THE SPINNING DONUT

A Space Settlement

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Introduction

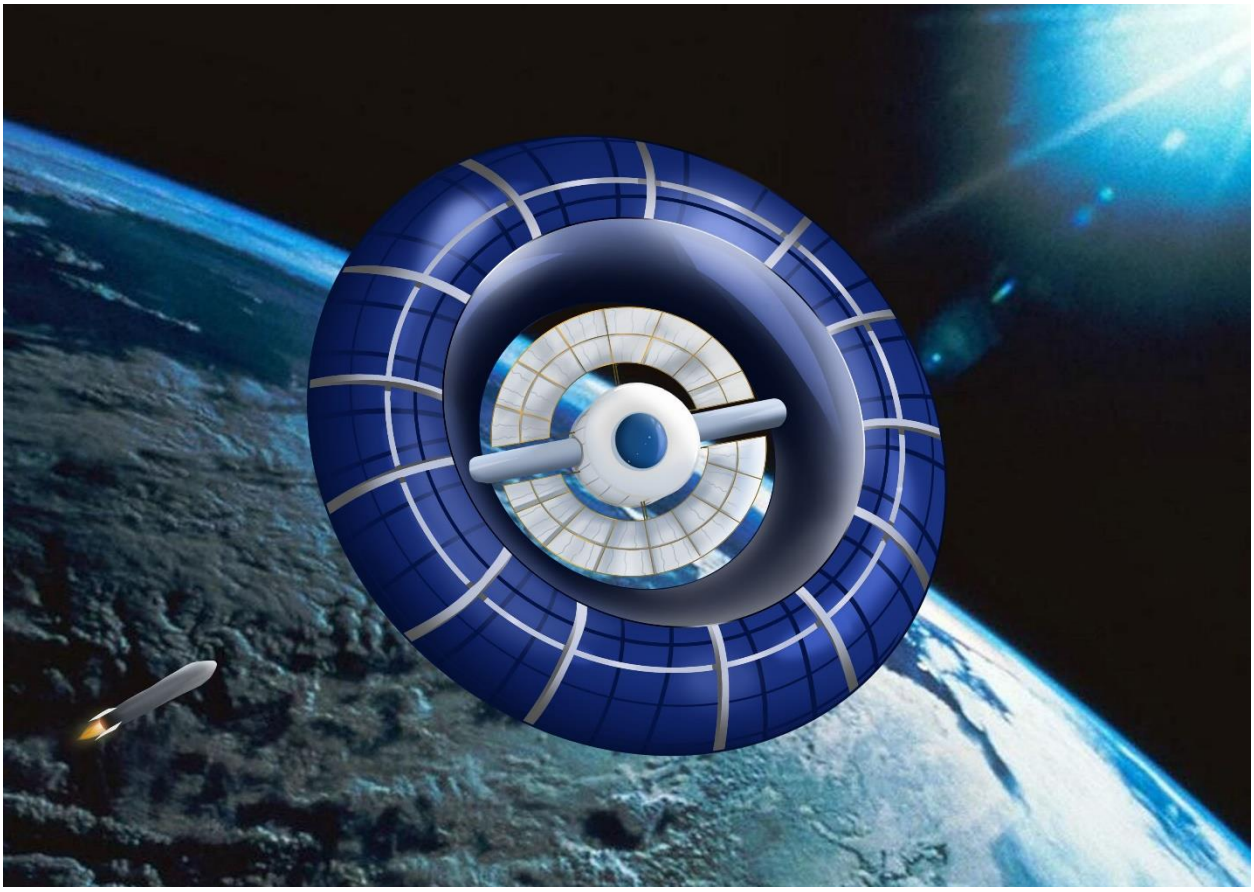
"You can design and create, and build the most wonderful place in the world. But it takes people to make the dream a reality."

-Walt Disney

The purpose of this settlement is to promote research, development, entrepreneurship, and most of all; interest in the future of space settlements among not only those already interested in space, but also among average individuals. It was designed in a way where it can be built exclusively using current technology, allowing it to not just be an idea that might be possible to build in the future, but an actual self-sustainable space settlement that can be built in the world of today. Keeping this goal in mind, every aspect of this settlement has been considered keeping the following two points in mind:

1. To keep the settlement as cheap, and thus as feasible as possible.
2. To make the settlement as desirable as possible, not only for its inhabitants but also for the people living on Earth.

The space settlement has been named The Spinning Donut due to the positive connotations associated with donuts, as well as the almost comedic effect of the name in order for the inhabitants to view the settlement in a positive light. The settlement has been designed to be able to sustainably hold a capacity of 100 people.



Gravity

"Everything every day here on Earth is based on gravity, and you don't realize it until you don't have it anymore."

-Peggy Whitson

Since people will be living in space for a long time, it is important to make the environment as similar to earth as possible to avoid health problems such as muscular dystrophy. Artificial gravity is necessary to accomplish this. We can create artificial gravity in two ways: acceleration and rotation. Accelerating the settlement at $9.81 m/s^2$ would indeed mimic the gravity of Earth but it is extremely expensive to accelerate an aircraft at this speed for a long period of time. The second method is rotation; the centrifugal force generated as an opposing force to the centripetal force can act as a substitute for gravity. Although it is by far the best way to create artificial gravity, it has its own set of constraints.

Size:

The best way to reduce costs is to decrease the size of the settlement as much as possible, however, decreasing the size too much will create more problems related to the centrifugal force. The formula for centrifugal force is $\omega^2 R$ where ω is the spin rate and R is the radius. With an exceedingly small rotating space settlement, if an individual is standing on the settlement, he/she would experience an artificial gravity of 1G on his feet but a much lower "gravity" on his/her head. This would cause the individual to experience tidal forces. This constrains the lower limit of the radius to about 17m.

Coriolis Effect:

The Coriolis Effect comes into play when the inhabitants of The Spinning Donut are in motion. The occupants must be moving perpendicular to the rotation vector in order to experience this effect (in the case of The Spinning Donut, moving along its 6m width). The formula for the total acceleration is:

$-\omega^2 r + 2\omega * v + a$

Here "a" is the linear acceleration; since the settlement will orbit at a constant velocity, its value will be 0. "$\omega^2 r$" will be the main component of acceleration and will create gravity. The other component in the formula is "$2\omega * v$" which is responsible for the Coriolis Effect where "v" is velocity.

Coriolis Effect has two types:

1) Vertical Coriolis

The effect of Coriolis is always perpendicular to both the rotation and velocity vectors, so in the case of The Spinning Donut, moving along its circumference would cause extra acceleration either upwards or downwards depending on the direction of motion of the individual. If an individual moves in the direction in which the settlement is rotating then he/she will experience greater gravity and if an individual moves against the direction of the rotation of the settlement, he/she will experience lesser gravity. The magnitude of this effect would increase as the radius of the settlement is reduced for the following reason: compare two objects in motion with same the speed in a circle but their circular path has a different radius, the object revolving with a lower radius will have a higher spin rate hence a higher centrifugal force. Because of this, the smaller the rotating settlement, the greater the difference in centrifugal acceleration when an object is in motion.

2) Radial Coriolis:

Gravity decreases as the distance between the center decreases, however, the rate of decrease of gravity per length would be exceedingly high if the size of the settlement is really small. A person going up or down the stairs might lose their balance due to the change in gravity; the problem can be solved by making specially designed stairs or lifts. However, in the case of The Spinning Donut, the radius of 50m is quite large and the change in gravity would be insignificant.

Canal sickness:

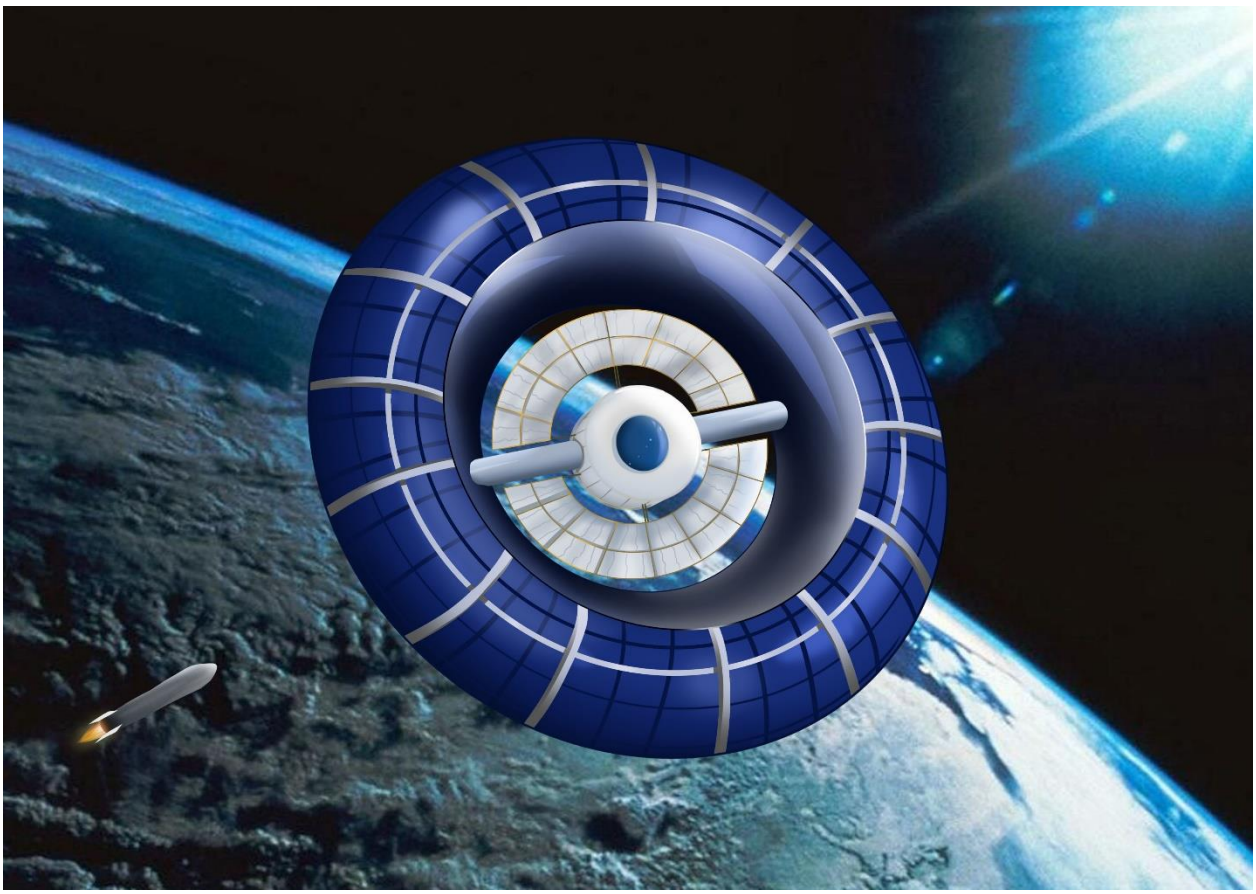
If an occupant in The Spinning Donut turns his head, each side of his head would experience Vertical Coriolis in opposite directions which means that there would be a different amount of centrifugal force in each ear canal, slightly changing the distribution of fluid inside. This will "confuse" the vestibular system creating a sense of nausea and sickness. Multiple experiments have been conducted on Earth in which people are told to complete tasks in slowly rotating rooms. These studies[1] conclude that at a rotation rate of fewer than 2 revolutions per minute, people can complete complex tasks but above this spin rate they take about a day to adapt, and above 6 RPM it is more difficult for them to adapt. If we apply this to The Spinning Donut, creating a gravity of 1G at 2 RPM would require a radius of more than 200 meters which is not feasible at all. Keeping the fact in mind that we want The Spinning Donut to be as feasible as possible, the spin rate must be as high as possible, and so we decided to have it spin at 4.2RPM. At this RPM, the inhabitants will be able to comfortably adapt in a few days. Using the formula

