don't drink and party.' People get up early in the morning, go to work, come back home, and repeat. Although this will lead to a lower work-life balance, in a hypothetical space colony's beginnings, incentives to maintain a productive/regular work schedule would likely be used to increase the efficiency and self-discipline needed for space-based life.

Finally, Singapore, due to its limited size, was highly dependent on neighboring counties such as Indonesia and Malaysia for various natural resources absolutely necessary to maintain life; principally water. At Singapore's conception, water was used as a political tool by other countries to pressure and persuade the nation. This led to creation of massive reservoirs within the geographical center of the country. In doing so Singapore created a nearly inexhaustible reservoir of freshwater for the nation's use and made a gigantic step towards increasing it's self reliance.[18] This is a major point. A colony dependent on Earth for basic survival will not ever achieve independence, and it's wealth will be continually siphoned offering payment for the basic needs of survival.

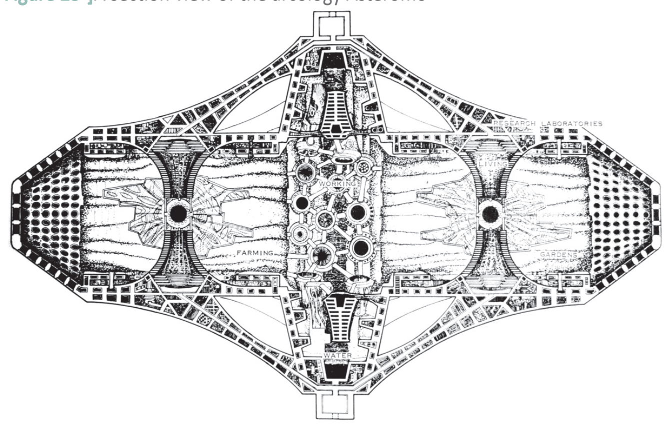
17 Singapore. Land Transport Authority. Train Fares &Travel Cards. Accessed November 9, 2015. http://www.lta.gov.sg/content/ltaweb/en/public-transport/mrt-and-lrt-trains/train-fares-and-travel-cards.html.

18 Onn, LEE Poh. Water Management Issues in Singapore. Proceedings of Water In Mainland Southeast Asia, Center for Khmer Studies, Cambodia. Singapore: International Institute for Asian Studies, 2005. 3-5. doi:http://khmerstudies.org/download-files/events/Water/Lee%20Nov%20 2005.pdf?lbisphpreq=1.

[Figure 22]A 3D view of the arcology Asteromo



[Figure 23]A section view of the arcology Asteromo

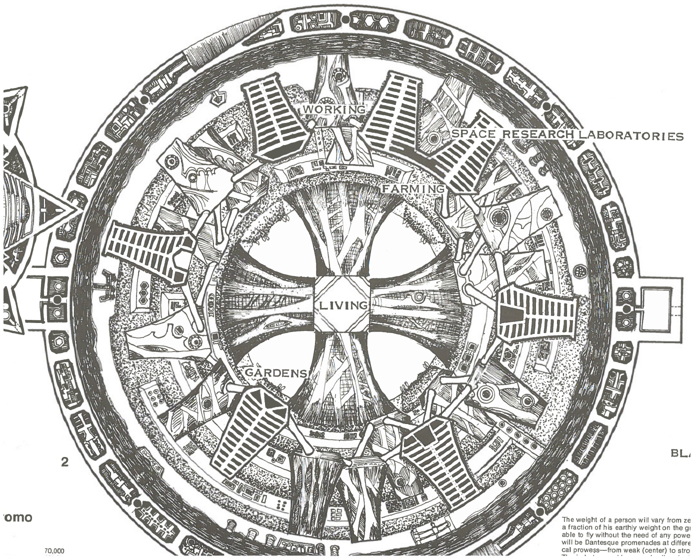


Arcology

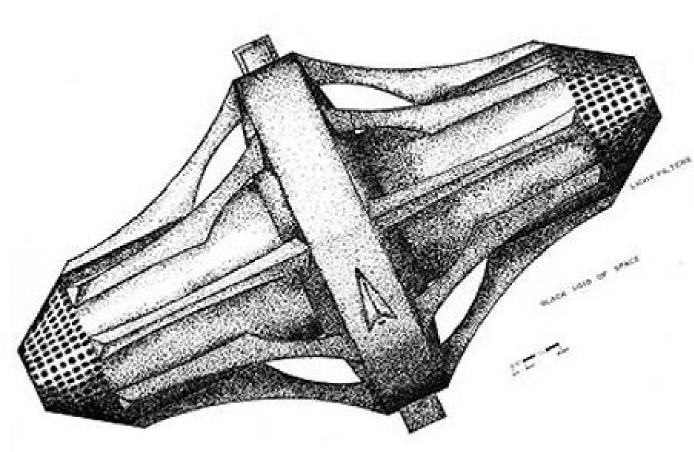
Arcology is a term coined in the 1960s by Italian Architect and professor Paolo Soleri that refers to a hyper-dense city, built in a self sustaining and ecosystemic manner, able to provide a comfortable, equitable life.[19] It's described by Soleri as the next evolutionary step for humanity. Essentially it is an alternate mode of city planning that is in direct contrast to Frank Lloyd Wright's territorially expansive Broadacre City. Soleri used the analogy of the brain to describe the concept. If one was to reconstruct all the connections of the human brain on a two dimensional surface, you would end up spreading over an area over of two square miles. However, when one takes advantage of the third dimension the result is the size of the brain that we have now, a biological and electrical miniaturization. Soleri believed that this type of miniaturization should apply to cities, essentially by trimming the spatial fat that was and still is rampant in today's cities like Los Angeles. An arcology lives only on the bare ecological and, more important, physical footprint required. The benefits of an

19 Soleri, Paolo. Arcology, the City in the Image of Man. Cambridge, MA: MIT Press, 1969.

[Figure 24]A section view of the arcology Asteromo



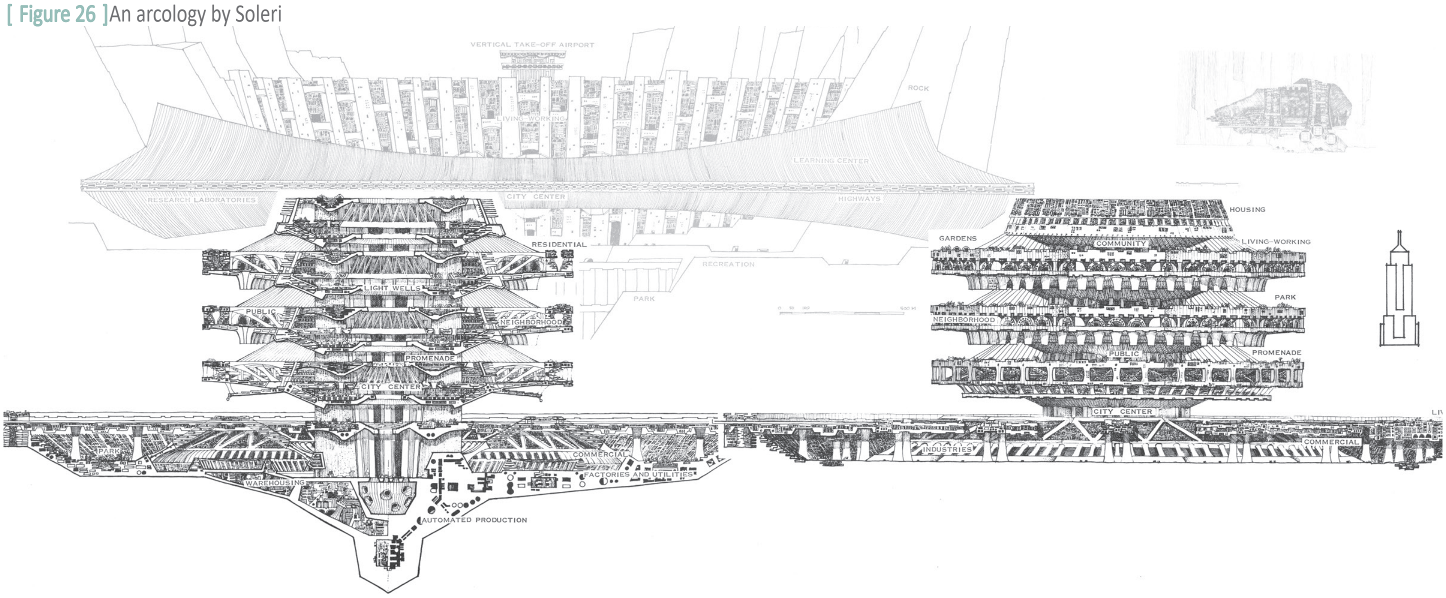
[Figure 25]A perspective view of the arcology Asteromo



arcology over a typical North American city would come from the culture that would be fostered through density, the minimal area used to set it on the planet, and the closed ecosystem it created resulting in minimal waste.

Soleri's arcology logic runs as follows: Humanity has reached its current point through evolution, a process that happens in steps whereas people become the sum of the what will better allow them to survive. We become exposed to environmental conditions that cause us harm, and the evolutionary process uses that vast information and uploads that into the next iterative human. Each iterative version of a human is a combination of the relevant experiences of the lives of its ancestors condensed into a person. The key word in that last sentence is "relevant" and we, a miniaturized version of the sum of characteristics, are transferred through generations most vital to our survival. This is miniaturization is the iterative improvement of us through accumulating humanity's past experiences, evaluating the positives and

[Figure 26]An arcology by Soleri



reinventing an alternative, one keeping purely the positives of the original. Without this process we would develope unnecessary ecological and social bulk that would stagnate humanity's evolution and growth.

Presently we have reached a point where we have become a 'super species.' As a species, we have nothing to evolve to that our current technology can't make up for in a quicker fashion. At the same time our population is increasing exponentially and with it so is our land usage. Soleri proposes that we take the reins on our evolution based on the principles of miniaturization; we evolve as a society, rather than individuals, and trim the fat that is our excessive land and resource use.

Supporting Soleri's view is the fact that he most idolized and touristically visited cities on Earth tend to be among the densest. These are cultural and festive hubs of the countries they reside in with examples ranging from Hong Kong, London, and New York. Soleri argues that density serves as a catalyst to cultural generation, and that cultural generation creates a unique and desirable city. Arcologies therefore should be dense three dimensional urban areas in order for them to be considered an improvement on modern urban planning.[20]

This future urban density also has the added benefit of lessening our footprint on the Earth and in making the most effective and efficient use of the planet's material resources. In our current habitation practices, the majority of the world's population live in low rise constructions and use a larger surface area than needed, a contrast to the potential of our new modern construction technologies. Soleri proposes bold arcologies or architectural ecologies; mega-structures that house the city's population in a manner that makes more use of the Z-axis or the vertical. Although not explicitly stated by Soleri, the benefits of this verticality are numerous. First, the human impact on the Earth's overall ecosystem is minimized; less forests are cut down and habitats are left intact. Second, due to the sheer number of people close together in an arcology, transportation will be completely public, the distances that people will have to travel will be a fraction of what they are now, and people will spend their time living life instead of behind a steering wheel of an autonomous vehicle roaming over suburban territories.

In all of the arcologies presented in Soleri's 1969 book, *The City in the Image of Man,* provisions for food production are drawn in, present within the mega structures themselves. Soleri paints a world where the majority, if not all, of the food locally sourced. This is where the root 'ecology' in arcology comes into play. Arcologies are to strive to be as self reliant as possible, with numerous advantages over our current setup. Often we think

20 Soleri, Paolo. Arcology, the City in the Image of Man. Cambridge, MA: MIT Press, 1969.

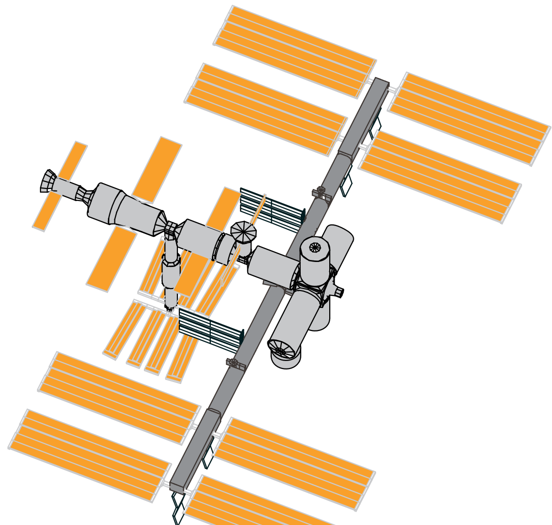
about the embodied energy in the refinement and production of materials, but what about transportation? I am currently writing this thesis in Cambridge, Ontario on an Asus Laptop that I purchased in Singapore (for the purposes of tax evasion) which has a sticker on it that says “Made in China.” This laptop also contains various parts, specifically superconductor materials, that are often sourced in Africa. Although Soleri undoubtedly doesn’t expect that every material used in a laptop would be sourced in each arcology, this extreme interdependence on other nations for our goods has increased the embodied energy of almost all our daily goods. By actively trying to keep the arcology contained through keeping materials and energies constantly recycled in as closed loops, the amount of energy used is lessened and is waste is dealt with on site. This lessens both pre-consumer waste by minimizing transportation needs, and gives the city a greater incentive to reduce, reuse and recycle post-consumer waste.

Soleri also brings to light the high sense of individuality that has developed in our society which has most likely resulted through hyper-democracy and suburban separation. This sense of socially desired individuality creates a heightened desire to establish control over one’s own personal bit of land. Along with such autonomy it can be argued that there develops an acute level of selfishness; in other words you care more for yourself and your land while paying less attention on your impact on the greater whole of society. As a whole, democratic systems promote this with your one vote serving you and you only. As individuals, we want the biggest house, more isolated land, and to accumulate more stuff before we die. This creates a greater separation from neighbours, and results in a loss of growth as a collective culture. Such a culture would potentially be disastrous on a hypothetical space colony in its unforgiving space environment and limited protected space.[21]

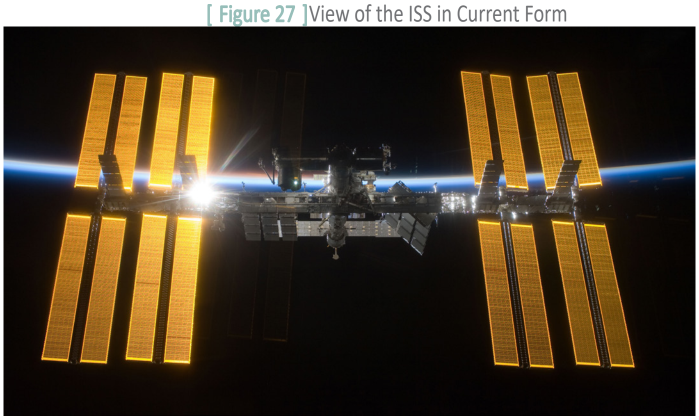
Human population density leads to culture, as the myriad

21 Soleri, Paolo. Arcology, the City in the Image of Man. Cambridge, MA: MIT Press, 1969.

[Figure 28] A Diagram of the ISS in its projected 2017 form



[Figure 27] View of the ISS in Current Form



of interactions foster exchanges of information and awareness to create a more critical and balanced society. A great space city could be on par with booming tourist cities like London, Paris, Shanghai, Tokyo, New York, and even Venice, and such a place would share the world's fascination.[22]

The International Space Station

The International Space Station (ISS), launched in 1998, was originally born out of the Space Station "Freedom" program by the *National Aeronautics and Space Administration* (NASA), a program especially promoted by the American President Ronald Reagan.[23] The United States government at the time allocated 8 billion dollars to the design, construction, and maintenance of the Freedom, all of which ended up being exhausted on the paying the salaries of the researchers and designers who failed to 'break ground' on the station.[24] This whole design process happened during the age of the Russian *Mir Space Station*, which was not only in orbit but which was faring significantly better and longer

22 ibid

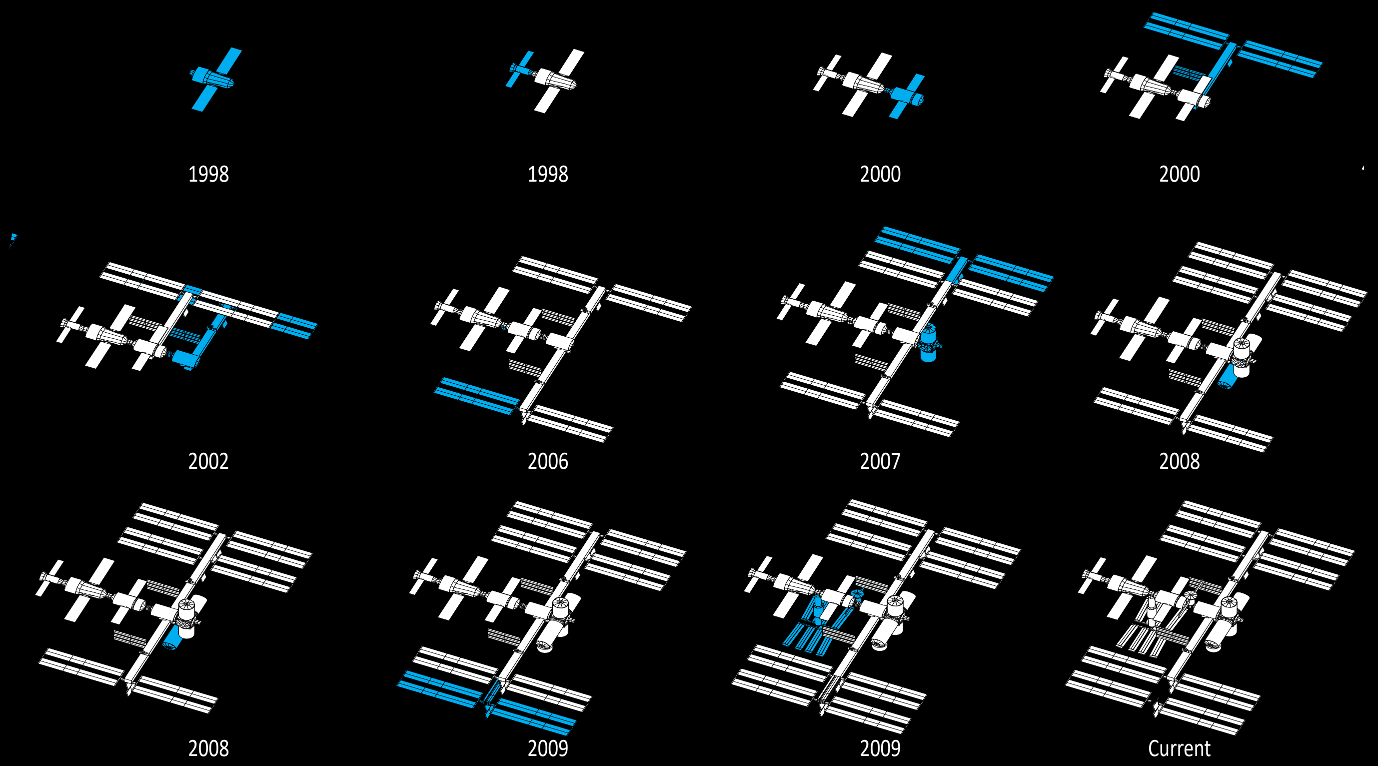
23 International Space Station Documentary. Accessed October 28, 2015. https://www.youtube.com/watch?v=TvLDfKf16pA.

24 ibid

25 ibid

26 Garcia, Mark. "International Cooperation." NASA. August 15, 2015. Accessed November 09, 2015. http://www.nasa.gov/mission_pages/station/cooperation/index.html.

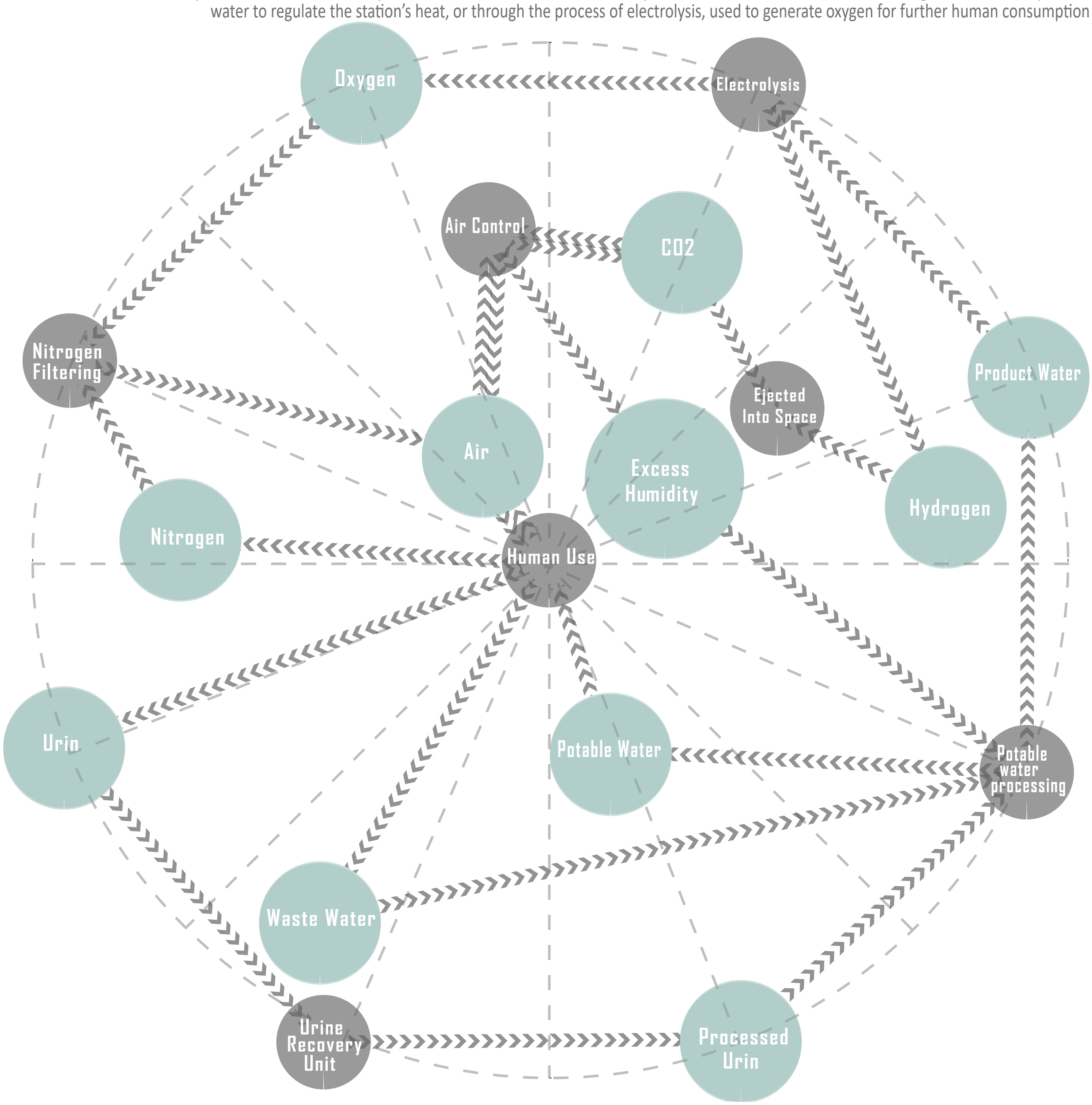
[Figure 29] Construction sequence of the ISS



than what its original design. The Mir, which by the mid 1990s had been well past its intended end-of-life, was in need of a replacement, a cost that Russia was not at all willing to fund. [25]

The United States of America in the mid 1990s was left with an unfulfilled promise to create a space station to further scientific research, but lacked the technology to do so. The Russians, on the other hand, had the technology and manufacturing skills but lacked the funds to launch another space station into orbit due to the 1990s collapse of the Soviet Union. The two counties along with

[Figure 30]The interactions between the components of the ISS Environmental Control and Life Support System, displaying the inputs and outputs of water in a closed system. On the ISS almost so everything is recycled. This chart shows the progression of how water is reused. For instance, human waste water, is processed and filtered to a potable level safe for human re-consumption. The same waste water after filtering, can be used as product water to regulate the station's heat, or through the process of electrolysis, used to generate oxygen for further human consumption



the European Union, Japan, Canada, and many other nations formed a joint venture to facilitate the construction and maintenance of a manned space station orbiting Earth.[26] The ISS along with the *Tiangong Space Station*, maintained by the *China National Space Program*, are currently the only two manned space stations in orbit. To this date the ISS is the largest built object created outside our atmosphere and continues to grow in space.

The ISS follows a modular design for easy onsite (in space) assembly. One of the more intriguing features on the ISS that pertains to the development of a full sized colony is its water reclamation system. All wastewater and excess humidity is cleaned to become potable water for consumption.[27] This is even more remarkable when considered that this is done in a zero gravity environment. The water is also separated into its two main components, oxygen, and hydrogen through electrolysis and the oxygen is fed into the air for crew consumption. The ISS also uses a vast array of solar panels for its main source of power.

The international space station provides an interesting financing model for how a space habitat can be created. Usually, world governments only come together when it comes to issues on climate change, trade, disaster relief, and war; in other words issues that affect their populations immediately. The ISS, on the other hand, provides no short term benefit to the population yet governments of the world were able to come together and continue to jointly fund and add on to it. The ISS has a symbolic importance, much in the same way that the Olympics do, as a show of a collaborative work of a world citizenry. In a world where countries are becoming more interconnected through the Internet and high speed travel, national boundaries have less of a hold on us and collaborative government projects are increasingly becoming the norm.

Brent Sherwood

Brent Sherwood is one of the main forerunners of the new industry of space architecture. He hold both a Masters of Architecture and a M.S. in Aerospace Engineering. He worked at

27 NASA. "Breathing Easy on the Space Station." NASA Science. November 13, 2000. Accessed November 09, 2015. http://science.nasa.gov/science-news/science-at-nasa/2000/ast13nov_1/.

the Boeing Company[28] for over 17 years and is a senior member of the American Institute of Aeronautics and Astronautics. Sherwood is extensively well written on the direct topic of space architecture and has published many articles on the subject. Due to his architecture background much of his focus is on the spacial qualities of the extraterrestrial enclosures, and highlighting the key shortfalls of the current manned space missions. He also brings up some of the many effects of 0 gravity on the human body such as a loss of bone density, and muscle. He also delves into some of the psychological effects of long term space habitation within our current means. The International Space Station for instance, because of its location in lower Earth orbit, orbits the Earth approximately once every 90 minutes. This inhibits the mind to be able to tell the difference between day and night and causes what is essentially the extreme opposite to polar day and night. This has resulted in loss in productivity due to days seemingly lasting forever. Sherwood also talks much about the windows in the ISS and how the astronauts never seem to tire from its view. Through this he argues for more openings to better ground the crew's psychological state despite the added cost and loss of structural integrity.[29]

Nikolai Fedorov

Nikolai Fyodorovich Fedorov (June 9, 1829 - December 28, 1903) was a Russian Christian philosopher who has been described as the father of Russian space exploration.[30] He is best known for his writings on the theoretical pursuit to reanimate the dead and control nature, what he named *The Common Task*. In the process of this quest he theorized that we would become an interplanetary

28 Sherwood, Brent. "Member's Profile – Brent Sherwood." Space Architect. Accessed November 09, 2015. http://spacearchitect.org/our-members/members-directory/members-profile-brent-sherwood/.

29 Howe, A. Scott., and Brent Sherwood. Out of This World: The New Field of Space Architecture. Reston, VA: American Institute of Aeronautics and Astronautics, 2009.

30 Knocking on Heaven's Door: Space Race. Directed by BBC. BBC. Accessed July 22, 2016. https://youtu.be/iO5MFXG-CSY.

species and through human augmentation, would evolve into immortal beings. Fedorov was a polymath and frequently held informal discussions with prominent intellectuals from a variety of fields. He had particular influence on Konstantin Tsiolkovsky, a Russian physicist discussed in the next section.[31]

Fedorov views the act of resurrection as the way to become one with God, as Jesus Christ did, and the method to reach a state of human evolution that will grant us heaven on Earth. *The Common Task* was to work against disintegration, believing that death was a symptom of our evil and ignorance. To unite the world in a common struggle to transcend death regardless of their race, sex or wealth is to pursue his philosophy. He believed that we need to include the dead in our immortality; to exclude them is selfish as they initially gave us life and their revival would provide everyone with kinship and family. Interestingly, despite being a devout Christian, he views this task as an objective that people must complete for ourselves, without the intervention of any form of God. Fedorov was convinced that one day reanimation and immortality could be achieved purely through scientific means. He then proposed that the oceans and outer space could be colonized to house this reanimated population.[32]

The body obtained when resurrected cannot allow for future death: a biological immortality must be achieved. Our current bodies do not allow for this and therefore the anatomy that the revived will inhabit will differ from a natural human body. Fedorov advocated for human augmentation and the elevation of the

31 Young, George M. Nikolai F. Fedorov, an Introduction. Belmont, MA: Nordland Pub., 1979.

32 Young, George M. Nikolai F. Fedorov, an Introduction. Belmont, MA: Nordland Pub., 1979.

species through future scientific breakthroughs. Resurrection and immortality were just the beginning. To him, all human physical limitations could eventually be solved through human innovation. If a person wishes to fly, have perfect eyesight, or regenerate limbs, we should work towards achieving that. He saw this as a oneness between body and soul, by matching what our soul yearns for and providing it to our physical form.[33]

Fedorov's task involves accumulating all of the original material that comprised a person at their death and reconstructing it to start the resurrection process. However, all organic compounds on the Earth exist within a nexus of constant reuse. Matter that once formed parts of a deceased person's flesh may decompose to form the nutrients for edible vegetation that another person consumes. In our current cycle we are consuming our dead ancestors. This will make it increasingly difficult to bring the deceased back to life because matter that was once comprised in their body will be consumed and have formed a part of another person's body. For this reason he insisted that our new biologically immortal bodies must include an internal ecosystem that no longer requires us to eat.[34]

In the west Fedorov is seldomly mentioned, yet his work had such a large rippling effect with influences that can be seen everywhere. Christopher Nolan's film, *Interstellar* (2014), is a great example of this. In the movie humans have transcended past our three physical dimensions, space is colonized, and a gravitational theory for propulsion that would allow a mass exodus from Earth is developed.[35] Fedorov's teachings were the first spark for what would

33 Young, George M. Nikolai F. Fedorov, an Introduction. Belmont, MA: Nordland Pub., 1979.

34 Young, George M. Nikolai F. Fedorov, an Introduction. Belmont, MA: Nordland Pub., 1979.

35 Interstellar. Directed by Christopher Nolan. Roma: Warner Home Video, 2014. Film.

later become the great flame of space exploration, a feat that would not be accomplished for 60 years after his death.

The Science Fiction of Konstantin Tsiolkovsky.

The inhabitation of space by humanity is the main theme of the science fiction books authored by Konstantin Tsiolkovsky (1857 - 1935), a Soviet writer and rocket scientist. The first book, *On the Moon*, starts off with the author and his physicist friend as they mysteriously find themselves on the Moon. By reading through the book, it becomes quickly apparent that the purpose of the story is to describe how we would adapt to the Moon's lack of atmosphere, longer day length, and lower gravity. Although convenient exceptions and exaggerations are made to the laws of physics and biology (by declaring the whole adventure as a dream) the book illustrates well what living on the Moon would be like. Of specific importance is how the lack of an atmosphere containing a mass of gas, which simultaneously retain heat and insulates from light spectrums that transfer heat, can cause harm to humans. Although we don't see it on Earth, the mass of our sea of air is what retards and smoothes the rapid changes in temperature, thus allowing us not cook during the day and freeze at night.[36]

In his second book, *Dreams of Earth and Sky*, Tsiolkovsky envisions an Earth where gravity, all of a sudden, ceases to exist. Much like the first book, the telling of the story revolves around how the setting changes as a result of the gravitational shift. It is clear that friction is our ball and gravity is our chain and without them, everything can and will move constantly. When you place a cup down a table, in a setting with no gravity for instance, the

36 T͡Siolkovskiĭ, Konstantin. "On the Moon." In The Science Fiction of Konstantin Tsiolkovsky, 10-52. Seattle: University Press of the Pacific, 1979.

transfer of forces will result in mayhem. You will end up slowly accelerating into the air in the opposite direction equal to the amount of force you applied the cup onto the table. The cup will transfer the force to the table, then to the floor, and floor (assuming the floor is bolted down) will exert a chain of forces applied in the opposite direction. This results in the table and the cup accelerating to a constant speed till they transfer their forces of inertia to another mass. Another important point made by Tsiolkovsky is how lower strength forces begin to dominate in a zero gravity setting. Capillary action, for instance, is a weak force of attraction of a liquid to a surface and a physical property of water. If gravity were 'turned off,' for long enough, an equally thick layer of water will crawl across the entire globe and envelope even the largest of mountains.

The second section of the book, is set on a series of mid sized asteroids, large enough to exert a gravitational force to keep a person grounded, but small enough that strong jump would allow a person to escape it. What is of interest to this thesis in this section is the creature the author communicates with. Here, Tsiolkovsky designs an alien. After communicating with the alien, it is determined that the alien generates solar energy in the same way as plants do. This alien produces no waste and its cells continuously regenerate without sequential degradation. This alien is immortal; it has an internalized ecosystem that provides all its needs without having to interact with other forms of life. This alien's body functions in the same way as that the combination of all the organisms on the Earth symbiotically support one another to further each species as a whole. So, much in the same way that every species can continue into eternity in a perfectly functioning ecosystem, so can this alien, and so could a space colony.[37]

In the second section of the second book, the alien describes to Tsiolkovsky how the infrastructure of its species is able to support transportation and generate energy. Although not specifically stated, what is emphasized here is how velocity is relative to a point of reference. These creatures have created a set of trains that circle an asteroid, where each train runs on top of the other, going incrementally faster as they go up. From the perspective of the rider, as he ascends these trains the relative velocity from one to another is small. However, while ascending through enough trains, the velocity relative to the ground quickly adds up. Eventually a point is reached where the centrifugal acceleration becomes equal to the gravitational acceleration and the rider may simply jump off the asteroid.

The third main point of interest in this book is the use of passive solar methods to generate energy. In the book, he describes a cylinder that is white on half the curved side and black on the other. This cylinder contains a gas and is spun along its axis such that it is perpendicular to the sun and alternating black white sides are revealed by the sun's surface. This in turn would heat of the gas inside when the black side is being faced and have a net loss in heat when the white side is shown. This would cause the gas to move about in the cylinder and if a turbine is placed inside, it could cultivate this kinetic energy.

On Vespa, Tsiolkovsky's fourth book, he assembles his fantasy team of physicists and plots them on a deserted island to build a space rocket. While reading through, you can't help but wonder if this book informed the roadmap to all space stations, and modern rockets or if Tsiolkovsky was able to strike the perfect level of efficacy

37 T͡Siolkovskiĭ, Konstantin. "Dreams of Earth and Sky." In The Science Fiction of Konstantin Tsiolkovsky, 52-155. Seattle: University Press of the Pacific, 1979.

with his description. This book follows the rest in the series where the characters theorize and conduct experiments. Here his team set out and design a rocket that contains strikingly similar design ideas to what would eventually become our first space rockets, despite the various gaps in the technology. Systems such as autopilot and rocket fuel are discussed in great detail; they even end up launching the rocket into an orbit only a few kilometers off from where the ISS currently stands today. In the process of getting to space, they mention creative ways to avoid the bodily harm caused by the intense acceleration, such as submerging one's self into a liquid with a density equivalent to the human body. Once inside, he talks about the various effects of weightlessness and the experiences of the other passengers. Most importantly however is that he mentions bringing plants to create a mini ecosystem within the space rocket. Due to this ecosystem, they are able to sustain their life (seemingly indefinitely) on the rocket and live up in space for an extended period of time while they venture to the Moon. While on the Moon, the crew faces similar hardships that are described in the first book, namely the extreme freezing and the long days.[38]

Today, the bulk of this information is well known, it's difficult to reach the age of 15 without watching at least one television documentary on space or the Moon. But some of these earlier books were written in the late 1800s; the first human spaceflight to the Moon was in 1969, the first satellite put into orbit was in 1957. Tsiolkovsky's work is based purely laws of physics and telescope images of space, taken with 19th century knowledge and equipment. Despite the fact that most of his assertions would not be proven till at least 65 years later, much of what he had written in his books, to at least some degree, was proven.

38 T͡Siolkovskiĭ, Konstantin. "On Vespa." In The Science Fiction of Konstantin Tsiolkovsky, 161-333. Seattle: University Press of the Pacific, 1979.

2020 — 7 758 157 — 100.84

2030 — 8 500 766 — 102.87 — Significant Investments Into Renewable Energy forms

2040 — 9 157 234 — 105.73

2050 — 9 725 148 — 109.97 — Peak Oil

2060 — 10 184 290 — 113.57 — Most of the developed world switches over to Tidal and Solar for >50% of its power

2070 — 10 547 989 — 117.17 — Maximum efficacy's reached with Solar, Wind, and Tidal energy generators

2080 — 10 836 635 — 120.77 — World nations start putting sanctions on counties still burning fossil fuels

2090 — 11 055 270 — 124.37 — CO2 Atmospheric conditions reduce to pre-industrial revolution days

2100 — 11 213 317 — 127.98
- 97% The whole world switches to renewable resources
- Any fuel source that produces greenhouse gasses or radiative waste is seen as archa

2110 — 11 466 958 — 131.58

2120 — 11 688 420 — 135.18

2130 — 11 909 882 — 138.78
- Maximum Food production matches average food consumption
- Price of meat skyrockets

2140 — 12 131 344 — 142.39 — 95% of arable land is used for either Housing, Energy production and food production

2150 — 12 352 806 — 145.99
- World Governments Institute birth control measures
- Energy demands still increase
- World governments decide that they can't sacrifice habitation and farming land for energy and look to fossil fuels that produce no waste.
- world governments start traveling to the moon to mine HE3

2160 — 12 574 268 — 149.59
- Food shortages plague the world
- A comet is captured and put into MELPI
- A space elevator is created on the moon and earth

2170 — 12 795 730 — 153.19
- Energy extracted from the moon starts to offset the land required for energy production
- More farming land is freed up and food becomes less scarce.
- Meat is still a rarity
- A small crew of 50 people are stationed on the moon and the comet

2180 — 13 017 192 — 156.79
- There are now 5000 people at any given time in space for the mining operation
- Mining becomes a very profitable business
- There emerges the moon mining economy
- There is a need for proper 1st world living standards
- Food begins to be produced on the moon

2190 — 13 238 654 — 160.40
- 20000 people are now stationed on the moon
- 5000 other people are employed in the service industry
- A new comet is captured and is tethered to the old one. The old one becomes purely for habitation
- A new city planning emerges, living on the comet becomes on par with living in a small dense city downtown
- a large population of newborns are born with a MELPI nationality

2200 — 13 460 116 — 164.00
- 50000 people make up the total population
- 95% of food is produced in the colony
- Changes on the surface of the moon become noticeable from

2250 — 14 567 427 — 182.01
- The colony reaches a population of 1 million
- The earth has launched 60 solar panels into GEO servicing 30% of its electricity
- The comets economy becomes increasingly service driven
- The comet's colony evolves into mining asteroids
- The first town on mars is established
- The pursuit to terraform mars commences.

