cicada

the strings of evolution

Foreword

the process of ecdysis and how it reflects and encourages the course of our journey from the Earth to outer space

The story behind the **name**

...A certain clarity arises among these blurred fragments of vision. Thus, the moment which unfolds is one of its kind, hopeful, and brilliant, and proud.

In the center of this moment, where life and death collide, the tiny cicada trembles; its weak body fails to surrender to the strings of its struggle. As if it knows. The creature is a coagulum of blood and organs, vibrating and spinning in a mixture of maddening dizziness. It is caught in a tumult of life, a tornado of strident colours whose rays evade the frail intensity of the air. Knocking on the shell above, the insect is once again reunited with the warm touch of the sun. Gradually, existence is unveiled, in its search for creation. Crawling out of its former exoskeleton, it rises up towards a new beginning. Much like an emerald, enlightened and crafted through the subtlety of time.

The tiny cicada is now even frailer. Even more vulnerable. And yet, most of all, even more magnificent.

This is the process of ecdysis. It occurs during the lifespan of some arthropods. Ecdysis involves the abandonment of the exoskeleton, in order for the arthropod to outgrow its previous size, despite having to go through a period of vulnerability, during which the new exoskeleton hardens.

As it undergoes the process of ecdysis, the tiny cicada, I believe, becomes part of a prophecy. The prophecy of life, engraved in the depths of the universe.

It goes without saying, there is a steady certainty which follows the course of our world.

Our world, as a thin string in the greater course of time, is boundless and remarkable. Our world is perfectly crafted, molded into details, patterns and layers, abstract and concrete, set afloat on a river of empty meaning and sour knowledge. Our world is a stranger to our rational limits. Our world is impulsive. Our world, above all, is conceived to seek evolution. Purely because it has been given the ability to do so.

Perceptively, each form or fragment of life in our world wishes to replicate this purpose through its own existential flow.

I find it strangely enchanting, how our journey in outer space is similar to that of the tiny cicada.

We too must learn how to crack open this shell, this Earth. To abandon, to conquer our limits and comfort, to venture into the unknown.

And, above all, to evolve.

A metaphor for a different mindset

Ecdysis is primal, simple, yet astonishingly extraordinary. Through such genuine acts, existence explores and redefines its boundaries, contributing to the meaning of time. It is fascinating, how an entity with no concept of its own self manages to capture and portray this beauty. Nature amazes us, because our valued rationality gives us few opportunities to replicate its evolutionary, momentous ruthlessness.

The contemporary world is chaotic, disoriented and lost in its own bubble. Our mentality is a complex network, tangled up in an endless cycle of social justification and desire for conquering. On an economical and political scale, humanity has always sought to obtain validation and confirmation of its power, despite the consequences which inevitably come tumbling down, in an avalanche of tragedy and suffering. From any given standpoint, it is quite clear that our objectives have not only kept their essence constant since historical times, but their misguided conceitedness has also been aggravated by our current scientific knowledge. It seems that we have not yet managed to extinguish the fire of conflict, as proven by the fact that we even choose to finance it and freely allow it to chase us down on a path of assured self-destruction. In its current form, humanity goes hand in hand with war.

We are at war with ourselves, we are at war with nature; ultimately, we are at war with time, although, in this case, we are reluctant as to which side to be on. We are at war and we are complicated.

Visualize our purpose: a string of ambition curled in a knot, stationary in front of the gates of progress, yet continuously becoming more and more attracted to the substance of its disorder.

Our progress is almost stagnant, if we take our true potential into consideration, because we are preoccupied with matters which turn us against each other and seek to validate our own individual well being and self-esteem.

The course of nature, on the other hand, is fluid, stretched out along the string of time, genuine and unaffected.

This mentality is directed towards the evolutionary essence of our world. We can only mimic this genuineness and try learning from it. Because there is a lot to learn from nature. And that is, essentially, that evolution is in our blood.

I believe that space colonization is, first of all, a change of perspective, a realization which imposes a much greater purpose for humankind. We must learn to let go of the mundane obstacles and discouragements which distract us from our primal evolutionary instincts.

The moment humanity, as a whole, chooses to invest its time and available resources into space related activities, extraterrestrial colonization becomes a feasible future prospect.

After all, it's a dual ecdysis, and both its courses are correlated and interdependent, abstract and concrete: breaking through our rational limits, through hopefulness and clarity, and breaking through the Earth's shell, through research and persistence.

In a world of endless possibilities, infinite and captivating, the seed of progress is cultivated through mutual belief and collective efficiency.

If we do not begin to realize what it is we are fighting for, we will never achieve our goal.

We do, sadly, have a tendency to procrastinate, and arrive late to our trial against time...

For once, we should be punctual.

Encourage space tourism and habitation. Cultivate awareness.


2017

In 1961, Roger Caillois Writes "Man, Play and Games" and separates games into four categories: Agon for competitive games, Alea to represent games that rely on luck and chance, Ilinx (vertigo) to convey a different perception of the world, and Mimicry, the game of imitation. Ludic reality imposes an alternate plane of actuality, built upon the player's awareness and willingness. Games are genuine and follow no concrete, material purpose, but rather an evolution and relaxation of the mind and the soul, existing outside the contemporary monotony, in a universe of their own.

The act of Mimicry, in particular, requires the player to wear a mask, to pretend to be someone else and envision the course of an alternate circumstance. An illusionary world is created and, based on it, a parallel time ax. Mimicry is a theatre and the stage is a hallucination, a hypnotizing and alluring version of our reality.

Thus came the derived term of biomimicry, through which humankind chose to find inspiration in the natural order. Nature seeks evolution and we are biologically and psychologically conceived to imitate this trait. The pillars of our society are an allegory derived from nature, in one way or another, which materializes itself in a ludic destiny.

Life is a game, indeed! And what a privilege it is to play this game!

Acknowledgments. Firstly, we would like to express our most profound gratitude towards those that dedicate hours of hard work in order to make this contest a reality, year after year, and continue to inspire young minds to believe in a prosperous future for humankind. We are deeply thankful to have such a wonderful opportunity to learn and express our ideas in regard to space exploration, a challenging and complex topic which allows us to discover and study more hidden layers of earthly existence. Secondly, we will truthfully admit that this would not have been possible without the unequaled guidance of our physics teacher, Maga Cristinel Constantin. We are genuinely very fortunate to have you by our side and owe all that is good about this project to your patience, dependability and warm words of encouragement.

NASA Ames Space Settlement Contest

2018

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List of abbreviations

ACS: Atmosphere Control and Supply
ARS: Atmosphere Revitalization Subsystem
ATCS: Active Thermal Control System
ATV-ICC: Automated Transfer Vehicle-Integrated Cargo Carrier
CDRA: Carbon Dioxide Removal Assembly
EATCS: External Active Thermal Control System
EDS: Electrodynamic Suspension
ELEO: Equatorial Low Earth Orbit
EPS: Electrical Power System
EVA: Extravehicular Activity
FG: fraction of grown food
GCR: Galactic Cosmic Rays
GN&C: Guidance, Navigation and Control
HI: Harvest Index
HEPA: High Efficiency Particulate Atmosphere
HZE: high (H) atomic number (Z) energy (E)
IATCS: Internal Active Thermal Control System
ISS: International Space Station
Maglev: magnetic levitation
MF: Multifiltration
MMOD: Micrometeoroids and Orbital Debris
MLI: Multi-Layer Insulation
PM&C: Propulsion and Motion Control
PTCS: Passive Thermal Control System
PVTCS: Photo-voltaic Thermal Control System
RO: Reverse Osmosis
SAC: Starved-air Combustion
SCWO: Super Critical Wet Oxidation
SPE: Solar Particle Events
TIMES: Thermoelectric Integrated Membrane Evaporation System
VAPCAR: Vapor Phase Catalytic Ammonia Removal
VCD: Vapor Compression Distillation
WRM: Water Recovery and Management

Table of contents

1. Executive summary

Cicada is a small habitat in the Equatorial Low Earth Orbit, designed as a hotel and amusement park. This project examines the circumstances which would envelop the construction of such a settlement, in the context of the 21st century, and examines the potential of space tourism as a possible approach to the development of space exploration.

In chapter 2, we discuss the advantages and disadvantages of the chosen location for the settlement and give details in regard to shielding requirements. Cicada is a habitat located in the Equatorial Low Earth Orbit, where radiation levels are lower, thanks to the presence of the Earth's magnetic field. Though this represents a great advantage in regard to radiation shielding, the settlement requiring minimal protection against galactic cosmic rays, it also involves a noteworthy drawback, which arises because of the necessity to shield the habitat against micrometeoroids and orbital debris.

We have separated shielding configurations into three types; each one of these is endowed for radiation shielding, micrometeoroid and orbital debris shielding and passive thermal protection. The first shielding configuration has an aluminum bumper, followed by a layer of beta cloth (which functions as a disrupter) and MLI blankets; the spacer/standoff consists of open cell foam and layers of Kevlar™ and Nextel™ [13]. A layer of polyethylene with a thickness of 1 cm is used as a stopper, but also as a means of radiation shielding, and the rear wall is mostly made out of aluminum (except for certain sections of the hull where the load is higher, such as the outer area of the residential component, or the dock, where a tougher material is required; for these, a titanium alloy was used). The second shielding configuration is similar, though it does not have a disrupter and the spacer is not as stuffed. The third shielding configuration is used for non-pressurized modules and has no additional radiation/thermal protection. A different shielding configuration was chosen for each of the settlement's components, depending on their likelihood of collision; also, in regard to the velocity vector and the trajectory on orbit, the settlement is positioned so as to maximize shadowing and reduce chances of detrimental impact. Chevron shielding will be used to illuminate the greenhouse, allowing the passing of light but not that of cosmic rays.

Chapter 3 is concerned with artificial gravity, the dimensions for each of the settlement's components, as well as their area allocations, and other characteristics of interior design. In its final form, Cicada will consist of a central sphere, a dock, an intermediate double cylinder, a hybrid torus, a cylindrical column, a smaller sphere and a torus (we consider the first 4 as the first part of the settlement and the last three as the second part). Out of all of its components, the greatest in size is the hybrid torus, which has a major radius of 75 meters and a minor radius of 15 meters (thus a maximum radius of 90 meters). Studies have shown that the human body can rather easily adapt to rotation rates of 4-5 rpm [5][31]. We have established a rotation rate of 2,45 rpm, which means that the maximum value for pseudo-gravity is 0,6 g (which is acceptable in the case of a hotel in space, where there would be no long-term residents, only tourists and staff working monthly shifts). Compared to 1 g, this value has the advantage of a lower gravity load and thus a lower load to be sustained by the settlement's hull; this ultimately reduces launch costs required to transport a greater quantity of materials from the Earth to the Equatorial Low Earth Orbit. The rotation mechanism relies on Electrodynamic Suspension, similar to the technology used for Japanese Maglev trains [10]; except for the dock and the central sphere, all of the components rotate. There are two separate Maglev guide-ways, one for the intermediate double cylinder and one for the column.

The hybrid torus has two separate floors; the residential area is located on the first floor, where artificial gravity is higher. The residential area consists of the three hotels (Agon, Alea and Ilinx) and the employee dormitory. The hotels have a total approximate capacity of 468 tourists, while the employee dormitory can accommodate around 136 staff members. As it is discussed in [1], we assign cardinal points to the floor plane of an object rotating around an axis. The East-West axis is where effects of the Coriolis force occur; thus rooms are mostly spread on the North-West axis. More area was allocated to create separate sets of stairs for ascend and descend, either facing East and West. Furnishings inside the hotel rooms and employee apartments are arranged so that cross coupled rotations of the head and the settlement occur as little as possible.

Other area allocations for the hybrid torus mostly include entertainment facilities, such as an adventure park, a water park, restaurants, shops, a casino, a theatre hall, a virtual reality gaming hall, a skating ring, a library and a sports hall, all in micro-gravity. The intermediate double cylinder is mainly used for food processing and water/waste treatment, storage and scientific research in different levels of micro-gravity. The central sphere and the dock are mostly used as depository modules for EVA equipment, batteries and propellant; additionally, they offer enough room for spacecraft maintenance. The column is mostly used as storage for the hybrid torus, which represents an Olympic stadium in low gravity; the small sphere is used as an observatory.

Chapter 4 offers details about support systems and other means of sustenance. The electrical power system relies mostly on solar arrays; the settlement has a total of 3 solar arrays, shaped as circular crowns, one on the central sphere, to support the rotation mechanism, one on the hybrid torus and one on the torus. Aside from photo-voltaic radiators attached to the solar panels, major pressurized components of the settlement (the hybrid torus, the intermediate double cylinder, the torus and the column) are also endowed with radiators, as part of the External Active Thermal Control System. The Guidance, Navigation&Control and Propulsion&Motion Control systems are located in the central sphere. Among main support systems, atmosphere revitalization will be performed mostly as a bio-regenarative cycle; however, this natural means of life support will be combined with physico-chemical technologies as well. Vapor Phase Catalytic Ammonia Removal will be used for urine distillation and multifiltration systems will be used for the filtration of hygiene water and condensate, which includes plant transpiration. Mainly, supercritical water oxidation will be applied to waste treatment.

Cicada's agricultural sector is placed on the first floor of the hybrid torus, on the circular side walls (which saves up a lot of space, given that the curved floor would not easily allow buildings to be constructed here). It is separated into four levels and functions as a hydroponics system. Enough space is provided to grow a variety of plants, which would meet the most of the dietary requirements of the inhabitants, especially since none of them live there permanently. Most of the chosen plants have high harvest indexes, in order for atmosphere removal to rely mostly on bio-regenarative processes to provide O_2 for the population and remove CO_2.

In chapter 5, we attempt to give insight on the various aspects which characterize entrepreneurship activities in the Low Earth Orbit. Space tourism will be a starting point towards advancements in space exploration, which will bring numerous benefits to the entirety of humankind; life beyond earthly boundaries will lead us to a more prosperous economy, due to the many employment opportunities and endless material and energy resources it has to offer. Our journey in the unknown territory of outer space will also mark our evolution in a cultural and intellectual sense and grant nations the opportunity to engage in peaceful collaboration.

The lack of investment currently represents a major concern for orbital space tourism. Mainly, this is likely caused by the enormous costs involved in such investments and the great delay for their return. Other noteworthy factors are the safety risks involved in transportation of people, the lack of interest and awareness from the general population and the absence of legal framework to properly outline the idea of business in outer space. In spite of the fact that some difficulties will have to be overcome in the beginning of space tourism, this emerging industry still possesses tremendous potential. Expectedly, a great portion of the investment for a space hotel will come from angel investors, but the general population might be able to contribute as well, through grass-root practices. It is also necessary to create a business climate that encourages and stimulates such investments, giving birth to coalitions as a method of collective investment. Governments can contribute by granting tax incentives and loan guarantees during early stages of development.

The construction of Cicada will be completed in two phases. The first phase implies the construction of the first part of the settlement (the central sphere, the dock, the intermediate double cylinder and the hybrid torus) and consists of two stages. During stage 1, one of the three hotels will be built. The time period between the two stages depends on the profits earned during stage 1. Phase 1 is over when all of the three hotels are built. When phase 2 is finished, the second part of the settlement will be added to the construction.

In order to estimate the cost concerned with the construction of an artificial habitat in the Low Earth Orbit, it is mostly necessary to determine its total mass, as launch costs overshadow the prices of the materials from which the hull and shield of the settlement are built; for a portion of the settlement's total mass, however, engineering/ manufacturing costs also have to be taken into account. With the greatest portion of its area allocated to entertainment facilities, Cicada can sustain a population of approximately 604 inhabitants. We consider a non-structural mass per person of 6,6 t; in order to determine the total internal mass, among others, the dry soil, the water in the soil, the internal structures and the solar panels also have to be taken into account. Thus, the internal mass of the settlement reaches a value of almost 16.000 t. Compared to launch costs, the price of the materials needed for the shield is insignificant. The masses of the three shielding configurations vary between 0,3 kt for the third shielding configuration and approximately 1 kt for the first one (without taking into account the mass of the rear wall). The thickness of the settlement's hull linearly depends on the gravity load and on the load imposed by the atmospheric pressure. Thus, we have determined that, for most components, a thickness of 5 mm is acceptable (far less is required for components with lower loads and this value was chosen for psychological comfort standards). For the outer cylindrical wall of the hybrid torus, a 6 mm-thick layer of titanium alloy TI-6Al-4V was used as the rear wall, instead of aluminum. The same material was used for the dock, which requires a higher resistance, though with a thickness of 5 mm. In order to transport the total mass (consisting of the internal mass, the shield mass, the shell mass and the air mass) from the Earth to the Low Earth Orbit, 346 launches would be required for phase 1 and 35 launches would be required for phase 2 (a great difference in the number of launches is justified by the fact that phase 2 does not contain residential components and thus the internal mass is considerably reduced). The approximate total cost of building the habitat rises up to a value of 68 $B, if reusable launch vehicles, with a price of around 90 $M per launch, are used for transportation (http://www.spacex.com/falcon-heavy).

As far as the unit price is concerned, it is necessary to determine yearly costs, which include the depreciation of the materials needed for the construction of the settlement and the buildings inside, salaries for productive and non-productive employees, maintenance costs, supplying, consumables and many other costs related to external services and investments. If we stop at phase 1-1, a unit price of 85.000 $ will grant a return on our investment after 15 years. If we enter and complete phase 1-2, with a unit price of 50.000$, only 9 years would be required for a full return on investment. What may seem out of the ordinary and unfair is that the unit price is extremely high compared to the average total costs (approximately 24.000 and 14.000 $ respectively). This is because technological progress will likely hold a fast pace and bring about a great decrease in prices, thus making it more difficult for us to recover our investment. However, compared to transportation costs, it is unlikely that this price will have a great impact on the mentality of the first space tourists. In regard to the break-even point, it is noteworthy to state that 25% of the quantity of output would ensure equality between revenue and costs during phase 1-1; if phase 1-2 is added, this value becomes 14%.

Though many processes on Cicada will be computerized and mechanized, a minimum number of staff members are still needed for the hotel, for maintenance, for the restaurants, for the hospital, for agriculture and other services in the park. Both tourists and staff will have to undergo medical examinations and a period of training before traveling to the Low Earth Orbit.

Based on existent surveys, the target market for the beginning of orbital space tourism expectedly consists of extremely wealthy individuals. Market research shows that many potential customers find the idea of space tourism appealing and thrilling; major impediments, however, are represented by incredibly high prices and uncertainty in regard to safety. These will likely become problems of the past once the product reaches maturity during its life cycle and the target market reaches its peak, as accessible prices begin to settle in and safer means of transportation are developed.

We also tried to imagine how the moral image of society would recreate itself in outer space. A code of ethics for the people of Cicada is included at the end of the project.

As an attachment to the project, we created a small promotional guide of Magicada, the amusement park on board Cicada, containing articles from space tourists all over the world. The publication date for this guide would be 2070, a year when, hopefully, space tourism will have already flourished. Similar to brochures on airplanes, tourists would be able to read this guide sometime during their flight to Cicada.

2.

Location and shielding requirements

2.1. ELEO. Overall location characteristics

The Universe, as seen beyond the Earth's protective shell, unveils a sort of loneliness, because it offers almost nothing as tribute to creation as we have grown to know it, in its concrete existential form. Envisioning the reality of life in the inhospitable, distant environment of outer space is an experiment based solely on the extent of our ability to replicate earthly conditions, which cultivate our survival, so that humankind can prosper and seek to expand its horizons as a civilization.

Radiations in space have harmful effects on the human health and, among others, might cause cancer, cataracts, sterility or cardiovascular diseases [2]. A habitat in outer space undoubtedly requires radiation shielding.

Settlements located in one of the Lagrange points, for instance, are exposed to high levels of radiation. One of the alternative, accessible shielding materials for such a habitat is lunar regolith. Given the limits of radiation levels for the general population (20 mSv/yr) and for pregnant women (6,6 mGy/yr) [2], this layer of protection would require a thickness of 10 tons per square meter [11], which is highly impractical and almost impossible for us to achieve, given our current standpoint in terms of research and space exploration. Better shielding materials, such as water or polyethylene, are viable, yet the mass of the settlement would still be a great impediment to its construction. The costs needed to build a structure of that magnitude in the fifth Lagrange point, using, for instance, materials found on the moon, would equal, if not exceed, the cost to launch an incomparably smaller quantity of materials from the Earth to the Low Earth Orbit [11].

Since better means of radiation shielding in deep space have yet to be revealed, the Low Earth Orbit provides us with conditions which would help us advance towards more distant destinations.

Aside from its proximity to the Earth, perhaps the most prominent advantage of locating a settlement in the Low Earth Orbit is provided by the presence of the Earth's magnetic field, which serves as protection against powerful radiations in space. In LEO, the decrease in radiation levels is determined by the decrease in altitude, as well as orbit inclination [2].

The Equatorial Low Earth Orbit (ELEO) is not only protected by the Earth's magnetic field and therefore characterized by much lower radiation levels, but it also has the advantage of not passing through the South Atlantic Anomaly, as opposed to other Low Earth Orbits, with a higher inclination [2], [6]. However advantageous this placement might be for a space settlement, shielding is under no circumstance completely eliminated, under the influence of two factors: radiation and meteoroids/space debris.

Radiation. Although significantly reduced as opposed to more distant locations, radiation is still present in ELEO. Noteworthy types of radiation which might affect spacecraft in this location are GCR (Galactic Cosmic Rays), SPE (Solar Particle Events) and particle radiation, caused by low energy particles in the Earth's magnetic field [6]. A major threat is imposed by Galactic Cosmic Rays, consisting of high-energy nuclei under the name of "HZE particles" [6]; they possess the greatest influence on shielding requirements: "*these particles have very high energies, sufficient to penetrate many centimeters of tissue or other materials. In addition, the HZE nuclei are highly charged and, therefore, very densely ionizing*" [Schimmerling, 6]. Solar Particle Events usually occur between 5 and 10 times per year; the density of those which impact the Earth is quite low, with rare exceptions, and their effect is significantly reduced, most of the time, thanks to the Earth's magnetic field [2]. Particle radiation is mostly relevant to extravehicular activities and should not be a concern for a space habitat.

Micrometeoroids and orbital debris (MMOD). A settlement located in a Low Earth Orbit, which includes ELEO, is prone to collision with meteoroids and space debris, among which some pose a serious threat to the integrity of a spacecraft, depending on their magnitude. Though larger objects can be identified beforehand and avoided, a shield is needed to protect spacecraft against objects with a diameter that is less than 10 centimeters.

2.2. Shielding

2.2.1. Micrometeoroid and orbital debris (MMOD) shielding

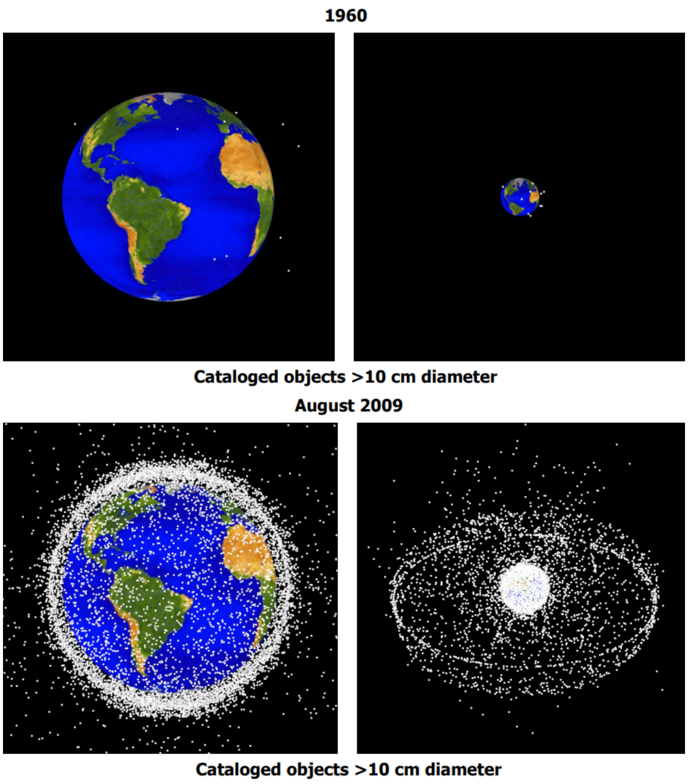


Figure 2.1. (orbital debris in 1960 and 2009) Source: https://www.nasa.gov/pdf/626427main_1-5_Rollins_Christiansen.pdf

The International Space Station (ISS) is protected against severely damaging impacts by a shield consisting of two main shielding configurations [4]:

- **Whipple Shield,** used for areas that are less prone to MMOD collision; it is made out of two layers, placed at a distance from each other, and is represented by an outer bumper and a catcher, for which aluminum is a commonly used material;
- **Stuffed Whipple Shield,** used for areas that are highly prone to MMOD collision; in comparison with the simple Whipple Shield, the Stuffed Whipple Shield has additional internal layers of Nextel[1] ceramic cloth and Kevlar[2] fabric [4]. The Columbus Stuffed Whipple Shield developed by NASA for the ISS consists of an external Whipple Shield (an outer aluminum bumper and internal catcher with a thickness of 2,5 mm), a layer of Nextel fabric and finally a mixture of Kevlar and Epoxy resin, the latter two used as intermediate bumpers [3].