[1] https://space.nss.org/wp-content/uploads/Space-Settlement-Population-Rotation-Tolerance-Globus.pdf

$\omega^2 R$, the radius of The Spinning Donut will be 50m at 4.2 RPM to generate an artificial gravity almost (9.67 N) equivalent to that of Earth. The settlement can be rotated using the engines of the docked rocket.

Dimensions:

The Spinning Donut has a radius of 50m and a width (perpendicular to radius) of 6m. The Outer Edge of the torus-shaped settlement will have a radius of 50m, and the inner circle of the torus will have a radius of 40m (the inhabitants will live between this region since gravity will be about 0.8g at 40m distance and 1g at 50m distance). The width of all the apartments and bathrooms in the settlement is 4.2m and the corridor has to be about 1.5m wide for unicycles to comfortable be able to pass through which leads to the conclusion that the width of The Spinning Donut has to be 6m. The height of the Spinning Donut (parallel to the settlement's diameter) is 10 meters because above this the gravity decreases to below 80% of Earth's gravity. There is a room in the center with a radius of 14m and a height of 3m which will have a dock on it to allow spacecraft to dock onto it easily by adjusting their own rotation. This room will be used for entertainment purposes. Two hallways with 5m diameters will also be built to allow access to the center room as well as for structural integrity.



Location

"In any situation, location is crucial."

-Gordon Ramsay

After considering many possible locations for the Spinning Donut, we decided that to have it orbit Earth would be the best option. This is because the purpose of this settlement is to serve as an affordable and feasible "gateway" into future, larger space settlements. Having it orbit Earth could allow for easy access and escape for the inhabitants in the event of an emergency, it would also be far cheaper and actually doable in today's world. During the construction of the Spinning Donut, it will orbit at an altitude of 300 kilometers, which is about 20 kilometers higher than the lowest flight rule limit[2] of the ISS so that it doesn't descend too fast towards Earth due to the thicker atmosphere and so doesn't use too much propellant to keep it in orbit, which would be unnecessarily expensive. This will reduce costs because less fuel will be used by the rockets to transport parts of the Spinning Donut to a lower orbit.

After the Spinning Donut's construction is complete, it will be boosted to a height of 500 kilometers using propulsion from the attached SpaceX Starship rocket. This is because the higher the settlement is, the less atmospheric drag it experiences and so the less boost is needed to stay in orbit. Launches from the Earth to the Spinning Donut will be rare at this point due to the habitat's sustainability and so launch costs will not play as much of a role as the propellant costs for the boost required to keep the ISS in orbit. The settlement will not have an altitude of above 500 kilometers because the Van Allen belt begins[3] from an altitude of 640 kilometers and allowing the spacecraft to orbit above 500 kilometers would result in inhabitants experiencing extreme levels of radiation due to their proximity to the Van Allen belt. The settlement will have an equatorial orbit while construction to reduce launch costs but will shift to a polar orbit as has been detailed in the "Energy" section of this document.

The Spinning Donut will have a docking module at its center of gravity which will have a SpaceX crew-rated Starship docked on it and will orbit with the docking module (and thus Starship) perpendicular to the surface of the Earth to allow maximum use of thrust when Spinning Donut is being boosted. The Starship will use its engine to boost the Spinning Donut when it drops to an altitude of about 450 kilometers, and when the fuel of the Starship is low enough, it will detach and land on Earth, and a new crew-rated SpaceX Starship will attach to the docking module. This Starship will also be used as the escape pod, as well as for the transport of notable figures which has been detailed in the "Emergency Services" and "Entertainment" sections respectively.

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[2] https://www.nasa.gov/centers/johnson/pdf/514212main_SJ-02_Overview_Flight_Rules.pdf

[3] https://www.forbes.com/sites/jillianscudder/2017/06/16/astroquizzical-van-allen-belts-barrier-spaceflight/?sh=b8553046f8d6

Structure

"We shape our buildings: Thereafter, they shape us."

-Winston Churchill

In a vacuum, the degradation effects of most materials are eliminated, but The Spinning Donut will be orbiting Earth and hence will be in close vicinity to the earth's atmosphere making the spacecraft material vulnerable to UV light, atomic oxygen, extreme temperatures, high-velocity particles, and radiation. These factors will decrease the lifespan of materials used for the spacecraft. To ensure that our residents live happily and healthily, these factors need to be accounted for, so we have created "tiles" as a solution.

The tiles will be made by assembling layers of materials with similar expansion coefficients to ensure complete protection. The top layer will be thick Aluminium Oxynitride Glass, withstanding possible extreme temperatures up to 2150 C and acting as a good shock absorber[4], it will be followed by a layer of Carbon-nanotubes, a strong yet light material making it perfect for our spacecraft. Being 100 times[5] stronger than steel and more than 30 times[6] stronger than Kevlar it will provide the perfect protection against high-velocity particles; its unique properties will allow it to be used in unidirectional sheets allowing it to be layered. Atomic oxygen will cause oxidation of materials and hence a layer of Sialon will be used which will act as an oxidation-resistant[7] layer to The Spinning Donut. This layer will be followed by the radioactive protection layer consisting of thick Polyethylene foam[8] which will absorb and disperse radiation, followed by a layer of Super Adobe which will be providing excellent protection from solar radiation[9]. Sealant gel will be the next layer as it will act as a repairing mechanism filling up the affected areas. The bottom layer underneath the tile will be a substrate layer which will function as an extra protective layer in case there are any penetrations. All these layers will be put together using RTV-3145 Adhesive, which due to its strong adhesive properties will allow the production of strong tiles. In addition to all its benefits, it will also add to protection from radiation[10].

The tiles on the outer surface of The Spinning Donut will have PETE solar panels under the Aluminium Oxynitride glass as is shown in the depiction of The Spinning Donut.

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[4] http://ceramics.org/wp-content/uploads/2013/02/march13_cover-story.pdf
[5] https://nanoscalereslett.springeropen.com/articles/10.1186/1556-276X-9-393
[6] https://nanoscalereslett.springeropen.com/articles/10.1186/1556-276X-9-393
[7] https://www.azom.com/article.aspx?ArticleID=15727
[8] https://www.ipen.br/biblioteca/2007/pps23/12463.pdf
[9] https://iopscience.iop.org/article/10.1088/1755-1315/143/1/012043/pdf
[10] https://pdf4pro.com/view/adhesives-dow-corning-3145-rtv-mil-a-46146-2d6702.html

Radiation could also be avoided by producing our own magnetic field, but that would require two huge magnets[11] which will be adding to the weight of the settlement and hence inefficient.

The tiles will be triangular due to the high structural strength of the shape. They will be 2m thick, and all the sides will be 3m in length, this will make their surface area of the tiles equal to $5.3m^2$. The surface area of The Spinning Donut is $8882.64m^2$, but the tiles will only be on the outer side of the settlement According to Pappus' First Centroid theorem: $2\pi(R+r+2r/\pi)(\pi r)$

The outer curved surface area of the settlement is = $5248.9m^2$ hence we require 990.5 tiles=991 tiles.

Why the chosen dimensions? If the dimensions were too small, the surface area would have decreased, and hence more tiles would be required which would cause a much larger quantity of adhesive to be used and hence adding to the weight and cost. If the dimensions were larger much larger robots would be required for maintenance which will increase the cost, the replacement process would be hard as such huge tiles will have to be removed and added, the recycling of faulty tiles will take much longer, and the strength will decrease considerably. The chosen dimensions are also chosen based on the fairing space within the SpaceX Starship rocket, to ensure the tiles can be stored in a hexagonal shape and so don't waste any space in the 9m diameter[12] of the fairing.

Repairs will be made by robots, that will be constantly monitoring the tiles as they will be equipped to make penetrant, ultrasonic, X-Ray, and Eddy current inspection for possible repairs. Where found faulty, the tile will be removed and a new one added. The faulty tile will then be broken down into its original components for them to be reused again. As the tile is being removed the substrate layer will temporarily function as the protection until the new tile is added.

The windows will be made from triangular glass sections in a 3-pane configuration with the same dimensions as the tiles, the outermost pane is the thermal pane made from fused silica[13] which is thermal-shock resistant, has a low expansion coefficient, and does not darken due to high radiation. The innermost pane is the primary pressure pane, and the middle pane will act as the secondary pressure pane in case the first one fails. The secondary pressure pane will be thicker than the primary pressure pane. Both panes will be made of strengthened

[11] https://scholarworks.wmich.edu/cgi/viewcontent.cgi?article=4014&context=honors_theses

[12] https://www.spacex.com/vehicles/starship/#:~:text=The%20Starship%20payload%20fairing%20is,current%20or%20in%20development%20launcher.

[13] https://www.azom.com/article.aspx?ArticleID=4766

aluminosilicate glass[14] as they have a high strain point, low thermal expansion, and a better UV light cut off than soda-lime glass.

Another problem to consider when choosing the material for the thermal pane were hypervelocity particles, on high-velocity impact most of the kinetic energy of the particles is converted to heat energy which causes melting and evaporation of the glass, but fused silica with its low expansion coefficient[15] has no effect to these severe conditions.

