
LUNA-CT

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She gazed down at her empty plate, stroking the wooden table beneath it with a sort of wistfulness; the realisation that this was the last time she'd touch wood for a very long time seemed to bother her more than anything else in that moment. Wood is such a distinctly Earthen thing: brown and intricate, ridden with the hidden complexities of the soil it once was part of. She thought about this some more, and probably would have continued thinking about it, had she not been roused from her trance by a familiar voice and a prod in the shoulder: "Nora." The voice was that of her friend, Ajay, who was waving a hand in front of her face with a look of subtle concern. "Hm?" she looked up from the table and began to remember where she was again: the dining hall. This is the hall where the first group of Lunacs, those meant to inhabit Luna-CT, had gathered to eat and share stories for the past 4 years. It was emptier now than it had ever been before, and the personal touches that had accumulated on the walls over the years had now been largely replaced by Luna-CT banners and a new layer of polished wood. "Everybody's leaving for suit-up, so you'd better stop overthinking it again and start moving." Ajay pushed his chair under the table before turning and heading towards the door where most of their fellow Lunacs had gathered to take in a last view of the hall before hurrying out the wide doors. Nora rose from her chair to join him, sliding it under the long wooden table. She made her way across the hall slowly, looking through every window, taking in every stain on the tables, and saluting the portraits of eminent scientists that had hung there collecting dust and praise since she first arrived. Once she reached the door she turned slowly, deliberately, her feet heavier than usual, and made one final scan of the hall. She had become so accustomed to seeing all the early Lunacs there all huddled together, making plans, sharing updates on Luna-CT's construction, that seeing it so empty made her uneasy. "Until next time," she murmured, not quite sure to whom or what, before exiting the hall for the last time, the wide doors shutting with a dull clang behind her.

The suit-up room she had been assigned to was small and cleaner than a hospital. A few people were pacing back and forth around the room, their white-and-blue pressure suits sleek and lustrous. A suit technician was fitting on her final glove: he pulled on a red string and zipped up the side, nodded to Nora, then left to assist someone else. Nora lifted her right arm to admire her newly-fitted glove, turning it and watching attentively as the light caught the subtle folds of the Nomex. "Nice, huh? I guess this makes us official starmen," said Ajay, strolling up to Nora, clad in the blue-and-white colours of Luna-C (the company behind the construction of Luna-CT). Despite the black being replaced with blue for the occasion, they were, in the end, still starman suits, and finally having them on was like the green light at the start of a race: there truly was no going back at this point. "All that's left to do is connect to the umbilicals and speak to Carter, then we'll be on our way to the launchpad," he said, glancing over at the clock above the door to the right. "Carter's coming to speak with us?" Nora asked. "Well yeah obviously, he's not gonna let us all leave the planet without telling us to remember to apply ourselves and all that," he smirked, probably remembering the long lectures Carter would give them on the importance of integrity in Luna-C. Carter was something of a supervisor for the Lunacs, he saw over their training and was always there to give a helping hand or a word of constructive criticism (the latter was more common than the former). But despite his cold manner and intimidating stare, he had become something of a friend to Ajay and Nora over their four years of training. He'd often join them for dinner to discuss anything they found interesting at the time, seemingly oblivious to the baffled looks of their peers, and it was probably because of him that they'd gotten the apprenticeships they did in Luna-CT. They were the youngest amongst the crew of 100 Lunacs, and so they were required to work two years of apprenticeships before they were assigned to a long-term position. A couple of years ago Carter announced that Ajay would be working with some researchers in the aeroponic farm, and Nora would be working on the cargo transport shuttles that came from the Moon. They found this strange because these were the exact positions they had been wanting since they arrived, and to add to the air of suspicion, Nora could've sworn she saw Carter wink at them both before he left the hall where it was announced.

She and Ajay were seated with the long umbilicals feeding cool air into their suits through their knees when the door opened and in came Carter, grey and stern-faced, his hands tucked into the pockets of his long coat. Behind him was a small robotic humanoid, bipedal with extremely human-like movements, and a pixelated smile on a screen for a face. Carter gave them a curt nod, but continued on to speak to the three Lunacs on the other side of the room. The robot, however, strolled right up to them, its metallic arms swinging a bit too forcefully at its sides. "Don't worry, I suspect he's just saving you for last," the robot said joyfully, it had the voice of a caretaker for the elderly. "Best for last, I suppose," said Ajay, crossing his arms and glancing over at Carter, who was now shaking the hand of a broad-shouldered Lunac. "Hey Marvin, which model are you?" Nora asked the robot. "Marvin 4.0 Compassionate," it replied, the pixelated smile on its screen widening ever so slightly. "That's what I thought," Nora sighed, a little crestfallen. It being the late 21st century, a good portion of the staff at Luna-C was robotic, and Luna-C decided to take a spin on things and name them all Marvin. The name Marvin, of course, was the name of a robot from a book that was required reading for all Lunacs in training. But instead of making these robots miserable cynics, they chose to give them the personalities of extraverted huggers. They came in different models,but the first was an all-time favourite of anyone lucky enough to come across one. Marvin 1.0 Prankish was known for its playful mischief and banter, but as it was only a test to see how far Luna-CT could and should push personality in robots, only a couple remained on the premises. The Marvin 1.0 that was assigned to the Lunacs had achieved both famousness and infamousness in a remarkably short amount of time, and Nora was hoping to see him before they left. "Don't worry, I'm sure Marvin's just been locked up in a broom closet somewhere so that he won't interfere with the launch," said Ajay, grinning at the thought of it. It was at that moment that Carter finished talking to the other Lunacs and came striding over to them, his long coat hugging his knees like a cloud of black smoke. "Yes I'm sorry, Marvin 1.0 wasn't able to make it today, he's needed elsewhere," he said coolly, his thick grey eyebrows furrowing as if in sympathy. "I bet you he's the one that put him in the broom closet," whispered Ajay. Nora feigned a cough. "What's that?" Carter raised one eyebrow, the wrinkles on his forehead tightening. When he didn't receive an answer, he sighed in exasperation and then began to bring them up to speed on the developments at Luna-CT. He explained to them the procedures that would take place up until docking (for the hundredth time); he told them that although the incoming crew's apartments had already been constructed, their first few weeks at Luna-CT would be spent helping out with the construction of homes; and he concluded by informing them that they would start their apprenticeships later than planned because of delays in aluminium shipments due to a minor mining incident on the Moon. It was uncommon for machinery to break down or for people to get hurt while on mining excursions on the Moon because great care was taken to prevent these things. But even so, the occasional incident was inevitable, and when it occurred at least some part of the operation had to halt, which affected Luna-CT's whole schedule. Fortunately, as Luna-C grew and expanded, its systems became more redundant and incidents became less and less common as time went by. As Carter wouldn't go into any further detail on the incident and Nora and Ajay weren't particularly inclined to ask, they all remained in silence until Marvin 4.0 interrupted by tapping Carter and saying "10 minutes until departure Mr. Carter." He nodded at the robot before turning to face them, his expression lightening "Well I suppose we'd best say our goodbyes now. I'll be up there with you in a year's time, so don't you two go around all pleased thinking you've seen the last of me," he said, tucking his hands behind his back, a subtle smile twisting his lips. "And yet I'm pretty sure you're going to be more pleased about us leaving Earth than we are," replied Nora. "Yes, I'll enjoy not having to respond to the countless reports of your attempts to reprogram every other Marvin to be more like the 1.0, only for everyone's laundry to be shrunk," Carter said in a sarcastic tone. "Hey, we were just letting our curious minds flourish, like you told us to!" said Ajay. Carter sighed, then kneeled down to be level with them in their seats. "You two are smart kids, you know that right? But when you're up there it's going to take a lot more than cleverness. It's going to take hard work and dedication. There's no going back now, which means no giving up. Apply yourselves, and don't forget: per aspera ad astra. Through adversity, to the stars." This was Carter's favourite saying, but he tended to reserve it for special occasions - which made its effect all the more powerful. "All right everyone it's time to go!" called a brown-haired suit technician, motioning for Carter to join her. "They'll probably just be needing me to go over the schedule again and review any changes," said Carter as he rose to his feet. Before walking away, he smiled at them and said "Good luck out there."

The bright rays of the Florida sun seeped through the windows of the car that Nora and Ajay were sitting in, their nitrous oxide tanks by their feet. They had just begun the half hour drive to the launch pad, and music was playing out of the speakers by their ears. Nora gazed out the window, watching the trees pass by in a green blur. "I heard the trees in Luna-CT are completely different. Real, but different," she said in a low voice, not wanting to speak over the track the driver was humming to. "I guess we'll have to wait and see for ourselves," replied Ajay, leaning his head against the glass. They spent the remaining thirty minutes in silence, tuning in and out of consciousness, transitioning between deep thought and shallow humming. Nora would occasionally crane her neck to get a better view of the file of white cars in front of and behind them sailing down the road like a fleet of oddly-shaped sailboats, their flanks glimmering in the sharp sun. It wasn't long before she could feel the subtle hum of the car begin to slow and see the driver straighten his shoulders: they had arrived. As soon as the car doors opened she leaped out, taking a deep breath of warm, salty air. "Look at it! Just look at it!" Nora gasped, looking up at the towering ship of steel that stood so tall it might have touched the clouds had there been any that day. "It's really hard not to look at it," said Ajay, more calm but not any less stunned at the sight of it, the steel giant, the Starship. They were roused from their trance by an almost-dictatorial voice. "Okay everyone, groups of ten! Ten people in the lift at a time!" called a stout and broad-shouldered woman that they had met only a couple of times: Captain Bennington, the person who would be supervising their trip to and initial operations in Luna-CT. The Lunacs quickly arranged themselves into groups of ten and made their way towards the elevator, Captain Bennington guiding them to their places as if she was marshalling an aircraft.

While they were waiting, Nora and Ajay pointed out the features of Starship to each other as if they were admiring a work of art. Nora was tracing the lines of the fins with her index finger and Ajay was counting the engines when they heard Captain Bennington calling over to them and the few Lunacs that stood around them. She was motioning towards the lift that stood at the foot of the giant tower that held Starship between its two mechanical arms. The Lunacs around them had expressions of calm composure, but their excitement was evident by the way they practically ran towards the elevator. Nora found herself, once again, rooted to the spot where she was standing, her limbs feeling heavier than they did at the door of the dining hall. She looked past the elevator at the sea, taking in the tides in all their glory one last time. This time, however, she didn't ruminate about every shade of blue she saw in a subconscious attempt to forget about the challenge at hand, but instead took a deep breath, exhaled, then put one foot in front of the other and didn't look back.

The elevator was much louder than the car, it screeched and rumbled until it came to an abrupt halt. With a light *ding,* the elevator doors slid open, revealing a small platform that ended in a large open hatch. Nora stepped out, followed by Ajay and then the other 8 Lunacs. A soft white light was coming from the open hatch, and Nora made her way towards it. The hatch opened onto the flight deck, a spacious floor filled with tilted seats, all occupied by Lunacs clad in blue-and-white. "Let's see who can remember their seat numbers. It's not like I changed them or anything," someone said in a strangely familiar robotic voice. Nora turned to see a small humanoid robot with a pixelated smile a tad bit too wide, its metallic arms folded behind its back. "Marvin!" Ajay gasped, "we thought Carter had you locked up in a broom closet!" "Who's to say he didn't?" Marvin replied. "No, I'm kidding. Carter arranged for me to join you on Luna-CT as kind of a parting gift, I think. He said something about me being useful for testing the skills of the repair mechanics. I didn't hear him too well, I was too busy swapping the seat numbers." He gave a robotic chuckle before skipping away, the sound of his feet echoing throughout the flight deck.

A few hours had passed and everyone was now in their seats, strapped in and ready. Nora could just see the back of the enclosed space closer to the centre of the deck where the commander and pilot sat, and she wondered what must be going on in their minds right now. The sound of communications came from the speakers fitted around the flight deck, finishing with "T-3 minutes." Those three minutes felt like 3 hours and 3 seconds at the same time, silent yet filled with noise. At around T-1 minutes the deck became eerily quiet, and the Lunacs stiffened in their seats. Nora thought of the years of planning and training that had led up to this moment, the weight of it all never fully sinking in. The brief static sounded on the speakers once more before the final countdown began. Those were the longest ten seconds any of them had ever experienced. "Liftoff," voiced the comms person through the speakers, as calmly as if they were stating the weather conditions. A deep rumble coursed through the floor of the flight deck and Nora found herself becoming increasingly pressed into her seat, feeling disproportionately heavy and strained. She closed her eyes, imagining the bright purple flame of the 33 engines at the bottom of the rocket exerting millions of pounds of force, more force than anything else that had ever left the Earth.

Like a wild horse the ship of mirror-like metal propelled itself into the blue sky, crossing the sound barrier as if it was just another hurdle in a long track, a track to the stars and beyond. Per aspera, ad astra.

The trip to the moon was about three days long, and a day had already passed. Starship was now careering through the blackness of space on an invisible trajectory towards an invisible orbit, riding on ripples in spacetime, and Nora was floating somewhere on the floor below the flight deck, watching the nothingness through the long windows in awe. Even though most of everyone's luggage was already on Luna-CT, they were allowed to bring some trinkets with them, and along with pictures of home and her family, Nora brought a book with her, a paper book. This, everyone thought, was odd. It's not that paper books were rare - most of the Lunacs had a collection of them waiting for them in their apartments at Luna-CT - but that they were seen as just that: collectables. Physical books had become rather quaint and why Nora felt the need to read one when it was probably available on the ship's database remained a mystery to everyone. The truth was perhaps even odder: to Nora, a book stored on a database told one story, but a physical book told many. Shen took with her one of the oldest books she owned: Plato's *Republic*. She found it in her parents' library as a child and read it, not really understanding much. But every year she'd come back and read some of it again, until the words had become clear and forever imprinted on her mind. She took this book not because she particularly liked it, but because of the stories told between its lines. On the first page was a faded scribble of black ink 'To my student and friend, in hopes it may answer some of your questions', and below it was scribbled in less faded blue ink 'To my friend, in hopes it will liven our debates', and below that in the darkest ink of all were written words of goodbye from her family and friends. Nobody really knew much about the book other than that it was printed in 1967 and permanently borrowed from a university library by Nora's grandmother. This book was the strongest tie she had left to Earth, and so she liked to keep it close.

It was well into the second day of the trip and Nora and Ajay were seated, or rather hovering, at a table, watching attentively as Marvin was trying to get himself out of the accusation that he had swapped a good portion of everyone's socks for mittens. "Marvin there's no point in trying to deny that it was you, just tell me how and why," Captain Bennington said, a pink mitten in her hand and an expression on her face that looked on the verge of rage, laughter, or both. "What's the difference? Everyone here has the same number of toes as they do fingers, and look, even I can wear them!" Marvin took one of the pink mittens and slipped it on one of his metallic feet "and I don't have toes at all!" he added triumphantly. Ajay and Nora burst into laughter, and the surrounding Lunacs followed suit. Captain Bennington turned pointedly, grabbed onto a handlebar, and floated out of the room; she might have appeared angry had she not been chuckling.

Apart from that, nothing else really happened that day. After lunch Nora and Ajay spent the rest of the afternoon by the windows, talking about all the things they'd see and do at Luna-CT like two children at the start of summer vacation, and it did feel like that: two kids squabbling about where the best swimming spot was.

The third day was busy, really busy. It felt like launch day all over again: the people rushing past each other in the halls (this time 2 inches above the ground), breakfasts eaten quickly or else left abandoned in the cafeteria, and Marvin singing rude rhymes at the top of his voice. This time, however, Nora wasn't nervous or anxious, she was excited, really excited. She woke up earlier than Ajay and went to knock on his door. He opened it in less than two seconds, a backpack slung around his shoulder and a resolute look on his face "I'm ready." They made their way to the cafeteria, which had now been cleared and was filled with people, eager to begin the final journey. Once everybody had found a place hovering next to a table or wall, Captain Bennington, standing at the centre of the room, cleared her throat to make herself heard. "All right I hope everyone knows the drill as well as if they had come up with it themselves by now, but we'll go over it one last time just to get ourselves in the spirit," she smiled briefly, before clearing her throat again and reciting their agenda for today: "We'll be arriving at Luna-CT in exactly 7 hours and 42 minutes, I'm sure you've seen the Moon by now, pretty hard to miss it. Once Starship has successfully rendezvoused with Luna-CT, docking will begin. We'll be docking onto the 0-g sphere and will be entering Luna-CT through a series of elevators on one of the hotel floors. After that, we'll spend the day getting settled into our new lives, that means getting through with all the unpacking and registering. Your tasks will be sent to you the next morning, and all the rest is up to you," she gave a little bow, then turned and glided out of the room, ticking a box on her digital notepad. A few moments of silence passed before everyone began to shuffle and get into their preliminary positions, engineers making their way to the lower decks, medics checking equipment for the millionth time, and people of every trade busying themselves with some task or the other. Nora and Ajay, not having been assigned to any official position yet, took to one of the tables and, for the first time in three days, began to talk of Earth. They had been so caught up in the trip and their mission that they hadn't really spared a minute to even think about the blue marble they had just left behind. But now they talked about Earth, about their hometowns, about Carter, and about random things like the sun rising in the east, as if by doing so they were paying homage to the planet they had just left behind. Talking about it all didn't make them sad, because leaving wasn't a sad thing, and if anything it just made them anticipate the arrival at Luna-CT even more. They had heard all kinds of things about Luna-CT, that the grass was green and thick and smelled like dew, that the way the sky curved so boldly made you dizzy the first few days, etc., and there was seldom a rumour or a whisper that spoke ill of Luna-CT. Nora checked her watch, 7 hours to go and counting.

Everybody was strapped into their seats again, listening idly to the comms, tapping their fingers on their armrests. This was it, the final stretch of the journey, the last lap in this race that there was no going back from. Before arriving at the flight deck Nora and Ajay had gone up to the very top deck where there was a giant window into space. The moon loomed so closely ahead it looked like the gleam of a lighthouse, only so much sharper, and it was splattered with puddles of grey that really did look like seas. They found it incredibly hard to leave behind that view of the moon, as if it had glued their feet to the floor and was telling them an interesting story. They eventually left, albeit begrudgingly, when Captain Bennington made a final call for everyone to be on the flight deck through the comms. Nora took a look around the flight deck one last time before closing her eyes and taking a deep breath and thinking: Luna-CT, here we come.

