ASTRUM

GALACTIC GET-TOGETHER

AEROSS

Delhi Public School, R.K. Puram

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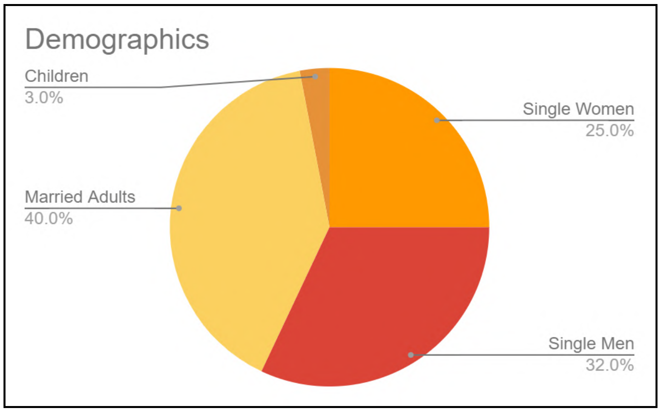
1.0 Executive Summary

Astrum will be the harbinger of a new age of space infrastructure, one where the construction and operation of space settlements is no longer an arduous dream. Astrum accounts for state-of-the-art technology, provision of all luxuries of life one might seek in a place of residence or work, and vast lands capable of fruitful commercial enterprises. With the increasing population, the settlement too shall expand, both in its boundaries and humanity's horizons.

Permanent Population	7500
Transit Population	350
Total Population	**7850**



Structure

Components of the structure

- **Hybrid Paraboloid** **-** A special shape to provide differential gravitation
- **Central shaft -** Provides a transportation unit in the settlement
- **Central Ellipsoid -** Industrial hub of the settlement
- **Solar Panels -** Power production
- **Docking ports and MRO -** Repair of spaceships and interplanetary ships
- **Manufacturing rooms -** Manufacture of spaceships and interplanetary ships
- **Rotational interface -** Provides a rotating medium for the hybrid paraboloids
- **Airlocks -** Air tight; Used in the seclusion banners.

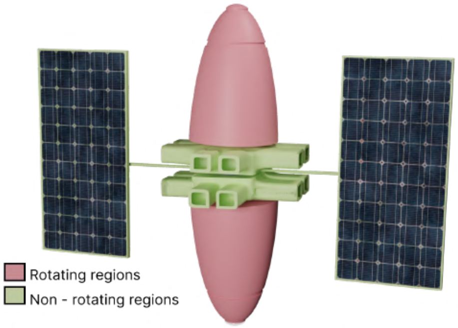


Fig 1.1 Rotating and Non-Rotating components

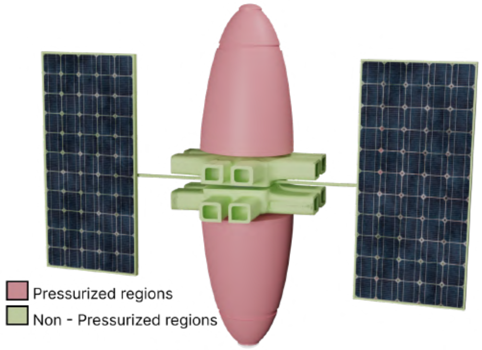


Fig 1.2 Pressurised and Unpressurised sections

- Calculations for stimulating artificial gravity on the settlement have also been provided.

Operations and Infrastructure

- The settlement is placed at the Earth-Luna L4 liberation point which has an equal distance from both the Earth and the Moon. Mining and processing of the lunar surface will be extensively carried out at the settlement. Adequate measures are implemented to ensure proper protection and insulation from environmental factors.
- Oxygen and Water is produced from Ilmenite, a resource abundantly available on Luna.
- The atmospheric composition is as earth-like as possible.
- Centrifugal compressors have been used for air regulation.

- Variability of wind speeds and the level of humidity along with the change of seasons has been incorporated into the operational system.
- In the agricultural area the amount of carbon dioxide and water vapor is increased to facilitate a healthier growth of plant life.
- The mechanism of Fogponics will be used for agriculture.
- For lighting purposes, electrochromic glass, as well as Coelux Lighting have been used. Coelux lighting creates the illusion of a blue sky with the sun shining in the center. This helps simulate an Earth-like environment for the people aboard.
- Interior communications are managed by Li-FI and Wi-FI and Personal Communication devices. The exterior communications will be governed by lasers. 2 ground stations will be present in the controlling headquarters and 4 satellites in the sun synchronous orbit.
- The primary source of power is solar panels, the secondary source is syngas and the tertiary source is lithium-ion batteries.
- Waste collection and segregation is done by a waste bin with two IR sensors and metal detecting sensor. The community cleaning bot is the waste disposal bot and will also segregate the non-biodegradable waste into recyclable, non recyclable and plastic.
- Two backup sources of generating power have also been included apart from just using solar panels.
- To make it easier to apply brakes in vehicles more efficiently in low gravity areas, a concept of electromagnetism and ferromagnetism has been used.
- There will be 5 space tug ports, 3 spaceship manufacturing rooms, as well as 8 standard MRO docks at IOC.
- The buildings all are equipped with safety measures in case of emergency. Separate routes and bots have been designed for contingency.
- Medical robots and emergency vehicles will look into the health status of people.
- Exclusive and trailblazing software ensures easy access and secure storage of data.
- The botmaker will be creating all the other bots and will quadruple its production level during types of expansion.
- The construction bots will be modified later to carry out the repair work as well.
- Details on how the Community Infrastructure will be expanded in future have also been provided.

Human Factors

- Lively and uplifting house plans will be available for the residents, including the transient population.
- Well-planned contingency measures will be initiated, including evacuation pods and temporary housing in the event of an emergency.
- Inflatable furniture will be used which will be imported from Earth.
- In order to protect the residents from radiation and solar flares, Astrum will be constructed with materials with great radiation resistance and thermal and mechanical stability.
- Specialized spacesuits with additional features and safety systems will be provided to every resident required for recreational activities, human inspection, exterior hull repair, etc.
- A variety of recreational activities, including both physical and mental health, will be available to entertain the residents, including power hour, augmented reality, VR meditation sessions, etc.
- Details on how the availability and need for amenities will increase with population increase have also been provided.

Automation

- Automated systems will be given to facilitate proper construction and repair of Astrum through specialized internal and external construction robots which will also help in repair processes later on.

- Robots and surveillance systems shall be provided for conducting regular operations in the settlement.
- Security measures will be detailed at each level, from households to control centres to help protect data. Encryption methods shall be used to preserve data privacy and security.
- For internal communication in the settlement, PCDs shall facilitate swift video calls and normal phone calls between inhabitants. VOAs shall provide help to people in their work.
- To react to emergency medical situations in Astrum, medical robots and emergency vehicles will be deployed immediately. They can also get notified by the PCD.
- To receive goods from outside, MRO docks with automated systems will fix any damages to space crafts or space tugs coming in the settlement to deliver goods.

Credits:
Structural Design: Manvik Kumar
Operations and Infrastructure: Mannat Kaur
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- Manvik Kumar (9)
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2.1 Structure
In order to provide variable gravity levels for residential areas, the following configurations were considered:
Table 2.1: Trade Study

Sphere	Paraboloid (closed)	Ellipsoid	Hybrid Paraboloid
S:V ratio is 4.83	S: V ratio is 4.23	S:V ratio is 3	S:V ratio is 5.15
Provides lesser surface area	Provides higher surface area	Provides less surface area	Provides higher surface area
Fall off ratio is high	Fall off ratio is low	Fall off ratio is low	Provides apt fall off ratio
Towards the ends of the sphere at the axis of rotation, the g value reaches 0, thus wasting area	Towards one of the ends of the shape at the axis of rotation on the flat side, the g value would be 0 and that part of the volume would be potentially wasted.	Towards one of the ends of the shape at the axis of rotation on the flat side, the g value would be 0 and that part of the volume would be potentially wasted.	Provides the required g value range in gradience 0.15 - 0.9g.
A sphere has smooth edges of conjoinment	A paraboloid has comparatively sharper edges of conjoinment	An ellipsoid has comparatively sharper edges of conjoinment	A hybrid paraboloid has comparatively gradual edges of conjoinment making it much more suitable.

The hybrid paraboloid was the most suitable configuration to meet the proposal's requirements. The arrangement of components in the structure (frame-like) give scope for future expansion.
The structure will be having several components which are as follows-

2.1.1 Components of the structure
- 2.1.1.1 Hybrid Paraboloid
- 2.1.1.2 Central shaft
- 2.1.1.3 Central Ellipsoid
- 2.1.1.4 Solar Panels
- 2.1.1.5 Docking ports and MRO
- 2.1.1.6 Manufacturing rooms
- 2.1.1.7 Rotational interface
- 2.1.1.8 Airlocks

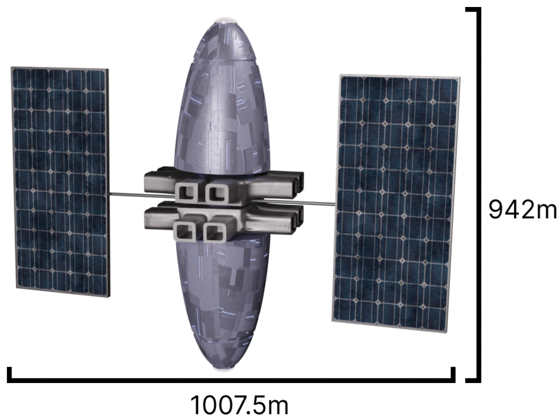


Fig 2.1 Labeled diagram of the structure

2.1.1.1 Elliptical Surface
The curve is a closed surface generated by rotating a parabola about its axis and then adding a duplicate copy of the same structure but rotated 90°.
The parametric equation of this structure is-
(3cost, (5sin(t))$^{1.3}$, 3sint)
The structure will be divided into 10 segments consisting of residential, agriculture and industrial areas using seclusion barriers consisting of airlocks for evacuation in case of emergencies. The seclusion barriers will be having 2 airlocks each in case one of them malfunctions.
This settlement will have **striped windows** running all across the settlement to provide natural views of the Earth and the moon.
There will be **two counter-rotating semi - hybrid paraboloids** spaced by the docks in between around the central shaft in the structure in the IOC so as to eliminate the gyroscopic effect. This curve was chosen as it provides gradual gravity change (0.15 - 0.9g) which is required by the residents. The curvature of this structure in this settlement is pretty gradual for a person to notice while moving from the bottom to the top. The Elliptical Curve provides a greater living surface also making it rotationally stable. Being one of the most prominent structures in the settlement, these curves will house the residential and agricultural sector of the settlement.
The structure will be tidally locked at the L4 lagrange point in order to provide sufficient sunlight to the external

solar panels resulting in higher energy production. Solar panels aligned to the curvature of the structure will result in less production than the expected amount.

2.1.1.2 Zero G industry

- Zero G industry will be enclosed by the central hybrid paraboloid which provides surface area for 0g industrial activities, storage and efficient transport.
- Zero G industry will have an elevator system for easy transportation.

2.1.1.3 Central Shaft

- The central shaft is the structure that provides support to the rotational interface of the settlement and will be connected only to the industrial segment of the settlement allowing for direct transportation of goods from the docks.

2.1.1.4 Inner Hybrid paraboloid

- It houses all the 0g industrial area
- A part of the inner hybrid paraboloid will be used for recreational activities.

2.1.1.5 Solar Panels

- For this settlement, multi-junction photovoltaic solar cells will be used. They are considered to be the most efficient solar cells available.
- The settlement will be having a main solar panel in the middle of the main grid-like structure having a length of 1000m and breadth of 625-1000m
- Conversion efficiency: 30-40%

2.1.1.6 Docking Ports and MRO

- The settlement will have up to 16 docking ports - 5 for space tugs, 8 for maintenance and repair of spaceships, and 3 for manufacturing of spaceships. (*refer to 5.5)*
- To provide for easy access between the docks and industrial segments, the ports will be situated between the two semi-hybrid paraboloids.
- The docking system will be outsourced according to the operational RFP.
- The MRO docks will be located inside the docking stations. They will have robotic arm tracks running on all room walls. Spaceships and space tugs will be brought in the room for repair and maintenance. 13 MRO docks will be provided in the settlement out of which 5 are for space tugs and 8 for spaceships. (*refer to 5.5)*

2.1.1.7 Manufacturing Units

- The Manufacturing units will be using the same mechanism as MRO docks. They will be building spaceships for interplanetary transport. Of these, 3 rooms will be allotted in the docking ports.
- These rooms can also be used as emergency MRO docks in case of an emergency.

2.1.1.8 Rotational interface

The settlement will have magnetic bearings for rotation:

- They have no friction therefore no lubrication required.
- Makes the settlement much more stable as bearing systems may induce friction making the settlement turbulent.
- Thrust is required to power rotation for lifetime.

Based on the trade study, magnetic bearings seem much more efficient as compared to ball bearings.

Table 2.2: Difference between rotational interfaces

Ball bearings	Magnetic Bearings
Very less friction	No friction
Lubrication required	No lubrication required to
Require excessive maintenance	Requires minimal maintenance

There will be some distance between the electromagnet and the semi paraboloids. In light of this, the optimal distance of 5 meters has been determined to be the ideal distance for smooth and efficient rotation of the structure around its axis.

2.1.1.9 Airlocks

A modular airlock system called the Advanced Docking System (ADS), created by NASA, enables quick and secure docking procedures between spaceships and habitats. Both manual and automated docking are supported by the system, which consists of two double-door airlocks and an interconnecting tunnel for crew and cargo transfers. In case of an emergency, it also has safety features.

2.1.1.10 Thermal Control System

The settlement makes use of several technologies for thermal control in the settlement. One of them is the use of radiators in the hull.

The settlement will be lined with radiator panels mainly consisting of Aluminum radiators reinforced with silicon and Shape Morphing Adaptive Radiator Technology (SMART).

Each Elliptical structure will have its own solar panels.

2.1.1.11 Warehouses and shacks

- These warehouses and shacks will be located in different industrial segments.
- The settlement will have large warehouses in the industrial area depending on the gravity required to store the equipment.
- Automation shack will be storing materials for the shack transport robot or the STR to aid the exterior construction process.

2.1.1.12 Trusses

The elliptical surface will be lined with trusses all across for the exterior repair and maintenance robot to for mobility across the settlement. These trusses are made of Titanium grade 5.

2.1.1.13 Thrusters

2.1.1.13.1 Rotational

The thrusters will be used to initiate the slow rotation to tidally lock the settlement to the Sun as well as change its orientation on any one of the three axes at a time.

2.1.1.13.1 Transational

The translational thrusters are placed to overcome any orbital decay or trajectory disturbance faced. The type of thrusters being used are chemical bipropellant thrusters.

2.1.1.13.1 Trade Study

Table 2.3: Trade Study

Electric Thrusters (Ionic)	**Chemical thrusters (Bipropellant)**
Partially controllable	Highly Controllable
Comparatively low thrust	High thrust

2.1.2 Construction Materials

2.1.2.1 HULL

Table 2.5: Hull materials

Hull Materials	**Characteristics**
HBN	• Mechanical strength and support • Space debris protection
Polyethylene boron	• Thermal insulation • Neutron Radiation Protection
Kevlar + graphene reinforced aerogel	• Space debris protection
Nextel	• Fireproofing
Lunar regolith	• High energy Solar protons shielding
PEEK	• Gamma rays shielding

Table 2.4: Hull materials

2.1.2.1 WINDOW

Table 2.5: Window materials

Window Materials	**Characteristics**
Perlucor	Thermal stability Mechanical strength
Transparent Spinel Ceramic	Structural strength Radiation shielding
Silicon Aluminum Oxynitride	Thermal insulation
Transparent Silica Aerogel	Radiation protection
Electrochromic glass	Provides artificial and uniform lighting.

2.1.3 Isolation

In case of an emergency such as depressurization, the residents will be required to evacuate. The structure has been divided into segments using seclusion barriers. Seclusion barriers will have surveillance cameras connected to the airlocks for efficient evacuation (*refer to 5.2.3)*

The structure will consist of 18 airlocks in total.