The next problem to consider is glass fatigue and slow crack growth, which is caused when the glass weakens due to the high tensile stress in the presence of moisture, water weakens Si-O bonds at crack tips. The solution is to use tempered alumina silicate glass as pressure panes, tempered glass eliminates the concern as it causes residual compressive stress to build on the surface of the glass, unless excessively large amounts of loads completely relieve that compressive stress there will be no slow crack growth.

In addition to this, the thermal pane made from fused silica cannot be tempered due to its low expansion coefficient. Although fused silica is less prone to effects leading to glass fatigue, we still want to be completely sure, to do that we will be able to control the flaw population in the glass surface to control the threshold stress at which the fatigue initiates.

The windows will be able to withstand a pressure of 1100psi which is about 75 times the pressure inside The Spinning Donut.

The whole inner surface facing the Starship will be made of these triangular windows as is shown in the image of The Spinning Donut. This part of the settlement is the least vulnerable to damage.

If large incoming asteroids are detected, the Starship rocket will cause The Spinning Donut to move upwards, once the threat is avoided, The Spinning Donut will move down to its original altitude from the presence of a very thin atmosphere.

The Starship will be used to transport the structure in space and will be able to carry 54 tiles per trip.

First, the dock will be sent and assembled. Then two connecting pathways each on the opposite side of the dock will be sent and assembled. The tiles will be used to cover and offer protection. Once, the two connecting pathways are made, the inner ring will be assembled. For this, triangular glass panes will be sent and used to assemble the inner ring which will be completely made of the three-pane glass configuration discussed earlier.

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[14] https://matmatch.com/learn/material/aluminosilicate-glass

[15] https://www.accuratus.com/fused.html#:~:text=Fused%20silica%20glass%20is%20a,hydrofluoric%20acid%2C%20which%20dissolves%20silica.

The inner surface when completed will be followed by more tiles being brought and assembled forming the outer ring. When completed, quality checks will be made, making sure everything is sealed and then the atmosphere will be released into the settlement.

The Spinning Donut will then be spun at 4.2RPM using the rotatable engines of the Starship rocker to create an artificial gravity, after which the internal construction will be done.

Estimated material costs

Materials	Required quantity per kg	Cost per kg ($USD) [16]	Total cost ($USD)
Aluminum Oxynitride Glass	7392000	30	221,760,000
Carbon-Nanotubes	2800000	50	140,000,000
Sialon	2167750	70	151,742,500
Polyethylene	Mentioned below	Mentioned below	152,353
Super Adobe	702986	100	70,298,600
Sealant Gel	800400	11	8,804,400
Substrate Layer	6403065	-	261,026,355
PETE Solar Panels	-	-	125,973,600
Windows	-	-	19,230,167

The cost of 4" thick Poly-ethene with dimensions 108"x 48" is $97.04[17]. The surface area needed to be covered is 5248.9m^2 and the number of such sheets required are:

Surface area of the sheets =3.344m^2
5248.9/3.344 = 1570 sheets

The PETE solar panels cost 25,000 $USD for a 50kW plant[18] and these solar panels will be generating a total of 251947.2 kW of energy which makes the cost of all the solar panels $125,973,600.

To calculate the number of trips required by the Starship we calculated the densities of the materials being transported and compared it to the density of a theoretical material which would have the maximum payload capacity mass and volume of Starship's fairing. Using this density, we figured out whether it would make sense to calculate how much material could fit in Starship's fairing based on volume or mass.

[16] https://space.nss.org/settlement/nasa/Contest/Results/2011/HYPERION.pdf
[17] http://www.usafoam.com/closedcellfoam/polyethylene.html
[18] https://gcep.stanford.edu/pdfs/PETEtalk_gcep2010_Melosh.pdf

Density= mass/volume
99790.32kg/1100m^3 = 90.71kg/m^3

The materials being transported are all less dense than this value, and hence the transportation will be judged with respect to the volume of the Starship fairing instead of its payload capacity. Water was the exception here having a density of 997kg/m^3, and so we calculated its transport by considering its mass.

The tiles are triangular in shape and their dimensions were decided to make their transportation efficient. The tiles will be arranged in a shape of a hexagon.

The height of the Starship fairing is 22m [19].
No. of tiles in the starship=22m height of fairing/2m thickness per tile = 11 layers of tiles
11 layers*6 tiles per layer (due to the hexagon arrangement) = 66 tiles
The number of trips required for tiles to be transported is: 991/66= 15.01= 15
(The remaining .01 will be made up for when transporting windows.)

The windowpanes will have the same dimensions as the tiles, except that they will be much thinner; 3".

The total number of windowpane tiles required will be:

Inner Surface Area= Total surface Area – Outer Surface Area
= 8882.64m^2 - 5248.9m^2= 3633.74m^2
3633.74m^2 inner surface area / 5.3m^2 windowpane tile surface area =685.6 windowpane tiles
Hence 686 windowpane tiles will be required.

The windowpane tiles will also be arranged in the Starship fairing in a Hexagon Pattern.

No. of tiles in the starship=
22/0.0762 =288.7 = 288x6 (due to the hexagon arrangement) = 1728, this is more than twice the amount we need to transport and the remaining .01 of the above trip will be made up for here.

Hence, 1 trip will be required for to transport the windowpanes. The fairing will still be half empty which will be used to transport the soil that will be required on The Spinning Donut.

[19] https://www.fool.com/investing/2020/04/12/spacex-starship-5-things-you-need-to-know.aspx#:~:text=According%20to%20SpaceX's%20Users%20Guide,current%20or%20in%20development%20launcher.%22

Life Support	
Recycling Units	$450000
Atmosphere	$100,000
Agriculture	$36160
Health	$567890
Temperature regulation.	$30000

We will be using 314.1 square meters of land for aeroponics, the cost of an $80m^2$ aeroponic system is $9,201[20], which means that the cost for agriculture will be = $36160.

Temperature regulation includes the cost of the radiators which will be made of Aluminum honeycomb panels, they cost $34.12 per square meter[21], with the radiators having a surface area of 156 square meters, the cost = $5323

The rest of the cost is the piping and the liquids required for heat flow.

	Kilograms	$USD/kg	Total cost
Water, Food, Medicine etc.	178000	20	$3,560,000
Transport Cost	Mentioned below	Mentioned below	$40,000,000

The starship has a cost of 20$ per kg for cargo transportation, with 140000 liters of water, the cost to take water will be $2,803,200.

The total number of trips that the Starship will make for the construction of The Spinning donut is 20; 16 for the complete exoskeleton and tiling of the settlement and 5 for materials required for the internal construction. As discussed in “Transportation”, the cost of one trip is $2,000,000.

So the transportation cost = $40,000,000

[20] https://www.researchgate.net/publication/257776568_Technical_and_Economic_Analysis_of_Aeroponics_and_other_Systems_for_Potato_Mini-Tuber_Production_in_Latin_America

[21] https://www.indiamart.com/proddetail/aluminium-honeycomb-panel-10833124688.html

Entertainment	Cost ($USD)
Appliances (TVs, Consoles, Lighting, Unicycles, PCs)	200000
Automated Services (Robots, Computer systems etc.)	259678
Internet	0

The Spinning Donut will be using a very small amount of SpaceX internet, in return SpaceX will be receiving a considerable amount of publicity being the internet provider of the first permanent space settlement.

TOTAL COST= $ 1,044,191,703

Transport Vehicle

"It [the rocket] will free man from his remaining chains, the chains of gravity which still tie him to this planet. It will open to him the gates of heaven."

-Wernher Von Braun

A transport vehicle will be required to transport sections of the Spinning Donut into Low Earth Orbit for construction, and to choose such a vehicle, launch costs and payload capacity were of the utmost importance. We considered three of the largest and most competitive vehicles, and compared them.

	SpaceX Starship	Blue Origin New Glenn	NASA Space Launch System
Cost Per Launch (USD)	$2,000,000[22]	Unknown	$2,000,000,000[23]
Payload Capacity (kg)	100,000[24]	45,000[25]	70,000[26]
Cost Per Kilogram (USD)	$20[27]	Unknown	$28,571

Comparing these three vehicles, it is obvious that the SpaceX Starship would be the most cost-effective choice by far. Although the "cost per launch" hasn't been released by Blue Origin as of February 2021, it can be safely deduced that it will not have a more competitive "cost per kilogram" due to its relatively small payload capacity considering economies of scale. However, this may change in the future once Blue Origin releases their cost per launch for the New Glenn, for now, the SpaceX Starship is the superior rocket for our purpose. SpaceX is currently planning to build the Starship in four different variants to make sure the spacecraft is specialized to perform its task, and the satellite delivery variant will be used to transport pieces of the Spinning Donut into Low Earth Orbit due to its large cargo bay door[28] designed for this purpose.

[22] https://www.space.com/spacex-starship-flight-passenger-cost-elon-musk.html
[23] https://www.whitehouse.gov/wp-content/uploads/2019/10/shelby-mega-approps-10-23-19.pdf
[24] https://www.spacex.com/vehicles/starship/
[25] https://yellowdragonblogdotcom.files.wordpress.com/2019/01/new_glenn_payload_users_guide_rev_c.pdf
[26] https://www.lpi.usra.edu/lunar/constellation/SLS_FactSheet_long.pdf
[27] https://wccftech.com/spacex-launch-costs-down-musk/#:~:text=These%20are%20military%20payloads%2C%20with,is%20certified%20to%20deliver%20them.&text=Returning%20to%20the%20moon%20missions,kg%20for%20delivering%20lunar%20payloads.
[28] https://www.liebertpub.com/doi/10.1089/space.2018.29013.emu

Image of Starship

Credit: SpaceX

For cargo that the Spinning Donut might need on an emergency basis, the Aevum Ravn X drone could be used which would be able to deliver said cargo in about 180 minutes[29]. It should also be noted that this drone is operational in 96%[30] of weather conditions, which is important for emergency delivery of any cargo.

The Ravn X drone. Credit: Aevum

[29] https://techcrunch.com/2020/12/03/space-startup-aevum-debuts-worlds-first-fully-autonomous-orbital-rocket-launching-drone/

[30] https://www.businesswire.com/news/home/20201203005732/en/Aevum-Rolls-Out-Ravn-X-The-World%E2%80%99s-First-Autonomous-Launch-Vehicle-and-the-Largest-Unmanned-Aircraft-System-UAS

Energy

"Energy can't be created or destroyed, and energy flows. It must be in a direction, with some kind of internal, emotive, spiritual direction. It must have some effect somewhere."

-Keanu Reeves

Power is necessary for the settlement to function and to aid those who reside within. The Spinning Donut will be orbiting the Earth outside most of its atmosphere, due to which there will be plenty of solar energy to be used.