“Docking operations terminated, ready for egress,” voiced the stranger through comms. A murmur of excitement rippled through the seated Lunacs like a wavelet in a still lake, unexpected but not unwelcome. Before long they were all on their feet, wrapped in their blue-and-white suits once more. They exited, or rather egressed, through the same hatch they entered, although the platform waiting on the other side was much wider. They exited onto a long white platform with curved walls, and one by one filed out through an opening onto the wider floor, waiting as Captain Bennington did something of a roll call. Nora found herself on what was indeed a hotel floor, though you couldn’t really tell at first glance: the walls were curved, white, and endless, and the floor looked like wood but was really some cleverly disguised aluminium. The things that gave it away were the potted plants, the secretary’s desk up ahead, and the giant sign on the wall behind the desk that said ‘Hotel 1st floor’. Then all of a sudden what she had previously presumed to be pillars opened up and revealed the interiors of large elevators, big enough to carry 20 people each. “All right everyone let's arrange ourselves into groups of 20 and make this last trip nice and easy,” said Captain Bennington, appearing as if from nowhere. They did so seamlessly, and before she knew it Nora was floating in an elevator beside Ajay, clenching her fists in either anticipation, foreboding, or mostly likely a mix of both. After a light chime, the elevator began to descend, and everyone grasped a handlebar to allow it to take them down with it. After a few minutes they were out already and had to board another set of elevators, nearly identical to the last. The end of the journey of the second elevators marked their exit out of the 0-g sphere. To nobody’s surprise (they had all listened to Carter explain this to them so many times before that Nora was sure everyone could hear his words as if he were standing next to them), the elevator opened under their feet, but since there was no notion of up or down in weightlessness, this was of no relevance. Everyone exited, making their way through an empty space into one last hatch with the help of some well-placed handlebars. Beyond the hatch there was another white room that you needed to crane your neck to see the end of, studded with metal handlebars. Around the sides there were even more elevators, only these ones were smaller. The journey down these elevators was strange, to say the least. The force of gravity came to their legs for the first time in three days, and it took everyone a minute to get adjusted to their renewed awareness of direction.

A familiar chime broke the silence in the elevator, and all of a sudden a strange tension built up between the people crammed onto that circular floor. There had been so many moments of anticipation over the course of the trip that Nora had lost count of how many times she had caught herself holding her breath or clenching her fists, but there was something distinctly different about this time. The silence was infinite, unbearable, but short-lived as the doors began sliding open shortly after the jingle had finished. A bright light flooded into the elevator and Ajay gasped, and Nora turned to see everyone's mouths hanging open or else covered by a hand in awe. Her stomach swooped when she pushed past Ajay and got a good look at what everybody was stunned by. It looked exactly like the pictures, even better. A giant city scape loomed in front of them, bright and clean and symmetrical and green, so green. She could smell fresh dew and the stone-like material beneath her feet glimmered in the light that streamed in from the glass in the distance. Their trance was broken by the whooshing noise of a train that whizzed past over their heads, gliding along the curved ceiling. "That would be our ride," said Ajay, grinning wildly at everyone. Just as they were about to board the monorail, Marvin came bustling out of one of the elevators, claiming he had gotten lost, before jumping into one of the carriages, shouting "Per aspera ad astra! Latin for hasta la vista!", a pink mitten still on his metallic foot.

Introduction

"Greetings"

I would like to start this project with a greeting: hello. Now that we've gotten that out of the way, I'd like to explain the name Luna-CT. The name comes from the first word that came to my mind when I first heard about space colonisation in March of 2022: lunacy. Then when I became convinced and decided to design one of my own around the Moon, I could think of no better name for the company that would build the colony than Luna-C, and so it logically followed that the name of the colony itself should be Luna-CT.

Perhaps the grandest things do have the most humble beginnings after all.

Executive Summary

Luna-CT is a space station in a near rectilinear halo around the Moon that supports 10,000 full-time residents and 5,000 Earther tourists. A location around the Moon was chosen because Luna-CT is a station meant to be built in the nearer future and therefore proximity to Earth for resource transportation and tourism is convenient; tourism also happens to be a major source of revenue in Luna-CT.

In the structural overview, I discuss my reasons for selecting the cylinder as Luna-CT's geometry, the dimensions of the station, the basics of the mirror system, the uses of the segments the station is divided into, and some solutions to wobble control. The station itself is divided into an inner and outer cylinder, and a smaller 'micro-g' cylinder in the centre. The inner and outer cylinders provide the essentials for life on Luna-CT, and the micro-g cylinder is used as a laboratory, swimming pool, and a connection point to the 0-g sphere. The 0-g sphere is a stationary sphere connected to the main station and is used for recreation and science. Above the station is a large spherical mirror made of aluminium panels to reflect light into the colony.

Luna-CT is in a 4:1 lunar synodic resonant L2 south near rectilinear halo orbit, an orbit similar to that of the planned lunar gateway. This orbit is chosen because it requires minimal maintenance and nearly always avoids eclipsing, which can be a security issue for settlements in free space. The characteristics of such an orbit and my reasons for selecting it are discussed in more detail in the section on location.

In the section on the mirror system and artificial sky, I outline the dimensions of the mirror and how the materials it's made from will be processed from lunar regolith; and how an artificial sky will be implemented in the inner cylinder of Luna-CT, the discussion of this implementation includes a process for creating temporary clouds as used by a famous photographer. The mirror used to reflect light into Luna-CT is spherical for ease of construction, and is made out of tens of thousands of aluminium panels, where each panel is curved slightly and cast in the same way metal is curved and cast on Earth, and the aluminium is extracted from lunar regolith along with other useful elements through the hydrofluoric acid leach process.

To determine how effective the mirror system is for bringing light to the station, I design and perform an experiment where I make a miniature model of Luna-CT and measure the illuminance values around the surface of the interior of the model using a light sensor and an arduino UNO.

This paper goes into great detail about division of space, as ensuring there is enough space for everyone is vital. I describe how much space is allocated for everything from housing for families to transportation. Great care is taken to ensure that there is enough 'breathing room' in Luna-CT to ensure comfort but that the limited amount of space is used as efficiently as possible. For this reason some things such as hotels and theatres are placed on the surface of the artificial sky, which is made of water, and apartment blocks are placed together in clusters, leaving room for wide stretches of park and green areas. Attention is also paid to architecture: Luna-CT embraces a funky, futuristic, yet efficient style, and I explain how this is incorporated by designing a family home based on the efficiency of dome houses and minimalistic style. To further demonstrate Luna-CT's style, I include an art wall showcasing some of the station's architectural elements.

To take a break from all the numbers, I decided to include a section on Luna-CT's education system. Education is an often overlooked aspect of societies in space colonies, but I believe it is incredibly important as the new societies started on these space stations may be the perfect opportunity to address some important issues faced by modern-day education. I discuss the less systemic approach Luna-CT takes towards education, and its focus on creativity and independence.

The micro-g cylinder and the 0-g sphere are two sides of the same coin, because they're both used for recreation and science, though the 0-g sphere also comes with a hotel. I describe how these are divided into different floors and uses, I design a mechanism to separate the rotating cylindrical station from the stationary 0-g sphere with no energy consumption, and go into detail about more specific functions of the 0-g sphere such as the 0-g theatre and the Hall of Dreamers.

Luna-CT gets its food from aeroponic farms, and I explain how these systems are designed, going into detail about things such as the effect of specific wavelengths of light on plant growth and how the Lunacs can get all their nutrients from a purely plant-based diet. To expand on Luna-CT's aeroponic system, I design another, bigger experiment to demonstrate the merits of aeroponics. I designed my own system to grow mint aeroponically, mimicking Luna-CT's system as closely as possible. To test this system against a traditional soil growing method you would have to grow mint in soil and then monitor the difference in each plant's growth speed, biomass, stem height, and taste over a one month period (testing period duration varies depending on whether or not you start from seeds). The results of similar experiments confirm that aquaponics is the way to go in Luna-CT.

Structural Overview

"What is it?"

Geometry

When designing a space habitat that will support thousands of people, the first question we should really be asking ourselves is what shape should it be. Because like there are only so many possible elements or ways to tie your shoes, the laws of physics and our own understanding of them limit our options. To give some background: for a space habitat to be able to take loads from pseudogravity and the atmosphere it must be a doubly-symmetric, closed shell of revolution. The basic shapes that meet that criteria are the torus, the cylinder, the sphere, and the dumbbell (two spheres on a rod) (NASA, 1977, pp. 39-41). In order to get a good comparison of these geometries I designed four separate colonies with the same arbitrary parameters: 120m²/person for 13,000 people. The cylinder required the least total mass (shielding, structural, and atmospheric masses) and was the most "open" of all the geometries. Thus it logically follows that the cylinder would be the best choice if little mass and a high degree of openness are your concerns. It just so happens that these are my concerns, so the cylinder it is; well, cylinder or rotationally stable hockey puck, whatever is your preferred term.

Luna-CT is a cylindrical space colony, and can be divided into three segments: the hull, the upper appendages, and the lower appendages. The complete colony is shown here:

Figure 1. The complete colony

The Hull

The hull is the main section of the colony where everybody eats, works, sleeps, and just lives out their lives. It's also the largest section of Luna-CT. The hull is divided into two main cylinders: the outer cylinder and the inner cylinder. The inner cylinder is connected to the outer cylinder with tension cables, as in (Globus et al., 2010). These cables also reinforce the outer cylinder and the hull structure itself, reducing the required structural mass. The outer cylinder is the "main" cylinder, with a radius of 360m and a length of 468m, it has 105,8591.061m² of surface area. The outer cylinder is where everything that most people don't want to see outside of their daily 9-5 is located. At any given point on the surface of the outer cylinder the inner cylinder is always 70m above you, and so the outer cylinder is sometimes separated into many levels, sometimes into one level with tall skyscrapers, and sometimes into segments of open space to complement that of the inner cylinder. The inner cylinder has a radius of 290m and a length of 398m; only roughly 66% of its surface area is really "habitable" though, the rest serves as an artificial sky made of water, called the sky pool. The 475,205.2482m² of the inner cylinder surface area that *is* habitable is, to be brief, a glorified suburban neighbourhood. The only catch is that it's 384,000km away from any other suburban neighbourhood. It's far from being desolate though, the inner cylinder houses pleasant residential areas, lots of open space decorated in a Singapore-like style, outdoorsy recreation, basically everything you'd hope to see on the ideal dog (cat, bird, etc.) walk.

Figure 2. The inner and outer cylinder

Upper Appendages

The upper appendages consist of the mirror system designed to bring light into the colony. The colony is aligned with the solar system's north-south axis, or in other words, it's floating through space upright, with the mirror system at the top and the lower appendages at the bottom. In this position sunlight hits half of the mirror at any given moment so it no longer becomes necessary to continually point the colony at the sun. The mirror system can be divided into two parts: the reflector, and the glass. The reflector is a large convex spherical mirror made up of 30,000 aluminium panels held together in a matrix.

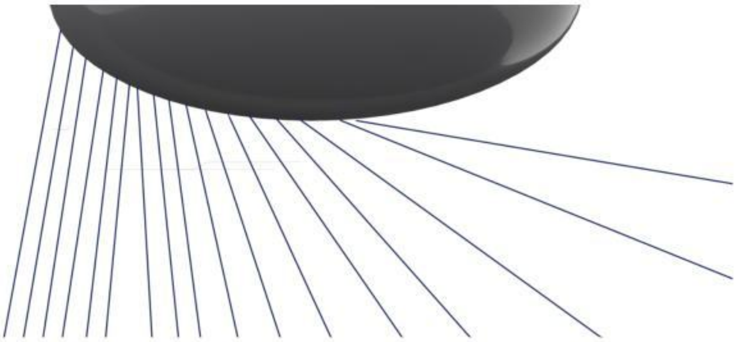


Figure 3. How light rays reflect off of the mirror

And the glass is the upper endcap of the hull made from silica glass and lined with chevron shields to protect Luna-CT's inhabitants from galactic cosmic radiation. For more information on the reflector and glass, see pages 16 and 17 respectively.

Lower Appendages

The lower appendages consist of the bottom endcap and the 0-g sphere, plus the elevators that connect them. Connected to the bottom of the hull is another flat endcap, and in the centre of this endcap another cylinder is constructed, a micro-g cylinder. This cylinder has a diameter of 119m, a length of 70m, and is at a height of 300.5m. It is used for recreation and science. The acceleration along the circumference of its structure is the same as Lunar gravity. This cylinder would be accessed through elevators placed around the surface of the outer cylinder as is shown below:

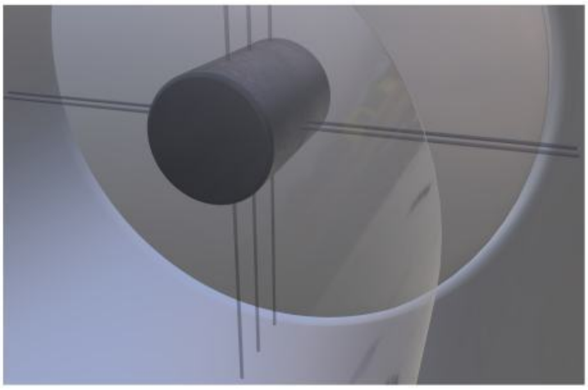


Figure 4. The micro-g cylinder (The transparent thing in the image is a visualisation of where the inner cylinder would intersect this structure.)

In the centre of the micro-g cylinder is an opening that connects to the column that transports people to the 0-g sphere.

The column has a diameter of 23m and consists of 25 elevators, altogether capable of transporting over 500 people at a time.

Then to enter the rest of the sphere there are passageways equipped with handholds which presumably shouldn't be too much of a hassle to use in the sphere's 0-g environment.

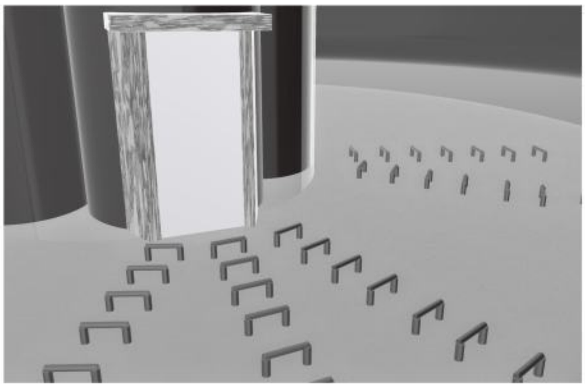


Figure 5. The handholds to grip onto

The 0-g sphere is a large sphere with a radius of 70m and is used for tourism, recreation, and science. The 0-g sphere has 1,436,755.04m³ of volume and is separated into many levels and functions as is shown in Figure 6. This sphere along with recreation is covered in more detail on pages 30-33

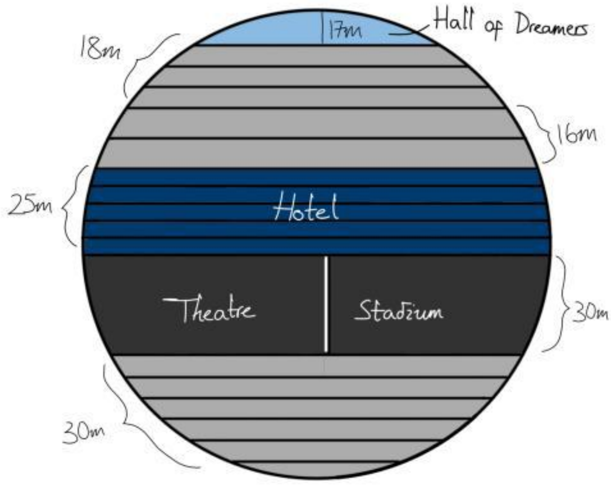


Figure 6. Division of the 0-g sphere

A cylinder length of 468m is chosen in order to address one of the main problems with cylinders, that problem being their tendency to become twirling batons when they get too long; because I just can't seem to find anyone who would want to live in one. The length in order to attain this rotational stability is 1.3r for a cylinder with flat end caps (which itself is the most stable cylinder, excluding one without end caps), (Globus et al., 2010). Hence the length of 468m.

Wobble Control

Even though we're past twirling batons now, the colony would still have some wobble due to uneven distribution of mass across the cylinder. This could be overcome by pumping fluid across the cylinder to counteract any concentration of any mass or by weights on winches like those used by Globus et al. (2010). This problem is not discussed here any further.

Rotation

"Try not to get too dizzy"

Weightlessness has some pretty wacky effects on your body. And not wacky in the "I can fly!" sense, wacky in the "oh no, all of my bone and muscle mass have completely deteriorated" sense. That got dark pretty quickly, huh? Being up on the ISS for a year is similar to being in bed for a year if you don't get your exercise while you're up there, but sometimes even that won't be enough. Astronauts who return from long-duration missions literally have to learn to walk again, and whilst in orbit astronauts experience bone loss, muscle atrophy, cardiovascular degeneration, and impediments to their regulatory physiology. And although there are methods of mitigating these effects through exercise and medication, they are only partially effective and some things, such as bone loss, are completely uncontrollable. The problems associated with weightlessness extend even further than human health, however. Many commonly used systems here on Earth have to be completely redesigned in weightlessness to account for the different way that fluids flow in the absence of gravity. It therefore seems inevitable that we should provide artificial gravity to those fortunate enough to be taking those first few steps down the winding path to the settlement of the stars. The only feasible way of producing this artificial gravity is by means of a centrifuge. The fundamental idea behind this concept is to replace the normal force (that which gives the sensation of weight) with the centripetal force, and to replace gravity with the centrifugal force; these forces are completely indistinguishable from those you'd experience on Earth.

But before we move on, we must first select an adequate rotation rate for the colony. Spin too fast and you get a lot of sick people in what begins to look like a spinning wheel the likes of which hamsters and other small rodents like to run on. Spin too slow and the whole project becomes infeasible. According to Globus & Hall (2017), humans can tolerate rotation rates of up to 6rpm with some training. For Luna-CT specifically, a rotation rate between 1 and 3rpm was deemed optimal due to two factors: the first the fact that Luna-CT doubles as a space hotel and is meant to be attractive to tourists, and let's face it, spending the first day of a vacation being sick isn't very welcoming; the second being that Luna-CT has a large population (10,000 residents and 5,000 tourists), and so needs a lot of space anyway. Thankfully, there's no lack of space (pun intended) in Luna-CT with $119m^2$/person of surface area for living in the hull alone. Luna-CT has a radius of 360m, and the artificial gravity at the outer rim of a spinning habitat is given by $A = \omega^2 r$ (the equation for centripetal acceleration). Since we want artificial gravity to be $9.81m/s^2$ at the outermost section of the colony (in this case the outer cylinder) we can rearrange the equation to solve for $\omega = 0.1650757402$ rad/s; multiplying this by the conversion constant $60/2\pi$ yields a rotation rate of ~1.576rpm for Luna-CT. This is a pretty optimal rotation rate, it's not so high as to be particularly noticeable but also not conservatively low either. The only issue that I can think of that would arise due to this rotation would be coriolis forces. Coriolis forces make themselves known here on Earth most notably in the form of hurricane Katrina, but they are present in any space habitat that spins too, albeit to a lesser extent. The coriolis force is actually something quite intuitive: imagine you're looking at a person standing in the centre of a spinning merry-go-round from above with a ball in their hands, now say they were to throw that ball out to the rim of the merry-go-round. Would you expect the ball's path to be a straight line? No, it would curve with the merry-go-round, right? Yeah well turns out this can be kind of a bother in space settlements. If you were to go for a jog along the diameter of the cylinder you might feel a tug down to the ground, or if you were to climb a ladder you might feel a tug in any direction depending on where you are in the cylinder. The acceleration you would experience due to this tug is given by $C_a = 2\omega v sin\theta$ (Bukley et al., 2007), where ω is the angular velocity of the station in rad/s, v is your velocity in m/s, and θ is the angle between your velocity vector and the angular velocity vector of the station. According to Bukley et al. (2007), a "noticeable" acceleration would be about 0.25g, but it states that this value may be conservative. If we want to keep the coriolis acceleration under 0.4g, the product of $sin\theta$ and v has to be less than or equal to ~11.9. This means that you'd have to travel 11.9 m/s or slower when going towards or away from the centre of the station (when $\theta = 90$), and you'd be able to travel faster as you travel in straighter lines across the circumference of Luna-CT.