Each seclusion barrier will have one large airlock (*refer to 2.1.1.9)*

2.2

2.2.1 Interior layout

Table 2.6: Area occupied

S.No	**Purpose of space used**	**Area occupied (m^2)**	**Percentage %**
1	Residential	352264	32.3

2	Industrial - Varied gravity	352264	32.3
3	Industrial - 0g	352264	32.3
4	Agriculture	33771	3.09
Total			100

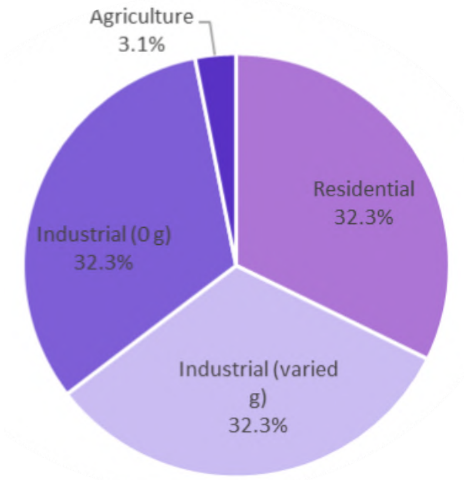


Fig 2.2 DSA allocation percentage

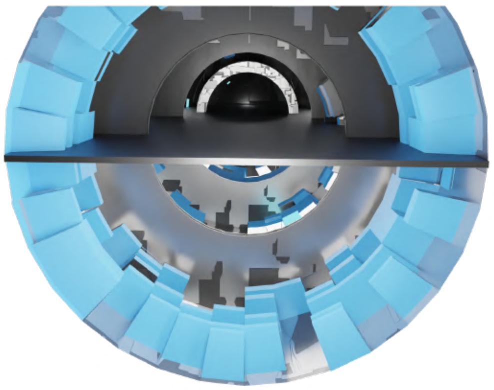


Fig 2.3 Volume Segmentation
This is a dissection of the settlement showing the living area in the settlement i.e the walls of the settlement

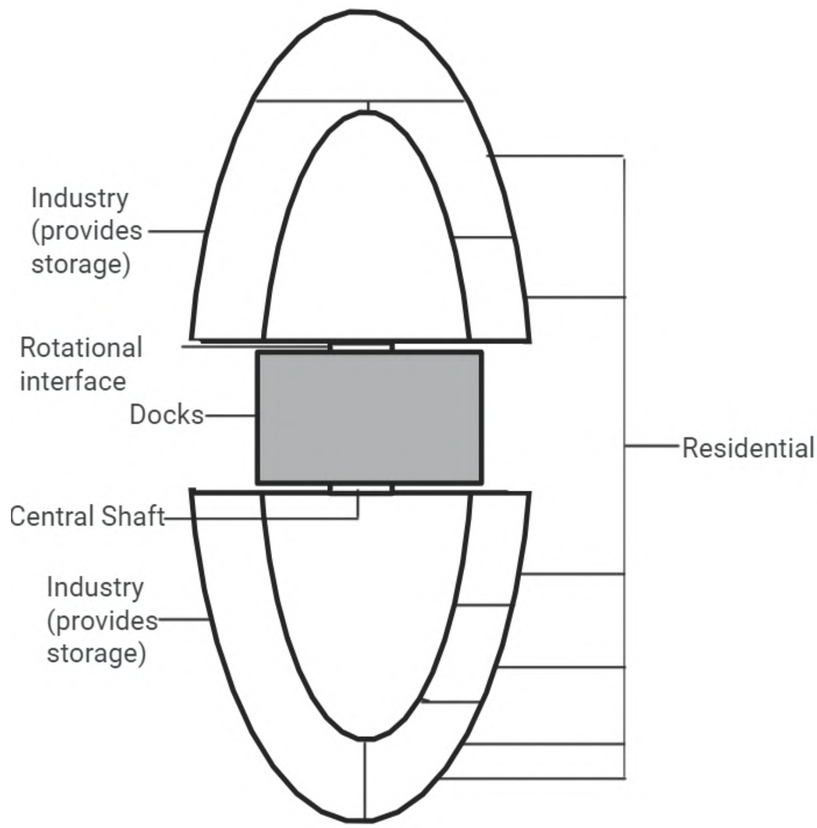
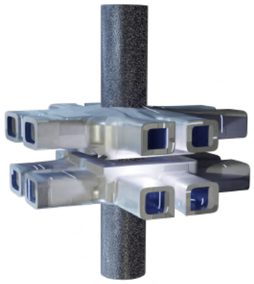


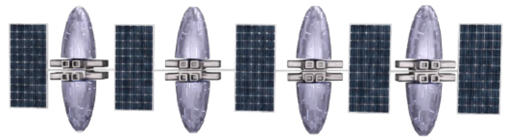
Fig 2.4 Volume distribution

2.3 Construction Phases

Table 2.7: Construction Phases

	Phase	Duration	Render

1.	The construction shack's assembly will take place and it will reach the designated orbital location. The construction shack mainly consists of eight docking ports, temporary solar panels and a hall effect thruster for minute movements. Material storage, two robot makers and a robot charger.	2 years (2046-2048)	
2.	A. Construction of the central shaft for transportation purposes throughout The construction will begin from the construction shack. This is the component where the construction material will be stored. B. Thrusters will be assembled near the docking stations at the corners of the settlement	2 years (2048-2050)	
3.	A. Exterior construction robots will start building the wireframes (Titanium grade 4) forsemi hybrid paraboloids. B. All solar panels will be placed permanently	2 years (2050-2052)	
4.	A. Hull of the semi- Hybrid paraboloids will be constructed. B. Rotational interfaces will be installed C. Interior finishing commences.	3 years (2052-2055)	
5. .	A. Interior finishing is complete B. Permanent solar panels are installed.	5 years (2055-2060)	
Initial Operation Capacity Reached (IOC) Total time taken to construct the settlement: 14.5 years (2043-2060)			

6.	A. wireframes of Al3O and Al4O will be constructed. B. Rotational interfaces will be installed C. Hull assembly of Al3O and Al4O will take place. D. Rotation will be induced in Al3O and Al4O.	7 years (2060-2067)	
Final Operation Capacity Reached (FOC) Total time taken to construct the settlement: 21.5 years (2043-2067)			

2.4 Artificial Gravity on the settlement

Centripetal force, $F = mr\omega^2$
Artificial weight, $W = mg$

Then as $F = W$
$\Rightarrow mr\omega^2 = ma$
$\Rightarrow r\omega^2 = a$

Maximum distance of the hybrid paraboloid from the center is 155 m.

Also, $a = g = 9.81\ m/s^2$
Using $T = 2\pi/\omega$ where T, is the time for one revolution per second, ω, is the angular velocity in radians per second.
Thus $a = r\omega^2$,
$\Rightarrow a/r = \omega^2$
$\Rightarrow 9.81/155 = \omega^2$
$\Rightarrow \sqrt{9.81}/\sqrt{155} = \omega = 3.14/12.5 = 0.25120$ radians/second

We know, $T = 1/f$ and $f = \omega/2\pi$ where f is the frequency in Hz.
$f = 0.25120/2\pi = 0.040064$ Hz or cycles per second

The rotation rate= $f \times 60 \approx 2.28$ rotations per minute

2.5 Volume distribution of the settlement

Volume for the industry excluding agriculture and MRO is roughly equivalent to double the volume for the residential community. Roughly half the industrial volume is in zero-g (inside the inner hybrid paraboloid), half in varying levels of artificial gravity (inside the hybrid paraboloid); half is a vacuum (inside inner hybrid paraboloid) and half is pressurized with capability for varying environments, approximately evenly allocated between g and zero-g.

Table 2.8: Volume distribution

S.No	Purpose of space used	Volume occupied	Percentage
1	**Industrial - Varied gravity (pressurized)**	22736667.3	33.14570803
2	**Industrial - Varied gravity (unpressurized)**	22736667.3	33.14570803
3	**Industrial - 0g (pressurized)**	22736667.3	33.14570803
4	**Industrial -0g (unpressurized)**	386111	0.5628759177

Total	100%

2.6 Future Expansion

According to the requirements, Astrum must accommodate 25000 residents and should expand its industrial DSA by 400%.

For expanding to its maximum capacity, three structures exactly the same as the IOC will be added to the structure. All these components will be connected to each other using a connecting shaft made of titanium grade 5 which advances in front of the solar panels. It connects the central shafts of the components to the central shaft of the other component.

Table 2.8: Construction Phases

Criteria	Sector	Initial Operating Capacity (IOC)	Final Operating Capacity (FOC)	Percentage Increase
DSA(m^2)	Residential	352264	1409056	400%
	Industrial - Varied gravity	352264	1409056	400%
	Industrial - 0g	352264	1409056	400%
	Agriculture	33771	135084	400%
	TOTAL	**10,90,563**	**43,62,252**	**400% (proved below)**
Volume (m^3)	Residential	22736667.3	90946669.2	400%
	Industrial - Varied gravity	22736667.3	90946669.2	400%
	Industrial - 0g	22736667.3	90946669.2	400%
	Agriculture	386111	1544444	400%
	TOTAL	68596112.9	274384451.6	400%
Docks	MRO docks for Spaceships	8	32	400%
	Interplanetary spaceships	3	12	400%
	docks	5	20	400%
Population	Residents(excess space can be used for transient)	7500	30000	400%
	Transient	350	1400	400%
Processing Capability(tons)	-	2500	10000	400%

3.1.1 Location

Table 3.1.1 *Orbital Location*

Orbital Location	Earth-Luna L4 libration point
Distance from Earth	3,84,400km (approximate)
Orbital Velocity	1.022 m/s
Eccentricity	0.05 (approximate)

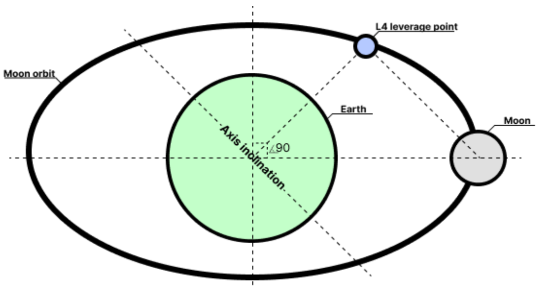


Fig 3.1.1 *Orbital Specifications*

3.1.2 Materials and Sources

All materials extracted from Luna and asteroids will be refined on the settlement itself.

Caddys are large containers that will be used mainly for storage, shipping and other secondary purposes in the settlement. They are 30 feet long with a square 15 foot cross-section and a holding capacity of about 16,000 kg. They will be used to ship any type of cargo from Earth, help in construction, bot assembly, water, waste storage, storage of extracted minerals and much more.

3.1.2 Materials

Table 3.1.2 *Hull Materials*

Hull Materials	Amount (kg)	Source	Features	Thickness	Caddys Required
HBN	479,895	Earth	• Mechanical strength and support • Space debri protection	0.65m	1,203
Polyethylene boron	442,980	Carbon - C-type asteroid Boron - Earth Hydrogen - Luna	• Thermal insulation • Neutron Radiation Protection	0.6m	2,419
Silicon	590,640	Luna	• Space debri protection	0.8m	1334
Nextel	221,490	Earth	• Fireproofing	0.3m	416
Lunar regolith	812,130	Luna	• High energy Solar protons shielding	1.1m	2,850
PEEK	221,490	Earth	• Gamma rays shielding	0.3m	883

Table 3.1.3 *Window Materials*

Window Materials	Amount (kg)	Source	Features	Thickness	Caddys Required
Perlucor	627,555	Earth	• Thermal stability, Mechanical strength	0.85m	-
Transparent Spinel Ceramic	922,875	Magnesium and Aluminium - Luna	• Structural strength, Radiation shielding	1.25m	1,262
Silicon Aluminium Oxynitride	590,640	Alumina - Luna Aluminium nitride - Earth	• Thermal insulation	0.8m	942
Transparent Silica Aerogel	442,980	Luna	• Radiation protection	0.6m	1,060
Electrochromic glas	184,575	Iridium - M-type asteroid Carbon - C-type asteroid Tungsten - Earth	• Helps in diffusion of light in order to create day and night cycles	0.25m	-

3.1.3.1 Equipment For Construction & Operations

Table 3.1.4 *Construction and Operation Machinery*

Equipment	Features	Quantity	Source
Exterior Construction Robot	Construction of wireframe and exterior structure as well as repairing damages in the hull.	400	Bot Maker
Shack Transport Robot	Transporting materials and assets to the exterior repair robot.	400	
Ground Layering Robot	Layering the surfaces of the ground	50	
Contour Crafting Robot 1	Assembling the interior buildings	90	

Contour Crafting Robot 2 (CCR-2)	Used for the the infrastructures building	90	
Interior Finishing Robot	Lining electrical wires, plumb water pipes and finishing houses	200	
Transportation bot	Transportation of Caddys and other materials	150	
Jigs	Provides support to bots during construction	500	

3.1.3.2 Transportation of materials and assets to construction locations

The Shack Transport Robot (STR) will help in the transportation of materials and assets to the construction locations from the automation shack. It will act as a storage unit for the external construction bot for the construction process. (*refer to 5.1.5)*

3.2.1 Atmosphere and Climate

- Oxygen will be produced and repurposed using **Ilmenite**, an oxide of iron and titanium found on the Luna. Ilmenite being weakly magnetic will be removed from the Lunar regolith by magnetic beneficiation.
- On heating it to around **1,000°C** with hydrogen reduces it to water, iron metal and titanium oxide. $FeTiO_3 + H_2$ --- > $Fe + TiO_2 + H_2O$

- The source for producing and repurposing water and oxygen will be the same.
- Some portion of the water produced during the decomposition of ilmenite will be electrolysed to produce oxygen and hydrogen which will be recycled. **8-10 wt% mass of oxygen per mass of ilmenite may be achievable.**
- Titanium oxide will be used as a water filter in the treatment process (refer to 3.2.4) and Iron will be used in the industrial activities.

$Molar\ mass\ of\ ilmenite\ =\ 151.7\ grams/mole\ =\ 0.1517\ kilograms/mole$

We know, $Moles\ =\ Given\ mass/Molar\ Mass$

$=>\ 1000\ grams/151.7\ grams\ =\ 6.6\ moles.$

$We\ start\ with\ 6.6\ x\ FeTiO3\ which\ means\ we\ need\ to\ produce\ 6.6\ moles\ of\ water.$

$Molar\ mass\ of\ water\ =\ 18.0\ grams/mole$

$Total\ mass\ of\ water\ produced\ =\ 6.6\ x\ 18.0\ =\ 119\ grams\ (approx)$

$Total\ mass\ of\ breathable\ oxygen\ produced\ =\ 106\ grams$

By cracking 1 kg ilmenite, 119 grams of water and 106 grams of breathable oxygen is produced.

- In order to maximise efficiency, by minimising cost and effort, it is essential to recycle the CO_2 produced upon respiration within the habitat. This CO_2 needs to be expelled from the habitat to maintain constant pressure composition within.
- Inert gases due to their unique properties can be easily separated, however, O_2 and CO_2 are hard to separate. **The gas diffusion coefficient of the CO_2 - O_2 binary pair at about 20°C, is 0.153 and 0.193 cm^2/s respectively.** Due to the difference being quite small, the separation technique must have high selectivity, however, it should not compromise on the permeability to ensure minimum fluctuation in the interior pressure
- **Zeolite membranes** which selectively separate molecules based on pore size and polarity will be used for the separation process.
- To recreate earth-like conditions, the amount of oxygen will be increased slightly to cancel out the ill effects of low pressure.
- The temperature regulation will include **mechanical thermostats and radiators.**
- Overall conditions will be maintained by the **Heating, Ventilation and Air conditioning system (HVAC)** which will be linked to the humidifiers and dehumidifiers, in each house.
- **Centrifugal compressors** will be used for air regulation. Centrifugal force is used by radial blades to spin and draw air in, increasing pressure and creating kinetic energy. To maximise air compression, it is feasible to exploit the kinetic air produced during this movement.
- The Caddys will be repurposed to store the gases and will be connected to the compressors.
- **Vacuum pumps** will be used for creating a pressure difference to create winds.

Table 3.2.1 *Atmospheric Condition*

Wind speed	Speed of **15.5 - 20 mph, 7-9 m/s**
Atmospheric Pressure	0.8 Earth Sea Level (81.06 kPa)

Table 3.2.2 *Season Maintenance*

Seasons	Temperature	Humidity	Duration
Summer	22-28 °C	37-40%	4 months
Spring	18-22 °C	32-35%	2.5 months
Winter	12-17 °C	25-30%	3.5 months
Autumn	19-20°C	35-37%	2 months

- The pipes carrying the gases will be replenished by directly connecting them to the Caddys which will be stored in the area below the docking ports. These will be automated with sensors installed in the walls which will detect the air composition and pressure and based on the readings, it will simulate a response from the mainframe control room which will then direct the Caddys to pump air according to the requirements.
- The control room will keep track of the plant growth and will plot the course of action for the agricultural bots accordingly.