The orbit of the ISS, if followed, would have caused night every 45 minutes[31], which would have created the following problems:

With sunlight only falling on the top of the settlement, there was less area for the solar panels to be attached to The Spinning Donut. In addition to this, the day-and-night cycle would be needed to be controlled, as we need to provide about 12 hours of daylight to accommodate the circadian rhythm. Another problem that is to be considered is that The Spinning Donut itself needs to be illuminated, and with the normal orbit, we would have to turn off the lights every 45 minutes.

To avoid these problems, we decided to shift the orbit to a polar orbit which would result in The Spinning Donut being exposed to sunlight all the time.

Solar panels will be under the first tile layer i.e., Aluminium Oxynitride Glass, which is transparent and will provide protection while allowing light to reach the solar panels. The solar panels will be installed on the outer surface of the settlement.

The solar panels used are Photon Enhanced Thermionic Emission (PETE) solar panels. These are twice as efficient[32] (50%) as normal solar panels and when coupled with the thermal conversion cycle can reach up to 60% efficiency. PETE solar panels make use of the heat energy other solar panels waste as they can only absorb certain wavelengths of light. Moreover, as compared to normal solar panels that stop functioning at 100^0C, the PETE solar panels can function[33] at 250^0C, which is appropriate to the extreme temperatures in space.

The total power required by the settlement is as follows:

Power usage for Household:

40 OLED 66" TVs with an average watch time of 3hrs and 30mins = 16240 kW per day

[31] https://www.nasa.gov/missions/highlights/webcasts/shuttle/sts112/iss-qa.html
[32] https://www.sciencedirect.com/science/article/pii/S0927024815002068
[33] https://www.offgridenergyindependence.com/articles/2538/using-both-light-and-heat-of-solar-radiation-to-produce-electricity

With a PS5 in each apartment and an average playtime of 1hr and 30mins = 2976kW per day

3 Compact Fluorescent bulbs for an apartment and 4 for each bathroom, with a lighting time of 18 hours = 49680+3312= 52992kW per day

No outside lighting will be required as we can control the window shutters for the day and night cycles.

Cell phone and Laptop charging= 2762kW per day

Agriculture = 500kW per day

Docks= 1500kW per day

Starship= 200kW per day

Automated Systems (including water and O2 recovery systems): 1000kW.

Total Energy required = approx. 79000kW per day

The solar panels will be only in the tiles that will be covering the outer curved surface of The Spinning Donut. According to Pappus' First Centroid theorem: $2\pi(R+r+2r/\pi)(\pi r)$

The outer curved surface area of the settlement is = 5248.9m^2

The PETE solar panels being 2 times more efficient than the normal solar panels will be producing 2kW/h of power per m^2. With a surface area of 5248.9m^2, the total power being produced will be 251947.2kW/ day, but as we will be in a polar orbit, with the settlement constantly rotating at a time only half the solar panels will be converting energy, hence the actual power produced is 125973.6kW/day, which leaves a lot of surplus energy.

Surplus Energy= 46973.6 kW/day

This surplus energy will be stored in XANTERX XW storage batteries to be used in case of emergencies or to accommodate future power usage needs.

Water

"Water is the driving force of all nature."

-Leonardo da Vinci

Usage:

Water is in fact, the most important nutrient for the human body and to live in space we don't want it to run out. We will be taking water with us as we do need something to start with, to be on the safe side we will initially be taking about 15141.65 liters of water. An average adult weighs about 62 kg[34] and requires about 2 liters of water daily. Showering, food preparation, dishwashing, toilet flushes, handwashing, and laundry accounts for 100 to 175 gallons per day. This is the normal use on earth, however, on The Spinning Donut, this can be greatly reduced. The most amount of water lost is due to toilet flushes which in this case is accounted to zero as the greywater (water collected during a shower) will be used. Dishwashing will also be partially done by greywater and then sterilized by hot steam which can be obtained from the filtration system discussed later. Clean clothes are also very important, we do not want people wearing the same dirty clothes for long periods of time. Garments will be "washed" by hydrogen peroxide which eliminates 99.99% of the bacteria[35], bringing the water consumption to zero. Showering time will be reduced to 6min to reduce water loss, with all the water being collected and used for hygiene and filtration.

After all these efficient measures the water consumption will drop down to 12 gallons for showers as 2 gallons for every minute of showering, 2 liters for drinking, 2 liters for food preparation, and with 5 minutes of faucet time 14 liters/day per person which account to a total of about 64 liters/day per person. With 100 people in the settlement, we will require 6400 liters of H20 daily. The efficiency rate of water recycling from waste and other sources is 90% which is not feasible when it comes to self-sustainability, so what do we do about the other 10%?

Well, we will be setting up crops and growing them with aeroponics, indoor crops grown using aeroponics transpire ¼ to 1/3 cups of water per day per square foot.[36] We will be setting up 314 square meters of space for aeroponics which will give us about 24.7 liters of transpired water daily. The question is that the water obtained does not matter because we must provide the crops with water, which is many times larger than the amount that transpired, so we will be reducing it to zero as the greywater will be filtered using reverse osmosis and recirculation.

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[34] https://bmcpublichealth.biomedcentral.com/articles/10.1186/1471-2458-12-439#:~:text=Average%20body%20mass%20globally%20was%2062%20kg.&text=North%20America%20has%20the%20highest,biomass%20corresponds%20to%2012%20adults.

[35] https://news.arizona.edu/story/doing-laundry-outer-space-shes-working-solution

[36] https://aeroponicsdiy.com/plant-transpiration-in-aeroponics/

Initially, a 20-day water supply will be loaded to be on the safe side, as we do need something to start with, this will equal to 128000 liters, 140000 liters, again, to be on the safe side, which will be transported in CWC's (contingency water containers) with one container being able to contain 41 kilograms of water[37]. 1400602 liters of water is equal to about 140160 kilograms which will be transported in a total of three thousand four hundred and thirty-four CWC's.

Filtration:

Water will be collected in the form of urine, sweat, respiratory gases, greywater, faucet water, and water left after washing hands, even water transpired by the 341 sq. meters of crops. This will be led to the filtration system where in the inner chamber the contents will be heated to evaporate water which is condensed and collected in the outer chamber. The water then will be heated once again to remove bad odors and then disinfected; iodine and silver are two contenders, but silver will be used as an excess amount of iodine can cause thyroid issues.

Unit Requirements:

An average person produces 1.4 liters of urine daily[38], with 100 people on board 140 liters of urine is produced daily. The urine processor assembly in one filtration unit corresponds to the needs of 6 people and handles a load of 9kg/day of urine.[39] Accordingly, 16 filtration units will be required to fulfill the daily requirement.

[37] https://science.nasa.gov/science-news/science-at-nasa/2000/ast02nov_1
[38] https://www.news-medical.net/health/Urine-Composition-Whats-Normal.aspx
[39] https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20090033097.pdf

Food

"One of the very nicest things about life is the way we must regularly stop whatever it is we are doing and devote our attention to eating."

-Luciano Pavarotti

Diet plan

It is estimated that an adult woman needs about 1600 to 2400 calories per day[40] and an adult man needs 2,000 to 3,000 calories per day[41]. For simplification for calculations, we will assume 2,200 calories intake for a person each day to stay healthy.

The following table shows a planned summary of the daily diet for each person, and the number of calories and basic nutrients it contains.

No.	Food	Daily intake per person/g	Calories	Protein/ g	Carbohydrates/ g	Fats/g	Fiber /g
1	Wheat	175	595	23.1	126.7	4.4	18.8
2	Spinach	100	23	2.9	4	0.4	2.2
3	Carrot	100	41	0.9	14.3	0.2	2.8
4	Potatoes	200	174	3.8	42	0.2	3.6
5	Soybean	150	260	24.9	19.4	13.5	9
6	Rice	200	260	4.7	58	0.4	0.8
7	Barley	150	531	18	109.5	3.5.	25.5
8	Raw oat	60	233.4	8.1	40.7	3.7	5.9
9	Oat milk	22g oat used to make milk	120	3	16	5	2
10	3 kg Garlic will be grown in 120 days to be used as a spice.						

Table 1 - Daily diet per person[42]

This diet was selected while keeping the caloric and nutritional needs of the population in mind. These food items will provide enough nutrients with less intake so the least possible area would be covered by the crops, and so more space on the settlement can be used for other purposes.

Dairy products are rich in Protein, Calcium, Vitamin D, and Potassium, but dairy animals are inefficient to farm because their farming requires a large amount of resources for a relatively

[40] https://www.nhs.uk/common-health-questions/food-and-diet/what-should-my-daily-intake-of-calories-be/
[41] https://www.nhs.uk/common-health-questions/food-and-diet/what-should-my-daily-intake-of-calories-be/
[42] All information for the calculations in this table has been obtained from:
https://fdc.nal.usda.gov/
https://www.healthline.com/

small amount of food. They need farmers and their time. They need water to drink and to grow crops for their food. More oxygen is needed for animals and their food crops to respire, putting a strain on our oxygen supply. Animal farms will take up a lot of land. The crops being grown on the settlement will provide all the above-mentioned nutrients that are present in dairy products. Oat milk was specifically added to the diet plan, acting as a substitute for dairy milk, because people may get exhausted with water as the only liquid intake and might have the craving to drink milk instead. It is a great source of Vitamin B, has beta-glucans which have heart health benefits, and is great for bone health[43]. All these factors preferred more plant growth to cover all the nutrients over animal farming.

Aside from the nutritious benefits, the selected crops can be cooked and eaten with a variety of recipes. Wheat can be used to make flour for bread and to make sugar free biscuits. Spinach can be boiled in water or stir-fried in vegetable oil made from soybeans. Soybeans can be eaten cooked as well. Other than being eaten raw, carrots can be used as a salad. With no spices, food seems bland and tasteless and that is why we are growing garlic, which is a great spice for food, with a lot of health benefits as well. A creative chef will also be one of the inhabitants and he will be responsible for making the food as appetizing and appealing as possible.

Aeroponics

After taking a lot of factors into consideration, we decided that an aeroponics system was the best option for growth in space. Aeroponics is a system of growing crops in an enclosed system, with environmental conditions being closely monitored, according to the requirement of the crops. There are several reasons for choosing this method.

- In an aeroponics system, plants can be grown vertically saving a lot of space on the settlement.
- It produces a yield approximately three times more than traditional agriculture.
- No soil is needed for the aeroponics system of growth.
- 98% less water is consumed in irrigation, as compared to the amount that is commonly used on earth.
- 60% fewer nutrients are used by aeroponics, with great precision, without any danger of them being wasted.[44]
- Pesticide usage is reduced by 100%.
- Maintenance is easily done because the primary task in maintenance is disinfecting and sterilizing the equipment.