Location

“So where on Earth is this thing?”,
“Well, it’s not”

Luna-CT, and you don’t need to be an expert in Latin to figure this one out, is located around the Moon. The Moon is the Earth’s sole satellite, the source of the poet’s inspiration and the scientist’s ponderings, the only other celestial body humans have set foot on (so far); but it is also an economy in the making. With Russia and China’s planned lunar research station and the United States’ upcoming Artemis program, the Moon is becoming the centre of attention for many nations. Though it is viewed largely as the gate to Mars, which is fair, I believe that the Moon will be the future Bahamas, and that any loss experienced in Luna-CT in terms of materials that would need to be shipped from Earth due to their unavailability on the Moon would be made up for by the profit of tourism. But the moon, though barren at first glance, has many of the materials needed to construct a space colony, elements such as Al, O, Si, Ti, Ca, Fe, and Mg can be found in relative abundance on the lunar surface. The dearMoon project, meant to take place in 2023 (as of mid-2022), will be the first such project to demonstrate lunar tourism, and is sure to inspire a generation to look up towards the moon and see, if not their dream vacation, then their future home. 1/3 of Luna-CT’s population (total population: 15,000) are tourists, and the other 2/3 are residents meant to keep the colony going and to expand further out into the stars. A lunar location is ideal because it’s convenient for tourism and tourism is a huge aspect of Luna-CT’s revenue. This revenue is key as it enables expansion further out into the solar system.

As to the *specific* location around the moon, there are many options to choose from. The orbit chosen for Luna-CT is technically not even a lunar one, but it is around the moon. Allow me to explain: in front of and behind the Moon there are two points called L1 and L2 respectively, these are two of the five lagrange points in the Earth-Moon system. Around these points there are families of halo orbits, and some of them intersect the moon so that they sort of *become* lunar orbits. These are large halo orbits called near rectilinear halo orbits (NRHOs), and it is fair to say that they are goldilocks orbits: they have low maintenance requirements, low delta-v requirements to reach from Earth and to get to the surface of the Moon, are ideal for launching interplanetary missions, have extended coverage over areas of interest on the Moon, and in some situations can even completely avoid eclipses from both Earth and the Moon (Williams et al., 2017). These NRHOs can be further classified into families of L1 North, L2 North, L1 South, and L2 South families of NRHOs, as is shown here in Figure 7:

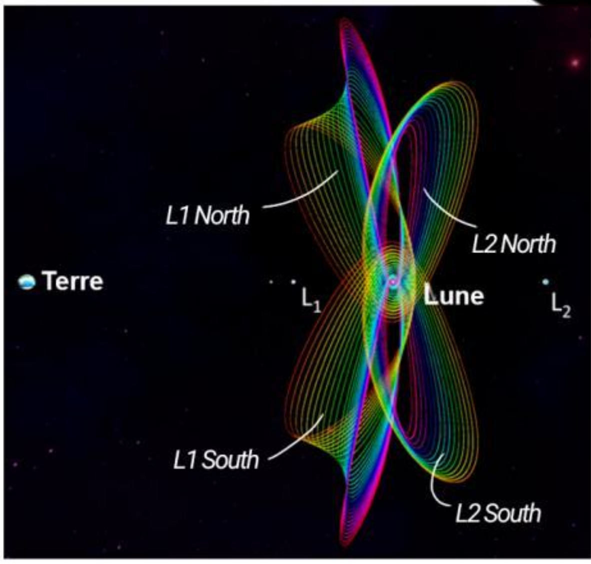


Figure 7. L1 and L2 north and south NRHOs
Credit: modified from NASA (https://ntrs.nasa.gov/citations/20170001347)

Eclipsing is a problem when you have a gigantic space city orbiting the moon, though that’s not something you hear people complain about often. Being blasted by the sun and then plunging into the freezing temperatures of space really tests the structural integrity of your station and if your power comes from the sun then the colony would need to rely on alternate power sources or have an immense battery storage capability during eclipses. Eclipses can be avoided, however, by applying something called synodic resonance. The principle behind synodic resonance is simple: for every x complete revolutions the moon makes around earth, Luna-CT makes y revolutions around the moon. It is then said to be in a y:x synodic resonant orbit around the Moon. Williams et al. (2017) ran a 19-year continuous trajectory approximation simulation using a full ephemeris model, and a 4:1 synodic resonant near rectilinear halo orbit completely avoided eclipses. The 4:1 synodic resonant orbit has a perilune radius of 5,750km, an apolune radius of 75,000km and an orbital period of about 7.3 days (Williams et al., 2017, p. 9).

And finally, in choosing between the L1 North, L1 South, L2 North, and L2 South families of orbits (as shown in Figure 7), I used similar criteria to NASA in its whitepaper on these orbits (NASA, 2019). The L2 family of orbits is chosen for its beneficial stability characteristics, and the L2 South orbit is chosen for coverage over the lunar south pole, which is an area of interest, and because it’s easier to return to the northern hemisphere of Earth from it. So to summarise, a 4:1 synodic resonant L2 South near rectilinear halo orbit is chosen for Luna-CT. That destination really doesn't sound good on a postcard though, and so from now on I will refer to it as “Luna-CT’s orbit around the moon”.

Mirror system and artificial sky

"Sun and sky"

The Sun is a funny thing, it's like that one big thing that all of life is dependent on, it rises and sets gloriously in our skies everyday (in most places anyway), but it's also that one thing that you can never really see with your own eyes. Well, not if you want to see anything after that anyway. It was Ramses II who said that the Sun is the giver of life, and that fact remains true both on Earth and off of it. If we're going to put a bunch of people in a metal can around the moon they're going to want to see the light of day, and a sky too preferably. So why don't we give the people what they want, this is *their* home after all, is it not?

The mirror system to reflect light into the colony is made of two main parts: the reflector and the glass. Together, these make up the upper appendages of Luna-CT. The reflector is a large convex spherical mirror that represents the bottom cap of a sphere with a cap diameter of 570m and a cap height of 135m. It is 250m above the rotating cylinder and has a radius of curvature of 368.33m and a focal length of 184.17m (under the paraxial approximation). To help visualise how light would interact with this mirror, I constructed a model ithe Ray Optics Simulation open-source web app built by Tu & Sun (2016):

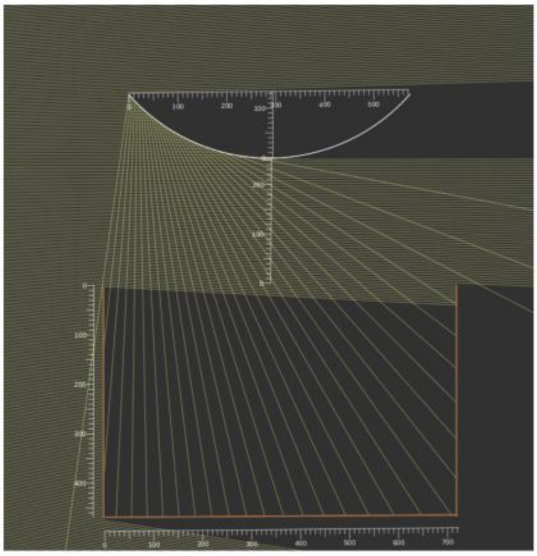


Figure 8. How light interacts with the reflector

The mirror is, like everything else about Luna-CT, ridiculously large. It has an area of 312,431.3894m² and is even larger than China's FAST radio telescope (FAST, 2022). The reflector is divided into 30,000 rectangular panels, each with an average area of 10m² (sizes may vary), and each panel is connected to all the surrounding panels via mechanical latches so that a teleoperated robot can remove any panel from the matrix to replace or repair it. The panels are made from sheets of aluminum extracted from lunar ore via the hydrofluoric acid leach process described by Jarrett et al. (1980), where lunar ore is passed through a bipolar fluoride cell with a cryolite electrolyte and base, the calcium and magnesium fluorides are removed, filtered, and separated into Mg and Ca, the oxygen bubbles out and is collected, and the remaining Al-Si-Fe-Ti alloy is separated into its constituents by vacuum fractional distillation. The aluminum can then be cast, hot rolled then cold rolled to form sheets as is done on Earth, then bent according to the curvature necessary to fit the mirror. At the very top of this reflector there are twelve thrusters, three on each side (North, South, West, and East) to align the reflector with Luna-CT. Below these thrusters, some 12m below the very top of the mirror, all around its circumference, is a roll of beta cloth. Beta cloth is a material made from silica fibres and can be made from lunar ore (Haskin, 1992). The cloth unfolds to a full length of 120m and makes an angle of 71 degrees with the mirror when supported by struts that fold out from the reflector. This cloth serves as a curtain or a blinder that prevents light from being reflected off of the mirror, and can therefore be used to create day and night cycles in the colony. Whenever a reflector panel is in need of repair or replacement, it should be done while the blinders are unfolded.

Figure 9. The spherical mirror with blinders unfolding (shown transparent for visual purposes)

The glass is the upper endcap of the colony, and is the part of the mirror system that actually brings light to your doorstep. It's a large plate made of silica glass with added lead oxide to protect from X-rays and gamma rays (NASA, 1977, p. 70). The plate, however, is not entirely glass; one has to take into account the constant stream of galactic cosmic radiation that would seep through such a thing. To prevent this radiation in the form of particles from the far reaches of our galaxy from butchering the inhabitants' DNA, Luna-CT's glass plate is lined with chevron shields. Chevron shields are handy mirror shields designed to reflect light into a space colony but not cosmic radiation. They look like Ls that have been tilted so that they form a 45 degree angle with the mirror surface. In other words, they form a chevron pattern, hence the name.

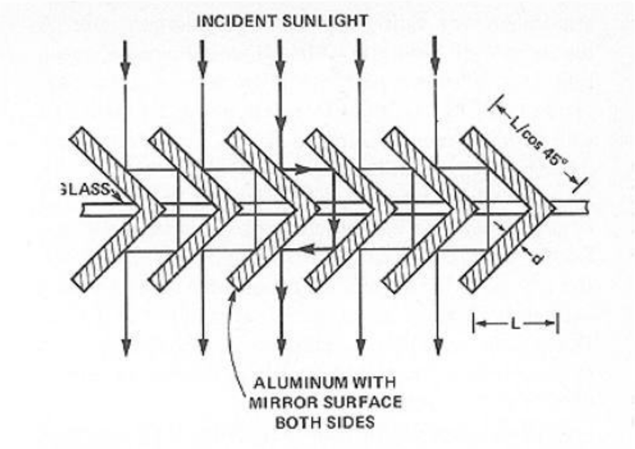


Figure 10. Chevron shield
Credit: (NASA, 1977, p. 114)

The distance between two chevron segments is 32cm and the width of each chevron segment is 1cm. These shields stretch across the entire glass plate and from above would probably look like really long, barely visible and uncomfortable benches. The glass plate sandwiched in between the shield has a thickness of 5cm.

The Artificial Sky

Is having an artificial sky necessary in Luna-CT? Probably not. Am I including one? Yes. This may seem like a bit of a waste of space at first, but it's important to consider Luna-CT's position in time. Luna-CT is not the kind of project you can just go and get a business loan for, not yet anyway. Something like this is best constructed once there's already a wider space economy and a few commercial space stations in LEO, maybe around the moon, so things like extremely efficient use of space are no longer a top priority. If you were to look out your window right now, it doesn't matter what's out there, the one thing your view has in common with mine is the sky. Whether clear and blue, cloudy, or dark and dappled with stars, it's always there and it's really hard to live without it. But you can never really know that until you have lived without it. I happen to have lived through some pretty extreme dust storms, and the psychological effects of being without a blue sky are interesting to say the least. When there's nothing to see when you look up, the whole of life becomes a dream, a long series of events loosely held together in a mind that desperately wants to wake up. This can lead to solipsism syndrome, a psychological state where one feels as if there's nothing outside of one's own mind. It is said that astronauts on long-duration space missions are particularly susceptible to this. Having some sort of a sky to look up seems to put everything into perspective, and the colour blue has been shown to evoke a sense of calmness and serenity (Cherry, 2022). It is for these reasons and many others that I choose to implement an artificial sky.

The sky will only be in the inner cylinder, and is created using water. The inner cylinder, with a radius of 290m and a length of 398m, has a usable surface area of 725,205.2482m². 250,000m² of this surface area is 15m deep in water. Water, in significant quantities, is blue. And luckily there's quite a lot of it on the moon: today there is an estimated 600 billion litres of water available at the lunar poles (Mehta, 2022). Luna-CT will only need 3.75 billion litres of water however, and for comparison, that's not much more water than England and Wales lose to leaky pipes every *day* (Baraniuk, 2020), no joke. There's also a certain need to have clouds in the sky, and for that it is possible to create clouds using water vapour and something akin to a smoke machine. This creates a cloud, albeit a temporary one (maximum of 10 seconds), and is the same process that the Dutch visual artist Berndaunt Smilde uses in his photography to make artificial clouds. When the daytime part of the cycle is over is when things really start to get interesting though. In the dark of the "night" the "sky" comes to life with an uncountable number of LEDs that imitate stars and the familiar constellations of Earth. Water shows will also become popular things to attend on weekends. Whole images can be projected onto high-pressure jets of water, and in Luna-CT such things may become commonplace and would serve as just another tourist attraction. When the water is especially still, it will also be possible to project images directly onto its surface. The uses of the artificial sky extend even further than tourism though. You can view the artificial sky as a large lake with several marine habitats, extensions of the buildings in the outer cylinder, and buildings on the lake constructed for tourism and recreation. Take the theatre and the sky city, for example (see page 21). An additional use of the artificial sky is as a reservoir. This sky wouldn't be quite the shade of blue we're used to seeing on Earth, but it would be blue, and that's better than nothing.

The Experiment

There is still one question that I would like to address before moving on however: how bright will the colony actually be? Will the mirror system be enough to keep the colony bright? The most exciting way of finding the answer to this question is of course to perform an experiment.

I decided that the best way to go about finding this answer was to build a miniature model of the colony, with the mirror system positioned exactly like it would be in the real version. I will then encase it in a closed box, and shine a light on the mirror to mimic the Sun. Then, using a light sensor that I will build using an Arduino UNO, I will measure the illuminance at various locations within the box: in front of the "Sun" and in many locations across the surface of the "colony". Illuminance is the amount of light there is across a given surface area, and it is measured in units of lux. I will then extrapolate the data collected from this experiment to find the real life values of illuminance across the surface of Luna-CT.

The first thing that I needed to do was build the light sensor. What I mean by" build the sensor" is receiving output from the sensor in terms of lux values. The sensor itself has already been manufactured. The illuminance sensor I'm using is the GY-30 BH1750 illuminance sensor module. I will connect this sensor to my ELEGOO UNO R3, and then program my board to receive data from the sensor and to display it on my computer.

First, I have to solder a header pin to the sensor and wire it up:

Figure 11. Soldering (this felt more epic than it looks)

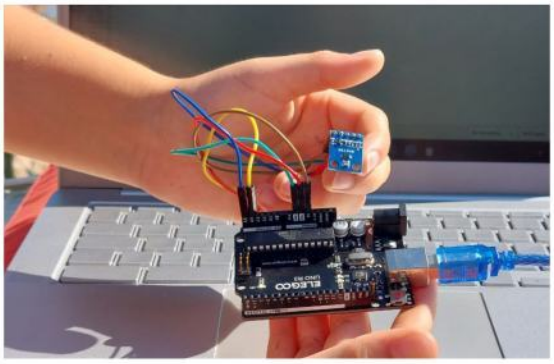


Figure 12. The final illuminance sensor

Then I have to program the board. The code is so simple that it doesn't need much explanation, but do note that I did import a BH1750 library to be able to receive output from the sensor simply and to make my life a whole lot easier:

```
#include <Wire.h>
#include <BH1750.h>
// Importing wire and BH1750 libraries in order to communicate
// using the i2c protocol and to get output from the sensor
BH1750 lightMeter;

void setup() {

  Serial.begin(9600);
  Wire.begin();
  lightMeter.begin();

}
void loop() {

  float lux = lightMeter.readLightLevel();
  Serial.print("Lux: ");
  Serial.println(lux);
  delay(750);
```

Figure 13. The code to program the arduino

The next thing to do is find myself a mirror.
Now, since the mirror is a spherical mirror, it's just a section of a sphere. Taking inspiration from how spherical mirrors are manufactured, I found a 12cm diameter stainless steel ball and will use only a section of it to act as my mirror. The way I'm going to go about metre values is by dividing them by 100 and then calling them centimetres. So, for example, a 100m segment of the colony in my model is 1cm long. So this 12cm diameter ball is equivalent to a 1200m diameter ball in real life. The radius of curvature of Luna-CT's mirror is 368.33m, which basically means that if it were to be a full sphere it would have a diameter of 736.66m. This means that my stainless steel ball is too big by a factor of ~1.63. So I'll have to increase the size of every measurement necessary in constructing a model colony by this factor, divide the value by a 100, but make the units centimetres because I don't have that much space in my room, or that much material.

So when I construct the colony, it has a diameter of ~11.73cm and a height of ~7.624cm. I made the colony out of black card stock, but since a black interior will absorb all the light reflected into the colony and won't imitate real life conditions, I lined the inside with some normal printing paper and coloured it with the blue, green, and grey colours that would be visible in the actual Luna-CT.

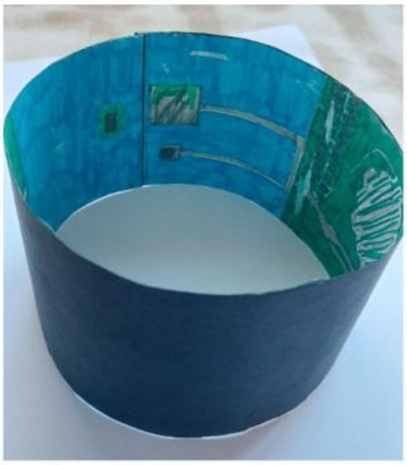


Figure 14. Mini Luna-CT

Now the only thing that's left to do is to position everything inside the box and get a light. I found a box with a height of 21.5cm, but the height that I need should be closer to 13.9cm since in this miniature upscaling of the colony the height of the colony is 7.624cm, the distance between the colony and the start of the spherical mirror segment is 4.072cm, and the height of the spherical mirror cap is 2.199cm. So to compensate for this I've just put the colony on a 7.6cm stand. Then I position the mirror by cutting a 9.285cm hole directly above the colony in the lid of the box and fitting the sphere right in. There is an opening to pass a light bulb through on the other side of the box.