In addition, according to E. L. Christiansen [8], another effective shielding configuration is the **Flexible Multi-Shock Shield**, made out of four Nextel bumpers and a Kevlar rear wall.

The purpose of the MMOD shield is either melting, vaporizing or fragmenting objects that collide with the spacecraft, thus absorbing the kinetic energy generated upon impact. This prevents the leakage of the atmosphere inside the pressurized modules.

Among materials which make up the layers of a MMOD Stuffed Whipple Shield or a Flexible Multi-Shock Shield, Kevlar (poly(p-phenylene terephthalamide)) has proven highly effective, as result of its thermal and chemical stability, high melting points, high strength and flexibility. Experiments have not only shown its noteworthy outgassing properties, but also its efficiency in terms of radiation shielding [3]. Data resulted from tests run on Kevlar have proven that it can even rise up to 80-90% of polyethylene's effectiveness regarding radiation shielding [3]. Nextel ceramic has also proven capable in terms of MMOD shielding, as well as thermal shielding, due to its high chemical and thermal stability and resistance against thermal shock. Generally, cloth or fiberglass materials have the highest efficiency in absorbing impact and capturing debris.

Thus, the intermediate bumper made out of Nextel fabric and Kevlar can be used to create a MMOD shield for inflatable structures, but also for transport vehicles, as in the case of the ATV-ICC cargo carrier, which supplies the ISS [3].

1. Nextel™ is a trademark of 3M Company.
2. Kevlar™ is a trademark of E. I. du Pont de Nemours and Company.

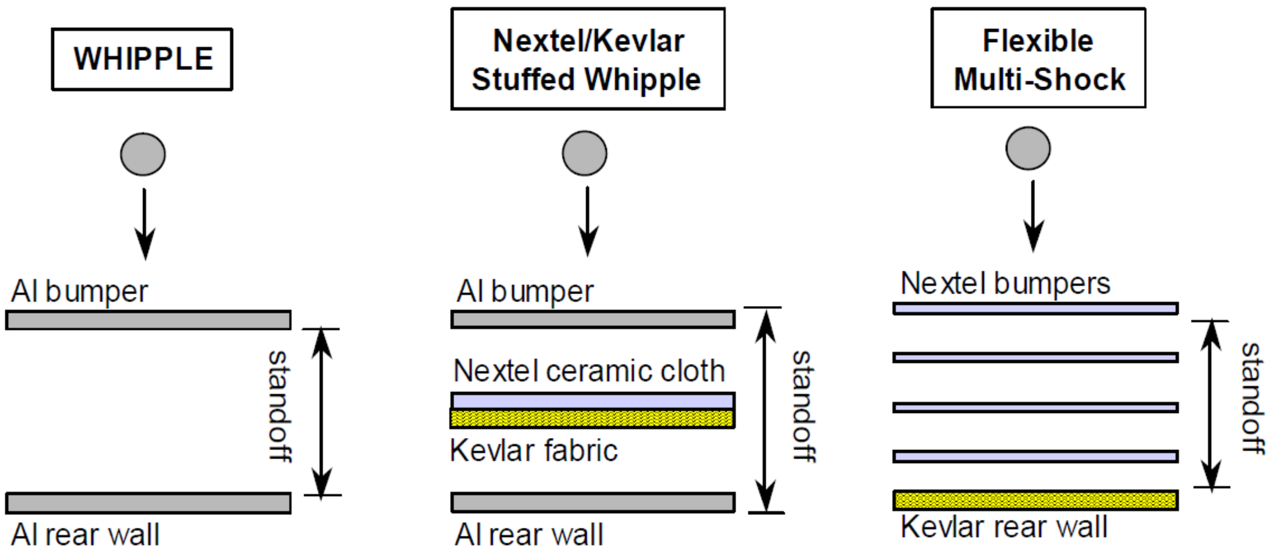


Figure 2.2. (types of MMOD shielding configurations)
Source: Eric L. Christiansen, Meteoroid/Debris Shielding [8]

Cicada's shielding configurations will depend on each module's exposure to debris and meteoroids and likelihood of collision. Areas with greater exposure will be endowed with more efficient shielding configurations. Additionally, its positioning in regard to the Earth and the velocity vector will seek to maximize shadowing, so that a greater area is protected from impact and thus the risk of detrimental collision is reduced; only a portion of the settlement's hull needs a more complex, tougher shielding configuration. The most favorable orientation of the settlement is with its vertical axis parallel to the Earth's axis and perpendicular on the orbital trajectory [8] (figure 2.3). This way, the intermediate double cylinder, the spokes which connect the torus to the column, a considerable part of the central sphere, the central rotating column, the internal sides of the hybrid torus, as well as those of the torus, are overshadowed and have a lower risk of collision. According to [8], the best orientation for a cylinder, in order to minimize the risk of impact, is with its vertical axis parallel to the Earth's North-South axis.

Additionally, the performance of the MMOD shield can be enhanced by using material combinations which prove to be the most effective upon testing, as well as by increasing the size of the standoff layers. The positioning of the spacecraft in regard to attitude also contributes to the overall performance of the shield; surfaces facing the Earth are less prone to detrimental collision. The habitat could also be separated into sections, which could either be connected or isolated; this way, if the shielding configuration which covers an unused/uninhabited section of the settlement fails to stop debris and the atmosphere inside leaks, other sections will not be affected [8]. Sensors should be used to monitor areas of the shield which are damaged, as well as indicate the size and depth of the penetration, so that destroyed segments can be repaired immediately and further damaging impacts in these vulnerable portions of the spacecraft are avoided.

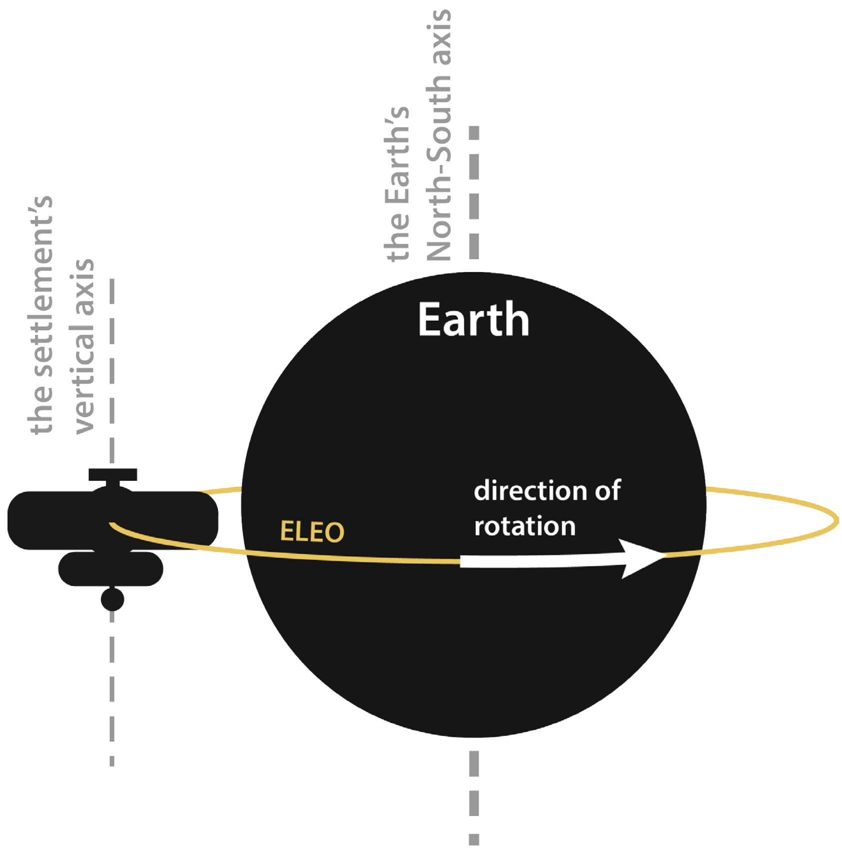


Figure 2.3. (the relative position of the settlement in regard to the Earth and the orbit)

2.2.2. Radiation shielding

Materials with contents that are high in hydrogen provide protection against GCR [2], [3]; polyethylene is a possible shielding material, whose thickness and correspondent radiation levels are superior to those of water and lunar regolith [2] (table 5, page 16). In ELEO, these values are considerably reduced to a lower limit of approximately 0.1 tonnes per square meter, at altitudes of 500 km [2].

Alternative means of radiation shielding to minimize cancer risks consist of measures which can be applied in order for the population to lead a more adequate lifestyle, such as banning smoking, introducing requirements for a proper diet and even selecting colonists based on their tolerance against radiations. Additionally, radon will no longer be present in the atmosphere. [2]

According to [Al Globus, Stephen Covey, 2], as it is indicated in table 6, page 18, the radiation levels which correspond to 0.1 tonnes per square meter of polyethylene (that is equivalent to a 1 cm thick shield wall), at an altitude of 500 km, are 17,1 mSv/yr for the general population and 3.6 mGy/yr for pregnant women (who might not be candidates for space travel, at least in the near future).

For a hotel in space, with no permanent residents, radiation shielding will still be considered. The selection of the staff might have to become a more thorough process, since they will have to work monthly shifts, but regular tourists should have no problem enjoying, say, their10-day holiday in space, as they would only be exposed to an additional 0,4-0,5 mSv/yr, during the time spent in the headquarters of the hotel, if visits are limited to one per year (consider as reference the fact that the dose for the average person is 0,6 mSv/yr and that airline crews get an extra dose of 2,2 mSv/yr; https://en.wikipedia.org/wiki/Background_radiation).

2.2.3. Overall shielding configuration

The two shielding purposes can be combined in one shield, also endowed for passive thermal protection, since cloth or fiberglass materials in debris shields also work for thermal insulation. MMOD shielding configurations can be adapted to function as radiation shields as well. It is possible to add polyethylene in the standoff layers or near them, in order to meet the required limits for yearly radiation doses, also taking into account Kevlar's radiation shielding properties, when applicable. For a tourist, however, the exposure period is considerably reduced, so the dose is much lower than that of a permanent colonist and long-term consequences are highly unlikely.

The location we have settled for is ELEO, at an altitude of 500 km. Thus we have separated shielding configurations into three types, for thermal, radiation and MMOD protection, in accordance with [8] and [13] (tables 2.1, 2.2

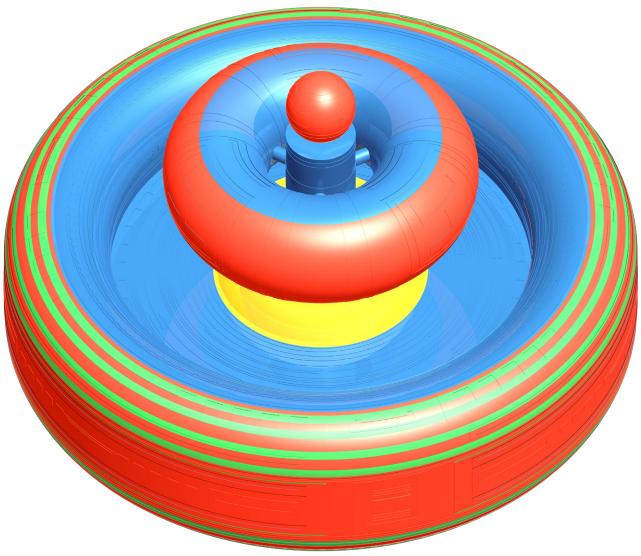


Figure 2.4. (bottom view; shielding configurations: shielding configuration 1 (red), shielding configuration 2 (blue), shielding configuration 3 (yellow) and chevron shielding (green)

Shielding configuration 1			
	Material	Thickness	Density
	Aluminum 6061-T6 (*bumper*)	0,25 cm	2,7 g/cm^3
	0,013 cm beta cloth (0,025 g/cm^2) (*disrupter*; outer cover of the MLI blankets) [13]		
	MLI (multi-layer insulation) (30 layers of aluminized Mylar[3]; each 0,0006 cm thick)	0,018 cm	1,39 g/cm^3
spacer/standoff	Open cell foam (polyamide AC550)	5 cm	0,0071 g/cm^3
spacer/standoff	Nextel AF10 (2 layers)	0,02 cm	2,7 g/cm^3
spacer/standoff	Open cell foam (polyamide AC550)	5 cm	0,0071 g/cm^3
spacer/standoff	Nextel AF10 (4 layers)	0,04 cm	2,7 g/cm^3
spacer/standoff	Kevlar KM2 (3 layers)	0,069 cm	1 g/cm^3
spacer/standoff	Open cell foam (polyamide AC550)	5 cm	0,0071 g/cm^3
	Spectra 1000 style 952 (polyethylene) (*stopper*)	1 cm	0,97 g/cm^3
	Aluminum 6061-T6 or Titanium alloy TI-6Al-4V (*rear wall*)	*	2,7 or 4,4 g/cm^3
	Total	~16-17 cm	

Table 2.1.

Shielding configuration 2			
	Material	Thickness	Density
	Aluminum 6061-T6 (*bumper*)	0,25 cm	2,7 g/cm^3
	MLI (multi-layer insulation) (30 layers of aluminized Mylar[3]; each 0,0006 cm thick)	0,018 cm	1,39 g/cm^3
spacer/ standoff	Open cell foam (polyamide AC550)	7,5 cm	0,0071 g/cm^3
spacer/ standoff	Nextel AF10 (3 layers)	0,03 cm	2,7 g/cm^3
spacer/ standoff	Kevlar KM2 (3 layers)	0,069 cm	1 g/cm^3
spacer/ standoff	Open cell foam (polyamide AC550)	7,5 cm	0,0071 g/cm^3
	Spectra 1000 style 952 (polyethylene) (*stopper*)	1 cm	0,97 g/cm^3
	Aluminum 6061-T6 (*rear wall*)	*	2,7 g/cm^3
	Total	~16-17 cm	

Table 2.2.

Shielding configuration 3			
	Material	Thickness	Density
	Aluminum 6061-T6 (*bumper*)	0,25 cm	2,7 g/cm^3
spacer/ standoff	Open cell foam (polyamide AC550)	7,5 cm	0,0071 g/cm^3
spacer/ standoff	Aluminum 6061-T6 (*intermediate bumper*)	0,3 cm	2,7 g/cm^3
spacer/ standoff	Open cell foam (polyamide AC550)	7,5 cm	0,0071 g/cm^3
	Aluminum 6061-T6 or Titanium alloy TI-6Al-4V (*rear wall*)	*	2,7 or 4,4 g/cm^3
	Total	~15-16 cm	

Table 2.3.

*the thickness of the rear wall varies; for each component, this thickness is calculated in Section 5.5.4

3. Mylar™ is a trademark of E. I. du Pont de Nemours and Company.

and 2.3).

The first shielding configuration (table 2.1) and the most complex one will be used for areas that are highly prone to MMOD collision and require additional thermal and radiation protection. These include the outer areas of the hybrid torus and of the torus, as well as the small sphere placed at the extremity of the habitat (figures 2.4 and 2.5). Note that a small portion of the outer area of the hybrid torus will be endowed with chevron shielding, right where the greenhouse is, to provide plants with natural sunlight. Also, the cylindrical component of the outer area of the hybrid torus will be built out of titanium alloy TI-6Al-4V in the rear wall instead of aluminum.

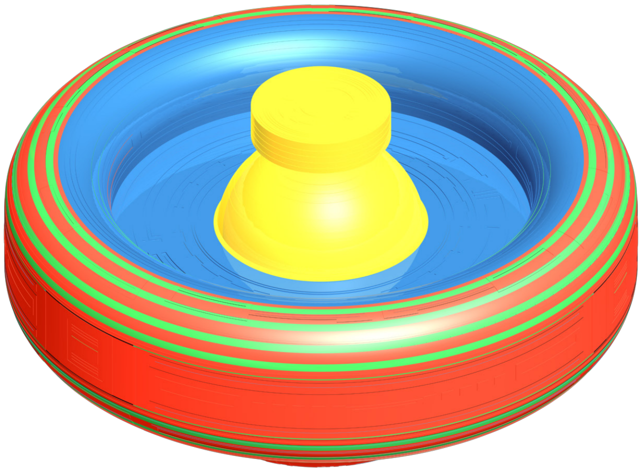


Figure 2.5. (top view; shielding configurations: shielding configuration 1 (red), shielding configuration 2 (blue), shielding configuration 3 (yellow) and chevron shielding (green))

The second shielding configuration (table 2.2) will cover the inner area of the hybrid torus and the inner area of the torus, as well as the pressurized portion of the intermediate double cylinder, the pressurized portion of the central column, the cylindrical passageway which connects the central column, the small sphere and the spokes which connect the torus and the central column. Quite like the first shielding configuration, this one also offers passive thermal and radiation protection.

The third shielding configuration is designed for those components which require EVA and are also non-pressurized: the sphere, the docking port and the non-pressurized portions of the central column and of the intermediate double cylinder. Instead of aluminum as the rear wall, the docking port will be made out of titanium alloy TI-6Al-4V, for increased resistance. This is a simple Whipple Shield, with an additional aluminum bumper.

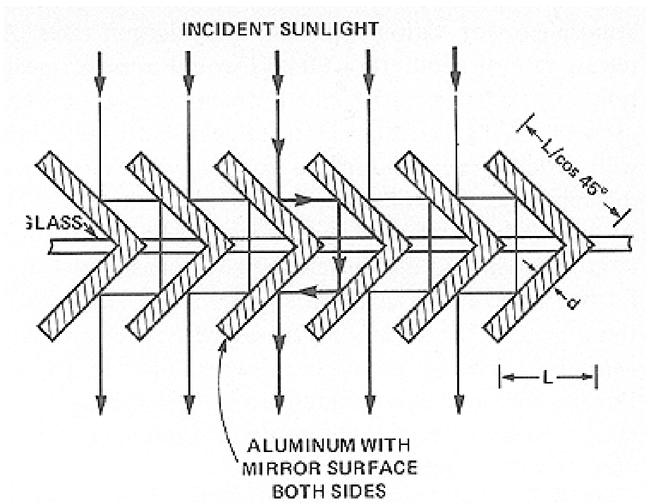


Figure 2.6. (chevron shielding)
Source: Space Settlement: A design Study, NASA, 1977 [12]

Given that a great deal of the hybrid torus is covered in greenery, a part of the settlement's hull will have to allow the passing of sunlight. Chevron shielding is used for this purpose. This type of shielding consists of chevron mirrors (placed on the glass surface at a 45° angle) which allow the light to pass through, but not cosmic rays [12]. The shield consists of aluminum 6061-T6, with Mylar-covered surfaces to reflect light. We have established that the distance between two consecutive chevron mirrors should be L=20 cm and that d, the thickness of a mirror, should be 2 centimeters (figure 2.6). This type of shield has an efficiency equal to that of an aluminum 6061-T6 shield, with a thickness of 2d/cos 45°=5,65 cm. The glass would need a thickness of 2,8 cm in order to resist the atmospheric pressure inside the habitat [12].

Chevron shielding will mainly be used on the circular side walls of the hybrid torus to provide sunlight for the greenhouse (Sub-Chapter 4.2).

3.

Structural overview

3.1. Artificial gravity

3.1.1. The impact of artificial gravity on the human body and psychology

Having reached a greater state of evolution than other earthly organisms, human beings are mentally and biologically less prone to change. Purely because of that, we cannot yet consider living in weightlessness: sadly, we are not "equipped" to do so. We do, however, possess an extraordinary tool, much greater than any known adaptation mechanism – and that is, undoubtedly, our brain. Our brain is capable of molding the world around us so that its environmental characteristics conform to our physiological and psychological needs; we were created to utilize and control that power.

Truth is, we need artificial gravity in space, because the lack of it would have severe consequences on our health, including the decrease in bone and muscle strength or cardiovascular problems. Although there is much research to be done regarding the safest, most efficient method of generating artificial gravity, so far it has been determined that rotation is a plausible way of replicating the gravity on Earth – but how will this influence our daily existence and long-term physical growth?

It is often argued that rotationally induced artificial gravity might have harmful effects on the human body, both short and long term, partly due to the occurrence of Coriolis forces and accelerations, which cause dizziness and disorientation, and the nature of the centrifugal force itself, whose purpose would be keeping our feet on the ground (if we may, in fact, call it a "ground").

It is questionable whether these concerns are valid or not – to a certain extent, they surely are; after all, our lives are at stake. According to T. W. Hall [1], the electromagnetic interactions between atoms are what influences the chemical, biochemical, mechanical and biomechanical functions of our body. Gravity merely acts as a force which helps these atoms interact, by pulling them against each other, and, therefore, its nature (earthly or artificial) should have no significant influence on our health.

An orbit itself is proof of the existence of gravity outside earthly boundaries – an "inward-acting centripetal gravitational field" [T. W. Hall, 1], something that keeps objects from drifting far, far away in outer space:

"Astronauts in orbit don't lack gravity. There must be something else we have on the Earth's surface, and they lack [...] That something is acceleration by another force [...] It is the upward acceleration of the floor, not the downward acceleration of gravity, that provides us with weight." [T. W. Hall, 1]

Essentially, the concept of acceleration, particularly mechanical acceleration, in outer space is crucial – theoretically, it should be able to replace the gravitational field on Earth, without harmfully impacting our health, because, on a molecular level, it can influence electromagnetic forces, so that their propagation through our body is ensured [1]. There are inconveniences which arise because of rotation, surely, and they are substantially determined by the reduced size of a space habitat; the Coriolis force is present on Earth as well, because it rotates – but the radius of rotation is so great that we are not able to acknowledge its effect. Until we manage to build a structure of that fabulous magnitude, we must learn to accept these drawbacks.

Research conducted by Michael A. Schmidt, Thomas J. Goodwin and Ralph Pelligra has shown that our body does not sense the difference between acceleration caused by gravitation and that caused by centrifugation and that the response is thus the same [1].

Generally, an angular velocity, ω, of 2 rpm has been regarded as a level of comfort, though the human body can adapt to much greater values.

Ashton Graybiel's experiments from 1977 reveal that an angular velocity of 1 rpm barely resulted in any symptoms; 3 rpm was a value for which the symptoms were not significant, 5.4 rpm was accessible to those who possessed greater adaptability, and 10 rpm was highly uncomfortable for all subjects [5].

The issue is not necessarily to adapt artificial gravity (although scientific progress might allow us to do so, in the future), but rather to take our time and wait until our body adapts to it – which will certainly happen.

3.1.2. Rotation parameters and implications

We have established a rotation rate of 2,45 rpm, which would generate a maximum artificial gravity equal to approximately 0,6 g, given the maximum 90 m radius of the hybrid torus (see Sub-chapter 3.2, Section 3.2.1). According to [11], [5], the human body can easily adapt to rotation rates up to 4 rpm, after a short period of training or adaptation. Taking this into account, as well as the comfort of the inhabitants, we regard a rotation rate of 2,45 rpm as reasonable.

Though better compared to the lack of gravity, this value would not be exactly suitable for permanent residents. However, in Cicada's case, it is a plausible alternative. There are no long-term colonists inhabiting this settlement – only tourists, whose stay would most likely not exceed a couple of weeks, staff, working monthly shifts, and eventually researchers and scientists, with a similar schedule. Thus, atypical gravity conditions are not out of the question; in fact, they even bring about numerous, significant advantages, mainly concerned with the costs involved in the construction of a space settlement.

Firstly, in particular, the aspect of artificial gravity has a great deal of emphasis placed on the thickness of the hull. Greater values of the gravity load impose the need for a stronger settlement shell, thus a greater quantity of material to pay for and, most importantly, to transport from the Earth to ELEO. Due to the fact that launch procedures in the near future will require a price of around $1700 per kilogram (for reusable launch vehicles; http://www.spacex.com/falcon-heavy) [11], compared to 1 g, 0,6 g is more advantageous in this case.

Secondly, the magnitude of the structure is reduced and hence the costs. For instance, let us consider a constant value of the artificial gravity, $\tilde{g}=\omega^2 r$. In accordance with the formula, if ω is multiplied by k, a positive real number, the initial radius is divided by k^2. If other dimensions are kept directly proportional to the radius of rotation, they decrease identically. Hence the volume of each of the components, calculated in cubic measure units, becomes k^6 times smaller, and so does the mass of the atmosphere inside the pressurized modules, which is obtained as the product between its volume and density, the latter being constant. The projected area, calculated in square measure units, is k^4 times reduced. Thus there would be k^4 times fewer inhabitants and therefore the individual mass per inhabitant would also become k^4 times smaller. Because the skin strength of the habitat linearly depends on the total internal mass, it is also at least k^4 times reduced (note that this reduction value does not take into account atmospheric pressure inside the habitat). Ultimately, mass reduction varies from k^4 to k^6 , if ω is multiplied by k and the acceleration caused by centrifugation has a fixed value, equal to $\tilde{g}$.