[43] https://www.healthline.com/nutrition/oat-milk
[44] https://www.nasa.gov/vision/earth/technologies/aeroponic_plants.html

Amount of nutrients and growing area needed.

Food	Growing period	Requirement at the end of growth/tons	Nutrients needed for one yield in traditional farming/kg	Nutrients needed for one yield in aeroponics (60% fewer nutrients)/ kg	Nutrients required at the end of 8 months/kg
Wheat	8 months	4.2	110	44	44
Spinach	42 days	0.42	7.6	3.04	17.5
Carrot	75 days	0.75	18.5	7.4	23.7
Potatoes	3 months	1.8	9	3.6	9.6
Soybeans	4 months	1.8	24.5	9.8	19.6
Rice	4 months	2.4	48	19.2	38.4
Barley	90 days	1.35	45.6	18.24	48.6
Oats	6 months	1.476	35.7	14.28	19
Garlic	120 days	0.003	0.1	0.04	0.08
Total		14.199	299	119.6	220.48

Table 2 Quantity and amount of nutrients for crops

A vertical aeroponics grow system can produce an average of 45.2 kg per square meter of crops. With this information, an area of only 314.1 square meters would be needed to grow 14.199 tons of crops.

At the end of eight months, the total amount of nutrients needed for all these yields will be approximately 220.48 kg. These nutrients can be obtained from the processing of human urine, which will produce about 302 kg of nutrients in 8 months.

Light and power for aeroponics

A report from Lightning Research Centre, Rensselaer Polytechnic Institute stated that LEDs are a better source of light than high-pressure sodium lamps, because their spectrum and intensity can be controlled.[45] They have low heat radiation. Fine-tune controls can allow optimal lighting conditions for farming. Thus, LEDs are chosen as a source of light for crops, saving a lot of expenses as well since LEDs are a lot cheaper than high-pressure sodium lamps.

Aeroponics does not use soil, but they do need water at high pressure, for which we need a power supply. A power supply is also required to operate the technology which will monitor the pH, oxygen, and carbon dioxide levels.

Labor required in aeroponics.

Since aeroponics is associated with advanced technology, people having advanced knowledge and experience in this field will be assigned to control the machinery. During the growth period,

[45] https://www.lrc.rpi.edu/resources/newsroom/pdf/2010/AeroFarms_8511.pdf

automatic machinery will be used. Temperature, pH, oxygen, carbon dioxide, and other environmental conditions will be set according to the crops' requirements. If the conditions are altered due to any problem, an alarm would sound to alert the technician. For irrigation and nutrients, the pumps could be set up to automatically provide water and nutrients at intervals. This way no person would be required to monitor the conditions 24 hours. A person will be assigned to check on the crops and their conditions after every 24 hours. There are 4 to 5 farmers for 1 acre in traditional farming. Since 314.1 square meters is not even $1/4^{th}$ of an acre, and the workload is a lot lesser than in traditional farming, 1 farmer is sufficient to harvest the crops.

Temperature

"It is always easy to create an ordinary city; what is difficult is to create an extraordinary one, peaceful and restful one, smart and tidy, artful and cultivated one, in short, a livable one! And Zurich is such a city!"

-Mehmet Murat ildan

In order for The Spinning Donut to be habitable and comfortable, the temperature inside it has to be close to room temperature. The structure of temperature regulation will be quite similar to the one in the ISS but on a larger scale since it is designed to hold a capacity of 100 people.

Removing excess heat from inside

After thermally insulating the inside of the settlement, all the electronics and humans will generate heat which will eventually result in overheating. To counter this, a thermal control system consisting of water loops, cold plates, and radiators is necessary. This system has been divided into three parts.

Heat acquisition/collection

In the first step, thermal energy from people and electronics has to be gathered, this task will be accomplished by installing cold plates throughout the settlement and in the apartment rooms. These cold plates will be exposed to the electronics and gain waste heat energy. As for the environment as a whole, pipes filled with water will be exposed and take in waste heat energy.

Heat transfer

After the cold plates gain energy from electronics and humans, it has to be transferred to the radiators so that this waste heat can be rejected to space. This is accomplished by the help of transport fluids connected to the cold plates and radiators and then circulated; the fluid would take energy from the cold plates and release it through radiator panels to outer space. The fluid should be efficient in heat transfer and also have an extremely low melting point so that it doesn't freeze when temperatures drop. A suitable liquid for this job is ammonia which has a melting point of -77.73 C. A two-loop system will be used. One loop will be water-based and will be installed where the inhabitants live to avoid poisoning in case of a leak. The other loop will be a more efficient ammonia-based loop which will be connected to the radiators. The energy has to be transported from the water to the ammonia, and so this will be done with the help of heat exchangers connected to both of the loops. Heat exchangers and cold plates will be made from stainless steel. Pump modules will be installed to circulate water or ammonia.

Heat radiation

After energy is transported to ammonia it will radiate heat away through radiators. They will be placed near the center of the settlement so that they don't suffer damage due to the large centrifugal force present near the edge of The Spinning Donut. On the ISS there is only a maximum of 6 crew members (heat is also generated by several operations on the ISS and by electronics). The Spinning Donut is built to hold a capacity of 100 people and has quite a bit of electronics as well. The number of panels used on the ISS can be multiplied by 100 and divided by 6 to find the area for radiators needed on The Spinning Donut. It is to be noted that the ISS has 14 radiator panels[46] with a total area of 156 square meters.

$$\frac{156 \text{ square meters}}{6 \text{ people}} = \frac{x \text{ square meters}}{100 \text{ people}}$$

X= 2600 square meters required.
Each panel has an area of 5.4 square meters (1.8m*3m), so

$$\frac{2600 \text{ square meters}}{5.4 \text{ square meters per panel}} = 482 \text{ panels will be required.}$$

We decided to attach the radiator panels between the inner ring of the settlement and the outer of the center room to reduce the amount of centrifugal force on the panels as well as to increase the structural integrity.

[46] https://science.nasa.gov/science-news/science-at-nasa/2001/ast21mar_1#:~:text=The%20heated%20ammonia%20circulates%20through,made%20of%20honeycomb%20aluminum%20panels.

Atmosphere

"I love to breathe. Oxygen is sexy!"

-Kris Carr

Atmosphere in space needs two main components: oxygen, and nitrogen. Pure oxygen can be used but this is highly flammable and thus dangerous. Nitrogen is an inert gas and will stay as it is forever. Oxygen will be used by the inhabitants to breathe, and so it has to be generated on a long-term basis.

Oxygen can be artificially generated using reactors. One example of this is MOXIE. It generates about 10g of Oxygen per hour[47]. This totals to 87.6kg per year. It is worth noting that this machine is small and for The Spinning Donut a larger version of MOXIE can be created. To create 10g of oxygen, a power supply of 300 Watts is needed. A 100 people on average consume 80kg of oxygen per hour so to create enough oxygen for 100 people, 2,400,000 Watts would be required.

A human consumes about 800g of oxygen per day which adds up to 292 kg per year. For a hundred people it becomes approximately 30000kg of oxygen per year. One way to generate oxygen is by trees. An average tree produces about 120kg of Oxygen per year. To generate oxygen for a hundred people we need about 250 trees. If each tree takes up $3m^2$ of space then 250 trees will take up an area of $750m^2$. It is known that the more the leaf mass (or the leaf area index), the more oxygen it can produce[48], so maple, true fir, and spruce are preferable.

A combination of a reactor and trees will be used because trees have many other benefits as well such as boosting the immune system[49], improve moods, and overall being aesthetically pleasing. A reactor can produce any remaining required oxygen.

The atmosphere can be delivered to The Spinning Donut using high-pressure tanks filled with the necessary compositions of gases that form air.

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[47] https://mars.nasa.gov/mars2020/spacecraft/instruments/moxie/

[48] https://nature.berkeley.edu/garbelottowp/?qa_faqs=which-trees-give-off-the-most-oxygen

[49] https://www.dec.ny.gov/lands/90720.html#:~:text=Exposure%20to%20forests%20boosts%20our%20immune%20system.&text=Phytoncides%20have%20antibacterial%20and%20antifungal,natural%20killer%20cells%20or%20NK.

Internet

"We are all connected by the Internet, like neurons in a giant brain."

-Stephen Hawking

The Internet has become almost a necessity in modern times to the point where paying the Internet bill is synonymous with paying the electricity and water bills, especially in developed countries. About 85%[50] of the United States population has access to the Internet, and this number is rapidly increasing due to constant innovation to make the Internet more accessible. The Internet will be imperative for the same reasons that it is used on Earth, for education, entertainment, communication, etc. but even more so due to the inhabitants living in a more isolated society and so it will also serve to "connect" the inhabitants of the settlement to the people of Earth. Thus, a livable space settlement cannot be built without considering how to provide Internet access to its inhabitants.

For the Internet to work, bits "0"s and "1"s must be transported from the Space Settlement to their respective data centers on Earth and back. The International Space Station achieves this by sending radio waves at two different frequencies signaling a "0" or a "1" to a relay satellite, which then sends the signal down to a space communication on Earth. Then the signal travels like it usually does through Ethernet and Optic Fiber cables to whichever data center has the information needed stored on their server. The bits then travel all the way back to the ISS through the same path. The ISS loses internet access for 15 minutes after every 90 minutes[51] due to it constantly orbiting the Earth and moving out of the satellite coverage zone.

This is the main fault of this method of connecting to the World Wide Web. It will be extremely annoying and inconvenient for the settlement inhabitants to lose their Internet connection every 90 minutes. The ISS also only has to provide Internet to the handful of Astronauts on board (usually about 6) whereas the Internet system on The Spinning Donut will have to work for a large community of about a hundred people. Another fault is the 0.5 second latency that the ISS has[52], which is 20 times slower than the average internet router latency of 0.025 second or 25 milliseconds due to the considerable distance the signal has to travel. The 600Mbps broadband of the ISS is also far too less for 100 people. Considering these factors, as well as the recent advancement of Internet providing satellites such as OneWeb, Amazon's Kuiper, and most notably SpaceX's Starlink, we came up with an alternate way to provide Internet to The Spinning Donut which covers the faults that the ISS has (which is fine for a crew of Astronauts, but less fine for a large, 100-person community) while providing high broadband internet to each inhabitant on The Spinning Donut.