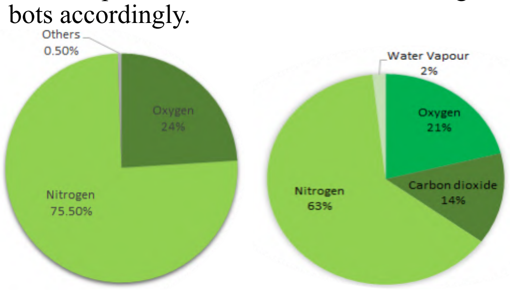
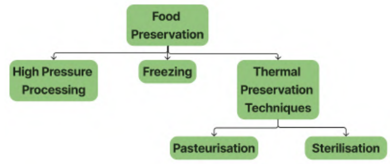


Fig 3.2.1 *Air Composition for Agricultural & Residential Sector*

3.2.2 Agriculture/Food Acquisition:

- The agriculture sector will be located at the apex of the elliptical surface of the settlement.
- The mechanism of **Fogponics** will be used for agriculture.
- Fogponics will be carried out in agricultural shelves. **Small, extendable robotic arms** are present below each shelf, to carry out agriculture processes using specialised farming tools.
- Fog will be supplied to the plants misted out from pipes underneath each shelf. The fog will be enriched with nutrients such as molybdenum.
- Overall supervision will be carried out by sensors present in the arms which will identify the crops that have decayed. They will transmit the information to control centres who will take the necessary measures.
- To get rid of unwanted diseases or viruses, small doses of **hydrogen peroxide** will be sprayed from time to time.
- Following each harvest, some food will be reserved, packaged, and stored in case of any food shortages.
- Specialised led lights will be used ranging from **400-700 nm** in wavelength and will consist of Blue & Red lights.
- **High pressure processing** will be used for processing food. It kills microorganisms through pressure without the use of heat or additives.
- The food will be frozen for storage and thermal preservation techniques including pasteurisation and sterilisation will be used.



Flowchart 3.2.3 *Food Preservation*

- In-vitro meat fertilisation will increase options for the consumers.
- Fermentation Vessels (FVs) present in the food production area will produce alcohol products such as beer. These shall be present near the food processing areas. Health deficits will be treated with dietary products like protein bars, multivitamins, and supplements like chlorella.
- **Almond milk and soy milk** will be used for deriving dairy products in the settlement.
- Due to its superior strength-to-weight ratio, **bio-polyethylene terephthalate** will be used to package the food. After every harvest, a group of 5–10 trained individuals will package the food before it is delivered.
- Farming storehouses will be located in the industrial and residential sectors of the settlement. Food will be delivered to these storehouses by transportation robots. These robots would then transfer the food to retail regions located in the residential sectors. The delivery drones will finally deliver them to residential households.

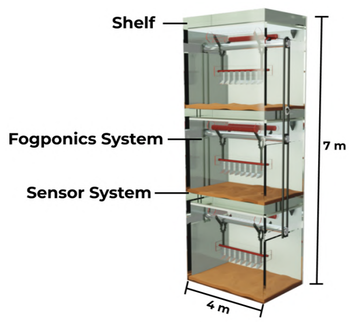


Fig 3.2.4 *Agriculture Bot*

Sources Of Consumables :

- The primary products obtained from the fogponic systems would be herbs, fruits, vegetables, pulses and spices. Additionally, tea, sugar, coffee & almonds would also be derived.
- Alcoholic drinks will be obtained from the Fermentation Vessels. Meat and Eggs will be produced through in-vitro meat fertilisation while almond milk will be extracted on the settlement itself.
- Commodities and other food products like salt, chocolate, medicines and other supplements will be imported from Earth. Water will be produced using Ilmenite.

3.2.3 Electrical Power Generation

3.2.3.1 Main Power Sources

3.2.3.1.1 Primary Power Source

- The primary source of energy will be **multi-junction photovoltaic solar cells.**

- The passivated emitter and rear contact solar panels are modified solar cells with crystallised silicon. The **96-cell monocrystalline solar panels** minimise the energy loss and increase the energy production by 6 to 12%, making them more efficient than regular panels.
- Since solar panels typically produce 50% (approx) less power due to their curvature in the structure, external solar panels have been used.

3.2.3.1.2 Secondary Power Source

- **Syngas** will be used as a secondary source of power. Heat and electricity will be produced by syngas combustion and later will be converted to other additional fuels.
- This production process is interlinked with the by-products produced during blackwater treatment. The solid carbon obtained from the carbon dioxide produced during the aerobic respiration of faeces will be converted to syngas under a controlled amount of oxidants in a gasifier. (refer to 3.2.4)

3.2.3.1.3 Tertiary Power Source

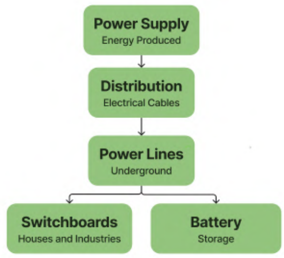
- For tertiary sources of energy, **sulfur lithium batteries** will be used. These batteries will be connected to solar panels. The energy produced by this will be sent to all households. The surplus energy produced will then be transported back to the batteries through wires.
- In this way, the surplus energy produced will be stored in batteries and used only when required. They shall be kept in the area allocated to the power generation sector.

3.2.3.2 Production & Storage Of Power Sources

- Batteries will be manufactured on the settlement itself. **Lithium and aluminium** will be extracted from the Luna, while sulphur will be shipped from Earth. To successfully manufacture sulphur lithium batteries, metallic lithium will serve as the negative electrode, aluminium as the electrolyte and sulphur as the positive electrode.
- After the batteries are manufactured in the industrial area, the transportation robot will move them to the power generation sector. (*refer to 7.1.1)*
- Power will be transmitted in copper wires in the form of High Voltage Direct Current, avoiding the Conductor Skin Effect.

Table 3.2.3 *Energy Requirements*

Sectors	Energy required (kWh/day)
Farm Areas	196,594
Residential	56,912
Automation systems	78,000
Ports/docks	135,600
Communication	127,766
Manufacturing	386,043
Contingency	86,593
Miscellaneous	2,168
Total	**954,686**



Flowchart 3.2.5 *Power Supply Chart*

3.2.4.1 Water Management

- Water supply will be provided by the decomposition of Ilmenite (refer to 3.2.1) and will be used for residential purposes and other purposes like agriculture, industry, extraction, recreation, etc.
- Water will be supplied directly from the Caddys to all the areas by capsule piping system. **CPVC** (Chlorinated Polyvinyl Chloride) pipes whose diameter can be modified as per use, has a high temperature and corrosion resistance will be used for distributing water throughout the settlement.

3.2.4.2 Water Distribution

Table 3.2.4 *Water Consumption*

Water Distribution	Approximate Qty (litres/day)
Residential Areas	1,180,000
Industrial Areas	250,000
Agricultural Areas	91,744
Fire Fighting	50,000
Back Up	125,000
Total	**1,696,744**

Daily Requirement = Water Requirement per person per day (average) * population + water for industrial, agricultural and research purposes + water for contingency measures

3.2.4.3 Water storage

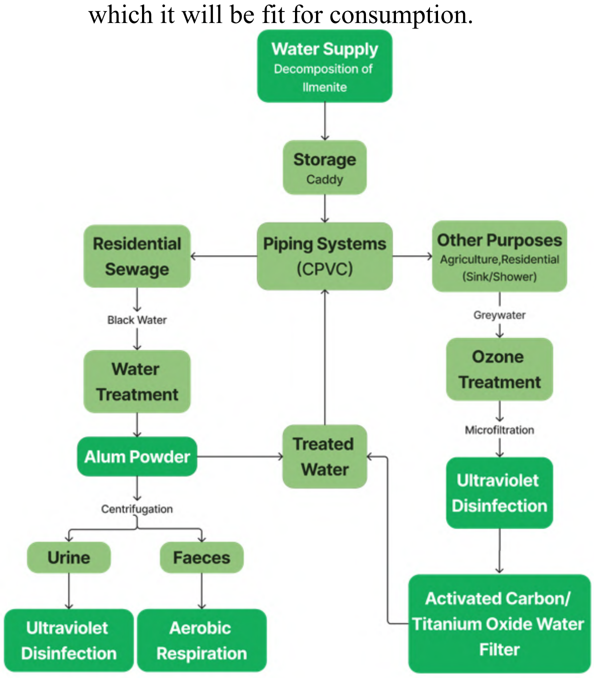
- Caddys will be repurposed for storage of water. One Caddy can hold up to 190000 litres (approx). 9 Caddys would be able to store the daily water requirement. 242 Caddys would store the water required monthly.

3.2.4.4 Water Treatment

- The used water will be treated and recycled for reuse to avoid wastage.
  - **Blackwater** (sewage from residential areas) will initially be treated with al**um powder** which acts as a flocculant where the heavy particles of dissolved alum deposit on the suspended bigger size particles in blackwater and settle down at the bottom. In order to make alum powder, we will extract aluminium and sulphur from the lunar ores.
  - It will then go through a centrifugation procedure to separate the urine from the faeces.
  - The urine is subsequently subjected to **ultraviolet disinfection**, while the faeces is subjected to **aerobic respiration**. The

carbon dioxide generated from aerobic respiration can be used in power production.

- The urine that has been treated can be used in agriculture as a **fertiliser**, if needed and the faeces matter will be used for **vermicomposting**.
- **Greywater** (water from residential areas, agriculture, etc) will be treated with Ozone which, being a powerful oxidising agent, produces biocide that has the capability of destroying all harmful bacteria.
- Subsequently, the greywater will be treated using **microfiltration and reverse osmosis**.
- To further destroy the germs, it will be subjected to **ultraviolet disinfection.**
- Finally, it will be filtered using an activated **carbon/titanium oxide water filter** after which it will be fit for consumption.



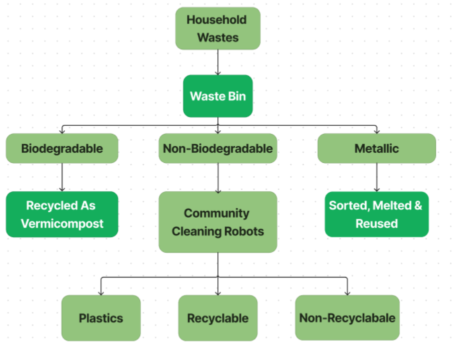
Flowchart 3.2.6 *Water Management*

3.2.5 Waste Management
3.2.5.1 Waste Collection

- The designing and installation of sewer systems will be designed using concrete, clay, steel and plastic (HDPE and PVC).
- All households will have a **Waste bin**. These bins will have two types of sensors; a **metal detecting** sensor and **IR** sensor, interfaced with the microcontroller which will help in commanding the lid of the system.
- These shall segregate the waste into **biodegradable**, **non biodegradable** and **metallic** wastes. The mechanism is activated when the waste material is placed on top of the lid.
- The three cases in this are as follows:
  a) **Metal Detector Activation :** Lid tilts towards the metallic waste section.
  b) **IR Sensor Activation** : Lid tilts towards the biodegradable bin.
  c) **No Sensor Activation :** The garbage might be plastic, glass, etc. The lid will tilt toward the non-biodegradable bin.

3.2.5.2 Waste Processing
3.2.5.2.1 Household Waste Processing

- The biodegradable waste will be recycled to produce vermicompost.
- Metallic waste will be **sorted**, melted and reused.
- The non-biodegradable waste will be taken by the **community cleaning robot**. It shall be segregated into **plastics**, **recyclable** and **non recyclable** waste.
- All plastics will be **separated** and sorted using NIR sensors.
- Ideonella sakaiensis and other plastic eating bacteria will be used to break the plastic waste down, and then will be recycled.



Flowchart 3.2.7 *Waste Management*

3.2.6 External & Internal Communications
3.2.6.1 External Communication

- The primary medium for external communication will be **Laser communication**. N slit interferometer lasers would be used for external communication.
- The communication system would comprise two parts **- the emitter and the receiver.** Both of these emitters and receivers will be present on Earth and the settlement. The data transmissions will be downlinked to the ground telescopes.
- **2 ground stations will be present in the controlling headquarters and 4 satellites in the sun synchronous orbit.**
- As a backup, Ka band radio transceivers will be put near the ports of Astrum.
- Planning for the future, our external communication system will be able to connect with other settlements.

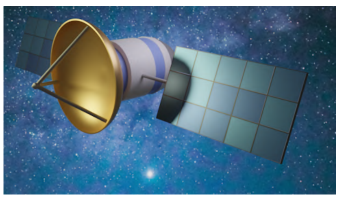


Fig 3.2.10 *External Communication Satellite*

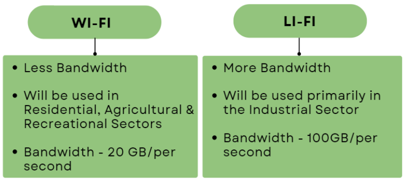
3.2.6.2 Internal Communication
3.2.6.2.1 Servers

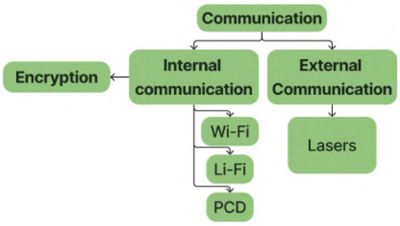
- The backend server system placed on Astrum will help facilitate Internal Communication. All internal communication will be end-to-end encrypted .

- Since communication is vital to our settlement we will also be having a backup server, which will be used in cases of emergency. Servers will be water cooled to prevent overheating.

3.2.6.2.2 Wi-Fi & Li-Fi

Keeping in mind security, privacy, transmission range, speed & power consumption, we have chosen **WiFi & LiFi** as our sources of wireless communication.





Flowchart 3.2.11 *Communications*

3.2.6.2.3 PCD

The **PCD** will be used to facilitate personalised communication. *(refer 5.3.3.1)*

- It will measure body parameters like brain waves, stress levels and body movements.
- It will have in-built bluetooth and Wi-Fi so that people can receive/host calls. People will be updated with news and weather updates through regular notifications.
- Additionally, it will provide users with choices of using AR to run games, play music and videos.

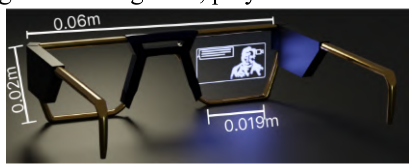


Fig 3.2.12 *PCD*

3.2.7 Internal Transportation Systems

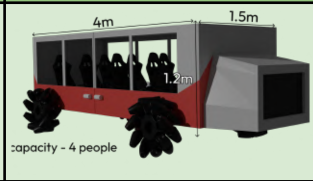
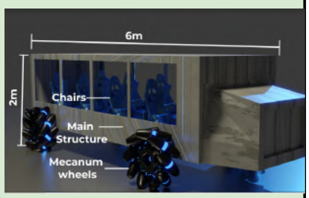
3.2.7.1 Vehicles

- In order to ensure safety and prevent accidents, vehicles would be automated. In order to apply brakes more efficiently in low gravity areas, we will be using the **concept of electromagnetism and ferromagnetism.** The lanes would be made of **Nickel, a ferromagnet** and will be coated with **a layer of teflon, an insulator.**
- The chassis of the vehicle will have suspended **electromagnets attached to it which won't be fully fixed and would have a little freedom of motion.** Whenever the brakes are applied, electricity would be passed through the electromagnets to activate them. This will hence slow the speed of the wheels and finally halt the vehicle.
- The energy for the activation of the electromagnets would be taken from the stored energy while charging the vehicle.

3.2.7.2 Walking

- There will be a special shoe mechanism to help residents to mobilise, move around the settlement. The shoes would have a non-burstable, compressible airbag attached to the bottom which would provide paramount comfort.
- While walking, whenever pressure would be exerted on the ground, **the airbags would repulse in the opposite direction and the momentum exerted would be absorbed by them**, making it easier for the residents to move around.

Table 3.2.5 *Table For Transportation Vehicles*

Vehicle	Description	Model
Emergency Vehicle	• Capacity: 7 ppl •Medical bots present for instant tests *(refer to 5.3.1)*	
Vaina	• Capacity: 10 people • Qty: 350 in each ellipsoid • Automated with ultrasonic sensors for slowing down & ensuring speed limit.	