If we evaluate the current standpoint of the space industry, immense expenses are probably the greatest issue which arises in regard to the construction of the first space settlements. These advantages are mostly relevant in relation to the costs of building the habitat, but a lower value of pseudo-gravity also adds up to the authenticity of an otherworldly experience, which might appeal to tourists, in contrast to permanent residents, in addition to allowing experimenting and training in different levels of micro-gravity. A small settlement, designed as a space hotel in low gravity, is quite likely the ideal place to start.

3.1.3. The rotation mechanism

P. Jevtovic [10] describes a method through which electrodynamic systems can be adapted in order to implement a rotation mechanism which would help generate artificial gravity in a self-reliant, orbiting space settlement.

EDS (short for Electrodynamic Suspension) is a type of technology which relies on repulsive forces, influenced by the positioning of super conducting magnets. Through optimization, it can be modified to conform to a circular path, which would fit the design of a rotating space settlement. The principle which supports this rotation mechanism is similar to that of Japanese Maglev (magnetic levitation) trains, where the controlled movement of the vehicle is enabled by the presence of magnetic forces and fields.

Outer space provides environmental conditions which favor the use of this technology [10]:

- **low temperature** and super conducting magnets are strongly correlated. For specific materials, the state of superconductivity is a consequence of extremely low temperatures. This also involves the occurrence of the Meissner effect, as the conductor becomes a superconductor and its interior magnetic field is excluded. In addition, the decrease in temperature brings about the decrease in electrical resistance and potential losses are significantly reduced. In contrast to earthly circumstances, enforcing the use of this method in outer space does not involve an additional cost, which would arise from the necessity to cool the materials;
- **weightlessness** naturally imposes levitation. The remaining issue is conceiving a system that allows controlled rotation, which requires lower costs for propulsion, maintenance, and also reduces the required size of the super conducting magnets;
- the propagation of electromagnetic waves is of higher quality in **vacuum** – the size of the super conducting magnets required to generate a magnetic field of a certain strength could be reduced. Vacuum also provides the lack of friction and, therefore, reduced power losses;
- the system can be powered through solar panels, given the fact that **solar energy** is an accessible source of energy in space. Though this source of energy might not be as abundant in ELEO as it is in deep space, given the frequent day-to-night cycle, it is still much more accessible than on Earth; nonetheless, the construction of solar panel arrays outside the Low Earth Orbit remains a future prospect.

Each rotation mechanism is made out of two main components:

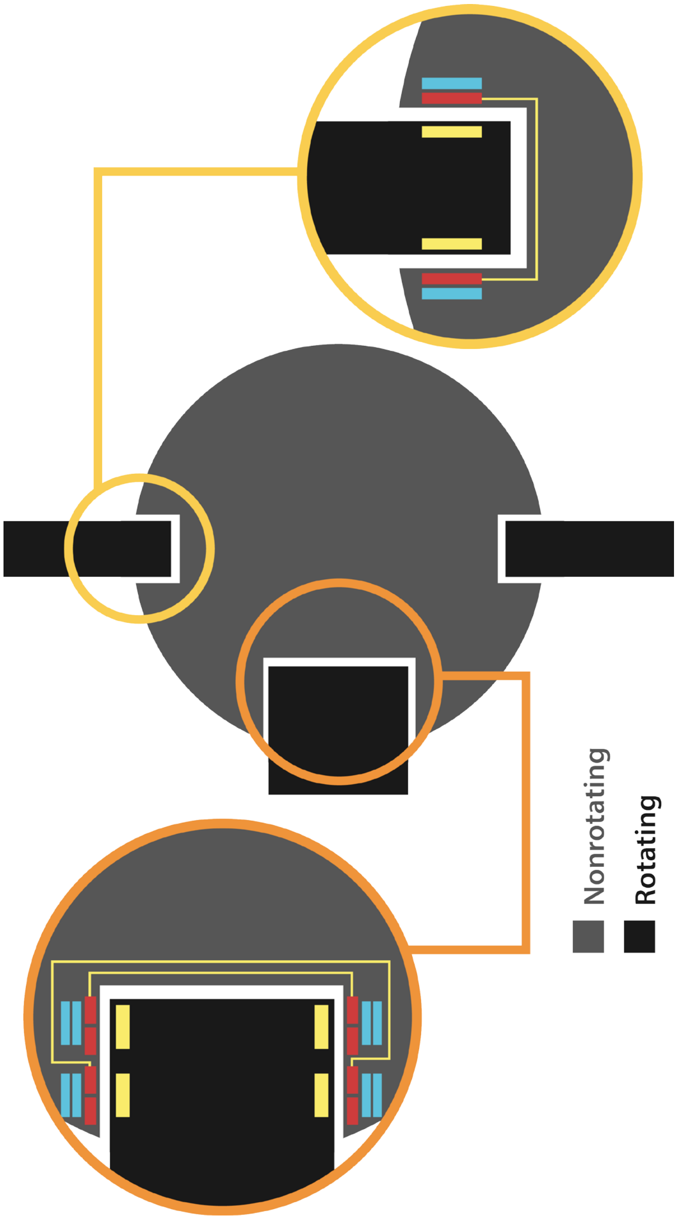


Figure 3.1. (the two rotating mechanisms (for the intermediate double cylinder and the central column) consisting of super conducting magnets (yellow), null-flux coils (red) and propulsion coils (blue); null-flux coins on opposing sides of the guide-way are connected)[10]

1. **the rotating component**, which is mobile and has super conducting magnets placed on its sides;
2. **the non-rotating component** (a supporting track/guide way), which is immobile and represents the location of propulsion and null-flux coils.

Propulsion is a result of the interaction between the propulsion coils and the super conducting magnets. The generated shifting magnetic field induces the movement of the super conducting magnets and helps propel the rotating component. These coils are connected to a source of energy, whose intensity can be controlled, also dictating the speed of the rotation. [10]

Guidance is a result of the interaction between the null-flux coils and the super conducting magnets. These coils are not connected to a source of energy; opposing coils facing each other can be linked through a cable, adding up to the completion of a loop. The interaction also imposes a state of equilibrium and thus the well-functioning of the system is automatically preserved, with little outside intervention. [10]

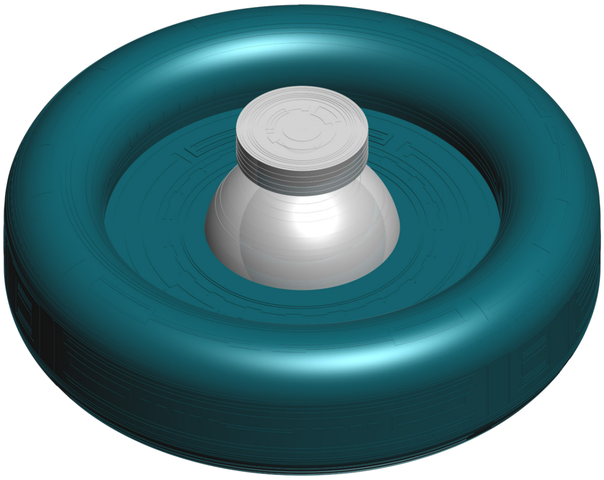


Figure 3.2. (rotating (blue) and non-rotating (gray) components of Cicada)

Thanks to the repulsive magnetic fields generated as the rotating component moves along its guide way, the rotating and non-rotating segments are kept at a constant distance from each other and they do not collide.

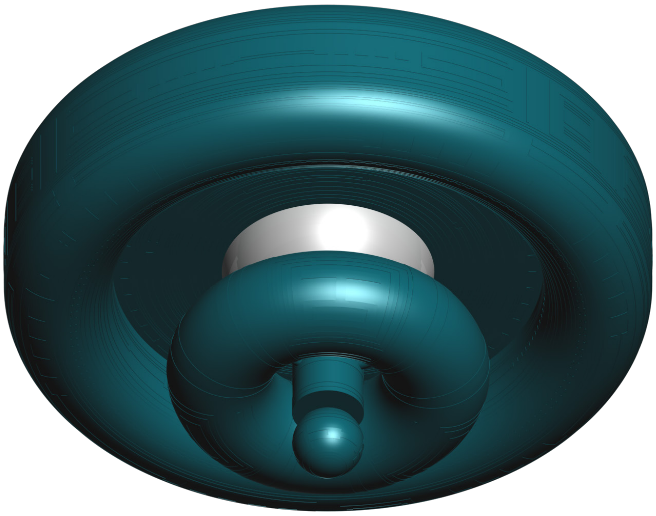


Figure 3.3. (rotating (blue) and non-rotating (gray) components of Cicada)

The system, which powers and, at the same time, guides the rotation, should be made out of one or more rails: circular paths, each consisting of three layers – the super conducting magnets, the null-flux coils and the propulsion coils, in this order, as shown in figure 3.1. Batteries located in the central sphere will be used to power the system if a power cut occurs. In case guidance fails, the system should be designed as to rapidly attach the intermediate double cylinder to the sphere and to avoid detrimental collision between the two components.

The only non-rotating components of the habitat are the central sphere and the docking port (given that a rotating docking port would make landing even more difficult than it already is). The two rotating modules (the first one consisting of the intermediate double cylinder and the second one consisting of the column, the torus and the small sphere) rotate in opposite directions, in accordance with the Law of Conservation of Angular Momentum.

3.2. External and internal structure

No taller than 122 m, nor wider than 180 m, Cicada is a small habitat, which resonates quite well with its name. It is designed to meet the characteristics of one of the first hotels in space. Its main goal is to help unleash the development of space tourism and space industry as a whole, eventually accommodating the general population with the idea of space travel and encouraging investors to further fund the construction of future self-reliant space settlements, with a greater magnitude and population sustainability.

In what follows, among others, we will calculate the values of the projected area and habitable volume of each component of the spacecraft. According to [12], projected area is defined as the area dedicated to the construction of buildings for the general population. The projected area belongs to a plane perpendicular to the direction of pseudo-gravity. Additionally, the habitable volume represents the volume in which the variation of the artificial gravity is not greater than a given value, Δg; thus this volume depends on the $\Delta g/g$ ratio [12]. Both the projected area and the habitable volume influence the density of the population.

Because artificial gravity is induced as a result of rotation, there are not many alternatives for shapes. A three-dimensional shape viable for such a structure should be obtained by rotating a closed, smooth curve around an axis (which is actually the central axis of the settlement). Preferably, this two-dimensional shape should also be double symmetric. Such shapes are the sphere, the torus, the cylinder, the double cylinder, the dumbbell and others obtained by combining or altering them.

3.2.1. The hybrid torus

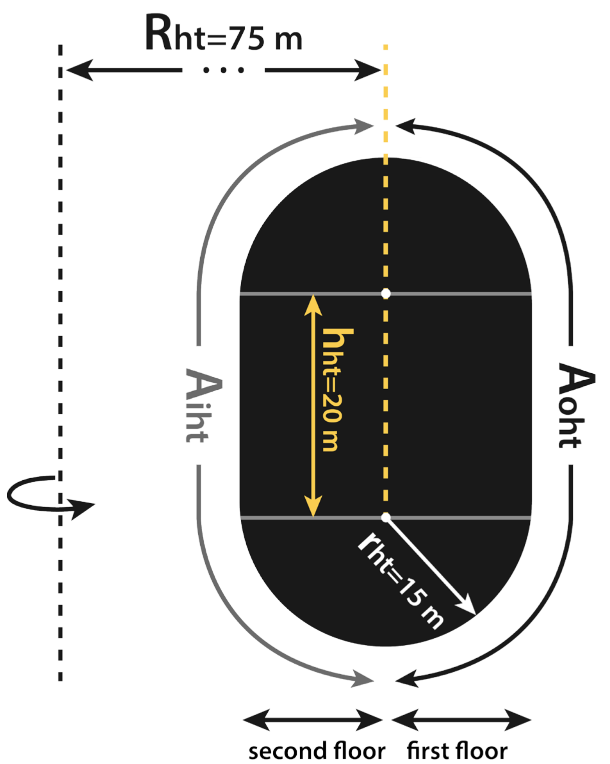


Figure 3.4. (cross section of the hybrid torus and its dimensions)

Among the components of the spacecraft, the hybrid torus is the greatest in size. Out of a restricted range of shapes which behave well in conditions of atmospheric pressure, we take into account a combination between the double cylinder and the torus.

One of the advantages of a torus is that it allows control of the small radius (which delimits the volume of the atmosphere), without the need to resize the radius of rotation. That is applicable to the double cylinder as well, if, instead of the small radius, we consider its height and width. The torus and double cylinder are superior to the cylinder and the sphere, in terms of reducing structural mass. If a certain projected area is desired, the structural mass of the sphere and the cylinder is greater than that of the torus and double cylinder [12, page 58]. Architecturally speaking, the torus is favored because it offers a large horizon, which visually combats the feeling of living in an enclosed space. The double cylinder offers constant pseudo-gravity on the hull and thus the maximum value for artificial gravity is constant on the residential area. Ultimately a combination of the two, a hybrid torus can be easily separated into more levels and built periodically, from smaller segments.

In this case, the habitable volume is equal to the total volume. The formulas for the total area and volume are as follows:

$$V_{Hht} = V_{Tht} = 2\pi^2 R_{ht} r_{ht}^2 + 4\pi h_{ht} r_{ht} R_{ht},$$

$$A_{ht} = 4\pi^2 R_{ht} r_{ht} + 4\pi h_{ht} R_{ht}.$$

In order to determine the outer and inner areas of the hybrid torus (A_{oht} and A_{iht}), as seen in figure 3.4, we will use Pappus' centroid theorem for areas (https://en.wikipedia.org/wiki/Pappus%27s_centroid_theorem), which states that "*the surface area A of a surface of revolution, generated by rotating a plane curve C about an axis external to C and on the same plane, is equal to the product of the arc length s of C and the distance d traveled by its geometric centroid (A=sd)*". It is known that the distance from the centroid of a semicircular arc to the center of the circle is equal to $2r/\pi$, where r is the radius of the circle (see figure 3.5).

First of all, we will calculate the inner and outer areas of the toroidal component, as shown in figure 3.5. The figure also depicts its two centroid points, C_{1o} $(0, R_{ht}+2r_{ht}/\pi)$ and C_{1i} $(0, R_{ht}-2r_{ht}/\pi)$. Therefore:

$$A_{1o} = (\pi r_{ht})\Big(2\pi(R_{ht} + 2r_{ht}/\pi)\Big) = 2\pi^2 R_{ht} r_{ht} + 4\pi r_{ht}^2,$$

$$A_{1i} = 2\pi^2 R_{ht} r_{ht} - 4\pi r_{ht}^2.$$

We will adopt a similar approach in regard to the inner and outer areas of the double cylindrical component, represented in figure 3.6. In this case, the centroids are C_{2o} $(0, R_{ht}+r_{ht})$ and C_{2i} $(0, R_{ht}-r_{ht})$. Thus we have:

$$A_{2o} = 2\pi h_{ht}(R_{ht} + r_{ht}),\ A_{2i} = 2\pi h_{ht}(R_{ht} - r_{ht})$$

Finally, by adding the areas previously determined, we have:

$$A_{oht} = 2\pi^2 R_{ht} r_{ht} + 4\pi r_{ht}^2 + 2\pi h_{ht}(R_{ht} + r_{ht}),$$

$$A_{iht} = 2\pi^2 R_{ht} r_{ht} - 4\pi r_{ht}^2 + 2\pi h_{ht}(R_{ht} - r_{ht}).$$

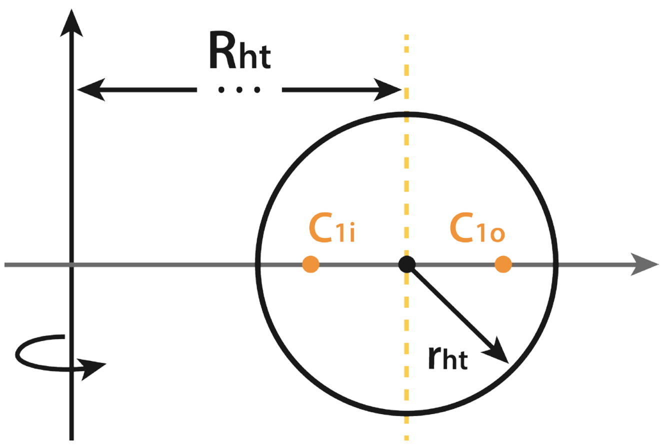


Figure 3.5.

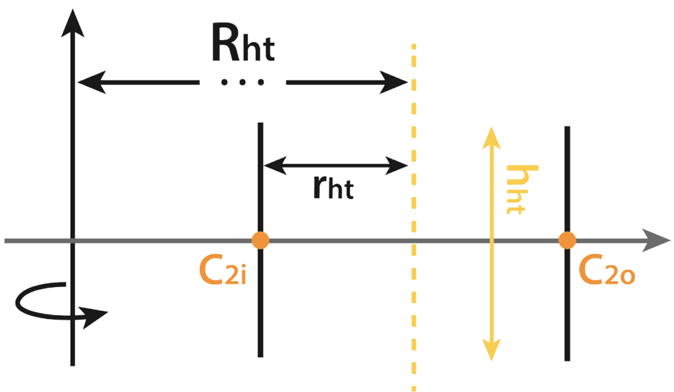
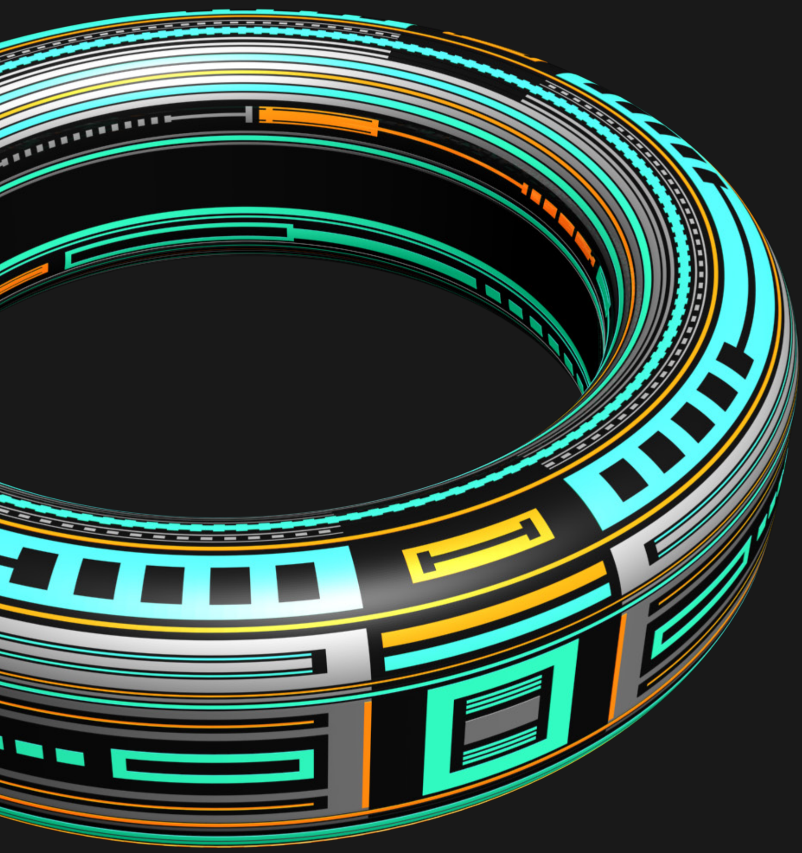


Figure 3.6.

Inner and outer areas (table 3.1) have been calculated in order to determine what areas are covered by each type of shielding configuration.

The projected areas of the first and second floor (figure 3.4) are given by the following formulas:

$$A_{1P} = 2\pi h_{ht}(R_{ht} + r_{ht}),\ A_{2P} = 2\pi R_{ht}(h_{ht} + 2r_{ht}).$$



Hybrid torus	
Major radius R_{ht} (m)	75,00
Minor radius r_{ht} (m)	15,00
Weight h_{ht} (m)	20,00
Angular velocity ω (rpm)	2,45
Total volume V_{Tht} (m^3)	615.361,50
Habitable volume V_{Hht} (m^3)	615.361,50
Total area A_{ht} (m^2)	63.208,20
Outer area A_{oht} (m^2)	36.314,10
Inner area A_{iht} (m^2)	26.894,10
Projected area A_{1P} (m^2)	11.304,00
Projected area A_{2P} (m^2)	23.550,00
g_{max} (m/s^2)	0,6g
$g_{secondfloor}$ (m/s^2)	0,5g
g_{min} (m/s^2)	0,4g
$\Delta g/g$	0,2

Table 3.1. (areas, volumes and values of pseudo-gravity calculated for the hybrid torus)

General characteristics of the hybrid torus:
-pressurized/unpressurized/partially pressurized
-rotating/non-rotating
-shielding configuration 1/shielding configuration 2/shielding configuration 3/chevron shielding (see figures 2.4 and 2.5 in Sub-chapter 2.2)

Area allocations: As the main attraction aboard Cicada, Magicada is a hotel and amusement park developed outside earthly boundaries, in micro-gravity conditions. It is only natural that the hybrid torus, with the greatest projected area and habitable volume among all components, would be entirely allocated to the micro-gravity park. Thus we have separated this module into two floors, each one with a height of 15 meters (as shown in figure 3.4).

3.2.1.1. The first floor

The first floor has approximately half the projected area of the second one (table 3.1), but is characterized by a greater value of pseudo-gravity, which is 0,6 g. Therefore, we have established that we would locate the hotel's headquarters here, which include the employee dormitory (these are more elaborately described in Sub-chapter 3.3, Sections 3.3.2 and 3.3.3). Other area locations will be represented by a shopping district, a food district, a small medical facility, food processing centers and a casino (figure 3.7). Given the total 15 meter height, it is possible to separate the hotel and employee dormitory into 3-4 levels and others into 2 levels (when applicable; mostly for closed areas, like restaurants and shops). Aside from working as a method to save space, if done correctly, this can also visually enhance the aspect of the park and add diversity to its range of attractions. The remaining area that is not occupied by buildings will be used as a relaxation/strolling area, filled with paths, benches and greenery in general.

Transport routes connecting the intermediate double cylinder to the hybrid torus (Section 3.2.2.), as well as the two levels of the hybrid torus, are separated into two categories; thus there is an elevator for cargo and one for people, each passageway with a maximum diameter of 8 meters (the height of the intermediate double cylinder).

An additional green area, separated into more levels (see Sub-chapter 4.3) will be added on the circular side walls (generated by the torus component of the hybrid cylinder) and will generally work as a hydroponics plantation.

Most of these area allocations are subjectively presented in the brochure attached to the project, *The tourist's guide to Magicada.*

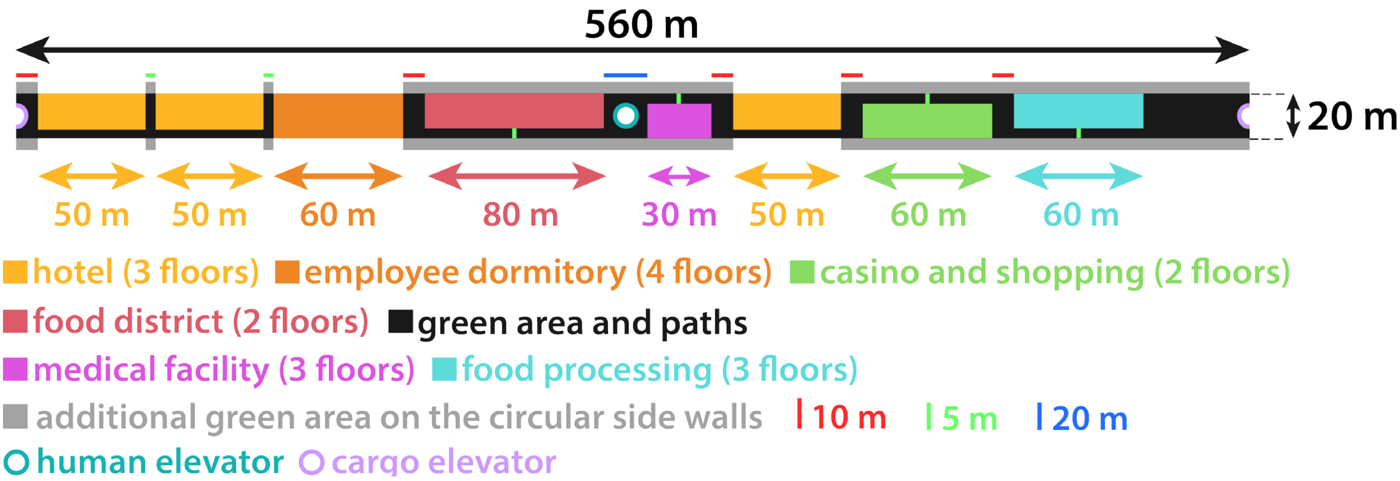


Figure 3.7. (area allocations on the first floor of the hybrid torus; note that the green area across the employee dormitory and hotels is only represented by the fourth level of the agricultural sector)

3.2.1.2. The second floor

The second floor is considerably more spacious (table 3.1) and features a maximum artificial gravity of 0,5 g. If the first level has the floor separated into a toroidal component and a cylindrical one, the second level has an identical configuration, but for the ceiling.