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[50] https://www.statista.com/topics/2237/internet-usage-in-the-united-states/
[51] https://www.kaspersky.com/blog/internet-in-space/28267/
[52] https://www.kaspersky.com/blog/internet-in-space/28267/

The inhabitants on the Spinning Donut wouldn't be able to tell if there is any difference between how the Internet works in their living areas versus on Earth, and that's because, within their living areas, there would be no difference. This would also help with adaptability. There would be a router in every living space that would receive data from any devices connected to it, just like on Earth. All the routers from each living space would each be connected to an Ethernet cable which would all transfer data to an Optic Fiber cable. The Optic Fiber would transfer data to the laser communication system. The laser communication system would then transmit data to a Starlink satellite (or one of its competitors) similarly to how SpaceX's current Starlink satellites in orbit do, with the exception being that for Starlink, these lasers are used to communicate between satellites. Lasers would be used due to their high-frequency bandwidth, which would allow them to carry more information than radio waves; appropriate for a 100-person space settlement, they also require less power than radio-based communication, which is a major advantage due to the limited supply of power on possible space settlements. The satellites are already configured to receive laser signals from other satellites, and so there would be no change necessary for the constellation of satellites, the Spinning Donut would behave just like another Starlink satellite in transmitting and receiving information due to the Spinning Donut orbiting at a similar altitude to the satellites. Just like the Starlink satellites, 4 lasers would be connected to a satellite each using because of the time it takes for a laser to connect to a satellite after it is out of proximity, this will be done by having 5 optical communication systems on the Spinning Donut. This will ensure an uninterrupted internet connection. The satellites would then transport the data via radio waves down to the Earth and back up using their phased array antennas. The inhabitants of the Spinning Donut can expect Internet speeds faster than 150 Mbps and a latency between 0.01 to 0.04 seconds[53], or 10-40 milliseconds, which is a speed fast enough to do anything required by an inhabitant, such as stream 4K video, or play video games.

These satellites are being aimed at rural, low-income areas, and so the costs to set up and provide internet to the Spinning Donut will be quite low. Morgan Stanley projects that space-based internet could be worth over $410 billion by 2040[54], aside from SpaceX's Starlink, many companies such as Amazon, Iridium, and Boeing are also planning to launch satellite internet projects which will increase competition and could drive down prices further.

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[53] https://www.satelliteinternet.com/providers/starlink/#:~:text=In%20private%20beta%20test%20results,low%20latency%20of%2020%20milliseconds.&text=Starlink%20tells%20customers%20to%20expect,in%20the%20beta%20testing%20phase.

[54] https://www.morganstanley.com/ideas/investing-in-space

Recycling

"All the human and animal manure which the world wastes, if returned to the land, instead of being thrown into the sea, would suffice to nourish the world."

-Victor Hugo

Human waste

Human urine and human feces are best to be collected and processed separately. They are also stored separately in the human body. A urine-diverting dry toilet will be used which will allow improvement in sanitation, because feces will dry, and pathogens will be killed more easily. This way urine can be treated and used as a potential resource for the extraction of nutrients, as human urine is an excellent source of the three primary nutrients used to fertilize crops. It contains 0.9% Nitrogen, 0.3% Potassium and 0.06% Phosphorus[55]. Considering an average amount of 1 liter of urine per person daily, about 302 kg of nutrients can be obtained from urine in eight months which is more than enough for aeroponics.

Human urine

A urine processor assembly can be used to process the urine to collect water and extract nutrients. One unit of a urine processor assembly handles a load of 9 liters per day of urine[56], and with 1 liter of urine per person daily, 11 units will be required to fulfill the daily requirement. One unit includes the following:

1. Wastewater storage tank assembly: Fresh human urine is free from bacteria, but after it is stored for over 24 hours, ammonia gas is released causing a pungent smell, so it is important to collect urine in odor-tight storage tanks. It is treated with Calcium Hydroxide. Calcium Hydroxide has a pH above 12 which will help to kill the germs and sterilize the urine. It will also form products calcium phosphate and nitrogen-rich ammonia gas.
2. Extraction of nutrients: The gas will be diverted to another chemical reaction vessel where it will react with sulfuric acid to form ammonium sulfate. Both ammonium sulfate and calcium phosphate are nutrients that are required to fertilize crops.
3. Distillation Assembly: At low pressure, water is evaporated from the urine and collected in a product water stream.
4. Recycle Filter Tank Assembly: Urine material left from the distillation process is concentrate. Non-condensable gases are treated to recover water and add to the product water stream.

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[55] https://pubmed.ncbi.nlm.nih.gov/17881847/

[56] https://www.google.com/url?sa=t&source=web&rct=j&url=https://ntrs.nasa.gov/api/citations/20030066933/downloads/20030066933.pdf&ved=2ahUKEwi05pbhm8vuAhWUX8AKHSjLAY4QFjAEegQICxAJ&usg=AOvVaw1kXZQpD1uYAgQkR3lb5opu&cshid=1612271423548

Human feces

Human feces are a potential source of biomass and fuel. Anaerobic digestion is the best way to obtain energy from human feces. Through anaerobic digestion, the separated feces can generate biogas (about 60% methane[57]). Anaerobic digestion is the bacterial breakdown of feces in the absence of oxygen. It allows for methane to be preserved and used in a beneficial way. Also, feces sludge can be dried and charred to be used as fuel, containing the same amount of energy as coal and charcoal. Sludge occupies less volume, and the process has low operating costs. All the human waste collected could serve electricity for 138 million households in the world[58]. The feces of a population of 6.8 billion people produce 5.98×10^{18} J per year[59]. Based on this information, a population of 100 people on The Spinning Donut will produce 8.79×10^{10} Joules of energy per year.

Metals

Parts of the settlement may get destroyed from time to time and will need regular repair and maintenance. Not recycling metals would cause metallic materials to be wasted and result in landfills which would be a waste of resources, both land, and metal. For this reason, it is important to recycle metals. They can be recycled again and again without losing their properties. First, the waste metal materials to be recycled will be collected. Then they will be sorted according to their types using sensors and magnets due to their different magnetic properties. They will then be shredded to increase their surface area to volume ratio so that they consume less energy to melt. To purify them, electrolysis can be performed. Finally, the metals are solidified and welded into the desired shape.

Plastic

It is important to recycle plastics for similar reasons for recycling metals. Plastic waste would cause unnecessary pollution if it were disposed of the way it is on Earth. Its recycling method is almost identical to metals. It includes collecting, sorting, purifying it by washing, shredding, melting, and then forming products by injection molding.

[57] https://phys.org/news/2015-11-human-excrement-fuel-world.html#:~:text=Biogas%E2%80%94about%2060%20percent%20methane,and%20Health%20said%20on%20Tuesday.

[58] https://inweh.unu.edu/wp-content/uploads/2015/03/Valuing-Human-Waste-an-as-Energy-Resource-Web.pdf

[59] http://large.stanford.edu/courses/2010/ph240/cash2/

Housing

"The ache for home lives in all of us. The safe place where we can go as we are and not be questioned."

-Maya Angelou

Taking into account that every area of the settlement is important, housing is designed in such a way that the least space possible will be used yet providing comfort to the residents. Inhabitants will be sent up to The Spinning Donut and will be chosen in pairs to promote mental health. To use up a minimum amount of space, we can design multiple floors.

When it comes to designing apartments in the settlement, we must keep in mind the differences between Earth and Space. On the earth, gravity acts downwards in all positions so the overall structure of apartments is usually rectangular, but if we apply this to our torus then some rooms will have tilted gravity (the gravity will at perpendicular to the surface of the settlement which is curved), this has been detailed below in Math Box 1.

One approach is to line the bottom floor with the edge of the settlement, with the top floors equally curved with the bottom one; this will solve the problem for the bottom floor but the rooms on the upper floor will still have the problem although much less significant compared to a rectangular-shaped building. We can line the bottom floor with the edge of the settlement with its walls perpendicular to the floor; this will cause the upper rooms to curve more and the problem of tilted gravity will be resolved.

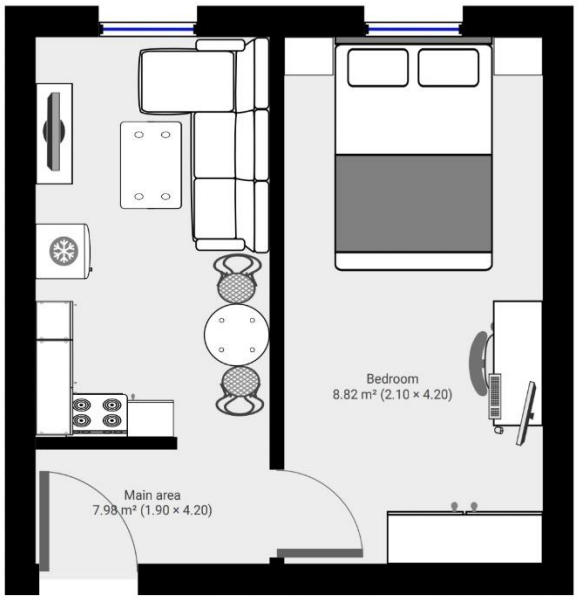
The overall shape will resemble a sector of a circle.

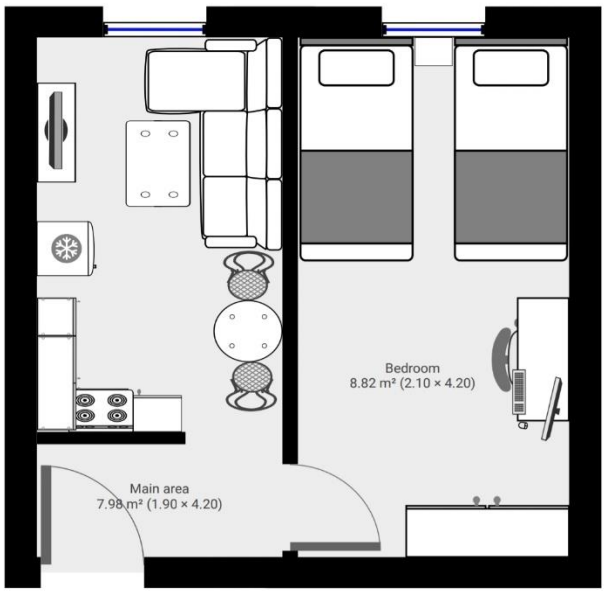
There will be 2 types of rooms, one for 2 people and another for just 1 person. The room for 1 person (3.00 x 4.20) m will be smaller than the room for 2 people (4.00 x 4.20) m. Since the overall structure of rooms will resemble a sector so the total length in higher floors will decrease; for this reason, there will be different combinations of rooms onea each floor. The length linearly decreases from ground to top floor, approximately 5 meters for every floor, more detail in math box 2. The table below summarizes the floor plan. The total number of rooms is 60. There is also a washroom on every floor.