> Case: It's not possible.
>
> Cooper: No, it's necessary.
>
> -Interstellar

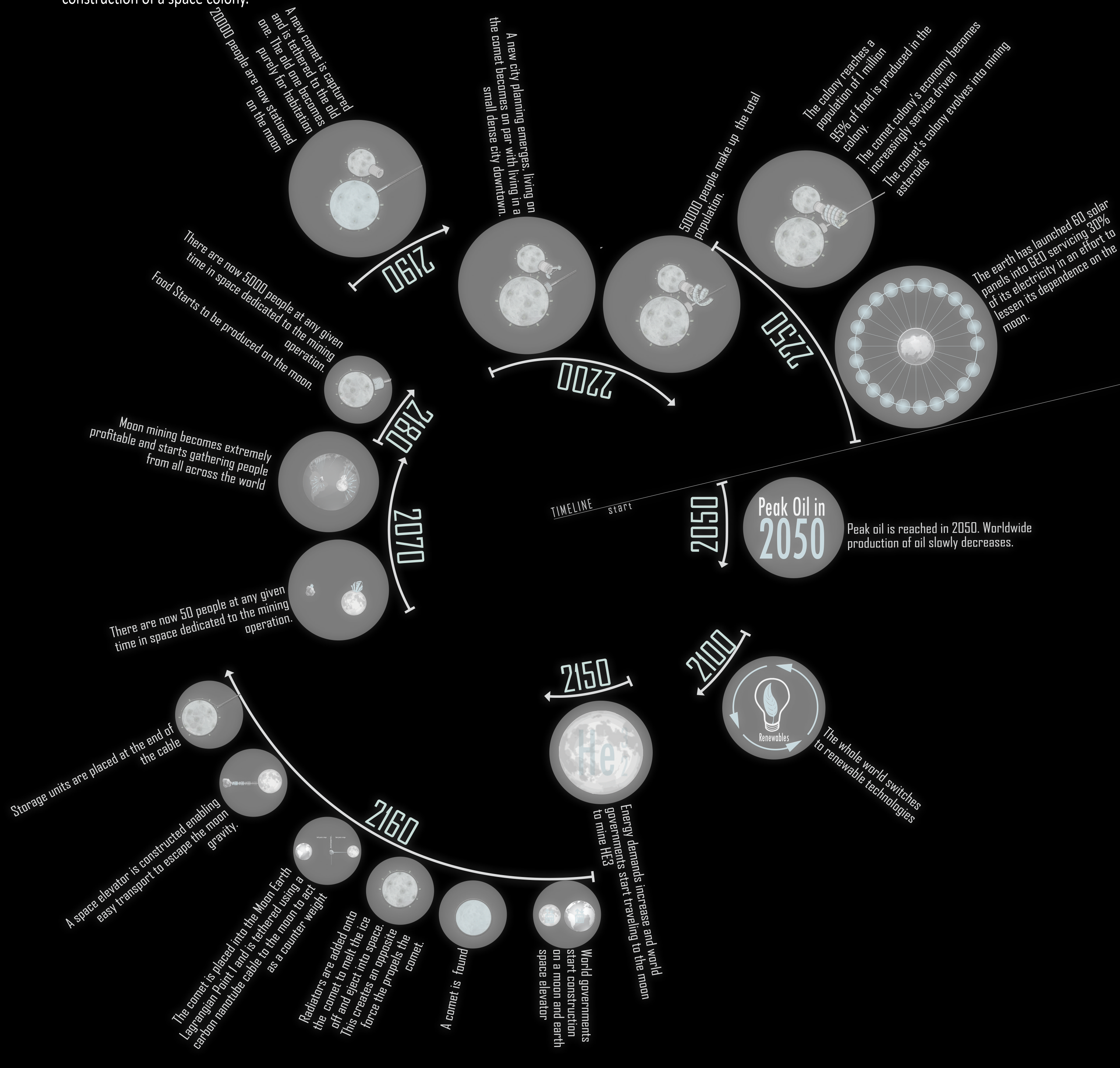
THE DESTINY PLAN

TIMELINE

Perhaps the biggest difficulty in the development of this thesis was trying to convince people that a colony in space will be necessary for humanity. Although most people become curious upon hearing of an architecture thesis on the topic of space colonization, they do so only through the lens of science-fiction. In order to drop the 'fiction' from the 'science,' this chapter has been prepared around the task of bringing credibility to this thesis by contextualizing it within our immediate reality. It focuses on two the previously mentioned "axioms," timeline of events and technology. As the events outlined here progress, however, they become increasingly circumstantial and more likely to occur in unexpected ways.

To begin, this chapter sequences hypothetical events following our global society's next major projected energy revolution into a narrative that will predict the beginning of human space colonization. The motives for this are in line with Fedorov's view of evolving the species of humanity to its next frontier and are established on real world issues that cannot be solved, in their entirety, on the Earth. These issues are largely based on energy demand, population growth, and the societal view of the environment. This sequence of hypothetical events shall begin in the present and transverse three major energy revolutions ultimately resulting in a space colony that is built to mine the Moon for energy, as well as a ring of solar panels in geosynchronous orbit around the Earth.

It is important to highlight that although this is the narrative chosen, there are numerous possible paths that can result in the colonization of space, however, a constant throughout them is the need to extract resources.



[Figure 31]Graphic time line of events leading up to the construction of a space colony.

The First Energy Revolution

We are in the wake of a major energy revolution. With our current energy demands, we are predicted to hit peak oil in the year 2020, [1] but we are not foolhardy enough to depend on fossil fuels until they completely run out. We will, in time, switch over to renewable forms of energy generation to supply the rest of our power demands. By making this move we will both secure our future energy needs while lowering our environmental pollution. Such an accomplishment will be major for humanity. We are about to reach a point of limitless renewable energy to meet all our energy demands.

The Second Energy Revolution

An important concept, not even noticed by its users, is that fossil fuels are a compact, efficient form of energy.[2] Comparatively, renewable sources such as solar and wind power require a much larger area of land to output same energy yield. Even now, increasing population growth and the spread of urban development is leaving usable land as an increasingly scarce resource. The area of available land is also a prevalent factor determining the maximum potential population of people that the Earth can support. A new problem, born from of our new land area demands after the switch to renewables, will cause us to rethink the extensive use of renewable energy. Because of the lower energy density of renewables, with replacement of fossil fuels land use will grow at a rate that we had never experienced before with the use of fossil fuels.

When demand on the amount of usable land available for all purposes lowers to a critical point, we will have to compromise on either our habitation land, our food production land, our land for the facilitation of vital natural ecosystems, or our energy production land. Otherwise, we will risk the decline of humanity. For survival, humans need shelter and food, while the destruction of vital ecosystems have a broad based rippling effect resulting in unpredictable outcomes. This leaves the last remaining sector, land for renewable energy production, to be sacrificed.[3]

Consumption of land for renewable energy farms is currently not an immediate threat to the land balance. This problem will not come for many decades after the complete switch to renewables. Therein lies a different problem, however. Decades into the future

1 The amount of energy generated from the use of fossil fuels is very great in comparison to renewable technology. For instance solar panels harvest energy at a rate of 1% efficiency from the sun and thus required a lot of land to operate efficiently. Also, solar is the most desirable form of renewable energy because there are no motorized parts, making it less likely to degrade. Wind turbines, on the other hand, need to be constantly monitored, and are only usable during times of high wind.

2 This is also taking into consideration the fact that by this point, because of the first energy crisis revolution, we will have poured years of research and funds into the creation of renewable technology and have reached their maximum efficiency.

3 Helium-3 is a non radioactive isotope of helium that is missing a neutron. Helium-3's atomic structure is composed of 2 protons and 1 neutron, whereas the vast majority of helium contains 2 protons and 2 neutrons. Both exhibit identical physical and chemicals properties.

we will see the harm and destruction that will have come through humanity's environmental abuse. Future national leaders will be the yet-to-be-born children of generations to come, people grown up bearing the price of today's mistakes. Even though we will still have some polluting fuel reserves, in this future the use of fossil fuels will be seen as an attribute of the developing world, and a remnant of the past. Nations in this time period will impose economic sanctions on countries still making use of any kind of energy that is toxic to the global environment. This would make re-engaging with fossil fuels political suicide for any nation.

The nations of the world will be faced with a near impossible task; find a dense source of energy that does not overuse or abuse the environment during extraction, use, or refinement, or risk societal extinction.

Helium-3: Back to Fossil Fuels

Eventually, governments of the Earth will look to the Moon, which throughout its lifespan, has been radiated with a light helium isotope, helium-3, across its surface from solar winds from the Sun.[4] The top layers of the Moon's soil contain a small percentage of helium-3, but the isotope is present in all of the celestial body's soil.[5] Helium-3 is of strong interest as an energy resource because it can be used as a reactive element, one where two helium-3 atoms undergo a nuclear fusion reaction in order to produce one typical helium atom and energy in the form of two hydrogen protons.[6] The benefit of this nuclear reaction is twofold: no radioactive waste is produced and the output is the inert, non reactive gas helium, and a charged atom. Because the yield is an electrical charge, rather

4 There is also helium-3 present in the Earth's crust, and in some places, in even higher concentrations than the Moon, but the overall quantity is far less.

5 32He + 32He →42He+ 211p energy yield of the reaction is 12.86 MeV

6 Energy conversion for heat maxes out at 40% typically while using a positively charged proton to electricity and a magnetic field you could convert it to electrical energy at 80% efficiency.

than heat, the energy produced can be converted more efficiently into electrical energy. Comparatively, conventional nuclear reactions produce heat energy, which is transferred to water and used to spin a turbine, which is then converted into electrical energy. By reducing the steps required to harness the energy the overall yield is greater.[7]

The idea of mining on the Moon for helium-3 has been a topic of interest for many years. The China National Space Administration has already stated on many occasions that one of the objectives of the Chinese Large Modular Space Station is to research the feasibility of lunar helium-3 mining.[8]

Infrastructure: The Elevator Cable

In order to extract resources and escape the Moon's gravity, a space elevator needs to be built both on the Moon and on the Earth. This infrastructure is the best way to escape Newton's Third Law: for every action there needs to be an equal and opposite reaction. Relying on jet or rocket fuel to propel space bound material against an the Earth's gravity is both expensive and wasteful. Many such launches are also environmentally toxic for a greenhouse gas filled atmosphere of the future. Using a space elevator would enable us to climb out of a planet's gravitational pull like using a ladder to rise out of a well. This will allow for the initial materials that will form the colony to be extracted off the Earth before the colony can switch to extracting materials principally from space.

A space elevator is a cable system that a cable car can climb up in order to escape a planetary body's gravity and deliver payloads to a place of lesser or zero gravity. The space elevator system is comprised of three main parts: the cable, the cable car, and a counterweight.

7 Opgenoorth, Hermann, and Detlef Koschny. "Chang'e-1 - New Mission to Moon Lifts off." European Space Agency. October 24, 2007. Accessed May 22, 2016. http://www.esa.int/Our_Activities/Space_Science/Chang_e-1_-_new_mission_to_Moon_lifts_off.

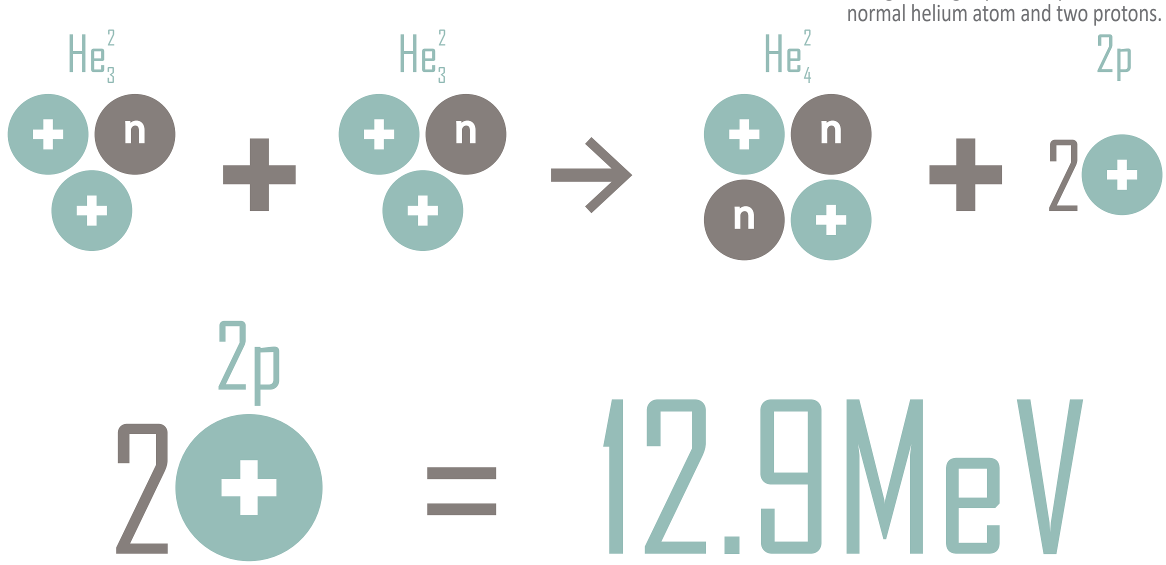
8 Edwards, Bradley C. The Space Elevator. MS, NASA. Accessed June 27, 2016. http://www.niac.usra.edu/files/studies/final_report/472Edwards.pdf.

The cable connects a planetary body such as the Earth or the Moon, to a counterweight. The counterweight, which can be a tethered celestial mass, is placed in space where it can maintain a geostationary position; as the host planet spins, so does the cable and counterweight in a vertical sync. The cable then acts as a steady ladder that the cable car can transverse while carrying a payload. As the cable car gets further away from the planetary body, and closer to the counterweight, the force of gravity that is exerted on the cable car decreases. Eventually, another force applied in the opposing direction of gravity, such as centrifugal force of the Earth's spin or the force of gravity of another celestial body, likely the anchoring body, will negate the host's gravitational force and the object will be in a point of equilibrium. Once the cable car, holding the payload, is far enough away from the planetary body for the sum of all forces acting on it to be close to zero, a space shuttle will then take the payload held by the cable car. The shuttle will then transport the payload elsewhere in space without having to use fuel to escape the planet's gravity. In this scenario, the shuttle also does not have to traverse and speed through the Earth's atmosphere, negating any air friction damage that would occur and allowing for a longer lifespan of the shuttle rocket.[9] Further, the rotational motion and energy of the attached shuttle will become its velocity on release.

The elevator cable itself is expected to be fabricated from a future development of carbon nanotubes. As of the present day, we are not able to produce this material at any usable length. In the future, however we should have perfected the technology. The advantage of using this substance is that it is the tensile equivalent of diamond. Carbon nanotubes are long strings of carbon, like graphite

9 "Nanocomp Technologies | Nanotechnology." Nanocomp Technologies | Nanotechnology. Accessed May 22, 2016. http://www.nanocomptech.com/what-are-carbon-nanotubes.

[Figure 32] The nuclear fusion reaction that produces energy from two helium-3 atoms. In this reaction the two atoms collide at a high enough speed to produce one normal helium atom and two protons.



and diamond, arranged differently. Unlike graphite, which has all of its carbon atoms laid out in a sheet, or diamond, which has all of its carbon atoms laid out in a lattice, carbon nanotubes have its carbon atoms laid out in a cylindrical tube. A cable made from multiple complications of this material will strike a desirable balance between strength and weight .[10]

10 The only type of heat transfer available in space is radiation. Convection and conduction both require a physical contact. After the ice heats up it will expand and eject away from the comet, propelling it in the opposite direction.

Infrastructure: The Counter Weight

The other component of a space elevator system is a counter weight. The counter weight object added at the end of the cable would not be an asteroid but a comet. The need for such a comet is twofold: a comet will hold some minerals useful for manufacturing the colony itself and it is comprised of ice which can be used as water for heat management and human survival. Ice is also important in its use as a propellant. The comet can be propelled using ice by delivering thermal energy to the ice through exposing the ice to controlled radiation, converting it into water vapour, and then ejecting that gas into space. This process makes use of Newton's Third Law and will propel the comet in the opposite direction of the water vapour.[11] In order to manipulate the direction of the comet, small radioactive radiators would be arrayed all throughout its surface, and then have their intensity manipulated individually by a controlled system to heat the ice, and eject water vapour into space. This allows the builders to drive the comet which will then be relocated to Lagrangian Point l between the Moon and the Earth[12] and tethered to the Moon's carbon nanotube cable.[13]

Infrastructure: Terrestrial Elevator

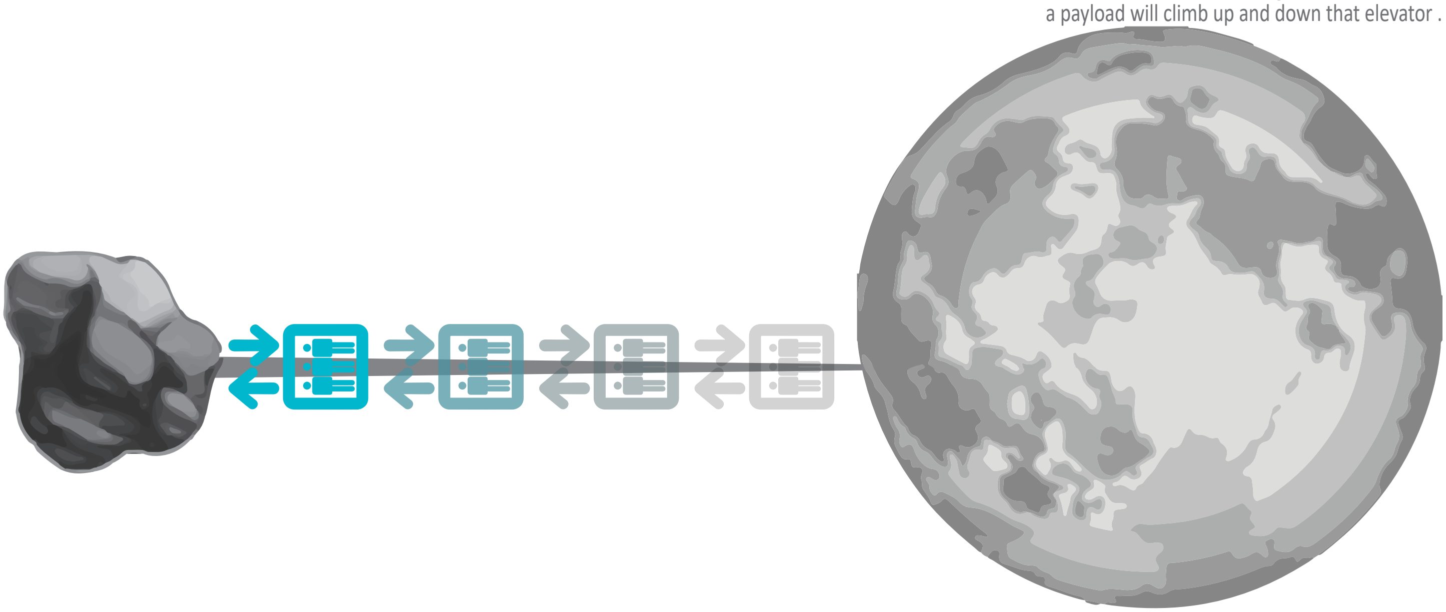
The difference between the lunar elevators and the terrestrial elevators are is their relative location. The lunar elevators are at Lagrangian Point 1 in between the Earth and the Moon while terrestrial elevators will need to be in geosynchronous orbit around the Earth. This difference in location occurs because the Moon is orbitally locked, meaning that the same side of the Moon always faces the Earth. This enables us to place a lunar elevator at the Lagrangian Point 1 along the most direct access between the Earth and the Moon. Lagrangian Point 1 is also the only suitable location for a lunar elevator to exist. The Earth, on the other hand, would require a terrestrial elevator in an equatorial location, and using rotational mechanics in order to keep itself stationary. Instead of using another planetary body to negate the gravity from the host's planetary body, engineers will by place the elevator in equatorial geosynchronous orbit, a stationary point above the Earth's surface where the generated centrifugal force of the orbiting platform's orbital velocity is balanced by Earth's gravity. An equatorial geosynchronous orbit is the orbit where a mass would take 24

11 The Lagrangian Point 1 is the point in which the force of gravity of the Moon and the Earth are exactly equal. If you are on one side of the point you drift towards the Moon if you are on the other side of the point you drift towards the Earth.

12 Edwards, Bradley C. The Space Elevator. MS, NASA. Accessed June 27, 2016. http://www.niac.usra.edu/files/studies/final_report/472Edwards.pdf.

13 Edwards, Bradley C. The Space Elevator. MS, NASA. Accessed June 27, 2016. http://www.niac.usra.edu/files/studies/final_report/472Edwards.pdf.

[Figure 33]How the lunar elevator will connect to the Moon. A comet will be tethered to the Moon using a tensile cable and a payload will climb up and down that elevator .



hours to complete a single revolution around the Earth staying stationary over one location. The orbiting platform and elevator would turn in sync with the Earth and be tethered to the ground at some consistent point along the equator. Because the Earth is constantly spinning, having only one space elevator would ultimately be insufficient, limiting the launch/receiving window to one short time of the day in only one location. In order to receive as much extracted helium-3 as possible, the Earth would have to install many equatorial elevators so that material could received at any time.[14]

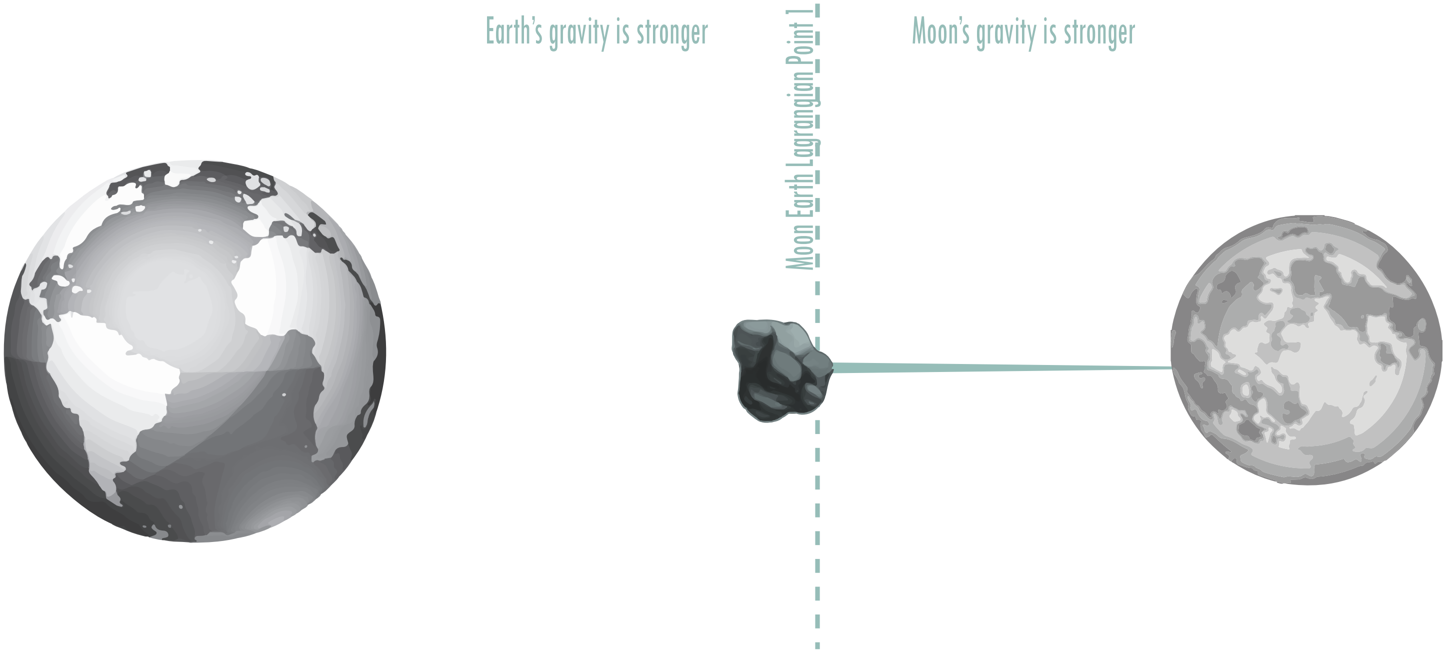
Living Conditions

Permanent onsite space habitation is crucial for effective mining because it takes three days in order to reach the Moon.[15] A bigger problem is that people are unable to live full-time on the Moon because of its lower gravity, which is one sixth of the gravity on the Earth. Long term reduced gravity exposure has

14 Sharp, Tim. "How Far Is the Moon?" Space.com. June 21, 2013. Accessed May 22, 2016. http://www.space.com/18145-how-far-is-the-moon.html.

15 This results in loss of bone density and muscle density and cannot be maintained long term.

[Figure 34]This is a diagram illustrating where the end of the elevator will be placed. Right at the Lagrangian Point 1 the equilibrium of the Moon and the Earth's gravity will be reached along the most direct axis between the two bodies



negative health effects on the body.[16] In order to combat this, there needs to be a habitat in another location near the Moon one with Earth-normal gravity of its equivalent. In such a man-made habitat, gravity can be controlled in order to give miners a place to stay on par with the Earth. The only way to do this is to have a habitat off the Moon where it is tethered to a comet counterweight by the elevator and where gravity can be provided for through centrifugal forces caused by the motion of the station's spin as in an O'Neill Cylinder.[17]

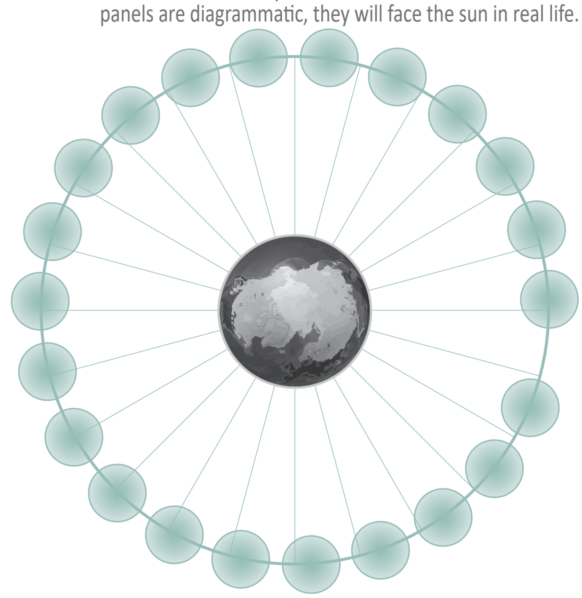
Initially, the colonies will just have to make do with what is immediately at hand and habitation qualities will undoubtedly suffer. This is similar to what astronauts have described while living on the first few generations of space stations.[18] The International Space Station has a complex habitation problem due to the exposure of space radiation, microgravity, and confined spaces, all of which prohibit users from staying for a longer period of time than a few months. This discomfort is often tolerated, due to the thrill and advantage of being one of the few humans

16 Centrifugal motion can create a force that can mimic gravity by housing people on the inside of an enclosure and spinning it along its axis, similar to a yo-yo or the 'Wall of Death' rides at an amusement park

17 A comment of the air quality on the Mir Space Station by an astronaut had him describing the air quality as so toxic that as soon as he suited up into his space suit, which had a filtered oxygen tank, he was disgusted by the air quality of the station when he reentered station.

18 This will be done because it's more economical to mine from a point in space as opposed to mining from the Earth, where one would have transverse through the Earth's atmosphere and gravity.

[Figure 35] This is a top view of the Earth. The blue disks represent the solar panels that will be placed in geosynchronous orbit when the Earth truly becomes self sufficient. These solar panels are diagrammatic, they will face the sun in real life.



to travel to space outweighing the negatives. This novelty would undoubtedly decrease, and as more people are exposed to space as their day-to-day job, they will grow to hate their lack of amenities and harsh conditions. People who will be employed for robotic lunar mining will be highly educated engineers with at least one university degree. These people will be used to an upper-middle class standard of living, motivating employers to prioritize their comfort levels in order to attract talent.

Moving forward with the space colony development timeline, amenities of the colony will grow increasingly to match those of the Earth causing the population to grow both through immigration and birth. An economy will develop out of the population increase and the colony's offerings will start to encompass more than just mining for helium-3. Eventually, because the engineers specializing and holding the most experience in space mining and space robotics will all be located on this colony, the colony will become the universal core of capturing, refining, and manufacturing materials found on the

Moon and other extraterrestrial bodies like asteroids.[19]

Cultural Beginnings

As lunar mining continues, back on Earth more land will be freed up for farming and habitation. More elevators on the Earth will be created and put into geosynchronous orbit in order to increase the receiving capacity of helium-3. This will cause an increased interdependence between the lunar mining operations and the Earth. The increase in demand for helium-3 will result in a 'gold rush' with economic opportunities driving an increase in the population of the mining community. This will demand that the physical size of the space colony grow and that living conditions be improved. As the population of miners increases, inhabitants will elect to permanently remain in the colony. Children will begin to be born in the habitat, and the increased isolation from the Earth will cause a unique culture to form among the community, a new form of humanity culturally and even physically, branching from that of the people from Earth. This could likely lead to an independence movement within the colony, much like the American colonies in 1776, especially if, like England, the mother ship Earth dose not recognize the ecological, cultural, and political challenges that need to sustain a wider changing human society.

Postscript: The Third Energy Revolution

Assuming the onset of strife, the nations of the Earth, after learning of an independence movement, will start to make plans to lessen their dependence on the lunar mining operation. By this time, the space travel, mining, and construction industries will have been revolutionized. The ability to export materials from the Earth

19 As the electrical needs of people increase the Earth could continuously build further into space creating more infrastructure to hold more solar panels

to space will be as streamlined as shipping from one country to another.

At the Earth's peak receiving capacity, the planet will have terrestrial elevators scattered across the equator at roughly an equal distance apart from each other, determined by how counties decide to construct them. Building off of the Earth's existing interstellar shipping infrastructure, they will start to place solar panels in geosynchronous orbit, beginning at the end of each individual Earth elevators and later in an array from elevator end to elevator end, forming a ring of solar panels around the Earth. This will allow for the Earth return to renewables, but within the limitless volume of space, and reach a point where the Earth becomes self-sufficient for its energy needs indefinitely.[20]

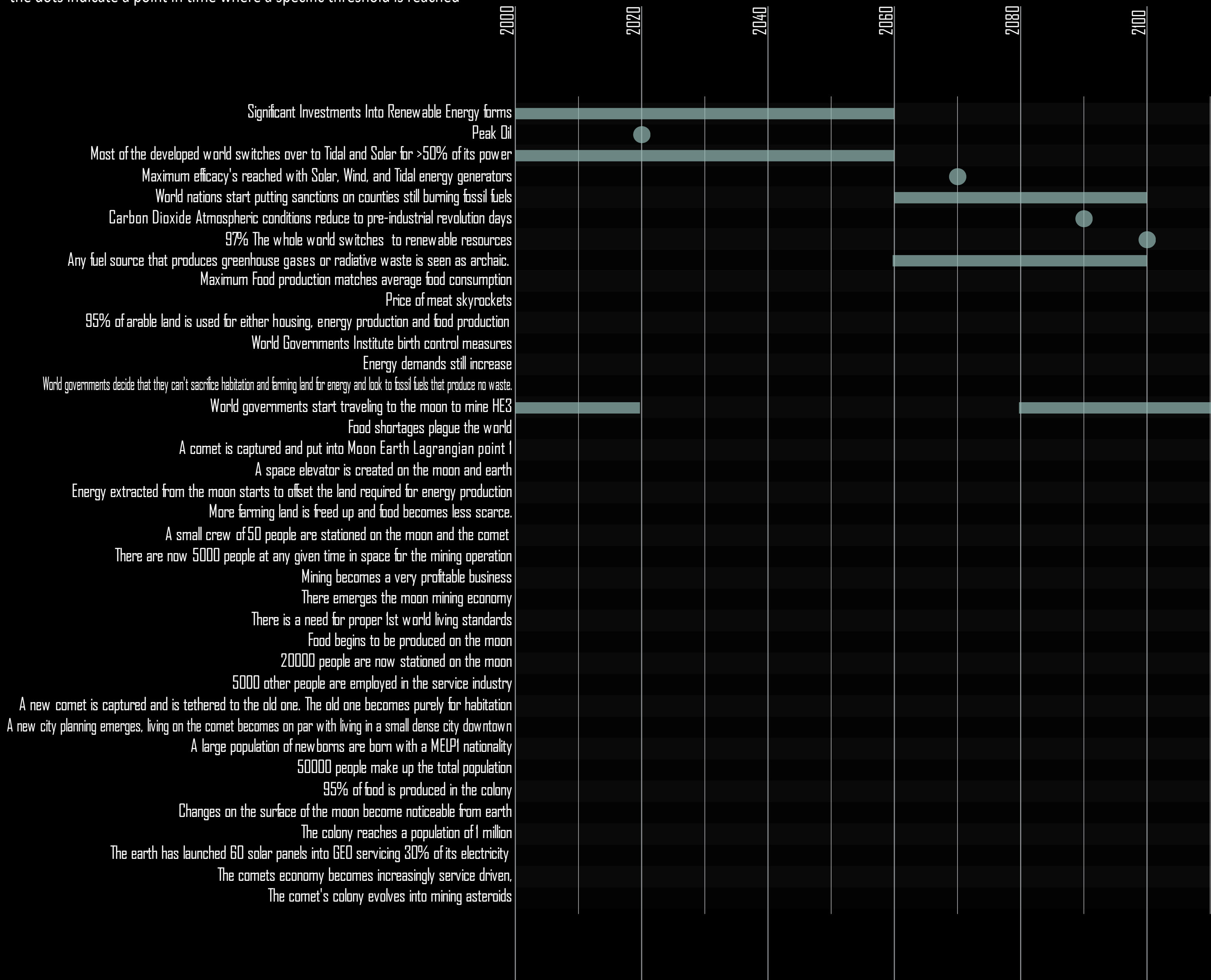
The Start of the Thesis

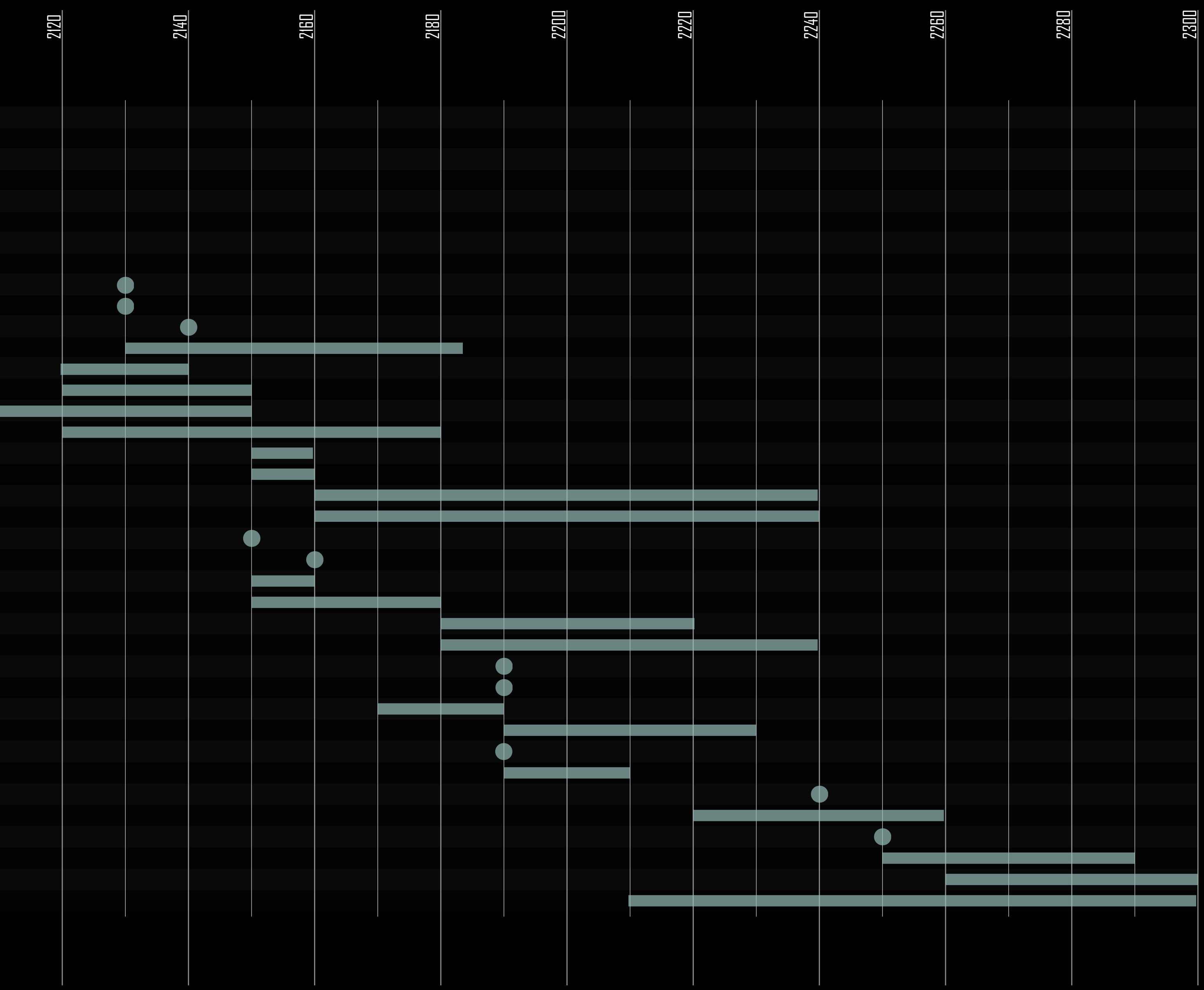
The separatist movement will result in the eventual independence of the colony from the Earth, first in terms of law, then in terms of economics, followed lastly in terms of survival. The economics of the colony will shift to encompass asteroid and comet resource mining to make up for the loss in helium-3 demand. The colony will then begin produce the majority of its food on the habitat in a final move to gain true independence.

As a result of this hypothetical series of events, the Earth will have solved its need for extra land for energy. The Earth will then start to run out of area for food and habitation and will have only the land dedicated to vital ecosystems to envelop. However, due to society's views on the environment at this point, this would be unthinkable. The Earth will incentivize people who are not necessarily needed to work on the Earth to work in outer space. Professions that offer intellectual services such as engineering, architecture, law, education, and other fields that require people to work with other people, will be most likely take root in space colonies. Eventually, this will lead to the creation of other colonies and the Earth will then simply become one of the solar system's many space station, albeit the biggest and oldest, but not for long.

The major events that occur in human history are reactions to a condition that society is currently in or foresees itself in further into the future. The main purpose of this narrative was to produce the foreseeable condition that would necessitate the creation of a colony in space dependent on the Moon for resource mining. As stated before, the path taken to this point could be numerous. It was necessary to create this prediction of the future because the end result of the space colony will be completely dependent on the problems that it was created to solve. A colony orbiting Mars, for example, will not have the same purpose as the colony described in this paper. As well, to assume a colony will simply appear is unrealistic. The ultimate outcome of this section was to provide the conceptual foundation that the colony can be built on, and to outline a possible narrative for its creation. The chart that follows in the next two pages lays out the long-reaching scenario for the creation of a space colony. Following , in the next chapters is a detailed outline of the parameters needed for the construction, habitation and form.

[Figure 36]Graphic time line of events leading up to the construction of a space colony. This chart is a prediction. The line represent the timespan that an event occurs within and the dots indicate a point in time where a specific threshold is reached




2120
2140
2160
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2220
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2280
2300

Cooper: We're still pioneers, we barely begun. Our greatest accomplishments cannot be behind us, cause our destiny lies above us.

-Interstellar.

JOURNEY

This interlude chapter provides reasons as to why a person might want to go to and explore space. It's explained from a very general perspective, and is used to inform the final design of the colony, to be presented in chapters outlining the last two "axioms," that of the mechanics of sustaining life and in the urban design of the space city. The potential explanations along this topic of motivation are numerous, and could even form a thesis within itself. Any reason for doing anything is highly individual. For example, a person might want to go to Mars so that they could be the first person to die there. Although that is an extreme example, that person would go down in history and he would be known as the first person to achieve that fate. The reasons explored in this chapter are the incentives that I believe would resonate with most

people.

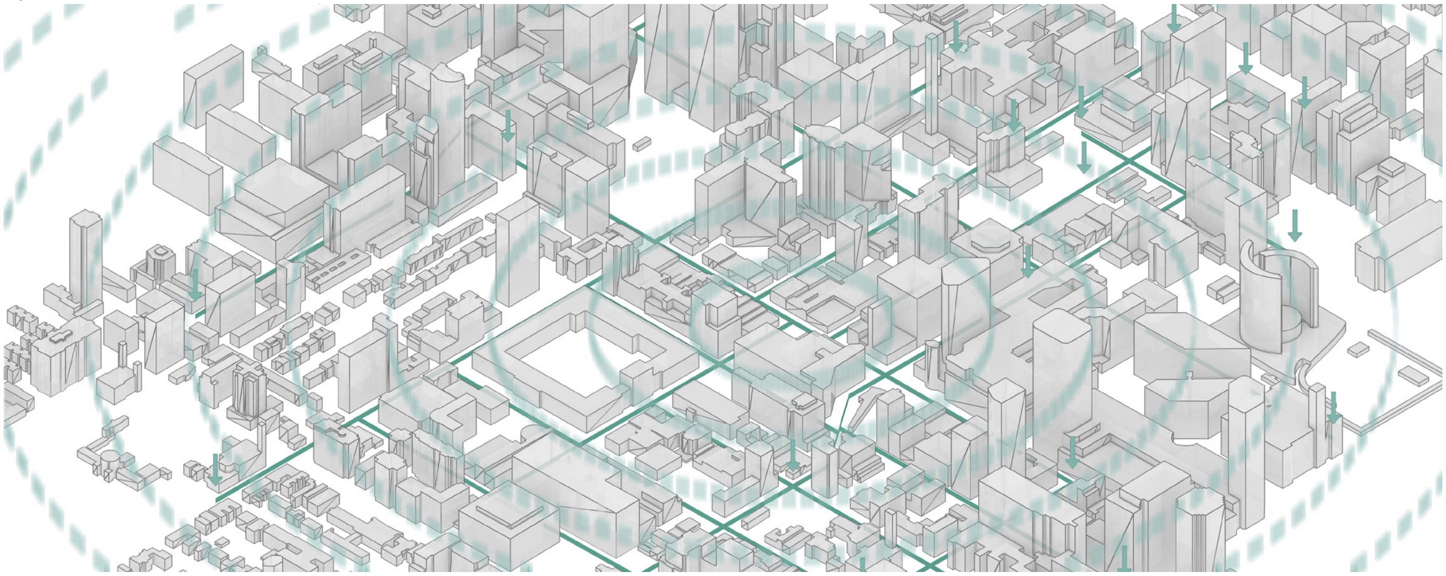
Curiosity

We currently live in a world where almost everything has been photographed, searched for, and found. Various providers of maps such as Google and Apple provide free access to every inch of the world, including the oceans. Google has even gone as far as providing photography of the entire

[Figure 37] When I say City, an info-graphic displaying how people view the city

surface of the Moon. [1] By the time I was born, in 1993, the whole Earth had been photographed many times over. [2] Space, however, is still uncharted territory. From where I'm writing this thesis, I can look on Google Street View to see what it would be like to walk by the Disney Concert Hall. We have no such ability to do that with a location in space or even on the Moon. Even imagining what the surface is like is quite difficult. Due to this gap in information, we want to see what it holds. This is most likely why many people tour through North Korea every year, because of secrecy.