3.2.7.2 Routing

Table 3.2.6 *Table For Lanes Compositions*

	Description	Width
Fitness Lane	• Contained roughened up pathways to provide more friction	1.3m
Pod Lane	• Provides transport for families through Vaina	1.5m
Service Lane	• For transportation robots to transport various goods	1m
Emergency Lane	• Used in emergency situations by fire trucks, medical robots etc. • Will be located underground	2.3m
Travelators	• Suitable for elderly people • Has walkways with a rough surface to enhance friction	1m

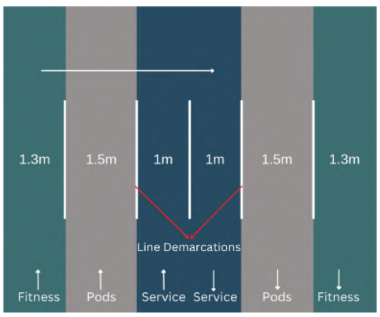


Fig 3.2.13 *Transportation Lanes*

3.2.8 Day and Night Cycle

- To control the lighting, we will be using electrochromic glass with adhesive smart film.
- The duration of day and night will be controlled by the control stations at the docking port. In individual homes, people can control the lighting through their smart films for comfortable lighting.
- During the time when the settlement is facing away from the sun, we will be using a very powerful **Coelux Skylight**. This light creates the illusion of day.

Table 3.2.7 *Table For Season Durations*

Seasons	Day	Night
Spring	12 hours	12 hours
Summer	13 hours	10 hours
Fall	11 hours	13 hours
Winter	10 hours	14 hours

3.2.9 Initial Quantities

Table 3.2.8 *Table For Caddy Requirements*

Component	Caddys Required (per day)
Water	9
Air	10
Liquid Consumable	20
Solid Consumables	63
Communication	1
Vehicles	55

3.2.10 Utility Routes

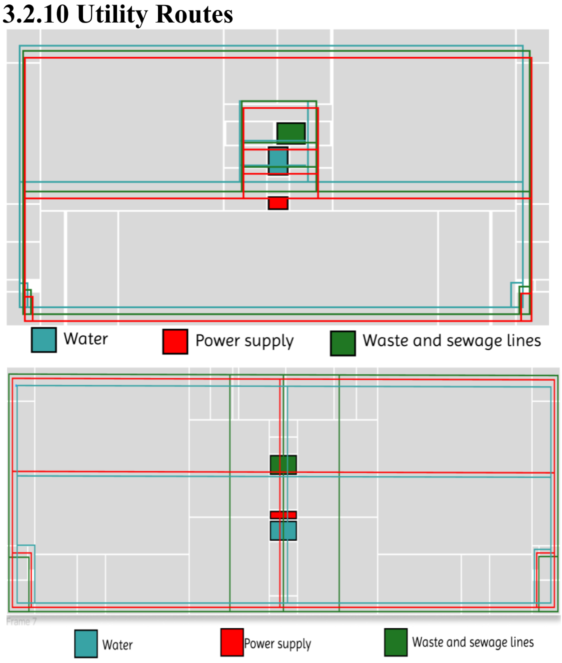


Fig 3.2.14 *Utility Routes*

3.3.1 External Construction

The construction of the hull component, wireframe and exterior structure will be carried out by the **External Construction Robot (ECR)**.

- First, the Shack Transport Robot (STR) transports the required materials and tools from the automation shack to the ECR. The STR will automatically dock with the ECR.
- The ECR will start 3D printing the tiles and assemble them between the trusses. Cameras will be installed on the robot itself, to allow for human supervision periodically.

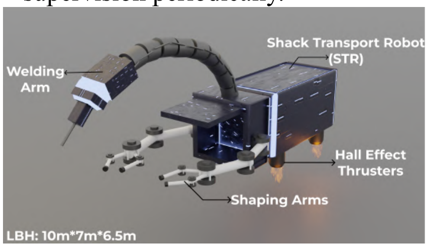


Figure 3.3.1 *External Construction Robot*

3.3.2 Internal Construction

The **Interior Construction Robots** will carry out the internal assembly. This will cover assembly of control centres, residential houses, and numerous other buildings.*(refer to 5.1.6)*

- There are 4 interior construction robots, the Ground Layering Robot (GLR), Contour Crafting Robots, and the Interior Finishing Robot (IFR). *(refer to 5.1.6)*
- The GLR constructs the ground layers of the settlement.
- CCR-1 robot 3D print buildings
- CCR-2 focuses on assembling utilities, such as footpaths
- The IFR completes the final furnishing of the settlement.
- The construction processes get started from the GLR, which constructs the basic ground areas of the settlement, followed by the Contour Crafting Robots, and finished by the IFR.

3.3.3 Jigs And Trusses

Trusses allow robots to cover large distances of area quickly to allow for efficient work. Robots use these trusses to move around the exterior part of settlement The jigs are built inside the trusses, and external robots clasp onto these jigs to traverse the area. To stop the robots at specific points, electromagnets will be activated. *(refer to 5.1.3)*

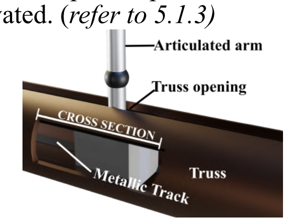


Fig 3.3.2 *Jigs*

3.4 MRO Docks

The MRO Docks will be used to attend to visiting spaceships and space tugs. Their primary objective will be to repair and maintain the vehicle docking at the port. These will be located in between the two semi ellipsoids, as this will provide easier access for spacecraft.

- The docking rooms will have a volume of 48000 metre cube, and will be equipped with an automated repair system to give repair and maintenance to the spaceships and space tugs. Additional rooms will also be present in the same area for manufacturing interplanetary spaceships. *(refer to 5.5)*

- Specialised adjustable roofs will be used, which will modify the docking and manufacturing rooms according to the spaceship's dimensions. Lunar landing rovers will be assembled here, to facilitate extraction and mining of materials found on the moon such as lunar regolith & aluminium. These manufacturing rooms would also be repurposed for assembly of robots.
- MRO docks will receive the gradually incoming transient population and the transportation of goods from Earth, moon and asteroids will also be delivered here (through Caddys).
- For operating in the long term, 5 docking rooms will be utilised for repair and maintenance of space tugs, while 3 rooms will be used for manufacturing of ships. These would be increased periodically as the transient population starts to come in, and the rate of manufacturing increases.

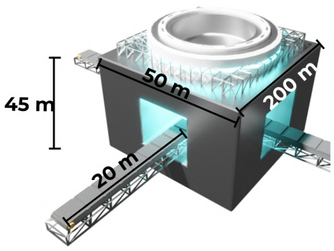


Fig 3.4.1 *MRO Dock*

3.5 Expansion Of Community Infrastructure

As the ellipsoids increase in future, they will have their own independent sustainable communities with a flexible, operational infrastructure. A well-planned urban community that allows for walking, biking, and recreation in places that are distributed throughout the entire settlement would be accommodated. Land area and automation services would be increased and innovative manufacturing, processing techniques will be incorporated. Internal communication would be made more personalised using 3D Holographic watches which offer a unique and stylish design, easy to read displays, durability and energy efficiency.

Automated appliances

- As the population increases, more bots will be designed/provided for home automation like assistance with cleaning and kitchen chores.
- Multitasking robots would carry out surveillance, inspection and assistance in emergency situations. Research and development capacity would be developed further.

Agriculture

- The network of fogponics would be made more extensive to boost the production of food and increase the agricultural output.
- LPWANs and LoRaWAN-compatible sensors would be used for gathering data about the agricultural conditions allowing greater precision and avoiding conditions that lead to drought conditions.
- The agricultural area would be made more localised by shifting the agriculture sector closer to the residential area, hence reducing food miles.

Water Management systems

- In order to streamline the operations, the water piping network would be revised and expanded further to ensure the supply of water to every dwelling unit.
- Smart metering which enables a utility to automate the metre-reading process and generates sensor data that can provide visibility into the efficacy of the distribution network would be deployed.
- Using this sensor data and the features of the LoRaWAN-enabled smart water management solution, the pumps would be remotely turned on or off to regulate the flow of water through the water transport system. LoRaWAN sensors would be embedded throughout the pump control system to optimise the water flow, reduce the pump rates, detect leaks and line faults, minimise water loss due to leakage and save on energy expenses by lowering pumping demands.
- Self-healing pipes that can adjust their size and wall thickness based on temperature, pressure and velocity would be used to meet the specific requirements of each segment of the settlement.

Power

- As the incoming transient population gradually increases, the existing power supply systems and solar panel installations would be periodically expanded to ensure sustainability.
- The waste management system will be expanded to produce biogas from organic wastes. An internal combustion engine will produce electricity from the biogas. This will allow for an eco-friendly method of electricity production.
- Microbial fuel cells, which utilise bacterias and microbes as catalysts, to produce electricity from waste water will act as an additional method.
- In case of extreme shortages of supply of electricity and power, CAES (Compromised Air Energy Storage) will be located in the industrial sector for emergency use. In this system, the energy will be stored when the energy demands are low and would be released when the energy demands are more. This will be valuable during sudden shortages of electricity on the settlement.

Public Transit and Transportation

- Public transit and micro-transit would be made efficient so that people can go wherever they want to.
- The current vehicle options would be diversified further to provide additional colour, design and style options.
- With the expansion, as the distance between the units of the settlement would increase, cycles and personalised vehicles would be introduced for personal transport.
- A concept inspired by the hyperloop rail technology would be looked into for longer haul transportation. Lidar would help in calculating the rail positions, collect real-time data on obstacles on tracks, flag future maintenance issues, etc.

4.1 Community Design

The residential area will be divided into **5 segments**, 2 segments will be of the first community map (174 x 316) and the remaining 3 will be of the second community map (174 x 471).

4.1.1 Community Layout

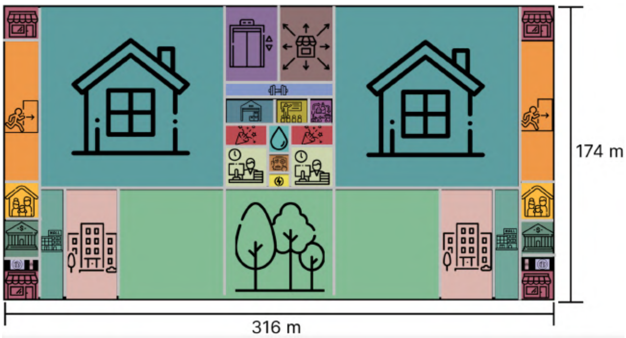


Fig 4.1.1.1 *Residential Community Layout 1*

Fig 4.1.1.2 *Residential Community Layout 2*

Table 4.1.1.1 *Community Layout Legend*

Symbol	Key	Layout 1			Layout 2		
		Area(ft^2)	**Unit**	**Area(m^2)/ unit**	**Area(ft^2)**	**UNIT**	**Area(m^2)/ unit**
	Greenery	12114	1	12114	18090	4	4522
	Office	1210	2	605	1810	2	905
	Malls	2010	2	1005	3015	2	1507
	Shop	1450	4	362	2170	4	542
	Recreation	583	2	290	870	2	435
	Hospital	400	2	200	600	2	300
	Schools	180	1	180	260	1	260
	Future Expansions	1333	1	1333	1440	1	1440
	Elevators	1290	1	1290	1404	1	1404
	Banks	960	2	480	1430	2	715
	Restaurant	120	2	60	180	2	90
	Transportation (roads)	1537	1	1537	3195	1	3195
	Miscellaneous	3876	2	1938	5790	2	2895

	Control Centre	123	1	123	190	1	190
	Storage	370	1	370	560	1	560
	Evacuation	3086	1	3086	4600	1	4600
	Gym	605	1	605	900	1	900
	Water Treatment	225	1	225	340	1	340
	Power	110	1	110	160	1	160
	Condominium	22315	2	11157	33330	2	16665
	Town Houses	850	2	425	1280	2	640
	Waste Treatment	237	1	237	340	1	340

4.1.2 Consumables

Table 4.1.2.1 *Consumables*

Consumables (per month)	Quantities per person per year (in kg)	Percentage	Anticipated quantities per year at IOC (in kg)	Source
Tea	17	97	129,447	Fogponics *(refer to 3.2.2)*
Coffee	21.5	80	135,020	Fogponics
Sugar	25	100	196,250	Fogponics
Salt	2	100	15,700	CASSSCs
Wheat	76.5	100	600,525	Fogponics
Rice	109.5	100	859,575	Fogponics
Milk	94.5	100	741,825	Fogponics (soy milk)
Alcoholic drinks (L)	18	60	84,780	Fermentation
Fruits	45	100	353,250	Fogponics
Vegetables	146	100	1,146,100	Fogponics
Cooking Oil	6	100	47,100	Import
Meat	62	70	340,690	In-vitro fertilisation
Juice	19	80	119,320	Fogponics
Pulses	44	100	345,400	Fogponics
Spices	2.4	100	18,840	Import
Water(L)	1460	100	11461000	Produced by decomposition of Ilmenite

				(refer to 3.2.4.1)
Eggs	15	90	105975	In-vitro fertilisation
Almonds	3	100	23550	Fogponics

These consumables will be **transported** from the Earth to the settlement using **Caddies**.

4.1.3 Consumer Goods

Table 4.1.3.1 *Consumer Goods*

Goods	Per Person/Per Year	Source
Paper (sheets)	2,500	Import
Pens	60	Import
Toothbrush & paste	4	Import
Toilet/Kitchen roll (No. of rolls)	37 rolls (1 roll=1000 sheets)	Import
Footwear	4	Import
Shampoo (L)	11 units (2.75 L)	Import
Detergent (Kg)	3	Import
Soap (L)	9	Import
Garment(Mts)	160	Import
Blanket	2	Import
Conditioner (L)	10 units (2 L)	Import
Medicines	As per requirement	Import
Supplements (sanitary pads, etc.)	As per requirement	Import

4.2 Residential Design

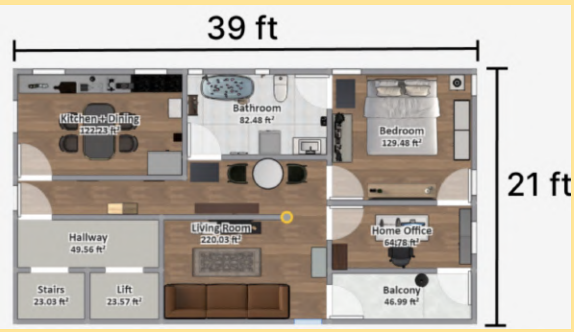
4.2.1 Interior and Exterior Designs of Permanent Residential Facilities

Design considerations in different g levels:

Table 4.2.1.1 *Interior and Exterior Designs*

Interior Design

Standard 1BHK



Area: 825ft^2
Ideal for: individuals
Floors: 4
Total apartments: 4275
Total buildings: 1069

Fig 4.2.1.1 *Standard 1BHK Floor Plan*

Exterior Design

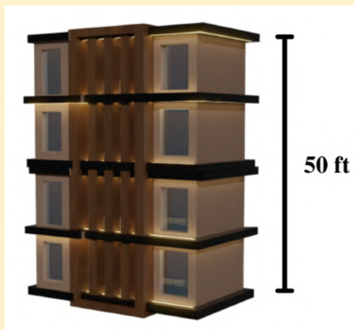
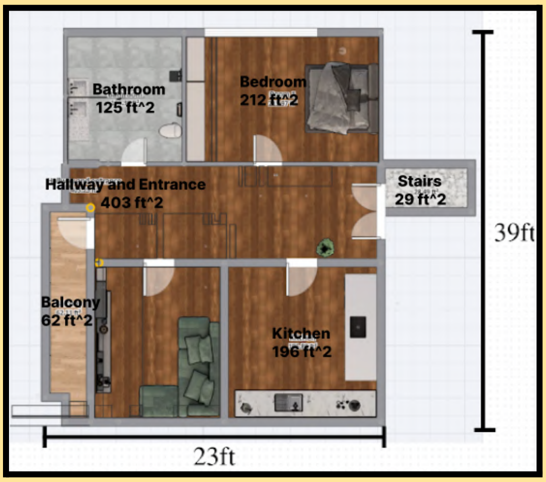


Fig 4.2.1.2 *Standard 1BHK Exterior*

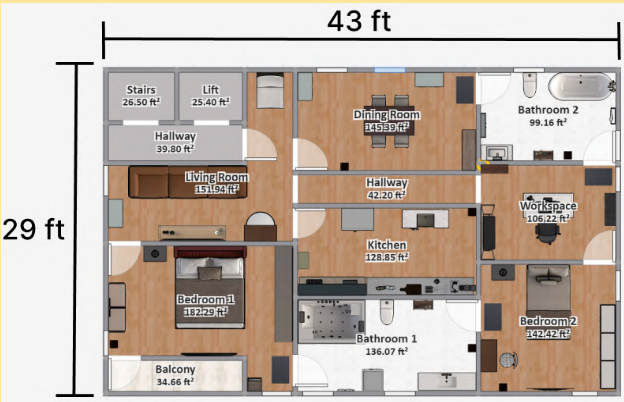


Capsule 1BHK

Area: 825ft^2
Ideal for: transient population (individuals)
Floors: 4
Apartments: 350
Building: 88