The one last thing that I needed to do before the experiment was complete though was to compensate for light reflection. Since the experiment is inside a closed box the colony will be brighter than it should be since light will reflect off of the top and the bottom of the box into the colony. To try and mitigate this issue I spray painted the lid of the box with a matte black spray paint and put a sort of covering underneath the colony to stop light from entering from below. All of this is summed up in the figure below:

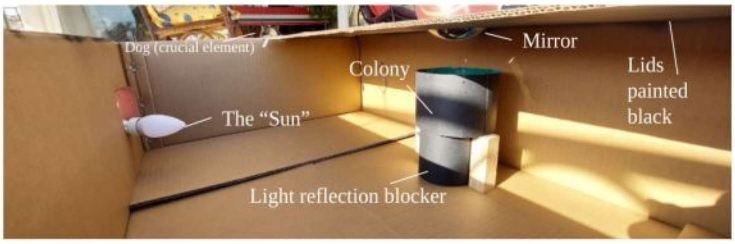


Figure 15. A very sophisticated experiment utilising high-tech composite cardboard technology

At last the time had come to perform my experiment. As the final rays of sunlight became hidden by the mountains in the west, I took my illuminance sensor in one hand, my cardboard experiment in the other, and began the long and lonely journey of preparation. I cut a hole in the cardboard beneath the colony, giving myself a way to measure illuminance across its surface. Once the sun had fully sunken and no more light could hinder this pursuit of answers, I carefully set the cardboard box between two objects in my room. Then I worked on through the night, bones aching from the cold hard floor, fiddling with wires until I had achieved the results that I so desired.

The experiment was complete. I performed it many times and though my results varied slightly, they have given me basically the same real-life illuminance values. I measured the lux value right in front of the mirror on a flat surface (this comes up later) and found it to be 165 lux. Then I measured the lux values around the surface of the colony and I found them to vary between 2.5 and 6 lux.

Extrapolating these values to find out the real lighting conditions in Luna-CT is actually pretty simple. For every watt of power that the sun radiates, it will produce 93 lumens of visible light ("Sunlight", 2023). And, since the moon has virtually no atmosphere, the watt/m^2 of power from the sun that reaches its surface is basically the same that would reach Luna-CT's mirror system. So all we need to do is find the total solar irradiance (W/m^2) on the moon, and multiply that value by 93 lumens/watt to get the illuminance of a surface in front of the real Luna-CT's mirror system. The total solar irradiance on the surface on the moon is not all that different from Earth's, and according to Kaczmarzyk et al. (2018), it varies between 1,310.44 W/m^2 and 1,416.36 W/m^2 depending on the positions of the Earth and the Moon, and whether we're talking about the near or far side of the Moon. I'll just take the average of these values and say that the total solar irradiance on the Moon is 1,363.4 W/m^2. Multiplying this by 93 lumens/watt yields an illuminance value of 126,796.2 lumens/m^2 (lux) on a hypothetical surface in front of Luna-CT's mirror system. This real life value is greater than the miniature scale value by a factor of ~768.5. So, by multiplying this factor by the measured lux values across the surface of the colony finally gives us the answer that we have been looking for. The answer to life, the universe, and everything. The lux values across Luna-CT's surface vary between 1,921.15 and 4,610.77 lux.

These values are just numbers though, so I'd like to provide some analogies to give you an idea of just how bright the colony will be. As I'm writing this it's evening, so it's not dazzlingly bright, but it's not dark either. It's evening, you get it. I took my illuminance sensor and found the illuminance value on an outside surface to be 500 lux. The darkest parts of the colony would be about 4 times as bright as this. Then the brightest parts of the colony would be over 4 times as bright as that. An overcast day's lighting conditions would be about 1000 lux, so Luna-CT is a lot brighter than that. Nevertheless, this is much dimmer than Earthen light conditions. Lights can be strategically placed around the colony to enhance lighting conditions, but whether this will be enough remains to be seen.

And now that I can say that I successfully predicted the behaviour of light in a space station using a cardboard box and craft paper, it's time to move on and discuss the infinitely fascinating topic of division of space.

Division of Space and Architecture

"Okay okay, but what does it *look like*?"

This section covers division of space in the hull. The hull, as was stated in the structural overview, is divided into two parts: the outer cylinder and the inner cylinder. The inner cylinder has a surface area of 725,205.2482m² (excluding end cap areas), and the outer cylinder has a surface area of 1,058,591.061m² (excluding end cap areas). The inner cylinder is used for residential space, open space, some recreation, and the artificial sky; and the outer cylinder is used for just about everything else. In division of space it's difficult to consider *everything* that takes up space in the colony, and so only a few broad categories are considered, but a lot of space is intentionally left over for miscellaneous things, various subsystems, power supply & distribution, plumbing, technology, recycling systems, manufacturing industry, etc. The categories considered are: residential, recreation, open space, transport, tourism, business & retail, schools, hospitals, and agriculture.

Inner Cylinder

Family Homes

A fair portion of the inner cylinder's space is dedicated to people's houses; 10,000 people finish school, work, designing space colonies, etc., and return to these homes every day, but if you were one of those people, what would you want your home to look like? The answer to that question is up to the colonists themselves, of course, but since those colonists may not even be born yet, I'll be deciding how much space they get, so good luck colonists.

First things first though, it's important to specify the demographics of these colonists. The word "colonist" is a little dull and reminds me too much of sombre history lessons, but although calling them lunatics instead seems more logical, it still gives the wrong impression, and so the colonists in Luna-CT will be called Lunacs. Amongst the 10,000 Lunacs, (the other 5,000 people are Earther tourists), there are 833 families of 4 and 556 families of 3, with a total of 2222 children and 2778 adults. This is a simplification of course, families of 5 and 6 are also welcome but anything larger than that is discouraged because the size of a family house is fixed. Then there are 4,000 Lunacs aged 21-45, 500 aged 45-60 and 500 aged 60+. The reasoning behind the small number of inhabitants over 45 is that, although Luna-CT is a little further down the line, it still needs most of its workers to be in their prime to facilitate efficient expansion into the solar system. 60% of those 5,000 Lunacs not in a family are assumed to be living with another to reduce housing requirements.

If each family gets a home, 1,389 homes are required. These homes are divided into three clusters, each with 463 families/homes. Each cluster is a honeycomb shape made up of 20 hexagons, 19 of which have 12 homes split into two stacks, each with 6 dome houses which themselves are split into two halves, and 1 has 7 dome houses, not split into two halves. Transport between hexagons is through 2m wide foot paths that weave between all 20 of the hexagons. Transport to the outer cylinder, where you'd most likely be working, is another priority. The three honeycomb clusters are all next to each other at the back of the colony, but between them there are 2 30m wide courtyards. It is in these courtyards that there would be stairs leading down to a platform in the outer cylinder with access to a system of monorails to transport people to various locations in the outer cylinder; think of the stairs to an underground subway. Each honeycomb cluster is 290m long and 290m wide, each hexagon has an area of 2,184.98m² (with half of the surrounding footpath), and the total area of each honeycomb cluster is 43,699.6m². The area of each of the two courtyards is 7,014.81m². Since there are 3 honeycomb clusters and 2 courtyards, the total area occupied by those 1,389 families for housing, access to transport, and open space is 145,128.42m². This open space includes the gardens in the centre of each hexagon that the surrounding residents share and tend to.

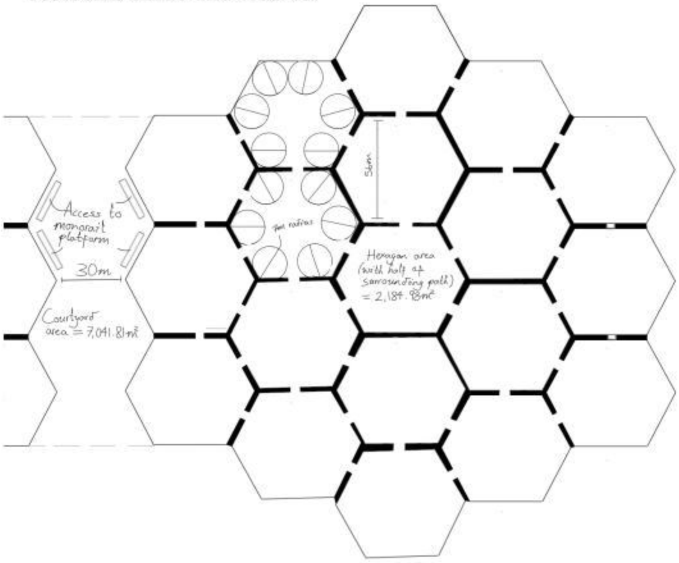


Figure 16. The honeycomb cluster

Apartments

As for the remaining 5,000 Lunacs, we find ourselves going from intriguing domes with flower pots on window sills and children yelling vaguely in the distance as parents try to herd them back home to classic old apartment blocks. Aesthetics are important though, so don't fret: the apartments will have flower pots on window sills too. Assuming that 60% of the remaining population lives with another person entails 3,500 apartments. These apartments are 60m², but are designed to make use of space as efficiently as possible. The apartments are divided into 47 apartment blocks, 19 of which are large with 126 apartments each, and 28 of which are smaller with 42 apartments each. These 42-apartment blocks have 6 apartments on each floor, have 7 floors, and a footprint of 552m2. The 126-apartment blocks are basically just three of the 42-apartment blocks combined. 20 42-apartment blocks are lined up in a kind of a street, with 10 apartment blocks on each side and access to the monorail station between them, as shown on the right side of the map in Figure 19. The remaining 27 apartment blocks are divided into 5 clusters, 4 with 4 126-apartment blocks and 2 42-apartment blocks, and 1 with just 3 126-apartment blocks. All of these clusters also have access to the monorail station and sufficient open space in the form of courtyards/gardens as shown in Figures 17 and 18.

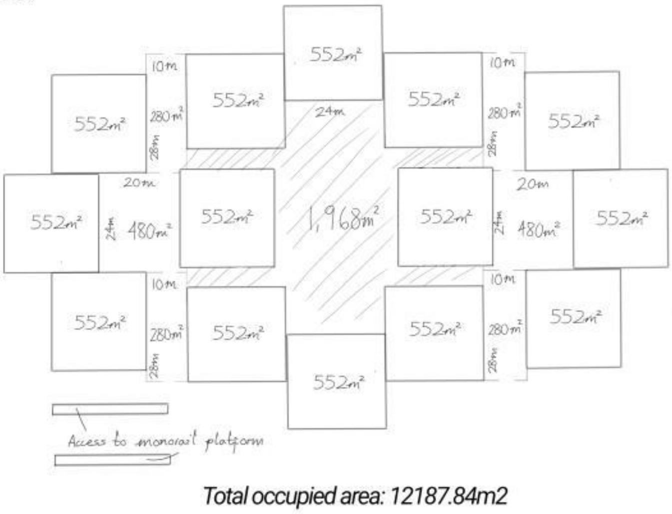


Figure 17. How the 4 main apartment block clusters are arranged

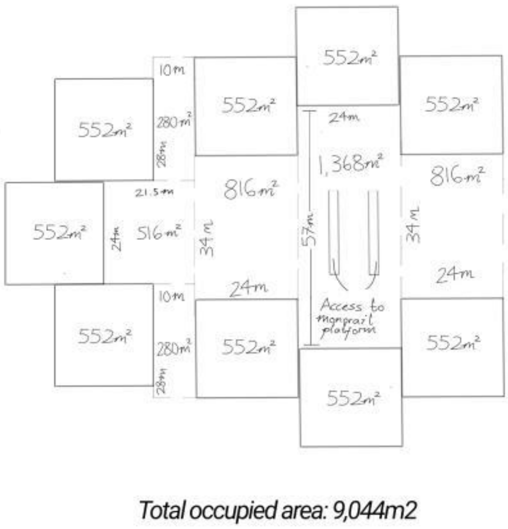


Figure 18. How the 1 smaller apartment block cluster is arranged

These residential areas are all connected via walkways. The remaining ~247,200m² of area is dedicated to these walkways and open space combined with outdoorsy recreation. A flattened out map of this section of the colony is shown in Figure 19.

Sky Pool

But there is another section of the colony whose space must be divided: the sky pool. The sky pool, or the artificial sky, takes up 250,000m² of the inner cylinder and has three main structures constructed on it: the hotel, the theatre, and sky city.

The hotel provides 1,000 high-paying tourists with most of what they need, and has a footprint of 13,500m² with 6 floors. The theatre is on a platform a bit away from the hotel and has 150 seats, this theatre is not quite as popular as the one in the 0-g sphere but it is situated on a large platform with small cafes and public spaces, and the theatre itself doubles as a community centre/public space. The platform has an area of 2,500m² and the theatre has an area of 745.29m². Last but definitely not least we have the sky city. The sky city, to me at least, is kind of like the hidden jewel of Luna-CT, it's not actually a city, it's more like an island made of pools, grassy outcrops, stone platforms and pillars, and trees stringed with lights. It's not accessible via any walkway, elevator or monorail so the only way to get to it is with a boat, kayak, etc. This place becomes truly magical at night when the LED stars and constellations in the water are lit. I chose to put it there because it's the kind of place I'd like to spend my nights, looking down at the stars instead of up to them, a good place to mark the end of a life's job well done. The sky city has an area of 1,500m². The theatre and hotel are accessible via either a pedestrian bridge or a monorail. The two bridges start at a 30 x 40m platform and end at their respective destinations. The bridge to the hotel is flanked by two hanging monorails while the bridge to the theatre only has one. Both pedestrian bridges are 10m wide. A layout of the sky pool is shown in Figure 20.

Outer Cylinder

The outer cylinder really is the downtown of Luna-CT. Its uses are too many to define in this paper, but in terms of the categories considered in this section, it is used for transport, tourism, business & retail, schools, hospitals, and agriculture.

Transport

All of those staircases in the inner cylinder lead to platforms some 10m below the ground of the inner cylinder. These platforms basically function as train stations, where people stand around waiting to board their monorail, eager to begin the day. The network of passenger monorails connect to other platforms, where elevators situated on those platforms can then bring people to their penultimate destination: the ground floor of the outer cylinder. Some stations also connect directly to the roof of the taller buildings in the outer cylinder. It is also necessary to have some sort of cargo transport. Raw materials are transported to Luna-CT and are turned into usable products by its manufacturing industry, and need to be delivered somehow to their distributors. To fulfil this requirement, cargo hanging monorails soar across the outer cylinder's ceiling directly to the shopping centre, hotel, agriculture centre, etc.

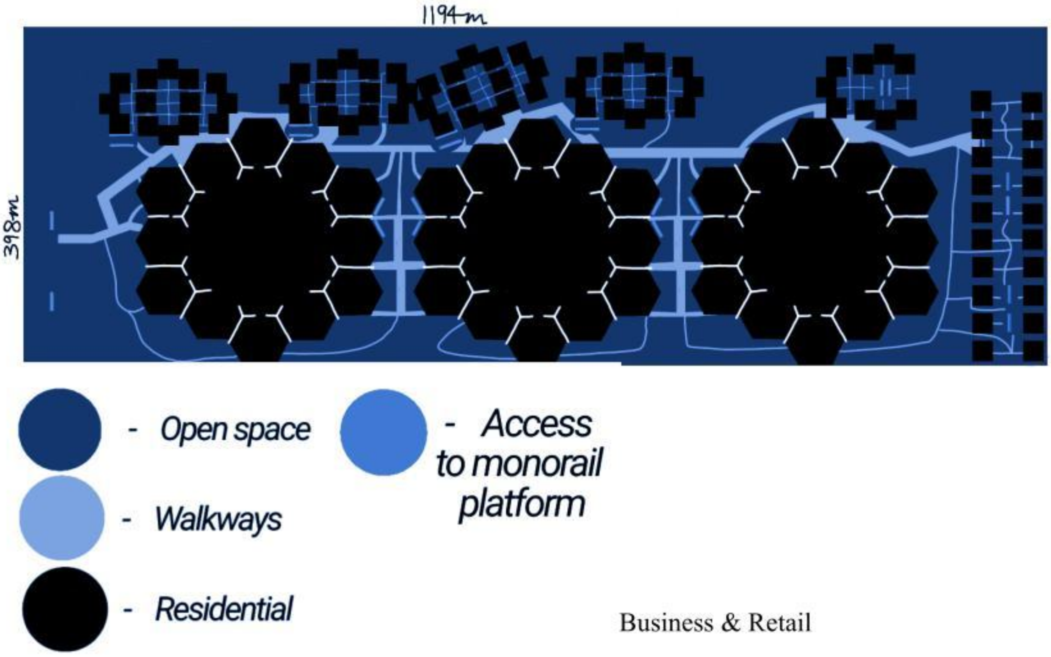


Figure 19. Map of the non-aqueous section of the colony

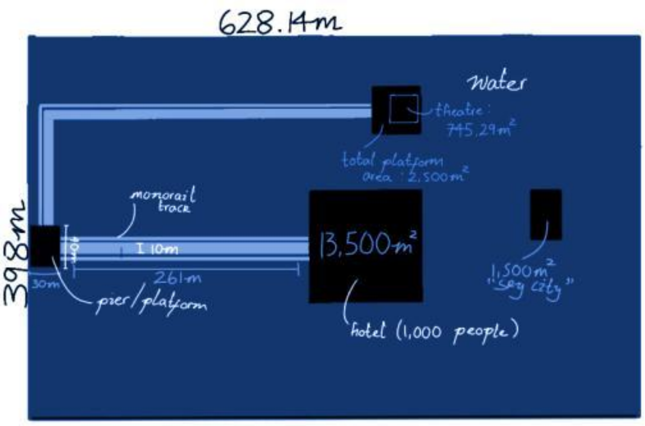


Figure 20. A layout of the sky pool

Across that dark ceiling they fly, like Santa's sleigh, stocked with toothbrushes, shelves, and fertiliser. The last form of monorail transport is emergency transport. Across both the inner and outer cylinder there are many emergency elevator stations used in the same manner as ambulances, they connect directly to an exclusive emergency monorail that goes directly to the hospital at a higher speed than any other monorail.

Tourism

Three hotels of the same size as in the sky pool are placed in the outer cylinder, housing a total of 3,000 people and occupying a total of 40,500m². The hotels are located on a 65,000m² piece of land and are strategically placed close to the shopping centre, micro-g cylinder and 0-g sphere.