[Figure 38]A map of downtown Toronto illustrating the distance from a given point and how far you can walk in 15min



A New Start

As American revolutionary Thomas Paine said, we have the opportunity to start anew. The same historical predetermined attributes for habitation defined by nature, proximity to water, forestry, farmable soil do not apply this time. We get to make them in a space colony to suit our needs.

Cities on Earth often suffer from short sighted laws and planning structures, for example, some created hundreds of years ago that restrict main circulatory arteries in city cores. Streets that should be six lanes wide in the city of Toronto are only four, two of which are dedicated to parking and bicycles. There is now a level of density in cities like Toronto that we can only control so far, and within the physical parameters established two hundred years ago and thousands of years ago for a city like Rome. In order to allow people to live on property in desired city locations, we have had to construct gigantic towers that leave the public space of the city in shadows. Then in order to restrict the growth, we have put a price tag on those properties that only the overtly wealthy can ever afford.[3] We are stuck in a new world

1 Google. "Our History in Depth – Company – Google." Our History in Depth – Company – Google. Accessed June 27, 2016. https://www.google.co.uk/about/company/history/#2005.

2 Reichhardt, Tony. "First Photo From Space." Air & Space Magazine. Accessed June 27, 2016. http://www.airspacemag.com/space/the-first-photo-from-space-13721411/?no-ist.

3 Nurmohamed, Salma. "Vancouver House Prices Hitting New Highs Because of Short Supply - British Columbia - CBC News." CBCnews. March 26, 2016. Accessed May 22, 2016. http://www.cbc.ca/news/canada/british-columbia/vancouver-real-estate-prices-1.3498070.

that accommodates more successfully for the wealthy. But in space we're starting anew and with the space colony we've seen the errors of the past. We do not have to repeat them, or simply live with their consequences in later generations.

Self Improvement

Throughout history we have always been deeply curious about what is beyond our current technology. Our intense curiosity of idealized possibilities of life inspires us to keep working with a purpose. We can imagine a world where we are rich, where people are pacifists, and where life is more efficient. We strive to inch progressively closer to that reality with each passing day. Much in this same light, historically, we have been mesmerized by the distance of the sky, the unwavering power of the tides, the monstrous height of mountains, and we imagine what kind of wondrous people could exist there. We have dreamed up tales of angels living in the clouds, the Greek gods looking over us on the mountain tops, and the citizens of Atlantis ruling the sea. With the passing of time, our curiosity has lead us to slowly embody these gods; we how have soared higher than the clouds, occupied the seas, and have conquered mountains much larger than Olympus. This thesis continues this train of thought within a modern context.

Pride

In the past, space exploration was used as a proxy to compete with other nations over prestige and global dominance. With creativity and technology being the greatest barriers to our potential in space, whichever nation that was able to reach the frontier first was deemed to be the most advanced of nations. This, as well as military the applications of space technologies, is what motivated the Soviet Union and the United States to rapidly develop their space programs at the end of the Second World War. As a result, the Soviet Union became the first nation to send a satellite into orbit and the first to build a manned space station.[4] The United States was the second country to partake in those achievements, but the first to send a manned space crew to the Moon.[5] With the collapse of the Soviet Union in the 1990s Russia has continued its leadership role now in partnership with the United States.

The necessity of manned space flight, as opposed to sending an unmanned probe, has also been justified through national pride, this despite the numerous danger that outer space exposes humans to and the extraneous cost of life support system. Popularity, in many ways, drives these missions. Most people in North America have a fundamental understanding of what the International Space Station is, and it would be hard to find a person who did not know that the United States was able to land a person onto the Moon. These two events in human history are found so interesting to the population, that entertainment companies have been able to produce full feature films with multi-million dollar budgets surrounding these achievements. But what about the Mars Exploration Rover (MER)? The first of the two rovers have been on Mars since 2004. The second rover has traversed over 45km of the Mars surface and has discovered potential evidence of water, but there are no

4 NASA. "Sputnik." Sputnik. October 2007. Accessed June 27, 2016. http://history.nasa.gov/sputnik/.

5 "The Apollo Missions." NASA. Accessed June 27, 2016. http://www.nasa.gov/mission_pages/apollo/missions/.

entertainment based feature films on the MER. The United States, Russia, and China all have rovers on the Moon, but few people even know that they exist. Having a human element makes the whole mission special to us because it is a testament to how far we have pushed the extent of the species of humanity.[6]

High Demand and Success

Relocating to space, from the perspective of the average person, will be a gamble. In general, most people understand that if you join a company and stick with it at its earlier days, you will be rewarded greater than if you joined after it booms. There is a larger risk involved, because the organization will be less stable, but the rewards can be potentially grand. This gamble is also what motivated Europeans to travel to North America.[7] If they got in early and were one of two people who knew how to manufacture masonry in the city, they would have made a heavy profit. By entering first, your skills are immediately in demand and the opportunity to 'make it big' is staring you right in face.

A New Way of Living

One thing I do not want to do in this thesis is to define how people live and then build a form around it based on what is possible. Rather, I would like to do just the opposite, see what is physically possible and imagine how people would live given these

6 NASA. "Why We Explore." NASA. Accessed June 27, 2016. http://www.nasa.gov/exploration/whyweexplore/why_we_explore_main.html.

7 "Why Did The Europeans Come To America." Why Did The Europeans Come To America. Accessed May 22, 2016. http://www.elearnportal.com/courses/history/american-history/american-history-why-did-europeans-come-to-america.

changed parameters. This is because in order for this visionary thesis to be believable, it needs to strike a balance between what we have been used to, and what has become possible. I would like an inhabitant living in the thesis space colony to be able to come and leave as they please and for that process to be as simple as going from one country to another on Earth. For this reason, it can't be too foreign to a terrestrial way of life, but needs to offer various advantages that are unique to space. The other problem associated with defining a way of life is that our way of life is constantly in flux. Just look at how people dressed in the 1990s, or our new-aged addiction to our smart phones. Any prescriptive life log would be outdated the second it is created and would have no hold in many years when this thesis becomes possible. Furthermore, historically it has been technology that has championed the mini cultural revolutions of the modern era. The elevator and high quality inexpensive steel made one hundred storey buildings a reality, computers have created new methods to socialize, and phones have redefined what distance and community can mean. In this same light, the novel physical possibilities enabled by space habitation should drive the creation of a new way of life; many new ways of life.

Weightlessness.

In North America, the majority of our superheroes originate from two different comic book franchises, Marvel Worldwide Inc.[8] and DC Comics,[9] (owned by Disney and Warner Brothers respectively). These two franchises each have an assembly of their superhero characters, named "The Avengers" for Marvel and "The Justice League" for DC. Of the five founding members of the

8 Marvel Entertainment, LLC. "About Marvel Comics." Marvel Comics. Accessed June 27, 2016. http://marvel.com/corporate/about/.

9 DC Entertainment. "About DC Entertainment." DC Entertainment. Accessed June 27, 2016. http://www.dcentertainment.com/about-dc-entertainment.

Avengers, four have the ability to fly on their own, or using an unorthodox vehicle specific to them.[10] Similarly, of the Justice League founders, five out of seven can fly on their own.[11] Most North Americans know that the Wright Brothers invented the first successful airplane, and one of this author's fondest memories is getting to sit in the cockpit of a private airplane as a kid. NASA regularly posts videos of how their astronauts seem to levitate on the International Space Station, and promote a view of how weightlessness can be very fun. Reduced-gravity aircraft companies, that allow people to experience weightlessness by safely nose-diving in an airplane, can operate while charging 4,950USD per flight because people are so interested in the adventure.[12] Humans want to be able to fly, and the freedom from gravity in space provides that.

10 "List of Avengers Members." Wikipedia. Accessed June 27, 2016. https://en.wikipedia.org/wiki/List_of_Avengers_members.

11 "List of Justice League Members." Wikipedia. Accessed June 27, 2016. https://en.wikipedia.org/wiki/List_of_Justice_League_members.

12 "If You've Ever Dreamed of Flying, You Can. It's Surprisingly Simple – but No Less Profound." Zero Gravity Corporation. Accessed June 27, 2016. https://www.gozerog.com/.

“

We’re not meant to save the world. We’re meant to leave it.

-Cooper, Interstellar

”

FRAMEWORK

The space colony proposed in this thesis will not be created for many decades and any detailed design produced here will be outdated by the time this becomes of any use. In order to produce a thesis that will add to the wealth of knowledge, however, this chapter serves instead to provide the design guidelines leading to a working process to build the station, instead of a "correct" prescriptive design like O'Neil's Cylinder.

The main goals of any spatial enclosure for humans is to provide a high level of health and safety to its inhabitants. In terms of health, having a steady flow of clean air, providing artificial gravity, and promoting healthy bodily functions are necessary in the design. In terms of safety, the ability to be reactive and proactive in terms of dealing with possible catastrophic failures of the space colony is very necessary.

Design Parameters

Designing without a clear goal is the same as running in a circle expecting to get somewhere. Parameters must be established to both evaluate the success of the design and to move the project forward along a direct path. The design speculation revolves the around four axioms mentioned earlier: technology, the series of events the lead up to its construction, life support, and urban design.

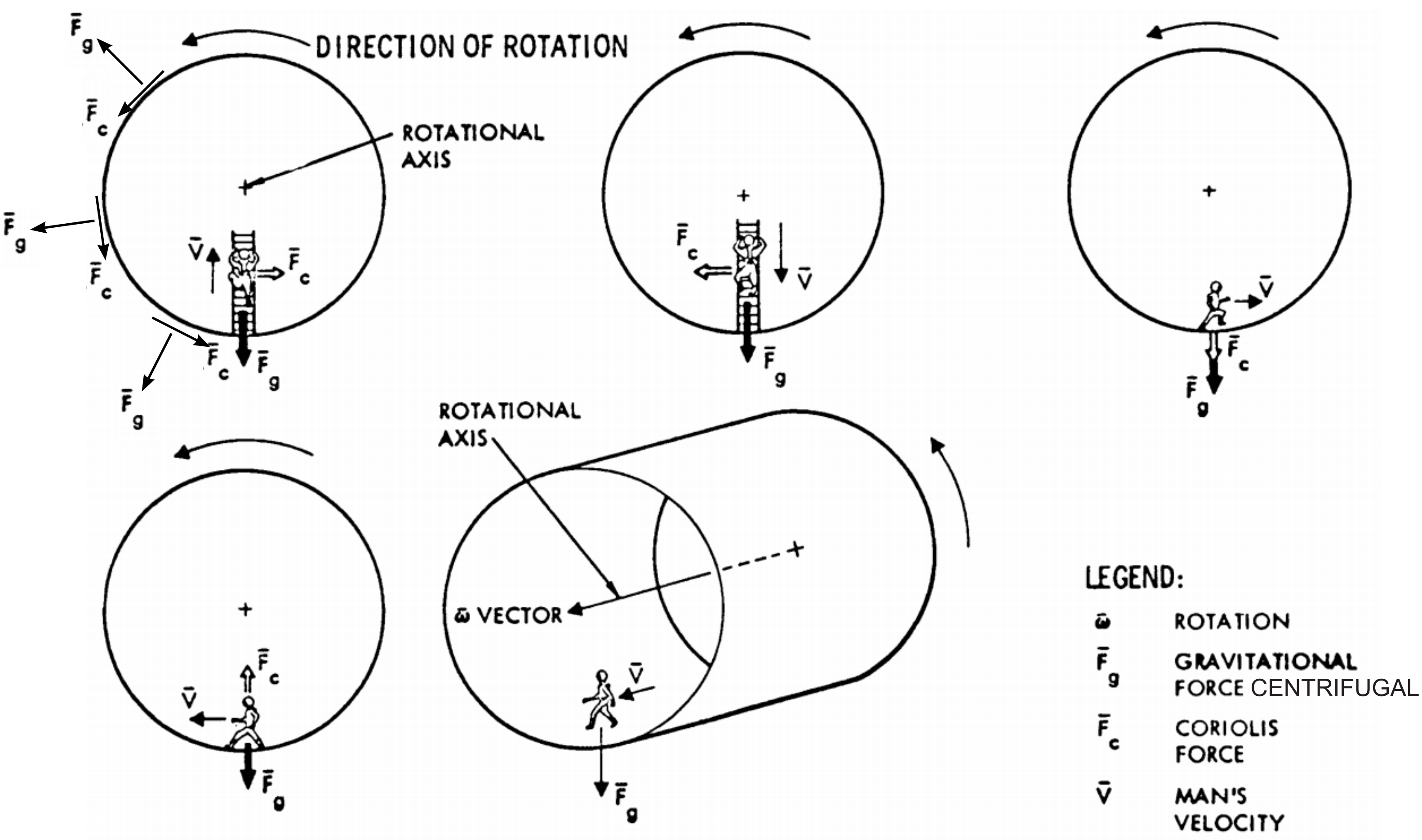
In reference to these axioms, the challenges set out for this thesis are defined below.

- The city must respond to a diverse and ever advancing population and needs to be able to grow in physical size to accommodate such population growth.
- The colony should be designed with a cradle to grave approach. Where could construction, energies, and materials come from and what should we do with them after they are decommissioned?
- The design must take advantage of the unique opportunities presented in space and should provide solutions for potential scenarios that could present harm to the colony, this considers physically, economically, and politically.
- The colony needs to offer a life that will be superior to life on Earth in order to give people incentive to live there and to keep living there.

Gravity

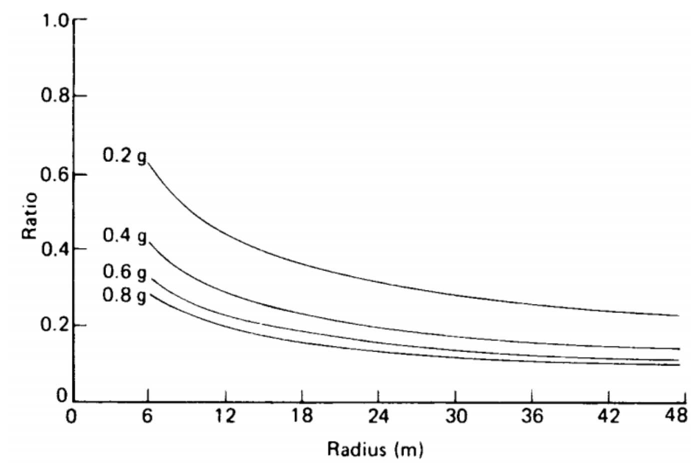
Although there will be areas in the colony where a form of altered and zero gravity are desirable (as in construction,

[Figure 39]Orbital force of gravity is actually centrifugal force caused by the transfer of the directional velocity caused by rotation of frames of reference which then create the perception of a force due to those constant incremental changes in velocity which follow the rotation. Change in direction creates acceleration, which in a mass generates a force. The centripetal force is provided by the skin of the cylinder resisting the outward tenancy. This is a drawing how the change in direction generates a force.

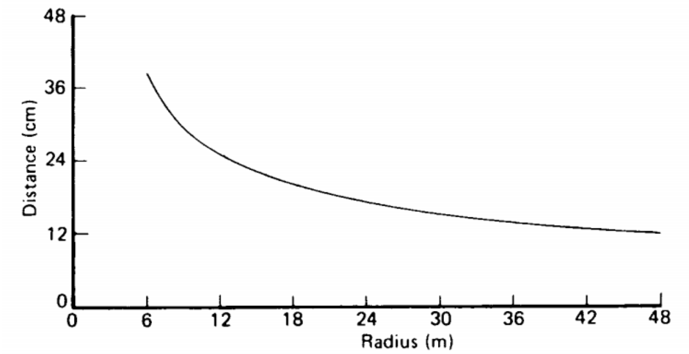


transportation, etc.), in terms of long term health, there are many negative effects that occur when mammals are exposed to a force of gravity that is either too little, or too high. We survive the best in a gravitational pull that is at a terrestrial 1g. Lower gravity can result in the loss of bone density. Long-term exposure to low gravity leads to people urinating out calcium that their body determines to no longer require due to the lack of forces on their body. For someone who wishes to ever return to the Earth, they would be at a higher risk of breaking their bones and would need to go through a period of rehabilitation to re-accumulate that calcium and bone density. There is a ripple effect that is created by

[Figure 41]Ratio of radial Coriolis Acceleration to artificial gravity versus radius of vehicle rotation. Curves shown are for radial Coriolis Acceleration caused by tangential motions at 1m/s in the rotating vehicle.



[Figure 40]Distance from expected position an object falls when dropped from 1m above the floor, plotted against radius of vehicle rotation.



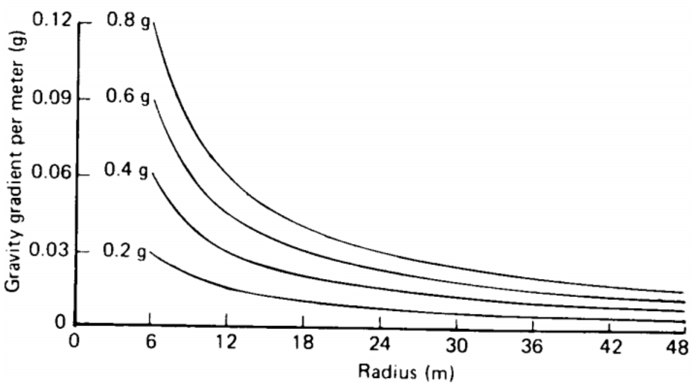
lower gravity which decreases the amount of force and stress on the muscles. This in turn makes the body believe that the excess muscle is unnecessary and muscle loss occurs. Lower gravity will also result in burning fewer calories during the day. Because our bodies are accustomed to consuming a certain amount of food each day, we may risk over-consuming leading to obesity. As we can see, maintaining an artificial gravitational pull that is similar to that of Earth throughout the majority of the colony is very necessary and must be designed for.[1]

To produce a force acceleration is required, and to actively create acceleration energy is required. There are two ways to create passive acceleration: centripetal motion, and gravity. Of those, only the former can viably create a constant acceleration equal to Earth's gravitational pull of 9.8m/s2 (1g). To produce 1g using gravity alone, a mass equal to the mass of Earth is required.

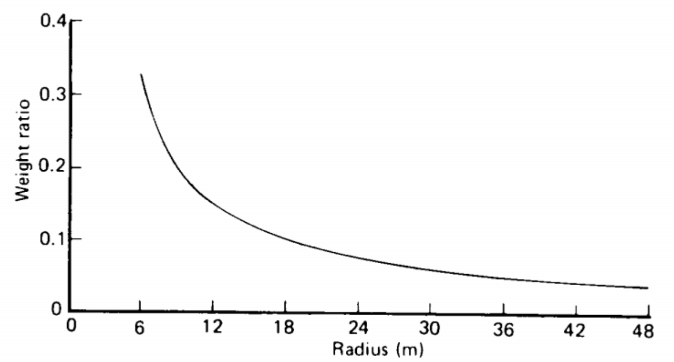
In terms of gravity due to magnetism, there a few ways use it to create a weak simulation of gravity: a charged surface paired

1 Howe, A. Scott., and Brent Sherwood. Out of This World: The New Field of Space Architecture. Reston, VA: American Institute of Aeronautics and Astronautics, 2009.

[Figure 42] Gravity gradient versus vehicle radius for various artificial gravity levels



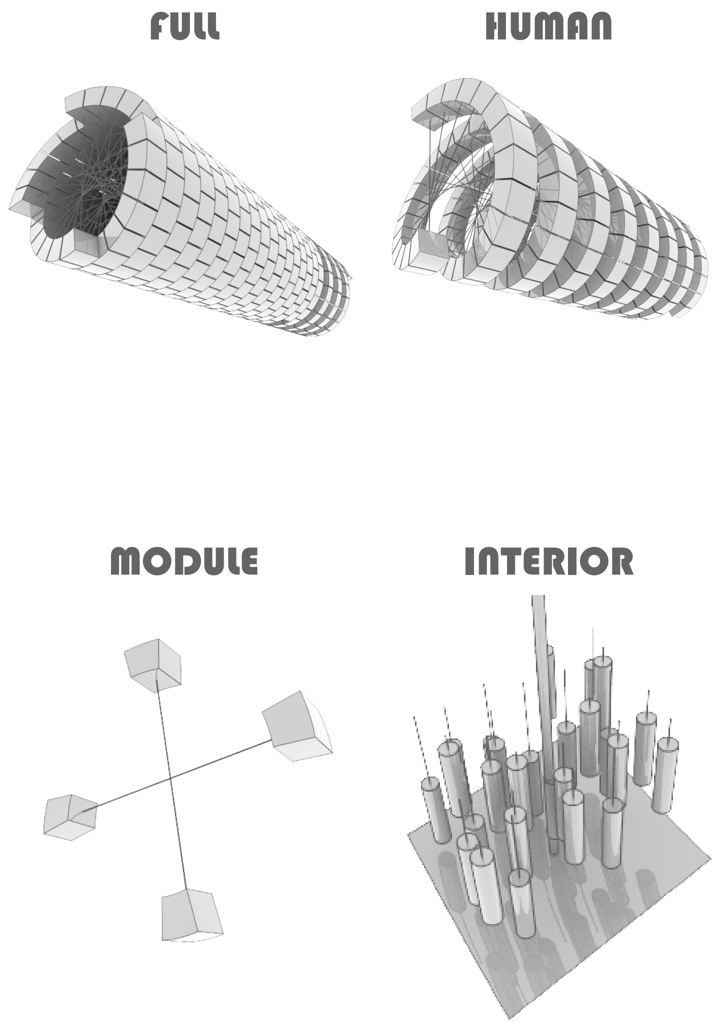
[Figure 43] Artificial weight change versus vehicle radius for a 2m difference in radial position of objects



with an opposing charged shoes, vest, or overall clothing to create a force that provides our bones and muscles with constant stimuli. This comes with the benefit of being able to choose to place the ground surface wherever needed. Also, a person would be able to experience 0g whenever needed simply by not wearing charged attire.

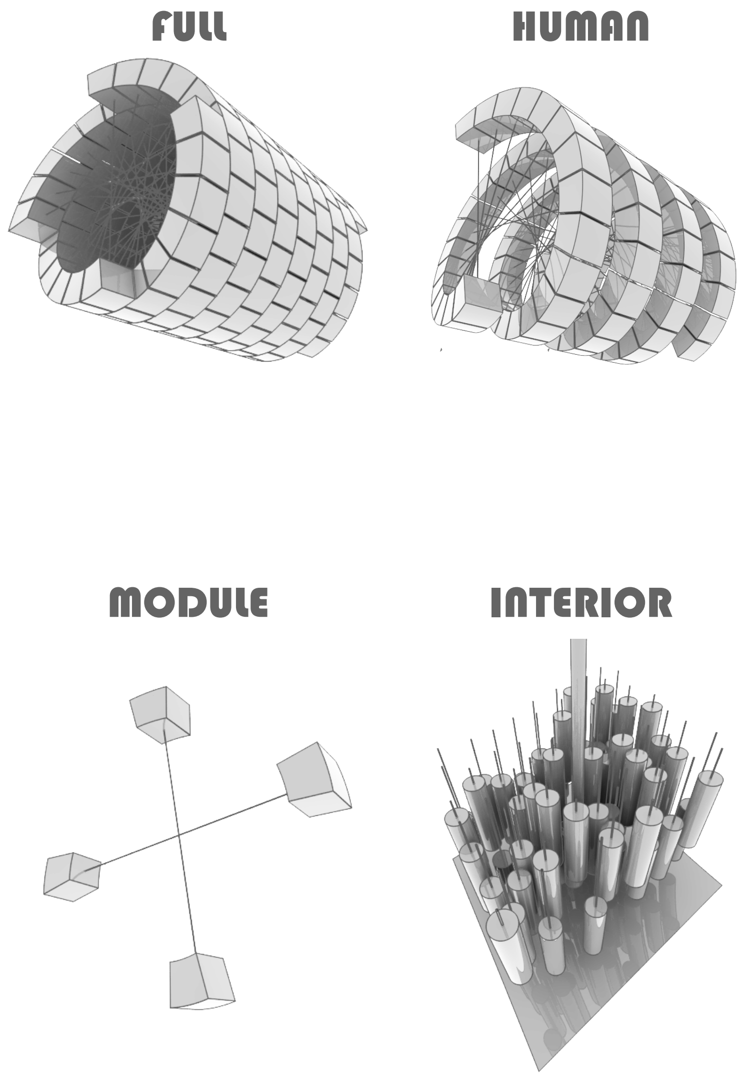
Problems arise when it comes to what kind of attire. Clothing, for instance, would need to be worn as high as possible because any body part higher than the clothing would still experience weightlessness. Having a magnetized hat, armbands, and vest would be required at a minimum to provide the stimulus on the body required so that the body's muscles and bones can maintain their protein and calcium. This means that the force would need to be calibrated to achieve 1g for each type of clothing. However, when the person sits down or falls, and is therefore closer to the charged ground, the artificial force of gravity would jump exponentially. The person may end up in a scenario where he is magnetized to the ground and unable to get

[Figure 44]Parametric modeling of the colony. This is the control, for the sake of comparison to the alternatives to follow.



up. For these reasons the use of magnetic forces to achieve gravity is not recommended and really not accurate in its simulation.

Gravity achieved through rotational acceleration is the recommended solution, one chosen by O'Neill and implemented in the design of the colony that will be presented in the next section. This can be achieved through having a space station, in the shape of a cylinder or ring, and like O'Neill's Cylinder, spin about its axis while housing people on the inside of the cylinder.



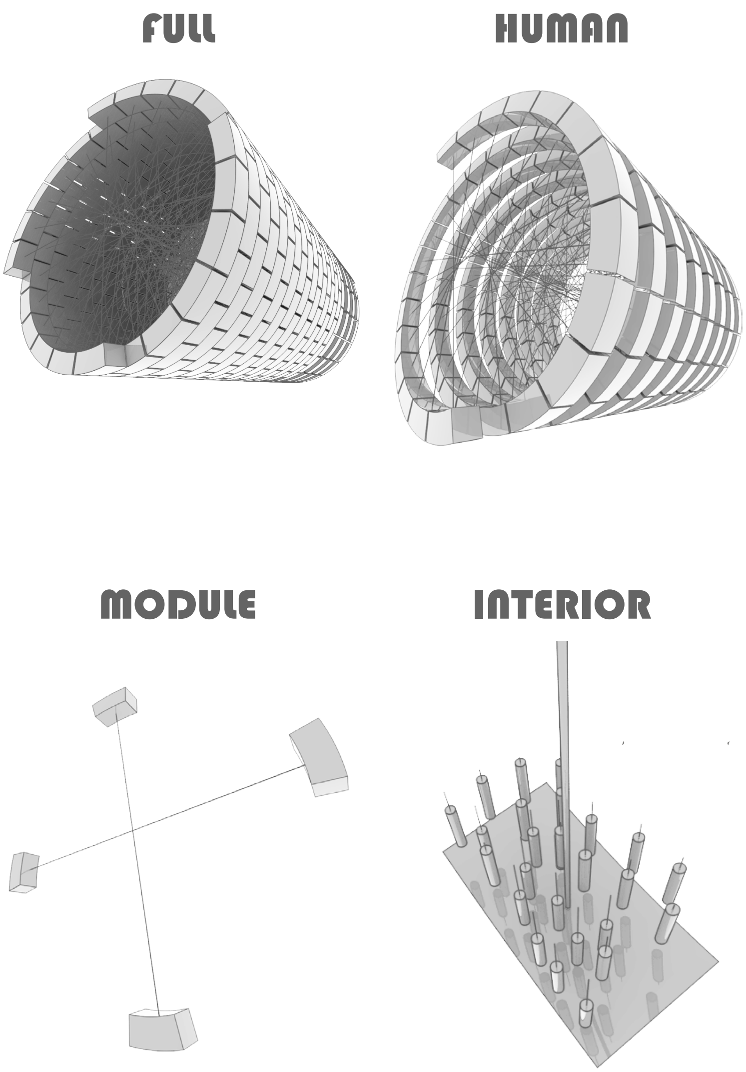
[Figure 45] Parametric modeling of the colony. This is the result of lowering the amount of rings to 3 while keeping the radius of the colony constant.

Coriolis effect	0%
Population Density	+167%
Energy Required	-55%
Radiation Exposure	-65%
Population Difference per mod	+8418

This process makes use of centripetal force and centrifugal force (which as already noted is a virtual force caused by shifting the frame of reference of a constant velocity, like that of an orbiting ship).When a person is spinning a bucket of water attached to a rope for example, centripetal force is carried by the rope and the bucket and points inward towards the center of the circle formed by the spinning bucket which is moving at a constant sideways velocity.

Centrifugal force is caused by the inertia of the water in the bucket. Inertia is the water's

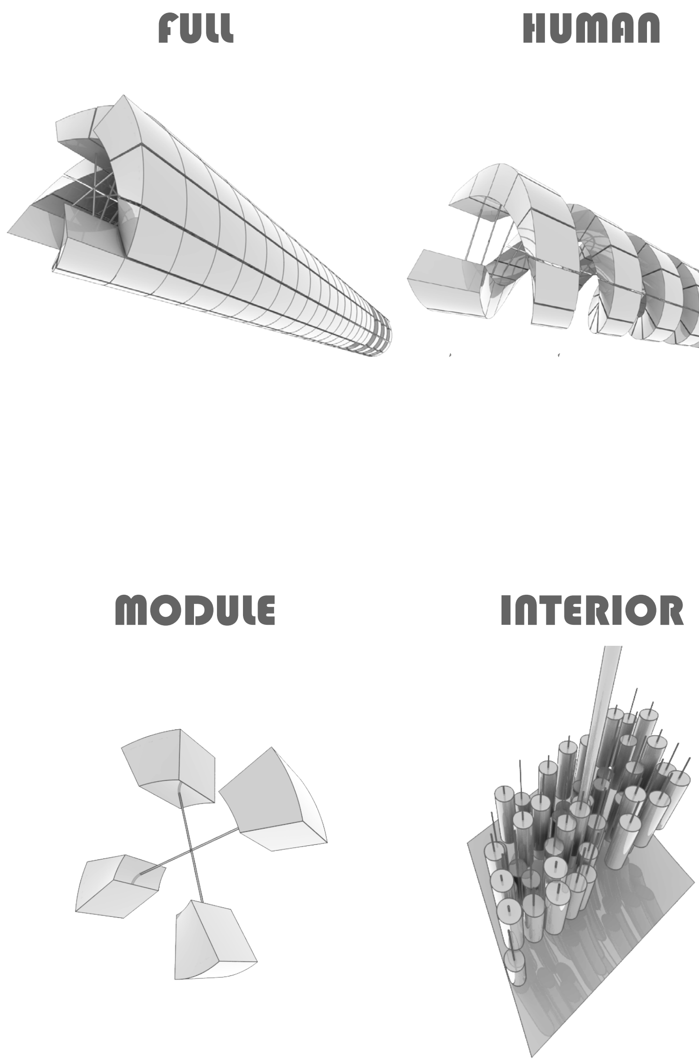
[Figure 46]Parametric modeling of the colony. This is the result of doubling the circumference of the colony while keeping all other variables constant.



Coriolis effect	-29%
Population Density	-50%
Energy Required	+113%
Radiation Exposure	+117%
Population Difference per mod	0

momentum to continue in a straight line at a right angle to the rope, tangential to the circle formed by the spinning bucket. Because the bucket is in continuous motion and the direction of the water's inertial momentum is changing as it travels in the circle, we feel a force acting the other way, what we call centrifugal force, the apparent force that draws the water in the bucket away from the center of rotation.

That centripetal force will operate radially towards the center of the ring from space colony and



[Figure 47] Parametric modeling of the colony. This is the result of reducing the circumference of the space colony to 36% of the control while keeping all other variables constant.

Coriolis effect	+232%
Population Density	+120%
Energy Required	-19%
Radiation Exposure	-35%
Population Difference per mod	+4261

act perpendicularly to the inside surface of the ring. The problem here is nausea caused by the sideways coriolis effect, and that the force of gravity is relative to one's velocity in the space colony inside the surface. The coriolis effect is a sideways altering force that balances out the vectors in the rotation frames of reference. On Earth, it is negligible due to the Earth's large diameter.[2]

The higher the rotations per minute (RPM) that the ring space colony operates at, and the smaller the ring space station's diameter, the greater the chance that nausea is induced. However, the lower the rotations per minute, the larger the ring space station has to be to maintain a terrestrial 1g. The disadvantage to this is that the ring space station would need to be of a mandatory minimum size in order to function, potentially resulting in a large demand for material.

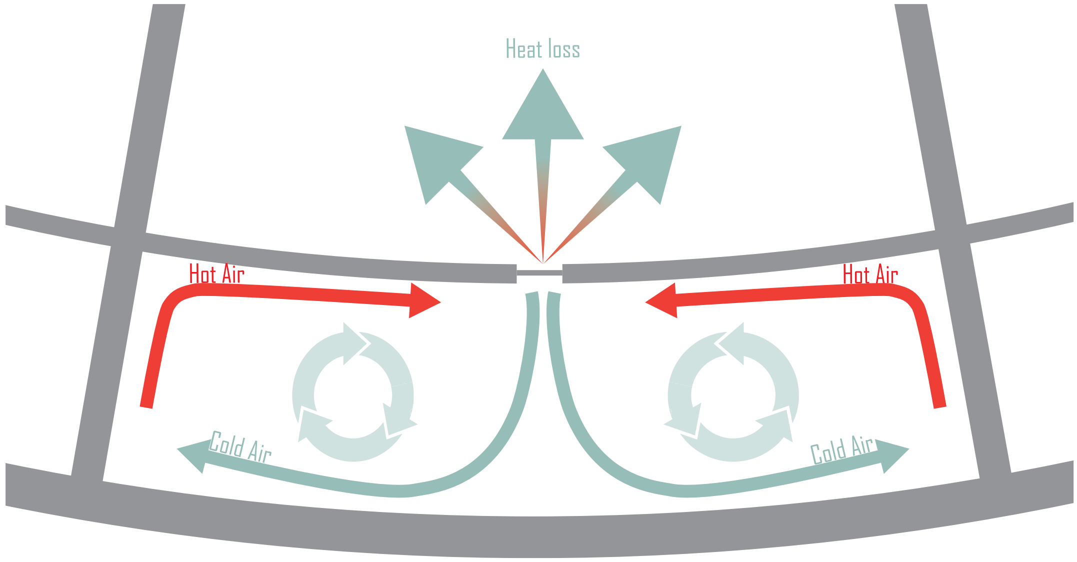
The Coriolis Effect, also has other implications. If one were to throw a ball directly upwards into the air inside a rotating ring space station, the ball would land offset from its origin, in the opposing direction to the spin of the colony at a distance directly dependent on the height that the ball was thrown at and the RPM of the colony.

The gravity in a rotating wheel is dependent on the velocity that the ring space station spins at. As a result, if a person runs in line with the ring's spin the force of gravity acting on that person increases, while if that person were to run in the opposite direction to the ring's spin, they would experience lower gravity. Depending on how fast a person may be allowed to travel, especially in a vehicle, and how small the ring space station is, this can have major implications.

In the process of developing this thesis parametric modeling was used to prototype 3D models of the colony and view the gravitational effects that would arise from the different variations. Figures 48 to 51 demonstrate a verity of explorations created to determine the appropriate size of the colony in reference to the Coriolis Effect. As the radius of the colony is lengthened, the Coriolis Effect is lowered and the centripetal force caused by the rotation of the colony increasingly closely emulates the Earth's gravity. This was then measured against the loss of heat energy that

2 Naval Aerospace Medical Institute. "Influences Of Artificial Gravity On Locomotion." In Fifth Symposium On The Role Of The Vestibular Organs In Space Exploration. Pensacola, Florida: National Aeronautics And Space Administration, 1970.

[Figure 48] A diagram displaying the passive production of wind within the colony by having an area with less heat insulation. The three arrows on top show heat escaping into space. The four on the bottom show the generation of air flow as a result of heat loss.



the colony would radiate into space as a result of the increased surface area of the space colony. The radial length of the space colony where a point of equilibrium is reached that allows for minimal heat loss and a gravitational pull of sufficient similarity to the Earth's is described in Table 2 in the following chapter.

Air

Oxygen is the most vital substance needed by the human body. Without it, within three minutes, we experience brain damage.[3] The mixture of gases in the air of the atmosphere serve two important functions: to deliver a fixed concentration of oxygen to our bodies, and to maintain the atmospheric pressure that our bodies have adapted too. Both of these factors are crucial to our survival. Air cannot be comprised completely of oxygen at full pressure because its richness causes oxygen poisoning, it needs to be diluted.[4] Plants on the other hand need other gases to be present in the air in order to thrive and grow, specifically carbon dioxide to generate carbohydrates, and nitrogen for chlorophyll

3 "How Long Can You Go Without Breathing?" Medical Daily. December 09, 2015. Accessed June 27, 2016. http://www.medicaldaily.com/breaking-point-how-long-can-someone-go-without-breathing-364450.

4 "Is It Harmful to Breathe 100-percent Oxygen?" HowStuffWorks. HowStuffWorks.com, n.d. Web. 29 May 2016.

and proteins.[5] Because of this complex web of needs, the air of a space colony needs to maintain the same concentration of oxygen, nitrogen, and carbon dioxide as what is present on the Earth.

In terms of gas pressure, the Apollo lunar missions were completed with 100% oxygen at 20% of atmospheric pressure and the astronauts had no adverse health effects, although they were only exposed for two weeks. Apollo 1, however, had a fire on its test launch pad where the entire crew was killed and the pure oxygen deeply increased the severity of the deadly combustion.[6]

Atmospheric pressure on the Earth also dictates many of the physical properties of substances. Water for instance will not boil at 100 degrees Celsius when the atmospheric pressure is altered. Machines and coolants on the colony would need to be specifically designed for one pressure or another creating environmental management complexity and lowering the colony's potential for manufactured exports.

Wind

The air is not simply comprised of gases and includes many airborne particles. These are often harmful to humans and must be filtered out. On Earth, we are fortunate enough to have wind currents that ventilate the air, sending it across to organisms that clean out various pollutants. This will not be true, however, in the space colony. In this setting there are no wind currents that happen automatically as in Earth's complex environments and they must be created.

Wind on the space colony can be created passively or actively. Active creation of airflow for a 18000000m3/module of contained

5 Galloway, J. N., F. J. Dentener, D. G. Capone, E. W. Boyer, R. W. Howarth, S. P. Seitzinger, G. P. Asner, C. C. Cleveland, P. A. Green, E. A. Holland, D. M. Karl, A. F. Michaels, J. H. Porter, A. R. Townsend, and C. J. Vöosmarty. "Nitrogen Cycles: Past, Present, and Future." Biogeochemistry 70, no. 2 (2004): 153-226. Accessed June 27, 2016. doi:10.1007/s10533-004-0370-0.

6 Moskowitz, Clara. "How the Apollo 1 Fire Changed Spaceship Design Forever." Space.com. Accessed June 27, 2016. http://www.space.com/14379-apollo1-fire-space-capsule-safety-improvements.html.

space is a massive undertaking requiring a large amount of energy and many circulation fans. There are, however, passive methods that can be employed by taking advantage of variable buoyancy. Even within artificial gravity created by centripetal spin, hot air will still rise due to its lower density and cold air will fall. In space, heat will only transfer through radiation and radiation exposure can be created by creating strategic holes in the colony's heat insulating envelope. This will create cold spots causing heat to escape and the surrounding air to fall. If enough heat is released, it will become a viable way to generate airflow within the colony.