Fig 4.2.1.3 *Capsule 1BHK Floor Plan*

Fig 4.2.1.4 *Capsule 1BHK Exterior*



Deluxe 1BHK1

Area: 1250ft^2
Ideal for: Married couples
Floors: 4
Total apartments: 1375
Total buildings: 344

Fig 4.2.1.5 *Deluxe 1BHK Floor Plan*

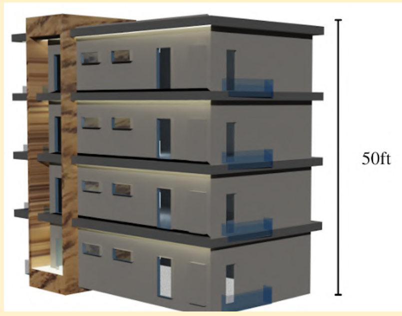
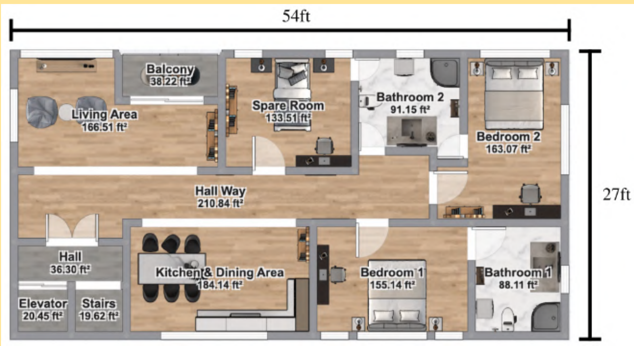


Fig 4.2.1.6 *Deluxe 1BHK Exterior*



King Standard 2BHK

Area: 1450ft^2
Ideal for: Married couples with 1 child
Floors: 4
Total apartments: 55
Total buildings: 14

Fig 4.2.1.7 *King Standard 2BHK Floor plan*

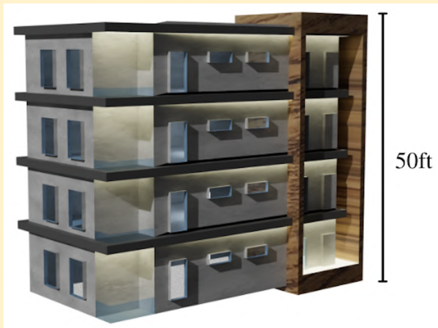
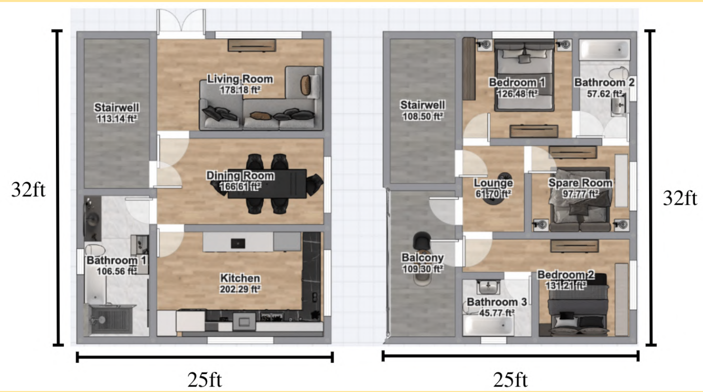


Fig 4.2.1.8 *King Standard 2BHK Exterior*



King Deluxe 2BHK

Area: 800ft^2
Ideal for: Married couples with 2 kids
Floors: 2
Total apartments: 40

Fig 4.2.1.9 *King Deluxe 2BHK Floor plan*

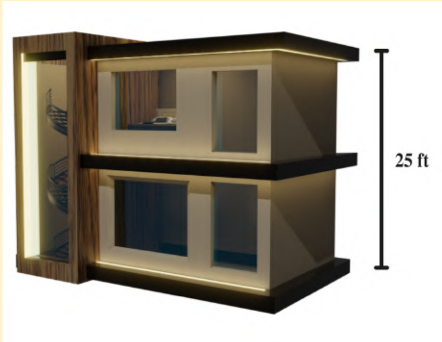
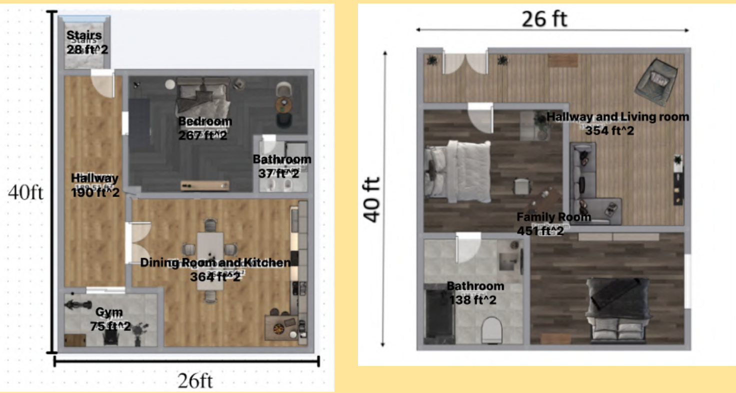


Fig 4.2.1.10 *King Deluxe 2BHK Exterior*



Family Suite 2BHK

Area: 910ft^2
Ideal for: Family with upto three kids
Floors: 2
Total Apartments: 20

Fig 4.2.1.11 *Family Suite 2BHK Floor plan*

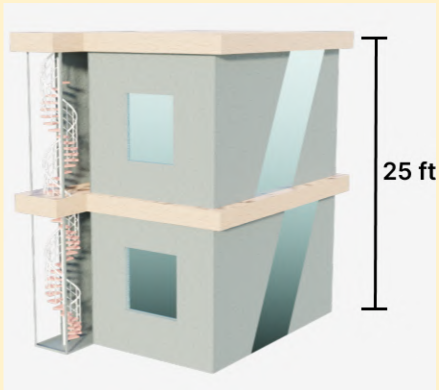
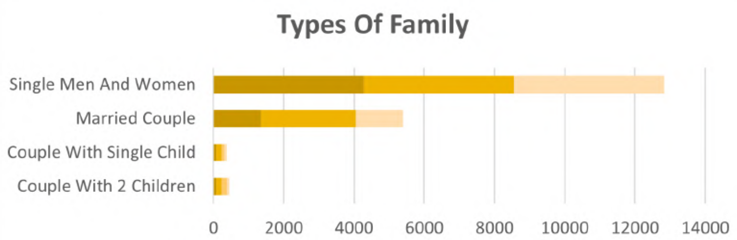


Fig 4.2.1.12 *Family Suite 2BHK Floor plan*



	Couple With 2 Children	Couple With Single Child	Married Couple	Single Men And Women
FAMILIES	75	75	1350	4275
NO. OF ADULTS	150	150	2700	4275
NO. OF KIDS	150	75	0	0
NO. OF HOUSES	75	75	1350	4275

Fig 4.2.1.13 *Types of Family*

4.2.3 Furniture, Appliances, and its Sources

The settlement will be furnished with **inflatable furniture**. It would make it easier to **import** the designed furniture from the earth while also saving space. Upon reaching the settlement, the furniture will be inflated with oxygen in the **industrial area**, and then will be supplied to the residences of the inhabitants.

4.3 Safety Systems

4.3.1 Evacuation and Relocation Plan

Each residential segment would have **airlocks** and people would be **evacuated** to the other segments through these airlocks only. The airlocks will be situated in the area allotted for evacuation in the community maps. The control centres would also act as **safe rooms** in case of emergencies only for a temporary basis.

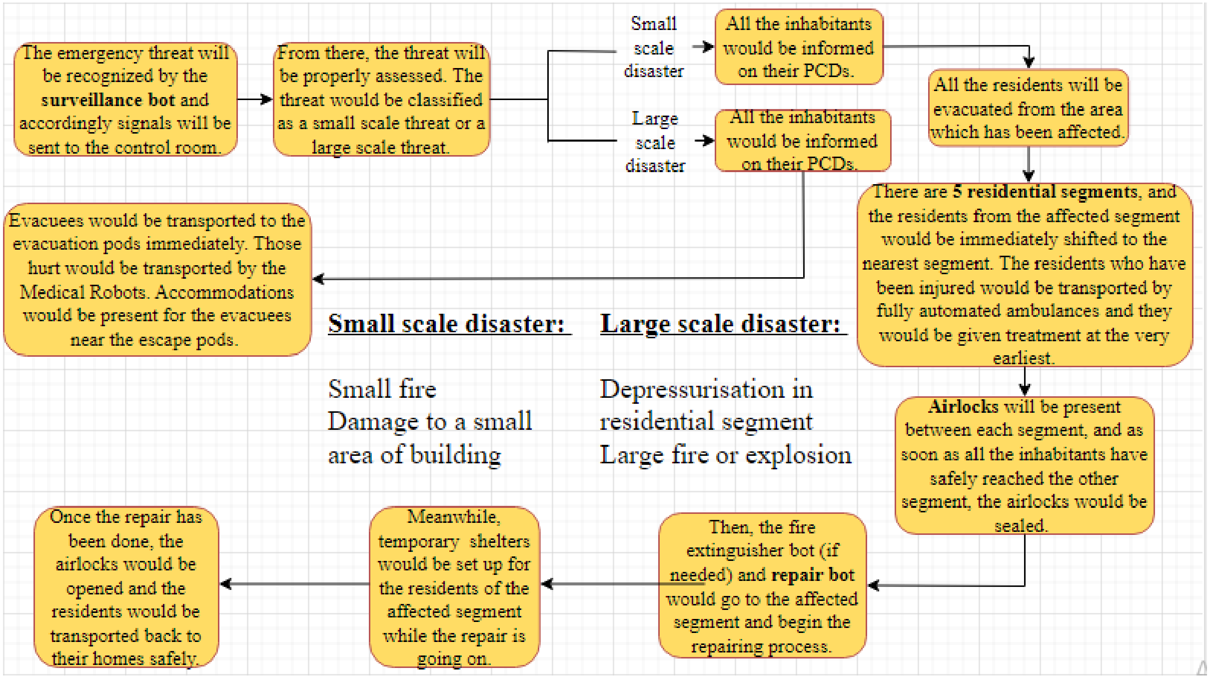
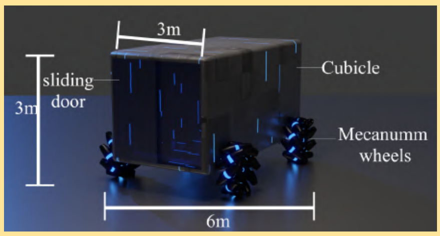


Fig 4.3.1.1 *Evacuation Plan*

Table 4.3.1.1 *Evacuation features in the settlement*		
Emergency Measure	**Features**	**Model**
Evacuation Pod	The evacuation pod will be used in cases of large scale disaster and will enable the transport of both humans and cargo outside areas of artificial gravity incase of emergencies. The pod will be able to seat 4 passengers and 1 crew member. The same pod would be used for human inspection and repair of exterior volumes with robotic arms attached to it which would be able to hold a variety of equipment. These arms will help in exterior repair of rotating volumes. It will be controlled either from inside the pod or from the settlement itself. Quantity- 50 Location- Community warehouse	 **Fig 4.3.1.2** *Evacuation Pod*
Medical Robot	The medical robot will act as an ambulance in Astrum *(refer to 5.3.1)*. Each individual's health will be monitored by their PCD which will send alerts to the medical robot if any medical emergency occurs, and the medical robot will come to the resident. This bot will also help in the evacuation process. It will help in transporting the injured residents to other segments, and also provide first aid to them at the earliest. Quantity- 350 (70 per residential segment) Location- Throughout the residential segments	 **Fig 4.3.1.2** *Medical Robot*

4.3.2.1 Spacesuit Design

The features in the hard-shelled spacesuits are as follows:

Table 4.3.2.1.1 *Additional features in spacesuits*

Additional Features	Description
Primary Life Support System (PLSS)	Will contain 2 tanks with 800L of oxygen each. The carbon dioxide will be eliminated by the **Contamination Removal Canister**, containing lithium hydroxide. **Contamination removal canister** is a device which contains a filter or a bed of adsorbent material and is used to purify air. The Lithium hydroxide will absorb the carbon dioxide from air, undergo an exothermic reaction and form lithium carbonate. In this manner, all the carbon dioxide would be eliminated. Both the PLSS's liquid and gas cooling loops will be able to reject heat through the **Porous Plate Sublimator**. **Porous plate sublimator** is a heat rejection device used to sublimate substances which consists of a porous plate with a large surface area and a heating element which is used to vaporize solid substances.
Helmet	Made out of polycarbonate, a highly-strengthened plastic. It will contain a gold visor to reflect infrared light, display the astronaut's bodily readings and inform them in the event of an emergency. A foam device is installed to press the astronaut's nose to equalise pressure. For communication, **CCAs (Communications Carrier Assembly)** will be used which is designed to support the transmission and reception of data/voice signals in a communication network and is a circuit board or metal frame that provides a platform for mounting and connecting various components, such as transceivers, optics modules, microphone
EC/HGS (Evaporative Cooling/Heating Glove System)	Enables the astronaut to grip extremely hot or cold (-200F to 200F) objects. Also maintains flexibility in the fingers and wrist.
Wrist Mirrors	Will help to see and operate the **display modules**.
Robotic Arms	Will offer structural & mechanical support for handling heavier loads and arduous maintenance tasks. To remotely control them while wearing a stiff, pressurised space suit, HMI (human-machine interface) will be integrated into the helmet and gloves.
Bladder Layer	Will be composed of a **silicon fabric** which will be supplied from Luna, decreasing the spacesuit's mass and increasing its flexibility.

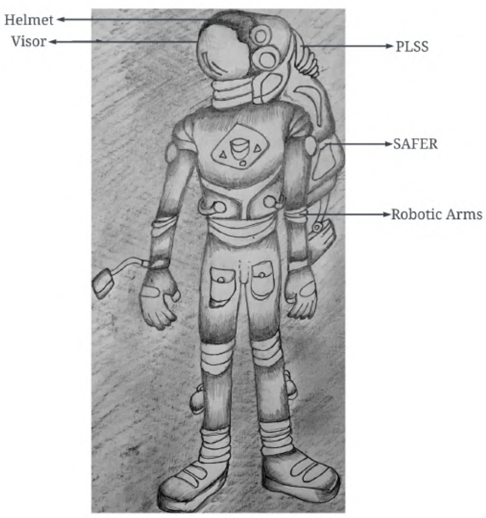


Fig 4.3.2.1.1 *Spacesuit Design*

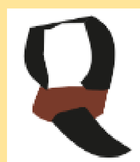
Compared to hard-shelled spacesuits, IVA (Intra Vehicular Activity) spacesuits would be more flexible and comfortable, and will be used for recreational purposes(*refer to 4.4).* For fire and abrasion protection, it will have a three-layer Intravehicular Cover Layer (IVCL) made of Nomex and beta fabric and will be manufactured in the industrial area. (*refer to fig 2.3*)

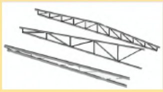
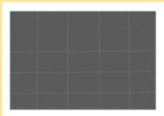
4.3.2.1 Quantity and storage locations

There will be **7850** space suits in the settlement, one for each person. For emergency purposes, there will be 150 extra spacesuits. The total number of spacesuits will be 8000, which will be stored in the **warehouses** located in the 0g Industrial Segment.

4.3.2.3 Safety Equipment

Table 4.3.2.3.1 *Safety Equipment*

Equipment	Description	Model
Tethers	Will be made of silicon	
Clamps	Will be used at each end of the space tether for attachment purposes	

Truss	Will act as a support system for the astronaut outside rotating volumes *(refer to 2.1)*	
Simplified Aid For EVA Rescue (SAFER)	Will be attached to the spacesuit's backpack. Contains 24 small nitrogen thrusters which will be activated to offer free-flying mobility if the astronaut becomes untethered or loses contact with the vessel.	
Padded Walls and Friction Pads	Would be used in microgravity areas to: • lessen the impact of the astronaut colliding with a wall • make walking easier	
Retractable Handrails	Will be made extendable to offer assistance and facilitate movement.	

4.3.3 Protection from Radiation and solar flares

The spacesuits are incorporated with external shields to block extreme radiation. An astronaut will be guided back inside the settlement using the thrusters on the PLSS in case of a sudden solar event flare.