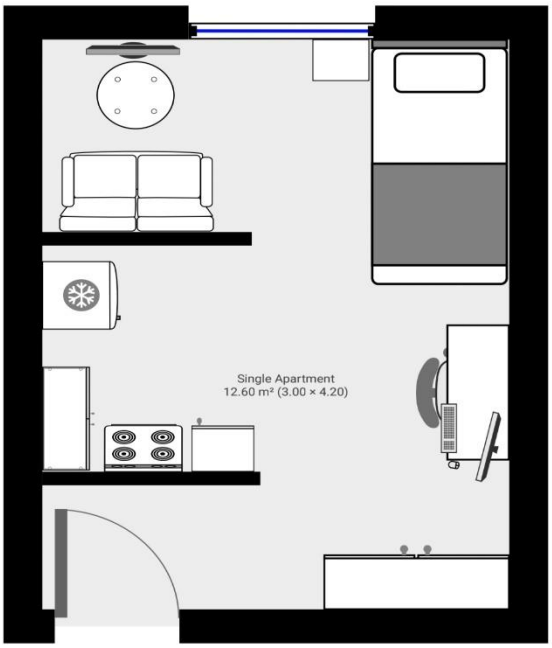
Floors	Ground	First	Second
# of apartments for two people	20	15	10
# of apartments for one person	0	5	10

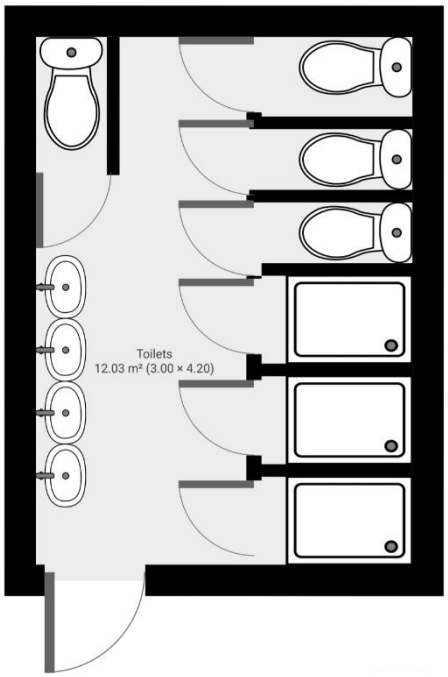
Apartments

A single apartment for two people has a main area, where there is a kitchen in the corner and a lounge. The main area has a door leading to the bedroom. Each apartment has two fixed windows, one in the lounge and one in the bedroom. Windows will help people not feel suffocated and enclosed in four walls. They will also provide a compelling view when they are bored. In half of the apartments, we have two single beds and in the other half, we have one double bed. A single apartment for one person has a single bed, a kitchen, a window, and a small lounging area as well.









Bathrooms

We have one washroom on each floor, to be shared by 20 rooms. The dimensions of each washroom are (3.00 x 4.20) m. It covers an area of 12.03 sq. m. Each washroom has 4 dry toilets and 3 showers. The timings to use the showers will be allocated to each room to avoid crowding and the formation of lines to use the showers. There are four sinks in each washroom.

Math box 1

To prove that a rectangular overall shape would have a tilted gravity is fairly straight forward. Imagine a circle of length 50m (length of the settlement) and a chord of length 83m (approximate total length of the bottom floor). Now we add a straight line from the center of the circle to the edge (radius), this line is the direction of the force of gravity; this line will be perpendicular to the edges of the circle and can be a perpendicular bisector of the chord. However, this line won't be perpendicular to the other points along the chord proving the fact that the gravity in this room will be tilted. The tilt increases with an increase in height.

Math box 2

It can be done using the concept of similar circles. The total length of the bottom floor is about 80m (not including the washrooms). Each floor has a height of 3m which means the distance from the center of settlement decreases by multiples of 3 for each floor.

Ground	49/49x83	83m (2sig)
First	46/49x83	78m (2sig)
second	43/49x83	73m (2sig)

Along the circumference of the circle the length of the smaller room (for 1 person) is 3 meters, and the length of the larger room (for 2 people) is 4 meters, a certain combination of these rooms will fit the total length. The width of all the rooms will be constant.

Transportation

"You cannot understand a city without using its public transportation system."

-Erol Ozan

Unicycle

Having roads and transport vehicles like cars is unnecessary in a small settlement of 100 people. It is an avoidable use of space and fuel. The inhabitants could always walk to the destination in most instances. But still, for distances that may seem long and to help conserve the inhabitant's daily energy use, each person will have a unicycle. Using a unicycle is preferred to using bicycles due to their more compact size. Bicycles are also heavier than unicycles and they will occupy more space in the apartments, whereas unicycles are easier to store. Where hoverboards are concerned, they require battery charging, for which more unnecessary power will be used, and their batteries degrade over time and so they don't last as long as unicycles.

It takes an average person 10-15 hours to learn to ride it[60], and then people get used to it just like a simple bicycle. It is thought that unicycles are difficult to balance because there are no handlebars, but the cycles that we selected have handlebars to make it easy for all people to ride them, and their seats can be adjusted for people of different heights. Using a unicycle is also a fun way of exercising for people to keep themselves active and in shape. It increases their coordination and balance. Although it has been observed that "the vast majority of unicycle falls result in the rider landing standing uninjured on their feet[61]", for safety purposes, like any other vehicle, people will be required to wear safety equipment, especially a helmet.

Corridor

A 1.5m wide path will be created which will go through all the major sites on The Spinning Donut. This width will help to reduce the chances of unicycles colliding with each other or other people.

[60] https://www.municycle.com.au/learning_to_ride.html
[61] https://www.municycle.com.au/learning_to_ride.html

Education

"Education is the kindling of a flame, not the filling of a vessel."

-Socrates

Since there will be no children in the initial population, the education plan will not come into action until a few years later.

There will be five stages of education.

1. Pre-primary
2. Primary (Grade 1-5)
3. Middle (Grade 6-8)
4. High School (Grade 9-12)
5. Specialization

Pre-primary

This is the stage where the basic numbers, counting, alphabets, colors, shapes, and writing are taught. Having these classes in school will require a special teacher to deal with the kids, so it is best to save people for other professions by handing the responsibility of teaching these learning steps to the parents.

Primary and Middle School

In primary and middle school, the basic subjects are Mathematics, English, History, and Natural Sciences. People will not be trained specifically to teach students these subjects. We will be only needing a special teacher for English, as Mathematics and Environmental Study can be taught by the engineers in the settlement. Natural Sciences can be taught by health professionals and History by Historians, who will be studying everything that led to the formation of the settlement and recording all the happenings since the settlement was made. A subject for religion will not be required as the settlement will consist of people with various religions, and children can get religious education from their parents. Thus, of the four subjects, three teachers will be specialists in the respective fields of subjects, and one teacher will be trained specifically to teach English.

High School

In High School, basic knowledge about subjects of different fields will be given. Students can choose any five subjects among all these subjects.

- Mathematics
- Physics
- Biology
- Chemistry
- Business Studies
- Economics
- Computer Sciences
- Politics
- Arts

Other than these, at a high school level, students will have compulsory classes where they will be taught how to administer first aid, be given general knowledge about operating a space settlement, and everything they need to know to help prepare them for emergencies. They will take the compulsory classes until they pass the final test. They can give the test for compulsory classes whenever they think they are ready.

All the subjects will again be taught by the professionals of their respective fields working on the space settlement.

Specialization

At this level, there will be no subjects. Students will be handed over to the departments they want to specialize in, and they will learn everything practically, working side by side with the department officials.

Education Building

Since we will have a small number of students for a single class, a small institute will be needed. An area of 5m x 4m will be enough. The building can be extended upwards if required later on.

Healthcare

"To keep the body in good health is a duty... otherwise we shall not be able to keep our mind strong and clear."

-Buddha

In The Spinning Donut a hundred people will be living completely isolated, so if a person gets ill or injured, sending him to earth and back is not a viable option, so a clinic is required on the settlement.

Since there will be 100 inhabitants, a medical unit of 5 will be sufficient.

Amongst them is an osteopathic who is a fully licensed doctor and can deal with all areas of medicine, this is necessary because the recommended population ratio[62] of people and doctors is about 1:1000 on earth, if we keep a doctor of every field then the number would rise to more than 10. Two surgeons (a male and a female so that the patients can choose whichever gender they are most comfortable with) will be needed for surgical for accidents and emergencies. The osteopathic can also provide assistance to the surgeons. Two nurses will be sufficient to provide overall assistance.

An emergency room to check for mild conditions (fever or nausea, there is a high possibility that people will suffer from nausea) or for more critical conditions, a small detention room, an isolation room for a contagious disease or an unidentified disease, a general operation room, and a small nursery will also be constructed. Medical equipment is made up of stainless steel which will be sterilized using hydrogen peroxide[63]. Since people will live on The Spinning Donut for a large period of time, there will be newborn babies at some point, and resuscitation equipment may be needed for them.

In space, there is a high risk of developing cancer due to radiation so equipment to deal with cancer will be needed like a basic blood test lab for checking symptoms of cancer. X-ray machines and ultrasound will be used to check for cancerous tumors.

An emergency room will be reasonably large as equipment for serious conditions will be required with enough space to move a stretcher so the area will approximately be $10m^2$. The detention room will have 4 beds with some space in between for drips and medicine, adding a desk for a supervisor will require an area of $20m^2$. The operation room with a stretcher, a tray of equipment, a monitor, and lighting will require $10m^2$, and approximately this same area will be required for a nursery. The total area of the clinic will be $50m^2$.

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62 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6259525/#:~:text=Considering%20the%20number%20of%20registered,2018%20by%20most%20conservative%20estimates.

63 https://extension.purdue.edu/elkhart/article/35678

Emergency Measures

"By failing to prepare, you are preparing to fail."

-Benjamin Franklin

No matter how well-planned anything is, the factor of unpredictability always exists, and so emergency situations must be accounted for while building a settlement.