Balance of Forces

Newton's Third Law dictates that for every reaction there is an equal and opposite reaction. This is how rockets launch into space and how an object initiates motion. In a colony large enough to support a population of a large city, there will be many individual parts. If any of these parts are moving or shifting against each other, even slightly, it will cause a cumulative mechanical stress on the colony. A monitoring system needs to be set up in order to maintain perfect rotational cohesion. When various large parts of the colony are out of balance, mass will need to be launched in a determined direction, into space, to regain the balance. People, containers, and supplies will, however, constantly enter and leave the colony, resulting in the colony's mass being in a constant state of flux. This means that the colony will be in a state that it will be constantly ejecting mass in order to maintain perfect rotational cohesion. 'Waste mass' then becomes a commodity, but also makes the colony constantly dependent on a steady flow of imported mass and a system for managing its placement.

To minimize the amount of corrections that need to be made in order to keep the colony spinning evenly, areas need to be allocated on the colony for the storage of mass. This will begin with the collected asteroids and raw minerals from the Moon. If the colony can amass a large enough stockpile of materials, thereby increasing the mass of the colony, any small shifts in its mass will have less of an effect on the rotational velocity of the colony. Then, The individual movement of parts of the colony can be limited to those within the built in tolerances. In this case, the colony would have to maintain a mandatory minimum amount of mass in storage at all times. If this mass is also added to the exterior part of the colony, it can also aid in the retardation of radiated heat loss and form a physical shield from debris and cosmic radiation.

Human Scale

One of the challenges that must be addressed in the colony's station is to ensure that the citizens do not feel as if they are forever enclosed within a small container. We are used to the perception of the nearly limitless extent of the Earth and being in confined spaces can be uncomfortable. The colony is not infinitely extended along its length and width, and there is a finite limited distance to how far you can go. This closed space is particularly concerning along the width of the colony which, given rotational necessities, would most likely be only a few hundred meters wide. Given this, one would still never want the citizens to be able to touch the wall of the colony. A non-physical barrier such as a river of water of sufficient width should be incorporated adjacent to the wall of the colony. If water is used, it can also act as a reservoir for both the hydration of the colony and as an emergency source of oxygen through the use of electrolysis and as a fluid mass balancing system.

The "Sun"

The 'Sun' of the colony is arguably the most important feature and it drives all the passive functions of the colony. Without it, plants would not be able to produce their own carbohydrates and oxygen for the colony. The sun, in effect, is the power supply behind the ecosystems that allows the colony to exist.

Lighting the colony can be completely artificial or through a redirection of the sun by a series of mirrors. If it is artificial, a light source would need to provide both heat, and light for the colony. This in turn would require a vast amount of energy. Currently the sun radiates 1370 W/m2 [7] on to the surface of the Earth, in order to meet that inside the colony, the bulb would need to radiate 123300000W at a minimum. This energy draw would be an enormous waste of resources and hence other solutions should be studied.

To passively create a sunlight system, as series of mirrors are necessary to redirect the sun's rays into the colony. As a species, we have adapted to an Earth with an atmosphere that absorbs 92% of the sun's rays so the reflected sunlight should only allow 8% of the total light. [8] The difficulty then becomes increasing and decreasing the amount of light to simulate a diurnal cycle. This can be done by rotating the mirrors away or screening the sun and in turn this adds a mechanical component to the system, one that will eventually degrade and need maintenance.

7 Edwards, David L., Whitney C. Hubbs, Douglas J. Willowby, Michael F. Piszczor, Jr., and Mary L. Bowden. "Space Environmental Effects on the Optical Properties of Selected Transparent Polymers." 4, no. 7 (1989): 204-08. doi:10.1016/0169-5347(89)90074-8.

8 Houghton, J. T. "1.2 Natural Climate Variations." In Climate Change 2001: The Scientific Basis. Cambridge, UK: Cambridge University Press, 2001. Accessed August 13, 2016. http://www.grida.no/publications/other/ipcc_tar/?src=/climate/ipcc_tar/wg1/041.htm#121.

Water and Radiation

Throughout this thesis, little mention has been made towards the physical materials that constitute the actual construction of the colony. This is a moot point because many years into the future, when this thesis scenario becomes possible, new materials will render any of today's current leading edge materials transformed or obsolete. Water, however, should and likely still will, make up a part of the colony's envelope.

In space there are three types of cosmic radiation that can cause harm: alpha particles, beta particles, and neutron radiation. Alpha particles are the least penetrating of the three, with a sheet of paper able to provide all the shielding necessary. Neutron radiation is the same type of radiation produced during nuclear fission reactions, they are free neutrons that can cause harm to organic life. This type of radiation is shielded using elements of a high atomic mass with increasing protection with a larger cross section of such shielding material. Beta particles are shielded in a similar way that neutron radiation is, except instead of requiring materials with a high atomic mass, materials containing atoms of a low atomic mass work the best.[9]

Pure liquid hydrogen would be the best insulator for beta particles due to its density, flow as a liquid, and because it has the lowest atomic mass. Hydrogen, however, is extremely reactive with one of the largest other masses present in the colony, oxygen, ironically to form water. Also, getting hydrogen to liquid form requires a temperature of 20 degrees Kelvin, a temperature difficult to obtain when directly adjacent to a large colony at 293 degrees

9 Wilson, J.W., J.L. Shinn, R.K. Tripathi, R.C. Singleterry, M.S. Clowdsley, S.A. Thibeault, F.M. Cheatwood, W. Schimmerling, F.A. Cucinotta, G.D. Badhwar, A.K. Noor, M.Y. Kim, F.F. Badavi, J.H. Heinbockel, J. Miller, C. Zeitlin, and L. Heilbronn. "Issues in Deep Space Radiation Protection." Acta Astronautica 49, no. 3 (2001): 289-312. Accessed August 14, 2016. doi:http://dx.doi.org/10.1016/S0094-5765(01)00107-2.

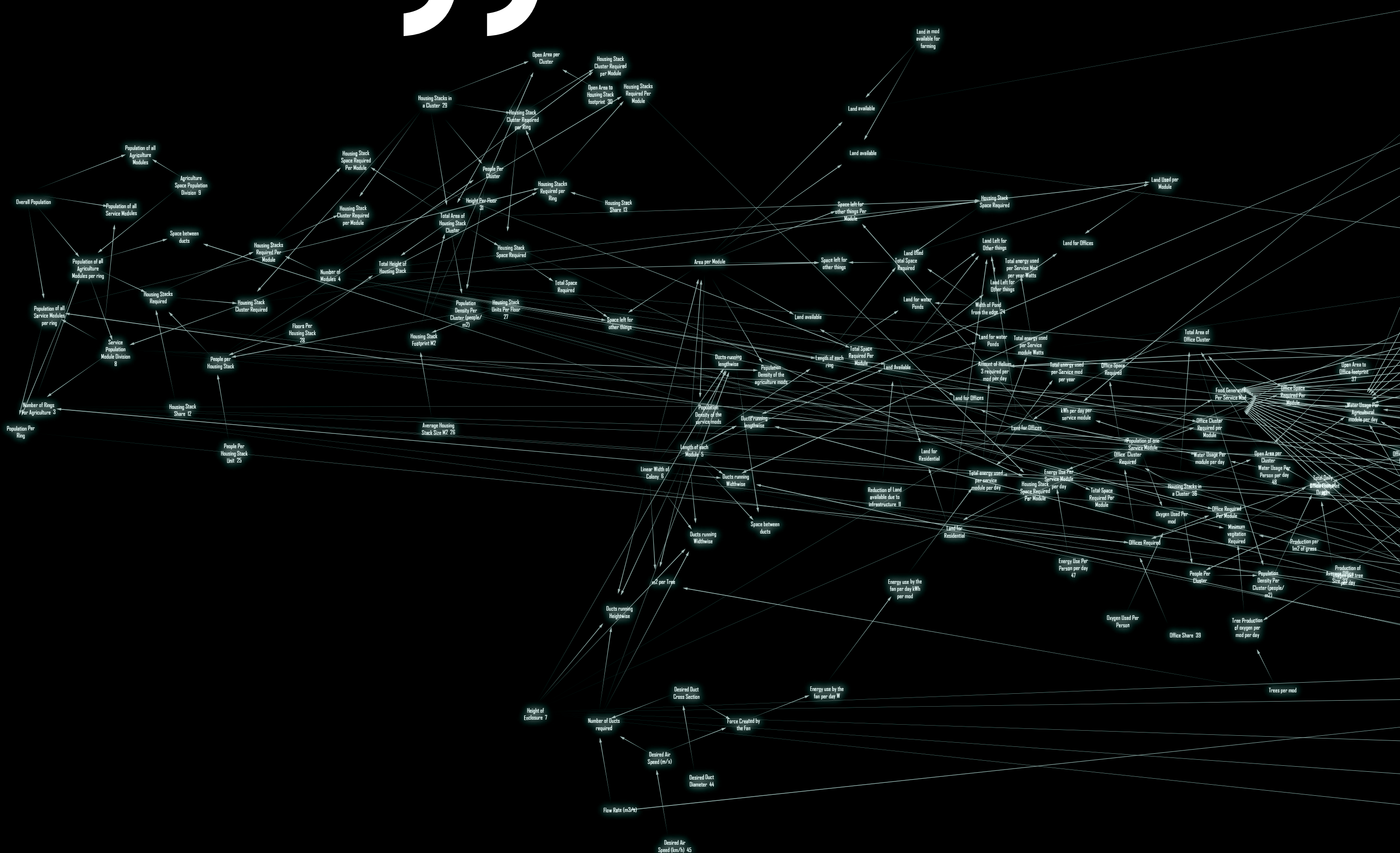
Kelvin or room temperature.[10] Liquid helium is also unsuitable for the same reason. Water, on the other hand, is nonreactive, liquid at room temperature in a pressurized environment and contains two hydrogen atoms to every one oxygen atom. For this reason, water can become part of the envelope and this exterior shielding can form part of the water reservoir for the colony's water needs.

Finally, as always noted, due to the complex makeup of the space colony and its purpose as a resource transit facility between the Earth and the Moon, maintaining the colony's center of gravity is impossible without an active system constantly making adjustments in its balance. Water can also be used as a liquid mass constantly shifting around the exterior of the colony to maintain a balance of rotational and orbital dynamics.

10 "Properties Of Gases." Properties Of Gases. Accessed June 27, 2016. http://www.roymech.co.uk/Useful_Tables/Matter/Prop_Gas.htm.

Cooper: Murphy's Law doesn't meant that something bad will happen. It means that whatever can happen, will happen.

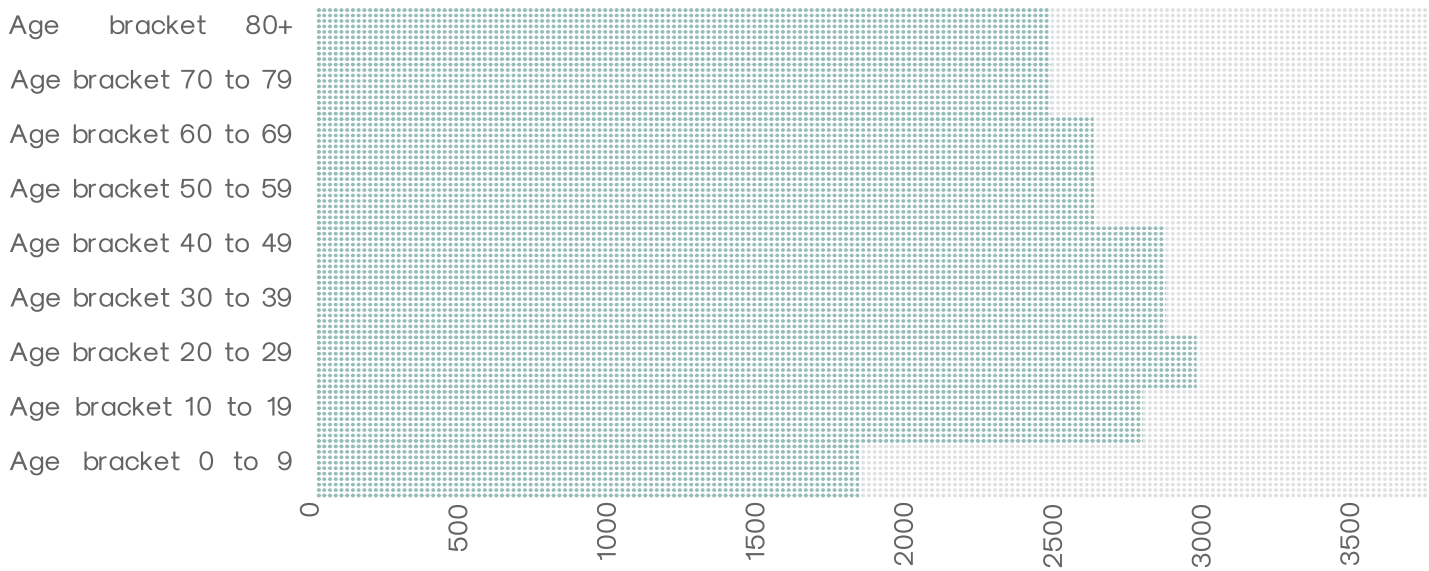
-Interstellar



ECOSYSTEM

Architects are required to design, first and foremost, for the protection of public safety. In the traditional sense of Hammurabi original code in ancient Babylon, this simply means constructing buildings that cause no harm to the inhabitants and the surrounding population. However, when it comes to a space colony, this responsibility is taken further to encompass the need for complete life support. Space is inherently a lifeless vacuum unsuitable for sustaining life, and we have no evolutionary defense that would allow us to live there. Typically on the Earth, whenever a failure occurs, more often than anything else, the number of people who get injured outnumber those who die. The smallest failure in the space colony could cause a complete collapse, and a scenario where everybody dies is much more likely than one where everyone gets hurt. Having examined, the first two axioms, how the colony could be built, looking at location and gravitational dynamics, as well as the timeline and basic narrative of its creation, the next axiom, the living system will be outlined. Information on the necessities for survival and their connections will be discussed. In order for people to survive, we need food, water, and oxygen to generate energy. Food needs to be grown, while water and oxygen need to be purified. Although these are all separate, they all exist in a nexus where the production of one aids in the production of another.

[Figure 49]Calorie consumption by age group of an active individual



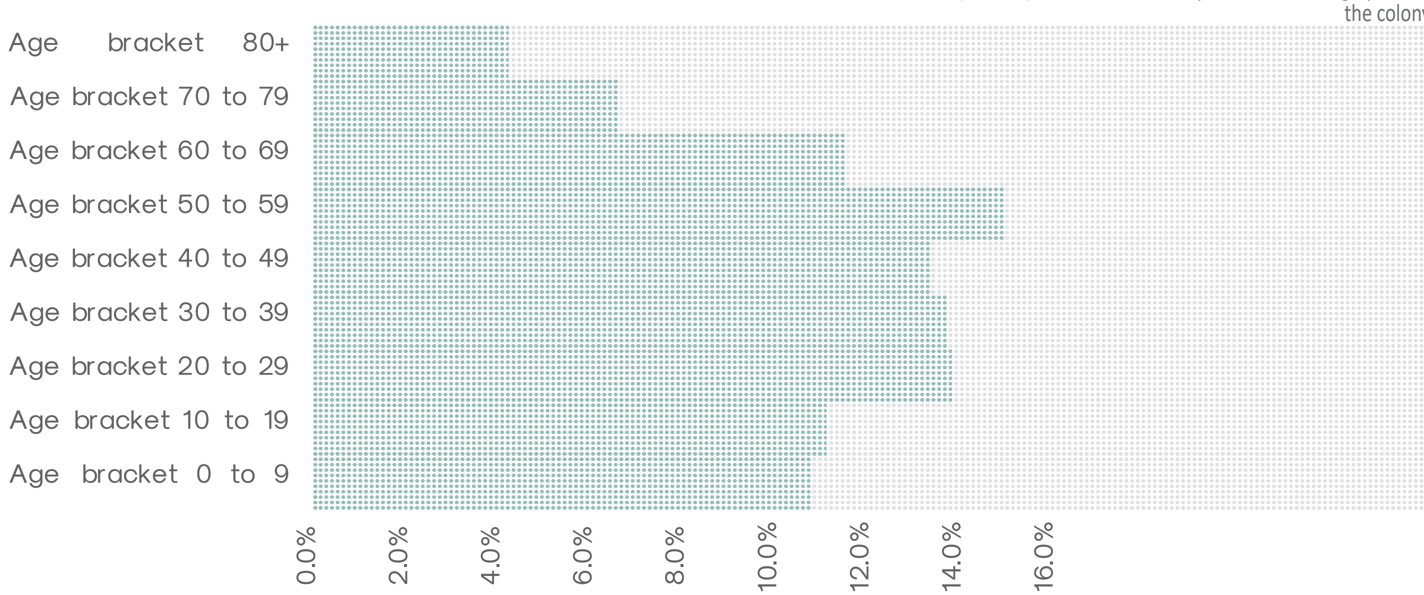
Food Production

Infrastructure will be required to create the space colony as a self-sustaining entity in terms of food, water, and oxygen supply. Although the colony is located along the direct path of two resource-rich bodies, the Earth and the Moon, self-sufficiency will also eventually create the conditions for some form of ecological and eventually political independence. It will avoid scenarios where the countries of the Earth use the threat of cutting off resources to get the colony to act in a certain way, the Singapore scenario.

Agricultural modules in the colony will be dedicated to the growth of crops, cattle, and fish. It is assumed that by this point in time the farming industry will also have embraced new forms of technology, such as new capabilities born through genetic engineering and synthetic foods.

Food production as a whole system is not an easy undertaking, as multiple factors induce the efficiency of food

[Figure 50]Age demographics of a first world nation (Canada) used as a model to predict the demographics of the colony



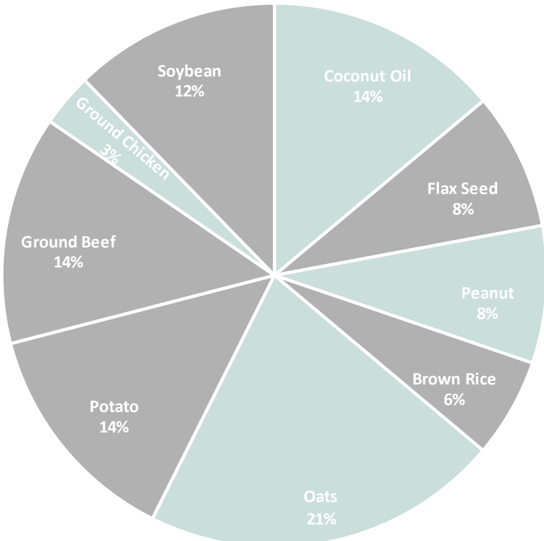
growth. There would be no humans to live full-time in the agricultural modules, so the atmosphere and lighting conditions can be adjusted to grow crops at their maximum potential and speed. An incorporation of something similar to that of today's hydroponics would be necessary but much more multifactorial. One of those major factors is the space required in order for food to be produced. Land, in a matter of speaking, will need to take full advantage of the vertical axis for high-efficient growth. This would demand the creation of a food growth mega-structure comprised of multiple levels which would host the growth of varied foods in their appropriate spaces.

Food Growth Requirements

The average sedentary human adult requires 2000 calories as well as associated nutrients like vitamins each day in order to maintain basic health.[1] Those calories are delivered to the human body in a varying combination of three macro-nutrients: dietary fats, proteins and carbohydrates. Each macro-nutrient has

1 Health Canada. "Estimated Energy Requirements." Estimated Energy Requirements. March 20, 2014. Accessed May 21, 2016. http://www.hc-sc.gc.ca/fn-an/food-guide-aliment/basics-base/1_1_1-eng.php.

[Figure 51]Land use to provide the same mass of food for each food.

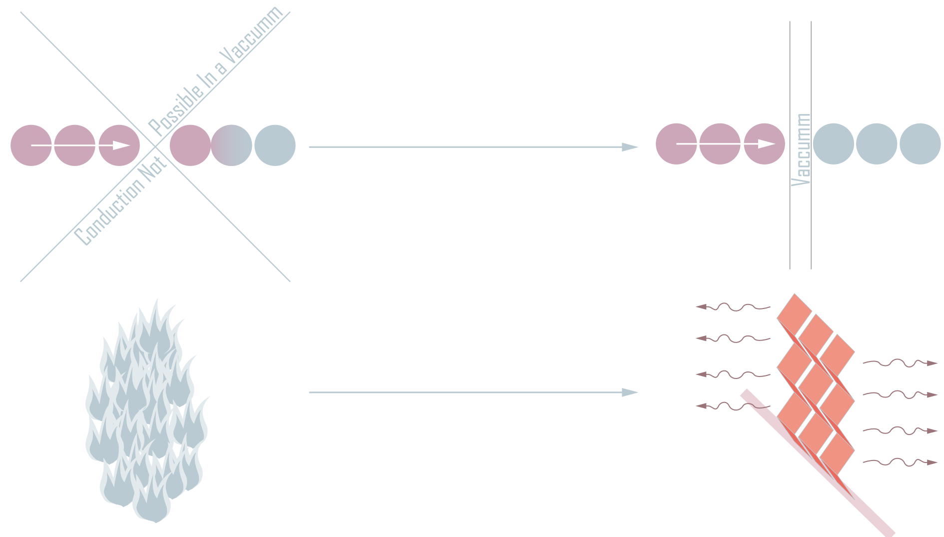


a specific energy yield based on its weight. Carbohydrates and proteins yield 4 calories per gram each while dietary fats yield 9Kcal/g. Using this information, we can estimate the mass of food needed in order to sustain a healthy human life. That mass of food, however, is not the pure sum of its macro-nutrients; water is present in most of the food we consume. Of all food produced, only a fraction makes it into our mouth. For this reason, the division of macro-nutrients in a sample set of nine foods will be used in this thesis, to estimate the mass-to-calorie ratio. This estimation is based on the calorie requirement of a population of active adult males, who individually requires a minimum of 3000Kcal/day, the extra to account for food waste. Using these parameters, for the purposes of constructing the thesis design guidelines, the required mass of food for farming will be determined.[2]

Three different indicator foods have been chosen in this thesis hypothetically to represent values for each macro-nutrient. Foods used in this study that contain primarily dietary fat are

2 Coleman, Erin. "Each Gram of Protein & Carbohydrates Contains How Many Kilocalories?" Healthy Eating. Accessed June 27, 2016. http://healthyeating.sfgate.com/gram-protein-carbohydrates-contains-many-kilocalories-5978.html.

[Figure 52]The cooling cycle in space. Because there is no matter in space, heat cannot be transfered through conduction and needs to be radiated out.



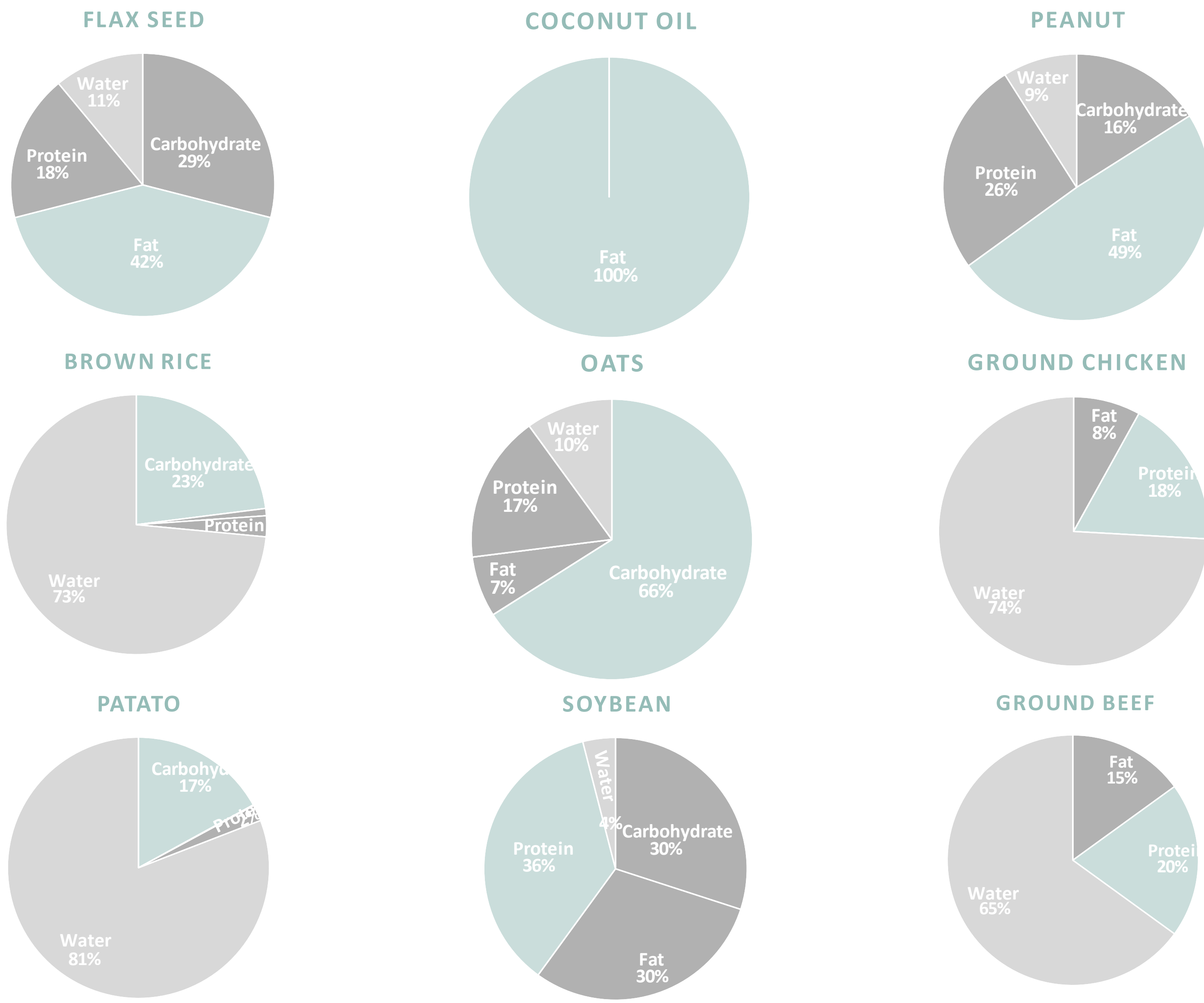
coconut oil, peanuts, and flaxseed. For proteins we will use soy beans, chicken breast, and ground beef. For carbohydrates there are brown rice, potatoes, and oats. These foods were selected due to their familiarity, nutrition, and ease of cooking. In this estimation, each of these foods will be given the exact same amount of land to grow. The purpose of this is to use the sample foods as a benchmark for a full scale 3D farming operation. What will actually be grown on the colony will be based on demand, and there will be many more than nine food items. Land allocation will also be based on demand once the system attains a large scale and sophistication.

According to the Canada Food Guide, the recommended amount of macro-nutrients should be broken down as follows: 20% of calories should come from protein, 30% from dietary fats, and 50% from carbohydrates. This is important because in order for a healthy person to function, each one of these macro-nutrients comes into play in a unique way. Proteins are responsible for rebuilding damaged tissue, dietary fats are

[Figure 53]Combination of parameters to create the ecosystem

required for healthy brain function and hormone production, while carbohydrates are the body's most preferred form of energy and prevent us from feeling fatigued. Although you could still live off one or two of the three macro-nutrients, it would eventually start to have an adverse effect on the human body in terms of muscle loss, lowered brain function, and fatigue. [3]

Each type of food has its own unique growing requirements. These parameters include, but are not limited to, humidity, temperature, air quality, water, and sunlight. Because food will be grown



[Figure 54]The amount of nutrients in each food item by mass

within a controlled enclosure, the parameters of each type of food will be tweaked in such a way to receive the largest possible yield. Each type of food will be closed off from another so that the sunlight, humidity, and temperature can be altered individually.

Water is required for photosynthesis in plants. Photosynthesis itself is an endothermic chemical reaction that produces a carbohydrate from water and carbon dioxide using energy absorbed from the Sun. Based on the law of conservation of mass, the input mass of water can be used to determine

[Figure 55]The equation for photosynthesis and how it applies to the sustainability of the colony. By knowing the quantity of water and carbon dioxide placed into the system, we can estimate the amount of oxygen produced based on the law of conservation of mass.

$$CO_2 + 2H_2O + \text{photons} \Longrightarrow CH_2O + O_2 + H_2O$$

$$44 + 36 + 0 = 30 + 32 + 18$$

$1\,m^3$ yields $1244m^3$

of Water of Oxygen

the output mass of oxygen that is created as a result of the photosynthesis chemical reaction. This oxygen can then be filtered out of the air and sent throughout the space colony to the habitation modules where it can be used in the broader colony ecosystem for sustaining human life. The pressure in the air can then be equalized through infill of carbon dioxide from the habitation modules. This provides a way of passively cleaning the air of carbon dioxide, and producing a steady flow of oxygen.[4]

Water

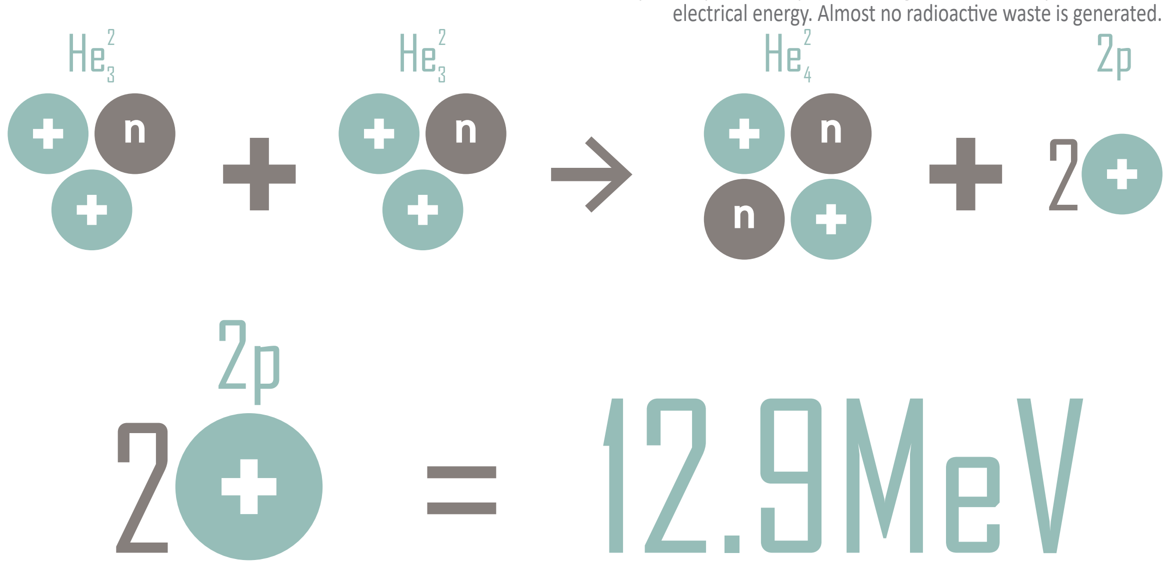
More important than food, water is the most desired substance for maintaining life. We can live longer without food than water and water carries both a biological and mechanical importance. It is used for everything from cleaning, humidification, heat transfer, and cooking. It is also required to grow plants and food. In Canada, the country's daily volumetric consumption of water can be expressed as 251L per person.[5] In order to keep water at a potable condition it needs to be cleaned, which uses energy. In order to transfer water from one place to

3 "Do Canadian Adults Meet Their Nutrient Requirements Through Food Intake Alone?" Health Canada. March 15, 2012. Accessed June 27, 2016. http://www.hc-sc.gc.ca/fn-an/surveill/nutrition/commun/art-nutr-adult-eng.php.

4 "The Chemical Equation of Photosynthesis." The Chemical Equation of Photosynthesis. Accessed June 27, 2016. https://msu.edu/user/morleyti/sun/Biology/photochem.html.

5 Stats Canada. "Residential Water Use in Canada." Government of Canada, Environment and Climate Change Canada. February 17, 2016. Accessed May 21, 2016. https://www.ec.gc.ca/indicateurs-indicators/default.asp?lang=en&n=7E808512-1.

[Figure 56] In the nuclear fusion reaction involving helium-3 (a light isotope of helium thats missing a neutron), the atoms are heated to a high temperature to cause the collision of 2 atoms, producing a helium-4 (normal helium) and 2 protons. The protons, because they already contain a positive charge, can be directly converted to electrical energy. Almost no radioactive waste is generated.



another, energy must also be used. Water will initially be brought from the Earth in limited amounts but later will need to be extracted from the ice of the captured comets, the same ones used initially to set up the mining operation and then more.

Because the colony's ecosystem is completely closed, no water should ever escape. Water will need to be continuously recycled, and the creation of a large system of reservoirs are necessary. Supply will also need to be monitored and added as the population grows. There is no adverse effect in storing too much water, but having too little puts the colony at risk. Losing water leads to losing its ability to efficiently regulate temperature will result in lower crop yields, and a hastened filter cycle, will increase the risk of contaminants and disease in the closed, still relatively small ecosystem of the colony.

Energy losses

The only way energy can truly leave the colony is through radiation. This is because there is no way for heat to conduct in space causing any heat generated in the colony will stay within the colony. Despite this energy still be use through pumping water, lighting homes, using computers, creating wind, and moving air from the vegetation modules to the human modules. In certain instances, especially with machinery closer to the outer shell, because there is no air, any heat that is generated will continuously build up in that particular area and will only be able to transfer through conduction to the other portions of the machine. This could lead to a buildup of heat so great that structural and functional parts melt because they are not able to exhaust their heat fast enough.

Energy Gains

As explained in the timeline section, electrical energy will be provided for through the use of Helium-3, which undergoes a nuclear fusion reaction in which two or even three atoms combine to form one helium atom and a proton. This proton, because it is positively charged, can be converted directly into energy through the use of an electromagnetic wave. This is advantageous because most energy production results in heat being produced instead of charged ions.

Light energy, as mentioned in the framework section, will be directed into the colony using mirrors. The light will bounce around the various surfaces of the interior of colony and slowly convert to heat energy in the process. Sunlight that comes into contact with the exterior envelope of the colony but does not enter will also act as an energy input. It is dependant on the surface area of the colony that faces the sun and reflectivity of the colony.

The Tools

In a space colony, as mentioned above, there are many different attributes that ultimately define how various components interact.

The more people in each module, the more food required the more food needed, the more water required, the more water needed, the more energy required to clean that water, the more plants are grown, the more oxygen produced the more oxygen produced, the more carbon dioxide is needed. Just like any other ecosystem, one small change has a rippling effect that makes defining attributes a difficult task. If one was to calculate all the attributes based on the relationship with one another it would be a lengthy process and limit the ability to test different circumstances.

For this thesis's exploratory investigations and to overcome the repetitive and lengthy process of calculating such attributes, a tool was developed to rapidly iterate different scenarios. In Microsoft Excel, a connected energy model was developed that linked all the individual calculations so that a change in one attribute would instantly yield the changes in every other affected attribute. With this tool virtual system prototypes of the colony were created that both provided instant energy, demographic, food and material feedback while also immediately displaying the form variations that the colony took. This tool was pivotal in the formation of this design. The table of values displays the different iterations of the colony. This model of attributes was then taken and using form modeling computer programs, Rhino 5 3D, Grasshopper, and LunchBox a virtual 3D colony model with a link to the Excel spreadsheet was created.

With this tool virtual system variant prototypes of the colony were created that both provided instant energy, demographic, food and material feedback while also immediately displaying the form of the colony version. This tool was also pivotal in the formation of this thesis. The table of values is provided at the end of this chapter.

The results of this tool are described and the tables that follow tell a narrative of the various elements that were considered and planned for in the design and creation of the colony. In the first table the space colony's population demographics are defined, ultimately setting the stage for the ecosystem's development. The point of interest here is the population density. As mentioned before, the space city needs to be dense to warrant the large cost of construction and to create the system efficiencies needed for life (and survival) in space at a large scale. The next table defines the geometric form that the colony will take and is used to rapidly prototype different variations of the colony. Tables 3 to 9 deal with the major land uses and urban design in the city and how the functional footprints are determined. This includes residential areas, commercial parkland and water features. Tables 10 to 17 address the inputs and outputs of the water-energy nexus, yielding the amount of energy required to run the system. The rest of the charts tally the amount of food required to maintain human health, the basic inputs required to grow the food, and the oxygen produced as a result of photosynthesis.

[Table 1] This table outlines the overall demographics. Included here are the division of ages in the colony and the population density. This was used to compare against other cities such as Paris and New York to determine a population density that is justifiable given the cost of land in the space colony.

[Table 1] Population

1	**Overall Population**	**1,000,000 People**
	Population of all Habitation Modules	900,000 People
	Population of all Agriculture Modules	100,000 People
	Population of all Habitation Modules per ring	112,500 People
	Population of all Agriculture Modules per ring	8,333 People
2	**Population Density of the Habitation modules**	**56,818 People/km^2**
	Population of one Habitation Module	5,114 People
	Population of one Agriculture Module	379 People
	Population Density of the agriculture modules	4,209 People/km2
3	Agriculture Space Population Division	10%
	Habitation Population Module Division	90%
4	Age bracket 0 to 9	10.8%
5	Age bracket 10 to 19	11.1%
6	Age bracket 20 to 29	13.8%
7	Age bracket 30 to 39	13.7%
8	Age bracket 40 to 49	13.4%
9	Age bracket 50 to 59	15.0%
10	Age bracket 60 to 69	11.5%
11	Age bracket 70 to 79	6.6%
12	Age bracket 80+	4.2%

1 Set thesis goal

2 "List of Cities by Population Density." Wikipedia. Accessed June 28, 2016. https://en.wikipedia.org/wiki/List_of_cities_by_population_density.

3 Dedicates 10% of the population to farming

4 H.R. Rep. No. 051-0001 at 1 (2015).

5 ibid

6 ibid

7 ibid

8 ibid

9 ibid

10 ibid

11 ibid

12 ibid

[Table 2] This table lists a series of attributes that define the overall geometry of the space colony. Included are all the basic massing dimensions and all of the information used to generate the parametric models in Grasshopper.

[Table 2] Enclosure

13	**Number of Rings For People**	**8**	**Rings**
14	Ratio of Agriculture modules to Habitation modules	1.5	Agriculture modules to 1 Habitation module
	Number of Rings For Agriculture	**12**	**Rings**
15	**Number of Modules**	**22**	**Modules**
	Length of each Module	**300**	**m**
	Linear Width of Colony	**300**	**m**
16	**Height of Enclosure**	**250**	**m**
	Length of each ring	**6,600**	**m**
	Area per Module	**90,000**	**m^2**
17	**Radius of colony**	**1,033**	**m**
18	End to End Length	1,200	m
	Structural member radius	6	m
19	Thickness of ground plane	35	m
20	**Levels of Land Required for Vegetation**	**8**	**Levels**
21	**Distance between levels**	**26.875**	**m**
22	Surface area of one module (not capped)	285,230	m2
23	Surface area of one ring	6,275,054	m2
24	Surface area of the Colony (capped)	125,651,071	m2
25	**Volume of a Module**	**19,447,480**	**m^3**
	Volume of a Ring	427,844,560	m3
	Volume of the total habitation space	3,422,756,479	m3
	Volume of the total Agriculture space	5,134,134,719	m3
	Volume of the total Colony	8,556,891,199	m3
26	Linear Velocity Required for 1g	100.7	m/s
27	**Rotations Per Min.**	**0.9**	**RPM**
	Seconds Per Rotation	66	s

13 Set to achieve the population density. This value is also abritary, the colony constantly grows

14 Based on the amount of food required per people

15 Based on a reasonable module size in referance to the overal colony

16 Height required to simulate a sky

17 Based on number of modules and length of each

18 The unwraveled length of one ring

19 The cross sectional radius of the main structural memeber connecting the one module to its opposite module

20 Refers to the amount of stories for farming required by the farming megastructure

21 Based on the ground to ceiling height of the module divided by the levels of land requried by the farming megastructure

22 Surface area of the module not including its ends

23 Surface area of one ring, not including its ends

24 Surface area of the whole colony

25 This value is needed to calcuate energy loss in the modules

26 This is the velocity that the outer ring of the colony will be traveling at

27 The rotations required to produce gravity. There is a conservative maximum of 6 RPM to prevent the coriolis effect. THE ROLE OF THE VESTIBULAR ORGANS IN SPACE EXPLORATION. Proceedings of The Fifth Symposium on the Role of Vestibular Organs in Space Exploration, Florida, Pensacola. 5th ed. NASA. 25-30. Accessed May 21, 2016.