The width of the park comes close to 50 meters (it is not exactly 50 meters, because a portion of the ceiling

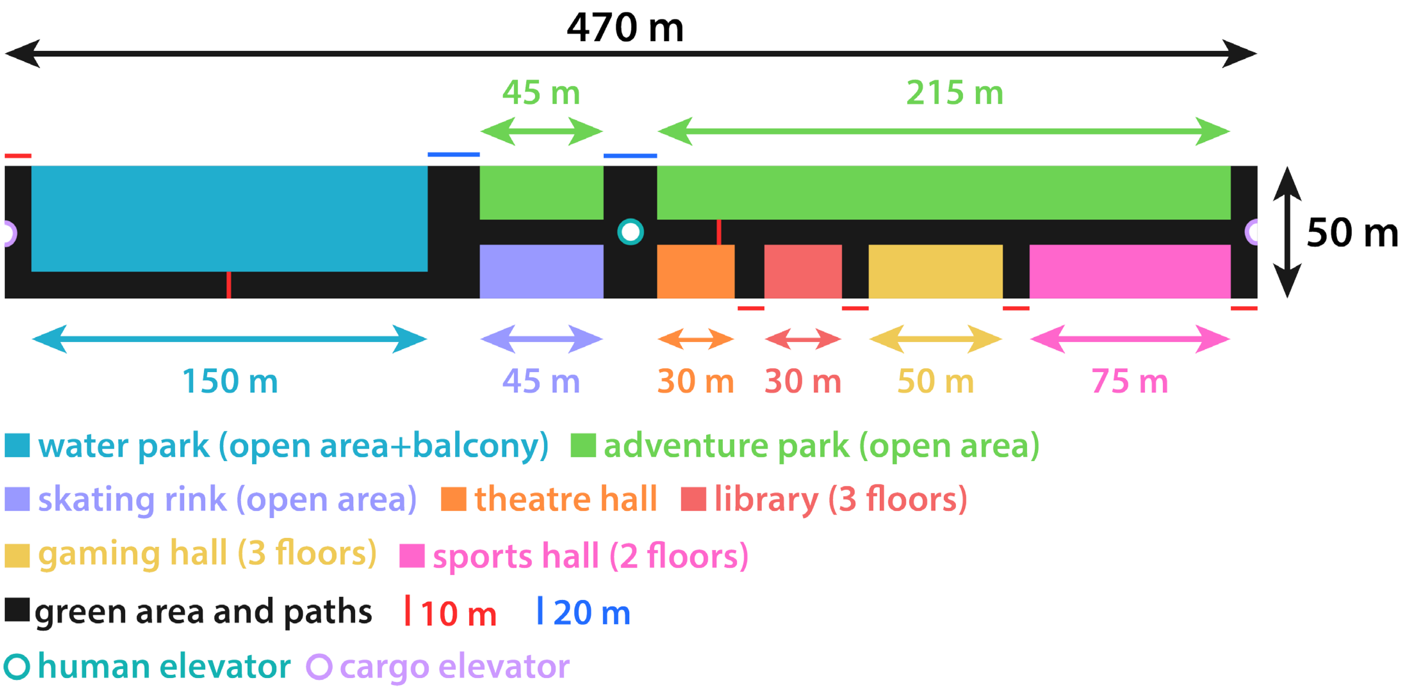


Figure 3.8. (area allocations on the second floor of the hybrid torus) (note that there is some unrepresented space between buildings and the settlement's hull)

is circular and, for a small distance, does not allow a minimum height of, say, 3 meters, enough for a person to pass through without having to bend); we take into account this approximate value (note that certain buildings will be built with circular exterior walls, mostly covered in windows, facing the part of the hybrid torus also covered in windows). The length of the second floor length is approximately 470 meters; given the reduced overall dimensions of the habitat, this is not quite as cramped as expected at a first glance.

We plan to create a small water park as part of the amusement park, with a length of 150 meters and a width of 40 meters. This would consist of a large pool, perhaps separated into age categories, but also a number of slides and jumping platforms alongside the gravity gradient (which goes up to a minimum value of roughly 0,4 g, right where the ceiling is). A second level can be added as a sort of balcony, to include one or more jacuzzi hot tubs and a SPA center. Aside from the water park, a theatre hall will be added in order to host concerts, opera and ballet shows, as well as theatre plays; the dimensions of the theatre are not as great, given the reduced population. Magicada is themed to resemble a fantasy forest, so a part of the remaining length will be allocated to an adventure park with two courses, one for children and beginners in general and one for more experienced/advanced users. As part of the adventure park or as an appendix, a zip-line will be added almost at maximum height, to circle the entire torus. Another area allocation will consist of a large skating ring. Additionally, a library will be built and designed as a maze, in order for tourists and residents to explore scientific and literary space-related works. The park will also include a gaming hall (for virtual reality games and other team games, such as laser tag), which will seek to engage the players physically, taking advantage of the micro-gravity environment. A sports hall will also be part of the park and will feature numerous sports which can be adapted and executed in micro-gravity. The remaining area will be filled with greenery and paths, as well as benches and other exterior furnishings for relaxation purposes.

Like the first floor, the second floor also has some area allocated to the two elevator routes coming from the intermediate double cylinder, both for cargo and for people.

As far as the decorating goes, the circular part of the ceiling will also be covered in windows. The straight part of the ceiling, where there are no transport routes coming from the intermediate double cylinder, will be covered by an aquarium.

Most of these area allocations are subjectively presented in the brochure attached to the project, *The tourist's guide to Magicada*.

3.2.2. The intermediate double cylinder

The intermediate double cylinder is an alternative to the traditional spokes. Given the small distance between the central sphere and the hybrid torus, this replacement is rather advantageous, offering enough space for the maneuvering of cargo. Additionally, this also involves a higher uniform gravity load on the inner wall of the hybrid torus, as opposed to the atmospheric pressure; thus this relative equilibrium state minimizes the potential buckling of the settlement's hull in that portion of the spacecraft.

A 5-meter portion of the double cylinder is integrated in one of the segments that were extracted from the sphere and used as the mobile component of the Maglev guide-way.

In this case, in order to determine the total and projected areas (for each of the 4 levels, denoted by A_{jP}), as well as the total and habitable volume (we consider that the habitable volume is equal to the volume of the pressurized segment of the double cylinder), we have the following formulas:

$$V_{Tc} = \pi h_c (R_c^2 - r_c^2),\ \ V_{Hc} = \pi h_c (R_c^2 - (r_c + 7)^2)$$

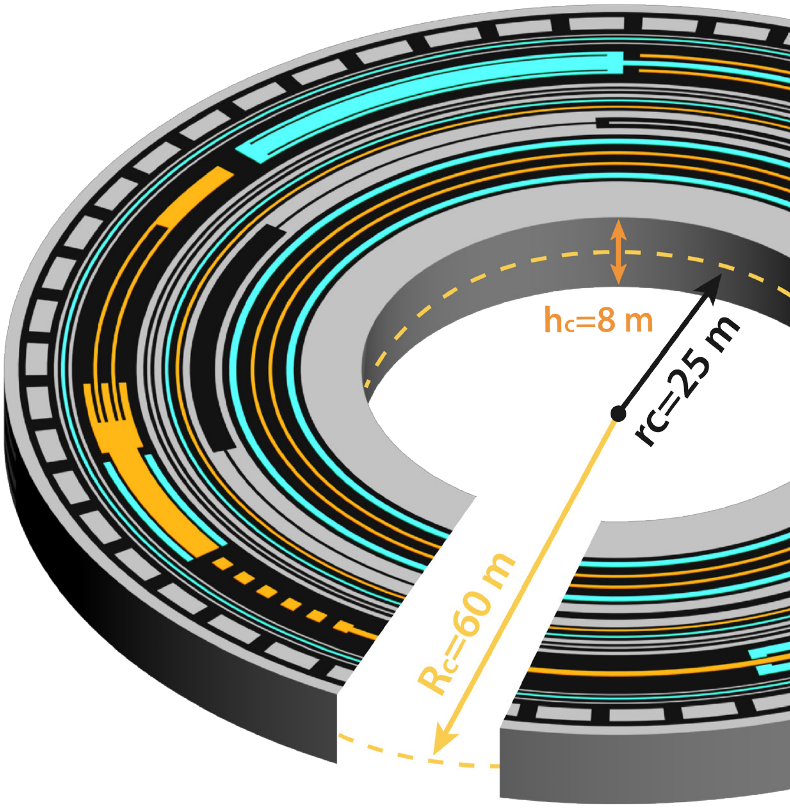
$$A_c = 2\pi h_c r_c + 2\pi (R_c^2 - r_c^2)$$

$$A_{jP} = 2\pi h_c(R_c - 7(j-1))\ j = \overline{1,4}$$

When we calculated the total area, we did not take into account the area of the common surface between the intermediate double cylinder and the hybrid torus.

Intermediate double cylinder	
Major radius R_c (m)	60,00
Minor radius r_c (m)	25,00
Height h_c (m)	8,00
Angular velocity ω (rpm)	2,45
Total volume V_{Tc} (m^3)	74.732,00
Habitable volume V_{Hc} (m^3)	64.709,12
Total area A_c (m^2)	19.939,00
Projected area A_{1P} (m^2)	3.014,40
Projected area A_{2P} (m^2)	2.662,72
Projected area A_{3P} (m^2)	2.311,04
Projected area A_{3P} (m^2)	1.959,36
g_{max} (m/s^2)	0,4g
g_{min} (m/s^2)	0,17g
$\Delta g/g$	0,23

Table 3.2. (areas, volumes and values of pseudo-gravity calculated for the intermediate double cylinder)



General characteristics of the intermediate double cylinder:
-pressurized/unpressurized/partially pressurized
-rotating/non-rotating
-shielding configuration 1/shielding configuration 2/shielding configuration 3/chevron shielding (see figures 2.4 and 2.5 in Sub-chapter 2.2)

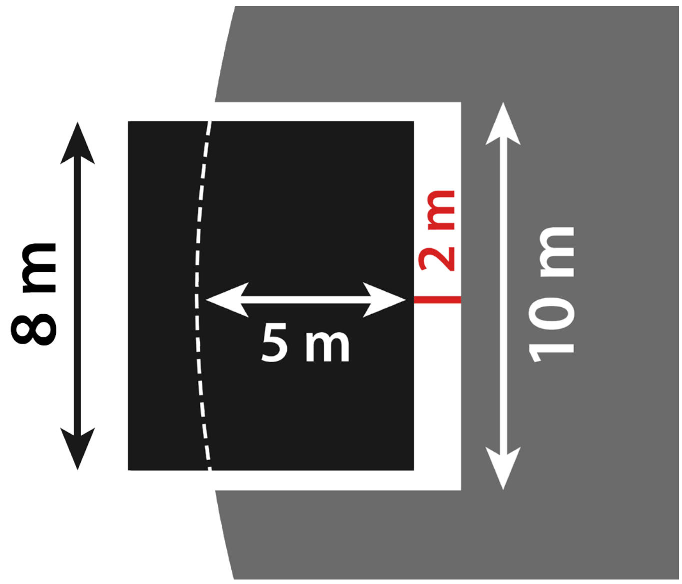


Figure 3.9. (distances between the double cylinder (black) and the central sphere (gray)

Area allocations: The intermediate double cylinder has an additional advantage over cylindrical spokes, because it manages to save up a great deal of the empty space between the hybrid torus and the central sphere. This space can be used for numerous purposes.

Firstly, as mentioned before, a 5 meter-portion of the double cylinder is "buried" in the sphere, working as part of the guide-way for the rotation mechanism (see Sub-chapter 3.1, figure 3.1). The double cylinder and the sphere are placed at a distance of 1 meter from each other, where the Maglev track is; the passage which will allow access from the sphere to the double cylinder and vice-versa is 2 meters tall (figure 3.9). Additionally, a 7-meter tall portion of the intermediate double cylinder is unpressurized and two airlock systems are placed at the passageways for human and cargo elevators (figure 3.10). We thought it might be more efficient to place airlocks here, because maneuvering cargo and moving in 0,2 g (generated by a radius of 32 meters and an angular velocity of 2,45 rpm) would be easier (or more controlled) than in 0 g. Also, the superconducting magnets and the coils would be isolated from the pressurized area. Like the central sphere, the non-pressurized area can be used as storage for propellant, EVA equipment Lithium-ion batteries and fuel cells.

The remaining pressurized portion has a height of 28 meters. It is separated into four levels (figure 3.10), each with a height of 7 meters, and it is characterized by a gravity gradient going from 0,26 g to 0,4 g at floor level. Other values can be obtained by adding intermediate levels, aside from these four. A third of this pressurized portion is filled with scientific laboratories, allowing research in different levels of pseudo-gravity. Tourists would also be granted supervised access to the laboratories, to perform experiments in micro-gravity. Servers and back-up servers are also located in the scientific laboratories. Almost half of the first floor will have recycling and food/water processing centers. The remaining volume is used for storage purposes, for water, gas tanks, materials and also for food.

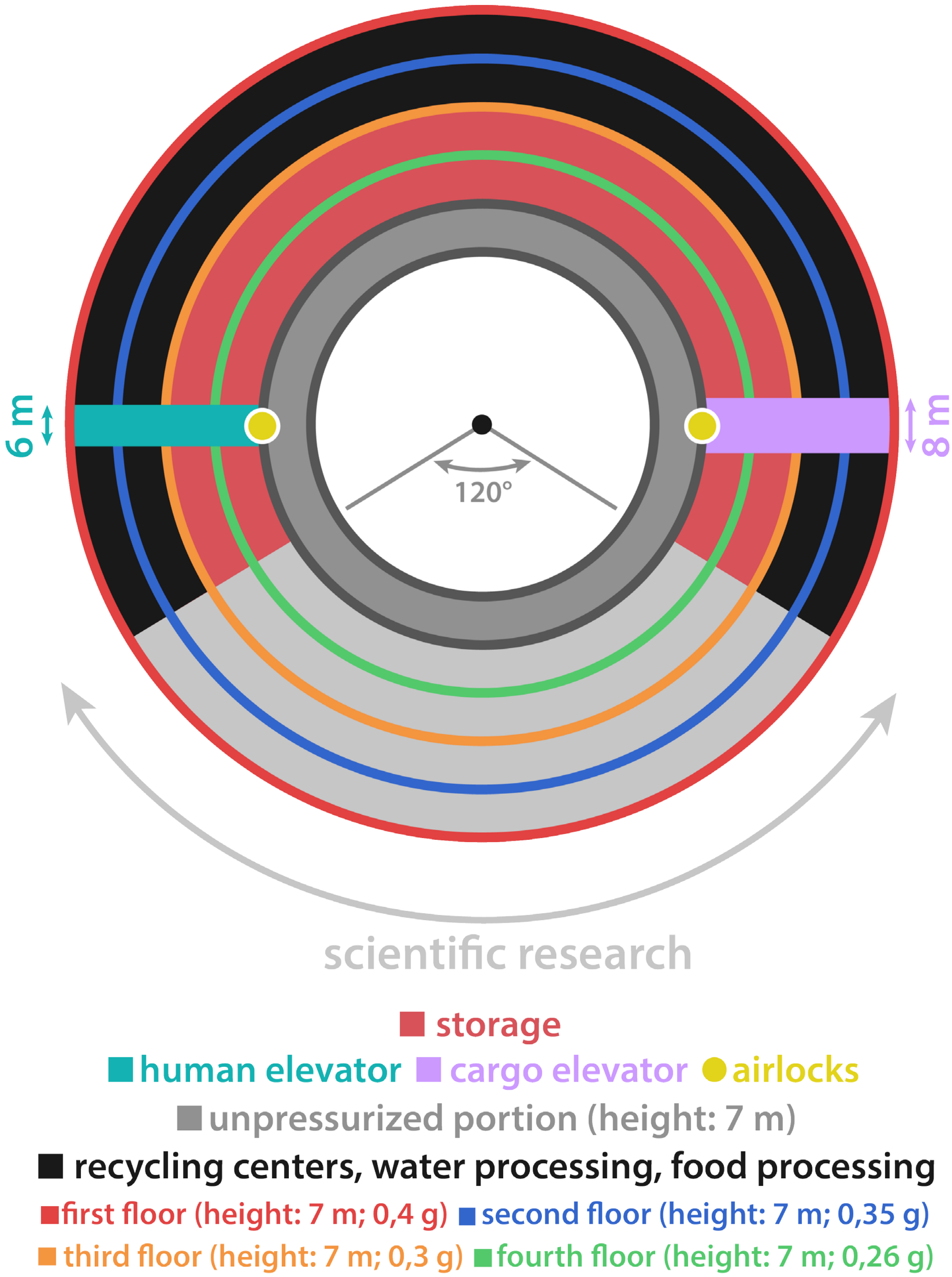


Figure 3.10. (area allocations for the intermediate double cylinder)

3.2.3. The central sphere

The central sphere is the main non-rotating component of the spacecraft. It offers support to the rotating modules and also serves as a communication path between the stationary dock and the moving, inhabited segments of the settlement. Given its central positioning, the sphere's main advantage is that it is spacious.

The volume and total area of the sphere were calculated as follows:

$$V_s \simeq \frac{4}{3}\pi r_s^3 - \frac{\pi}{4} d_4 d_3^2 - \pi d_1 (r_s^2 - (r_s - d_2)^2),$$

$$A_s \simeq 4\pi r_s^2 + \pi d_3 d_4 + 2\pi(\ r_s^2 - (r_s - d_2)^2\ ).$$

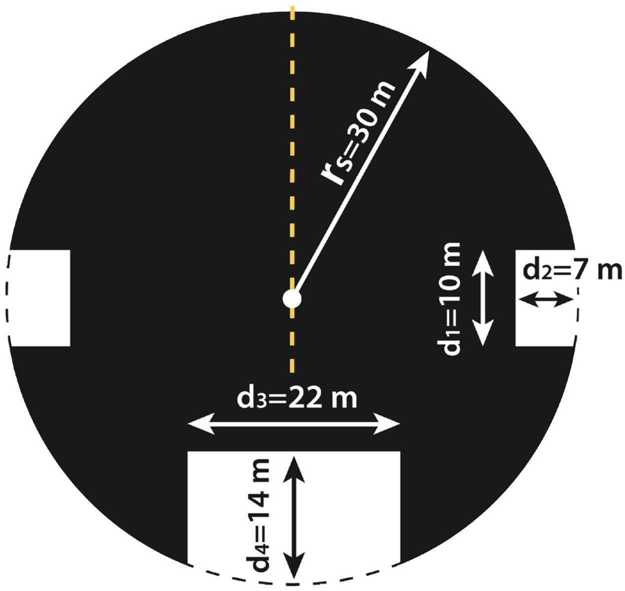


Figure 3.11. (cross section of the sphere and its dimensions)

These are approximate values, because we have considered that the segments we cut out of the sphere are a double cylinder and, respectively, a cylinder, when, in fact, their outer walls are slightly curved (given the curvature of the sphere). This curvature, however, is almost unnoticeable and thus the approximations are rather close to the accurate values.

General characteristics of the central sphere:
-pressurized/unpressurized/partially pressurized
-rotating/non-rotating
-shielding configuration 1/shielding configuration 2/shielding configuration 3/chevron shielding (see figures 2.4 and 2.5 in Sub-chapter 2.2)

Central sphere	
Radius r_s (m)	30
d_1 (m)	10
d_2 (m)	7
d_3 (m)	22
d_4 (m)	14
Area A_s (m^2)	14601
Volume V_s (m^3)	96071,44

Table 3.3. (areas and volumes calculated for the central sphere)

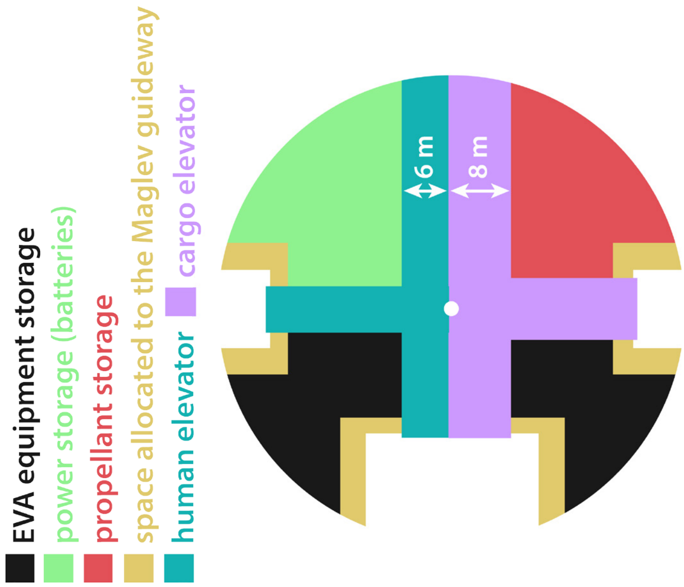


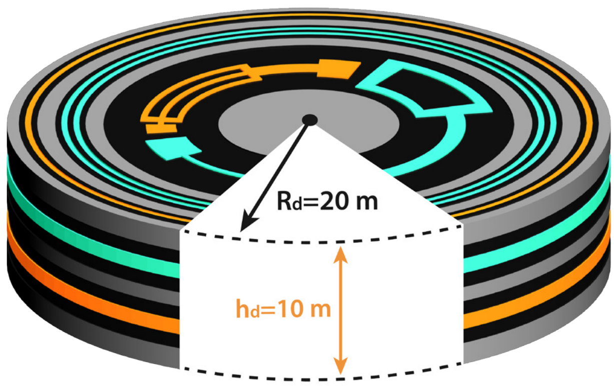
Figure 3.12. (area allocations for the central sphere)

Area allocations: A part of the central sphere will be allocated to spacecraft manufacture and repair, as well as propellant storage. The remaining volume will be used as storage for EVA equipment, propellant and H_2-O_2 fuel cells and Lithium-ion batteries (among others, these are needed to support the rotating mechanism in case of a power-cut). Passageways will be designed for cargo and for people, to allow transport between the dock, the central column and the intermediate double cylinder (ultimately the hybrid torus).

3.2.4. The dock

Attached to the central sphere, the dock is immobile. The passageway between these two non-rotating components is a small cylindrical column, that is 4 meters tall and 14 meters wide, in order to allow more accessible transport of cargo and people.

Area allocations: The dock has a conventional purpose (landing and take-off of cargo carriers, spaceships designed for space tourism and others). The interior volume is allocated to spacecraft manufacturing and repair, but also to storage.



General characteristics of the dock:
-pressurized/unpressurized/partially pressurized
-rotating/non-rotating
-shielding configuration 1/shielding configuration 2/shielding configuration 3/chevron shielding (see figures 2.4 and 2.5 in Sub-chapter .2.2)

3.2.5. The column

Similar to the docks, the column rotates by means of Maglev technology. 12 meters of it are buried inside the sphere; the non-rotating support and the rotating support of the Maglev guide-way are placed at a distance of 1 meter from each other, while the access way between the sphere and the column is 2 meters tall.

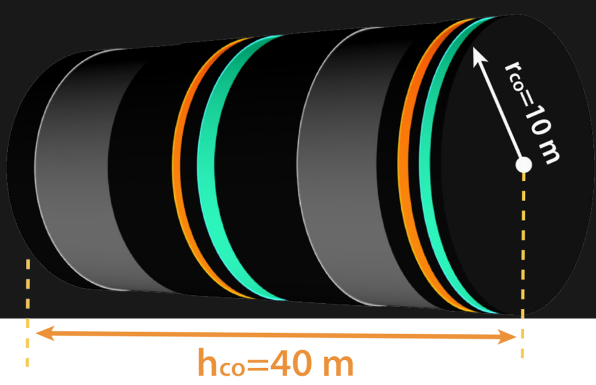
Here are the formulas to calculate the total and projected areas and volume of the central column (A_{pco} represents the lateral area of the cylinder without the pressurized portion):

$$V_{Tco} = \pi r_{co}^2 h_{co},\ \ A_{co} = 2\pi r_{co}(r_{co} + h_{co}), A_{Pco} = 2\pi r_{co}(h_{co} - \mathbf{12}).$$

Column	
Radius r_{co} (m)	10,00
Height h_{co} (m)	40,00
Angular velocity ω (rpm)	3,00
Volume V_{co} (m^3)	12.560,00
Area A_{co} (m^2)	3.140,00
Projected area A_{pco} (m^2)	1.632,80
g_{max} (m/s^2)	0,1g
g_{min} (m/s^2)	0,00
Δg/g	0,10

Table 3.4. (areas, volumes and values of pseudo-gravity calculated for the column)

General characteristics of the column:
-pressurized/unpressurized/partially pressurized
-rotating/non-rotating
-shielding configuration 1/shielding configuration 2/shielding configuration 3/chevron shielding (see figures 2.4 and 2.5 in Sub-chapter 2.2)



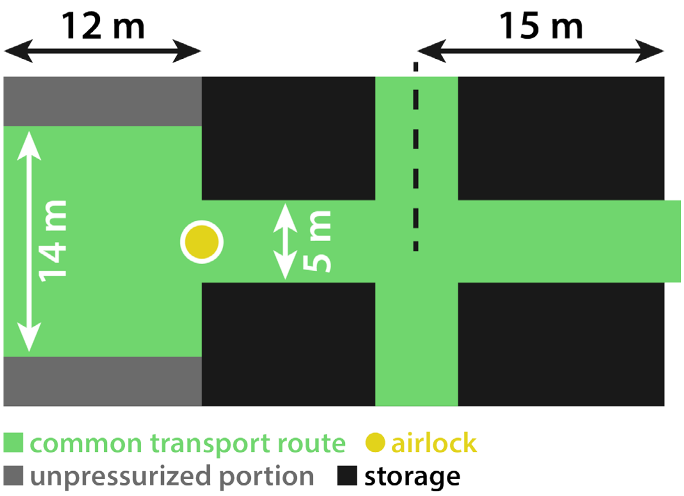


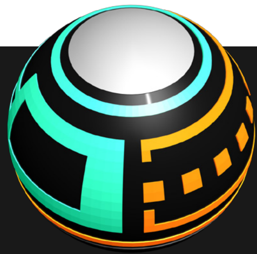
Figure 3.13. (area allocations for the column)

Area allocations: The first twelve meters of the column, which are integrated in the sphere and mostly serve as support for the Maglev guide-way, are unpressurized, but can nevertheless be used for storage. The two transport routes are merged into one. A common transport route for both cargo and people leads to the torus (placed at a distance of 15 meters from the top of the column) and the small sphere (figure 3.13). Note that, because the torus is supported by three 6 meter-thick spokes, there are also three lateral transport routes which could not be depicted in a two-dimensional representation. The remaining volume is used as storage for gas tanks, water, materials, food, batteries and others, given its position in the vicinity of the torus.