Fire

To avoid fires, flammable materials such as wood furniture and items or paper wouldn't exist on the Spinning Donut, and so the only two "fire catching" or "fire starting" things would be trees, and electrical wires/devices/appliances. It is highly unlikely, almost impossible for any tree on the Spinning Donut to catch on fire due to the temperature-regulated environment of the Spinning Donut, the only way for a tree to catch on fire is through any nearby faulty wiring. This can be addressed by planting trees at a safe distance of 6 meters[64] away from any electrical wires, and by having a trained (Electrical Engineer) inhabitant checking the condition of the wires yearly[65]. All appliances and devices must also be checked yearly for any defects or signs of wear and tear and maintained or discarded accordingly by the same trained inhabitant who also checks the wiring. Fire doors must be used at the entrance of each apartment to contain the spread of a potential fire which could be caused by a faulty electrical appliance, or by accident. Circuit breakers should also be installed to prevent damage and fires from short-circuiting and overloading. Taking these measures will ensure that all inhabitants are safe from any possible fires without the use of fire extinguishers, which are non-reusable and so compromise on the self-sufficient aspect of the Spinning Donut.

Medical Emergencies

Every inhabitant on the Spinning Donut will be given first aid training to ensure that they are able to respond effectively to basic emergencies that their fellow inhabitants may face, such as choking, cardiac arrest, or excessive bleeding. The training will include how to give CPR, different maneuvers used to dislodge obstructions in the windpipe, and how to stop and treat excessive bleeding from cuts and scrapes. Every inhabitant will also be given a smartwatch that will monitor each inhabitant's heart rate and will alert other inhabitants in case of abnormalities, such as if the heart rate increases to 400 beats per minute which is a sign of an

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[64] https://homeguides.sfgate.com/far-tree-safe-build-fire-pit-55837.html#:~:text=As%20a%20rule%2C%20build%20fire,free%20of%20trees%20and%20plants.

[65] https://www.intersafe.co.uk/news/how-often-should-fixed-wire-testing-be-carried-out/#:~:text=5%20Year%20Fixed%20Wire%20Testing,at%20least%20every%205%20years.

oncoming cardiac arrest[66]. The smartwatch will also allow inhabitants to manually turn on the alarm in case of some other emergency for which they need assistance. Once the alarm is activated, that inhabitant's door's smart lock will automatically open to allow other inhabitants to enter and respond to the emergency.

Extreme Emergencies

Despite all of these measures, if an unanticipated emergency occurs, there should always be a backup plan. For the Spinning Donut, this will be in the form of a docked SpaceX crew-rated Starship which has a capacity of 100 people, enough to allow all inhabitants to escape if needed. This "Titanic" will have enough lifeboats for all of its passengers. A Ravn X drone can be used to send emergency supplies that may be required, such as fire extinguishers, in about 180 minutes, which has been detailed in the "Transport Vehicles" section.

The "unsinkable" Titanic serves as a reminder to always prepare for all eventualities.

Credit: By Willy Stöwer, died on 31st May 1931 - Magazine Die Gartenlaube, en:Die Gartenlaube and de:Die Gartenlaube, Public Domain, https://commons.wikimedia.org/w/index.php?curid=97646

[66] https://www.healthxchange.sg/heart-lungs/sudden-cardiac-arrest/arrhythmia-abnormal-heartbeat-sudden-cardiac-arrest

Economic System

"Happiness is not in the mere possession of money; it lies in the joy of achievement, in the thrill of creative effort."

-Franklin D. Roosevelt

When considering an Economic system suitable to the characteristics of the Spinning Donut, we considered Communism, Socialism, Capitalism, and everything in between and we concluded that a pure communist economy would best serve the needs and the wants of the inhabitants of the Spinning Donut.

This is true for several reasons; first of all, due to the severely limited factors of production, (land, labor, capital, and entrepreneurship) which makes it impossible for the inhabitants to produce all of each other's wants and needs. Due to the small size of the settlement, the price mechanism also won't work because there will be a monopoly on each good and service that the inhabitants require, and so while the demand will remain constant, the supply can be adjusted by the seller to manipulate the price, which will be extremely damaging to the rest of the inhabitants and can be used to control them, especially considering that most of the goods and services that will be produced will be needs and not wants. Capitalism is efficient due to competition and so it won't work in this small settlement due to the limited resources and complete lack of competition. Socialism also depends somewhat on the private sector and the free market and so it is also inappropriate for such a settlement.

Due to the equal distribution of resources in a Communist economy, there will be a lack of inequality between inhabitants and thus less of a chance for conflicts to develop regarding resource allocation. There will be more of a sense of community and support between the inhabitants because they will all be striving to achieve the common goal of self-sufficiency.

Most of the disadvantages of a communist economy are mitigated due to the special circumstances of this isolated and small economy. Communism usually results in either a shortage or surplus in resources because the price of resources isn't decided by the price mechanism and so isn't as responsive to changes in supply and demand, however, this won't be a problem in the economy of the Spinning Donut because the demand and supply of goods and services will stay constant due to limited factors of production and a limited population of 100 people. Another disadvantage that communist economies usually have is a lack of incentive for individuals to work as a consequence of the lack of a profit or wage, this also won't be as much of a problem for the inhabitants of the Spinning Donut because everyone will be dependent on each other and so there will be a communal pressure for all the inhabitants to work. The passions of each individual will be considered when choosing them to inhabit the Spinning Donut to ensure that each person only does the job which they are passionate about.

Political System

"The rights of every man are diminished when the rights of one man are threatened."

-John F. Kennedy

To avoid injustice and to ensure that each of the citizens participates in the selection of their leadership, we decided on direct democracy as the best option to select the leadership. Every inhabitant will get to vote on who should be the leader. No inhabitant will stand as a candidate. Instead, all habitants will vote anonymously to decide on who they think would be the best fit for this job. The elections will occur every five years. The time was kept this long to ensure stability. Otherwise, changing leadership every couple of years might develop chaos.

The leader will be responsible for finding solutions to any problems that the inhabitants bring to him. He will ensure that the resources are equally divided and that everyone is doing their share of work in the settlement. The leader will also have the power to sign legislation and change it according to the needs of the settlement. The leader will be required to work alongside a secondary leader who will be the candidate which had the second-most votes. The secondary leader will help decrease the burden on the President and decide on matters alongside him, as well as will help to represent views that a large minority of the settlement might hold. They will be responsible for the implementation and enforcement of laws in the settlement for a firm and steady community.

The constitution will be formed beforehand on Earth. However, if the citizens want any laws to be added or changed, the leadership is required to hold a settlement meeting to debate the advantages and disadvantages of the proposed change. After that, a vote will occur where a majority vote will be required to implement the change.

The constitution of the settlement stresses on the fundamental rights of the citizens. The citizens will have the following rights and protections:

- Freedom of speech
- Freedom of religion
- Freedom of assembly
- Right to petition the leadership
- Protection against unreasonable search
- Protection against cruel and unusual punishment

Justice System

"If we do not maintain justice, justice will not maintain us."

-Francis Bacon

On Earth, the legal system for punishments is mainly prison. But construction of prisons will only pressurize the settlement's resources. First, it will occupy a lot of physical space, which is not beneficial to the settlement where every square meter is important for other vital needs. In prisons, prisoners are fed and provided with resources and in return, they do labor work. But on the settlement, there will not be any labor work because every part of the settlement is to be operated by professionals. Thus, it will be unjustified to the rest of the citizens who work, and then get their part of resources. Also, guarding prisons will require guards and will put a strain on labor needed for other work.

Due to the equal distribution of resources, the chances of crimes against property and white-collar crimes occurring are extremely low. Thus, our settlement will presumably be peaceful. But in the case of a slight chance of people committing crimes, the offenders will be punished according to the extent of their crime by their rations being reduced, by banning them from entertainment for a limited period of time, or by working overtime. In case their rations are reduced, those resources will be provided to the victims to repay for their loss. The offenders will also be given therapy for a period of time from the psychologist in the settlement. For capital crimes such as murder and rape, because this small settlement's purpose is just to promote further growth in the space settlement industry and it is not equipped to handle criminals of this caliber, the criminal will be sent back to Earth where he/she will face justice accordingly. He will be kept in isolation until a rocket is sent back to earth for refueling or other purposes. A replacement for the offender will be requested and sent on the journey back to the settlement. The offender may be required to continue working until then under strict supervision depending on their job's immediate importance to the functioning of the settlement.

To make sure that the offenders are fairly accused and punished, surveillance cameras will be located all over the settlement. Where a room without surveillance is concerned, cameras located in the hallways leading to that room can be checked. The footage will be used as evidence. An electronic vote will occur, and if the majority, i.e., 50% of the population charges the offender as guilty, then combined with the leadership's decision, the offender will be penalized according to the crime.

We will also carry out psychological evaluations on the citizens before selecting them for the settlement, similar to the evaluations done while choosing astronauts for NASA. This is a preventative measure to decrease the likelihood of crimes being committed on The Spinning Donut.

Entertainment

"In this age, in this country, public sentiment is everything. With it, nothing can fail; against it, nothing can succeed. Whoever molds public sentiment goes deeper than he who enacts statutes, or pronounces judicial decisions."

-Abraham Lincoln

Because the goal of this settlement is to promote the creation of entrepreneurship for future space settlements, public perception is of extreme importance, and so it is important to plan the most fun experience possible for the inhabitants by considering the entertainment that will be available to them. Some sustainability can be sacrificed to achieve this because of the small size of this settlement and it being the first settlement of its kind. Future, much larger space settlements on other celestial bodies may not have to rely on Earth for entertainment.

The Spinning Donut has large, 10-meter-wide windows so that people can look up and see space and the stars in vivid detail due to the lack of a high-density atmosphere at the height which The Spinning Donut will orbit at. As well as this, each apartment in The Spinning Donut will contain a PS5, an Xbox Series X, an Alienware Aurora R11 gaming PC, and an HTC Vive Cosmos Virtual Reality headset with fast internet, which has been detailed in the "Internet" section of this document. In return for increased exposure and branding through the use of these devices, all games will be made free for inhabitants of this space settlement.

Every year, the winner of the GRAMMY "Best new artist" award will be invited to perform on The Spinning Donut for its inhabitants. This event will be live-streamed for viewers on Earth as well. The artist will be transported along with any celebrity which the inhabitants of The Spinning Donut want to meet (decided via a poll), as well as with that year's winners of The Nobel Peace Prize and The Nobel Prize in Physics when the attached Starship has to go down back to Earth for refueling. The latest gaming and technology equipment which the inhabitants request will be transported up with the Starship as well.

Finally, the room in the center of The Spinning Donut (with a 14-meter radius) will have a zero-gravity effect due to the lack of centrifugal force that will be present. This room will be used for inhabitants to play games and sports, relax, and have fun. Entertainment related events will be organized by the inhabitants themselves as well.

These entertainment opportunities will keep the inhabitants happy and allow The Spinning Donut to act as a catalyst for the development of far larger space settlements in which people can live further away from Earth on other celestial bodies in the far reaches of space.