These hotels would each have a height of about 30m and can be accessed either through the roof by elevators connected to monorail platforms or just through the main door if descending through the ceiling isn't your thing.

Business & Retail

Luna-CT is a small-ish colony, and isn't meant to have a flourishing economy filled with successful start-ups and business opportunities: it isn't Silicon Valley. But it will still have the standard retail & service stores that flank our streets today. NASA (1977) recommends 10 shops per 1,000 people, so Luna-CT is given 150. 100 of these are located in a shopping centre 50m tall and with a footprint of 10,000m². The shopping centre is designed to have 10 floors, where the uppermost floor serves as a grocery market for the Lunacs. The shopping centre can be accessed in the same way that the hotels can, either through the ceiling or through the door. A lot of the stores in the shopping centre are more tourist/recreation-oriented, such as cinemas, restaurants, and places that sell souvenirs. The remaining 50 stores are retail/service stores and are more dispersed across the outer cylinder, though they still remain within a certain radius from the rest of the buildings. These stores collectively leave a footprint of 7,500m² and their individual footprints vary between 100 and 200m².

Schools

There are 2222 Lunac children. If we can assume that the ages of these children are between 6 and 18 then we can divide them into four schools: one for children aged 6-9, one for children aged 9-12, one for children aged 12-15, and one for children aged 15-18. Half of these schools have 556 students and the other half have 555 students. I took the average size of a bunch of schools in my area, and found the average amount of space in a school is 10-12m² per student. Because of the changes I've made to the school system discussed on page 26 I've expanded this to 20m² per student. Thus the space required per school is 11,100m²; split over 4 floors this results in a footprint of 2,775m². Around each school there is also some open space and outdoor facilities, so the total footprint of each school is 5,000m². Across all 4 schools this is 20,000m².

Hospitals

To figure out how much space we need to block out for hospitals, we first have to figure out how many beds we need. It is possible to do this by estimating the percentage of the population that will fall ill and how long they'll stay in the hospital and frequency of accidents and whatnot but that's extremely cumbersome and the result will most likely be a little bit off. So instead, we can look at how many hospital beds other countries have and take it from there. If you go to ("Hospital beds", 2019), you'll find information on hospital beds per 1,000 population for countries all over the world all the way from 1960. Currently, Japan is leading with 12.98 beds for every 1,000 people. But, in 1992, Monaco had a whopping 21.68. Given the "special" circumstances of residing in a shiny metal can with pretty flowers and sharp things careering through space 384,400km away from the nearest (Earther) hospital, I think it's safe to have 20 beds per 1,000 population, just in case. According to the WHO guidelines for district hospitals (WHO, 1996), a hospital with 300 beds should have 333m² of space per bed. This results in 99,900m² of required area, but split over 6 floors the hospital only has a footprint of 16,650m². Access to the hospital from the ceiling, as mentioned before, is strictly reserved for emergencies. The main entrance is through a door on the ground floor.

Agriculture

50,000m² of space in the outer cylinder is devoted to agriculture. This consists of towering vertical farms, collection & processing areas, space for other methods of growing plants, and more.

Totals

This results in a total footprint of 169,150m² for the categories considered, which is only about 16% of the available area in the outer cylinder. We can assume 8m²/person of space required for pedestrian passage between buildings and open space, which results in a footprint of 289,150m², or about 27% of area available in the outer cylinder. This leaves plenty of space for all the categories of division of space not considered, such as manufacturing, power, storage, recycling systems, life support, IT hardware, etc. A layout of the outer cylinder is shown in Figure 21.

Family house architecture

There is so much I would like to discuss about architecture in Luna-CT, but there is so little space to do it and so I will only cover the family home architecture. The architecture of many other structures and locations in Luna-CT is displayed on the art wall on page 25. The one thing to note about architecture in Luna-CT is its deliberate eccentricity. Again, Luna-CT is not quite as focused on maximising efficiencies everywhere possible, especially when it comes at the cost of people's well-being. So instead of making Luna-CT just another suburbia, because come on, we're building a space city here, it goes all out on making everything unique and on the brink of being outright bizarre just to give the Lunacs a memorable home and the tourists a worthy destination.

Exterior

All family homes are geodesic domes because geodesic domes are remarkable in their strength, minimal material requirements, ease of construction, low energy usage, and their quirky appearance (Laila et al., 2018). It's imperative that Luna-CT makes as efficient use of available materials on the moon as possible, and the geodesic dome sure fills this requirement, with as little as 25% of the materials needed to build it compared to your typical square house (Legal Eagle Contractors, n.d.). Also of note is the dome's energy efficiency: instead of warm air rising and being lost to the flat roof of a typical house, in a dome house air is circulated back to the centre of the dome, which can lead to significantly less energy requirements for the Lunacs. Along with being energy efficient though, these domes also require less artificial light as any light entering the dome is refracted and stays in the dome longer than in a traditional home (2-1 Builders, 2022); this is great for maximising use of Luna-CT's lower light levels. The last factor I considered in choosing this house shape was ease of construction: these domes can be built by the colonists themselves within days.

All the necessary parts for the construction of these domes are prefabricated. The struts are made of aluminum for its high strength-to-weight ratio and the panels can be made from either fibreglass or ceramics, both of which can be made from lunar soil as is described by Haskin (1992).

The dome houses are arranged into hexagons that collectively form a honeycomb cluster as was mentioned previously. Each hexagon has 12 geodesic dome houses, but these houses are divided into two "stacks", with 6 on each level. Each geodesic dome is further split in half, creating two homes in one dome. Thus, there are a total of 24 family homes in 12 geodesic domes in each hexagon. Each dome has a radius of 7m and so each of the 24 homes has a ground floor area of ~76.97m². Each home is divided into two floors though, leaving each home with a total floor area of ~128.8m². The area of each hexagon is ~2036.89m² (excluding surrounding pathways), subtracting the area occupied by the geodesic domes leaves ~1,113.26m² of open space. This open space serves as a courtyard/garden that the surrounding residents take care of, this helps foster a sense of community while also ensuring aesthetic quality for the residential spaces. A sketch of one of these geodesic dome "villages" is shown in Figure 22.

Figure 21. A layout of the outer cylinder

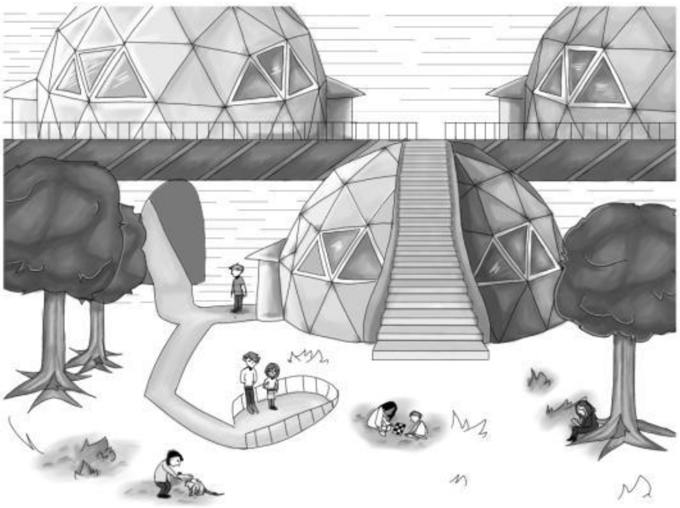


Figure 22. A sketch of what life would look like in the hexagons of the honeycomb family housing cluster

Interior

The look of the interior design of the family homes and of any structure in Luna-CT is shaped by the need to prioritise use of materials that are obtainable from lunar regolith. Materials common in Earther homes such as wood, plastic and a variety of textiles will be something of a luxury on Luna-CT. You probably wouldn't leap in joy upon receiving an item of wooden furniture here on Earth, but for the Lunacs this may very well be the case as such items would have to be specifically ordered and made room for on a cargo ship leaving for Luna-CT. The materials that will be extensively used in interior design as well as everywhere else will be concrete, fibreglass, ceramics, aluminum, glass, and textiles woven from glass fibres.

The ground floor of each home has an area of ~76.97m². 20m² is dedicated to an integrated kitchen and dining room, and another 20m² is set aside for a master bedroom. The remaining ~36.97m² of area is used as general living space. In the centre of this living space, in order to save floor space, a spiral staircase leads to the second floor. The second floor has an area of 51.83m². The staircase leads to a 4 x 4.9575m landing with entrances to other bedrooms and a bathroom. The number of bedrooms varies depending on family size and since the size of a family house is fixed so does their size. For a 4-member family with two children, each bedroom size is 12m². Assuming they have separate bedrooms leaves 24m² of area required for bedrooms. Also connected to the landing is an 8m² bathroom. A layout of both floors is shown below in Figure 23:

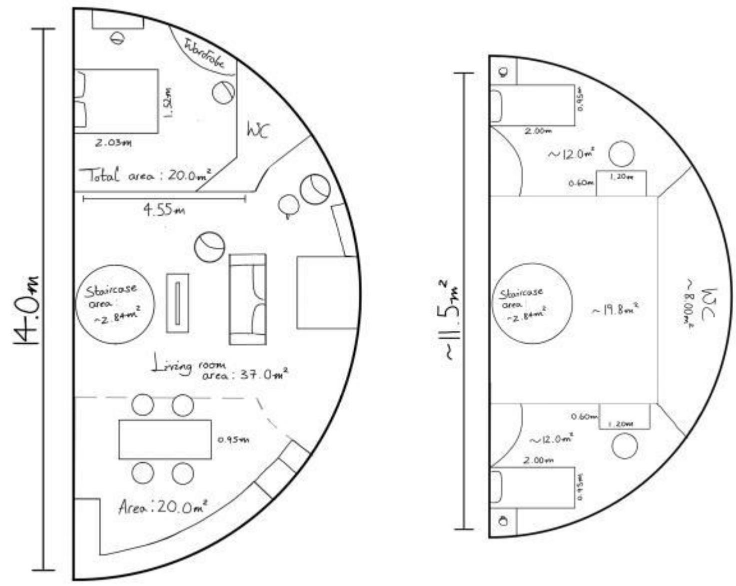
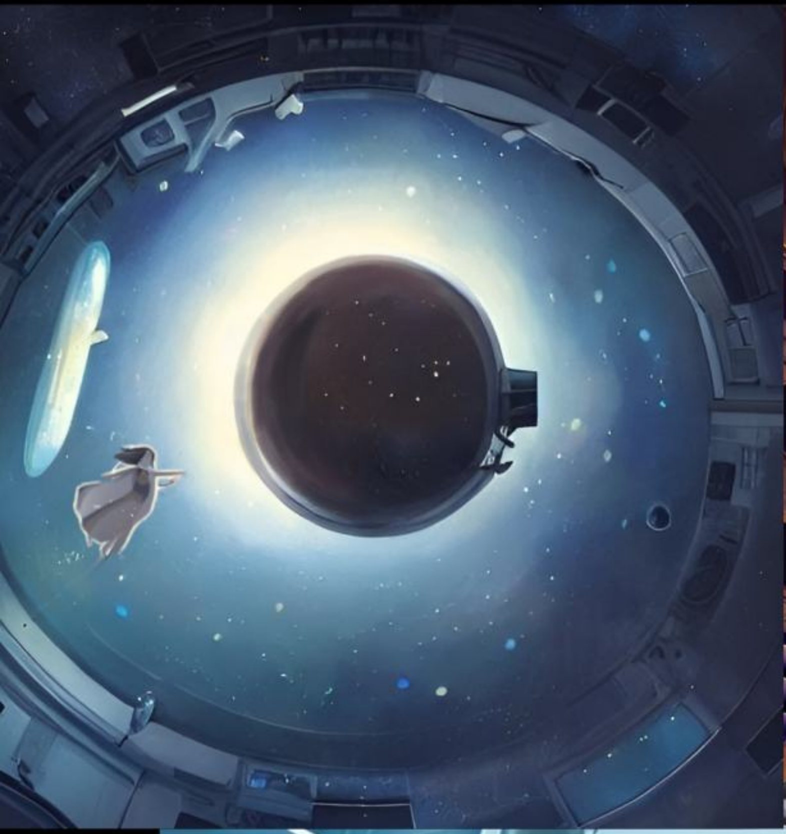


Figure 23. A layout of the ground floor (left) and the second floor (right)

The actual interior design of the family homes may differ depending on individual tastes, but it is probably inevitable that the Lunacs will come to embrace minimalist design given the material constraints at Luna-CT.



The Education System

“Taking fish down from trees and letting them swim in the seas of potential”

Education is a core value of Luna-CT and its people. It is the beauty of learning and a lifelong dedication to it that makes Luna-CT the flourishing society that it will be. Luna-CT’s education system is completely unorthodox though, because unlike on Earth, its purpose is not to produce droves of drained memorising robo humans whose only goal is to pass an exam and go to college, but to ensure that each individual achieves their maximum potential and guides them through their pre-adult life in a way that actually benefits them. Education extends much further than history and calculus, after all. I have based Luna-CT’s education system on the ideas of the now deceased Sir Ken Robinson and others, as well as the Finnish education system.

In what was probably one of the greatest Ted talks of all time (TED, 2006), Robinson stated that we know three things about intelligence, 1) it’s diverse, 2) it’s dynamic, and 3) it’s distinct. The Lunac’s education is based on these three pillars. Another key aspect of the education system in Luna-CT is its focus on school environment and recognizing and nurturing individual talents and interests from an early age.

Luna-CT’s education system is also heavily inspired by the Finnish education system. Finnish schools consistently rank somewhere at the top of the list when it comes to mathematics, science, and reading. The key difference? They only have a couple of lessons a day, don’t have standardised testing (optional test for university admissions), teachers are some of the most well-respected people in the country, and schools have a more relaxed environment (Colagrossi, 2018). It should therefore be no surprise that Finland ranks as the happiest country in the world (Helliwell et al., 2022), the 6th most free (Vásquez et al., 2021), the least corrupt (tied with Denmark and New Zealand) (Transparency International, 2021), and the 11th most developed (UNDP, 2022, p. 272).

Luna-CT seeks to learn from these things but also to build on them to create a creative, intellectual culture in the colony.

The way Luna-CT’s education system works is simple, only a few subjects are compulsory, and these subjects are: mathematics, with a focus more on its application and beauty, especially for younger students; finance; communication, lessons on effective communication through speech and writing, covers things like debating; history, with more of a focus on stories and moral lessons; computer science & technology, with a lot of stress on applications; and workshop: workshop is a subject that takes full advantage of the diversity, dynamicity and distinctness of intelligence. Workshop is a subject where classes come together and work on a project of some sort, be it constructing makeshift vehicles or rewriting shakespeare. It will exercise students' creativity, critical thinking, collaboration, and communication, all of which are key values in Luna-CT. Then Luna-CT offers a wide variety of subjects which are not compulsory, ranging from all the sciences to music to the culinary arts.

Students start school at age 6, where they are taught basic literacy in mathematics and English, and then by the age of 8 they begin to take up the compulsory and non-compulsory subjects. There is no testing and no grades, but every year each student is given an individual evaluation by their teacher, where the student’s skills and interests are combined to cater a more specific course of study to the student to maximise their potential and happiness. Take for example a student who excels at and loves theatre, such a student would be given additional material and lessons in place of subjects that are not quite as useful or enjoyable to them, say science or advanced maths. Such a degree of specialisation cannot be achieved within one school and so education extends further out into digital mediums and apprenticeships. Then by the time this student finishes their third stage of education at 15 years of age, they now go into the final stage of their education before university where they can choose between a more theoretical course of study (more for students who wish to study at university on Earth) or an applications-based course of study where that student would receive mentorships at Luna-CT’s theatres and be prepared for a fulfilling career and a meaningful life.

Most of the education in Luna-CT is non-compulsory, but the Lunac culture is one that hails skill and education as their highest value, not in a “study harder, get good grades” sense, but in a “education is the most powerful weapon you can use to change the world” (Nelson Mandela) sense. Homework is not homework but rather interesting topics that the students are encouraged to research in their own time, and is of course non-compulsory.

The culture in schools and in life in Luna-CT is to find your own path from a young age. Children are encouraged to find their passion and to pursue it with tenacity and resources and support from their schools, to think freely and originally, and to grow into the person they want to be. This culture is reinforced by Luna-CT’s teachers, the best on Earth and now the best in space. Lunac children will be very familiar with a saying by Gandhi: “Live as if you were to die tomorrow. Learn as if you were to live forever”.

Micro-g Cylinder

"The outer space experience - without the outer space part"

Okay I may have been a little harsh on micro-g before, in reality it can be really useful, and fun. Being in a state of free fall or being outside of a gravitational field facilitates the undertaking of a whole wealth of scientific research. The research being conducted in the ISS' "0-g" (g on the ISS is actually far from 0, it's falling and missing the ground, leaving everything inside in a state of freefall, or weightlessness) conditions cannot be done anywhere here on Earth for more than a few minutes, making the ISS an extremely valuable laboratory. Experiments on the ISS include everything from cancer research (along with many other diseases such as Alzheimer's and Parkinson's) to printing tissue, and not the paper kind. Luna-CT's micro-g cylinder and 0-g sphere will also be used as laboratories, enabling many more experiments to be done in this abundant, albeit rare environment. An example of one such experiment that can be performed in micro-g was launched to the ISS in 2018 and performed successfully in 2020. Scientists created the fifth state of matter, a Bose-Einstein condensate, in space (O'Callaghan, 2020). In the absence of gravity, such a substance will remain compact for much longer, allowing us to gain more insights into the very fundamental nature of our universe. This is of course very cool and all, but there aren't quite as many tourists who go all the way to the moon and back to see a Bose-Einstein condensate as there are those who go to have a good time. For that reason, a lot of emphasis is placed on making the most out of low gravity for the entertainment of the masses. Luna-CT offers a wide range of entertainment, everything from 0-g theatres to 0-g tennis; nobody gets bored on my watch.

Micro-g Cylinder

Three things are contained within the micro-g cylinder: a water disc (a pool), a laboratory, and an exit to the 0-g sphere. Entrance to each of these sections is by separate elevators and it is not possible to travel from one section to the other from the inside. It's called the *micro*-g cylinder because gravity at the cylinder's surface is actually lunar gravity. I chose to simulate lunar gravity because of the swimming pool the micro-g cylinder houses and because of the fact that with gravity levels ranging from 0 - 0.165g, more types of research can be conducted. How the micro-g cylinder is divided into the three sections is shown in Figure 24.