The settlement will be built using a variety of radiation shielding materials to shield the residents from solar flares and other forms of radiation.

Table 4.3.3.1 *Protection from radiation*

Material	Location	Features
HBN	Hull	• Mechanical strength • Space debris protection
Polyethylene boron	Hull	• Neutron Radiation Protection • High-temperature stability
Nextel	Hull	• Fireproofing
Lunar Regolith	Hull	• High energy Solar protons shielding
PEEK	Hull	• Gamma Ray Protection
Perlucor	Window	• Thermal stability • Mechanical Strength
Transparent Spinel Ceramic	Window	• Radiation Protection • Structural Protection
Silicon Aluminum Oxynitride	Window	• Thermal insulation
Transparent Silica Aerogel	Window	• Radiation Protection
Electrochromic glass	Window	• Helps in diffusion of light in order to create day and night cycles

4.3.4 Informing of emergency situations

The emergency would be accessed using the surveillance bots that would be installed in the settlement and would determine if it affects the residents directly or indirectly. For an emergency that will affect the inhabitants directly (eg. fire, explosion, depressurization, hull breach, etc.), a siren would go off in the affected area. There would be allotted lighting in the surveillance bots *(refer to 5.2.7)* installed in Astrum which would inform the habitants about the emergency. Pet bots*(refer to 5.3.7)* and mobile notifications will also alert the residents of the affected area. For an emergency that would not affect the inhabitants directly (eg. system hacking, server breach, food shortage, etc.), the residents would be informed on their PCDs *(refer to 5.3.3.1)* and they would also get a mobile notification. Lightings in the surveillance bots would also be used to inform the residents.

4.4 Recreational Activities

Table 4.4.1 *Recreational activities*

Recreational Activity	Description	Age Criteria
Augmented Reality	PCDs will have an additional feature where augmented reality would be integrated to view virtual notes tagged to specific locations, modified scenes, etc.	13+
Drone-vis	Drone-vis would be synchronised with the PCDs and residents will be able to control the drone through them, giving them a feel of flying.	13+
Spacewalk	Scheduled spacewalks will be available for residents to enjoy for which they will be guided by experts for sightseeing. Training sessions will also be offered. Doffing and donning of the spacesuits will take place in the airlocks *(refer to 2.1.9)*	18+

Virtual Reality	VR rooms will contain VR headsets and treadmills where people can play various types of games, visit concerts & museums, play laser tag, etc.	13+
Floatball	A game of football will be played in low gravity levels with the players' shoes being magnetic and the ball having a tri-axial-accelerometer which measures force and determines the ball's propulsion speed and trajectory. Padded walls will be installed to ensure that no one gets hurt during the game.	All ages
Power Hour	Live fitness shows will be broadcasted in the televisions every week. These shows will be categorised according to difficulty levels and will ensure physical health for everyone.	All ages
Paintball	The famous exercise scene from the movie 'Ender's Game' will be recreated in this activity. This will be played in low gravity areas where obstacles will be floating around, and the players will adhere to the concept of paintball.	13+

4.5 Population Increase

Slowly as time progresses, the population of the settlement will also increase and in order to accommodate them, the number of ellipsoidal spheres will increase (refer to 2.5) and the community DSA will also increase. Certain changes will be made in Astrum in the habitable factors of the settlement to accommodate the increased population.
The following arrangements will be made to provide the necessary amenities and housing for these people:

Table 4.5.1 *Changes in amenities with growing population*

Amenities	Changes in amenities
Food	The network of fogponics would be made more extensive to boost the production of food and increase the agricultural output. The agricultural area would be made more localised by shifting the agriculture sector closer to the residential area, hence reducing food miles. Sensors would be used for gathering data about the agricultural conditions allowing greater precision and avoiding conditions that lead to drought conditions. 15 more internal transportation bots would be manufactured per 2000 person increase in the population for supplying food to all the residents. *(refer to 5.1)*
Permanent residences	Permanent residences would also be built for the increased population in the new ellipsoidal spheres. More bots will be deployed for home automation like assistance with cleaning and kitchen chores. Research and development capacity would be developed further and these robots would be specifically used for research tasks.
Hospitals	A new hospital would be built per 4000 person increase in the population to provide main medical facilities. The hospital would be built in the community map of the new spheres.
Spacesuits	700 more space suits would be manufactured per 2000 person increase.
Schools	A new school would be built per 4000 person increase in the population to provide education to the increased amount of children. This would be built in the new communities.
Recreation	New recreational centres like museums, sightseeing rooms, talent carnivals etc would be built so that the recreational centres don't get too crowded. 1 new recreational centre would be made per 4000 person increase in the population.
Public Transit and Transportation	Public transit and micro-transit would be made efficient so that people can get around wherever it is that they want to go. A concept inspired by the hyperloop rail technology would be looked into for longer haul transportation.

5.1 Construction Of Settlement Structures

5.1.1 Specifications Of Robots

	Robot	Qty	Type	Materials	Coating
1	Bot Maker	30	6-axis articulated arms, 6 axis parallel fixed base	Titanium Grade 4	Titanium Dioxide Paint
2	Hexapus	10	Hall effect thruster mobile body, 6-axis articulated arms	Titanium Grade 4	Titanium Dioxide Paint
3	Wireframe Robot	500	Hall effect thruster mobile body, 6-axis articulated arms	Titanium Grade 5	Kevlar
4	Truss Robot	500	Hall effect thruster mobile body, 6-axis articulated arms	Titanium Grade 5	Kevlar
5	Exterior Construction Robot	400	Jigs based cartesian body, 6 axis articulated arms	Titanium Grade 5	Kevlar
6	Shack Transport Robot	400	Hall effect thruster mobile body, 6-axis articulated arms	Titanium-Tungsten Alloy	Titanium Dioxide Paint
7	Ground Layering Robot	150	4 wheeled mobile body, 6 axis articulated arms	Titanium Grade 5	Titanium Dioxide Paint
8	Contour Crafting Robot-1	75	4 wheeled mobile body, 6 axis articulated arms	Titanium Aluminide	Titanium Dioxide Paint
9	Contour Crafting Robot-2	75	4 wheeled mobile body, 6 axis articulated arms	Titanium Aluminide	Titanium Dioxide Paint
10	Interior Finishing Robot	200	4 wheeled mobile body, 6 axis articulated arms	Silicon, Titanium Grade 5	Titanium Dioxide Paint
11	Transportation Robot	150	12 wheeled mobile body	Copper-Manganese Alloy	Titanium Dioxide Paint
12	External Repair Robot	100	Jigs based cartesian body, 6 axis articulated arms	Titanium Grade 5, Glass	Kevlar
13	Internal Repair Robot	100	4 wheeled mobile body, 6 axis articulated arms	Titanium Grade 5	Titanium Dioxide Paint
15	Agriculture Mechanism	15	6 axis articulated arms	6061 Aluminum Alloy	Titanium Dioxide Paint
16	Medical Robot	350	4 wheeled mobile body	High carbon steel	Titanium Dioxide Paint
17	Surveillance Robot	7500	6 axis parallel fixed base	Electrochromic Glass	Kevlar
18	Personal Cleaning Robot	7500	6 axis parallel fixed base	High carbon steel	Kevlar
19	PCD	7840	Accessory	Glass, Tungsten Oxide	Kevlar
20	Jigs	500	One wheel mobile base, 6 axis articulated mobile joints	Titanium Grade 4	Titanium Dioxide Paint
21	AIt Assistants	N/A	ANI	N/A	N/A

22	Evacuation Pod	50	Hall effect thruster mobile body, 6-axis articulated arms	Titanium Grade 4	Titanium Dioxide Paint
23	MRO Dock	16	N/A	Titanium Grade 5	Kevlar

Table 5.1.1 *Settlement Robots*

5.1.2 Toolkit

Toolkits are present in all the variable ending arms of robots. It holds all components for the variable ending arms to work with, and the arm locks into it to use it when required. The toolkit will consist of the following tools ; a welder, gripping hand, cutter, paint nozzle (IFR), spray nozzle and a screwdriver.

5.1.3 Jigs

The jigs will be support systems that will help in the locomotion of the robots and grip them in place during the construction processes. They will be built with titanium, which has prolonged durability & can withstand enormous pressures. Sizes will vary.

- The jigs will be running throughout the interior of the trusses. They will be cube-like structures that shall be moving with their corners in contact with the surface of the truss.
- If there is a specific location where the jig has to stop, an electric current is passed through it to form an electromagnet at the bottom of the jig. The jig will clamp onto the corner track in order to halt.
- An articulated joint connects the jig to the external robots. This helps the robots to pivot and have multiple degrees of freedom. There is a hole at the top of the truss, so the articulated joint and bot can clasp onto each other.

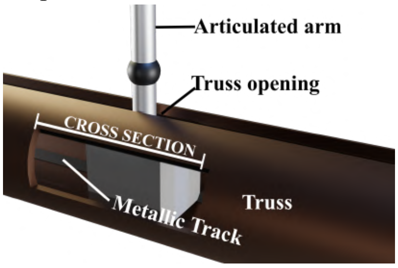


Fig 5.1.1 *Jigs*

5.1.4 Bot Maker

For building all robots, the Bot Maker will be used. It will be present in a room of side 40 meters. Multiple 6-axis robotic arms and a 6-axis circular stationary platform will be there in the room. These robotic arms have 360 degree capability and will be clasped on to the ceiling for greater maneuverability. A 3D printing machine would also be present in the room to print parts if needed.

5.1.5 Exterior Assembly

5.1.5.1 Robots For Initial Construction

5.1.5.1.1 Wireframe Robot (WR)

The Wireframe Robot will have a thin cuboidal shape with 2 rounded edges and a square opening in the front to push out the titanium bars. They will be equipped with hall-effect thrusters to facilitate movement to the construction site, and welding and shaping arms to make the wireframe.

The Shack Transport Robots will primarily transport construction material from the automation shack to the WR, by docking to the docking port of the WR. A power source will be installed in the shack transport bot which, when docked to the WR, will share its power source (*refer to 5.1.5.3)*

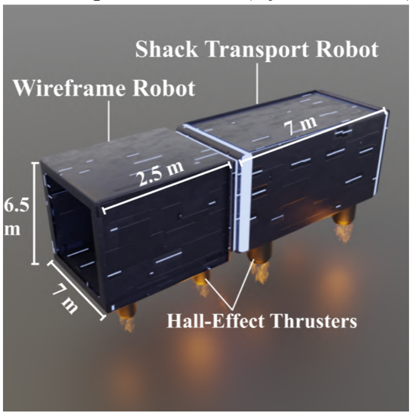


Fig 5.1.2 *Docking Of WR & STR*

5.1.5.1.2 Truss Robot (TR)

The Wireframe Robot will be modified for this.

5.1.5.2 Hexapus

Hexapus is a robot shaped like a hybrid Torus. It will be robotic and shall also contain a docking port. Its function is to construct the spokes for the rotational interfaces and the central shaft in the settlement. The hexapus will be using ionic thrusters for minor movements of the robot

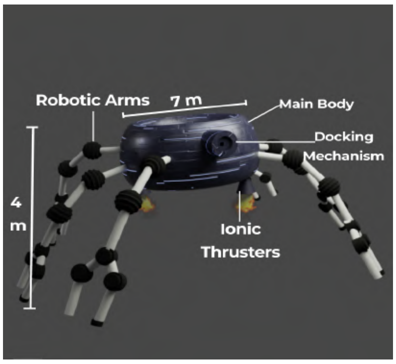


Fig 5.1.3 *Hexapus*

5.1.5.3 Shack Transport Robot (STR)

Shack Transport Robots are cuboidal storage units made of titanium-tungsten alloy (TiW). Its goal is to fetch construction material from the automation shack. The STR will dock onto the WR, and later the ECR for providing storage for the construction process. (*refer to 5.1.5.4 and 5.1.5.1)*. Automated robotic arms will be added to the STR which help it dock to the exterior construction robot properly. The STR will be using Hall-Effect Thrusters.

5.1.5.4 Exterior Construction Robot (ECR)

The exterior construction robot will be repurposed from the Truss Robot. A major modification is that it won't have thrusters, it shall always be located at the site of construction, clasped to the jigs in the trusses. Tiles, used for constructing the outer area of Astrum , are stored in the STR. These tiles get pushed out through the ECR's opening. The hands present on both sides of the robot fit the tile into the wireframe slot with accuracy. While they hold it in place, the welding arm welds it to the frame.

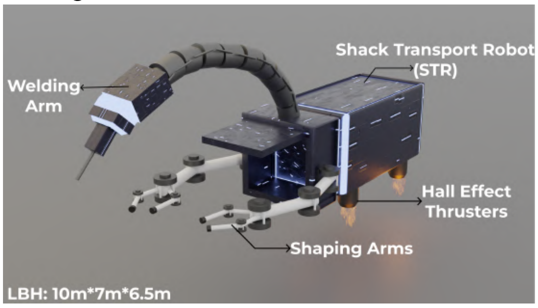


Fig 5.1.4 *External Construction Robot*

5.1.6 Interior Assembly

5.1.6.1 Ground Layering Robot (GLR)

The **GLR** is a versatile body whose chief function is to layer the ground surfaces of Astrum. It will be made of titanium grade 5, with 4 mecanum wheels to implement omnidirectional capability, along with a large storage area at the top, containing tools and holding soil for the assembly. It will contain 4 variable ending arms for joining the tools.

5.1.6.2 Contour Crafting Robot 1 (CCR-1)

This will be repurposed from the GLR to primarily make large interior buildings.. It is extendable, and will have a minimum and maximum height of 7 and 21 meters respectively. The CCR-1 will contain 3D printing arms and a leveler.

The transportation robot will unload equipment from Caddy's into the storage compartment of the CCR-1 when required. To use the Caddy container itself, circular saws shall cut into the container, dropping hunks of it into the CCR storage area. *(refer to 5.1.7)*

5.1.6.3 Contour Crafting Robot 2 (CCR-2)

Contour Crafting Robot 2 is a smaller version of CCR-1. CCR-2 will be building lanes and utilities like parks and streets..

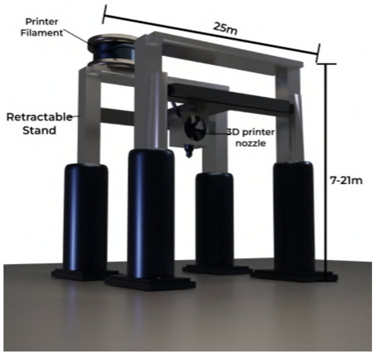


Fig 5.1.5 *Contour Crafting Robot 1*

5.1.6.4 Interior Finishing Robot(IFR)

Interior finishing robot is a cuboid with rounded edges, composed of silicon as it is strong, and can be sourced from Luna. It'll have mecanum wheels for precise movement, along with two variable ending arms, & a 3D printer. A camera will be using a laser scanner to scan parts for the 3D printer to print parts for final assembly. A nanobot compartment will be added to the robot in case of a minor crack. IFR will line electrical wires, make water pipes, and finish houses.

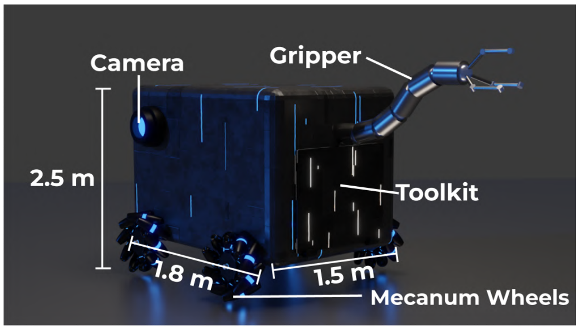


Fig 5.1.6 *Interior Finishing Robot*

5.1.7 Transportation Robot

The **transportation robot** will have a large automated trailer in its base with 12 mecanum wheels attached, enabling the robot to move in all directions. It shall be made up of a copper-manganese alloy.

- There will be fully automated robotic claws attached to the transportation robot, which will be able to lift the Caddys and load it into the robot. They would also be used for unloading the Caddys.
- Additionally, two robotic claws of the transportation robot shall be equipped with circular saws. The Caddy will be held up above the storage area of the CCRs, and the saws will cut through the container, resulting in pieces of magnesium dropping into the storage.
- A mechanism with electromagnets and ferromagnets would be used for efficient movement in low g areas. *(refer to 3.2.7.1)*
- It will be coated with a thin layer of teflon, an insulator. Electricity would be passed through the EMs whenever the brakes would be applied.

Energy would be stored while charging the bot for powering the EMs.