[Table 3] This table assigns the width of the rivers, that run along the side of the space colony, which are used as a buffer to prevent the citizens from touching the edge of the colony. This is used help determine the amount of water needed housed in the enclosure.

[Table 4] These are the parameter that govern the housing sizes, the amount of people insides each unit, and the amount of public space the is needed to be directly adjacent to the property. They are based on the average condo size in Toronto (which is rather small).

[Table 3] Side Rivers

28	**Width of River from the edge**	**30 m**
	Land Used for Rivers per module	18,000.0 m2

[Table 4] Housing Parameters

29	**People Per Housing Stack Unit**	**2.5 People**
30	Average Housing Stack Size	95 m2
	Houses Per Floor	4 Units
	Floors Per Housing Stack	20 Floors
31	Housing Stacks in a Cluster	3 Housing Stacks
	Ratio of Open Area to Housing Stack footprint	**12 x**
	Height Per Floor	3.5 m
32	Open Area per Cluster	13,680 m2
	Housing Stack Footprint	380 m2
	People per Housing Stack	200 People
33	Total Area of Housing Stack Cluster	14,820 m2
	People Per Housing Stack Cluster	600 People
	Total Height of Housing Stack	70 m

28 Rivers that run across both sides of the colony to stop users from reaching the edge of the colony

29 Based on the amount of people living in a private residance in Toronto City of Toronto. 2011 Census: Marital Status, Families, Households and Dwelling Characteristics. Report. September 19, 2012. https://www1.toronto.ca/city_of_toronto/social_development_finance__administration/files/pdf/censusbackgrounder_hhds_2011.pdf.

30 Based on average Toronto condo size "Toronto's Shrinking Condos: Built for Families, Perfect for Roommates or Couples without Kids." The Globe and Mail, January 23, 2015. http://www.theglobeandmail.com/news/toronto/condos-for-families-without-the-space/article22602785/.

31 A cluster is a group of houses that share the same public space

32 open area dedicated to parks immediately around the housing cluster

33 This includes the open space around the housing stack dedicated to the residence

[Table 5] This table outlines the overall amount of housing required in the colony. It is based on the values found in Table 4. As the population grows the amount of housing automatically adjusts to compensate. A housing cluster is an amalgamation of housing towers that are grouped together to form a community.

[Table 6] This is the same information as Table 5 as it applies to the housing in the agricultural modules.

[Table 5] Habitation Housing Stats

Housing Stacks Required per Ring	563	Housing Stacks
Housing Stack Cluster Required per Ring	188	Clusters
Housing Stack Space Required	2,778,750	m2
Housing Stacks Required Per Module	26	Housing Stacks
Housing Stack Cluster Required per Module	9	Clusters
Housing Stack Space Required Per Module	126,307	m2
Total Space Required Per Module	126,307	m2
Space left for other things Per Module	-36,307	m2
Total Space Required	2,778,750	m2

[Table 6] Agriculture Housing Stats

Housing Stacks Required	42	Housing Stacks
Housing Stack Cluster Required	14	Clusters
Housing Stack Space Required	205,833	m2
Housing Stacks Required Per Module	1.9	Housing Stacks
Housing Stack Cluster Required per Module	0.6	Clusters
Housing Stack Space Required Per Module	28,068	m2
Total Space Required Per Module	28,068	m2
Space left for other things	61,932	m2
Total Space Required	205,833	m2
Space left for other things	1,774,167	m2

[Table 7] These are the parameter that govern the average office size and the amount of land needed for them. This is accounted for due to the transition that will occur from a resource and manufacturing economy to a service driven economy.

[Table 8] The average amount of offices dedicated to the housing modules. This table is similar to Table 6.

[Table 7] Office Stats

People Per Office Unit	7	People
Average Office Size	130	m2
Office Units Per Floor	10	Units
Floors Per Office	20	Floors
Housing Stacks in a Cluster	5	Offices
Open Area to Office footprint	4	x
Height Per Floor	4.5	m
Total Height of Office	90	m2
Open Area per Cluster	26,000	m2
Office Footprint M2	1,300	m2
People per Office	1,400	People
Total Area of Office Cluster	32,500	m2
People Per Cluster	7,000	People
Population Density Per Cluster (people/ m2)	0.2	People/m2
Space Person Floor Space	18.6	m2/person

[Table 8] Office Space

Office Share	60%	
Offices Required	48	Housing Stacks
Office Cluster Required	10	Clusters
Office Space Required	313,393	m2
Office Required Per Module	2	Housing Stacks
Office Cluster Required per Module	0	Clusters
Office Space Required Per Module	14,245	m2

[Table 9] This table outlines the amount of land dedicated to each sector in the colony per each ring.

[Table 10] The amount of energy gained through radiation from the sun. This is based on the surface area of the colony that faces directly towards the sun. This energy will be absorbed in the form of heat and is used to offset the amount of energy radiated out into space

[Table 9] Habitation Land Use

Reduction of Land available due to infrastructure	80%
Land Available	1.58 km2
Land for Residential	1.26 km2
Land for Offices	0.31 km2
Land for Water Ponds	0.40 km2

[Table 10] Gained Through Radiation from the Sun

	Radiation Conductivity	0.1
34	**Energy output from the to the average distance from the Sun (same distance as earth)**	**1,370 W/m²**
	Surface area of side always pointing towards Sun	1,953,823,490 W
	Surface area due to Mirrors	690,665,206.36 W
	Total Radiation gain from the Sun	2,644,488,696.72 W
	Total Radiation gain from the Sun in kWh	9,520,159,308 kWh
	Total Radiation gain	952,015,931 kWh

34 Tmurphy. "Basking in the Sun." Do the Math. January 17, 2012. Accessed May 21, 2016. http://physics.ucsd.edu/do-the-math/2012/01/basking-in-the-sun/.

[Table 11] This table outlines the amount energy lost to space through black body radiation. This rate is dependent on the surface area of the colony and the average temperature.

[Table 12] This table outlines the oxygen requirements for each module. This is based on the population of the colony.

[Table 13] This table outlines the amount of oxygen produced by vegetation. Because the amount of oxygen produced vastly outnumbers the amount oxygen required, the remaining oxygen needs to be burned to create enough CO2.

[Table 11] Loss through radiation to space

35	**Temperature min (at night)**	**16.0**	**Degrees Celsius**
	Temperature Max (During the day)	**25.0**	**Degrees Celsius**
	Average Temp	**20.5**	**Degrees Celsius**
	Radiation Conductivity	1.0	
	Watts lost through radiation	52,974,793,687.6	Watts
	Energy lost through radiation per day	190,709,257,275.2	kWh
36	**Energy needed to be generated per mod**	**9,487,862,067.219**	**kWh**

[Table 12] Oxygen Used Per Habitation modules

37	Oxygen Used Per Person	0.55	m3/day
	Oxygen Used Per module	2,813	m3/day

[Table 13] Oxygen Produced Through Plants in Habitation modules

38	Production per 1m2 of grass	0.0000006	m3/m2*day
	Grass Coverage	60%	
	Oxygen production by grass	0.05	m3/day
39	Production of oxygen per tree per day	0.2	m3/day
	Trees per module	1,000.0	Trees
	m2 per Tree	90	m2/Tree
	Tree Production of oxygen per module per day	226	m3/day
	Oxygen production by farming per mod	31,545	m3/day

35 Temperature change from day to night

36 Need to be cooled out

37 "How much oxygen does a person consume in a day?" 1 April 2000. HowStuffWorks.com. <http://health.howstuffworks.com/human-body/systems/respiratory/question98.htm> 21 May 2016

38 Nowak, David J., Robert Hoehn, and Daniel E. Crane. "Oxygen Production by Urban Trees in the United States." Arboriculture & Urban Forestry, May 2007, 220-26. http://www.nrs.fs.fed.us/pubs/jrnl/2007/nrs_2007_nowak_001.pdf.

39 "How much oxygen does a person consume in a day?" 1 April 2000. HowStuffWorks.com. <http://health.howstuffworks.com/human-body/systems/respiratory/question98.htm> 19 March 2016

[Table 14] This table outlines the amount of energy used by each person in the colony based on the amount of energy used by the average Californian. California was used in this instance because of its constant but not overly hot weather and their high minimum standards for building enclosures that result in a low amount energy used on HVAC.

[Table 15] This table outlines the amount of water used per person, based on the water use of the average Canadian, and the estimated amount of energy used to transport and clean that water.

[Table 16] This table outlines the combined energy, outlined in the previous, tables, used in the whole colony as outlined .

[Table 14] Energy usage by individuals per module

40	**Energy Use Per Person per day**	**50 kWh**
	Energy Use Per Habitation Module per day	254,567 kWh
	Energy Use Per Agricultural Module per day	18,857 kWh

[Table 15] Water Usage

41	**Water Usage Per Person per day**	**251.0 L**
	Water Usage Per module per day	1,283,522.7 L
	Water Usage Per Agricultural module per day	11,319,439.8 L
42	kWh per litre	0.015 kWh/L
	kWh per day per Habitation module	19,191.715 kWh/L
	kWh per day per agricultural module	169,252.527 kWh/L

40 U.S. Energy Information Administration. Household Energy Use in California. Report. 2009. http://www.eia.gov/consumption/residential/reports/2009/state_briefs/pdf/CA.pdf.

41 Stats Canada. "Residential Water Use in Canada." Government of Canada, Environment and Climate Change Canada. February 17, 2016. Accessed May 21, 2016. https://www.ec.gc.ca/indicateurs-indicators/default.asp?lang=en&n=7E808512-1.

42 "Water-Energy Connection." United States Environmental Protection Agency. February 23, 2016. Accessed May 21, 2016. https://www3.epa.gov/region9/waterinfrastructure/waterenergy.html.

[Table 17] This table defines the amount of energy generated in the colony using helium-3 fusion to make up for the energy demands of the colony. These values are based off the theoretical yield of the Helium-3, no large scale fusion reactor has ever been built.

[Table 16] Total energy usage

Total energy used per Agricultural module per day	9,488,050,176.5 kWh
Total energy used per Agricultural module per year	3,463,138,314,436.6 kWh
Total energy used per Agricultural module Watts	2,635,569,493.5 W
Total energy used per Habitation rings per year	961,982,865,121.3 W
Total energy used per Habitation module per day	9,488,135,825.6 kWh
Total energy used per Habitation module per year	3,463,169,576,361.5 kWh
Total energy used per Habitation module Watts	2,635,593,284.9 W
Total energy used per Habitation module per year Watts	961,991,548,989.3 W

[Table 17] Energy Generation

43	**Helium ^{3} Fusion Yield**	**12.86 MeV**
	Amount of Helium ^{3} required per Ag module per day	**165,172 g/day**
	Amount of Helium ^{3} required per module per year	**60,288 kg/year**
	Amount of Helium ^{3} required per habitation module per day	**165,174 g/day**
	Amount of Helium ^{3} required per module per year	**60,289 kg/year**
	Total Helium ^{3} Required for the colony	**26,526,797 kg/year**

43 Kulcinski Kulcinski, G.L. "3He Fusion: A Safe, Clean, and Ec 3He Fusion: A Safe, Clean, and Economical Energy onomical En-

[Table 18] The dietary requirements required by people in the colony. This is based off the Canada Food Guide. This information is used to inform the amount of growing required to satisfy the human nutrient needs, outlined in the following tables.

[Table 18] Food Use

44	Consumption Age bracket 0 to 9	1,850	Calories/day
45	Consumption Age bracket 10 to 19	2,825	Calories/day
46	Consumption Age bracket 20 to 29	3,000	Calories/day
47	Consumption Age bracket 30 to 39	2,900	Calories/day
48	Consumption Age bracket 40 to 49	2,900	Calories/day
49	Consumption Age bracket 50 to 59	2,650	Calories/day
50	Consumption Age bracket 60 to 69	2,650	Calories/day
51	Consumption Age bracket 70 to 79	2,500	Calories/day
52	Consumption Age bracket 80+	2,500	Calories/day
	Waste Per Food Eaten	1.1	x
	Food Generated Per Habitation module	15,106,078	Calories/day
	Food Generated Per Agriculture module	1,118,969	Calories/day
	Total Food Generated for the Colony	2,954,077,500	Calories/day
53	Fat	30.0%	Calorie Intake
54	Protein	20.0%	Calorie Intake
55	Carbohydrates	50.0%	Calorie Intake
	Fat Mass Generated Per module	**373**	**kg/day**
	Protein Mass Generated Per module	**559**	**kg/day**
	Carbohydrates Mass Generated Per module	**1,399**	**kg/day**

ergy Source For Future Generations Generations " 29 March 1996. 14 May 29 March 1996. 14 May 2006<http://fti.neep.wisc.ed http://fti.neep.wisc.edu/neep602/lecture27.html u/neep602/lecture27.html>

44 Health Canada. "Estimated Energy Requirements." Estimated Energy Requirements. March 20, 2014. Accessed May 21, 2016. http://www.hc-sc.gc.ca/fn-an/food-guide-aliment/basics-base/1_1_1-eng.php.

45 ibid

46 ibid

47 ibid

48 ibid

49 ibid

50 ibid

51 ibid

52 ibid

53 "Do Canadian Adults Meet Their Nutrient Requirements Through Food Intake Alone?" Health Canada. March 15, 2012. Accessed June 27, 2016. http://www.hc-sc.gc.ca/fn-an/surveill/nutrition/commun/art-nutr-adult-eng.php.

54 ibid

55 ibid

[Table 19] This table outlines growing requirements for coconut oil. Included are the macro-nutrients of dietary fat, carbohydrate and protein. Coconut oil is chosen as a method to primarily provide our dietary fat needs. In this table the coconut oil is responsible for 45% of all the dietary fat needed to be produced on the colony. The Land Use field is calculated based on the amount of land a coconut tree requires to grow, the amount of coconut produced per tree and the amount of oil that can be extracted per coconut.

[Table 20] Similar to the previous table, this table outlines growing requirements for flax seed.

[Table 19] Coconut Oil Generation

56	Coconut Oil Carbohydrate	0.0%	of total weight
57	Coconut Oil Fat	100.0%	of total weight
58	Coconut Oil Protein	0.0%	of total weight
	Total Amount required Carbohydrate	0%	
	Total Amount required Fat	**45%**	
	Total Amount required Protein	0%	
	Mass Needed	168	kg
	Land Use	**61,500**	**m^2**
	Oxygen produced per day	3,232	m3
59	Water USe per day	3	m3

[Table 20] Flax Seed Generation

60	Flax Seed Carbohydrate	29.0%	of total weight
61	Flax Seed Fat	42.0%	of total weight
62	Flax Seed Protein	18.0%	of total weight
	Total Amount required Carbohydrate	16.02%	
	Total Amount required Fat	**18.92%**	
	Total Amount required Protein	12.91%	
	Mass Needed	168	kg
63	**Land Use**	**360,676**	**m^2**
	Oxygen produced per day	504,178	m3
64	Water Use per day	405	m3

56 United States Department of Agriculture. Oil, Coconut. Report no. 04047. Accessed May 21, 2016. https://ndb.nal.usda.gov/ndb/foods/show/659?fgcd=&manu=&lfacet=&format=&count=&max=35&offset=&sort=&qlookup=Oil coconut.

57 ibid

58 ibid

59 http://agridr.in/expert_system/coconut/coconut/coconut_irrigation_management.html

60 United States Department of Agriculture. Seeds, Flaxseed a B. Report no. 12220. United States Department of Agriculture, 2016. Accessed May 21, 2016. https://ndb.nal.usda.gov/ndb/foods/show/3716?fgcd=&man=&lfacet=&count=&max=35&sort=&qlookup=12220&offset=&format=Abridged&new=&measureby=.

61 ibid

62 ibid

63 "Growing Flax." Saskatchewan Flax Development Commission. Accessed May 21, 2016. http://www.saskflax.com/growing/seeding.php.

64 Minisry of Agriculture, Food and Rural Affairs, and OMAFRA Staff. "Other Crops." Other Crops. April 30, 2009. Accessed May 21, 2016. http://www.omafra.gov.on.ca/english/crops/pub811/7other.htm#flax.

[Table 21] Similar to the previous table, this table outlines growing requirements for peanuts.

[Table 21] Peanut Generation

65	Peanut Carbohydrate	16.0%	of total weight
66	Peanut Fat	49.0%	of total weight
67	Peanut Protein	26.0%	of total weight
	Total Amount required Carbohydrate	8.84%	
	Total Amount required Fat	**22.07%**	
	Total Amount required Protein	18.64%	
	Mass Needed	168	kg
68	**Land Use**	**360,676**	**m^2**
	Oxygen produced per day	1,628,655	m3
69	Water Use per day	1,309	m3

65 United States Department of Agriculture. Peanuts, All Types, Raw. Report no. 16087. Agricultural Research Habitation. Accessed May 21, 2016. https://ndb.nal.usda.gov/ndb/foods/show/4825?fgcd=&manu=&lfacet=&format=&count=&max=35&offset=&sort=&qlookup=peanut.

66 ibid

67 ibid

68 "Growing & Harvesting." Peanut USA. Accessed May 21, 2016. https://www.peanutsusa.com/about-peanuts/the-peanut-industry3/11-growing-harvesting.html.

69 "National Peanut Board." National Peanut Board How Peanuts Grow Comments. March 24, 2016. Accessed May 21, 2016. http://nationalpeanutboard.org/the-facts/how-peanuts-grow/.

[Table 22] Similar to the previous table, this table outlines growing requirements for brown rice.

[Table 23] Similar to the previous table, this table outlines growing requirements for oats.

[Table 22] Brown Rice Generation

70	Brown Rice Carbohydrate	23.0%	of total weight
71	Brown Rice Fat	0.9%	of total weight
72	Brown Rice Protein	2.6%	of total weight
	Total Amount required Carbohydrate	**12.71%**	
	Total Amount required Fat	0.41%	
	Total Amount required Protein	1.86%	
	Mass Needed	773	kg
	Land Use	**261,167**	**m^2**
	Oxygen produced per day	1,377,108	m3
	Water USe per day	1,107	m3

[Table 23] Oats Generation

73	Oats Carbohydrate	66.0%	of total weight
74	Oats Fat	7.0%	of total weight
75	Oats Protein	17.0%	of total weight
	Total Amount required Carbohydrate	**36.46%**	
	Total Amount required Fat	3.15%	
	Total Amount required Protein	12.19%	
	Mass Needed	773	kg
76	**Land Use**	**940,202**	**m^2**
	Oxygen produced per day	2,327,396	m3
77	Water USe per day	1,870	m3

70 United States Department of Agriculture. Rice, Brown, Long-grain, Cooked. Report no. 20037. Agricultural Research Habitation, 2016. Accessed May 21, 2016. https://ndb.nal.usda.gov/ndb/foods/show/6506?fgcd=&manu=&lfacet=&format=&count=&max=35&offset=&sort=&qlookup=brown+rice.

71 ibid

72 ibid

73 United States Department of Agriculture. Oats. Report no. 20038. Agricultural Research Habitation, 2016. Accessed May 21, 2016. https://ndb.nal.usda.gov/ndb/foods/show/6507?fgcd=&manu=&lfacet=&format=&count=&max=35&offset=&sort=&qlookup=oats.

74 ibid

75 ibid

76 Prairie Oat Growers Association. "Promoting Canadian Oats." Oats by the Numbers. Accessed May 21, 2016. http://poga.ca/about-oats/oats-by-the-numbers#!OatsByTheNumbers1.

77 Boehrer, Katherine. "This Is How Much Water It Takes To Make Your Favorite Foods." The Huffington Post. April 13, 2015. Accessed May 21, 2016. http://www.huffingtonpost.com/2014/10/13/food-water-footprint_n_5952862.html.

[Table 24] Similar to the previous table, this table outlines growing requirements for potato.

[Table 25] Similar to the previous table, this table outlines growing requirements for ground beef.

[Table 24] Potato Generation

78	Potato Carbohydrate	17.0%	of total weight
79	Potato Fat	0.1%	of total weight
80	Potato Protein	2.0%	of total weight
	Total Amount required Carbohydrate	**9.39%**	
	Total Amount required Fat	0.05%	
	Total Amount required Protein	1.43%	
	Mass Needed	773	kg
	Land Use	**60,013**	**m^2**
	Oxygen produced per day	272,867	m3
	Water USe per day	219	m3

[Table 25] Ground Beef Generation

81	Ground Beef Carbohydrate	0.0%	of total weight
82	Ground Beef Fat	15.0%	of total weight
83	Ground Beef Protein	20.0%	of total weight
	Total Amount required Carbohydrate	0.00%	
	Total Amount required Fat	6.76%	
	Total Amount required Protein	**14.34%**	
	Mass Needed	401	kg
84	**Land Use**	**6,018**	**m^2**
85	Water USe per day	66	m3

78 United States Department of Agriculture. Potatoes, Raw, Skin. Report no. 11362. Agricultural Research Habitation. Accessed May 21, 2016. https://ndb.nal.usda.gov/ndb/foods/show/3090?manu=&fgcd=.

79 ibid

80 ibid

81 United States Department of Agriculture. Beef, Ground, 85% Lean Meat / 15% Fat, Loaf, Cooked, Baked. Report no. 23571. United States Department of Agriculture, 2016. Accessed May 21, 2016. https://ndb.nal.usda.gov/ndb/foods/show/7615?fgcd=&manu=&lfacet=&format=&count=&max=35&offset=&sort=&qlookup=ground+beef.

82 ibid

83 ibid

84 "Water Requirements of Livestock." Water Requirements of Livestock. Accessed May 21, 2016. http://www.omafra.gov.on.ca/english/engineer/facts/07-023.htm#2.

85 Cattlemen's Beef Board and National Cattlemen's Beef Association. Modern Beef Production | Fact Sheet. Report. September 2009. Accessed May 21, 2016. http://www.explorebeef.org/cmdocs/explorebeef/factsheet_modernbeefproduction.pdf.

[Table 26] Similar to the previous table, this table outlines growing requirements for chicken breast.

[Table 27] Similar to the previous table, this table outlines growing requirements for soybean.

[Table 26] Ground Chicken Generation

86	Ground Chicken Carbohydrate	0.0%	of total weight
87	Ground Chicken Fat	8.0%	of total weight
88	Ground Chicken Protein	17.9%	of total weight
	Total Amount required Carbohydrate	0.00%	
	Total Amount required Fat	3.62%	
	Total Amount required Protein	**12.80%**	
	Mass Needed	401	kg
89	**Land Use**	**13,984**	**m^2**
90	Water Use per day	4.9	m3

[Table 27] Soybean Generation

91	Soybean Carbohydrate	30.0%	of total weight
92	Soybean Fat	30.0%	of total weight
93	Soybean Protein	36.0%	of total weight
	Total Amount required Carbohydrate	16.57%	
	Total Amount required Fat	13.51%	
	Total Amount required Protein	**25.81%**	
	Mass Needed	401	kg
94	**Land Use**	**542,346**	**m^2**
	Oxygen produced per day	7,766,194	m3
95	Water USe per day	6,241	m3

86 United States Department of Agriculture. Chicken, Ground, Crumbles, Cooked, Pan-browned. Report no. 05333. Agricultural Research Habitation, 2016. Accessed May 21, 2016. https://ndb.nal.usda.gov/ndb/foods/show/1059?fgcd=&manu=&lfacet=&format=&count=&max=35&offset=&sort=&qlookup=Ground+Chicken.

87 ibid

88 ibid

89 Texas Agricultural Extension Habitation. Cost and Yeild Comparisons Of Ready-to-Cook Chicken Products. Report no. L-2290. Accessed May 21, 2016. http://posc.tamu.edu/wp-content/uploads/sites/20/2012/08/l-2290.pdf.

90 "Water Requirements of Livestock." Water Requirements of Livestock. Accessed May 21, 2016. http://www.omafra.gov.on.ca/english/engineer/facts/07-023.htm#6.

91 United States Department of Agriculture. Soybeans, Green, Raw. Report no. 11450. Agricultural Research Habitation. Accessed May 21, 2016. https://ndb.nal.usda.gov/ndb/foods/show/3162?fgcd=&manu=&lfacet=&format=&count=&max=35&offset=&sort=&qlookup=Soybean.

92 ibid

93 ibid

94 World Soybean Production: Area Harvested, Yield, and Long-Term Projections, 2009. Accessed May 21, 2016. https://www.ifama.org/files/20091023_Formatted.pdf.

95 "FAO - Water Development and Management Unit - Crop Water Information: Maize." Crop Water Information: Soybean. Accessed May 21, 2016. http://www.fao.org/nr/water/cropinfo_soybean.html.

[Table 28] This table shows the space requirements for livestock and vegetation based on current growing technologies. In this table the area needed to grow food per each agricultural module is divided by the ground surface area of the colony.

[Table 29] Similar to table 28 this table details the space requirements for livestock and vegetation based on an estimation of future growing technologies and crop yield capabilities. This information is used to inform the design needs of the farming mega structure and used to determine the amount of storeys the agricultural module should include in order to house the farming operation.

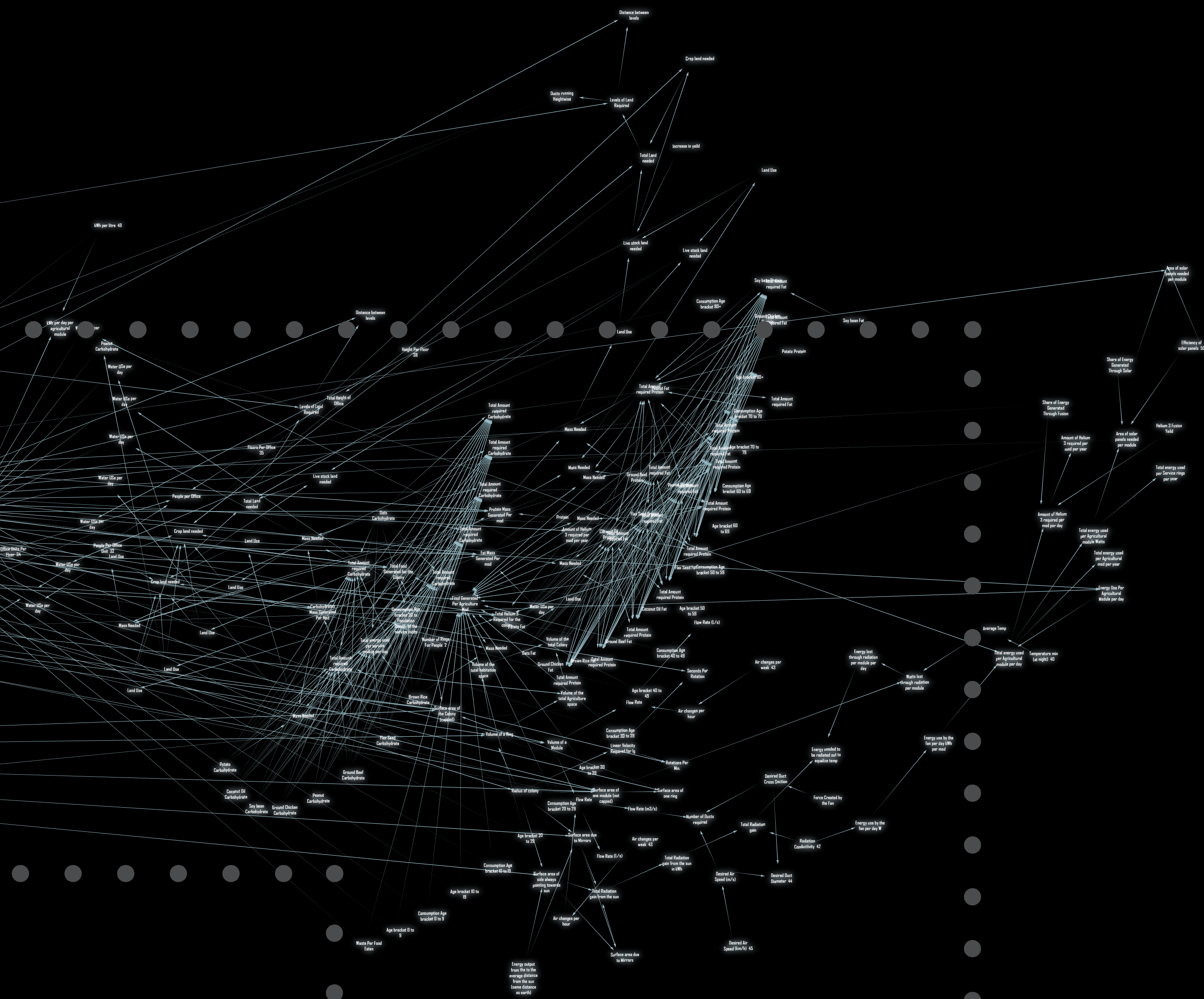
[Table 28] Land Based on Calculated food requirements per module based on today's efficacy

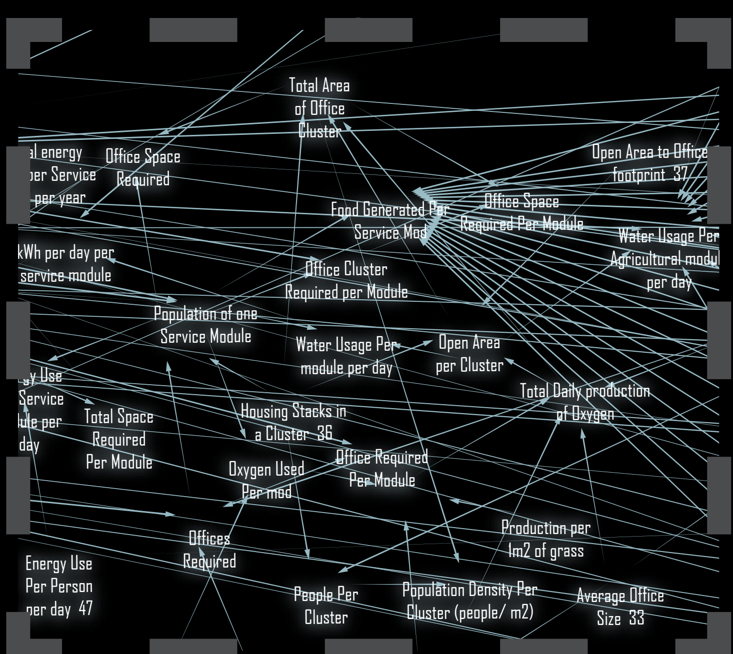
Cropland needed	2,325,413 m2
Livestock land needed	20,001 m2
Total Land needed	2,345,415 m2
Land in module available for farming	70%
Land available	63,000 m2
Levels of Land Required	**38**
Distance between levels	**5.657894737 m**

[Table 29] Land Based on Calculated food requirements per module based on predicted efficacy

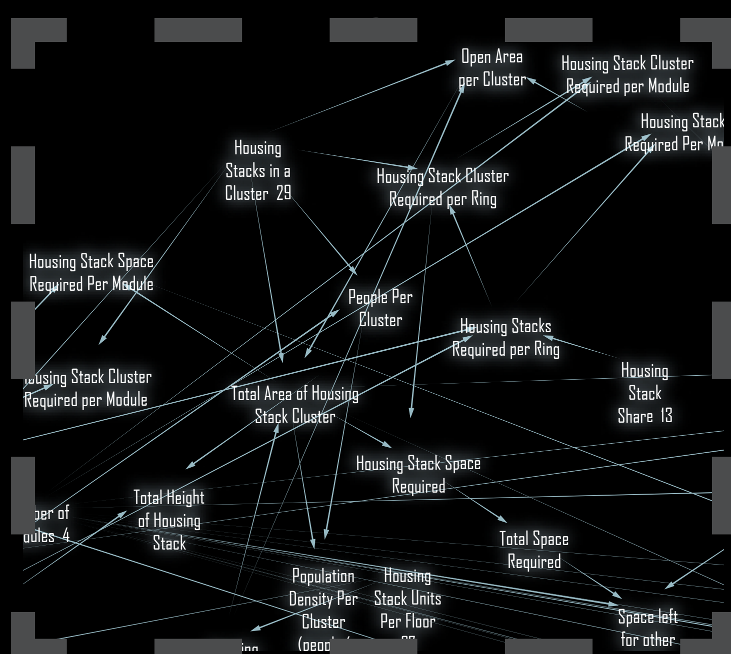
Increase in Yield	**5 x**
Cropland needed	465,083 m2
Livestock land needed	4,000 m2
Total Land needed	469,083 m2
Land in module available for farming	70%
Land available	63,000 m2
Levels of Land Required	**8 Levels**
Distance between levels	**26.875 m**

[Figure 57]A visualization of the Excel spreadsheet used to model the ecosystem and create the previous tables.





Total Area of Office Cluster
Office Space Required
Food Generated Per Service Mod
Office Space Required Per Module
Open Area to Office footprint 37
Water Usage Per Agricultural module per day
Office Cluster Required per Module
Population of one Service Module
Water Usage Per module per day
Open Area per Cluster
Total Daily production of Oxygen
Total Space Required Per Module
Housing Stacks in a Cluster 36
Office Required Per Module
Oxygen Used Per mod
Offices Required
Production per 1m2 of grass
Energy Use Per Person per day 47
People Per Cluster
Population Density Per Cluster (people/ m2)
Average Office Size 33



Open Area per Cluster
Housing Stack Cluster Required per Module
Housing Stacks in a Cluster 29
Housing Stack Cluster Required per Ring
Housing Stack Space Required Per Module
People Per Cluster
Housing Stacks Required per Ring
Housing Stack Share 13
Total Area of Housing Stack Cluster
Housing Stack Space Required
Total Height of Housing Stack
Total Space Required
Population Density Per Cluster
Housing Stack Units Per Floor
Space left for other

Mankind was born on Earth ...
it was never meant to die here.

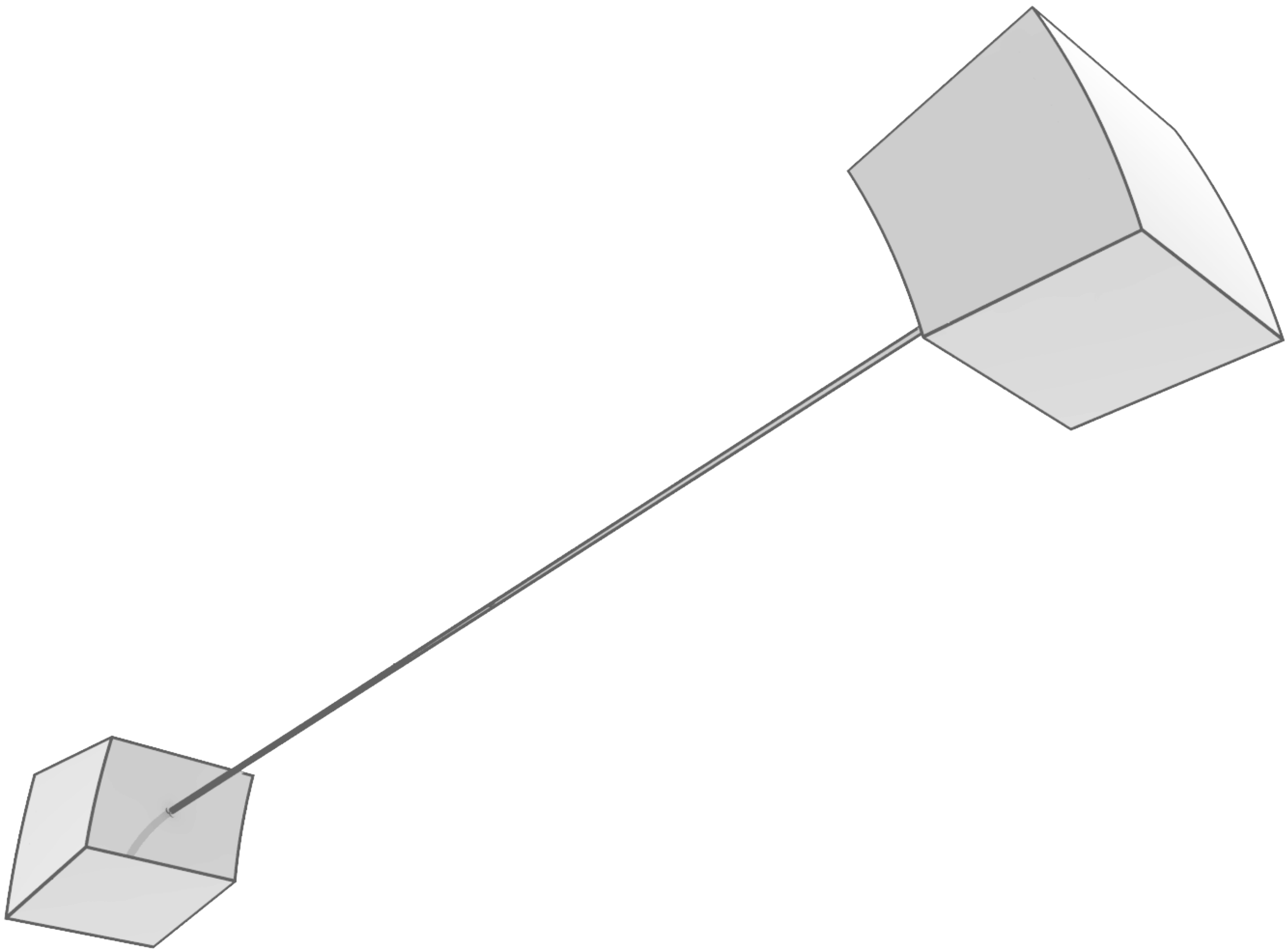
–Cooper, Interstellar

DESIGN

Designing in space is different than designing on the Earth. There is no gravity, no atmosphere, and we have no way of naturally surviving within its vacuum. A building rarely reaches completion by the efforts of one builder and this thesis involves a level of complexity beyond the scope of my discipline. I know that I'm making a city of 1 million people and that it is set in space, but every detail past that will be made based on predictions that will not be confirmed for many years even decades.

This section, however, still takes the strategy narrative and ecosystems speculation into one that is very speculative but still realizable.