3.2.6. The small sphere and the torus

Area allocations for the small sphere: The small sphere has a 10-meter radius and it is connected to the column by a cylindrical passageway that is 1 meter tall and 5 meters wide. It will be designed as an observatory, covered in windows for the most part, where pseudo-gravity is almost 0 g.

General characteristics of the small sphere:
-pressurized/unpressurized/partially pressurized
-rotating/non-rotating
-shielding configuration 1/shielding configuration 2/shielding configuration 3/ chevron shielding (see figures 2.4 and 2.5 in Sub-chapter 2.2)



The torus is connected to the central column by three spokes, each with a radius of 3 meters and a height of 5 meters. The small sphere is located at the extremity of the column, linked to it by a passageway in the form of a cylinder, with a radius of 2,5 meters and a height of 1 meter.

For the volume and total area of the torus there are the following formulas:

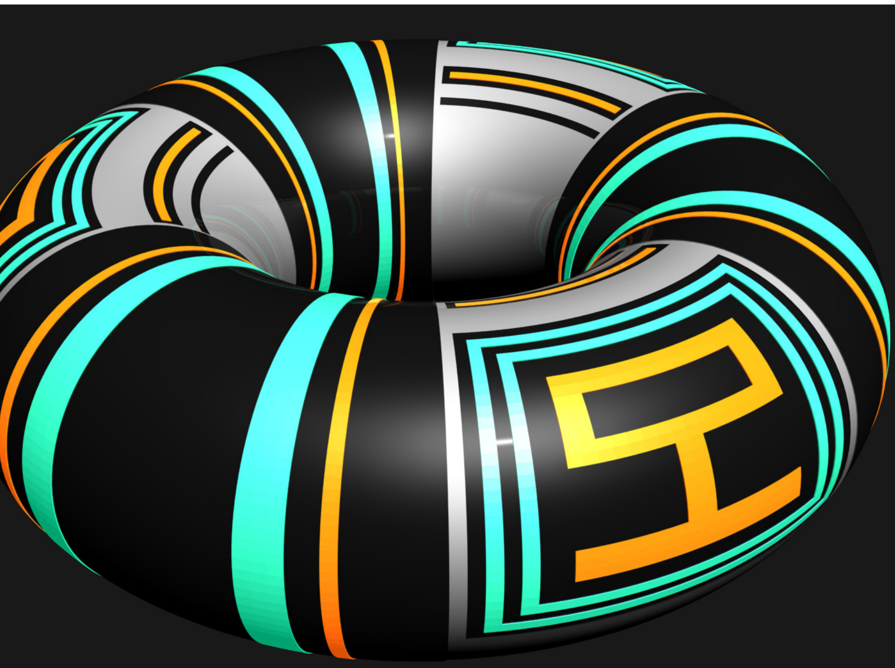
$$V_{Tt} = 2\pi^2 R_t r_t^2,\ A_t = 4\pi^2 R_{ht} r_{ht}.$$

As in Subsection 3.2.1, we use Pappus' theorem to determine the inner and outer areas of the torus (figure 3.14):

$$A_{ot} = 2\pi^2 R_t r_t + 4\pi r_t^2,\ A_{it} = 2\pi^2 R_t r_t - 4\pi r_t^2.$$

General characteristics of the torus:
-pressurized/unpressurized/partially pressurized
-rotating/non-rotating
-shielding configuration 1/shielding configuration 2/shielding configuration 3/chevron shielding (see figures 2.4 and 2.5 in Sub-chapter 2.2)

Area allocations for the torus: Being one of the components of the second part of the settlement, the torus is also a future prospect, built using the profits obtained from the hotel and park. Therefore, the torus will be entirely allocated to the construction of a micro-gravity Olympic Stadium, with a maximum value of pseudo-gravity equal to 0,45 g.



Torus	
Major radius R_t (m)	30,00
Minor radius r_t (m)	15,00
Angular velocity ω (rpm)	3,00
Total volume V_{Tt} (m^3)	133.104,60
Habitable volume V_{Ht} (m^3)	133.104,60
Total area A_t (m^2)	17.747,28
Outer area A_{ot} (m^2)	11.699,64
Inner area A_{it} (m^2)	6.047,64
g_{max} (m/s^2)	0,45g
g_{min} (m/s^2)	0,15g
$\Delta g/g$	0,3

Table 3.5. (areas, volumes and values of pseudo-gravity calculated for the torus)

As it is illustrated in figures 3.15 and 3.16, the area allocated to the sports fields and halls is, in fact, the lateral area of a cylinder with a height of approximately 22 meters and a radius of 40 meters (R_t+r_t-5). The height was determined by applying the Pythagorean theorem in the right triangle formed by the small radius of the torus as the hypotenuse, a 10-meter side and another side which represents half this height. We have established an approximate value of 5500 m^2 for this area, which forms a rectangle with a width of 250 meters and a height of 22 meters when unrolled (figure 3.16; note that, in this case, this area and the food court area form the projected area of the torus); if we subtract the area allocated to passageways, we are left with 5170 m^2, which can be separated into 3 sectors. The first sector contains an ice rink, for ice skating and hockey. A swimming pool, an area for gymnastics and dancing and one for boxing and martial arts are located in the next sector. The third sector will have a tennis and badminton court and other halls for sports such as basketball, volleyball or rugby. Many courts and fields will be covered, except for the ice rink and the swimming pool. The maximum value of artificial gravity here is 0,4 g and the surface is slightly curved, due to the curvature of the cylinder; this means the fields, halls and ice rinks will be curved as well and play styles will change. Skaters might surpass the quadruple Axel jump (which has not yet been demonstrated in a competition) and, like dancers and other performers such as gymnasts or synchronized swimmers, will highly likely be able to execute exceptional sets of movements they would not have been able to pull off on Earth, where gravity is more than two times greater. Other environmental conditions that a rotating habitat provides are caused by the Coriolis effect. Running in the direction of rotation will make you feel heavier and running in the opposite direction will make you feel lighter; perhaps this would particularly affect athletics (for instance, the long and high jumps, both also influenced by the value of artificial gravity). For some sports, Coriolis forces and accelerations would also affect the trajectory of the ball and even that of divers jumping in the pool, passing through a gravity gradient. Small levels of artificial gravity also play an important role in regard to earthly sports; slightly more violent sports such as rugby or martial arts might become less risky. Many sports will evolve to be played in differently designed courts, following different rules and requiring numerous new team play techniques. It is perfectly plausible to assume that

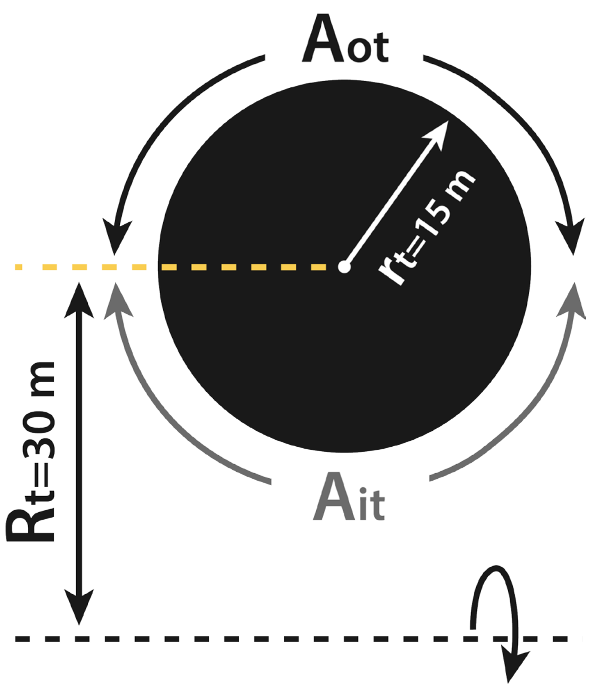


Figure 3.14. (cross section of the torus and its dimensions)

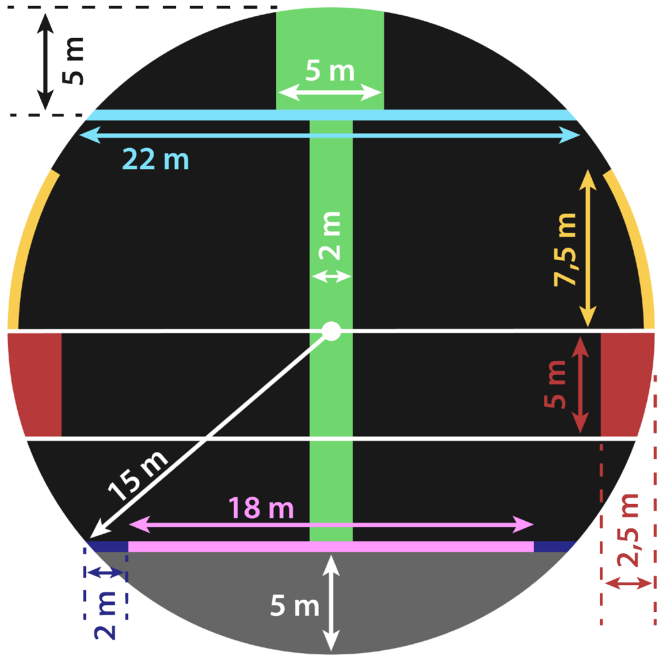


Figure 3.15. (cross section of the torus and its area allocations)

new sports will be developed to replace these traditional ones and that our body will also evolve to perform them at a peak level, in 0 g or rotating habitats in outer space.

Access is granted by the three spokes which support the torus and thus there are three passageways for elevators. The elevators first stop at the food court, which is, at most, 5 meters tall, and then go further down towards the sports fields and stands.

As it can be seen in figure 3.16, the access ways are 5 meter wide and separate both the stands and the sports fields into three sectors. Because there are only going to be two rows of chairs, one under the other, and determining the area would not make much of a difference regarding this arrangement, we only need to determine the length of the tribunes. These lengths are in fact the lengths of the circles that are formed when a point placed somewhere on the row rotates around the settlement's rotation axis. The radius of this circle would be approximately 30 meters for the upper row and approximately 35 meters for the lower row (for both, give or take a few meters, since narrow access ways will be added). The length of the circle for the upper row would be approximately 188 meters and that for the lower row would be 219 meters (173 and 204 if we subtract 15 meters for the passageways); these values would also be doubled by two, since there are two sets of stands on opposing sides of the stadium. These values allow for a capacity of more than 700 people, which is more than enough considering the maximum capacity of around 604 inhabitants for the settlement (Section 5.5.1).

Locker rooms are located under the fields, reaching a maximum height of 5 meters. Large windows (that would be covered when not in use) will also envelop a great portion of the circular area above the stands, so that spectators will have the opportunity to enjoy the otherworldly view of space.

Though not very efficient in terms of saving space and material, the torus certainly provides a marvelous location for a stadium, given that it is very spacious and combats the feeling of being in an enclosed space. The circular section of the torus certainly fits the standards of an extraterrestrial Olympic Stadium and, though very challenging, if manipulated right, its architecture will most surely remain in history as a visual serenade and graceful tribute to the evolution of human culture in outer space.

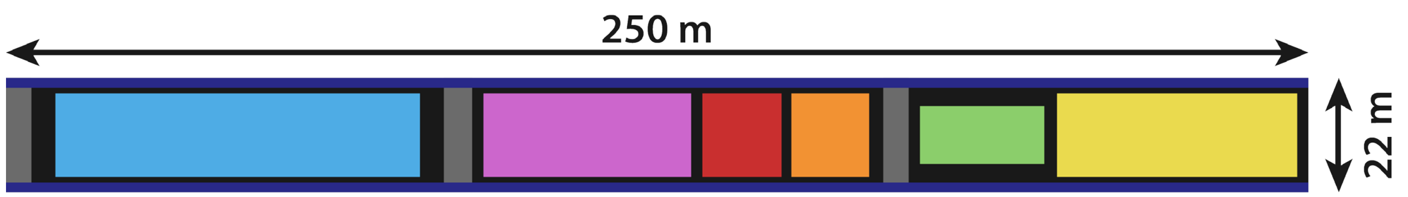
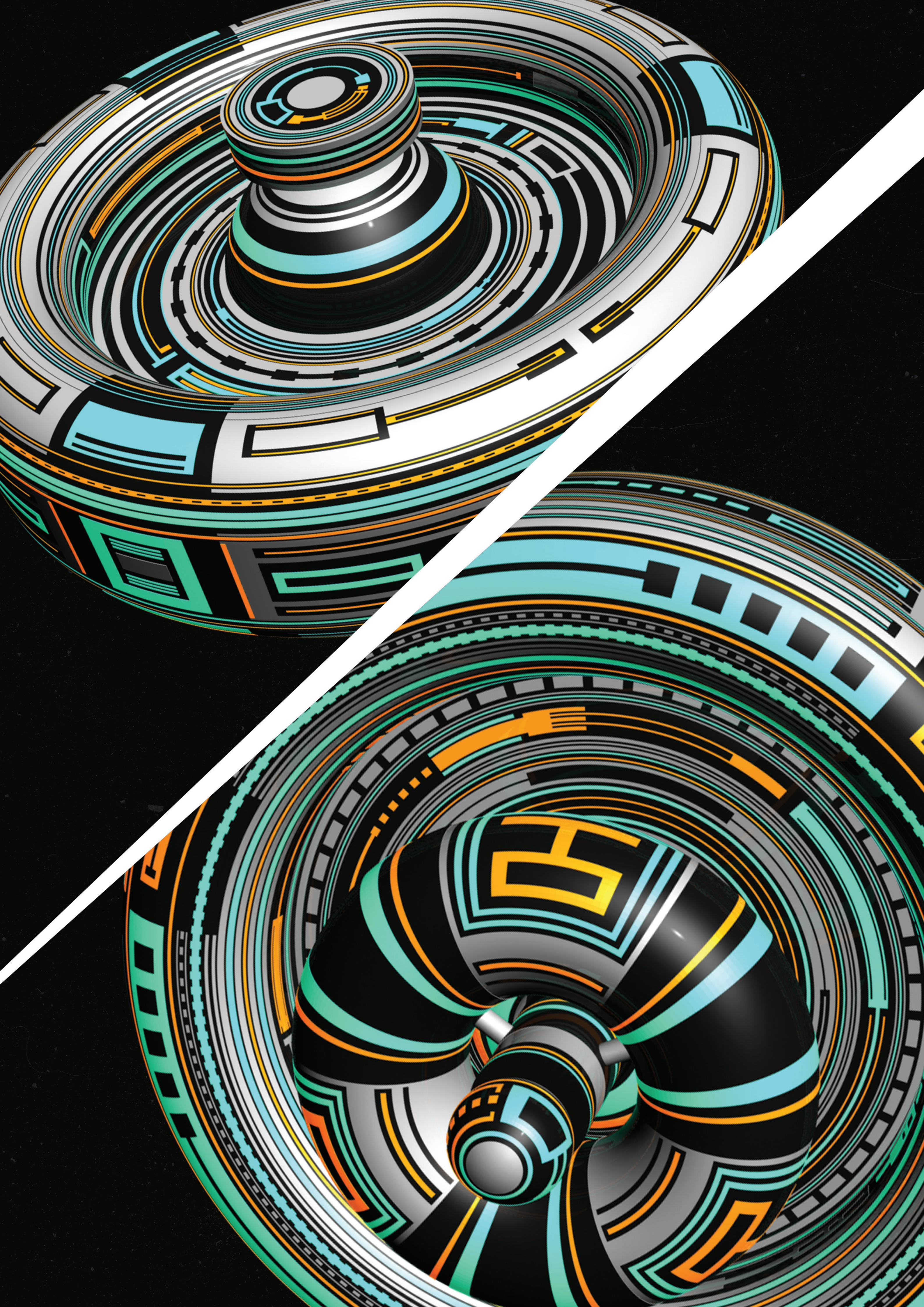


Figure 3.16. (area allocations for the stadium; the figure depicts the unrolled view of the lateral area of the cylinder formed if we section the torus with a plane on which artificial gravity is perpendicular)



3.3. Interior design

3.3.1. Design considerations to minimize discomfort in a rotating habitat

Alongside the external structure, the interior design of the habitat also strongly depends on the implications of artificial gravity generated through rotation. It is possible to optimize the internal arrangements of the settlement and to instruct the staff/tourists in such a way, so that the risks of dizziness, sickness and disorientation associated with a rotating structure are reduced and, ultimately, through long-term accommodation and adaptation, eliminated (or blended into a state of normality).

The placement and any additional improvements of common furnishings and appliances, such as mundane objects in our daily lives, essentially depend on the correlation between the tasks they contribute to and the effects of the Coriolis forces and cross-coupled rotations. Through a detailed analysis of possible interior designs, a significantly higher level of comfort can be achieved with no additional costs.

The basis of designing the interior of the habitat, specifically the residential and touristic areas, should be a sketched representation, depicting the direction of rotation and the cardinal points which define the orientation inside the inhabited modules [1], as shown in figures 3.17 and 3.18.

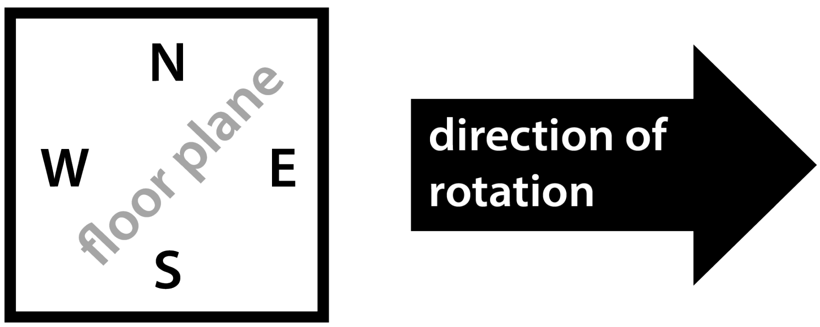


Figure 3.17. (assigning cardinal points to a two dimensional representation of a rotating object)

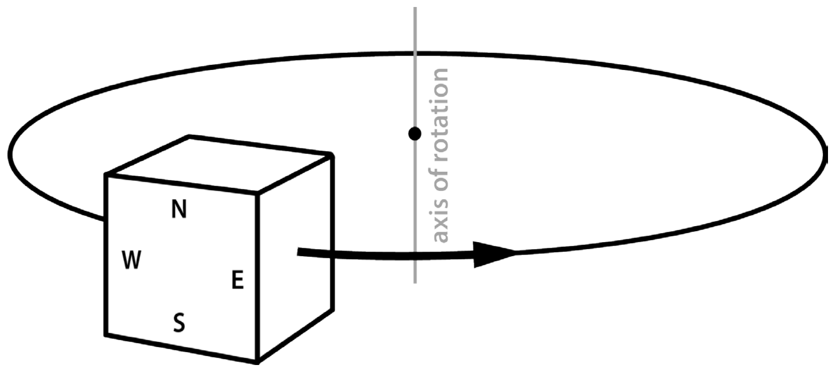


Figure 3.18. (assigning cardinal points to a three dimensional representation of a rotating object, as explained in [1])

The vertical plane which contains the West-East axis, alongside all of its parallel planes, is where all of the Coriolis accelerations occur; movements parallel to the North-South axis are unaffected. By assigning cardinal points to the plan, it is easier to determine the correct positioning of the furnishings inside an apartment or a hotel room, in connection with the occurrence of Coriolis forces and accelerations and their effects. The importance of a detailed and pondered plan is well justified. For instance, a poorly positioned ladder can lead to serious accidents. Depending on whether they are ascending or descending, a person moving along a ladder is either getting closer to the radius of rotation or distancing themselves from it. The fact that the tangential velocity of the object (the person, in this case) and the radius of rotation are directly proportional ($v=\omega R$) means that the value of the tangential velocity also changes, thus resulting in an acceleration (the Coriolis acceleration) and

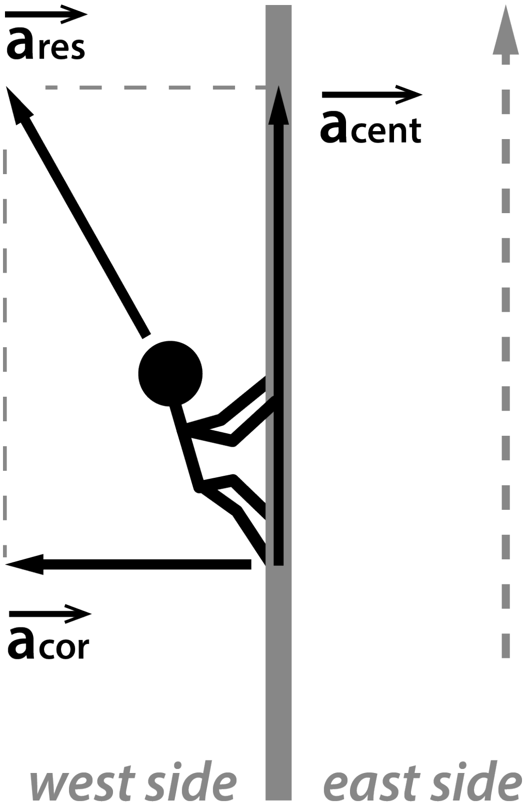


Figure 3.19. (ascending)

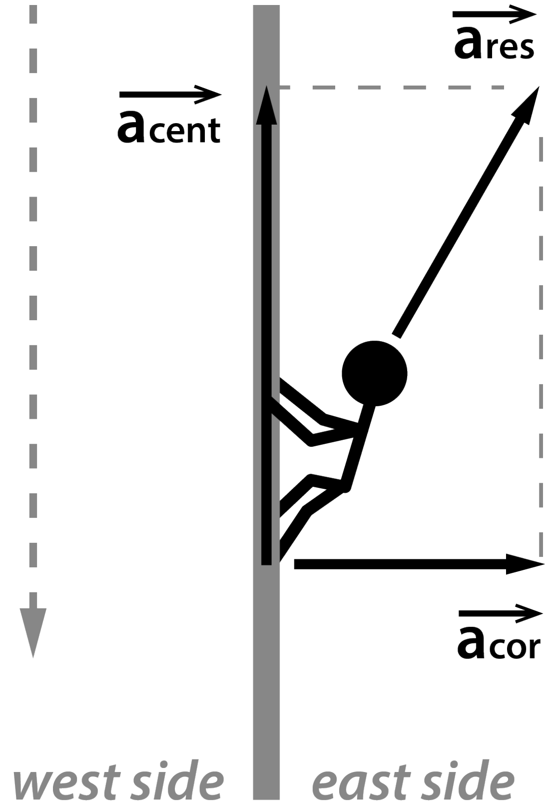


Figure 3.20. (descending)

an inertial force (the Coriolis force). To ensure that the person and the ladder are not being pulled apart from each other, there are two different situations to consider [1] (figures 3.19 and 3.20):

- ascending – in which case, the person would have to use the west side of the east ladder;
- descending – in which case, the person would have to use the east side of the west ladder;

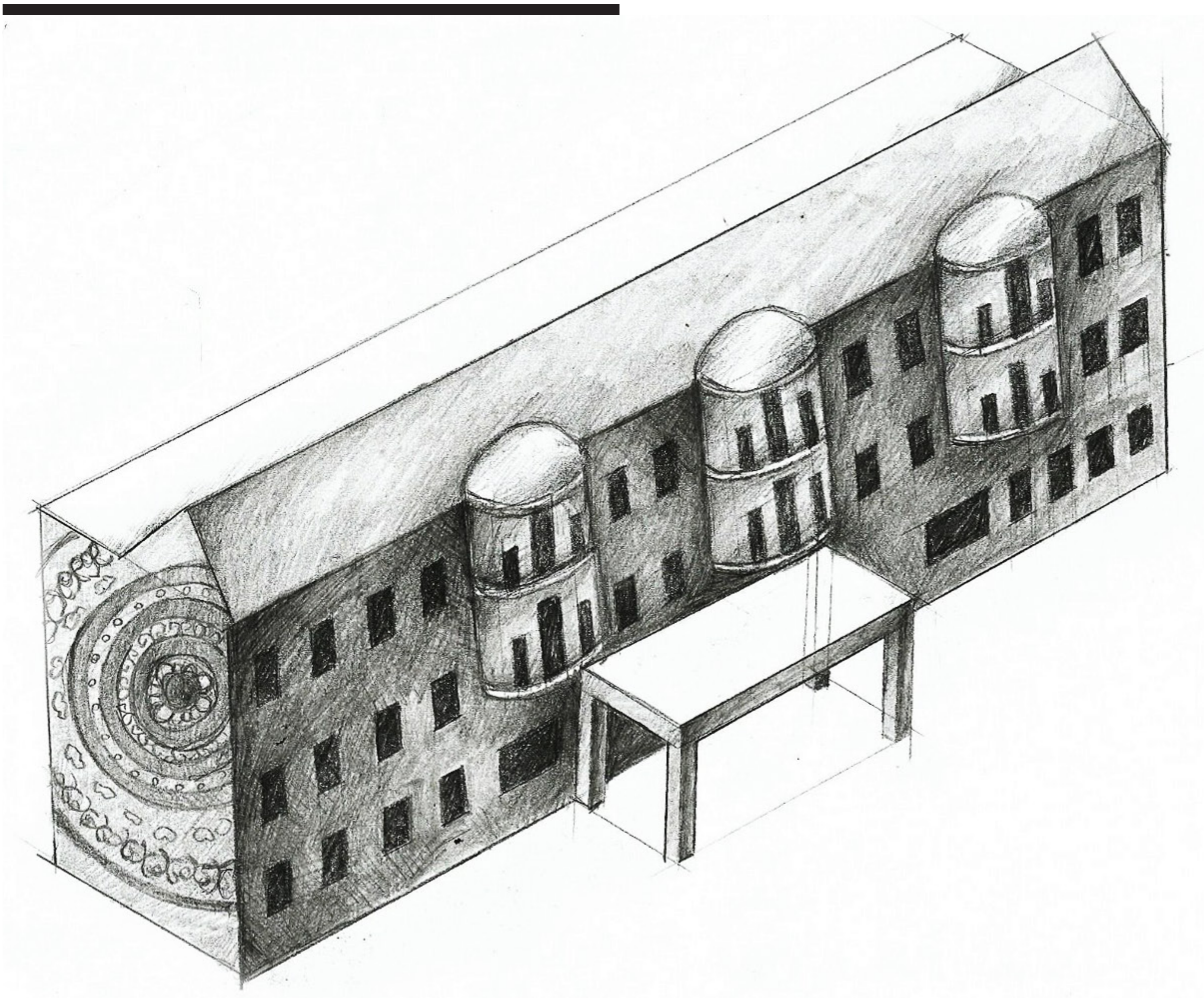
Defining these requirements for ascend and descend can be achieved through implementing a set of two ladders, one for each purpose [1], to avoid confusion and to minimize risks. Aside from ladders, elevators are also affected by Coriolis forces and accelerations and should be designed accordingly, in terms of internal design, as well as engineering considerations, in order, for instance, to minimize friction and reduce the risk of failure.