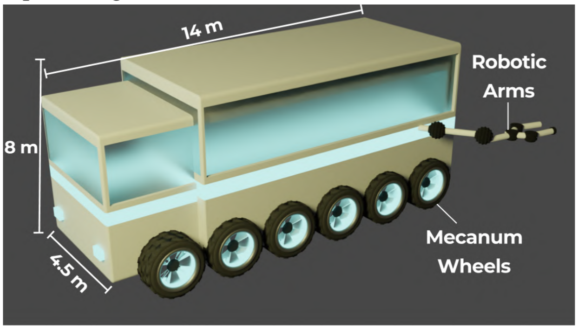


Fig 5.1.7 *Transportation Robot*

5.2 Automation For Operating Settlement

5.2.1 Repair

5.2.1.1 External Repair Robot (ERR)

This shall be repurposed from the External Construction Robot (ECR), and will carry out repairs to any damaged areas of the hull. This can be done completely with automation, however it will also be modified to accompany a cockpit. This will allow for human inspection of the repair processes. It will be made out of Titanium Grade 4, which protects it from solar flares.

5.2.1.2 Internal Repair Robot (IRR)

The IRR carries out a crucial role in the settlement's maintenance. It has a cuboidal body with rounded edges and a tool kit is placed in the middle of its structure for the variable ending arms to tether its end with the tool. The IRR will consist of 4 variable ending arms, 4 mecanum wheels for easy movement, and a voice recorder to record unusual data, and transmit it back to the control center. Additionally, the rims of its wheels will be lined with gecko pad lining, to help it traverse the hull if required.

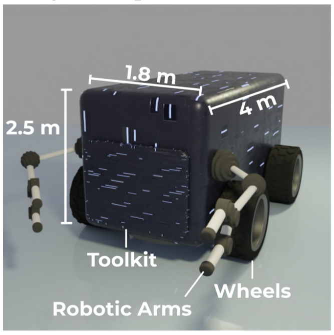


Fig 5.2.1 *Internal Repair Robot*

5.2.2 Industry

Belvistat will house a lot of industries which will be manufacturing articles based on demand. Industries in Astrum will be extremely customisable.

These industries will be having different bots for different activities. Each robot will be given a specific region to work in the factories. These walls can be moved back and forth making it customisable for the bots to function efficiently.

Modern Japanese houses are nowadays made keeping in mind compact yet spacious designs for houses. Walls in these houses can be personalized according to demands of the event. The walls can be moved back and forth making the house compact at a moment and spacious the next moment.

5.2.3 Surveillance Bot

The surveillance robot shall be made primarily out of silicon. A hemisphere will be attached to the top of its cuboidal structure. It'll be made of electrochromic glass. Surveillance robot has been equipped with a 180° camera with MEMS barometric sensors for air pressure and a thermometer for measuring temperature.

A speaker will be installed in this bot to help in evacuations. In case of an emergency, the alarm starts in accordance with the contingency and the evacuation plan will be announced. *(refer to 4.3.1)*. If there's any issue with the environment simulated in the settlement, the surveillance robot will inform the control center to take action for it.

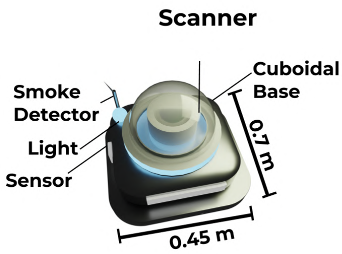


Fig 5.2.2 *Surveillance Robot*

5.2.4 Agriculture Bot

Our agricultural robot will be inspired from a shelf based design. It will be composed of 3 shelves. On the upper side of the shelves, a pipeline system will be placed that will enable our Fogponics system to work. Nozzles will be equidistantly placed to release fog which is nutrient enriched and has moisture. The nozzles will open at scheduled times during the day to release the fog. LED's will also be placed in between the nozzles so as to provide adequate light energy for the plants to grow.

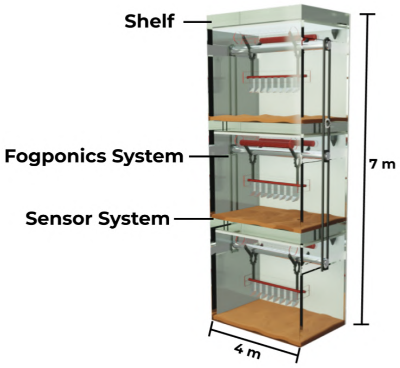


Fig 5.2.3 *Agricultural Robot*

5.2.5 Evacuation Pod

It will allow for rapid evacuation of residents in case of a huge emergency. *refer to 4.3.1*

5.2.6 Control Centers

Each sector of Astrum will contain 3 control centers each, and each center shall consist of 2 floors each in their structure.

Floor	Data	No. Of Staff
0	• The ground floor will include 3D-printing appliances for printing • These will print required robot parts as and when needed.	1
1	• All the low ranking and junior personnel are accommodated on the first floor. • They will be the first line of surveillance.	25
2	• It will hold offices for the experienced and senior personnel. • These supervisors have to give the go-ahead for any contingency measure and declare warnings in an emergency.	15-20

Table 5.2.1 *Control Centres*

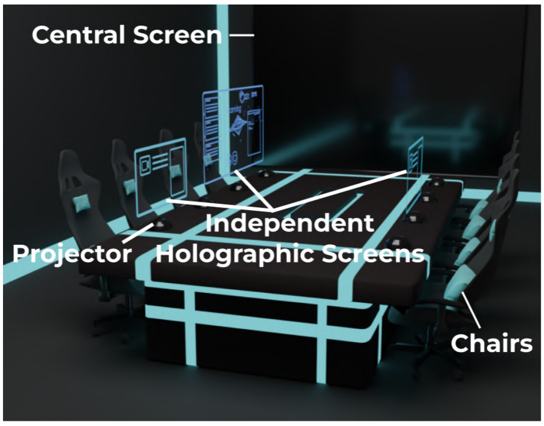


Figure 5.2.4 *Control Centres*

5.2.7 Human Intervention

Human intervention will be present at the decision points throughout automated processes, though the majority of it will be handled by robots. But when deemed necessary and urgent, human veto power can be used to take over the robot and make certain key decisions. For example, if repair robots run into some abnormal issues during operations, they will be told to continue or change the operation as the human intervener says. Humans will do this while keeping in regular contact with Control Centres in every torus. Senior personnel can also put the required safety proceeding into effect, if necessary

Lvl	Biometrics	Authorized Personnel	Data	Place
1	Manual codes	Residents	General Assets	Community Structures
2	Iris Recognition, Manual codes	All Home Owners	Personal Data	Personal Homes
3	Retina Scanning, Manual codes	Employees	Company Data	Warehouse and Workplace
4	Manual codes, Palm Vein Mapping, Retina Scanning	Supervisors, Technicians	Public Data	Control Centers

Table 5.2.2 *Biometrics*

5.2.7 Contingency Measures

Risks & Alerts	*Precautions*	*Safety Measures*	*Contingency Measures*
Server Failure/ Cybersecurity Issue	*Encryption methods will be used to safeguard privacy. Biometric security will also be established*	*The main epicenter of the issue is identified and the server is taken offline.*	• *The breached servers are restored, after the backup server restores data.* • *Data is backed up constantly.*

Toxic Gas Leak	*Air vents in the structure will suck up all gasses in case of leakage.*	*Airlocks will be activated.*	● *The moment surveillance robots detect leakage, citizens will be evacuated instantly. refer 4.3.1* ● *Airlocks covering that segment will immediately close, preventing mixing of air and toxic gases.* ● *Air vents will activate instantly, evacuating the gases into outer space.*
Solar Flares (Identification - Solar Activities)	*Materials have been incorporated into the hull and windows which are radiation shielding.*	*Only if a powerful flare approaches, surveillance bot give warnings.*	● *All robots will give warnings to make citizens aware of an approaching flare.* ● *Residents will be sent to safe rooms.*
Fire (Identification - Sensors, Surveillance Bot)	*Several materials have been incorporated in the hull & windows which are incombustible, and have fire resistance.* *Fine water mist would also be used for fire suppression and control.*	*All residents will be evacuated according to the evacuation plan, and procedures to be followed will be announced by surveillance bots. (refer to 4.3.1)*	● *Distress bots will help citizens.* ● *Extra vents will be constructed apart from the normal vents in the spaceship, which contains an airlock. Any fire will be able to get exhausted through these specialized vents* ● *After this, any structural damage will be fixed by repair bots.*
Hull Breaches (Identification - Surveillance Bot, Ultrasonic Sensors)	*Atmospheric readings and temperatures would be supervised by surveillance bot, and ultrasonic sensors present in tiles of the hull material would help in recognition.*	*Alerts would be sounded across the settlement by surveillance robots.*	● *The middle layer of the hull comprises gelatinous substances and non-newtonian fluid.* ● *Whenever an asteroid hits the hull, the non-newtonian fluid turns hard, preventing a hull breach to absorb this impact, gelatinous substance will be places under the non-newtonian fluid layer* ● *If, by any chance, the hull still gets breached, residents will be evacuated and repair robots will be released to repair the hull. refer to 4.3.1* ● *Also, since there are fluids between the hull coverings, depressurization will not occur.*

Table 5.2.3 *Contingency Table*

5.3 Home Automation

5.3.1 Medical Robot(MR)

- The Medical Robot gets a notification by the PCD of a person whose health levels are dangerously low, and instantly reacts to the situation. Other than this, they also carry out periodic checkups on all residents.
- A blood sampling mechanism will instantly be activated to recheck the BPM, oxygen levels and other health data.
- There will be Magnetic Resonance Imaging (MRI), Diagnostic Medical Sonography (DMS) & X-Ray Facilities in the robot to identify injuries. A team of 2 people will be present to oversee the procedures.

5.3.3 Home Assistant Devices

5.3.3.1 Personal Communication Device (PCD)

Our Personal Communication Device (PCD) are smart glasses personalized for every resident in Astrum. These will keep track of a person's health, allow access to robots and provide communication, entertainment, information, and computing purposes.

Information & Communication

- People will be updated with the latest news and weather updates through periodic notifications delivered to the user.
- The PCD will have in-built bluetooth and wifi, so people can receive or decline calls. Video calls between people are also feasible.
- The user has the option of ordering food and consumables, which are later delivered by delivery robots *refer to 5.3.7*'.

Entertainment

- For playing music & videos, PCD will have speakers. Additionally, it will provide users with choices of using AR to run games such as Pokemon Go and view virtual notes. People can also attach earphones into the frame of the glasses itself. This will allow for a private music experience.

Health & Monitoring

- It has the capacity to measure data like stress levels, body movements and brain waves. If there is a discrepancy between the required and actual levels, remedies will be provided to manage anxiety, avoid distractions & be more productive.
- The user has an option of connecting the smart glasses to a watch, to facilitate measurements of crucial body statistics like heart rate.
- In the case of any unsettling stats, the closest medical robot will be immediately notified to attend to the person.

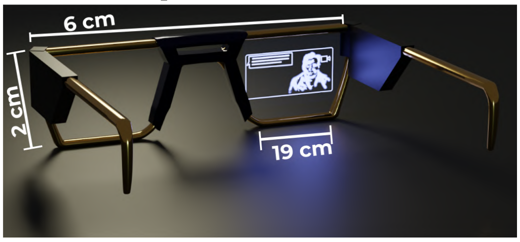


Fig 5.3.2 *Personal Communication Device*

5.3.3.2 Virtual Office Assistants (VOA)

To improve productivity and help in time management, directing conferences and assisting research work, the Virtual Office Assistant (VOA) will be used to assist people in their critical tasks such as calculations, generating documents, compiling reports and overall producing productive, high quality work. VOA is connected to home automation robots and the PCD, so that it can give residents access to robot systems.

5.3.3.3 Personal Cleaning Robot (PCR)

Personal Cleaning Robots (PCR) will be present in all households for the cleansing of the entire home. It will have four soap dispensers present at the bottom face and mop in the middle. It also has several small tires, which are utilized as gecko pads. This enables the robot to climb up walls and vertical surfaces.

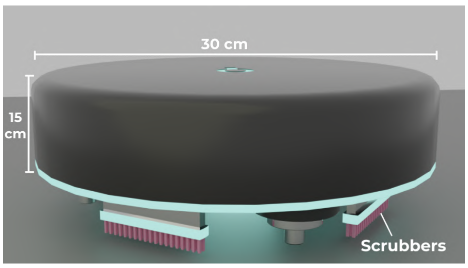


Fig 5.3.3 *Personal Cleaning Robot*

5.3.4 Data Privacy

Lvl	Encryption	Uses
1	RSA	Preserves assets, works well with a small amount of files
2	RSA	Preserves assets, works well with a small amount of files
3	AES	Contains powerful security protocols, protects information securely
4	Quantum Cryptography	Properly safeguards and preserves high level and classified data

Table 5.3 *Encryption Methods*

5.3.6 Pet Robot

The Pet Robot will be made in the shape of a cat, out of aluminized magnesium. It'll be available in different colors and sizes & each robot shall be customized for the owner

5.3.7 Delivery robot

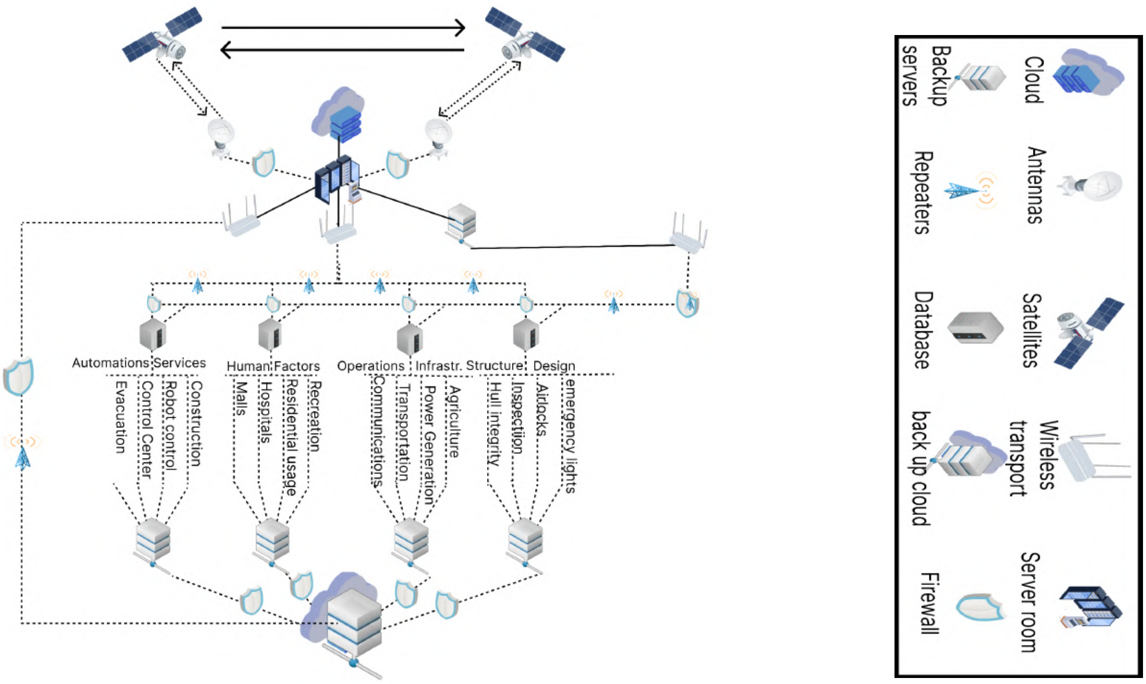
Delivery robots are mid-sized robots which help in delivery of supplies such as medicines, foods etc. these have one camera. It has one ultrasonic sensor to detect any obstacle while delivery. It has an openable lid at the top in which the supplies can be put and the lid can be closed. When the robot reaches its location, the citizen opens its lid and can

collect its supplies. It has 6 mecanum wheels installed with shockers for a stable transportation.

5.3.8 Network Chart

Astrum has connecting systems all across for a fail proof data protection. Every 30 meters, a **repeater** is placed which may record the algorithms and rebuild them in case it breaks.

Astrum will be using Quantum Encryption. The settlement will be using 1.2 gigabits per second so the settlement can communicate with earth stations. Every department has its own secondary server to store data and all data is linked to a secondary backup cloud. In case of a cloud failure, Astrum will be using the backup cloud until the main cloud is retrieved.