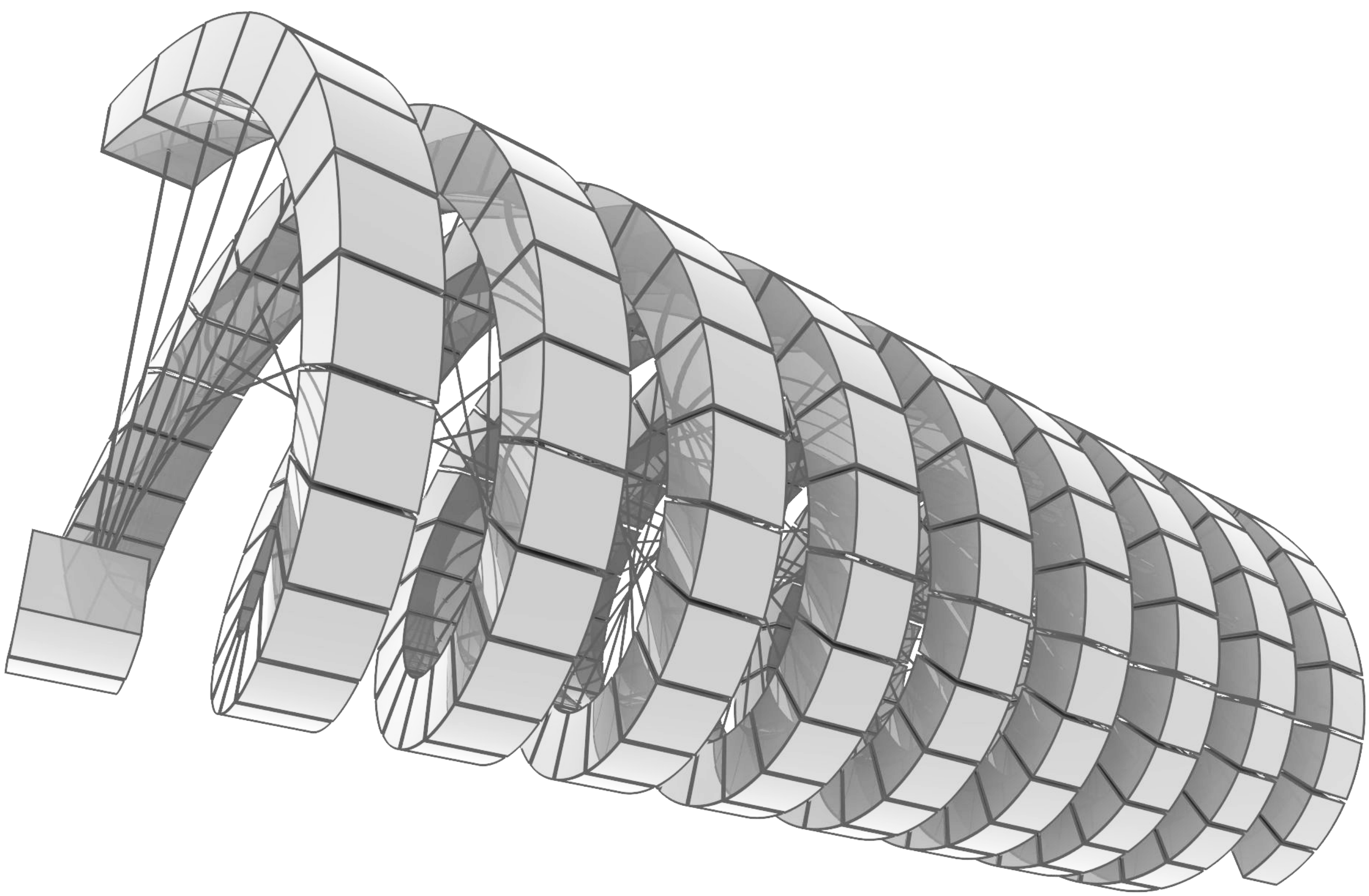
[Figure 58]Initial habitation modules. This will grow into a double helix. The two modules need to be made in pairs in order to maintain complete balance



Massing

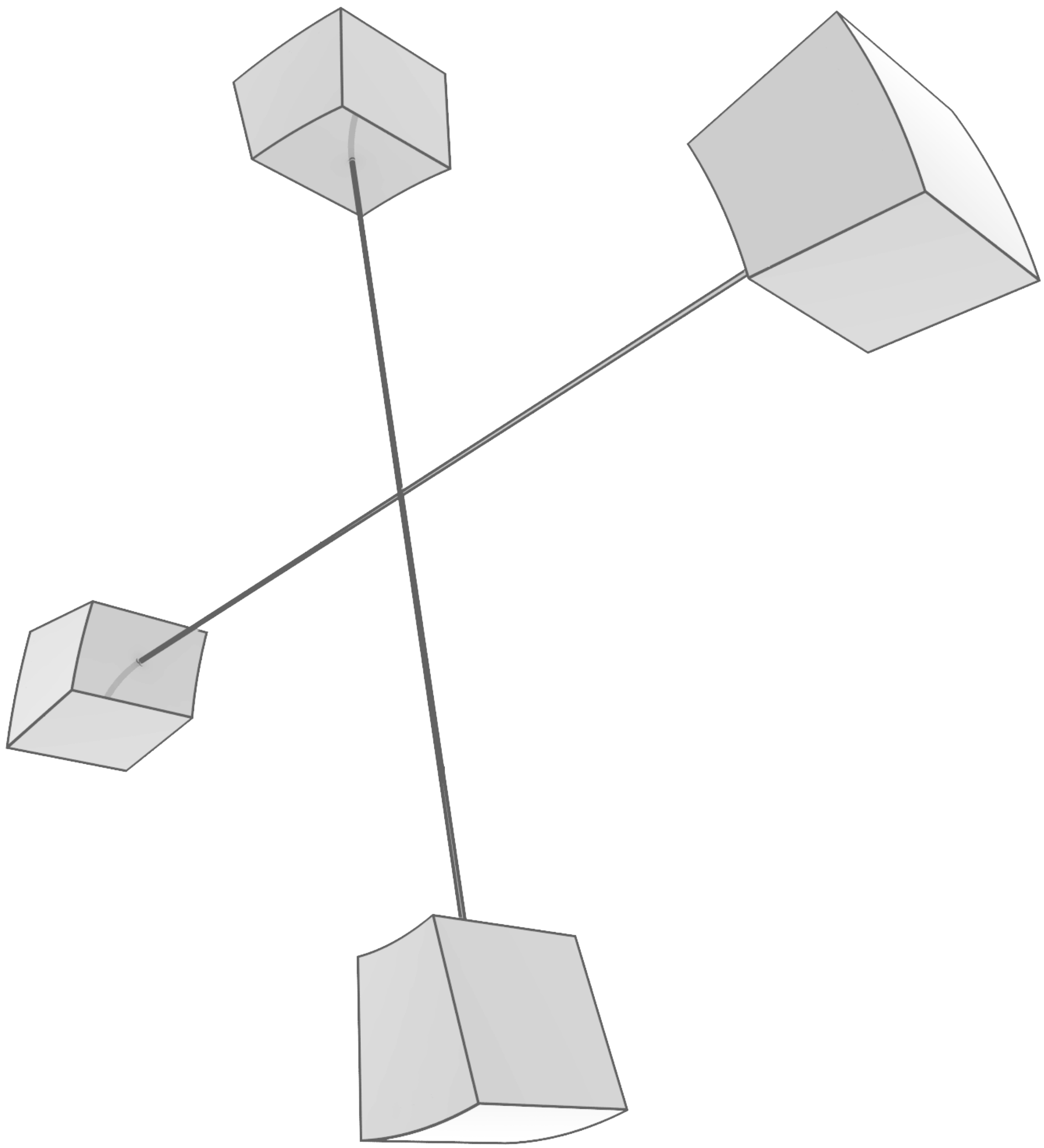
This colony will be built in stages to accommodate its increasing autonomy. It will begin as a primitive mining town, built on top of a comet, completely dependant on the Earth. It will grow into an assembly of prefabricated modules where people can live without needing a primary place of residence on the Earth. The modules are built in opposite pairs of equal mass attached to each other using one structural member, most likely a high tension cable. These pairs of modules are spun about

[Figure 59]This is the full double helix. At his point the colony is only comprised of habitation modules and has no modules dedicated to farming.



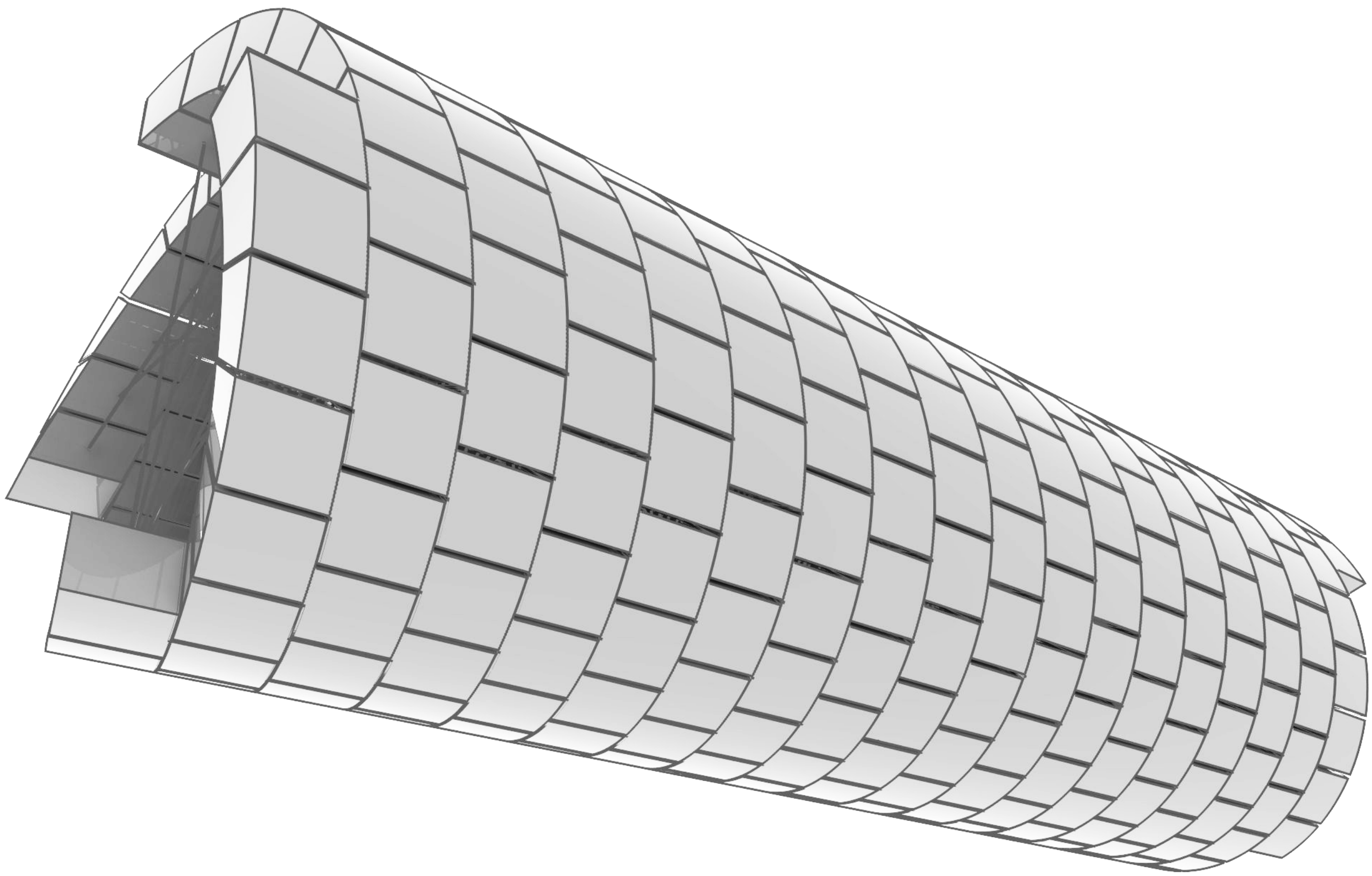
their center of gravity to create a centripetal force great enough to equal the Earth's force of gravity. The mass of each pair of modules will be monitored to maintain a complete balance. As the colony grows, more modules will be attached to the previous and the colony will begin to form a double helix . Much like in O'Neill's cylinder, the population will be housed on the inside of the enclosed helix and a person standing upright in the colony will have his body pointing towards the colony's axis of spin. Unlike O'Neill's cylinder, the form of a helix allows for the colony to be built sequentially in smaller parts while still maintaining complete balance as it spins to create its artificial gravity.

[Figure 60]At this stage initial modules for agriculture are added. The colony as a whole, when the agriculture modules are added, will grow as a quadruple helix to form a cylinder. The two agricultural modules also need to be made in pairs in order to maintain complete axial balance. They do not need to match the mass of the habitation modules which will also have mass balance.



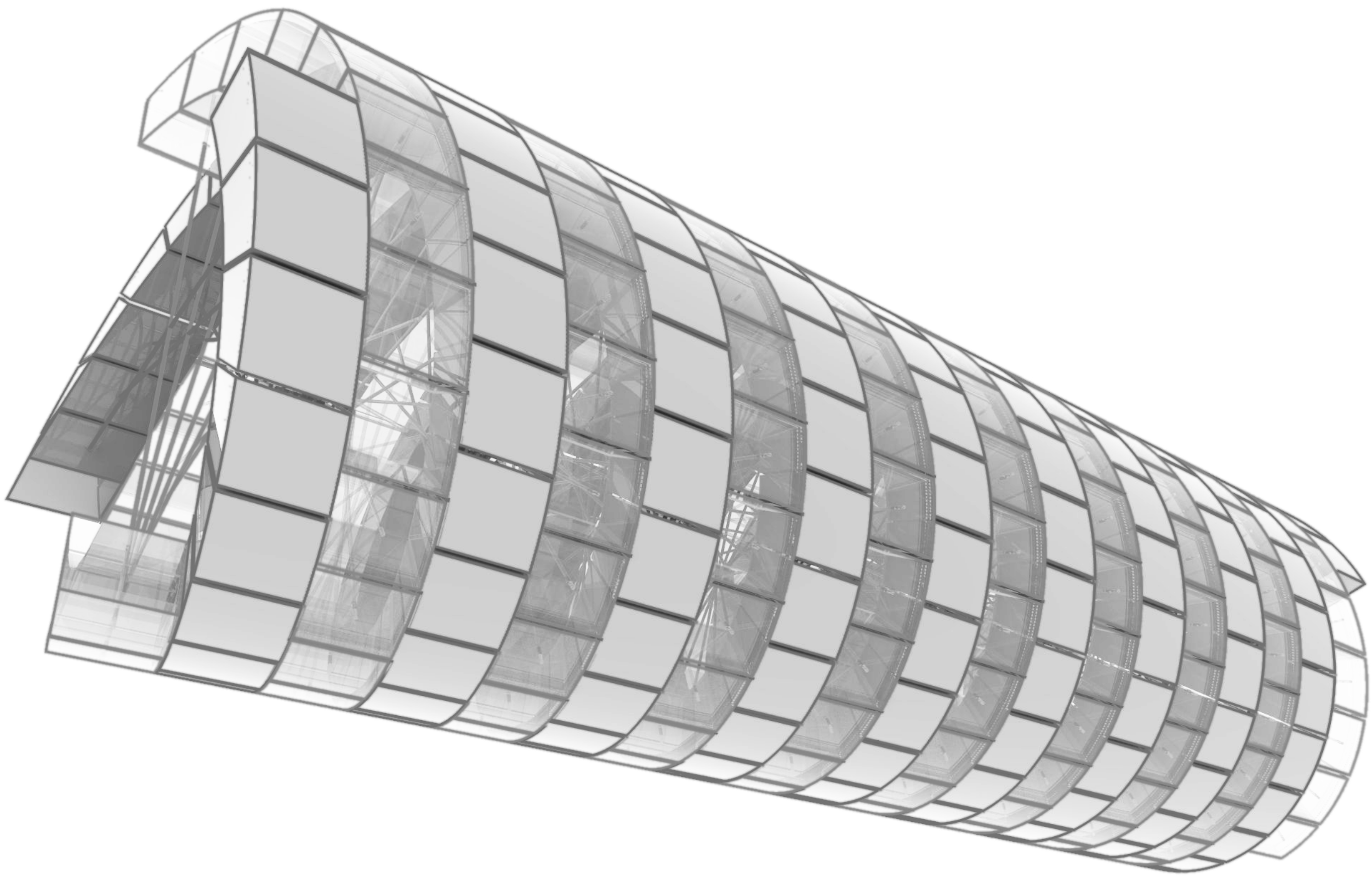
Growing food on the colony will be more economical than shipping it from the Earth but the effort to grow it will need to be in development. Once the technology is up to par a second set of modules that mirrors the habitation modules will be built to house vegetation. The colony during these stages will grow from being form and a mass built to accommodate the bare necessities of life, to a prefabricated set of living modules growing as a double helix and then, to a quadruple helix that forms a hollow cylinder to accommodate food growth.

[Figure 61]The completed Massing of the Colony



The quadruple helical form grants the colony the convenience to grow the habitation modules and agricultural modules at different rates while maintaining the colony's axis of rotation. This will help accommodate the gradual shift from terrestrial resource dependence to the colony's own independence. Within this framework a series of alternating housing and vegetation rings will be constructed adjacent to each other). This will cause any catastrophic impact damage from space debris to the colony to be spread across an array of both housing and agricultural modules. If such an event would occur, the inhabitants will be able to evacuate to the adjacent low population agricultural

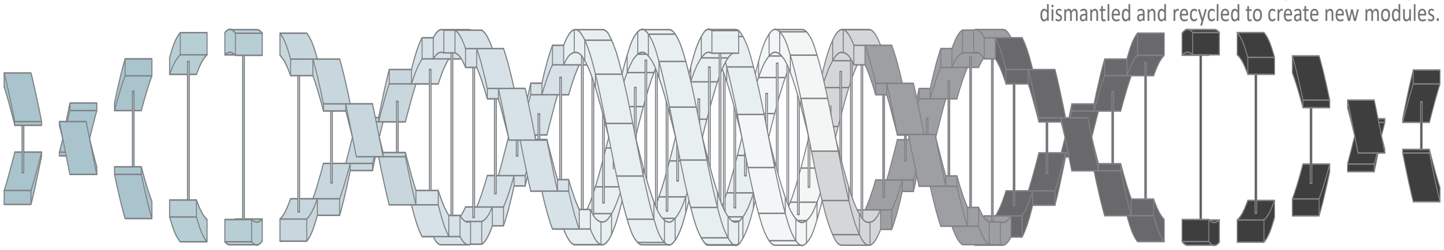
[Figure 62]This image illustrates how both the agriculture and habitation modules can grow continuously but never conflict with each other. The solid colour illustrates the habitation modules and the clear illustrates the agricultural modules.



modules, increasing the safety and efficiency of the whole evacuation process. Also, if the impact was great enough to damage more than one module, instead of multiple habitation modules (carrying a population of 5000 people each) being harmed, the damage will be spread across more agricultural modules with lower populations.

The helix allows for the colony to be physically extended at one of the end of its overall form. This ability to grow sets it apart from its previous space colony proposals such as O'Neill's c ylinder

[Figure 63]This colony is a mechanical object. At some point in time it will eventually fail. For this reason, it is designed as an entity to exist in a state of constant construction. At one end, additions are being continually added in the form of double habitation modules. This leaves the other end of the colony with the oldest modules, closest to their end of their life. They will eventually be dismantled and recycled to create new modules.

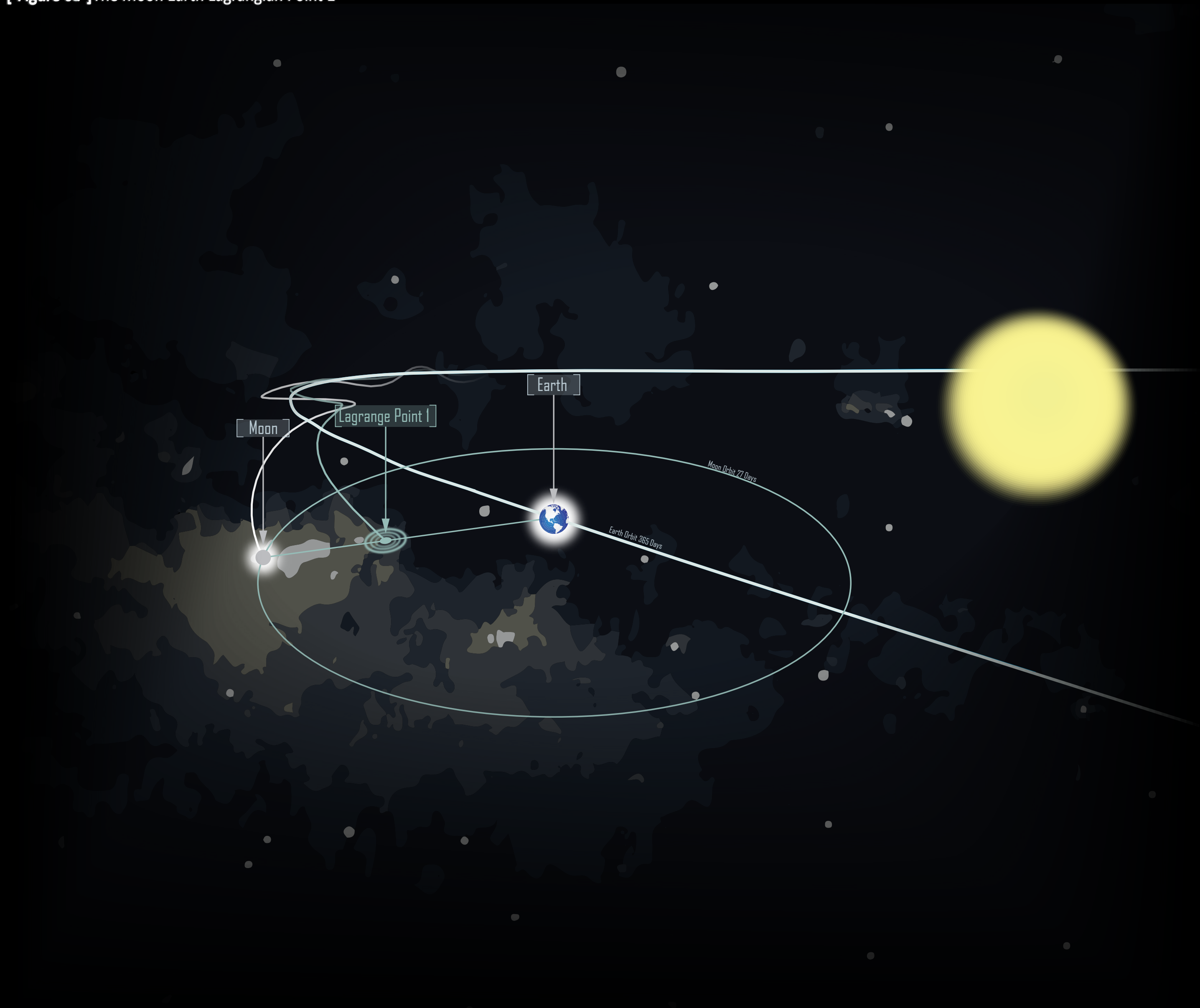


or the circular space station like Elysium or in Interstellar. All space habitats, due to their mechanical nature, will suffer from degradation and eventually reach their end of life. This would cause the whole population to evacuate the station. In this thesis such catastrophe is prevented with the helical massing. The station can be partially decommissioned while it grows. As the colony grows on one end, the opposite end will always be the oldest and most likely to be repaired or decommissioned. This portion can then be recycled. Throughout the repair, the colony's inhabitants will simply move over to the other, newer, rings allowing the colony as a whole, and the culture it maintains to live on.

Setting in Space

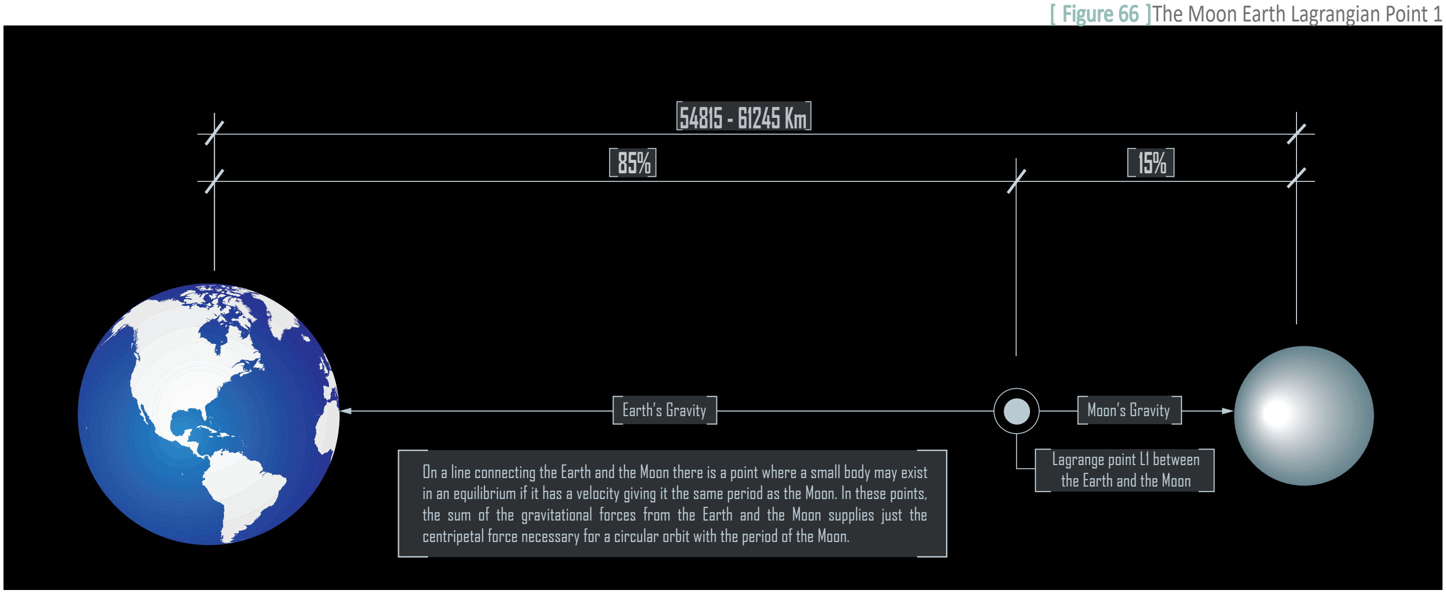
The colony is situated in Lagrangian Point 1 in between the Earth and the Moon along the most direct line between the two bodies. This establishes the colony as a convenient port in between the Moon and the Earth for mining purposes and transportation logistics.

[Figure 64]The Moon Earth Lagrangian Point 1



If the Moon is mined, the spacecraft that would be required to deliver directly from the Moon to the Earth will undergo significant wear and tear, specifically when entering the Earth's atmosphere. The Moon on the other hand lacks an atmosphere and any spacecraft entering into the Moon's gravity would experience no frictional drag that would add to the degradation of the spacecraft. To avoid this wear, colony-to-the Moon spacecrafts can be designed to be used multiple times, while spacecrafts arriving at the Earth may only be used once. Eventually, space elevators will be used to replace ground to space shuttles entirely. The colony can also act as a place of refuge in case of an emergency on the

[Figure 66]The Moon Earth Lagrangian Point 1



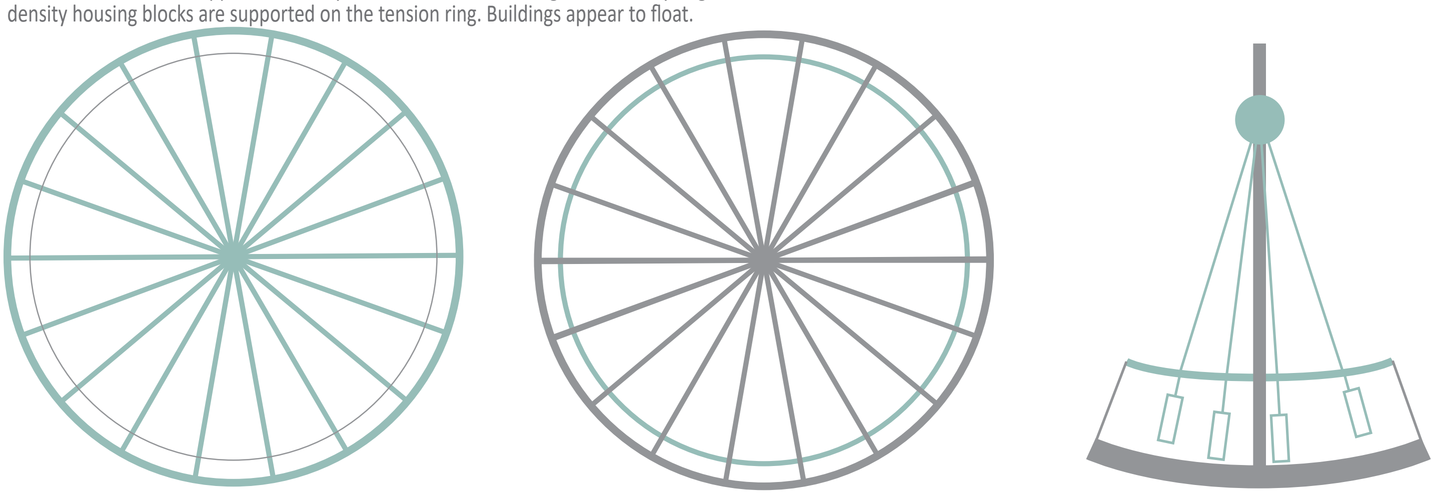
mining area of the Moon.

Structure For Building

The major structural supports of the colony resemble a bicycle wheel in elevation. In a similar method that bike spokes support the wheel, the primary structure is composed of tensile members connecting each module pair to support the helix. The ground of the helix becomes a beam spanning between the major structural support cable (the spokes) in a curved manner. High-density multi story residential structures, with a low building footprint, are essentially large point loads and are inefficient to have scattered across this beam. Instead of having those high point loads rest on the beam, what would happen instead is a grid of two way beams would line the sky and be tied back to the main structure via a tensile rod. The buildings would then be hooked onto this series of beams and hang, appearing to be hooked onto the sky. The inhabitants will have a vista of floating buildings.

Housing

As mentioned above, large buildings will be dominated by tension based forms, causing an inverted construction, instead of building up, we will build down. In this context current methods of construction would be difficult and hard to incorporate in this

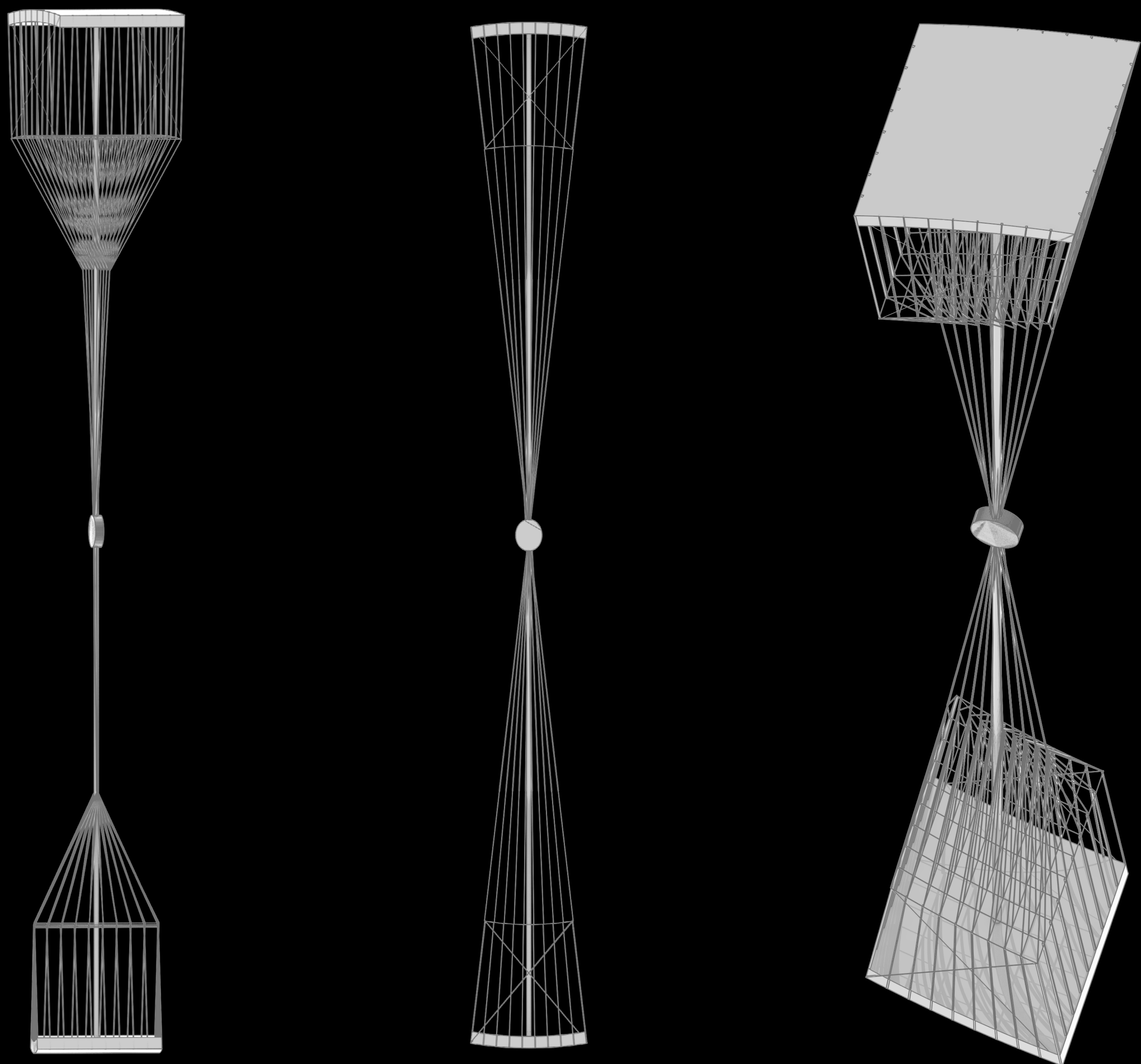


[Figure 67]Tensile members act like bike spokes to support the floor of the colony. Tensile Members also support a two way beam that line the ceiling of the colony. High density housing blocks are supported on the tension ring. Buildings appear to float.

enclosure. The tradition of cast-in-place concrete, wood-frame construction, or even structural steel framing would all have to be rethought in a construction method that is dominated by tension rather than compression. Within these parameters it is advantageous to explore the new possibilities through modularity and prefabrication.

On the Earth, large scale prefabrication is very limited, especially in climate zones with harsh weather like Canada. Due to the hostility of some outdoor environments and the energy required to mechanically maintain a comfortable indoor environment, various types of complex building enclosures have been mandated. These enclosures, however, require a large sense of customization and are comprised of many different materials, hampering our ability to efficiently prefabricate them. To 3D print an occupiable house in Canada, you would need to simultaneously print the insulation, the structure, barrier membranes and finishes; which although is technically possible, is difficult and inefficient to do in a prefabricated manner. In the space colony, however,

[Figure 68]Detailed views of the module pairs shown in elevation and axonometric. A series of tensile cables are attached to the pair of module's centroid and radiate out to support the two-way beams at their intersection. Buildings are hung at these intersections along the beams

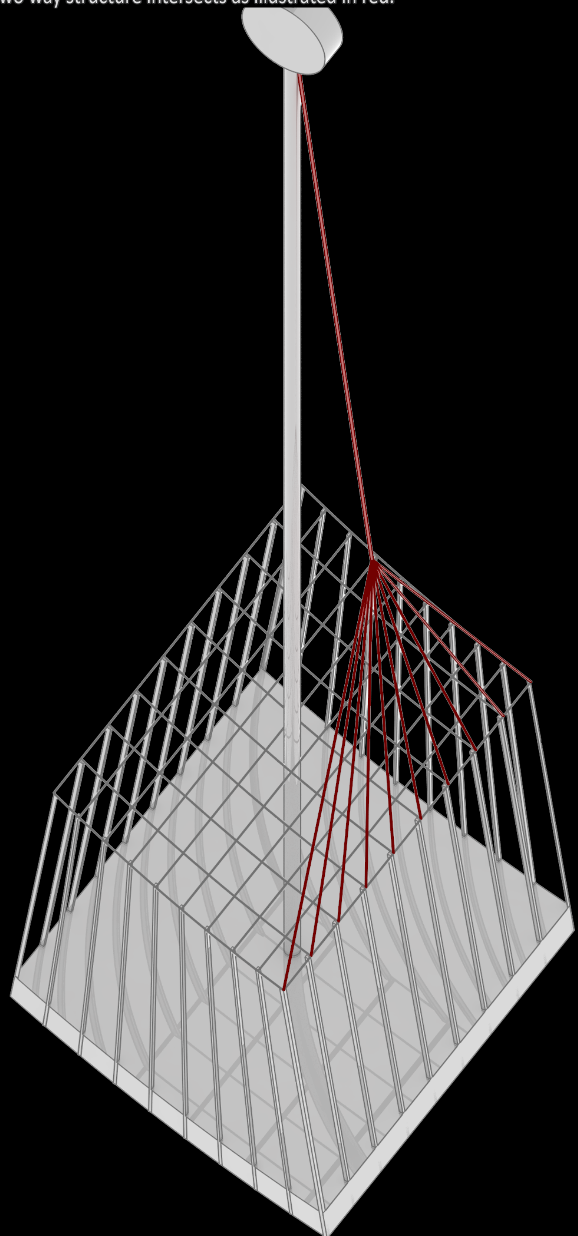


the individual level, with very little constraints to adhere to.

Districts

The city itself will be divided into the various modules which will form the different districts in the colony. Since the colony itself is outside any nation, it will draw people in from every nation; not prioritizing one nation over another for its citizens. Historically, people tend to live close by people of the same race and culture when immigrating. That's why in the major cities of Canada and the

[Figure 69]A detailed view of the how each the two-way beam structure is tied back to the centroid. One tensile member that radiates to form a series attach to each place that the two way structure intersects as illustrated in red.



United States, there exists a Chinatown, Little India, Little Italy, and a Koreatown. These districts are important because they allow for people to live among people of similar race, cultures, and ideologies and then slowly allow themselves to assimilate, understand, and accept the new culture where they now find themselves in. This segment acts as a basis for a cultural district to start developing .

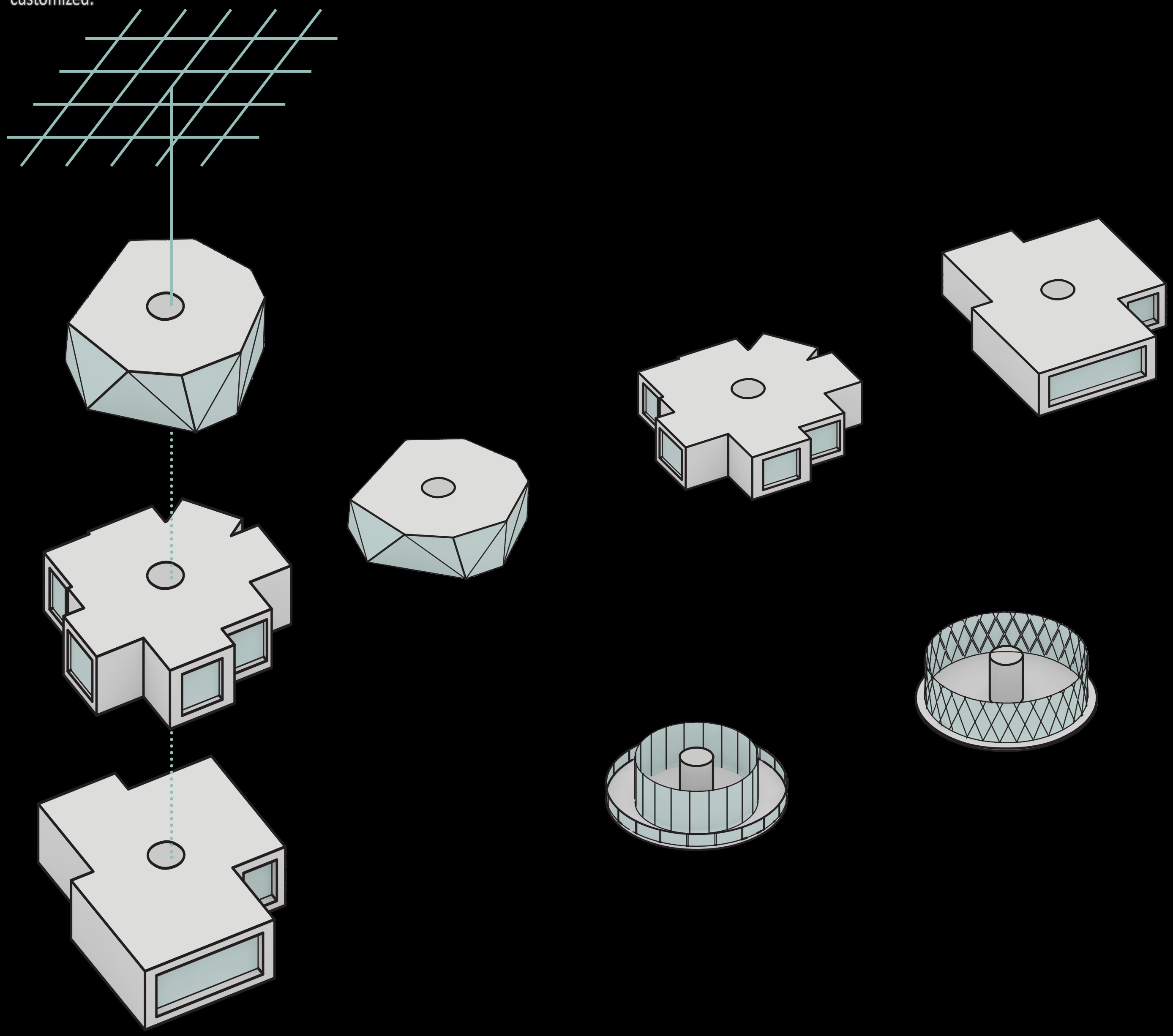
Privacy

The temperature, humidity, and lighting inside of the buildings can match that of the inside

[Figure 70] Housing units and other large items can be manufactured in 0 gravity and hung into place.

the building enclosure issues can be taken care of at the level of the enclosure of the entire colony, allowing for a very simple envelope for the building enclosure. So, instead of having an enclosure made of multiple layers including the vapor barrier, the insulation, drainage gaps, and the water proofing, you would only need the one layer which can act structurally to become the main wall. Such simplicity allows for the 3D printing of the enclosure with technology that currently exists and will become far more sophisticated. Manufacturing would also be more streamlined by taking advantage of 3D printing in controlled gravitational zones of the colony. Also, the scale at which we can print in space is limitless. Current terrestrial 3D printing and modular capabilities are limited to what can fit on a flatbed truck or what could be lifted by air helicopter. In a space station not bound by the transportation norms of the Earth, no such limits exist and the infrastructure can be created such that very large scale masses could be transported anywhere throughout the colony. In summary any enclosure would be quickly 3D printed, comprised

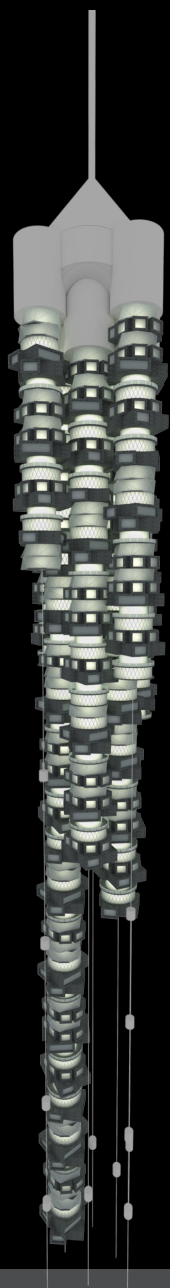
[Figure 71]Instead of going through the typical construction process, buildings are hung off each other in a method resembling a grape vine. This allows for buildings to be prefabricated off-site, brought directly under the site, and hung into place. Because all building science is taken care of at the level of the colony, building envelopes can be very simple, allowing them to be easily 3D printed. Also, tensile construction requires only one point of connection to remain balanced. Now if all housing followed a simple set of rules regarding where to put its one structural member, all housing can be completely customized.