It is crucial that tasks similar to using a ladder, which require high mobility, are prioritized when planning the interior design of the hotel rooms and the employee dormitory, in particular. In addition, furnishings and appliances associated with head pitch – such as a desktop, a kitchen counter or a dining table – should be located so that the person using them is facing east or west. This helps avoid cross-coupled rotations, as a cause of disorientation, because the rotation of the head would be parallel to the rotation of the habitat. Consequently, objects which correspond to tasks that do not demand a lot of movement (also regarded as everyone's cup of tea) – for instance, recreational activities, but also storage – should have the least priority in terms of positioning. [1]

Another way to combat disorientation, as a precursor to dizziness, would be to provide different visual stimulants (mostly essential for east and west) to indicate the cardinal points or, simply, to establish orientation. This can be achieved through assigning different colors or shapes to each coordinate, or through certain decorations of the internal settings, also in regard to their additional psychological benefits and overall impact on the visual aspect of the room.

Other instances which demonstrate the occurrence of the Coriolis effect, especially when the value of the angular velocity is quite high, are associated with moving alongside the east-west axis. Running towards the east, in the direction of rotation, would result in a greater angular velocity and thus the person would feel heavier. Similarly, running towards the west would make the person feel lighter. Such particular cases might evolve to be applied in sports, for instance.

3.3.2. The hotels



The location of the hotels is introduced in Sub-Chapter 3.2, Section 3.2.1. These hotels are placed on the first floor of the hybrid torus and have a length of 50 meters and a width of 15,5 meters. It can be considered a small hotel chain, consisting of three separate hotels: Agon, Alea and Ilinx (terms which stand for categories of games defined by Roger Caillois in "Man, Play and Games", as we discussed in our introduction). Each one of them is separated into three levels, the last two being 3 meters tall and the first one being 4 meters tall, given that the lobby is also located there and should be more spacious (therefore a hotel is 10 meters tall). Their structure is identical, for the most part, each of them having a number of 4 suites, 68 double rooms and 8 single rooms; thus there are a total of 80 rooms per hotel and, if we consider that a suite has an average capacity of 3 people, we conclude that each hotel can accommodate around 156 tourists, perhaps even more. Therefore the settlement's maximum (and final) capacity, if we exclude staff, would be around 468 tourists. We plan to build the hotel chain as a two-phase process, gradually increasing the habitat's capacity, firstly building one of the hotels and then the next two.

As we will discuss in Sub-chapter 4.3, the circular side walls on the first floor will be used for agriculture. However, the first three levels of this agricultural area will be eliminated from the portions of the circular side walls in the front and in the back of the hotels and employee dormitory and replaced with windows.

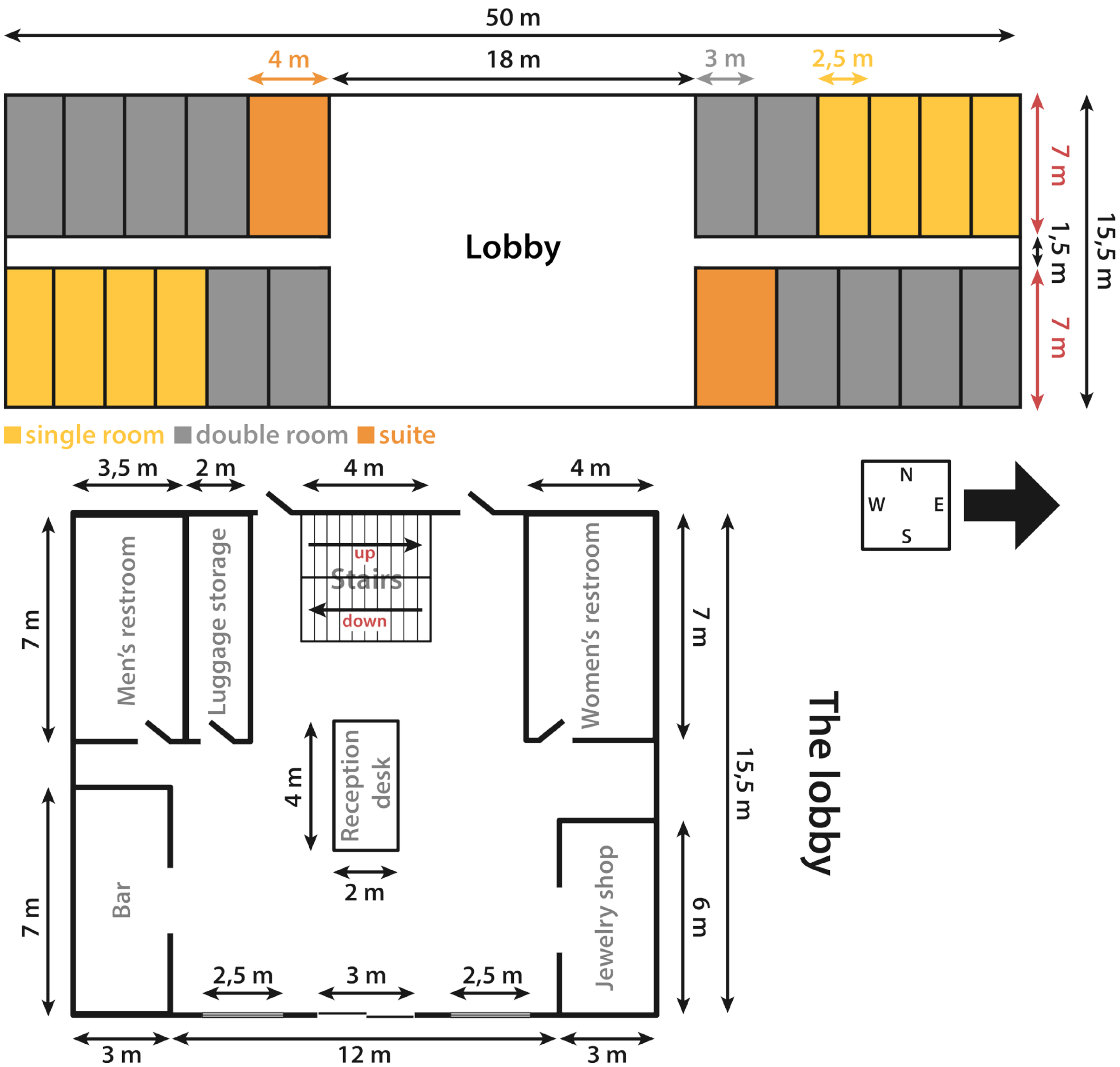
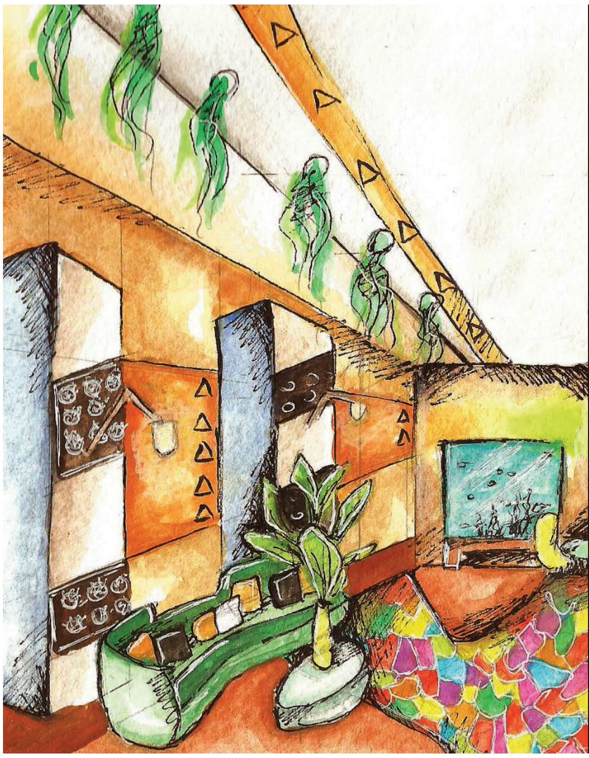
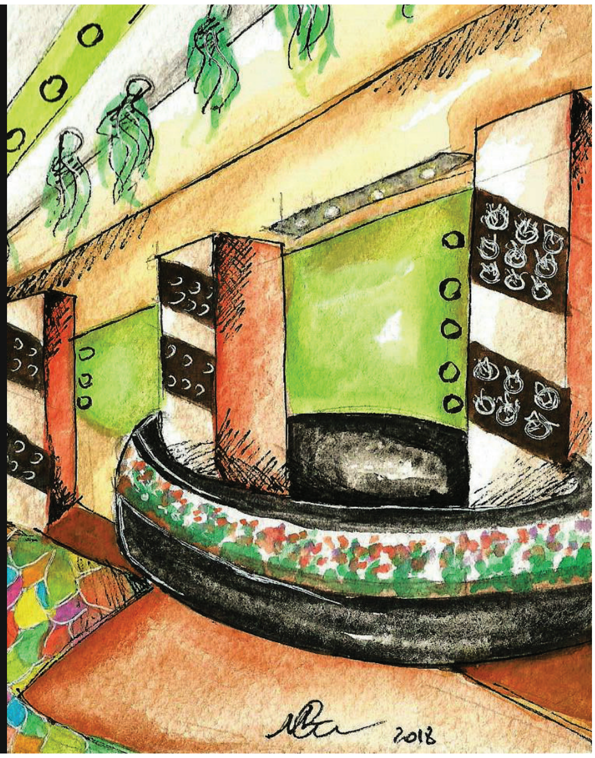


Figure 3.21. (the floor plan for the first level and the lobby; the remaining area is used for relaxation or waiting; note that the reception desk would be facing either east or west; stair directions are represented in regard to the upper level)



the East and West sides of the lobby, each represented by a set of complementary colors (blue/orange and red/green)



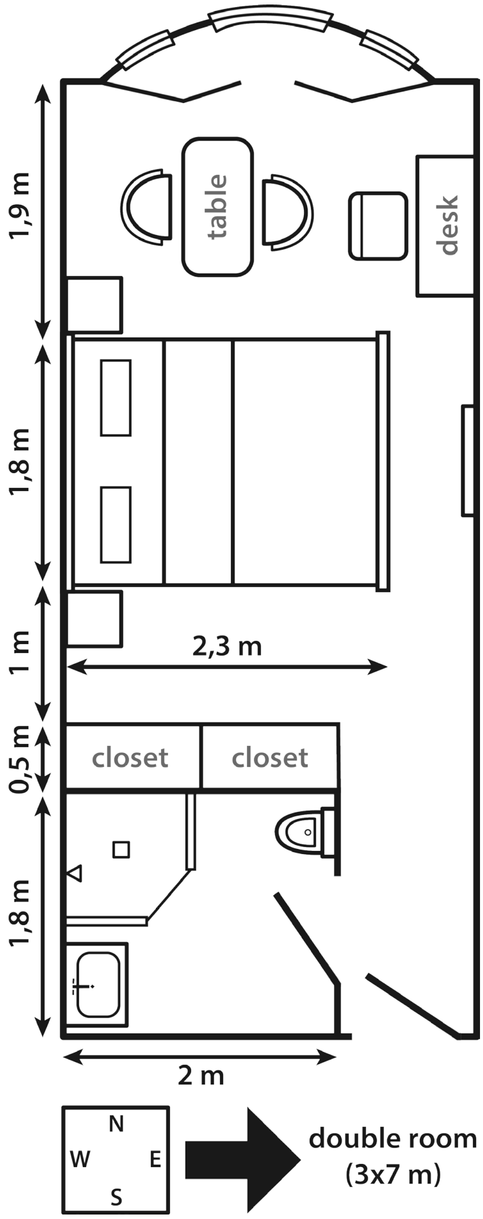


Figure 3.22. (floor plan for a double room)

This is because tourists and short-term residents should be able to look out the window from their room and admire the otherworldly scenery provided by the location. The fourth level will remain, since these buildings are not tall enough to reach it. Though windows are problematic for the structural integrity of spacecraft and shielding requirements, they are nevertheless needed to enhance the visual aspect of the habitat, especially since it is a touristic destination.

We have illustrated the plans for each of the hotel's levels (figures 3.22 and 3.23), as well as the hotel lobby (figure 3.22). Even though their inclination will not be 90° and the distances between levels are not that great (so the Coriolis effect will not be extremely noticeable), note that stairs will be facing either west or east and there will be separate stairs for ascending and descending [1]; this is because the angular velocity exceeds 2 rpm, the radius is quite small and tourists might not always be instructed to avoid accidents on stairs, which could be caused by the Coriolis effect. Also, rooms are mostly spread on the North-South axis, so more ample movements throughout the room will not be affected by Coriolis forces and accelerations.

By placing desks on the North-South axis, facing either West or East, we try to avoid cross-coupled rotations that may arise when a person is a rotating habitat rotates their head [1]. Other furnishings such as tables, desks, the sink and mirror in front of it, even the shower head, are also positioned in regard to this aspect.

Other characteristics of the rooms will include providing different visual stimulants for East and West (mostly), by decorating walls and other appliances in different ways. The two cardinal points could be distinguished through associations of geometric shapes and contrasting colors [33]. This can be done all throughout the habitat.

Note that the dimensions on the figures are approximate, because the thickness of the walls was not taken into account.

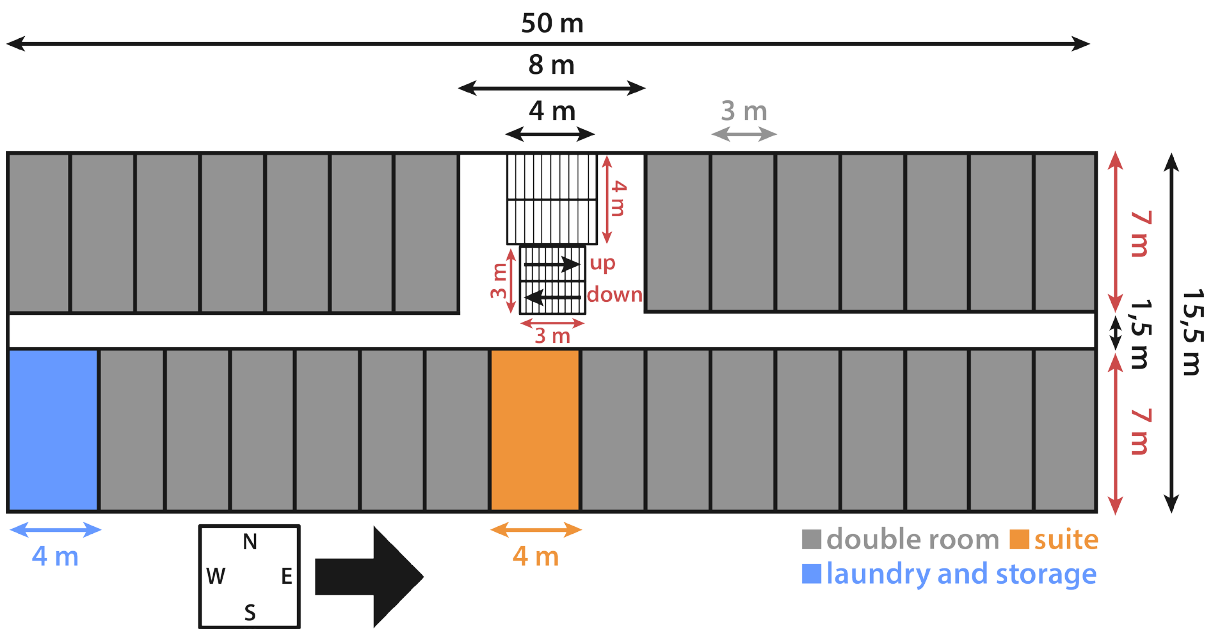


Figure 3.23. (the floor plan for the second and third levels; stair directions are represented in regard to the upper level (and therefore only on the plan for the second level); note that the 4x4 set of stairs will not be present on the third level and could be replaced by a relaxation area)

3.3.3. The employee dormitory

It is only natural that a space habitat demands constant supervision and maintenance in order for it to achieve absolute safety standards. That is why human presence is needed in the form of personnel, which would ensure a state of stability and security for the settlement as a whole and for the people inhabiting it. A selection process will undoubtedly be conducted to assess the capabilities of possible employees and those chosen will surely have to go through a period of training (see Sub-chapter 5.6, Section 5.6.2). However, because of the lack of space and because costs naturally increase when the population aboard increases, many tasks will be mechanized and will require no human assistance. For instance, robots could replace humans when it comes to handing out a receipt in a store and they could also help clean the rooms in the hotels; the hydroponic system in the greenhouse would be mostly mechanized as well. More details about the staff on the settlement are also discussed in Sub-chapter 5.6, Section 5.6.1.

A dormitory is needed to accommodate staff on Cicada, who would typically work on the settlement for a few months in order to complete their shift. As it is illustrated in figure 3.7 from Sub-Chapter 3.2, the employee dormitory, like the hotel, is located on the first floor of the hybrid torus. It has a length of 60 meters and a width of 20 meters (because the first floors of the agricultural area are not included behind and in front of the employee dormitory, lateral entries/exists are possible to add if a passageway is built on the circular side walls; this would also allow more efficient transport on the first floor). The employee dormitory has 4 levels, each 3 meters tall, and therefore a total height of around 12 meters.

Each of the levels will have 34 rooms, with an arrangement similar to that of the hotel rooms. If we consider that only one inhabitant will live in an apartment, we obtain a maximum capacity of 136 staff members. If some employees choose to share their rooms with someone, this value changes.

The design of an apartment is similar to that of a hotel room. Most furnishings which require rotations of the head (such as tables, desks, sinks, kitchen counters) are pointed either towards east or towards west. The 9,2-meter length is spread across the North-South axis. In order to save space, we included a sofa bed, an expanding dining table and an under-counter refrigerator (figure 3.24).

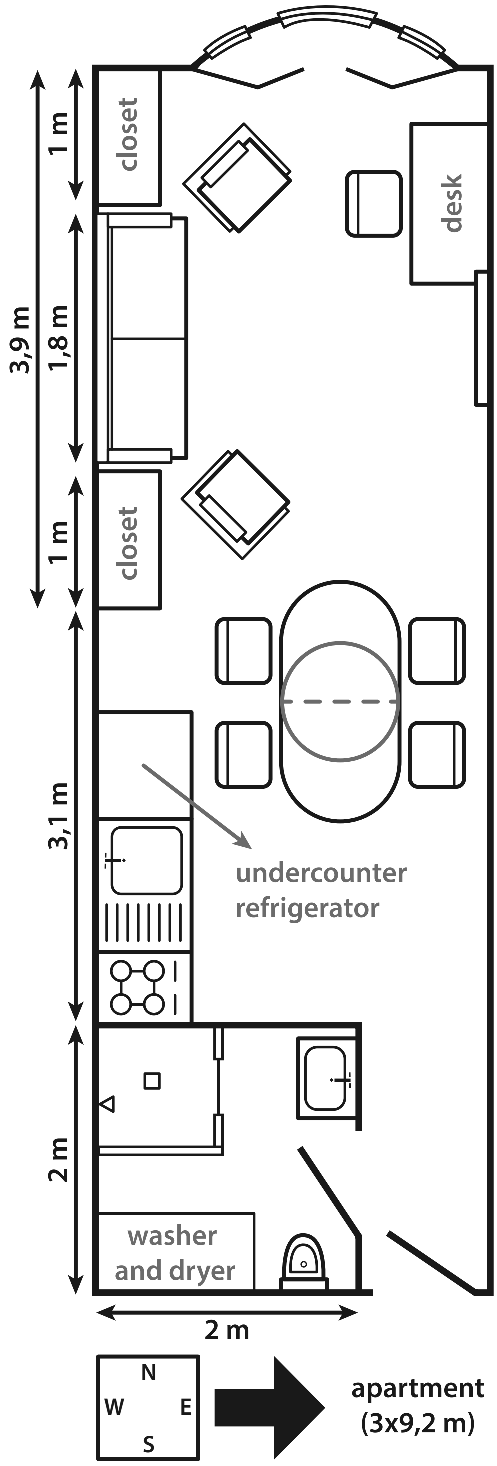


Figure 3.24. (floor plan for an apartment)

4.

Life support and sustenance

4.1. Support systems

4.1.1. Electrical power system

The Electrical Power System (EPS) provides control of power generation, distribution, storage and conversion.

Power generation is concerned with the main energy sources which supply the habitat. Cicada will rely on solar arrays for the hybrid torus and intermediate double cylinder and to power the rotation mechanism supported by the central sphere (figures 4.1 and 4.2.). The second part of the habitat will also be powered using solar arrays (figure 4.3). Energy conversion will be achieved using Photo-voltaic panels. Like each of the ISS' Solar Array Wings, Cicada's will also consist of more Photo-voltaic blankets. Beta Gimbals and Solar Array Rotating Joints will be used to track sunlight and orient the panels in regard to the sun. Electrical energy is stored using Lithium-Ion batteries [4] and fuel cells (where energy is stored in the form of oxygen and hydrogen) [9]. These will be located in the central sphere and the intermediate double cylinder, but also in the column (see Sub-chapter 3.2).

Circular solar arrays on the central sphere, the torus and the hybrid torus will be made out of more identical solar blankets. These will function independently from each other, so that one's failure will not cause the failure of the entire Photo-voltaic system and will be built periodically, as the settlement's capacity increases. We will use solar panels with increased efficiency. In 2017, Guangdong Aiko Solar Energy Technology Co., Ltd. developed bi-facial solar panels that are highly efficient and have conversion rates of more than 30% (around 20% on one side and 15% on the other).