Solid Line - Wired Connection
Dotted Line - Wireless Connection
Flowchart 5.1 *Network Chart*

5.4 Loading & Unloading Of Caddys In The Settlement

Mechanical systems consisting of Claw and Tagging robotic arms will each have a 3 point articulation. The claw arms will pick up the Caddys and place them from the ship on to the settlement. The build and structure of this mechanical system will be repurposed from that of the Transportation Robot. (*refer to 5.1.7*)

The Claw arm will also serve as the tagging arm. The tagging mechanism will tag the Caddy with a barcode. This data will then be uploaded on the server. This will help to identify the Caddys with the ore content later on. These same arms will also be present at the warehouse facilities. These arms will be attached to the ground, and will automatically readjust themselves on the volume of the ore. On arrival of the Caddys, it will be scanned to detect the ore composition present. A spectroscopic sensor will be utilized, to determine its exact composition. After this the Caddy will be further transported to the warehouse by Transportation Robots.

5.5 MRO Dock & Manufacture Of Spaceships

Their main purpose is to repair the vehicle docking to the port. The dock will have several tracks running all over the docking room. The dock will have approximately 800 robotic arms all over to facilitate repair and maintenance of space tugs/spaceships and manufacturing of interplanetary spaceships. Jigs will be used to transport required arms from one end to the other end of the intersection. The docking room will be using a laser scanner to scan the damage on vehicles, and print parts accordingly. A 3D printer will be installed at the corners. Robotic arms installed in this room will have variable ends to change their end tools according to requirement. The variable ending arms will be controlled by control centers. If anything goes wrong, humans can take over. These dock rooms will have adjustable roofs due to diversity in spaceship designs. Acc. to dimensions calculated, the volume of the room will be 48000 m^3.

Maintenance Of Space Tugs & Spaceships

Astrum will be using the same machinery as in the MRO docks. 5 rooms will be allotted for repair and maintenance of space tugs. 3 rooms will be allotted for manufacturing of spaceships in Astrum.

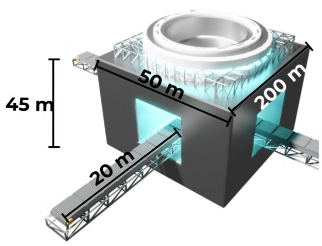


Fig 5.4 *MRO Dock*

WBS NUMBER	TASKS	INITIATION DATE	DURATION (IN DAYS)	ENDING DATE
0	Preparation			
0.1	Date Of Contract Awardment	15/05/2043	0	
0.2	Research & Development	15/05/2043	1250	16/10/2046
1	Phase 1			
1.1	Assembly & Launching Of Construction Shack	16/10/2046	185	19/04/2047
1.2	Initial Docking Ports	19/04/2047	60	18/06/2047
1.3	Arrival Of Temporary Thrusters And Ant	18/06/2047	93	19/09/2047
1.4	Arrival Of Construction Robots	19/09/2047	191	28/03/2048
2	Phase 2			
2.1	Construction Of Central Shaft	28/04/2048	321	15/03/2049
2.2	Installation of Temporary Solar Panels	15/03/2049	85	08/06/2049
2.3	Installation of Antennas	08/06/2049	91	07/09/2049
2.4	Assembly And Setting Up Of Thrusters	07/09/2049	195	21/03/2050
2.5	Modifying Construction Shacks To Act As Temporary Storehouses	21/03/2050	102	01/07/2050
3	Phase 3			
3.1	Permanent Placement Of Solar Panels	01/08/2050	163	11/01/2051
3.2	Assembly Of Wireframe Of The Cylinder	11/01/2051	230	29/08/2051
3.3	Construction Of Interior Hull	29/08/2051	308	02/07/2052
4	Phase 4			
4.1	Construction Of Wireframes Of Al10 & Al20	02/08/2052	283	12/05/2053
4.2	Assembly Of Hull Of Al10 & Al20	12/05/2053	300	08/03/2054
4.3	Construction Of Wireframe Of External H	08/03/2054	275	08/12/2054
4.4	Installation Of Rotational Interfaces	08/12/2054	230	26/07/2055
5	Phase 5			
5.1	Complete Construction Of External Hull & Surfaces	26/08/2055	448	16/11/2056
5.2	Addition Of Gelatinous & Non-Newtonian Fluids In Hull	16/11/2056	240	14/07/2057
5.3	Assembly Of Docking Ports	14/07/2057	297	07/05/2058
5.4	Construction Of Internal Infrastructure	07/05/2058	660	26/02/2060
5.5	Creating Additional Volume For Final Op	26/02/2060	304	26/12/2060

2043 2044 2045 2046 2047 2048 2049 2050

6.1 Schedule

6.2 Costs For Structures, Robots, Operations & Human Factors

Phase(P)	Specifics	Cost
	Research & Development	$67,500,000
1	Assembly & Launching Of Construction Shack	$2,66,50,00,000
	Initial Docking Ports	$24,22,72,727
	Arrival Of Temporary Thrusters & Antennas	$12,11,36,363
	Arrival Of Construction Robots	$103,00,000,000
2	Construction Of Central Shafts	$5,350,000,000
	Installation Of Temporary Solar Panels	$6,000,000
	Installation Of Communication Systems	$89,000,000
	Assembly And Setting Up Of Additional Thrusters	$302,84,090
3	Permanent Placement Of Solar Panels	$2,000,000

	Construction Of Interior Hull	$15,000,000,000
4	Construction Of Wireframes Of Hybrid Paraboloids	$6,400,000,000
	Assembly Of Hull Of Hybrid Paraboloids	$3,400,000,000
	Construction Of Wireframes Of External Hull	$32,000,000,00
	Installation Of Rotational Interfaces	$64,000,000,00
5	Complete Construction Of External Hull & Structures	$3125,000,00,00
	Assembly Of Docking Ports	$12,000,000,000
	Construction Of Internal Infrastructure	$20,000,000,000
	Creating Additional Volume For Final Operating Capability	$2,59,92,27,72,720
	Total Cost(IOC)	**$55,56,45,00,000**
	Total Cost(FOC)	**$1,92,85,80,00,000**

Robots	**Units**	**Cost of 1 Unit**	**Total Cost**
Medical Robot	350	$45,000	$15,750,000
Ground Layering Robot	55	$830,000	$46,000,000
Contour Crafting Robots	90	$320,000	$30,000,000
Exterior Construction Robot	400	$2,500,000	$1,000,000,000
Bot Maker	30	$70,000	$2,100,000
Hexapus	10	$500,000	$5,000,000
Wireframe Robot	500	$750,000	$375,000,000
Truss Robot	500	$750,000	$375,000,000
Shack Transport Robot	400	$1,500,000	$600,000,000
Exterior Repair Robot	100	$40,000	$400,000
Interior Finishing Robot	200	$25,000	$5,000,000
Internal Transport Robot	150	$20,000	$3,000,000
Internal Repair Robot	100	$42,000	$4,200,000
Pet Robot	7840	$10,000	$78,400,000

Jigs	500	$40,000	$20,000,000
Total			**$2,558,850,000**

Human Factor

Amenities	**Units**	**Cost Per Unit**	**Total Cost**
Parks	15	$6,500,000	$97,500,000
Malls	7	$275,000,000	$4,125,000,000
Recreation	10	$9,000,000	$90,000,000
Hospitals	12	$200,000,000	$2,400,000,000
Restaurants	15	$17,000,000	$255,000,000
Control Centers	10	$2,000,000	$20,000,000
Stores	25	$10,000,000	$250,000,000
Offices	20	$15,000,000	$300,000,000
Schools	5	$11,000,000	$55,000,000
Banks	15	$16,000,000	$240,000,000
Gyms	9	$60,000,000	$540,000,000
Storage	8	$40,000,000	$320,000,000

Total (HF)	**$8,692,500,000**

Operations & Infrastructure

Operations	**Total Cost**
Atmosphere & Climate	$183,500,000
Agriculture & Food Production	$5,000,000,000
Water Management	$3,278,511,380
Waste Management	$92,200,000
Power Generation	$2,954,163,410
Internal & External Communication	$35,000,000
Internal Transportation	$15,000,000
Total Cost	**$11,558,374,790**

Grand Total (IOC)	**$78,37,53,09,790**
Grand Total (FOC)	**$2,15,66,78,33,290**

Human Resources On The Settlement

Resources	**R&D**	**P1**	**P 2**	**P 3**	**P 4**	**P 5**	**Salary p.a**
Engineer	200	70	120	145	190	220	$225,000
Agri	45	-	-	-	40	90	$120,000
Supervisor	80	65	85	100	130	180	$230,000
Architects	55	30	45	70	105	80	$240,000
Total	**$1,085,000**						

7.1 Business Development

7.1.1 Production of goods

The main production of goods will occur in the main central shaft as it has zero gravity.

The minerals in the lunar regolith do not produce a magnetic field themselves which is why inter-particle magnetic attraction is not feasible.
Beneficiation technologies to separate individual elements' ores from lunar regolith will therefore use physical properties like density, surface properties and electrostatic separation.

Lunar regolith with low electrical conductivity, moisture and dielectric losses is ideal for Triboelectrification and electrostatic beneficiation of minerals. Tribocharging works by taking raw charged regolith as the input, the triboelectric effect causes charge to accumulate on particular minerals, producing electrically neutral grains sorted by mineral and size. The grains of lunar regolith and the lunar environment are suitable for triboelectrification and electrostatic separation because it prevents the grains from sticking together, lack of atmospheric gaseous breakdown allows higher voltages to be used on the separation plates, and the gravity being only 1/6 that of the earth, will provide the particles longer charge contact durations.
Once the CASSSCs with the raw ores arrive at the processing facility, it will be separated into individual elements' ores and the methods given in the table below will be used to process them. As mentioned in the table, some of the by-products of the extraction process would be used later in other extraction processes. The end products of each process are mentioned at the end. (*refer* to 5.4)

Element	Method of Extraction	By- products to be used later	End product
Silicon from silica sand	• Finely powdered silica is mixed with Magnesium powder and the mixture is heated in a fire clay crucible furnace. Some portion of the extracted Magnesium is used for the reaction. • The products, magnesium oxide and silicon are washed with dilute hydrochloric acid to dissolve magnesium oxide. • Silicon is washed with hydrofluoric acid to remove the unreacted silica. • The powder left behind is silicon in its amorphous form.	Magnesium Oxide (Heated with hydrogen to produce Magnesium)	1) Silicon (Partly used as a reductant in the extraction of Magnesium)
Aluminum from Bauxite Ore	• Baeyer's process is used for the removal of ferric oxide and silica from bauxite ore. • In Hall's process, impure Bauxite is converted into Sodium aluminate which is further converted into Aluminum hydroxide and finally into pure alumina. • Alumina's electrolysis is done with cryolite and fluorspar by the Hall-Heroult method.	Sodium Hydroxide (Used in the extraction of Titanium)	1) Aluminum (Partly used as a reductant in the extraction of Magnesium) 2) Carbon Dioxide 3) Sodium Carbonate 4) Water
Calcium from Calcite	• The process of extracting pure calcium from an ore is through electrolysis. • A paste of slaked lime and mercury oxide is prepared on which electrolysis is done. • Mercury is removed from the calcium-mercury mixture by distillation and calcium is extracted.		1) Calcium 2) Mercury
Iron from Hematite	• Concentration of ore through calcination and roasting is done to remove water and volatile impurities such as sulphur and carbonates. • This concentrated ore is mixed with Limestone and Coke and fed into the blast furnace from the top where the concentrated ore is reduced chemically to its liquid metal state using carbon monoxide, a byproduct from the extraction of Titanium from its		1) Iron 2) Carbon Dioxide

	ore. • Additional Iron is extracted from the Ferric oxide separated from the Bauxite ore.		
Hydrogen	• Hydrogen is extracted from water ice by the process of electrolysis.	Hydrogen (Heated with Magnesium oxide to produce magnesium)	1) Oxygen
Magnesium from Dolomite	• The extraction of Magnesium from its ore is carried out using the Pidgeon process which includes dolomite decomposition/Calcination and magnesium oxide reduction. • The calcined dolomite is mixed with a reductant, Aluminum and heated at approximately 1150-1400 °C. A portion of the extracted silicon and Aluminium is used as a reductant. • Magnesium Oxide, a by-product of extraction of Silicon, is heated with hydrogen to produce additional Magnesium.		1) Magnesium Used in the extraction of Silicon 2) Carbondixode 3) Calcium silicate
Titanium from rutile and Ilmenite	• Titanium is extracted using the Kroll process where the ore rutile is heated with chlorine and coke at a temperature of about 1000°C. • The ore is converted into titanium (IV) chloride and then reduced to titanium using molten sodium. Sodium hydroxide, a by-product of the extraction of Aluminium, is electrolysed to produce sodium.	Carbon monoxide (Used in the extraction of Iron)	1) Titanium 2) Sodium Chloride
Helium 3	• Helium-3 is extracted from the lunar surface by heating the lunar dust to around 600°C.		1) Helium 3

In order to allow for extraction levels between absolutely minimal and full, the extraction process can be stopped at any step (for varying demands).
The factory where the extracted metals would be made into alloys and the desired forms would have adjustable, customizable walls whose dimensions could be minimised and maximised according to requirements. This would enable us to control the production of goods in accordance with the demands in a given circumstance.

Sulfur lithium batteries for storing energy will be manufactured in Astrum itself. For production, Lithium and Aluminum will be extracted from the lunar surface and Sulfur will be shipped from Earth.

Provision of storing 2500 tonnes of mined regolith at a time has been provided in the settlement.

Element	Abundance	Amount	Waste Generated	Metal Extracted
Silicon	45%	1125 tonnes	187.5 tonnes	937.5 tonnes
Aluminium	19%	475 tonnes	317 tonnes	158 tonnes
Calcium	13%	325 tonnes	227.5 tonnes	97.5 tonnes
Iron	11%	275 tonnes	110 tonnes	165 tonnes
Magnesium	8%	200 tonnes	167 tonnes	33 tonnes
Titanium	4%	100 tonnes	33 tonnes	67 tonnes
Hydrogen				
Helium 3				

Total	100%	2500 tonnes	1042 tonnes	1458 tonnes
Area (DSA)	110 m^2		Volume	1652 m^3

The mined regolith would be stored in a warehouse in the varied gravity industrial area with a volume of 2833 m^3 and DSA of 189 m^2.
The extracted ore would be stored in another warehouse with a volume of 1652m^3 and DSA of 110 m^2.

The machines used for extraction of metals from the ores will be made of ferromagnetic materials. While extracting the metals, electricity will be induced in order to activate the electromagnet and stop metals from flying. If the metal isn't ferromagnetic and tends to fly off, it will stick to the body of the machine as the body will be lined with gecko pads.

7.1.2 Manufacturing of spacecraft for service only in space

Due to the diversity of spaceship designs, the MRO docks will have adjustable roofs (and walls). The MRO docks will also have numerous tracks arranged in a grid-like pattern all through the docking chamber. The dock will be equipped with robotic arms to make it easier to manufacture interplanetary spaceships and repair and maintain space tugs and ships. Jigs will be utilised to move the necessary arms from one end of the intersection to the other.
Dock room will also use a laser scanner to inspect the damage onto the structure of space vehicles and print the necessary replacement parts. Each room will have a toolkit and 3D printer installed in the corner with electromagnetic bases for the variable ending robotic arms to stick on to them. The same machinery as used for maintenance and repair of space tugs would be used for the manufacturing of interplanetary spaceships. 12 rooms will be allotted for manufacturing of spaceships in Belvistat. *(refer to 5.5)*

7.1.3 MRO of ships and other space infrastructure elements

MRO docks will have specialised adjustable, retractable roofs to modify the docking rooms according to the spaceship's dimensions. The jigs will be running throughout the inside of the trusses, even during the construction process. They will be moving inside cuboidal trusses, embedded in the room's surface, with their corner in contact with the surface of the truss through metallic tracks. The dock will also have variable ending robotic arms to change the end tools according to requirement. A 3D printer and toolkit will be affixed to the corners with tools having electromagnetic bases for the variable ending arms to stick on to them. As discussed in 2.5, as the number of hybrid paraboloids increase, the number of docking ports supporting those will also increase to 64 docks in total - 20 for space tugs, 32 for space ships and 12 for manufacturing. All the details have been provided in 5.5.

7.1.3.1 Dock for Space tugs

To assist disabled vehicles, Atrum will operate a fleet of ten space tugs, Astrum can dock up to five vehicles at any instant at once.

7.1.3.2

Hazards	Solutions
Solar flares	• Wipe and clean all the metallic equipments
Hull breaches	• Exterior repair bots will be sent to reconstruct the damaged parts.
Harmful gasses	• Gas monitors will identify potentially hazardous, flammable gasses.
Explosion	• Retract all robotic arms • Cover fragile substances • Structural damage will be fixed by repair bots

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