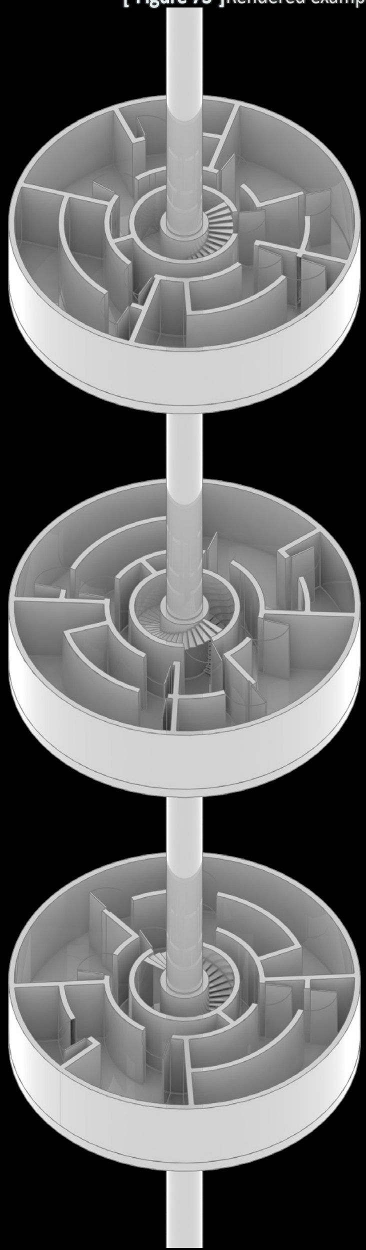
of an endless mass, and that mass could be transported efficiently anywhere throughout the colony.

Working within these parameters, I am suggesting a housing construction method that would start with a tensile rod hung from the aerial structural grid to support a series of housing modules which are completely fabricated off site. This housing module would have a series of hooks on its top and bottom, and would allow for another housing module to be attached from its bottom. In order to minimize the amount of onsite construction a framework that will define the locations of all the

[**Figure 72**]An example housing stack

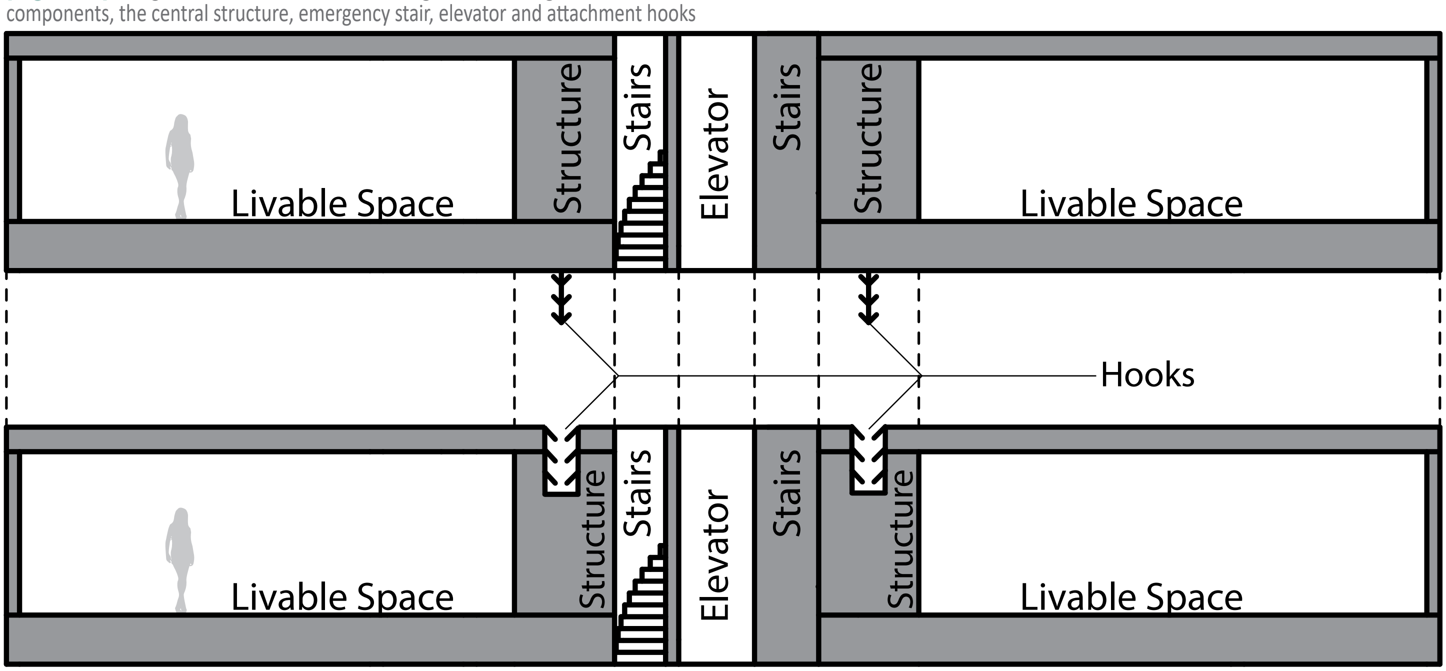


[**Figure 73**]Rendered examples of housing units



elevators and emergency egress stairs relative to the attachment hooks will be followed. A chain of housing modules, stacked one below the next, in succession would then form. This housing module will be 3D printed in the manufacturing area along the center axis of the space colony in controlled gravitational zones and it would then be transported to the ground of the colony. From there, it would be positioned right under the building, hoisted into place using a motorized pulley, and then hooked on to the lowest suspended housing module. This same process would be repeated going down, growing slowly as needed, with each unit being attached to the housing module below.

[Figure 74]A diagrammatic section of two housing units outlining the main components, the central structure, emergency stair, elevator and attachment hooks



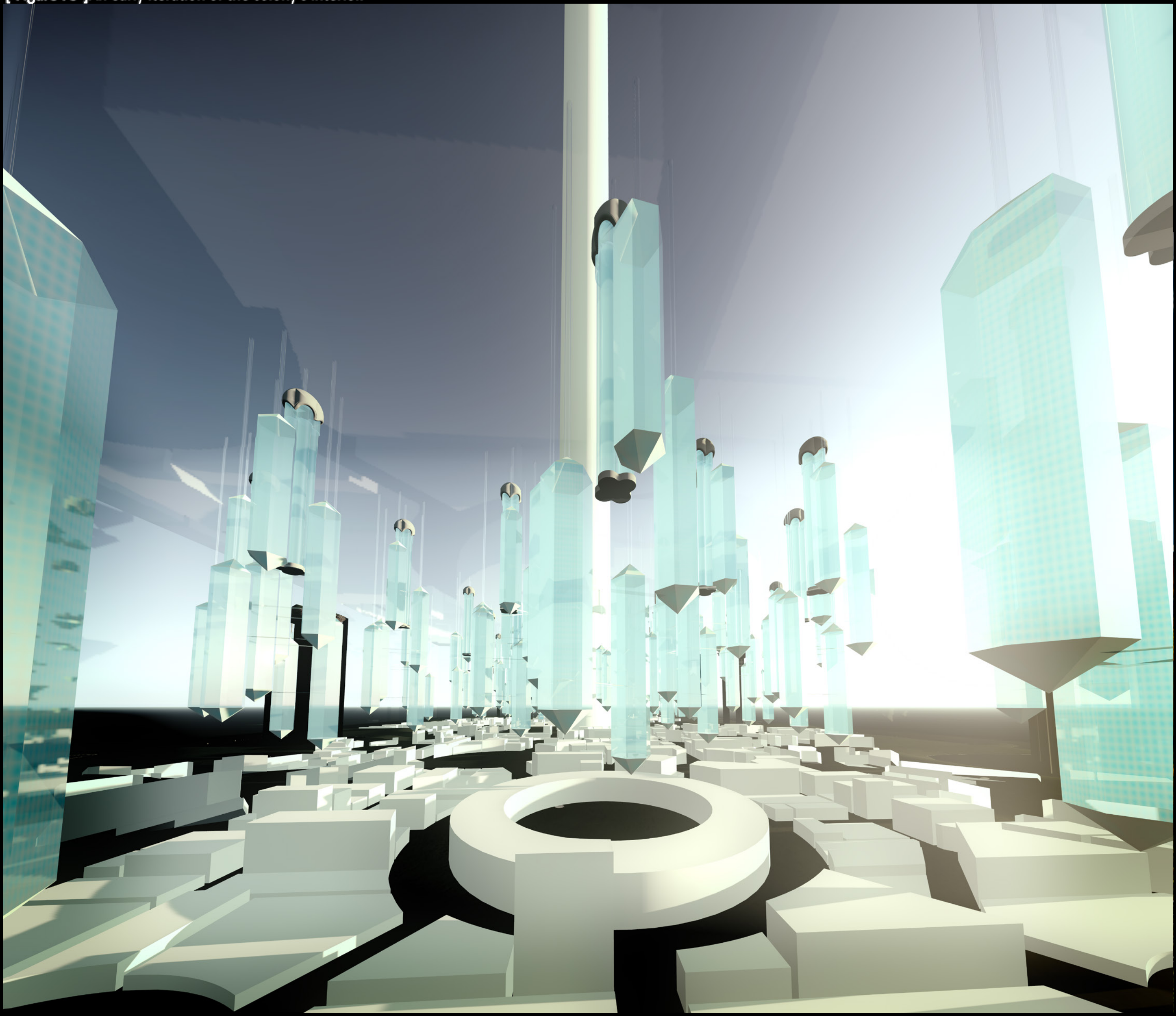
This allows for a new level of freedom to the homeowner by providing them the ability to design their house in whichever form they desire, so long as they can abide by the framework defined by that housing chain. In addition, because building envelope considerations are taken care of at the level of the colony, instead of the house, any structural engineering could be relatively simple. Most common structures could be calculated using a basic computer application to determine the required structural loads in the module allowing for true freedom and the design of each module. So, although, the population is still living in a condo, it sets itself apart from the condos that we have on the Earth with its truly customizable design allowing for the owner to edit the form of the inside and the outside at this colony. Buildings within the colony no longer become shelters, they become separators. It becomes a barrier from your neighbors, from other people; in essence, something that you go to be more private. This begs the question 'what is a building in this context?' and 'what kind of activities will go on within?' Studies have shown that the more office workers are connected to the outdoors through windows, the more productive and happier they are. [1] This could mean that all office work could be done outside without the need to be housed within a building. Buildings ranging from gymnasiums, schools, and casinos could no longer demand a shelter. Cooking and eating could become a communal activity with less of a barrier imposed by walking outdoors. There may even be people who elect to live in a house that is completely open to the outdoors.

The importance of public space also becomes re-imagined through this process. When there are more things that you can do in public spaces more interactions end up occurring. This in turn will help define a culture within this colony and foster a more social way of life.

Conclusion

This design, through its construction, proposes a new way of life. As in O'Neill's original idealistic colony meant to liberate us from want, this thesis is also an effort to clarify a road to the future and correct the problems of the past. Within this colony, climate will be completely controlled and pollution will not exist. We will no longer exploit resources in ways that will damage ecosystems; mining will be done in outer space where no organisms exist. The ground plane is significantly freed up with the largest land user in

[**Figure 75**]An early iteration of the colony's interior.



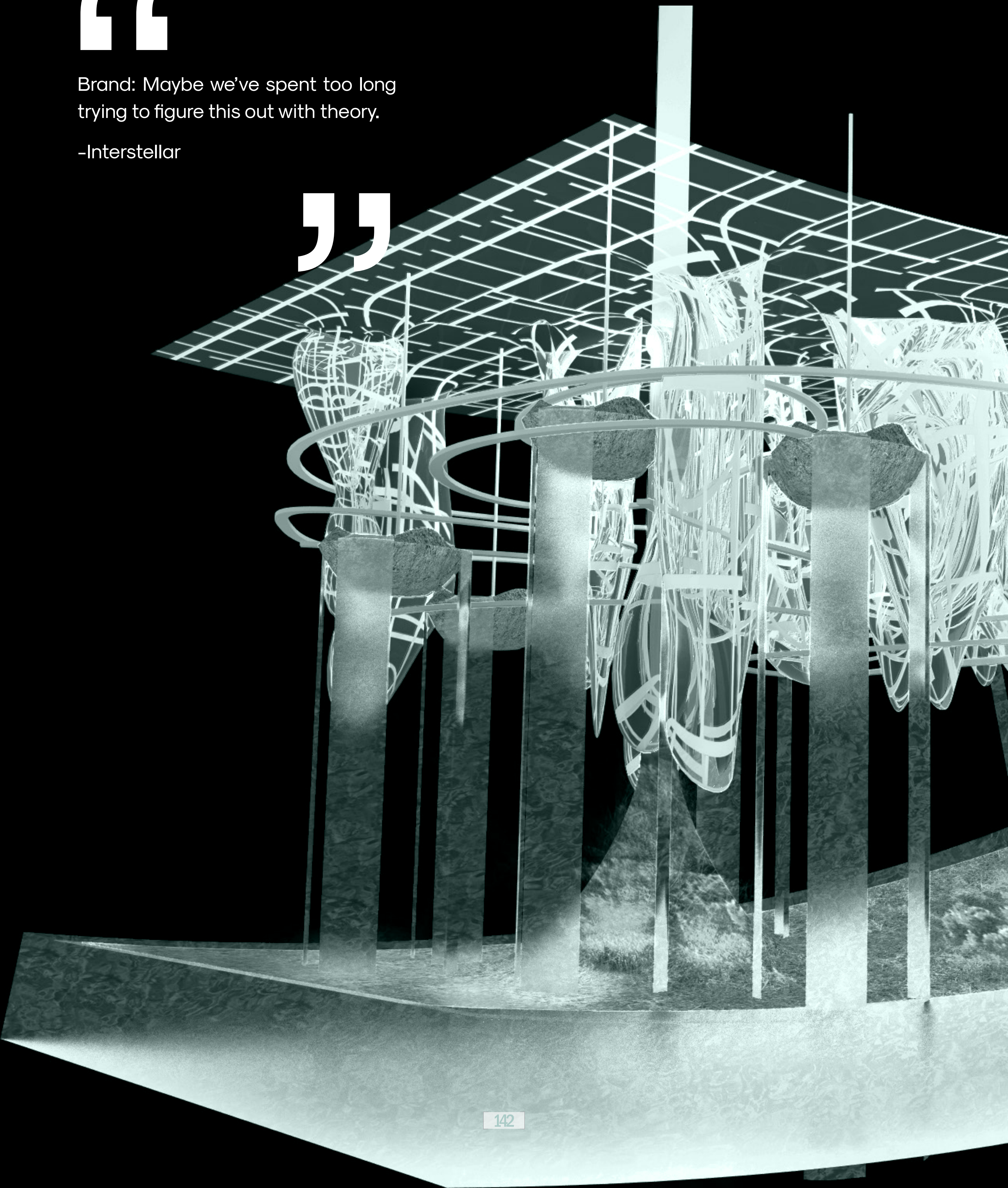
most cities (residential buildings) lifted into the sky, allowing for a re-integration of nature back into the city in the continuous parklands. There, nature has been taken under our control; humanity is no longer at the mercy of hurricanes, tsunamis, and earthquakes. Only the animals that are required for the ecosystem in the colony to function and provide pleasure to human life will be included. Utopia literally means 'no-place' or 'nowhere' and space is a vacuum, an infinite place of nothingness. If nowhere is the only place nothing can exist, perhaps space should be the next frontier to look for Utopia.

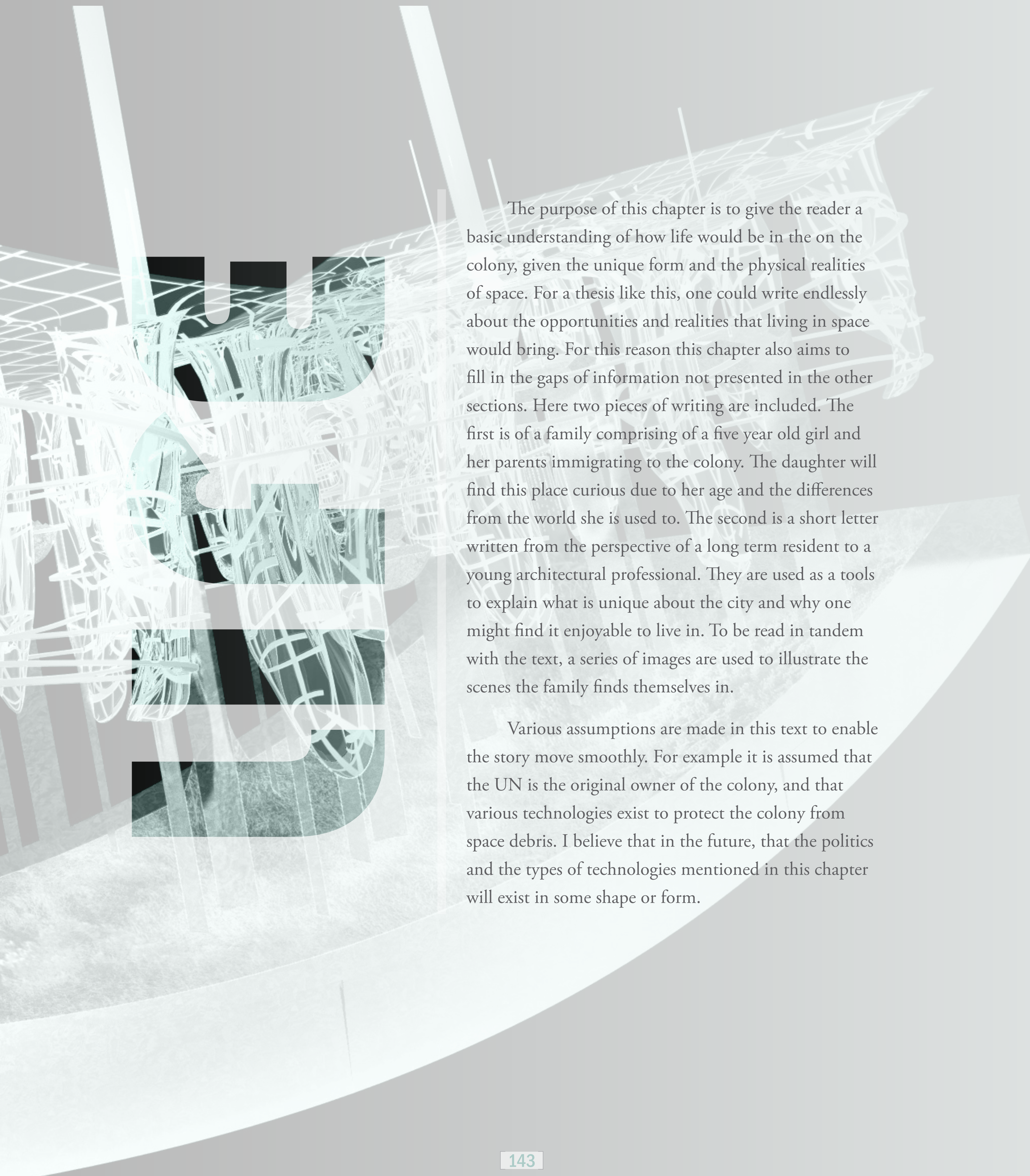
“

Brand: Maybe we’ve spent too long trying to figure this out with theory.

-Interstellar

”





The purpose of this chapter is to give the reader a basic understanding of how life would be in the on the colony, given the unique form and the physical realities of space. For a thesis like this, one could write endlessly about the opportunities and realities that living in space would bring. For this reason this chapter also aims to fill in the gaps of information not presented in the other sections. Here two pieces of writing are included. The first is of a family comprising of a five year old girl and her parents immigrating to the colony. The daughter will find this place curious due to her age and the differences from the world she is used to. The second is a short letter written from the perspective of a long term resident to a young architectural professional. They are used as a tools to explain what is unique about the city and why one might find it enjoyable to live in. To be read in tandem with the text, a series of images are used to illustrate the scenes the family finds themselves in.

Various assumptions are made in this text to enable the story move smoothly. For example it is assumed that the UN is the original owner of the colony, and that various technologies exist to protect the colony from space debris. I believe that in the future, that the politics and the types of technologies mentioned in this chapter will exist in some shape or form.

Starting From Earth

Father: Come get ready, we do not want to miss our flight at the spaceport!

Daughter: Why do we have to go? I don't want to go to space!

Father: Mom got a job on the Moon, so now we all have to move up there.

Daughter: We get to live on the Moon?!

Father: Well, near it... Living on the Moon is unhealthy, so what we are actually going to do is move to a place near it.

Daughter: Why is living on the Moon unhealthy?

Father: Because the Moon is smaller and has lower gravity than the Earth. If we live there we will become weaker because we won't have to work as hard to move.

Daughter: Does that mean I can run faster?

Father: Well, it means you can run easier. Oh! And you can jump 6 times higher on the Moon.

Daughter: What! I don't care if it's unhealthy. I want to live there.

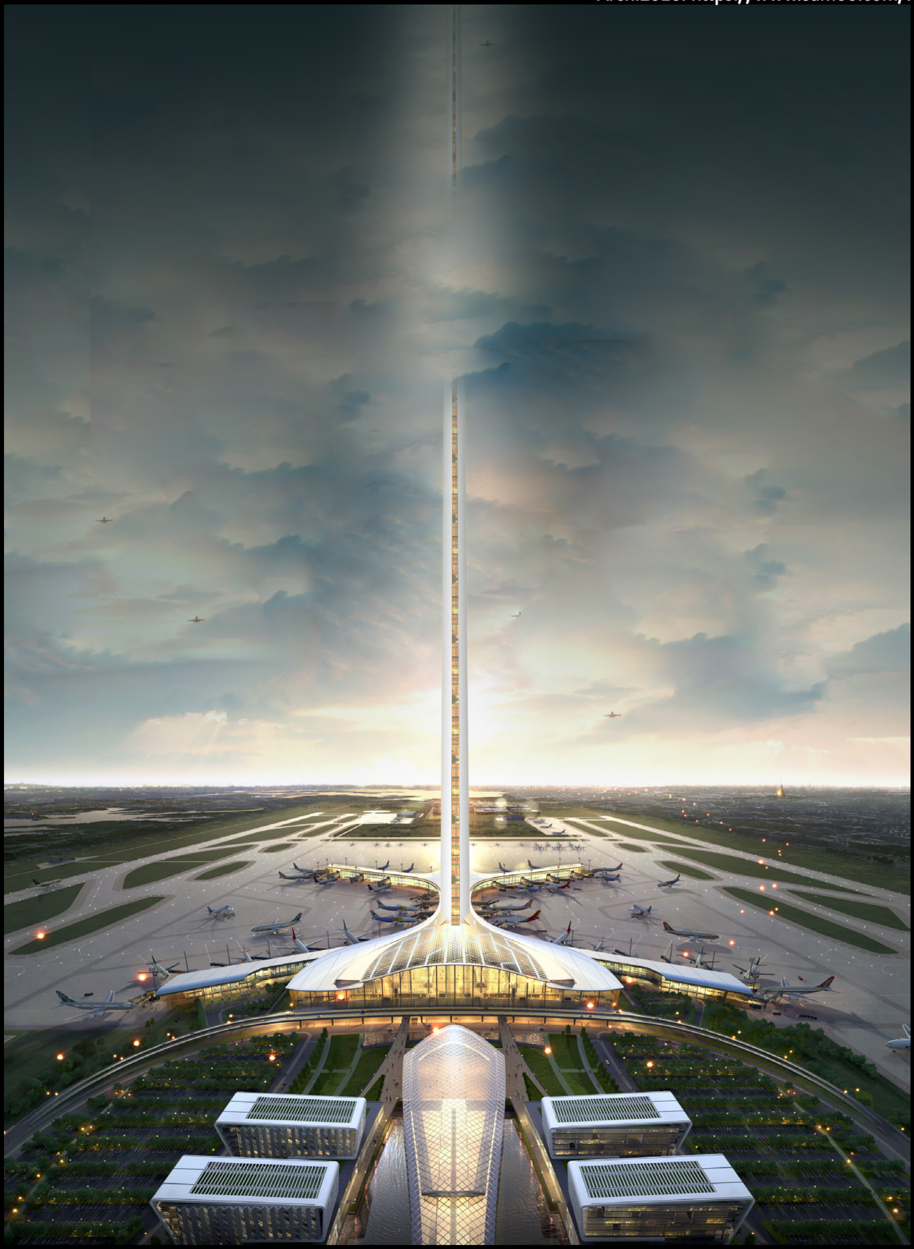
Father: We cannot sweetie. One day on the Moon is 28 days on Earth and half of that will be night. Do you want to live in 14 days of night?

Daughter: That sounds scary.

Father: Yep, and it's really cold too.

Daughter: I want to go where Mom is!

[**Figure 76**]The space elevator attached to an airport (this image is not the work of the author.) Lightly edited version of "Incheon Airport." Digital image. Samoo Archi2016. https://www.samoo.com/.



Father: Me too. And don't worry; I have been there once. It's really cool; we will be right next to a comet and the Moon looks way bigger!

Inside the Space Port

Border Guard: We need to see your and your daughter's visas.

Father: I have them right here.

Border Guard: Alright. Local flights are Terminal One, international are Terminal Two and interstellar are Terminal Three.

Daughter: Oh cool. I've never been to Terminal Three before.

Father: Yeah. I've only been there once too. Back when I was your age, they only had the first two terminals. Almost all airports have been renovated to accommodate a space port.

Daughter: But Dad, I don't see the building!

Father: Well Terminal Three isn't exactly here. First we need to take a very long elevator ride.

Daughter: How long?

Father: A few hours. But don't worry; it's like taking a train, and it's really cool. The elevator goes up that cable and takes us into space.

Daughter: Wow! I can't even see the end of the cable. It's so high.

Father: You're not scared?

Daughter: Nope. That's where Mommy is, right?

Father: Well, almost. There's a few more stops we need to take before we get there.

Up the Elevator

Daughter: Wow! this is an elevator?

Father: Yep. Isn't it cool?

Daughter: But it's so big, and it has windows!

Father: Make sure to keep your seatbelt on sweetie.

Daughter: But I don't have to keep my seatbelt on airplanes.

Father: Yeah. But, this works a bit differently. Soon after the elevator goes up, you are going to feel really heavy for a little while. It won't be too uncomfortable but it might be too much for you to be able to stand up.

Daughter: I can do it Dad.

Father: Sorry kiddo, but it's more than that. Afterwards, the opposite thing will happen, you will feel really light, and eventually you will start to float.

Daughter: So I can fly?!

Father: No. Remember those shoes they made you put on? They are magnetic and will keep you on the ground, but you'll feel completely weightless.

Daughter: But I want to fly!

Father: I know. But what happens if you jump too fast and end up ramming into the ceiling? That would really hurt, wouldn't it?

Daughter: I will be careful.

Father: But you have never been able to float before. You don't even know how strong you are! Your own super strength might be too much.

Daughter: Will I be able to fly when I see Mom?

Father: No. There's artificial gravity where Mom is, remember?

Arriving at the Terminal

Daughter: Woah, Dad look how strong I am! I can hold up all the luggage.

Father: Yes sweetie. We're at the end of the elevator and everything here is completely weightless.

Daughter: Why? We are still close to the Earth.

Father: We are spinning, and that creates a force that is equal to the force of gravity, in the opposite direction. The forces cancel each other out.

Daughter: Oh, um... okay.

Entering the Shuttle

Daughter: Ugh. Dad the TV screens in here are so old.

Father: Yeah. They are almost 20 years old.

Daughter: Why don't they just get new ones?

Father: Well the whole shuttle is really old. They might not work with new ones.

Daughter: Wait does that mean the shuttle is 20 years old?

Father: Maybe even older! Because there's no air in space, the shuttles don't go through the same wear and tear that airplanes go through, so they can almost be reused indefinitely.

Daughter: Oh okay, Dad I heard that back in the day they used to just launch rockets right from the Earth. Why don't they do that anymore?

Father: It became really expensive and wasteful to launch rockets directly from the Earth because rockets use fuel. By launching from the top of the elevator we don't have to use as much fuel.

Daughter: Whats fuel?

Father: Fuel is basically a liquid that creates a controlled explosion which propels us in the opposite direction. But the closer we are to the Earth's surface, the stronger the gravity, and the more fuel we need to use to counter it. That's why we built the elevators. It's like a cheat by taking a head start. Also, because there's no air in space we don't feel drag. So you know when you are running against the wind and its a lot harder to run as fast? The same thing for a space shuttle. In the old days they used to have to re-enter through the drag and heat up. Not today though.

Some time later

Father: Do you see it?

Daughter: See what?

Father: There in the distance, that gray cylinder thing?

Daughter: Oh yeah.

Father: That's where we are going to live.

Daughter: What? It's so small though.

Father: Nope. Wait another hour.

Hours pass

Daughter: Oh my god! Dad IT'S HUGE!

Father: Yeah and it's spinning.

Daughter: Why is it spinning?

Father: You know when you swing a yo-yo in a circle, you need to grasp it harder the faster you spin it?

Daughter: Yea

Father: Well, this is because a force is being created that makes the yoyo want to go away from your hand. Now if we think of that whole cylinder as a yo-yo, anything inside it will want to go away from the center and if we're inside it, we'll have a force on us that propels us away from the center. That's what creates gravity for us so we do not float away.

Daughter: Wow. Dad that's so cool!

They get closer to the colony

Father: Okay kiddo, are you buckled in?

Daughter: Yep. Why? What's happening next?

Father: We are going to land on our new home!

Daughter: Cool!

Father: Yea so you see that central part there, we're going to land there and get take another elevator down to where Mom is.

Daughter: Then do we get to see her?

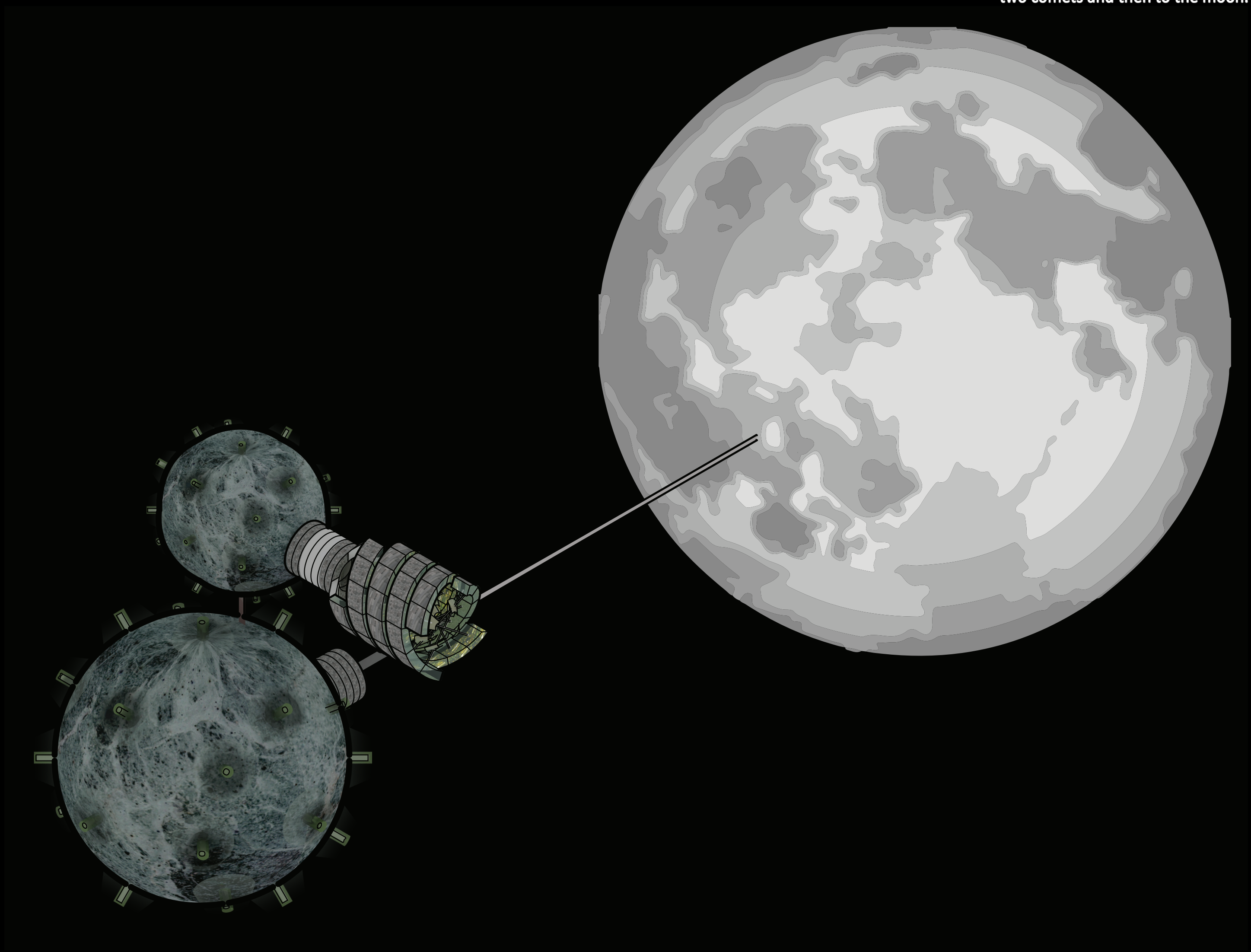
Father: Yep. She will be waiting right there.

Inside the Spaceport

Daughter: Dad can I take off these magnet shoes now?

Father: Not until we get to the bottom of the elevator.

[Figure 77] The colony and its attachments. In this situation the colony is attached to two comets and then to the moon.



They travel down the elevator.

Daughter: Oh wow. Dad I feel heavy again.

Father: Yes, it makes sense after being weightless for all those hours. Feel free to hold my hand if you need to.

Inside the spaceport lobby

Daughter: Mom!

Father: Hi hun, how are things?

Mother: Fine so far. I just came back from the Moon yesterday; what a trip that was! It's times like those that I'm really glad we have robots gathering all that helium and not us. Fourteen days of straight night with a sky that seems darker than black is a bit maddening. But thankfully, I only have to go once every two weeks to perform maintenance. How are things with you?

Father: I just got a message back from the manufacturing company. They didn't even ask for an interview, I got hired just based on my resume.

Mother: Yeah. That's starting to become a common occurrence here. They are trying to shift the economy from energy extraction to mineral extraction and 0g manufacturing. It seems the government is trying to cultivate as many engineers as possible.

Father: Does that have to do with the whole independence movement?

Mother: I wouldn't really call it an independence movement. The colony was essentially a country owned and governed by the UN; it never truly belonged to any country anyways. But because of the struggle between trying to satisfy all the needs of the countries that helped finance the colony, the needs of the residents in the city itself have been neglected. In any case, all the counties have benefited enough. They made their return on investment a long time ago. Instead of being owned by the UN we should become an equal part of it, just like any country on Earth.

Father: That's true. This colony has started to govern itself like a country anyways. I heard that it used Singapore as its governing model.

Mother: Yes, and just like Singapore they're trying to depend less on resource extraction and move to a more manufacturing and service based economy. This is especially important since after we claim independence, they can't force helium-3 mining quotas onto us.

Father: Wait. There's no way that the Earth will just give away its biggest resource extraction colony!

Mother: I'm guessing and am hopeful that the shift to independence will be gradual and there will be treaties to help with the transition. The Earth is already preparing for it with all the money they've been investing into launching solar panels into orbit. If you think about it, constantly shuttling helium-3 back and forth is expensive and although the supply of it is vast, it's not limitless.

Father: Wait. Does that mean your job will be phased out?

Mother: Well, the colony can still run off helium-3. There's enough to last us thousands of years. Also, there's no way the Earth will be able to place all of the solar panels that it needs into orbit anytime soon. But yeah. We'll probably reach peak helium soon and then decline.

Father: I guess it makes sense that they'll be moving over to 0g manufacturing to drive the economy. I can't even imagine all the different things you could build here!

Daught: What kind of things are you going to be building Dad?

Father: Well technically we could build anything that is really heavy and we could build it a lot easier because we wouldn't have to worry about bracing it while we put it together. Don't worry. I'll bring you to work one day and you'll see how cool my work is.

Outside the Spaceport

Daughter: Woah… The buildings... They're floating!

Father: Yeah… I've always wondered what it would look like in real life.

Mother: You guys will get used to it eventually, but it makes things a lot nicer since everything is closer.

Father: Oh yeah. I see the platforms and bridges. It's like they brought the street up into the air.

Mother: Yeah. It's pretty awesome, there's shops and urban parks on every level.

Father: What usually ends up on the ground then?

Mother: Mostly parkland, forestry, and high end specialized shops. It's pretty expensive to live on the ground so most people don't do it.

Daughter: Why can't the building float back home?

Father: Well, they're not really floating. They're hung from a rod off the top surface of the colony. You see that up there? It's not like the sky we're used to. If you go high enough you'll be able to actually touch it!

Daughter: It looks so similar!

Father: I know, I'm surprised they managed to get it to look so similar.

Mother: They're really good at simulating the weather conditions here. For example, in order to water all the vegetation in the colony, they have sprinklers across the top surface of the colony to simulate rain. The nice thing is that we can request that it rains only on certain days through an online forum.

Daughter: What's that mean?

Mother: It means we can pick whatever weather we want!

Daughter: So we can make it snow every Christmas?

Mother: Exactly!

Getting Closer to the House

On public transport

Daughter: Mom, how come you don't have a car here.

Mother: They don't have cars here. The subway will take you a five minute walk from anywhere you want to go. But because of that, the subway cars are a lot nicer looking than the ones back home, aren't they?

Daughter: They're also so much bigger. It's like you can fit two subway cars beside each other in one car here!