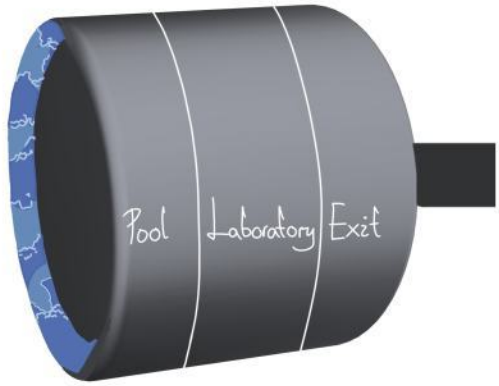


Figure 24. Division of the micro-g cylinder

The Water Disc

The water disc is a 25m section of the 70m long micro-g cylinder with a surface area of 9,346.24m². The swimming pool is in a lunar gravity environment because of the complications of swimming in a 0-g one. And by complications I mean the fact that the water will aggregate into huge bubbles making swimming almost impossible, water will stick to your face because there's no longer anything to force it down, and there's no buoyancy to force you back up. To swim comfortably in such an environment would entail swimming with full scuba gear in an enclosed tank, but what's the sense in that? But in lunar gravity, swimming becomes much less of a nightmare. It will be possible to stride on water with fins, as was confirmed by research done by Minetti et al. (2012). Water fights will be something that the casual passer-by should be weary of, as waves will be huge. Even in lower gravity, it will still be possible to make bubbles of water, and since it will be possible to leap as high as a dolphin out of the water, water polo will be the new marco polo. The possibilities of such a pool are elaborated by Heppenheimer (1977), and a lot of the above activities are referenced from it.

The Micro-g Laboratory

Adjacent to the water disc is another 25m section of the micro-g cylinder. This section is dedicated to the pursuit of science, and is divided into three floors. The first floor is along the surface of the cylinder, the second is 20m above the first and the third is 20m above the second. Together these form three separate cylinders, the first one with 9,346.24m² of surface area, the second with 6,204.65m², and the third with 3,063.05m², all of which leave a total of 18,613.94m² of surface area just for science. Space in the micro-g laboratory is rented on a weekly, monthly, or yearly basis, depending on the experiment, creating yet another source of revenue for Luna-CT.

Exit to 0-g Sphere

Transport to the 0-g sphere, as was mentioned in the structural overview, is facilitated by a 23m wide column containing 25 elevators. This column must be counter-rotated in order to preserve Luna-CT's rotational stability; not counter-rotating it would move too much mass away from the cylinder, creating an imbalance in the maximum moment of inertia. To avoid the large cost in energy in counter-rotating the column electromagnetically, a system of planetary gearsets are used. Planetary gearsets are handy gear systems commonly used in transmission in vehicles, and consist of four components: the ring gear, the planet gear(s), the planet carrier, and the sun gear. It is called a planetary gearset because in it the planet gears, being carried by the planet carrier, revolve about the sun gear. It has two inputs and one output, but one of the inputs is usually held stationary. The possible input/output combinations are as follows:

1	Inputs: Sun & Carrier	Output: Ring
2	Inputs: Ring & Sun	Output: Carrier
3	Inputs: Ring & Carrier	Output: Sun

What this means is that if you were to provide power input to the ring gear and wanted to hold the sun gear stationary, for example, the power output would be from the carrier gear. To help visualise how one component in this system of moving gears can be held stationary, the following figure may be useful:

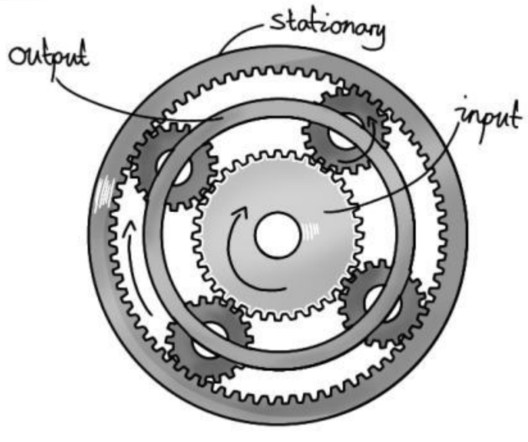


Figure 25. An example of a simple planetary gearset

But how can this be used as a counter-rotation mechanism? If we provide power input to the ring gear from the rotation of the colony (i.e. connect it to the rotating colony), we can keep the sun gear stationary. This means that if we turn the column into a sun gear by placing teeth around its cross-section we can hold it stationary with 0 energy consumption.

The column has a diameter of 23m and so as a gear it would have 23 teeth. We know that it has to be stationary so its angular velocity is 0 rad/s, and we also know that the ring has to have an angular velocity of 0.1650757402 rad/s (the angular velocity of the colony). This is actually pretty much all we need to know to calculate the number of teeth (and therefore the diameters) and angular velocities of all the other components.

We want the mechanism to be compact, so we can choose a small number of ring teeth, so long as it's an odd number. I chose 31 ring gear teeth. From the following equation, taken form Woodgears (n.d.), the number of teeth on a planet gear can be found to be:

$$N_r = 2N_p + N_s$$

$$N_p = (N_r - N_s)/2$$

$$N_p = (31 - 23)/2$$

$$= 4$$

Where N_r, N_p, & N_s represent the number of teeth on the ring gear, planetary gear(s), and sun gear respectively.

Then to calculate the angular velocities of the carrier and planet gears, we can use the following equations, derived from the equations in "Epicyclic gearing" (2023):

For a stationary sun gear,

$$\omega_c = \omega_r[N_r/(N_s + N_r)]$$

$$\omega_p = [(N_s + N_p)\omega_c]/N_p$$

we find that ω_c = 0.09476570271 rad/s and ω_p = 0.6396684933 rad/s.

Where ω_r, ω_p, & ω_s represent the angular velocities of the ring gear, planetary gear, and sun gear respectively.

Note that there are two planet gears in this mechanism connected by a carrier. To summarise, the planetary gearset used as a counter rotation mechanism for the column has a ring gear with 31 teeth getting power from the rotation of the colony and moving at an angular velocity of 0.1650757402 rad/s, two planetary gears connected by a carrier, where each planetary gear has an angular velocity of 0.6396684933 rad/s and 4 teeth, and the carrier has an angular velocity of 0.09476570271 rad/s, all rotating about a stationary sun gear with 23 teeth.

If the outermost gear, the ring gear, within which all the other gears are contained, has 31 teeth, it must have a diameter of 31m; this also means that the planet gears have diameters of 4m. So the entire counter-rotation mechanism can be housed within an area of ~755m². Images of the rotation gearset and how it integrates with the column and colony are shown below:

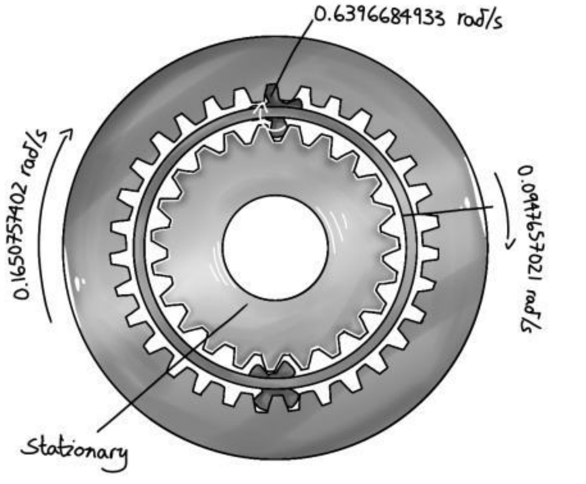


Figure 26. What Luna-CT's counter-rotation mechanism looks like

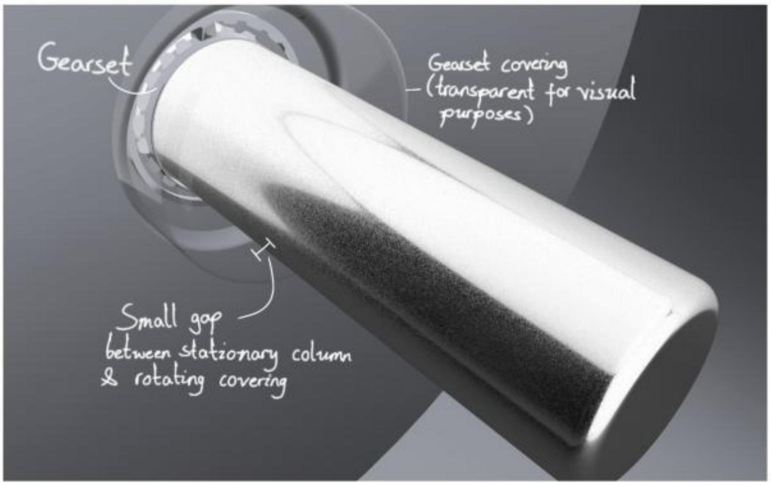


Figure 27. The counter-rotation mechanism with the column

There is still one problem that needs to be addressed with this mechanism, however. As shown in Figure 27, there is still a gap between the rotating colony and the column from the cap covering the gearset (it has been exaggerated in Figure 27, so no worries). This gap can be made to be exceptionally small, but it would still lead to a leak. The rate at which air flows through this gap can be calculated from (taken from TLV (n.d.)):

$$Q_a = 0.667 \cdot 4.17 \cdot C \cdot (d_o/4.654)^2 \cdot p_1 \cdot \sqrt{(F_\gamma \cdot x_T)/T_a}$$

Where Q_a is the air flow rate in Nm^3/h, C is the discharge coefficient, d_o is the orifice diameter in mm (it is assumed that the air is leaking through a circular orifice, but this assumption is circumvented below), p_1 is the pressure of the pressurised segment in kPa, F_γ is the specific heat ratio factor (specific heat ratio/1.4), x_T is the terminal pressure ratio, and T_a is the temperature of the air that is leaking out in degrees K.

We can assume that the gap between the gearset-covering cap and the stationary column is 0.01mm, and treating this gap as an annular ring we can find the gap area to be ~722.57 mm², and since this calculation assumes that the air is flowing through a circular orifice, we can equate this gap area to that of a circular orifice with a diameter of ~30.332 mm. The discharge coefficient is given a value of 0.9 since air is not a very viscous fluid, the internal pressure can be taken to be standard atmospheric pressure 101.325kPa, F_γ is equal to 1 since the specific heat ratio of air is 1.4, x_T is 0.72 (from TLV (n.d.)), and the temperature of the air is 293.15 K.

By plugging these values into the equation we can calculate the rate at which air leaks out of the gap to be ~533.92 Nm³/h. A Nm³ of air represents the volume of air at atmospheric pressure and at a temperature of 0ºc. It is perhaps more useful to convert Nm³/h to kg/h. The density of air at sea level pressure and at 0ºc can be found from "Density of air" (2022) to be 1.2922 kg/m³, and from this we find that the rate at which air seeps through the gap is 689.93kg/h. This isn't exactly comforting, so the way I've thought about circumventing it is to split the section of the micro-g cylinder that serves as an exit to the sphere into two parts. One part is a 6m section of the 20m exit section and contains the stationary column. The other part is the remaining 14m section. These two sections are separated by a wall, and in the centre of that wall is a hatch that opens to allow people to pass into the 6m section and enter the column. The 6m section that houses the column is continually pressurised, and if there is a system failure the hatch will automatically seal and after everyone is evacuated from the 6m section to the sphere it will open to allow technicians to pass through. There shouldn't be too much of a panic in this kind of a situation though, as these technicians will have over 5 days until full depressurisation to solve the problem.

0-g Sphere

“The outer space experienced - enhanced”

The 0-g sphere differs from the micro-g cylinder in two ways: the first being that it is a sphere, and the second being their difference in gravity. The micro-g cylinder simulates lunar gravity, which gives it its unique functions, whereas the 0-g sphere doesn’t have any angular velocity at all, meaning that everybody inside of it is weightless. This gives the 0-g sphere a completely new set of functions, which when combined with the micro-g cylinder’s, satisfy all the recreational, scientific, and touristic needs of Luna-CT.

The 0-g sphere has a radius of 70m and a volume of 1,436,755.04m^2. It is divided into 17 floors, which are themselves divided into many different sections. The uses of the 0-g sphere are mainly focused around tourism, recreation, and science. The final remaining 1,000 tourists will have their hotel in the 0-g sphere. These tourists are short-stay tourists who don’t stay for much longer than a week in order to make sure their return is comfortable. Given the size of both the 0-g sphere and the human imagination, whatever recreational activity possible will probably be going on somewhere in the 0-g sphere. Sports will range from the traditional to the reimagined to the completely new, with everything from tennis to quidditch to figure skating on air at everyone’s disposal 24/7. Some of the more notable recreational activities are the 0-g theatre and the Hall of Dreamers, which we’ll get to in a bit. Then there is of course science. The potential for scientific research in micro-g/0-g conditions is enormous, as I have mentioned before. But a unique benefit of science in the 0-g sphere over science in another 0-g environment such as the ISS is the 0-g sphere’s volume. Experiments will be able to be done on a much larger scale, with less concerns about weight constraints and size limits.

Division of the 0-g Sphere

The 0-g sphere is divided into 17 floors. The first floor is the “station floor”, where people entering from the column first arrive. There the elevators are situated along with some tourist help centres and small 0-g art exhibitions. The second floor serves to showcase the peculiarity of the 0-g environment, with art, science demonstrations, and more. The floors up to the 6th floor are dedicated to sports and recreational activities, with some laboratories here and there. The 6th floor houses the 0-g theatre and a large stadium The tourist hotel starts on the 7th floor and ends on the 11th, covering only 5 floors unlike the other 4 hotels that cover 6, but each floor covers much more area than the floors in the other hotels do, so the area remains virtually the same. Floors 12 - 16 serve a variety of purposes, but are primarily focused on science. The 17th and final floor, named the Hall of Dreamers, is the very bottom of Luna-CT and is the only view out onto the universe in the entire colony.

To calculate the areas of each of these floors requires only a bit of the Pythagorean theorem. The area of a given floor in the 0-g sphere is equal to the area of the sphere’s cross-section at that point. That area is equal to πr^2, where r in this case is equal to the radius of the circular floor. We can find the radius of any floor knowing only its height and the radius of the sphere using a formula $r = \sqrt{R^2 - (R - h)^2}$ where R is the radius of the sphere and h is the height of the floor (height = 0 is 4m below the “station floor”). This formula can be easily deduced if we observe the following image:

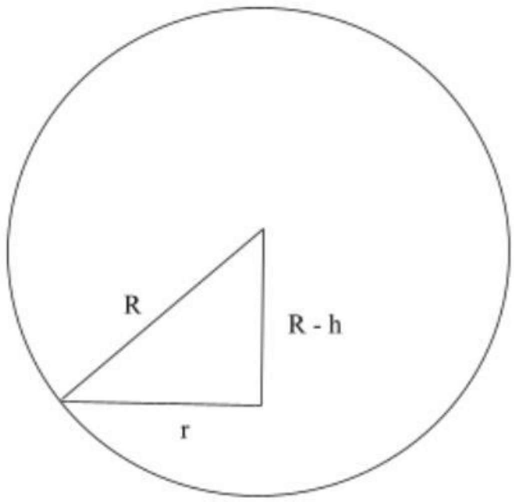


Figure 28. The image from which the formula for the formula for the radius of a circular floor is derived

By using the Pythagorean theorem we find that r is equal to $\sqrt{R^2 - (R - h)^2}$. This describes half the length of a line in a two-dimensional circle, but if we move into three dimensions it represents the radius of a circular cross-section.

Using this formula the areas and heights of each floor are shown below:

Floor Name	Area	Ceiling height
Station Floor	1,709.0264 m^2	6m
2nd floor	4,084.0705 m^2	6m
3rd floor	6,232.9198 m^2	6m
4th floor	8,155.5745 m^2	6m
5th floor	9,852.0346 m^2	6m
Theatre & Stadium floor/6th floor	11,322.300 m^2	30m

Hotel first floor/7th floor	15,280.707 m²	5m
8th floor	15,390.662 m²	5m
9th floor	15,343.539 m²	5m
10th floor	15,139.335 m²	5m
Hotel last floor/11th floor	14,778.052 m²	5m
12th floor	14,259.689 m²	8m
13th floor	13,103.583 m²	8m
14th floor	11,545,353 m²	6m
15th floor	10,112.787 m²	6m
16th floor	8,454.0258 m²	6m
Hall of Dreamers/17th floor	6,569.0702 m²	17m

These will come in handy when dividing each floor into specific functions. But for now we'll just focus on the 6th and 17th floors. The 0-g theatre and the Hall of Dreamers.

0-g Theatre

No society is complete without a theatre. Theatre is something that's just in our blood, we've been going to see people tell and enact stories for thousands of years, and Luna-CT will not mark the end of that. Rather, it will mark a beginning, a new way of theatre made possible by the 0-g sphere's weightless environment.

The 0-g theatre will incorporate many familiar aspects of theatre into its design, but will also have some key differences. For example, every seat will have seat belts to keep the audience rooted to their seats, and performers will quite literally have the ability to fly. With all the things a 0-g environment makes possible, theatre will be forever changed once it leaves the ground.

But before we can talk about plays and trapeze without the trapeze, we first have to start from the very basics. How do we arrange the theatre? According to Hildy (2022), there are 4 basic forms of theatres: arena stage theatres, end stage theatres, thrust stage theatres, and flexible stage theatres. Arena theatres have the stage in the middle and the audience all around, as in an amphitheatre. While these theatres may appear quaint, they pose many challenges. The performance would have to be structured so that nobody has their back turned to one side of the audience for too long, and props and special effects can block the view of the performance too. Trying to meet these demands, in my view, would deduct from the play and put too many constraints on what can and can't be done. The thrust stage theatre suffers from the same problems from the same problems, though changing actors and props are made simpler as the audience is only on three sides of the stage instead of four, as is noted by Hildy (2022). An end stage theatre is one that has a stage at the end of the theatre, hence the name. Performance execution is greatly simplified in an end stage theatre, as the audience is only on one side, allowing performances much more freedom in actor, prop, and special effect placement. A lot more attention is drawn to the stage in this type of theatre too, perhaps making performances more immersive. A flexible stage theatre is one in which the stage can be placed in any of the above formats; the theatre in the sky pool is a flexible stage theatre. The 0-g theatre, however, will be an end stage theatre, as anything can be performed in such a theatre without needing to worry too much about the placement of things and instead being able to focus completely on the performance itself.

Dimensions

The theatre takes up half of the 6th floor and has a total area of 5,661.15m². At the front of the theatre there is a stage with a length of 20m and a width of 10m, and behind that is a backstage with a length of 20m and a width of 20m. Starting on each side of the backstage and ending 5m into the stage are two rooms for prop storage 15m wide and 25m long. On each side of the backstage/stage is 1,125m² of area for restrooms, restaurants, docking areas for the elevators and cargo, small artistic features, box offices, and business offices on the higher floors. In front of the stage is an orchestra pit 5m wide and 8m long with a pit orchestra size of 25, according to the average size mentioned in "Pit orchestra" (2022).