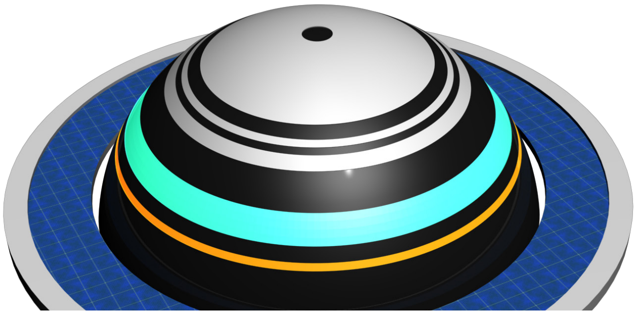


Figure 4.1. (photo-voltaic radiator and solar arrays on the central sphere, powering the rotation mechanism; top view)

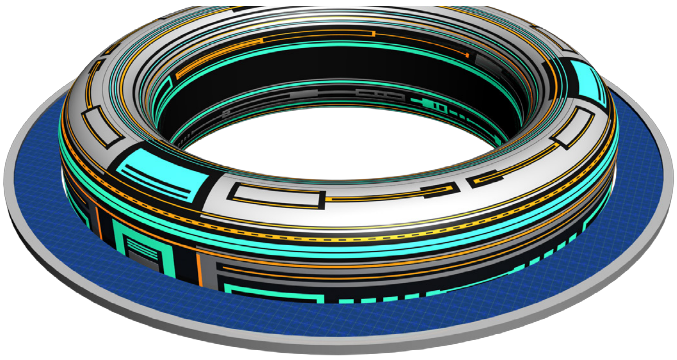


Figure 4.2. (photo-voltaic radiator and solar arrays on the hybrid torus; top view)

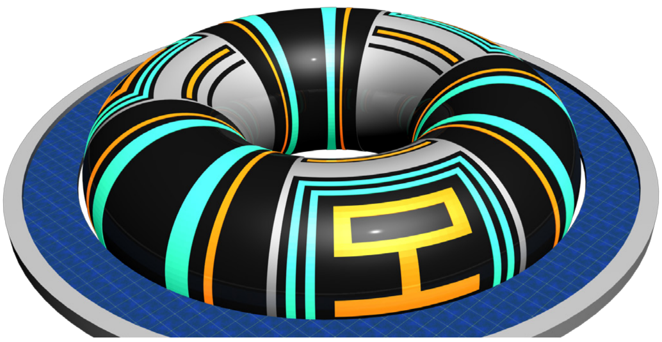


Figure 4.3. (photo-voltaic radiator and solar arrays on the torus; bottom view)

We consider that the average power consumption is 6000W per person [16]. This power output is the product between the total area per person, the solar irradience (around 1361 W/m^2; http://journals.ametsoc.org/doi/full/10.1175/BAMS-D-14-00265.1) and the conversion efficiency (we approximate it to 3/10). Therefore the area required per inhabitant would be around 14, 7 m^2. For a number of 600 inhabitants this area becomes 8814 m^2, which we approximate to 9000 m^2. In figure 4.2, the solar array wings are represented as circular. That area is equal to the area of a circular crown. We consider a 1-meter space between the hybrid torus and the panels, thus the first radius, R_1, would be 91 meters. The formula for this area is $A= \pi(R_2^2-R_1^2)$ and thus R_2=105 m. The difference between the radii of the circular crown would be approximately 14 m.

A solar array outside LEO to transfer energy using microwaves remains a future prospect, perhaps for even larger settlements/colonies in outer space.

The activity of the Electrical Power System is linked to that of other support systems to maximize the efficiency of power management and distribution.

4.1.2. Thermal control system

Environmental conditions in outer space are characterized by extreme temperatures. The purpose of the thermal control system is to keep temperature inside the habitat relatively constant, so that environmental conditions aboard manage to satisfy certain comfort standards and equipment is able to function properly. The functioning of the thermal control system relies on the performance of the passive and active thermal control systems (PTCS and ATCS). As discussed in Sub-chapter 2.2, Section 2.2.3, part of the passive thermal control system are the multi-layer insulation blankets included in the shielding configurations 1 and 2; additionally, heaters, heat pipes, radiator louvers and surface coatings also help passively maintain temperature [4][9].

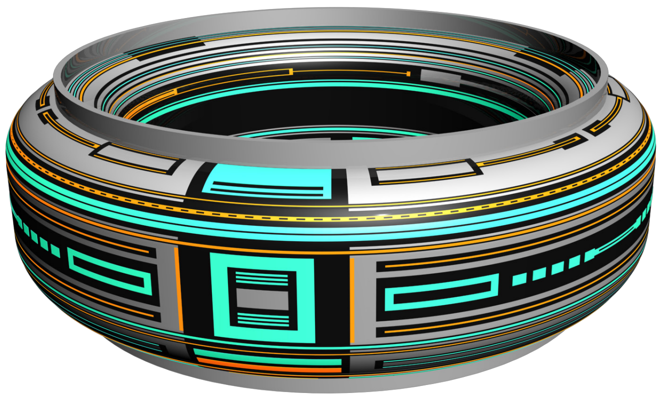


Figure 4.4. (radiators for the hybrid torus)

The active thermal control system is used to ensure the rejection of excess heat generated by equipment inside the spacecraft, in cases when the passive thermal control system is not endowed to do so. The ATCS collects, transports and eventually rejects waste heat [15]. On the International Space Station, the main components of the ATCS are the Internal Active Thermal Control System (IATCS), the External Active Thermal Control System (EATCS) and the Photo-voltaic Thermal Control System (PVTCS).

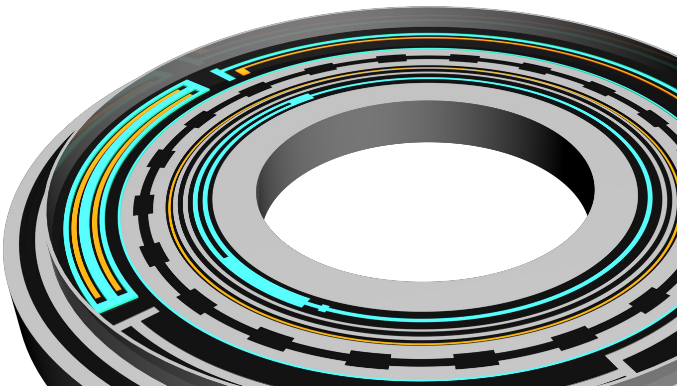


Figure 4.5. (radiators for the double cylinder)

IATCS maintains an accessible temperature of the inside equipment by collecting waste heat and further transferring it to the EATCS. Water provides thermal conductivity for this system and the heat is transferred through a closed loop [15]. All of the pressurized, inhabited segments of the ISS are endowed with such systems, which mainly use cold-plates and heat exchangers [9].

The EATCS on the ISS has ammonia as a transfer fluid and operates outside inhabited modules. EATCS consists of two loops which help release heat through sets of radiators; the loops function independently, so that one's failure does not affect the other's capabilities [15]. EATCS helps reject waste heat generated inside

Figure 4.6. (radiators for the column and the torus)

the pressurized portions of the spacecraft and from the equipment used to distribute power throughout the habitat.

Radiators on Cicada are placed near the hybrid torus, the intermediate double cylinder, the column and the torus. They consist of more sets of radiators and ammonia coolant loops.

Similar to the EATCS, the PVTCS uses ammonia loops to collect waste heat eliminated by the Electrical Power System consisting of solar arrays. The transfer fluid is pumped and the excess heat that reaches the Photovoltaic Radiators (figures 4.1, 4.2 and 4.3) is eliminated.

4.1.3. Guidance, Navigation and Control System. Propulsion and Motion Control System

There are two main categories of systems which assist in maneuvering spacecraft [9]: the Guidance, Navigation and Control (GN&C) system and the Propulsion and Motion Control (PM&C) system.

The GN&C system is mainly concerned with orienting the spacecraft and maintaining stability. The functioning of this system has a great deal of emphasis placed on its correlation with other systems, which oversee thermal adjustments, communications, structural characteristics of the spacecraft, mission and payload requirements, as well as propulsion [9]. The main functions of the GN&C system are [9]: controlling disturbance torques (often caused by gravity gradients, solar pressure, magnetic fields, atmospheric drag and internal disturbances), stabilizing and controlling the spacecraft's orientation/attitude in regard to the Earth and the Sun (in order to adjust orbital trajectory, rotational requirements and to achieve effective guidance; passive and active control systems are utilized, additionally influencing thermal adjustments, communications and energy consumption), and navigating (which involves staying in orbit and determining attitude by using reference frames and planes; this also involves controlling periodical re-boosts for constant altitude).

By means of propulsion, the P&MC system helps achieve a stable attitude and adjust orbital trajectory; propellant is needed, as well as energy sources and converters.

GN&C and P&MC systems are interdependent and crucial parts of a settlement. Aside from their usual functions, they also assist in avoiding collision with orbital debris and meteoroids of a greater magnitude. Given their overall purpose, these systems, which are used in maneuvering spacecraft, should hold a central positioning; in Cicada's case, this will be the central sphere.

4.1.4. Environmental Control and Life Support Systems

4.1.4.1. Atmosphere

The composition of the atmosphere

Like the gravity load, the load imposed by the atmospheric pressure is one of the main loads which directly influence the cost of a habitat in outer space. A lower atmospheric pressure naturally means that the settlement's hull would be thinner and a reduced quantity of material would be used for its construction.

On Earth, at sea level, the partial pressure of the oxygen in the atmosphere is around 25kPa, which decreases to 20kPa at an altitude of 2400 m. For oxygen, a partial pressure of 23kPa was chosen in Cicada's case, given that most inhabitants are tourists and staff can be selected to adapt to this pressure (which certainly does not raise as many selection constraints as a pressure of 20kPa [16]).

Though favorable in terms of costs, an atmospheric composition with low density and oxygen as its only component does cause a few disadvantages; these are mainly concerned with the weak propagation of sound, issues which arise in regard to the cough mechanism and the high risk of fire danger [16]. To combat such drawbacks, the atmosphere should contain an inert gas. Even though helium has a lower density and lower risk of causing bends (also known as decompression sickness; this condition is caused by the bubbles released by a gas under fast decompression [16]), nitrogen is a more plausible alternative, since it is one of the components of the atmosphere on Earth and does not turn inhabitants into cartoon characters by altering their voice.

In accordance with [16], we have established the following atmosphere composition for partial pressures:

$$p_{O_2} = 23\text{kPa},\ p_{N_2} = 27\text{kPa},\ p_{CO_2} < 0,4\text{kPa},\ p_{H_2O} < 1,3\text{kPa}.$$

Because the temperature and atmospheric pressure inside the habitat are relatively low, these gases can be considered ideal gases. Therefore, in accordance with Dalton's law, the total pressure of this mixture of gases is equal to the sum of their partial pressures (this is because the molecules of an ideal gas do not interact with each other, due to the fact that there are great distances between them). The total atmospheric pressure on Cicada is equal to approximately 0,5atm, which is half of the atmospheric pressure on Earth:

$$p = p_{O_2} + p_{N_2} + p_{CO_2} + p_{H_2O} \simeq 51,7\text{kPa}.$$

By applying the ideal gas law, we are also able to determine the total mass of the atmosphere inside the habitat per liter (for V =1 L and T=23 °C=296K, p_{CO2}=0,4kPa, p_{H2O}=1,3kPa; note that the ideal gas constant is R=8,31kPa · L/(mol · K)):

$$\nu_{O_2} = \frac{p_{O_2}}{RT} = 0,093\text{mol}, \nu_{N_2} = \frac{p_{N_2}}{RT} = 0,109\text{mol},$$

$$\nu_{CO_2} = \frac{p_{CO_2}}{RT} = 1,62 \cdot 10^{-4}\text{mol}, \nu_{H_2O} = \frac{p_{H_2O}}{RT} = 5,28 \cdot 10^{-4}\text{mol},$$

$$m = m_{O_2} + m_{N_2} + m_{CO_2} + m_{H_2O}$$

$$= 32 \cdot 0,0093 + 28 \cdot 0,0109 + 44 \cdot 1,62 \cdot 10^{-4} + 18 \cdot 5,28 \cdot 10^{-4} = 0,62\text{g/L}.$$

We needed to calculate the mass of the atmosphere, because it is part of the internal mass and it influences the thickness of the settlement's hull, therefore the costs.

Atmosphere Control and Supply (ACS) Subsystem. Atmosphere Revitalization Subsystem (ARS)

The ACS Subsystem oversees the composition of the atmosphere, as well as the partial pressure of its components. By monitoring the state of the atmosphere, the ARS operates as to provide air that humans can breathe while maintaining a healthy functioning of their respiratory system.

The partial pressure of oxygen must always be kept constant or in-between certain limits (in cases of emergency), because low oxygen pressure is associated with altitude sickness (which often involves nausea, headaches or shortness of breath [9]). On the contrary, carbon dioxide must be continuously removed from the atmosphere, since, when inhaled, a great quantity of it may cause fainting, increased heart and respiration rates, nausea or dizziness, among others [9].

A human being roughly breathes out 700 grams of carbon dioxide per day (https://www.globe.gov/explore-science/scientists-blog/archived-posts/sciblog/index.html_p=183.html) and, though almost inexistent, there will be some pollution factors aboard (the recycling and food processing centers, for instance). Methods through which carbon dioxide can be removed from the atmosphere include bio-regeneration (this involves photosynthesis, which additionally produces oxygen), absorption using Lithium hydroxide canisters (this process is applied for EVA suits), separating and collecting carbon dioxide using molecular sieves (crystalline materials made out of silicon or aluminum) or the Sabatier process (the Sabatier reaction: $CO_2+4H_2=CH_4+2H_2O$; water can be converted into oxygen and hydrogen through electrolysis; a Sabatier reactor is used to achieve this separation, eliminating the methane) [9]. The Carbon Dioxide Removal Assembly (CDRA) on the ISS uses silica gel to separate and collect carbon dioxide from the atmosphere, in order for it to be eliminated or further processed; this also involves the use of cold air obtained from the Ventilation, Temperature and Humidity Control Subsystem [9]. In addition to CO_2 removal, these systems must also ensure removal of other contaminants in the air. To purify the atmosphere, HEPA (High Efficiency Particulate Atmosphere) filters will be added in the ventilation systems.

Ventilation, Temperature and Humidity Control Subsystem

The Ventilation, Humidity and Temperature Control System maintains comfort environmental standards inside the pressurized modules. The continuous flow of air inside pressurized modules and between them keeps the atmosphere homogeneous , helps maintain normal temperatures (around 23 °C) and humidity levels (varying between 50-70%), interfaces with cooling systems from the Internal Active Thermal Control System and allows smoke detectors to respond in a timely manner [9].

Fire Detection and Suppression Subsystem

The Fire Detection and Suppression Subsystem helps detect fire aboard and provides equipment needed to extinguish it and to keep the population safe. Carbon dioxide, nitrogen or halon are efficient in suppressing fire; because it is an accessible source and has to be constantly removed, carbon dioxide will be stored and used to extinguish fires aboard Cicada. Smoke detectors, integrated in ventilation systems or placed in air cooling ducts, and flame detectors, for open areas inside the pressurized modules, adapted to a micro-gravity environment will be installed [17]. In case of a fire, a part of the pressurized module can be isolated, evacuated and perhaps even unpressurized. Additionally, smoking is forbidden aboard.

4.1.4.2. Water Recovery and Management (WRM) Subsystem

Because it is an indispensable element to the continuity of life, water can surely be considered a crucial resource for inhabited spacecraft. The average person would require around 8 kg of water per day, for consumption and personal hygiene [17]. For long-term missions and self-reliant settlements in outer space, effective water management contributes to the completion of a closed loop for Environmental Control and Life Support System. The WRM subsystem reduces the need for frequent resupply and is advantageous in economic terms.

Water recovery subsystems on Cicada will have separate functions. One of these subsystems will perform distillation of urine and flush water, while the other will filter more dilute feeds, such as water used for hygiene or laundry. The latter would be used as potable water. Engineering requirements for such systems additionally state that they should be designed to operate in low gravity conditions.

Though water recovery would mostly constitute a closed loop, water production also results from processes which involve carbon dioxide reduction and removal (the Sabatier or Bosch processes, for instance [9]). The process of CO_2 reduction produces pure water which might need little to no post-treatment; water can also be generated from H_2- O_2 fuel cells [17].

Distillation

Urine is a concentrated feed, containing large quantities of contaminants, and should undergo careful distillation processes before reuse. Most of the water resulted from urine processing will further perform electrolysis, in order to generate oxygen for the atmosphere inside the pressurized modules of the habitat. Some may also become potable water. According to [17], the most well known subsystems designed for urine processing are:

- **Vapor Compression Distillation (VCD);** a VCD subsystem functions based on a thermally passive process and employs the use of an evaporator, a compressor and a condenser. This subsystem can function in micro-gravity conditions and is characterized by low power consumption, but it requires additional brine storage and produces gases which pollute the habitat.
- **Vapor Phase Catalytic Ammonia Removal (VAPCAR);** the VAPCAR subsystem oxidizes vapors of impurities, turning them into harmless gases, and therefore operates by making use of a chemical process. Like VCD, a VAPCAR subsystem can be adapted to low gravity. Additionally, feeds processed by this subsystem do not have to undergo pre-treatment and require very little post-treatment (though only when potable water is desired).
- **Thermoelectric Integrated Membrane Evaporation System (TIMES);** TIMES, like the VCD subsystem, is also based on a thermal process (though demanding active temperature control). The circulation of heat from the condenser to an evaporator is achieved using a thermoelectric heat pump. Though it contains mostly stationary equipments, TIMES' major drawbacks are its reduced efficiency compared to other subsystems and higher risk of failure.

Other urine processing subsystems are Air Evaporation Systems (ACS) or Super Critical Wet Oxidation (SCWO). Though very efficient, ACS requires a considerable amount of power to function and urine pre-treatment. SCWO employs the use of metals whose corrosion might lead to water contamination and is therefore better suited for other types of waste processing.

Because TIMES requires active control and its components are more exposed to failure, the remaining systems for selection are VCD and VAPCAR, both with a lower energy consumption and better processing rates. We choose VAPCAR for urine filtering, because it weighs a lot less than VCD and does not rely of pre- or post-treatment [17].

Filtration

Water can also be recovered from the atmosphere, where it usually ends up as a result of breathing, sweat evaporation or activities such as cooking or taking a hot bath. In this case, WRM interfaces with other subsystems, such as the Ventilation, Humidity and Temperature Control Subsystem [9]. A large percentage of water requirements is satisfied using water recovered from condensate. Plant transpiration can also be collected and filtered with little effort, since it is of high quality (see Sub-chapter 4.3).

Potable water will result mainly from recovered personal hygiene water and water recovered from condensate. Main filtering processes include (according to [17]):

- **Reverse Osmosis (RO);** this process involves transferring water from a compartment to another, from a high concentration to a lower one, by applying pressure. RO requires pre- and post-treatment, due to the reduced filtering capabilities of the semipermeable membrane.
- **Multifiltration (MF);** the MF process is more efficient than RO, as the basis of its technology is simpler, involving the passing of water through multiple filters. However, MF components are in need of constant replacement and have quite reduced durability.
- **Electrodyalisis,** which filters impure water by means of ion exchange resins and membranes; in comparison with MF, the process employs a more advanced technology, less accessible for use in space, and requires additional brine storage.

Cicada will rely on MF subsystems to produce potable water, given that the technology is not complex. Additionally, the quality of the water produced will be continuously monitored, to ensure that it is perfectly safe for consumption.

4.1.5. Waste management

Because this is not the case of a shot-term missions, where waste is usually just stored and not recycled, waste generated on a habitat in outer space needs to undergo treatment and recycling processes. Categories of waste on spacecraft are represented by solid waste, liquids (mostly concentrated) or harmful gases, each of these either decomposable, not decomposable or metabolic. Waste management is concerned with sorting, collecting, stabilizing and decomposing waste. Processing techniques for waste recycling are often associated with the release of carbon dioxide, through oxidation, whether used in photosynthesis or removed; both alternatives would generate oxygen, some of which could reenter oxidation to be reused for waste treatment. Minerals which result from physico-chemical oxidation will likely be used as nutrients in the hydrophonic culture. [17]

According to [17], the main processes to treat mostly solid waste are:

- **Wet Oxidation;** such subsystems oxidate semi-solids (1-10% solids [17]), mostly generating carbon dioxide and water, but also, among others, C, N, O or H, for high temperatures and pressures. Though good for habitats endowed for agriculture and able to provide water recovery, wet oxidation still requires a large quantity of oxygen and dangerously high pressures.
- **Super Critical Water Oxidation (SCWO);** these technologies enable recycling of any type of waste and utilize supercritical water as a solvent, allowing oxidation to become a one-stage process, as opposed to simple wet oxidation. SCWO is able to additionally provide potable water, but, like wet oxidation, the technology needs to be improved and safety risks need to be minimized in order for such systems to be suitable for space applications.
- **Combustion/Incineration,** mainly considered to be applied in the form of dry incineration or starved-air combustion (SAC). Dry incineration has reduced efficiency. SAC utilizes a smaller quantity of oxygen and has a higher stability (gas input can be controlled and thus gas products as well).

Electrodynamic Incineration and Waste Management-Water Systems are other alternatives discussed in [17]. We will mainly consider SCWO for solid waste and conduct research to improve its efficiency, perhaps eventually utilizing it for urine treatment as well. Starved-air combustion might be used for waste with high toxicity.

4.2. Transport inside the settlement

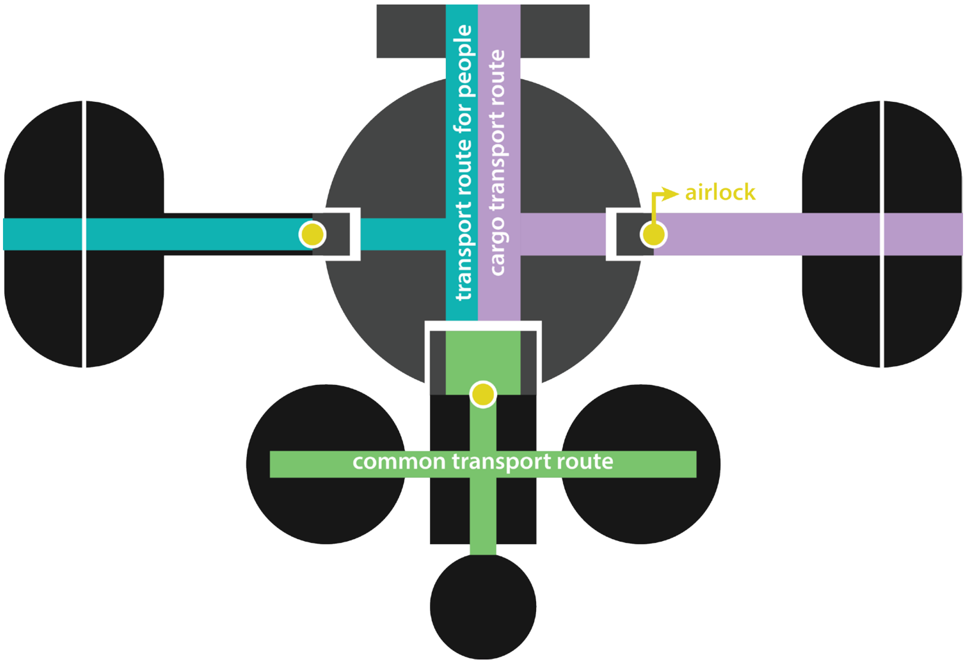


Figure 4.7. (transport routes in pressurized (black) and non-pressurized (gray) components))

Transport routes throughout the habitat are separated in three categories; thus there are transport routes for cargo and for people, from the dock to the hybrid torus, through the sphere and double cylinder, and common transport routes, in the column, the small sphere and the torus. The width of the cargo transport route is 8 m, while that of the transport route for people is 6 m. Common transport routes are either 14 m wide, in the unpressurized portion, where the two merge into one, or 5 m wide throughout the remaining pressurized portion of the second part of the habitat. Transport routes that connect pressurized portions to unpressurized ones are separated by airlocks. Among others, this is the reason why transport might have to be scheduled and access to transport routes might often not be continuously allowed.

The two rotating modules cannot be connected, as they rotate in opposite directions. Other issues concerning transport in a rotating habitat arise because of the need to connect rotating and non-rotating modules. In the case of a Maglev guide-way, EVA would also be needed, as the rotation is frictionless. Therefore, transferring cargo and people between rotating and non-rotating components is done only between unpressurized chambers, because airlocks in such a scenario would cause additional difficulties. For transfers between the intermediate double cylinder and the central sphere, a gondola lift system could be applied for people (the 2 m distance between the components would not be a problem, as the intermediate double cylinder could be sectioned). Especially in the case of getting from the sphere to the intermediate double cylinder, design challenges for such a system are complex, partly due to the gravity gradient, but mostly due to the fact that gondola lifts would be traveling with a tangential velocity of around 6,4 m/s; getting from the sphere to the gondola lifts would be like catching a running car, traveling at a speed of 25 km/h. A rotating band could be placed on the central sphere to function only when transfer is required, so that the relative speed of a gondola would be lower in regard to a person standing on the band (another challenge would be to keep the person attached to the rotating band in 0 g); if the rotating band could be synchronized with the rotation of the intermediate double cylinder so that attachment joints and gondola lifts would belong to the same rotation radius, transport might be even easier. Human transport will require at least partial mechanization, to help people get from one component to the other, without having to rely much on physical capabilities. Cargo transport could be entirely mechanized, given that, especially for heavy loads, it would be more accessible in 0 g or low g; a similar mechanism could be applied. Transfers from the sphere to the column might not be as difficult, given the fact that a gondola lift could be placed so that it would pass through the middle of the column and thus would rotate around its vertical axis, unlike gondolas for the intermediate double cylinder, which rotate around the settlement's vertical symmetry axis.