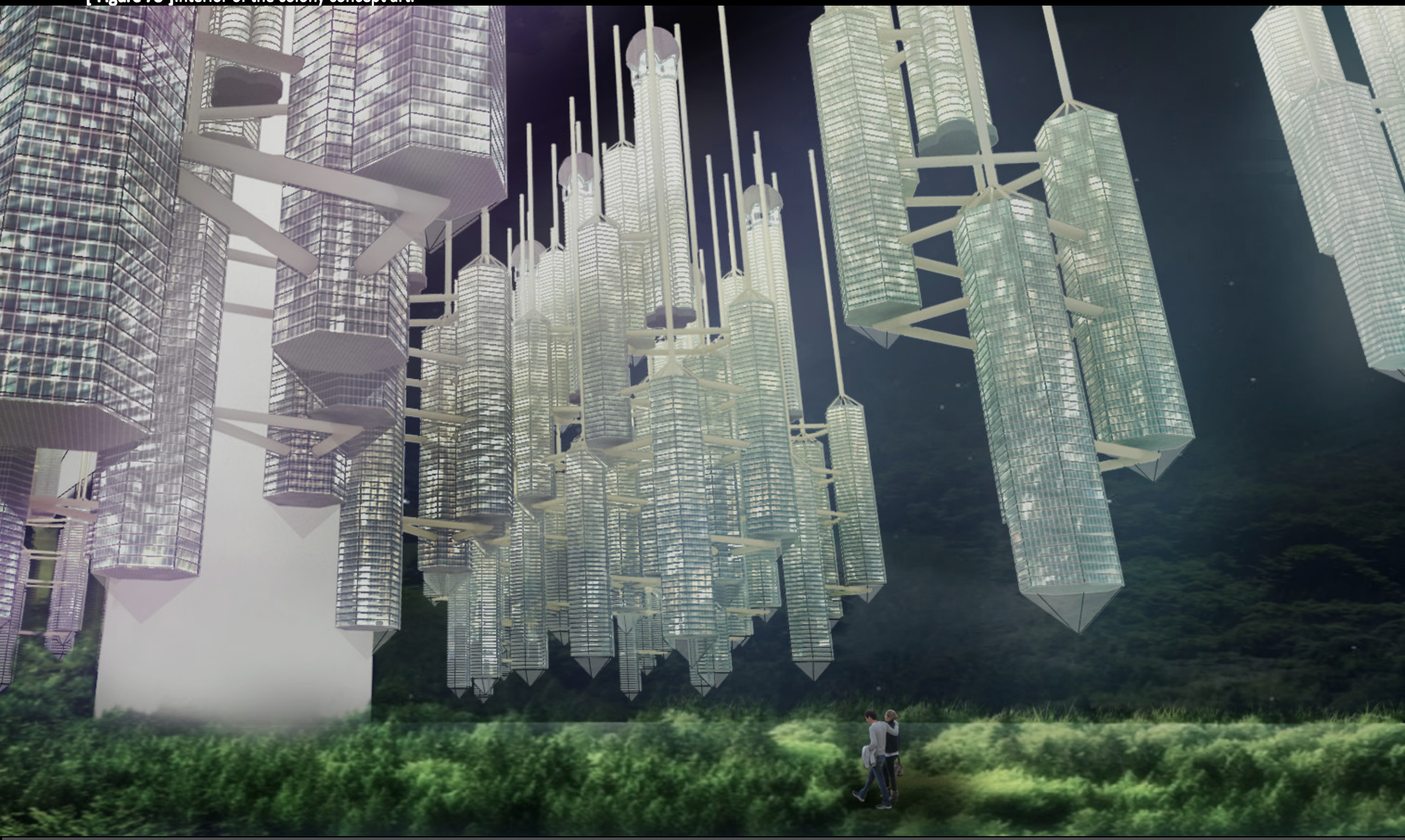
Mother: Okay the train is about to move. Better hold sweetie, and you too (looks to the husband).

Father: I think I'll be fine….

P.A. System: This is an express train and will be traveling in the opposite direction with the city's rotation. Please hold on as the weight on you lowers.

Father: Woah! I feel a lot lighter.

[**Figure 78**]Interior of the colony concept art.



Daughter: Me too! What's happening?

Mother: Because we're going in the opposite direction with the city's rotation, less centrifugal force is acting on us.

Father: Remember the yo-yo I was talking about after we took off? It's the same thing, just you're spinning the yoyo slower

Arrive at the stop

[**Figure 79**]Interior of the Chinese module

Daughter: Woah! This place looks completely different from the subway station near the airport! It looks like we're in Chinatown!

Father: Yeah this setting is completely different. Is this where our apartment is?

Mother: Yep it's located right there. As a show of good faith, when the Chinese government joined the mining operation they sponsored this module and had it designed to have a mix of traditional and contemporary Chinese architecture.

Father: Are all the different modules like that?

Mother: The older modules are. Before this current colony was built, there was an older colony where people worked. Due to the harsh conditions that came with living up there full-time, they needed to build this colony to stop people from quitting. The first few modules that are now gone, were built and designed around the first few counties to fund the colony. After that, it just became customary that new counties to join had to construct the next set of modules.

Father: Well I do like the idea of living in a floating Chinese Temple. Wait since the UN took control of the colony, how are the newer modules built?

Mother: Well, they're not based around the traditions of any one nation anymore. It's more of a cross between all the nations and some new contemporary styles that are developing on the colony. Although, because everything is in tension, it's still different from that of Earth too. My brother likes to talk about it a lot since he's on the urban planning committee. He describes it as a new style that's evolving because of our distance from the Earth.

At Their Community

Father: I love this outdoor park.

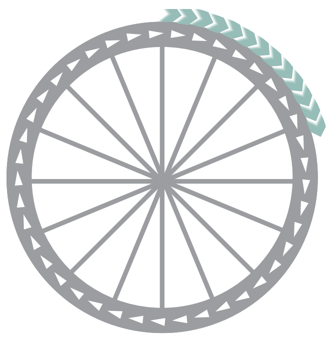
Daughter: Oh wow Mom, they have so many swings and the pond is so pretty!

Mother: Come on, we need to drop off your things at the house.

Father: So why are we at a park?

Mother: You see those glass tubes over there? Elevators run through them and take you up to the building.

[Figure 80]Subway poster detailing the gravitational implications of each train in relation to the colony's spin.



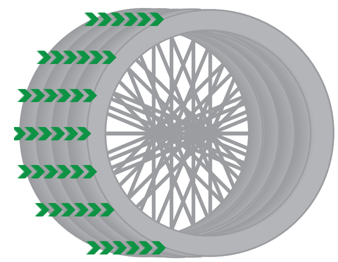
In-line Travel

Blue line trains run in same direction that the colony rotates, and **INCREASES** all gravitational force.

It is **MANDATORY** by law for passengers to forfeit their seat to the elderly and those with higher mobility needs on all blue line trains.

All passengers are advised to grab onto one of handles or bars within reach to brace themselves for the increase in body weight.

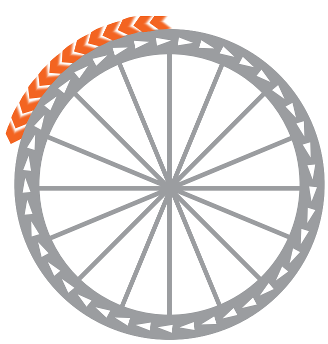
All carry on items must remain on the floor.



Inter-Ring Travel

Green line trains travel perpendicular to the direction that the colony rotates and have **NO EFFECT** on artificial gravity.

We ask that passengers forfeiter their seat to others with mobility issues.



Counter-line Travel

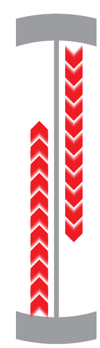
Orange line trains run in the opposite direction that the colony rotates, and **DECREASES** all gravitational force.

We ask that passengers forfeiter their seat to others with mobility issues.

All passengers are advised to grab onto one of handles or bars within reach to brace themselves for the decrease in weight.

Please be aware that rising too quickly from your seat and moving at a fast pace may cause you to lose balance.

All carry on items will appear lighter, please be careful not to hold anything that may be too heavy under normal gravity.



Opposing Module Travel

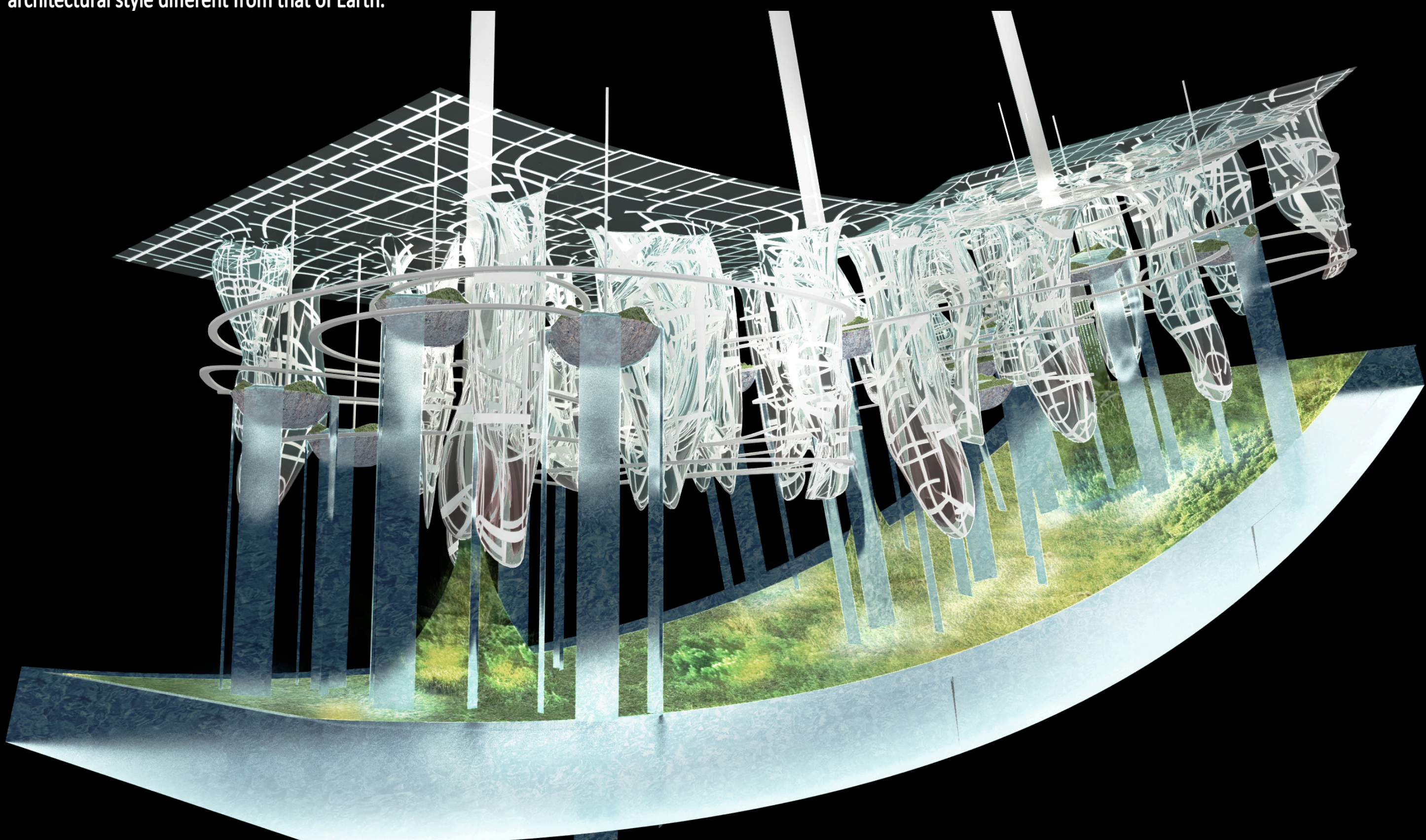
Red line vertical trains run between opposing modules. Artificial gravity **GRADUALLY DECREASES TO ZERO AND SUBSEQUENTLY INCREASES BACK TO 100%**

It is **MANDATORY** by law for passengers to be seated with their seatbelt on during the entire trip.

All carry on items must be stored in the containers in the floor provided.

Please be aware that when the trains reach the halfway point at zero gravity the seats will turn clockwise to face the other side so that the gravitational force will always be exerted against the chair and not the belt.

[**Figure 81**]Concept art of colony interior showing the development of a new architectural style different from that of Earth.



Father: Wait so our place is situated right under a huge park, with a swimming pool?

Mother: Most of the buildings have that, there's a few more shops and amenities when we go up.

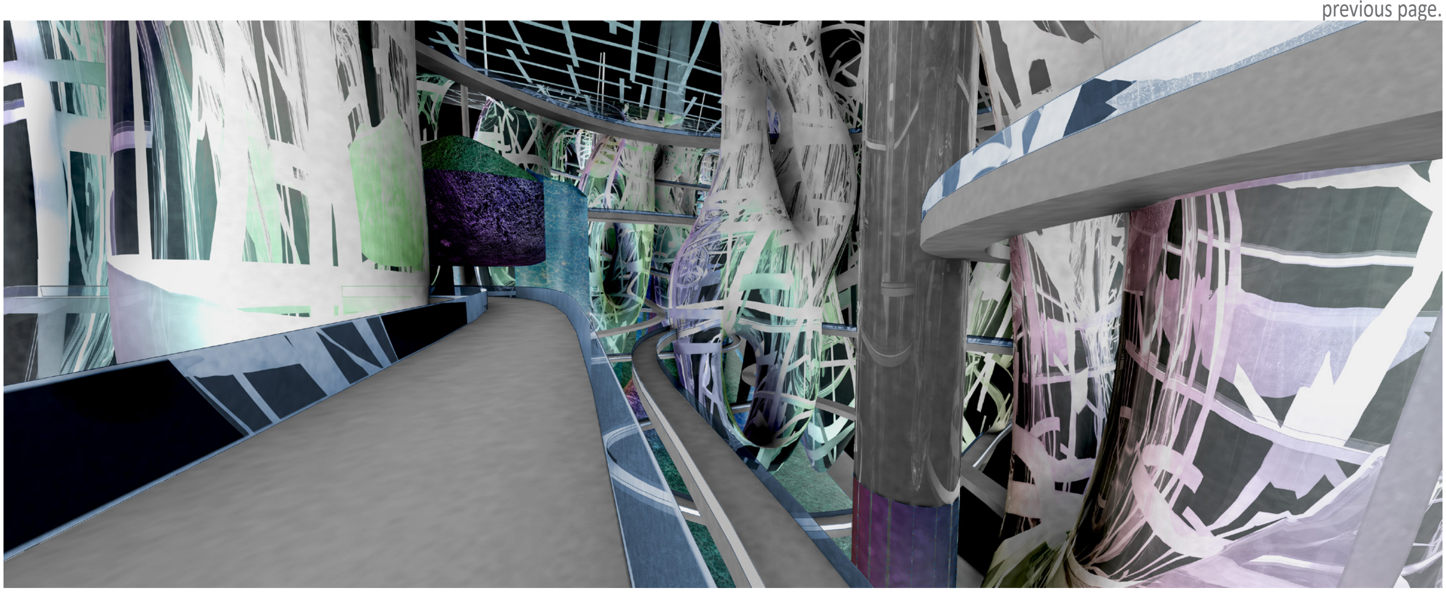
Inside the building

Daughter: I can't wait to see what my room looks like!

Mother: I think you'll like it, your uncle finished the design last week and it got delivered today.

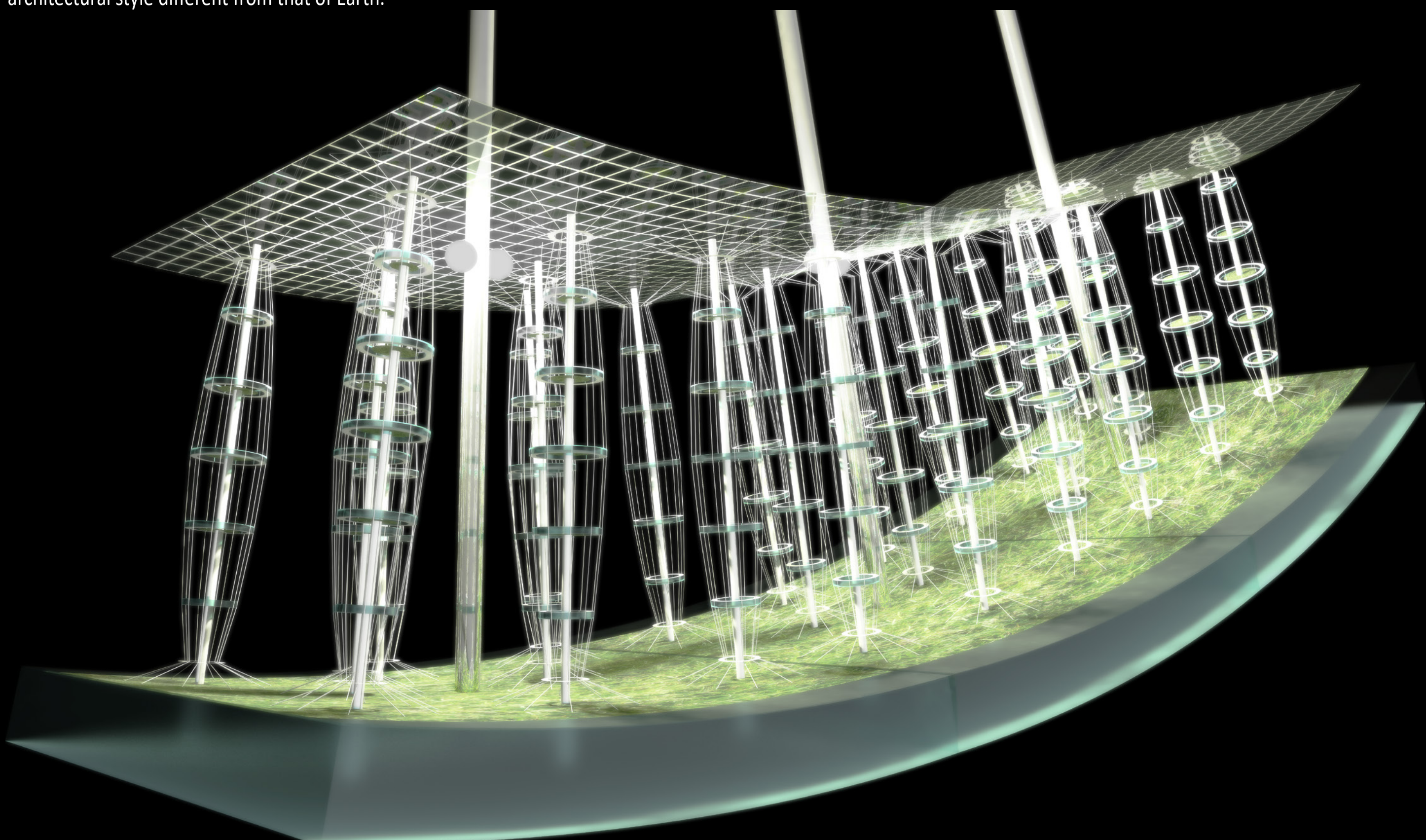
Daughter: They managed to make a whole condo in a week?

[Figure 82]Interior perspective of the image on the previous page.



Mother:	The whole thing is 3D printed in the 0g area by machines. Yesterday I was the first person to touch it!
Daughter:	Oh cool. We're the first stop!
Mother:	Yeah sweetie, the newest unit always gets placed on the bottom of the housing stacks. But soon, as more people move in, there will be more units placed under us.
Daughter:	I can't wait to explore this place!
Father:	Apparently they give tours to the 0g factory where I work. Would you like to go with me?
Daughter:	Yeah I want to see where Dad works!

[Figure 83]Concept art of colony interior showing the development of a new architectural style different from that of Earth.



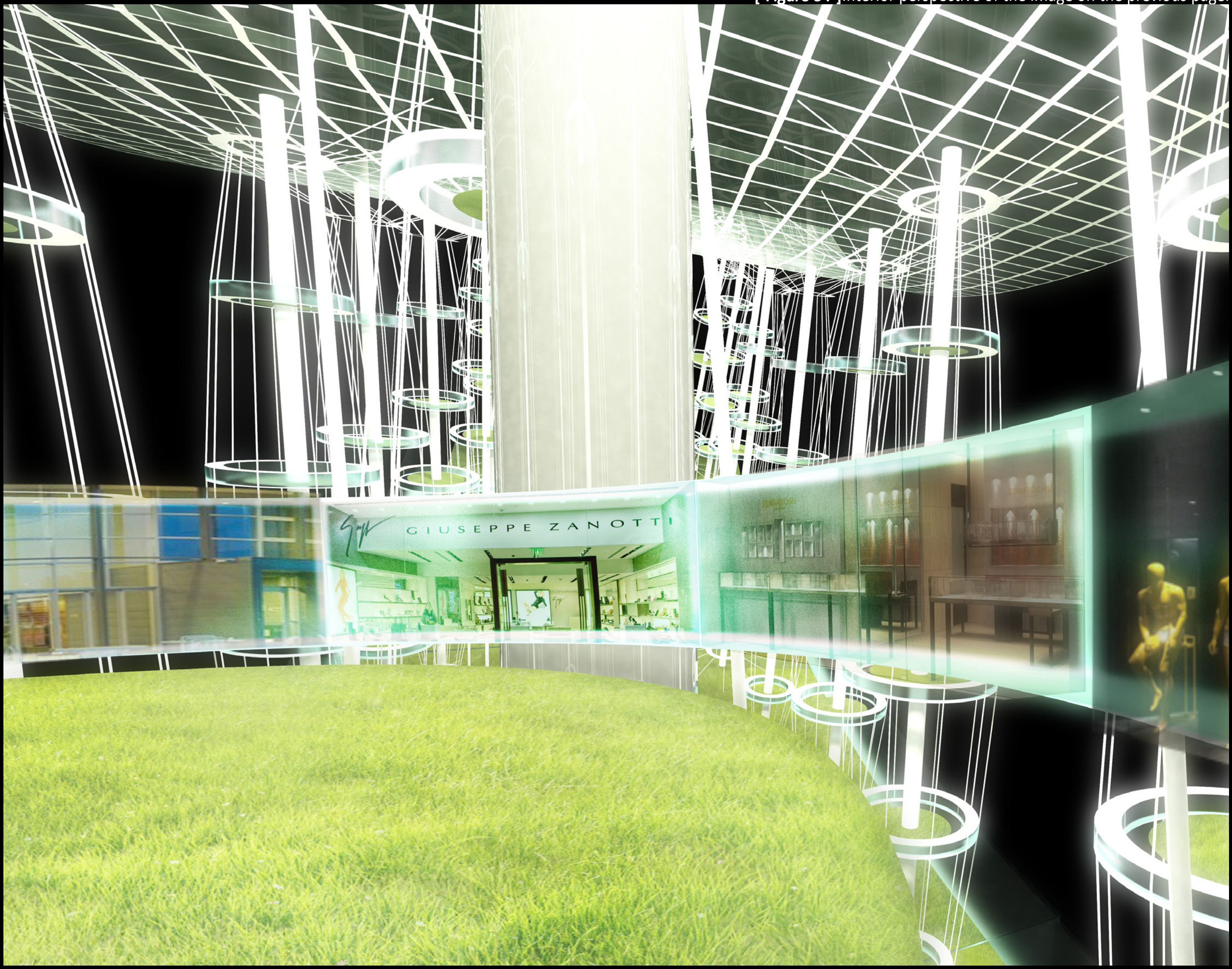
Father: Alright. I'm going to go to unpack and go to bed, goodnight! I'll take you next week.

At the Manufacturing Facility.

Father: So this is what Dad does!

Daughter: I thought you build things. Why are we in an office?

[**Figure 84**]Interior perspective of the image on the previous page.



Father: Well, what I actually do is design things that build things. Back when your grandfather was your age, everyone used to build cars and machines by hand, just like how you build things out of blocks. Now, on the Earth, most things have been taken over by people building things using big machines. But up here they don't even need humans!

Daughter: Why do they need people on Earth but not over here?

Father: That's because there is no gravity in space and things don't need to be braced as much. Also, the forces acting on it are all controlled by us when we're in space. This makes it easier for computers to accurately predict how things will come together. On the Earth, because everything weighs so much, sometimes things shift while it's being built so you need someone to constantly monitor everything.

Daughter: Can we go to where the machines you're going to be building are?

Father: Sure thing!

Traveling to the assembly plant.

Daughter: Dad why do I have to wear this itchy helmet and poofy clothing?

Father: We're going to enter the 0 gravity zone in the center of the colony. But because we're not used to our own strength in 0 gravity, you might end up pushing off a surface too hard and hitting your head. If you end up getting a job here, you can pass a test and they'll let you be in this area with a lot less padding.

Daughter: So then I can fly?

Father: As much as you want.

At the assembly plant.

Boss: Hello little girl, I'm your father's new manager.

Father: Nice to see you, this is my daughter. She also just moved here and I'm giving her a tour.

Boss: My family has been on this colony for five generations. I can promise you, little one, that you'll have an amazing time here!

Daughter: Thank you sir!

Boss leaves

Daughter: Wow. He's so tall and his muscles are huge!

Father: Yep. It makes sense. His family has been here since the start of the colony. Back then, you needed to pass rigorous physical exams in order to for them to let you up here.

Daughter: Why didn't they let everyone come?

Father: When the colony was first built, it was hard to tell what kind of problems could occur and whether or not people would be safe. To increase the odds of survival, they only allowed people with strong survival skills on board. His whole family is probably tall and muscular like him.

Arriving to the 0g manufacturing facility

Father: Now we're on an elevator traveling to the center of the colony, as we go up, you're gonna get lighter. Are you ready?

Daughter: Yes! I can't wait.

Father: Okay. Just make sure to hold onto the handlebars.

Daughter: Dad, why did I have to take out my hair pin?

Father: A lot of the machinery in the factory use directional magnets to retrieve items while they are floating in air. Depending on what way the magnets were pointing, they would pull that pin right off your head!

Daughter: Wow. That would hurt!

Inside the manufacturing facility

Daughter: Oh wow. I can fly!

Father: Yep. Use the handle bars to crawl up the tube.

Daughter: It's so quiet in here. Is everybody gone? You said there were large machines everywhere. Why can't I hear them?

Father: This factory became completely unmanned 10 years ago, and all the materials are produced in a vacuum where sound doesn't travel. This is done to stop materials from reacting with the air under high temperatures, which might result in impurities. Oh, and look to your left.

Daughter: Woah! That's so cool! It's a house made of metal that they cut in half!

Father: It hasn't been cut in half. Only half of it has been built so far with the 3D printer. Give it 10 more minutes and the rest of the main structure will be finished. If you want we can follow this house throughout the factory?

Daughter: Will we get to see exactly what it ends up looking like?

Father: Yep. And it should only take an hour more.

Daughter: Oh they just finished it. Now what will happen?

Father: They'll add the windows and doors.

Daughter: Oh my god! What are those giant robot spiders doing on it?

Father: Because all of the different houses are custom built, they require mobile machines in order to assemble all the parts. They are responsible for spray painting the interior and installing the components of the house. They have four legs for balance.

Daughter: Oh wow. It's almost done! What happens now?

Father: They'll take it in through the airlock and use a mass transportation vehicle to deliver the house to its address.

Daughter: Was our house made like this?

Father: All of them are.

Outside the Entrance to the colony.

Father: Okay. Let's take the subway back.

Daughter: Why did everything just flash red?

Father: It's the colonies way of notifying that there's at least a 1% chance that something small might collide with it and cause tremors.

Daughter: Something is going to hit us?

Father: No. They have computer systems monitoring all the debris in space, so they will be able to stop any kind of mass from hitting us. The flash is merely to let us know that something is happening and that something is being done to fix it. But it's a good idea for us to stay inside or go near shelter.

Daughter: Where are all the shelters?

Father: All around you. Every single building in here is designed as a shelter. All the public buildings on the ground even have lifeboats.

Daughter: Has anything bad ever happened in the past?

Father: Usually nothing big. There have been one or two incidents where a large meteorite struck the colony when it was first being developed but no one was harmed. As a result they have employed electromagnetic fields to repel the metal in asteroids and comets.

Daughter: Can we see what they look like inside?

Father: Well, they are actually gonna make you do drills when you start school.

Daughter: What happens if I don't make it to a lifeboat in time?

Father: Don't say that, but on top of the lifeboats you can run to the other modules. The colony is constructed out of a very high strength tensile mesh that doesn't break easily. Even an atomic bomb would not be able to destroy the whole colony.

Daughter: So what's the biggest threat to the colony then?

Father: To be perfectly honest, the biggest threat to the colony is ourselves and our human errors.

Daughter: What do you mean?

Father: Well, as you can see, a lot of the things in the colony has become automated and a lot of the work has been taken over by machines. The reason for this, is because people tend to make mistakes every once in awhile and sometimes the smallest mistakes can result in huge catastrophe. There's a better chance of us are forgetting to clean out the filters in the air supply chamber then there is of a large asteroid hitting us.

Daughter: Wow. I never thought about it like that!

Returning Home.

Father: So after everything you've seen, what do you think about this new place?

Daughter: I love waking up every morning and having such a high up view of the place!

Father: Yeah. What else?

Daughter: I like how there's always so much people around and how everything is so lively. Also the view of the Moon and the Earth is so pretty from here! My favorite part was when I was flying, can we do that more often?

Father: I can't bring you to work all the time but there are weightless amusement parks that you can only get here. We can go there whenever you want!

Daughter: Awesome! I also like how there is people here from all over there world and going from one district to another is like going to a whole other country!

Father: Yeah, that's really- **Daughter cuts him off*

Daughter: Also, everything in the newer districts seems so futuristic! It's so cool how there's grass and trees at every level of the colony! And the buildings are all connected; I wanna try to go through all of them without ever having to go on the ground! Also, the pond right outside our house is so pretty! I can't believe that everyone has a park right outside their building. Oh, and it's nice and pretty outside but there's no misquotes. I can't wait to explore the forest and the trees; it's so awesome that we have this huge forest right there.

Father: Wow! You really do like this place.

Daughter: Oh! And the beach! When we were at home I saw that there was this huge beach on both side of this place. I wanna check it out! I love that I can walk around anywhere and not have to worry about looking both ways when crossing the streets cause there aren't any cars; I can just go from one side to the other! It feels so free, like there isn't two small sidewalks but one big one! The buildings on the ground are so nice and cosy, while all the super monster buildings are in the air and out of sight. I can't wait to explore the rest of the place

Father: Yep. Every module is different in its own unique way and they're always adding more. You're gonna love it!

A letter to Earth

Dear Amrit,

This letter is in regards to the series of questions you asked me about living on the colony and the architectural industry. Coming to the lunar colony to explore an internship in architecture is a great idea; it's a good way to enjoy yourself and see the universe. I imagine since you have traveled quite a bit, you'll like it here. I've known people who have stayed here temporarily and on a long term basis, I think I've personally found my home. My wife and I have been here for twelve years now and are about to have our second child. We've built a home here, she works in the lunar energy sector and I'm an architect who has owned my own firm for about five years now.

Creating buildings here is quite different. Although many of your skills and expertise transfer over, there is still a number of new attributes about stellar construction that are completely different. On the Earth architects typically produce a set a drawings and send them off to contractors to build it.. Since nearly everything on the colony is prefabricated, instead of having a contractors that are separate from architects, we fabricate the components directly. We export the shop drawings to our own robotic manufacturers and code in the machine instructions that construct the buildings. Because of this, construction typically reaches completion in a faster-paced manner and a lot of our time is spent designing rather than supervising construction. It also allows us to design as we build the various components of the building. Although this is all technically possible on Earth, the environment on the Earth is less controlled and robots cannot build everything like they can here; there is a higher level of complexity that results from having to depend on more human power. For example, contractors on Earth will typically ask that all the details are figured out before they engage in the work, causing architects to schedule construction months in advance, and arrange a pay schedule for different aspects of the work and deal with constant misinterpretation issues.

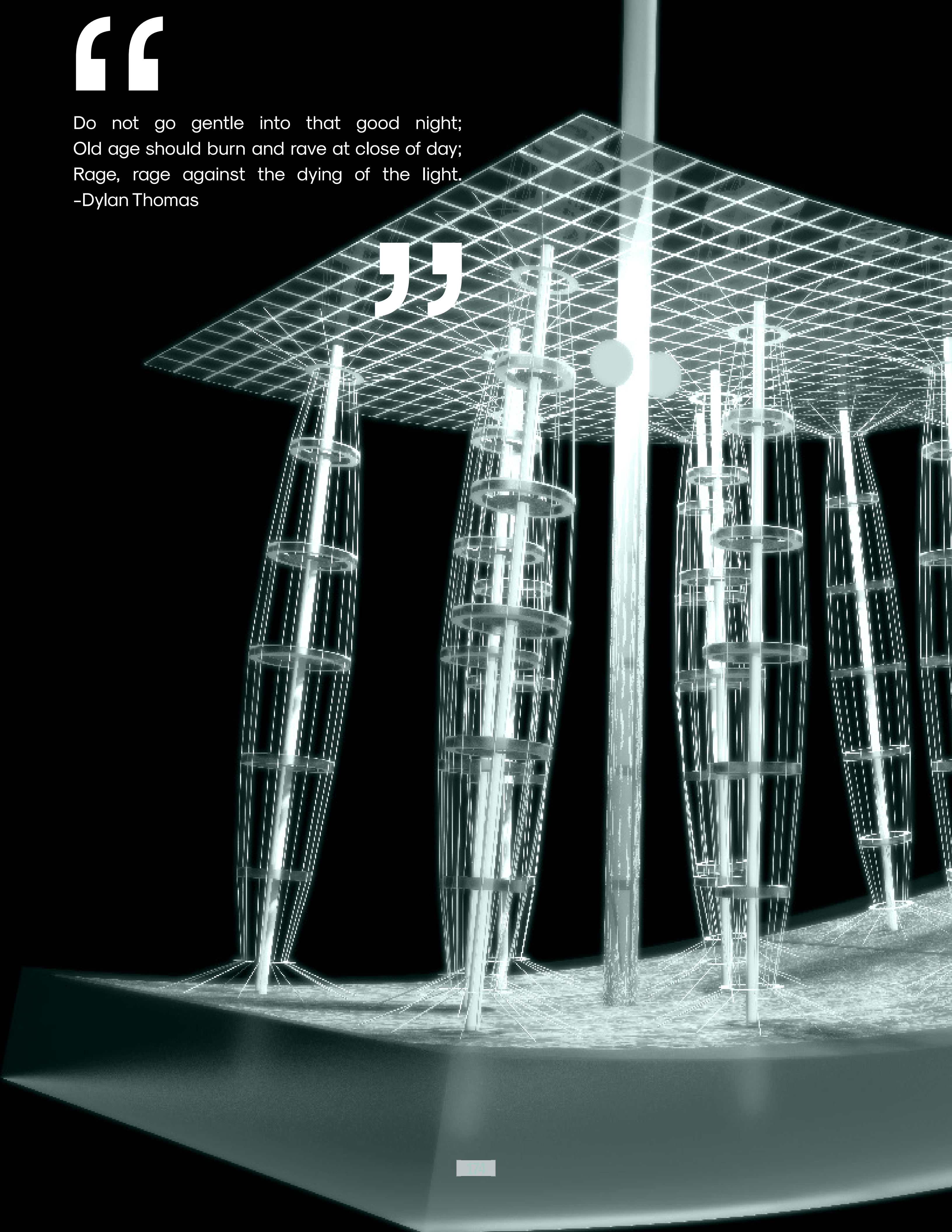
Manual labour is also plagued by its own human disadvantages, they are limited to certain times of the day to complete the work (and if you need to get them to work on a weekend the construction price just skyrockets). Here we can simply design what we needs to be built, input the machine instructions, then have the fabrication robots work 24/7 until the whole process is complete. Most offices own a fabrication robot that produces in the zero gravity areas of the colony, and because everything can be virtually prototyped we can provide instant feedback in regards to the exact cost it will take to create each component. Our specific office tries to conform to a schedule that allows us to design and code during the day and have something lined up for the fabricator to complete overnight, allowing us to constantly have a building component under construction.

In terms of actual life here, I believe you will have quite a bit of fun. The city is dense. There is an unfathomable amount of people here but the way the city is designed allows for it. The vertical space inside the colony is broken down into a series of different street levels with different services offered on each level. Building then align their floors to this framework, a could be inside the 20th story in a tower and only be 4 levels up or down from 90% of all the services and utilities that you'll ever need to use. The ground level for example is almost completely forestry with parks and low rise buildings. It really blends hyper urban living with a whole ground plane of nature and recreation. The amount of people also make it really easy to interact with people and you'll never run into a scenario where you've run out of new people. Because of the density there's usually a lot going on almost all the time, you'll always find at least ten festivals going on each day. For the most part this city is pretty fast paced, but the ground is almost completely forested and there are many areas where you can go to find seclusion.

There is definitely something here for everyone and I'm sure you'll enjoy your time here; wife and I can't dream of a better place to live out the rest of our lives together.

Hope to see you soon!

> Do not go gentle into that good night;
> Old age should burn and rave at close of day;
> Rage, rage against the dying of the light.
> -Dylan Thomas



conclusion

In Chapter 5: Framework, under the heading 'Design Parameters', a list of goals were defined for the design presented in this thesis to respond to. Those goals were defined within the first two months of starting the thesis (out of a total of eleven months) and they have not been altered or removed throughout the development of this thesis. This concluding chapter is written to summarize how each one of those goals were met.

Finishing the Argument

The original objectives and achievements that form the foundation of this thesis are described as follows.

Objective: To create a conducive setting for a diverse population to thrive.

Result: Because the space colony will be driven by a shortage of energy supply that all the nations in the world will experience, the colony will draw experts from every country. People will be given an opportunity to connect with others from different backgrounds fostering an acceptance of the differences in others. In the beginning, with only the first two modules built, the colony will only support a population of up to 10,000 inhabitants. The small population will cause this multicultural interaction to happen right from its initial beginnings, thus creating a new multicultural world.

Objective: To be able to grow sequentially in size in response to population growth and slowly allow for the transition to onsite food growth.

Result: The space colony is built out of a series of modules that can be sequentially added to form a double helix. As food starts to grow on the colony, a second double helix of modules will be created to house the farming operation. These modules are built in pairs to keep the colony in perfect balance. Although the double helix for farming and the double helix for living are intertwined, they can be grown at different rates to accommodate the transition to onsite farming.

Objective: To protect the citizens within the space colony from the physical hostility of outer space.

Result: Although the space colony is tethered to the Moon, this habitation is a vehicle able to eject mass and change its location in space. Today we have the technology to detect asteroids within the Earth's vicinity. Currently, NASA keeps track of every object in Lower Earth Orbit larger than 2 inches to maneuver the International Space Station around.[1] Using a similar method the colony will have the ability to avoid any large space debris. It will be built to defend against smaller debris by keeping a stockpile of captured asteroids that will line its exterior. Since each module functions as its own individual space habitat, if there is any damage done to one of the modules, the citizens can travel a short distance to another module. Each module will also be stocked with life boats to guarantee the safety of its citizens in the case of a calamity.

Objective: To protect the citizens within the space colony from political harm and control by other nations.

Result: This is done through a transition of dependency on the Earth to the space colony's complete self-sustainability. Since the colony will be constructed to mine Helium-3, the Earth will insist upon minimum mining quotas in order to receive life-sustaining supplies. Eventually, as space-based technology improves, the colony will adapt to encompass a full functioning closed ecosystem, having all of its food and potable water produced onsite. This will allow for the colony to function as an independent nation.

1 Garcia, Mark. "Space Debris and Human Spacecrafts." NASA. September 26, 2013. Accessed June 27, 2016. http://www.nasa.gov/mission_pages/station/news/orbital_debris.html.

Objective: To protect the citizens within the space colony from economic harm.

Result: Any space vehicle launched from the space colony would require less fuel, undergo less wear, and could potentially be much larger than one built on the Earth. This results from the absence of gravity and an atmosphere. Furthermore, the space colony will be the largest zero gravity manufacturing facility, and the majority of specialists in space mechanics will be residents of the colony. For this reason even after the demand for helium-3 dies down, the colony will be the most ideal place for space manufacturing and resource extraction. The high concentration of space robotic experts will also make the colony the most ideal location to place a engineering university specializing in space mechanics. This will create a status for the colony as the space-brain of the universe, much like how Silicon Valley is currently the technology hub of North America.

Objective: To be designed from a cradle to grave approach.

Result: At the space habitat's early beginnings, materials will be sourced from the Earth, and then later from comets, asteroids and the Moon. These resources will used to construct the modules and everything inside them. These modules however, are comprised of mechanical parts and are ultimately doomed to eventually fail or become obsolete. For this reason the growth of the colony will be restricted to one of the ends, leaving the other end to be comprised of the oldest modules that are the most likely to fail. In pairs, these modules will be decommissioned, melted down, or repaired, and used to create the next set of modules.

Objective: To take advantage of the unique design opportunities enabled within an outer space context.

Result: Tall buildings are hung from the interior ceiling of the space colony rather than built up, providing a vista of floating buildings for the inhabitants. Opportunities for large scale asteroid and lunar mining is opened up by having a permanent space presence. Furthermore, manufacturing of large objects can happen in zero gravity, allowing for larger, quicker, and more predictable assemblies. Weather is also completely under our control; building science is taken care of at the level of the colony, so exterior walls in buildings need only be cosmetic, allowing for a new level of form generation.

Objective: To offers a life that will be better than life on Earth.

Result: This objective runs parallel to with some of the accomplishments mentioned in the objective mentioned above. The space colony's robust public transportation and the high population density will prohibit the need for cars. This will motivate people to live closer to their place of work and defeat congestion. The design of colony also provides a superior setting by riding the ground plane of large buildings, freeing the ground plane for forestry, parks, and buildings at a human scale.

Final Thoughts

The research and design contained within this thesis displays a potential outcome of the involvement of the architectural profession in outer space habitation. Our education and training bestows upon us the ability to analyze complex design challenges and propose solutions with a blended perspective of art and science. Architects understand the importance of material efficiency while possessing an uncompromising regard for design. Additionally the profession consistently advocates for great architecture to be built on altruism that creates social integration and promotes overall human wellbeing. Our human centered design approach makes architects the ideal tree trunk that leading space habitation designers should branch off from. Eventually this field will grow to be much broader, and the results of this experiment will potentially provide a methodological approach for emerging space professionals. The space industry is still vastly undefined, and in its wake a new profession will emerge: the space architect.

BACK MATTER

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