2m in front of the orchestra pit is where the seating begins. There are a total of 350 seats split into 7 rows and 2 balconies. Each seat has an area of .715m², which is the average of the recommended values listed by Archi-Monarch (2022). In the middle of rows 1 - 5 is a second "satellite stage" which, because of the 0-g environment, can be accessed from the main stage relatively easily. On each side of this satellite stage is a 1.5m gangway. In the 1st row there are 13 seats on each side of these gangways, in the 2nd row there are 14 on each side, in the 3rd there are 15 on each side, in the 4th there are 16 on each side, and in the 5th row there are 18 on each side. In the 6th row there are 7 seats in the middle of the two 1.5m gangways instead of the satellite stage, then there are 22 seats on either side of those two gangways, then there is a second pair of 1.5m gangways, and on each side of those there are 10 seats, for a total of 71 seats in the 6th row. The 7th row has the exact same format except that there are 13 seats on each side of the second pair of gangways instead of 10, for a total of 77 seats in the 7th row. The distance between each row, or the clearway, is 50cm (based on the requirements listed by Archi-Monarch (2022)).

Over the first few rows on either side of the theatre are two balconies, each housing 25 people. The final arrangement of the theatre is shown below:

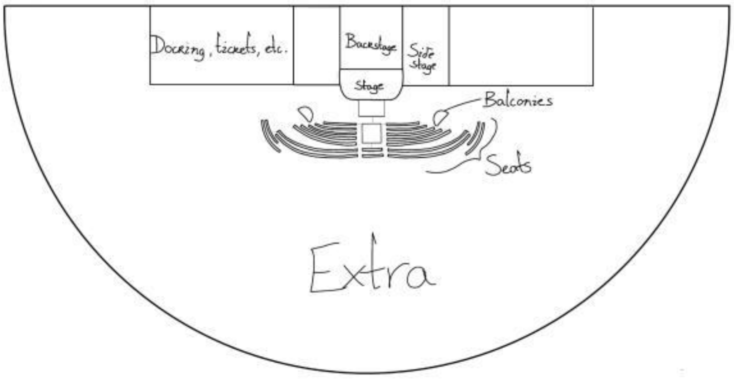


Figure 29. Theatre layout

Acoustics

Though the 0-g theatre has the basic outline of a half-circle, its actual shape will differ greatly. This is because acoustics depend heavily on the shape of an auditorium. Box shapes are avoided because parallel walls can cause too much reverberation resulting in an echo that can make the performance difficult to hear, so curved walls and shapes are used heavily in the design of the 0-g theatre to diffuse sound. To perfect the sound quality within the auditorium, the 0-g theatre will leverage parametric design. The general shape of the auditorium and the acoustic requirements will be fed into an algorithm which will design thousands of individual acoustic panels to diffuse, reflect, and absorb sound waves in exactly the right spots. The Elbphilharmonie concert hall in Hamburg Germany provides a great example of how AI can be used to master the acoustics in a room, with over 10,000 individual acoustic panels made up of all kinds of grooves meant to shape sound in the perfect way so that everybody hears an equally clear sound (*Elbphilharmonie acoustics*, n.d.). Sound amplification via speakers will be used in Luna-CT only when it is needed. Acoustic panels will be made from materials readily available from the moon such as fibreglass, concrete, and aluminium.

The 0-g Environment and Entertainment

The way things are performed will likely change in the 0-g environment. Things such as dance which are astonishing in their own right will become even more so in the 0-g theatre, with performers suspended in the air without ropes and acts performed in seamless slow-motion. To move around performers will have to use a combination of hand holds and small propulsion systems. They'll use a hand-held propulsion gun similar to the HHMU used on the gemini missions and later on Skylab ("HHMU", 2021). The gun is a cold gas thruster that performers will learn to use to move around mid-air and between the two stages. It has to be pointed through the performer's centre of mass to avoid them spinning out of control. Cold gas thrusters are used for their simplicity and the safety of their exhaust (Luna-CT uses non-flammable inert and readily available gases). Their design consists of only a tank, a nozzle, a valve and some plumbing and can be miniaturised ("Cold gas thruster", 2023).These will be used to provide small corrections, while lines, handholds and places to push off from will provide the performers with their main source of propulsion. Performers will need to be trained in moving in 0-g to the point that Luna-CT will have to create a new profession: weightless acrobatics instructor.

Architecture

Theatres tend to be places of architectural glory, and the 0-g theatre is no exception to this. It will be the area in Luna-CT with the most imported materials from Earth while also basking in its Luna-C uniqueness of style and form. Concept art of the theatre is shown below:

The Hall of Dreamers

I've added quite a few personal touches to Luna-CT, but this one is a true gem. The Hall of Dreamers is at the very bottom of the 0-g sphere. It's like the cupola on the ISS except much larger. It's a window to the rest of the universe, a place to contemplate existence itself and no doubt a popular place in Luna-CT. I added it for the same reason I added sky city and the 0-g theatre: it's a place I would want to spend my time, and a place I know others would want to spend their time too.

Dimensions

The Hall of Dreamers is on the 17th floor of the 0-g sphere and can be thought of as either a penthouse or a bottommost floor depending on your reference frame. The floor itself has an area of 6,569.0702m², and the distance from the floor to the very bottom (or top) of the sphere, or the floor height, is 17m.

The volume of the Hall of Dreamers (from $V = \frac{\pi h^2}{3}(3r - h)$ ("Spherical cap", 2022), where h is the height of the hall and r is the radius of the 0-g sphere) is 58,409.538m³. It can accommodate up to 100 people at a time but numbers are usually kept lower than that to improve experience.

The Window

The whole Hall of Dreamers is the window into space, and there are few other things in there apart from the greatest view a human can ever know. The glass (or in other words, the walls) is itself split into two layers. The outer layer is a 1cm thick glass covering made of silica with lead oxide to protect the Lunacs from X-rays and gamma rays, the same as the upper end cap in the colony. It is lined with chevron shields each 1cm thick and 20 cm apart from one another. If Luna-CT detects any danger such as orbital debris, meteoroids, etc. the outer layer of the Hall of Dreamers' windows will become covered by a shield.

Micrometeoroids and other space rouges pose an obvious threat to any space habitat. But if we really want to live in space we're going to have to figure out a way around these dangers. According to NASA (1977), a 1g meteoroid will hit an area of 1 km² every 10 years, and a 100g meteoroid will hit an area of 1 km² every 2,000 years. The numbers just get larger the higher the mass of the meteoroid. In the case of meteoroid detection, the outer layer of the glass in the Hall of Dreamers will become covered by a multi-shock shield. A multi-shock shield is similar to a Whipple shield in that its purpose is to disperse an incoming piece of debris so that its force is dispersed more widely over a given surface area. The key difference is that a multi-shock shield is made up of multiple layers, or bumpers. The multi-shock shield used in the Hall of Dreamers is the one described by Miller et al. (2015). It consists of 7 bumpers, has a total width of 2.65m, and can stop space rocks with energies up to 14.25MJ. More specifically, it consists of four bumpers of fibreglass, each made up of 22 layers of fibreglass 3784 blankets; 1 bumper made of 7 layers of steel mesh; and two bumpers each made up of 45 layers of Kevlar KM2 blankets. An image of how these bumpers are distributed and the spacing between them is shown below:

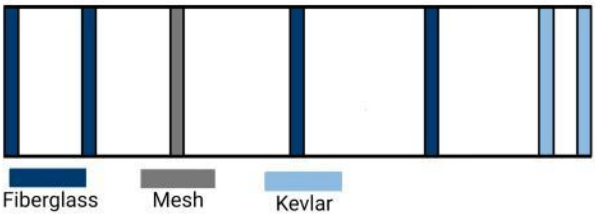


Figure 30. Multi-shock shield

The Hall of Dreamers is truly a special place. It's a place to come and just look. Just look at the stars and planets, unobstructed by a turbulent atmosphere. Just look at the dim reflection of yourself in the glass and marvel at the thousands of years of progress that it took to get you here, and the thousands of years of progress yet to come. At the top (or bottom) of the Hall of Dreamers is a sort of plate, and inscribed on that plate is a poem by Walt Whitman which I think captures the essence of Luna-CT quite nicely:

I Dream'd in a Dream

I DREAM'D in a dream, I saw a city invincible to the attacks of the
whole of the rest of the earth;
I dream'd that was the new City of Friends;
Nothing was greater there than the quality of robust love--it led the rest;
It was seen every hour in the actions of the men of that city,
And in all their looks and words.

Agriculture

"What's for dinner?"

Humans worship food. We all have a respect for the culinary arts, and some of life's finest moments take place around the dinner table. The very last thing that I wish for the Lunacs is for them to come back home after a long day and set the table, only to find that dinner is, once again, cricket powder and multivitamins. Just, no. So then, how do we grow food in Luna-CT?

The question of growing food in Luna-CT is more complicated (and interesting) than you'd think. Since there's normal gravity, why not just farm the same way we do here on Earth? That's because the way we mere Earthlings farm is embarrassingly inefficient, it's no wonder the extraterrestrials don't want to bother with us. In Luna-CT, farming is optimised as much as possible to produce as much yield in as little space and time as possible. That's why Luna-CT will use aeroponics to power its residents. Aeroponics is like its more familiar relative, hydroponics, in that nutrients are delivered to the plant with a water-based medium, but it's just so much more efficient. The idea behind aeroponics is that instead of planting a plant in soil, you leave the roots exposed to the air and spray them with a nutrient-rich mist or spray. This is so incredibly efficient in that it uses 98% less water than traditional farming techniques (NASA, 2006, pp. 64-67), and since the plant roots absorb all the nutrients they need right away and are less prone to disease, plants grown using aeroponics see an increase in yield ranging from 7 to 65% compared to traditional farming techniques (Chandra et al., 2014), and grow 3x faster (NASA, 2006, pp. 64-67). To top that all off, you can grow pretty much anything with aeroponics. Just to make this all even more efficient, plants are grown vertically, on trays stacked up to the ceiling or along poles to maximise use of space, and have optimised climates and lighting conditions. But before we can get into any more detail about Luna-CT's green thumb (and try to recreate one of our own), we're going to have to figure out what the Lunacs need to eat in the first place.

Nutrition Requirements

To greatly simplify food production, the Lunacs will have a primarily plant-based diet, though there is a possibility of adding space for meat production in the outer cylinder. Outlined below, however, are the Lunacs' nutrient requirements assuming a vegan diet.

There are 6 major nutrients that are found in food: carbohydrates, lipids, and protein, which make up most of the diet and are called the macronutrients, and vitamins, minerals, and water which are called the micronutrients (Carpenter, 2021).

Carbohydrates provide most of the energy to the body, and there are three main types: sugars, starches, and fiber. To satisfy their starch and fiber needs, the Lunacs will eat starchy vegetables such as peas, corn and potatoes, dried legumes, grains, fruits with edible skins, and nuts. Their source of sugar and sweet foods will be much the same as ours, being able to bake a variety of goods with sugar extracted from sugar cane and beetroot. It is worth noting that honey will be something of a specialty, there will of course be bees to pollinate the land, but only just enough to meet some basic requirements and to keep the Lunacs comfortable, so honey will likely be much more expensive.

Lipids are fats and oils. We really don't need too much of these, but the Lunacs will get enough from avocados, nuts & seeds, vegetable oils, dark chocolate, tofu and soy-based products.

Protein is a bit trickier, since most plants lack at least one of the 9 essential amino acids (the building blocks of proteins) that your body needs, but quinoa and chia seeds have them all (Harvard, 2021). Some other plant-based sources of proteins include legumes, nuts & seeds, and whole grains.

Minerals and vitamins will be obtained from vegetable oils, fruits, vegetables, grains, cereals, and nuts.

Last but definitely not least, water. The Lunacs will get their water from atypical sources: from the Moon, treated urine, transpired water from plants, water collected from the atmosphere, and treated water from the reservoir/sky pool.

Details of the agricultural system

50,000m2 of area is allocated to agriculture in the outer cylinder, as was mentioned on page 23. Since the height in the outer cylinder is 70m, Luna-CT's farm has a maximum theoretical volume of 3,500,000m3.

Luna-CT's farm will be split into multiple floors, each floor having 50,000m2 of surface area. Each floor is divided into multiple "bays", where each bay is an enclosed section of the floor containing rows of a specific type of plant. Each bay is enclosed and has an atmosphere optimised for the plant. Winter wheat, for example, grows optimally at CO2 concentrations between 899.6 and 967.8 ppm according to Xu (2015). Passage between sections is facilitated by airlocks. Plants are picked by robots, who pick plants from a bay and store them in an in-built "basket". The use of robots further increases efficiency and helps prevent pests and disease from entering the plant bays. They then travel to one of several delivery stations on the floor where they deposit the fresh goods in a lift. Each floor has several lifts and these lifts all take the harvested plants and transport them to the top floors of the agricultural building. In these top floors the plants all get sorted and are transported onto the cargo monorails to reach their destinations. Some plants, such as fresh greens, may be transported directly to the top floor of the mall which is where Luna-CT's grocery store is located. Other plants, such as wheat, may need to be processed and turned into finished products such as bread before they reach the grocery store. In that case the wheat would be loaded onto a cargo monorail that would take it to a separate processing facility which would serve as its penultimate destination before reaching the grocery store.

That pretty much concludes the big picture view of the agricultural system. Now it's time to focus on the specifics of the aeroponic system, and put it to the test by constructing one of our own.

We've already discussed the basics of aeroponics. You take a plant and you let its roots dangle in the air. The plant is usually held with a foam-like clamp at the stem. The roots are then sprayed with a food spray to deliver all of its required nutrients. Think windex, but for plants. But this leaves a lot of unknowns, like for example, how do you grow heavier plants like fruit trees?

Trellising will be used to support heavier and vining plants. Structures can be built out of aluminium to support the growth of heavier plants and to allow winding vine plants to spread out and do their thing.

Having optimal lighting is extremely important when it comes to growing plants. The ISS' Veggie experiment has magenta lighting, and there's a pretty good reason for that. Magenta is nothing but the overlapping of red and blue wavelengths, and those wavelengths are the colours under which plants thrive. Li et al. (2020) looked into the effects of red and blue light on sweet pepper, and to quote from them directly:

"Biomass accumulation and CO_2 assimilation were significantly enriched in B- and RB-grown plants, especially the latter treatment. Their leaves were also thicker, and photosynthetic electron transport capacity, as well as the photosynthetic rate were enhanced."

According to (Fluence, 2019) green light can also be beneficial to plants as it penetrates deeper into plant leaves and helps excite chloroplasts at a deeper level. This promotes photosynthesis across the entire plant, so a small amount of green light is added to Luna-CT's plant lighting.

Infrared also plays its part in plant development. There is a protein in plants called phytochrome which regulates when a plant switches from a vegetation period to a flowering period, and it is sensitive to infrared radiation. Having enough infrared in the plants' LEDs can promote flowering (Sawyer, 2018).

UV light can play a crucial role in plant growth, but only when used in the right amounts. When exposed to UV-A light (320 - 400 nanometre wavelength), plants see increased photosynthesis and dry weight (Growace, 2020). Ultraviolet light also increases resin production, which results in more terpene and flavonoids. These give plants their taste, smell, and colour. An increase in resin production also helps plants protect themselves from pests and disease.

These are the wavelengths of light used in Luna-CT. Each plant has its own needs and therefore the amount of each light used will vary depending on the species of plant. Providing light to grow enough plants to feed 15,000 people is going to cost a lot of energy, so Luna-CT will use LEDs to make the most efficient use of the energy available. These will have to be imported from Earth.

Aeroponics surely will have come a much longer way by the time Luna-CT is ready for construction. Countless species of plants have been grown successfully aeroponically, and some have a harder time. Luna-CT's agriculture system will be flexible and may incorporate elements of hydroponics and other farming technologies should it be necessary.

That being said, there are some crucial points that make aeroponics a more attractive method than hydroponics for Luna-CT. The first reason is the benefits of root exposure to air. Plants convert the sugars they produce during photosynthesis to energy via the process of respiration, which requires oxygen (Lopez, 2022). Having plant roots suspended in the air provides more oxygen for the plant and results in increased plant growth. The other benefit of aeroponics compared to hydroponics and other growing techniques is efficient resource utilisation. Hydroponics uses 80% less water than traditional farming techniques, whereas aeroponics saves 95% according to Brio Hydroponics (2020), and NASA (2006, pp. 64-67) claims it can reduce water consumption compared to traditional farming techniques by as much as 98%. Aeroponics is also more efficient with its nutrients: Klingler (2021) claims that hydroponics requires 4 times more nutrients to grow a plant than aeroponics does.

This concludes the basics of Luna-CT's agricultural system, but just speaking about aeroponics may not be convincing enough, so why don't we design an experiment? I was initially going to perform this experiment but unfortunately I didn't have enough funding to carry it out in the end and so the details and results from similar experiments will have to suffice for now.

Aeroponics Experiment

"Tea, anyone?"

Aeroponics sure does sound great, doesn't it? So great, in fact, that I wanted to see if I could design an aeroponic system of my own. I'm going to design an aeroponic system as close to the one used in Luna-CT as possible, using a traditional growing technique (soil) as a control. I decided to grow mint because of its compatibility with aeroponics and because I really like mint tea (this is a very important factor in experimentation, believe it or not). The effectiveness of the aeroponic growing method over the traditional one will be measured in terms of the difference in each system's biomass accumulation, stem height, growth speed and taste. The experiment itself will unfortunately not be performed here due to lack of resources, but results will be cited from similar experiments and an argument in favour of aeroponics will be made all the same. Perhaps this could even serve as a weekend project kind of thing for any interested reader.

Mentha

Mint is a pretty easy plant to grow, but there's still some variables we'll need to keep an eye on if we want it to succeed in an aeroponic system. The first of these variables is pH. pH (percent hydrogen) is a way of measuring the acidity or alkalinity of a solution on a scale of 0 to 14, with 0 being the most acidic and 14 the most alkaline. The optimal pH for a soilless growing system, according to Roosta & Rezaei (2013), is between 5.4 and 6.0. According to the same source, a higher or lower pH can reduce nutrient availability to the plant. The concentration of the nutrient solution should be between 1400 and 1600 ppm for mint according to a variety of sources, but as these sources weren't the most reliable, it's best to experiment a bit with these values. According to Hocking (2007), mint thrives on warm days (~25ºC) and cool nights (~15ºC); these temperatures will be constantly monitored and maintained in the aeroponic system. Since mint is a long-day plant and we want to avoid flowering, the mint plants should only be exposed to the grow lights for 8-10 hours a day.

How the System will be Constructed

The aeroponic system, in its most basic form, consists of two parts: the chamber itself, and the supporting electronics. The chamber will be built using a 23L plastic tub filled ⅔ of the way with distilled water and a nutrient solution. Six holes will be drilled into the top of the box to make way for the net cups. The net cups will suspend the mint plants' roots above the water, and the stems will be held with foam. To deliver the nutrient solution to the plant roots, I would use an ultrasonic mister. Ultrasonic misters produce very small droplets of water, similar to the high-pressure atomisers used in Lua-CT. According to Lakhiar et al. (2017), they result in a high yield, good humidification, and increased root exposure to oxygen. To provide light to the plants I would use a full-spectrum LED grow light similar to the one used on Luna-CT. A system to control the amount of time the light is on can be built using a relay and clock module programmed by an arduino UNO. Another system should be built to measure water and air temperatures using the same arduino UNO and an LED display screen.

Monitoring

The variables that should be kept an eye on during the aeroponic growing process are: nutrient solution pH & ppm, temperature of water and environment, and hours of light. For the traditional growing technique the plant(s) should be put in the same conditions. Throughout the course of the experiment the variables that should be monitored are biomass accumulation, stem height, and growth speed. At the end you should see if there's a difference in their tastes.

Parts That Need to Be Automated

To better mimic the environment of Luna-CT, certain parts of the aeroponic system should be automated. The parts that are automated in this system are light cycles and temperature monitoring.

Automation

Temperature monitoring is done using a DS18B20 temperature sensor and a 20x4 LCD display screen. The circuit diagram of this system is shown below:

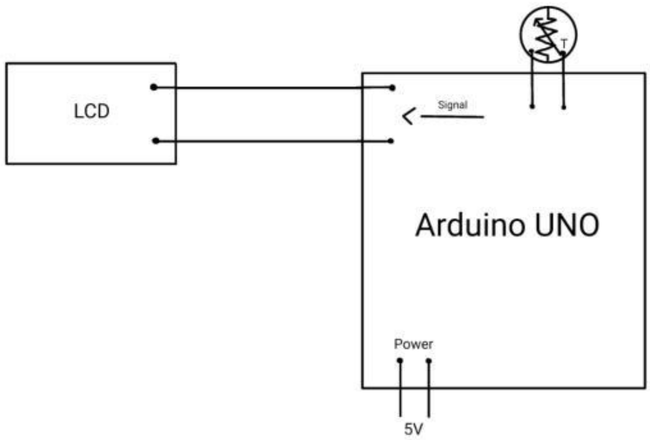


Figure 31. Circuit diagram of temperature monitoring system

The code is shown here:

```
#include <OneWire.h>
#include <DallasTemperature.h>
#include <LiquidCrystal_I2C.h>

const int sensor = 10;

OneWire oneWire(sensor);
DallasTemperature sensors(&oneWire);
LiquidCrystal_I2C lcd(0x27, 20, 4);

float tempF; //temperature in degrees Celsius
float tempC; //temperature in degrees Fahrenheit


void setup() {

  sensors.begin(); //initialise sensors
  lcd.init();
  lcd.backlight();

}

void loop() {


  sensors.requestTemperatures(); //request temperature from sensor
  tempC = sensors.getTempCByIndex(0); //get temp in C
  tempF = tempC * 9 / 5 + 32; // convert Celsius to Fahrenheit

  lcd.clear(); //print requested values of temperature
  lcd.setCursor(0, 0);
  lcd.print(tempC);
  lcd.print((char)223);
  lcd.print("C");
  lcd.setCursor(0, 1);
  lcd.print(tempF);
  lcd.print((char)223);
  lcd.print("F");

  delay(1000);

}
```

Figure 32. This code to read and display temperature is based off of code by ArduinoGetStarted (n.d.)

The light switch mechanism is a little different because in order to simplify things I think it would make sense to use a 230V DC 5V relay module to turn the current inside an extension lead on and off. The grow light would then be connected to the extension lead. The relay module is connected to the arduino UNO along with a DS1302 RTC clock module to control the times at which it is switched on and off. The circuit diagram for this system is shown below:

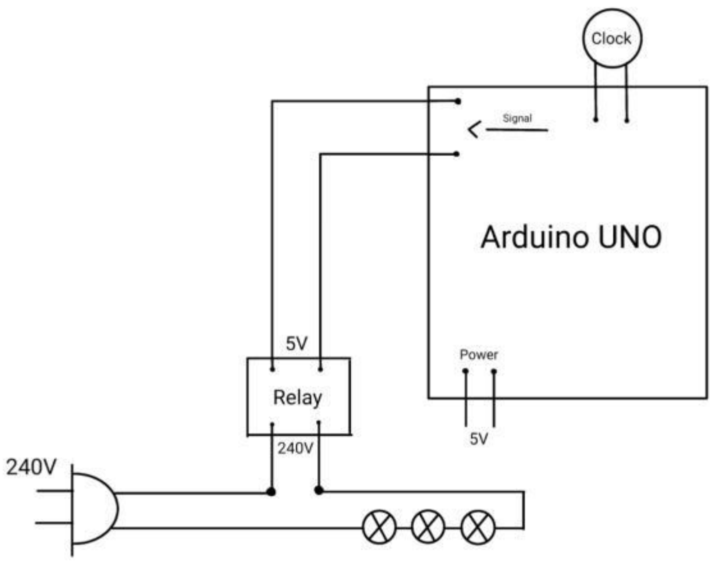


Figure 33. Circuit diagram of light automation system

The code is shown here:

```
#include <LiquidCrystal_I2C.h>
#include <DS1302.h>

int Relay = 9;
DS1302 rtc(2, 3, 4);

Time t;
LiquidCrystal_I2C lcd(0x27, 20, 4);


void setup() {

  rtc.halt(false); //setup
  rtc.writeProtect(false);
  lcd.init();
  lcd.backlight();

  Serial.begin(115200);
  pinMode(Relay,OUTPUT);
  digitalWrite(Relay, LOW);

}

void loop() {

  t = rtc.getTime(); //getting the time

  lcd.clear(); //printing the time on the lcd
  lcd.setCursor(0, 2);
  lcd.print(t.hour);
  lcd.print(":");
  lcd.print(t.min);
  lcd.print(":");
  lcd.print(t.sec);


  if (t.hour > 10 && t.hour < 18) { //Light on between 10 AM & 6 PM


    digitalWrite(Relay, HIGH);
  } else {
    digitalWrite(Relay, LOW);
  }

 delay (1000);
}
```

Figure 34. This code to switch the grow light off and on is modified from code by MORYTECH (2019).

Note that this code is untested and in an actual experiment would probably be modified, so take the above with a grain of salt.

Materials for Monitoring

Some basic equipment is necessary to monitor the aeroponics experiment that wouldn't be necessary for the traditional soil system. The amount of equipment depends on how much you want to monitor, but since a temperature sensor is already included in this experiment, a ppm and pH sensor should suffice for this experiment. In Luna-CT additional things such as humidity sensors would be implemented, but that is unnecessary for this demonstration. A ppm sensor is necessary to determine whether the concentration of the nutrient solution is within the 1400 - 1600 ppm range, and a pH sensor is necessary to be able to adjust the pH levels of the solution. pH levels would have to be adjusted with pH buffers.

Monitoring Period

The duration of the monitoring period really depends on how you decide to grow the mint plants. It is possible to get "starter plants", with roots already formed, in which case the monitoring period would be reduced. If you decide to start from scratch, it takes mint seeds 7 - 14 days to germinate (Kelloggarden, 2020), which can increase your monitoring period. You can choose to grow the plants until one of them flowers, or stick to a specified growing period such as 30 days. Or you could even continue pruning them and keep the mint plants long-term. For this experiment I advise using starter plants and monitoring both systems over a period of 30 days.

Results From Other Experiments

As I have stated before, I was unfortunately unable to perform this experiment myself, but we can still make conclusions about the results of this experiment by looking at the attempts of others.

The first results from a similar experiment can be cited from Chandra et al. (2014). Leafy plants (chard, parsley, red kale, and basil) and fruits (bell pepper, cherry tomatoes, cucumber, and squash) were grown aeroponically and in soil until harvest. The results of the experiment showed that the plants had up to a 65% increase in yield and had overall similar phenolics, flavonoids, and antioxidant properties, though these varied for each plant, with some performing worse in aeroponics and others performing better.

Souret & Weathers (2000) tested the difference between aeroponic/hydroponic and soil systems in growing saffron. They report increased corn growth on a dry weight basis in both aeroponics and hydroponics compared to soil, reduced root length but unaffected shoot development, and the same concentration of the constituents of saffron.

Li, Q. et al. (2018) performed a similar experiment to that of the above, but with lettuce. They grew lettuce using three methods: aeroponics, hydroponics, and substrate. They concluded that aeroponics led to significantly better root growth, with greater root length, root/shoot ratio, and root area and volume compared to the substrate and hydroponic systems. The hydroponic growing method led to greater shoot growth, but the researchers concluded this was due to lack of nutrients and water in the aeroponic system. With the appropriate misting intervals and nutrient concentration, the shoot would likely be much larger.

Conclusions

I think aeroponics is the best way to go about agriculture in Luna-CT. Its demonstrated productivity compared to other methods and efficient use of resources make it highly attractive for an environment such as Luna-CT's. That's not to say that aeroponics is without its faults, however. There is still a lot of research that needs to be done on aeroponics and there is so much room for improvement. That being said, it's not like Luna-CT is going to be built next week, so rest assured that aeroponics will probably be ready by the time such a project would be undertaken. I predict that the results of this experiment would demonstrate the merits of aeroponics and that the aeroponically grown mint would grow faster and have greater yield.

Now that the discussion of agriculture at Luna-CT is over, this paper must come to an end. Below you will find some final remarks, a continuation of the opening story, and the references. I hope you've enjoyed reading this paper as much as I enjoyed writing it. Per aspera ad astra.

-Diana

Final Remarks

"Cheerio"

This marks the end of this paper, though you'll find a continuation of the opening short story below. I'd like to thank my family and friends for keeping me going throughout this project and putting up with my experiments at absurd hours of the night. All the work in this project was done independently. I'd also like to note that although this project has reached an end, Luna-CT has not. Its influence will live on, and who knows, maybe one day it'll be built for real.

Per Aspera, Ad Astra.

A wide path was filled with people, all walking one way or the other; it was the height of the afternoon, and also Luna-CT's busiest hour. Schoolchildren were huddled in groups, their blue uniforms bright in the light streaming from the glass; some Earther tourists stood on the edge of the path, taking pictures of the curve of the station as if it was a wonder of the world; and all other kinds of Lunacs walked up and down the path, busy with their day-to-day lives. The sound of their chatter and footsteps came to a sudden halt when a bright light shone from a tall building right in front of the path. On the side of the tall, grey building there was now a large screen, and from that screen came the voice of a woman. She had excessively curly blonde hair, a blue pinstripe suit, and used lively hand gestures when she spoke. "Good morning Luna-CT! I'm sure we've all been busy this past week with the celebration of Luna-CT's 100 year anniversary," she paused for a moment as a few people clapped and whooped "but nevertheless, it's important to not let the festivities get in the way of your preparation. Luna-CT, as you all know, is going to be officially decommissioned next week, and so we should all be prepared to make our leave tomorrow at 11 AM sharp. All right, that's it for now. Per aspera ad astra everyone!" she gave a quick wave before the screen faded and the side of the building was just smooth concrete once more. The tourists set off, the suitcases that were previously hidden behind their feet now dragging behind them against the path. The group of students looked away from the building, looking rather excited. One of the children, however, looked rather solemn, a golden bandana in his hands. "Don't look so blue Finn, no pun intended," said the girl standing across from him, the same golden bandana wrapped around the arm of her blue uniform. Finn sighed, tying the bandana around his arm "I don't know why everyone's so happy about leaving home, Jada, that's all. Because I know I'm not." "Maybe it's because this station is the oldest of all the ones Luna-C built and Auda-CT is just so much cooler. I heard they have ski slopes!" she replied quickly, surprised that this wasn't more obvious to Finn. "Yeah but don't you see? That's the problem. Luna-CT is the original CT. There's an entire history built into these walls," Finn brushed his hand on the bannister that lined the path, thinking of the pioneers who had built the station from nothing. "Well if you say so," Jada turned and stalked off, the blue ribbon in her hair flailing about behind her rather dramatically.

Finn leaned over the bannister, watching the water rush between the pebbles in the stream below the path, and he realised that very soon that water would stop flowing, and that the material on the stream's bank would be recycled, along with everything else in Luna-CT. Reborn, just like everything else.

That evening Finn had a final dinner with his family. They, just like everyone else, seemed excited and spoke joyfully of the new things they'd experience in Auda-CT. Finn's show of disinterest did not go unnoticed, and his parents made many attempts to cheer him up, but to no avail, because no amount of high-tech ski slopes could ever replace Luna-CT. "Cheer up Finn. If you can't be happy about Auda-CT, then at least be excited to be on the Starship X-42, it'll be your first time," his mother said, putting a hand on his shoulder. For this he was in fact excited, for he had a passion for spacecraft, and the Starship X-42 was like no other: it made the trip to the moon in a fraction of the time that any other spacecraft could with its fusion reactors. But trips to the moon were rare for the X-42, as it was mainly used for missions to Mars and the asteroid belt, but somehow Luna-C managed to get access to one and would use it to transport the Lunacs of Luna-CT to Auda-CT, its newest station in the same orbit. He smiled in response, and trod upstairs a little happier than he had been before. That night he still found himself staring at the ceiling, however, going over everything he had experienced at Luna-CT: the sky pool, his upcoming final years of school, riding on the old monorails, anything to keep his mind off the journey tomorrow.

The next morning Finn was awoken by his mother, she had an exasperated look on her face when she drew the curtains of his room open and said "You were supposed to be up half an hour ago." Finn sighed, heaved himself out of bed and walked over to the window. The window overlooked the garden in the centre of a cluster of dome houses, still green and in full bloom despite it being the last day that anybody would tend to it properly. Finn opened the window and took in a deep breath only to realise something he hadn't been expecting: he was excited. Finn rushed downstairs, a bag slung around his shoulder. The kitchen was empty and everybody was waiting for him outside. He squinted his eyes against the light, and was rather surprised to find a mass of people all gathered in the courtyard, all making their way along the winding paths between the domes; it looked eerily like an evacuation, except everyone had a certain bounce in their step and an air of joy and excitement. Finn practically had to break into a run to catch up with them all.

A few hours had passed and everybody was now in the 0-g sphere, sorting themselves into groups and checking their watches feverishly. It had been decades since pressure suits were mandatory on Starships, but some part of Finn wished they still were. Finn knew this floor had once been the first floor of the hotel, but since tourism at Luna-CT had weakened since the opening of the next stations, it had been turned into an extended docking platform. Finn was talking to one of his teachers when he was interrupted by a humanoid robot a little shorter than him "Mr. Finn, you've been requested at the Hall of Dreamers." "What?" said Finn, completely baffled as to who would call him up to the Hall of Dreamers an hour before he was bound to leave it behind for good. "The lady Nora requests your presence, Mr. Finn," the robot elaborated. "Oh, okay - I'll be up right away," Finn looked over to his parents, who nodded, as if giving him permission to leave so closely behind departure time. He grabbed onto a handlebar and pushed himself in the direction of an elevator and pushed the top button, labelled 'H'. The elevator was obviously empty, but it still felt weird to be alone in an elevator that was usually packed with people. Nora was Luna-CT's oldest living resident, and was one of the adults he was closest to. She told everyone endless stories of the early days of Luna-CT, of "the times before Hollywood stole all the glory and truth", as she liked to call them. But she and Finn were especially close, and he often came over for tea to her apartment. What perplexed Finn was why Nora was calling on him now, and why send him to the Hall of Dreamers? Surely she could tell him whatever she needed to once they were boarded. But somewhere deep inside, Finn was glad he was going to see the Hall of Dreamers for the last time, it was one of his favourite places to visit and seeing it one last time might be just the goodbye he needed. The elevator doors opened after the end of a well-worn jingle to reveal a huge room enclosed with glass walls. It was scary walking through that room at first, because it felt so exposed, so vulnerable to the void of space with its transparent walls and dim lighting. Finn saw the moon first, and the outline of a person seated on an armchair second. He immediately knew it was Nora and glided towards her, wondering how she managed to stay still for so long in 0-g. Her eyes were closed, but once she heard Finn approaching she opened them, looking at him seriously. The grey light of the moon made her seem older, every fold in her skin highlighted by the sharp light. "Finn, I'm glad you came," she smiled at him, motioning for him to take a seat by her side. Finn tried to fold himself into a plausible seating position as best he could, but didn't quite manage: moving in 0-g wasn't something he had quite mastered yet. "Shouldn't you be down there with everyone else?" Finn asked her. A look of sadness seemed to pass over Nora's eyes for a split second, but it disappeared as quickly as it came and she just continued smiling softly. "I won't be joining you on your trip to Auda-CT, I'm staying here, in Luna-CT," she said, each word spoken with calm deliberation. "What do you mean? How? This place is being decommissioned," Finn looked up at her, now becoming increasingly concerned. "I am old Finn, and I won't be much of a use to anyone over there," she looked at him as if she had been expecting this. "What do you mean you won't be of use to anyone? You're of use to me!" Finn blurted out without really thinking. Nora chuckled, putting a hand on Finn's shoulder. "My life started with Luna-CT, and I'd like for it to end with it too. I've dedicated my whole existence to this marvel of a project, and I think it's only fitting for me to see it off. A captain should go down with her ship, after all." Finn wished he didn't hear her say that, but he couldn't help but understand. Nora had always referred to Luna-CT as her ship, and she had even acquired the nickname 'Captain' somewhere along the road. He nodded, and she knew he understood. "But before you go, I want to give you something," Nora said, handing him a book he hadn't realised she was holding at her side. A paper book, an actual physical book. "Wow," Finn breathed, turning it around in his hands; it was an old copy of Plato's *Republic*, and had the passage of time embedded in it. "Thank you," he said, looking up at her and smiling, unsure of how to show his gratitude. They talked a while longer, but at some point Finn checked his watch and started to find that it was 10 minutes before departure. "I have to go, I'm sorry Nora," he said, scrambling to a standing up position. He made to leave, before turning to see her, still in that armchair, watching him as contentedly as if he had been leaving for school, promising to return the next day.

"Go, I will be fine," she said, her tone unwavering. Finn knew she had probably made this decision the day she had first arrived at Luna-CT, and so he didn't question her further. He rushed towards the elevator, taking one final look at Nora hidden in shadows on that armchair and the bright light of the Moon and the stars surrounding her. But before he could say anything more, the elevator doors closed on him and he was drifting slowly down to the docking platform. When his mother asked him what Nora had wanted in the Hall of Dreamers, Finn gave no answer. They all boarded their Starships contentedly, without sparing a thought for anything else but what lay ahead of them. As the Starships took off, Finn watched Luna-CT get smaller from his window. It looked like a hockey puck, a strange ship floating through a black void. It also looked enchanting, as if the stories of all the people who dreamt of it, designed it, and eventually lived in it were written on its walls. He waved to it, wondering if Nora was waving back. Finn opened the book Nora had given him, and found written on the first page, beneath scribbles of faded ink 'To my dearest interlocutor, Per Aspera Ad Astra.'

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