4.3. Agriculture

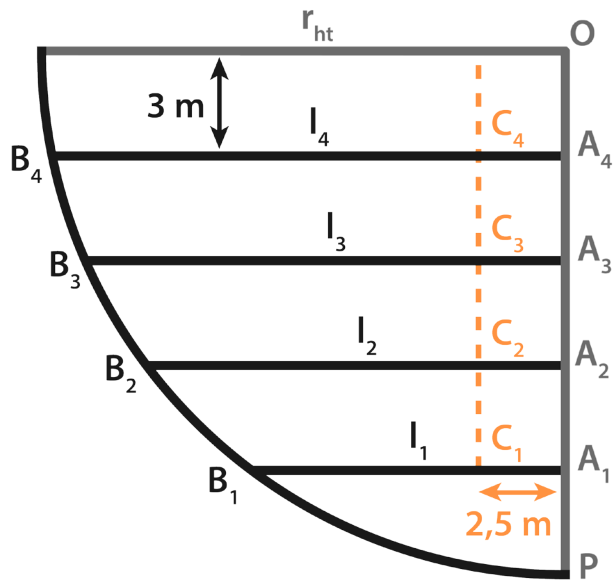


Figure 4.8. (agricultural area on one of the circular side walls)

Agriculture is part of what makes a habitat in outer space self-reliant and self-sufficient. Aside from providing an regenerative food source for the population, plants also contribute to atmosphere regeneration and carbon dioxide removal. However small the settlement might be, it is crucial to allocate some of its available area to agricultural purposes, which would eventually reduce its long-term sustainability costs and lead it towards fully achieved independence. It would not be advantageous to rely strictly on food transported from the Earth, at least if we take into account today's enormous launch costs.

On Cicada, we will use a hydroponics system for the agricultural area, given that it does not involve the use of soil, in addition to being more efficient in terms of growth rates and water management. Because the population is quite reduced and short-term residents and tourists do not necessarily require a perfectly balanced diet, the area allocated to agriculture offers no possibility for future expansion; it is nevertheless more than enough.

The hydroponics culture will be located on the first floor of the hybrid torus (see Sub-chapter 3.2, Section 3.2.1), on the circular side walls. As figure 4.8. illustrates, the system consists of four levels for each one of the two circular side walls. Each level is 3 meters tall and the first level is located 3 meters above the ground. Each of these levels has an access way, which is 2,5 meters wide.

In regard to figure 4.8, we have the following dimensions:

$$PA_1 = A_iA_{i+1} = A_4O = 3m, i = \overline{1,3}, \quad A_iC_i = 2,5m, \ OB_i = r_{ht} = 15m, i = \overline{1,4}.$$

In oder to determine the length of each level, we apply the Pythagorean theorem in the right triangles with the hybrid torus' small radius as hypotenuses:

$$\Delta OA_iB_i, \ m(\widehat{OA_iB_i}) = 90° \Rightarrow A_iB_i = \sqrt{OB_i^2 - OA_i^2}, l_i = B_iC_i = A_iB_i - A_iC_i, \ i = \overline{1,4}.$$

The first three levels will be eliminated from the areas near the hotel and employee dormitory. The fourth level is not sectioned. The areas were calculated as the lateral area of a cylinder:

$$A_{ai} = l_i\big(2\pi(R_{ht} + OA_i) - 210\big), \ i = \overline{1,3}, \ A_{a4} = 2\pi l_4(R_{ht} + OA_4).$$

Level	Length (m)	Area (m²)
First level: l_1	6,50	2.186,34
Second level: l_2	9,50	3.016,44
Third level: l_3	11,25	3.359,47
Fourth level: l_4	12,20	5.974,55
Total agricultural area	29.073,60 m²	

Table 4.1. (dimensions of the agricultural sectors; note that the total agricultural area was obtained by multiplying the area of the levels by 2, since there are 2 identical agricultural sectors, on each of the circular side walls on the first floor of the hybrid torus)

Area allocations for the agricultural sector vary between 20 and 30 m^2 per person and are calculated based on the cultivated species [21]. We estimate a maximum population of approximately 604 inhabitants. The agricultural sector offers an area of approximately 48 m^2 per person. This area is definitely not the maximum one; for shorter plants, intermediate levels can be added, which is common for the design of a hydroponics system.

Harvest Index

The harvest index is defined as the ratio between the edible mass of a plant species and its total biomass. It is used to determine crop yield (http://plantsinaction.science.uq.edu.au/content/641-harvest-index). Most plants used in agriculture are characterized by a harvest index of around 0,5 [17]. Plants with this harvest index ensure a constant oxygen supply for the population and eliminate the CO_2 from the atmosphere; consequently, those with lower harvest indexes produce less O_2 and those with higher ones produce more O_2 (which could enter waste oxidation (starved-air combustion or super critical water oxidation) to generate CO_2 for plants or be stored). Harry Jones [22] states that the harvest index indicates "what fraction of the food must be grown to provide all crew oxygen and absorb all crew carbon dioxide": (HI=harvest index, FG=fraction of grown food)

Photosynthesis: $6CO_2+6H_2O=HI \cdot C_6H_{12}O_6$ *(edible biomass)*$+(1-HI) \cdot C_6H_{12}O_2+6O_2$ *(inedible biomass)*

Respiration: $FG \cdot C_6H_{12}O_6$ *(mass of grown food)*$+(1-FG) \cdot C_6H_{12}O_2+6O_2$ *(mass of supplied food)*$=$
$6CO_2+6H_2O$

The edible biomass is always equal to the mass of grown food. The conclusion that arises from these two opposite reactions is as follows: if we wish to fully rely on bioregenerative systems for oxygen supply and carbon dioxide removal, it is necessary for the harvest index to be equal to the fraction of grown food. Otherwise, if HI<FG, more supplied food, which exceeds the inedible biomass, is required and thus plants are not able to provide enough oxygen and remove all the CO_2 generated as a result of respiration. In contrast, if HI>FG, the quantity of oxygen generated through photosynthesis is greater than that required by the population and the CO_2 resulted from respiration is not enough for the plants, because the quantity of supplied food is less than the inedible biomass; one use for the excess oxygen could be to enter oxidation processes which ensure treatment of the inedible biomass [22]. A balance between the average harvest index and the food grown will be needed or, if possible, a slightly higher value of the harvest index.

Transpiration

Aside from being used in atmosphere revitalization, plants also play crucial roles in water recovery. Water transpired by plants is usually of high quality and can be used as potable water/food-preparation water or can reenter the hydroponics system, after being purified. Transpiration can be controlled in regard to humidity levels and exposure to light. Condensed transpired water can be almost 100% recovered and could constitute a closed-loop system. [17][21]

Consumption	Amount	Production	Amount
Carbon Dioxide	40-300 g/m²/day	Oxygen	30-220 g/m²/day
Water	5-10 kg/m²/day	Transpiration water	5-10 kg/m²/day
Mineral nutrients	10-100 mg/m²	Edible biomass	20-40 g/m²/day
Illumination duration	8-24 h	Inedible biomass	4-20 g/m²/day
Energy	13-170 W/m²		

Table 4.2. (consumption and production values for high plants)
Source: N. El Basam, Requirement for Biomass Production with Higher Plants in Artificial Ecosystems [23]; Peter Eckart, Spaceflight Life Support and Biospherics [17, page 279]

Selection of cultivated plants

An important requirement for the agricultural sector is to grow a selection of plants with high harvest indexes, great adaptability and, if possible, continuous harvesting [17]. According to [12], [17], [21], higher plants recommended for a hydroponics system for a habitat in outer space mostly include wheat (HI: 0,55), soybean (HI: 0,3-0,4), rice (HI: 0,5), potato (HI: 0,82), tomato (HI: 0,5-0,6), lettuce (HI: 0,9-1), cabbage (HI: 0,6-0,7), carrots (HI: 0,6-0,7) and peanut (HI: 0,5). Aside from these, we will also grow species of pea (HI: 0,4-0,5) and bean (HI: 0,3-0,4), spinach (HI: 0,9-1), broccoli (HI: 0,8-0,9), onion (HI: 0,7-0,8), pepper

Energy (kcal)	1970
Protein (g)	65,4
Vit. A (mcg)	2102
Vit. D (mcg)	5
Vit. E (mg)	10
Vit. C (mg)	180
Thiamine (mg)	1,9
Riboflavin (mg)	1,2
Niacin (mg)	18
Vit. B6 (mg)	2,2
Folacin (mg)	400
Calcium (mg)	594
Phosphorus (mg)	1368
Magnesium (mg)	300
Iron (mg)	19
Zinc (mg)	15
Iodine (mcg)	150
Sodium (g)	2,2
Potassium (mg)	4100

Table 4.3. (dietary plan for a vegetarian)
Source: Controlled Ecological Life Support System, Use of Higher Plants, Edited by T. W. Tibbits [19]

(HI: 0,7-0,8) and fruit such as strawberry, raspberry, blueberry, melon (HI: 0,5-0,6) and pineapple; given the fact that the agricultural levels have a maximum height of 3 meters, we can also choose to grow fruit trees such as lemon trees or tangerine trees, and olive trees; these can also be grown in the park, to enhance its visual aspect and to save space for the agricultural sector. These species of plants complete each other in terms of nutritional values and offer a variety of flavors, creating a dietary plan which tries to replace animal protein. The low harvest indexes of the fruit are balanced by the higher harvest indexes of the leafy greens. A future prospect for us is to build an aquarium on the ceiling of the second floor of the hybrid torus and provide a source of animal protein for the crew, without the need to transport it from the Earth and sell it at ridiculously high prices.

Table 4.4 illustrates how the agricultural area can be divided in order to provide a complete dietary plan (table 4.3) for the population of Cicada (we consider an approximate population of 600 inhabitants); this is mostly relevant for staff members, but we take into account tourists as well. We have chosen a selection of 10 crops; however, half of these will be harvested during certain periods and half during others. Harvesting seasons will not overlap. Therefore, the table does show a total energy value of 4186 kcal, but this is calculated for overlapping harvesting seasons. For a selection of 5 out of 10 crops, we can create a dietary plan with an energy value of around 2000 kcal. Thus the total area required to provide food for 600 people is reduced to around 100.000 m^2. Also, because each year is made out of four non-overlapping harvesting seasons, this are can also be divided by 4. We conclude that a total area of around 25.000 m^2 is enough for these crops. Cicada's agricultural sector meets this requirement. If we take into account the fact that each level of the hydroponics system can be divided into smaller ones (for shorter plants), we also conclude that this area allows us to grow a variety of other plants (which were mentioned before). Certainly, a few of these plants which can also be used for decorative purposes can be grown in the park. Many types of foods and beverages we are not able to grow or process will be brought from the Earth; we expect that, in the near future, launch costs will hopefully not be as high as they are today.

Crop	Quantity per person (g/day)	Quantity per season (g/m^2)	Harvest season (days)	Quantity for 600 people (kg/year)	Total area (m^2)	Energy value (kcal/100g)	Total energy value (kcal)
Soybean	100	900	90	21.900	24.333	470	470
Wheat	200	2.800	90	43.800	15.643	379	758
Rice	100	600	90	21.900	36.500	409	409
Carrot	100	2.000	90	21.900	10.950	41	41
Lettuce	100	2.400	90	21.900	9.125	288	288
Bean	100	1.000	90	21.900	21.900	386	386
Pea	150	800	90	32.850	41.063	317	475,5
Potato	200	2.800	90	43.800	15.643	373	746
Tomato	100	3.000	90	21.900	7.300	339	339
Spinach	100	800	90	21.900	27.375	274	274
Total	1.250				209.832		4186,5

Table 4.4. (allocations for a selection of plants, to meet dietary requirements)
References: Space Settlement: A Design Study [12], Expected yields [25]

5.

Business prospects

5.1. The potential of space tourism

Why? Because champagne tastes better in space, it has to... when the Earth lies beneath your feet. And you may even dare gaze down upon it, with starry freckles in your eyes and a blessed dizzy mind...

The slender glass which sits on the table has a subtle elegance. Careful hands languidly envelop the bottle, giving it a firm inclination, just enough for the liquid to come pouring down. A teasing sound fills the ears – a mixture of the whispering river and the untamed sea. The sight is splendid; as the champagne is rising up towards the edge of the glass, a modern spaceship with hundreds of tourists on board is taking off, the number of hotel chains in space is rapidly rising, the last ticket to the Space Olympics is being sold, the second trip to Saturn is being planned and children are giggling while driving racing rockets above the Earth.

Truthfully, if humanity ought to hold a celebration for its future, space tourism would be the finest champagne.

The golden liquid

The liquid which fills the glass is clear and radiant, almost as if it were a treasure; its brightness imitates the dancing rays of the sun.

One of the greatest appeals of space tourism is its potential to result in economic prosperity. Extraterrestrial industry opens the gate to endless material and energy resources (given the access to numerous celestial bodies, from the asteroids to the mighty sun), as well as employment opportunities. This aims to solve a great deal of the issues concerning today's society, among which we can also identify increasing unemployment rates and the threat of resource wars, caused by our planet's limited, as well as fast diminishing supplies. The development of orbital hotels, asteroidal and lunar mines, eventually even self-reliant space settlements, steadily tied to the economic circuits of the Earth and those of other unearthly establishments, will not only result in more workplaces, but it will also expand our horizons and hopefully unveil a sense of reassurance, because resource wars would be devoid of any logical justification. Certainly, space tourism is a first step in revitalizing the industrial world and further strengthening the foundations of our economic progress.

The purifying foam

The foam decorates the glass, like a marble column ascending towards the sky, then elegantly crumbles down and disappears beneath the surface, further enriching its charming nobility.

As a precursor to space colonization, space tourism will most likely bring about a cultural revolution. The monotonous and materialistic world we are living in is currently dominated by a dull mentality; as discussed in [7], we are in desperate need of a second Renaissance. It is crucial that the upper class of today's society recognizes the potential of space tourism and culture and chooses to manage a part of its wealth so that it contributes to the evolution of our civilization as a whole. Artistic expression in outer space, in all its forms, should be encouraged and appreciated, so that it can help build the cultural foundations of future generations, with a different mindset and regained spiritual values.

The rich, cleansing flavor

The champagne rolls off the numb, captivated tongue and travels further down the throat with tickling steps.

The act itself is meaningful in its essence, because it is similar to the act of birth [7]. Freed of its "pregnancy", mother Terra should finally be able to slowly start returning to its previous state. The possibility of the ever-growing space industry would considerably reduce pollution, given the material and energy resources available (among many others, abundant solar power).

The blissful effect

The mind is hazy and awake all the same. It shows no signs of trivial concerns, but rather a refreshing placidity.

Space tourism offers nations all around the world an opportunity to collaborate and unleash a new beginning in the future of humankind – selflessly, prudently, successfully. And, most importantly, together. A collective effort can lead to a more peaceful, less competitive coexistence, if we learn to overcome our pride and allow it to do so. Although the thought itself might be considered naive, it is certainly not entirely foolish to believe in our potential and to hope that space tourism will eventually become a window to an ideal world, free of hatred, violence and conflict.

What is an essential first step in developing the space industry is that we grasp the urgency and need of developing accessible space travel. The concept of reusable launch vehicles ought to reach a more advanced state of development, so that the general public, as well as investors, can benefit from practicing tourism in outer space. A greater demand can be created, and thus a greater profit. The attitude towards space related activities undoubtedly has to change and humanity has to reevaluate its true potential.

5.2. Investment

A major hurdle blocking the path towards the development of the space industry is the lack of funds. Without greater investment, the technological progress needed to launch the idea of accessible space tourism is slowed down by a considerable amount, perhaps even completely stalled for the years to come – quite likely, until it becomes a necessity and our planet's resources begin to near complete extinction, the space industry will continue to receive little to almost no attention from the general population or the majority of investors. A very pessimistic and apathetic mentality envelops this topic. In the past, many writers and researchers predicted that, by now, space tourism will have flourished and become an industry of its own. While we have evolved tremendously in terms of technology and there are a few people continuously funding the idea of space exploration, we still haven't managed to reach that point.

Reasons for low investment

Naturally, the lack of interest for the growth of space tourism has influenced investors to adopt a reluctant approach. There is still a considerable amount of market research to be conducted in order to fully characterize the parameters of such an investment and its likelihood to result into a profitable decision. It involves enormous costs and there is a faint chance that the return will be satisfactory and not greatly delayed, at least in the beginning of space tourism. Having been given the label of "unexplored territory", accessible space travel for the general population still involves considerable safety risks and it might take a lot of time until this is proven otherwise; this might be among the reasons why governmental funding for space tourism (or reusable launch vehicles to allow the transport of the general population into space) is either absent or extremely low and launch permits from governments are extremely delayed and almost unaccessible for commercial use. Additionally, the absence of legal framework for space investment is a delicate matter for entrepreneurs to consider and should be among the first problems to be remedied before space tourism becomes a feasible future prospect.

Possible sources of investment

Nonetheless, in spite of many discouraging considerations, space tourism still remains an ambitious business domain with great potential and numerous investment sources can be found. Financial support might come from atypical types of entrepreneurs: for instance, young investors who dare evade common entrepreneurial practices and venture into a riskier and more thrilling business experience, or "business angels" – wealthy benefactors who choose to invest in modern, highly promising start-ups; such individuals will most definitely play a crucial, if not completely mandatory, part in building the pillars of the space industry. The development of space tourism and space exploration, until this point, owes a great deal to the contribution of angel investors.

Coalitions can be formed in order to raise collective efforts for the development of the space industry [14]. This would be preferable to individual investment and also more efficient. Another such collective investment is fundraising, at larger and smaller scales, associated with grass-root practices. Lotteries, for instance, can be adapted to fit such practices (rewards should be specific and related to the cause: for instance, a chance to be among the first tourists accommodated in a space hotel). In 1865, a group of Romanian literati planned the construction of an athenaeum as a symbol of national culture and art. A lottery was organized to raise funds from common people; the supportive slogan – "Dați un leu pentru ateneu!" – roughly translates to "Spend a dollar for the athenaeum!" (the *leu* is the currency in Romania and, though its value is not equal to the dollar, the quote would not make sense if it were translated in monetary value). Thus lottery tickets were sold for the price of one *leu* and around 500.000 *lei* were raised to build the athenaeum. This did not only serve as a way to enhance the cultural value of the nation, but it also strengthened the patriotic feeling of the people and their trust and willingness to unite their forces and change their country for the better. There is still hope for today's society, even though, as the years pass by, it grows to be more and more materialistic. If such events are conducted by trustworthy companies or even by governments, the common people would have the opportunity to demonstrate their contribution.

Reaching the general population as a possible investment source can also be achieved through the selling of merchandise directed at space enthusiasts or through the use of social networking as a method to raise global awareness.

Aside from providing governmental funds, governments can also contribute by granting loan guarantees, as a way to reassure private investors and stimulate their participation [14]. Other financing sources could arise from the collaboration between investors as well, by delivering economic bonds, in place of bank loans.

The lack of funds is an on-going issue, surely, but there are few to almost no opportunities for investors to actually contribute to the development of the space industry. Incentive programs can gather investments by encouraging and stimulating investors in regard to the idea of space tourism and colonization. Similarly, investment summits and venture funds could represent great opportunities for investment funds, given their influence [14]. Space companies also have the possibility to obtain financing by engaging in other lines of business or by seeking sponsorships.

Obtaining investment funds

Though various financing sources are available, many aspects should be handled correctly in order for these funds to actually be obtained and to ensure that further investment in the space industry will be present. For example, a well structured business plan could have a great impact on a possible investor. It serves as a way to persuade and inform, because it represents a document which builds up the credibility of a business. It is also necessary to provide legal framework to allow entrepreneurial activities in outer space [18]. Additionally, governments ought to grant tax incentives to space entrepreneurs and deliver a more suitable climate for investment. This does not only encourage private companies to help unleash the beginnings of space tourism, but also to further invest in its development, perhaps eventually branching towards space colonization.

Bootstrapping is another solution to the lack of funds [14]. This practice involves receiving investment for other business activities, offering a satisfactory return on this investment, and then investing the profits into space tourism. Many business angels in the space industry have raised their wealth from other lines of business.

Investor relations determine the way in which the new-born space industry might grow to be perceived, as well as the general attitude towards its financing. The investment community should be truthfully informed regarding the risks and benefits of space tourism; the goal is to create transparent investor relations that ensure fluid collaborations between companies and potential investors. If presented carefully and convincingly, ideas for entrepreneurship always manage to attract enthusiasts. Among others, round-tables, conferences, parties and online communication are favorable environments for such practices. Moreover, the emerging space industry could also benefit from using the voice of famous people. Celebrities have the power to influence many and may become advocates of space tourism.

5.3. Legal framework to define the idea of space tourism

An an emerging business domain, space tourism undoubtedly lacks a trait that is essential to its development: thorough legal framework. It has been previously discussed that the concept of commercial space travel raises a major sense of uncertainty in regard to its legal trace. This represents a crucial impediment to private investors and ultimately has a mandatory role in deciding the future of accessible space tourism and exploration, considerably influencing the possibility of involvement on a larger scale. It is important to acknowledge that space tourism holds the key to the future of humankind and to adopt legislation to support its promising growth. The legal framework that concerns today's space-related activities is not enough to properly establish the legal boundaries of commercial space travel.

The current standpoint of commercial space travel is comparable to the first years of development of commercial airlines, which have now become part of a routine and a very common means of transportation. It is stated that liability applicable to space tourists should be similar to that described in the international Warsaw Convention, which delimits carriage by air, or even an extension of it. Space law can also be compared to high-risk adventure tourism law [26]. Consequently, insurance is necessary for space travel, especially since it is an industry still in early development; this poses a great challenge. While it may result in greater profit, it is also characterized by great safety risks. Certain limits for insurance may be required in the early stages of space tourism and the role of governments could be to support insurance companies in case highly detrimental events occur. As mentioned in the previous Sub-chapter, another contribution that governments could provide would be to offer tax incentives, at least until the industry flourishes; this implies that not having to pay enormous taxes might encourage investors to contribute with less restraint. In addition, as a follow-up to the involvement of private investors in this industry, laws have to be developed to define and impede criminal activities in outer space. Other adjustments to provide a safe and peaceful touristic environment in outer space are concerned with license and registration, mostly for reusable launch vehicles, which would mainly be connected to each state's legal regime [18].

Other issues related to legal framework in outer space are raised by the concept of territory. It is questionable whether countries should be able to claim certain regions of the Low Earth Orbit or more distant locations in space as national property. Regarding private space hotels or other private touristic destinations, an idea is that the laws aboard should be those of the country of origin of the private company [20]. It is only natural to expect the selective involvement of nations in the commercial space industry; hopefully, though, collective efforts will be initiated to turn the idea of space tourism into reality (an affordable one).

Undoubtedly, the rights and obligations of a space tourist and of spacecraft personnel will have to be respected, in order for a harmonious community to be created outside earthly boundaries. We have also developed a code of ethics for our business in outer space, building the pillars of untainted moral standards and a polished mentality.

5.4. Construction phases

5.4.1. Phase 1

Phase 1 ends when the construction of the first part of the settlement reaches completion. This means that the dock, the central sphere, the intermediate double cylinder and the hybrid torus are all built during phase 1. In total, in order to be able to build the entire structure, not taking into account the internal mass and the mass of the atmosphere for the pressurized modules, around 60 launches would be required (see table 5.14). That is, if the rocket used to transport cargo and people into orbit has a capacity of at least 50 metric tons; Falcon Heavy, developed by SpaceX, can carry around 53-54 metric tons worth of payload into the Low Earth Orbit, thus earning its title of “the world’s most powerful rocket” (http://www.spacex.com/falcon-heavy).

After the first launch, a small cylindrical structure will be taken into orbit, along with EVA equipment and a portion of the solar array linked to the central sphere (this portion represents a circular crown with radii of 30 and 34 meters; the final solar array is a circular crown with radii of 30 and 38 meters). This cylinder has a height of 14 meters and a radius of 7 meters; in a more advanced stage of construction, it will serve as a passageway between the central sphere and the dock (note that this passageway is only 4 meters long, but another 10 meters can be added from the dock’s height). The cylinder will be endowed with 3 docking ports and GN&C and P&MC systems (whose location will be changed after the central sphere is built); it will mainly function as a base, until the construction of the central sphere is completed.

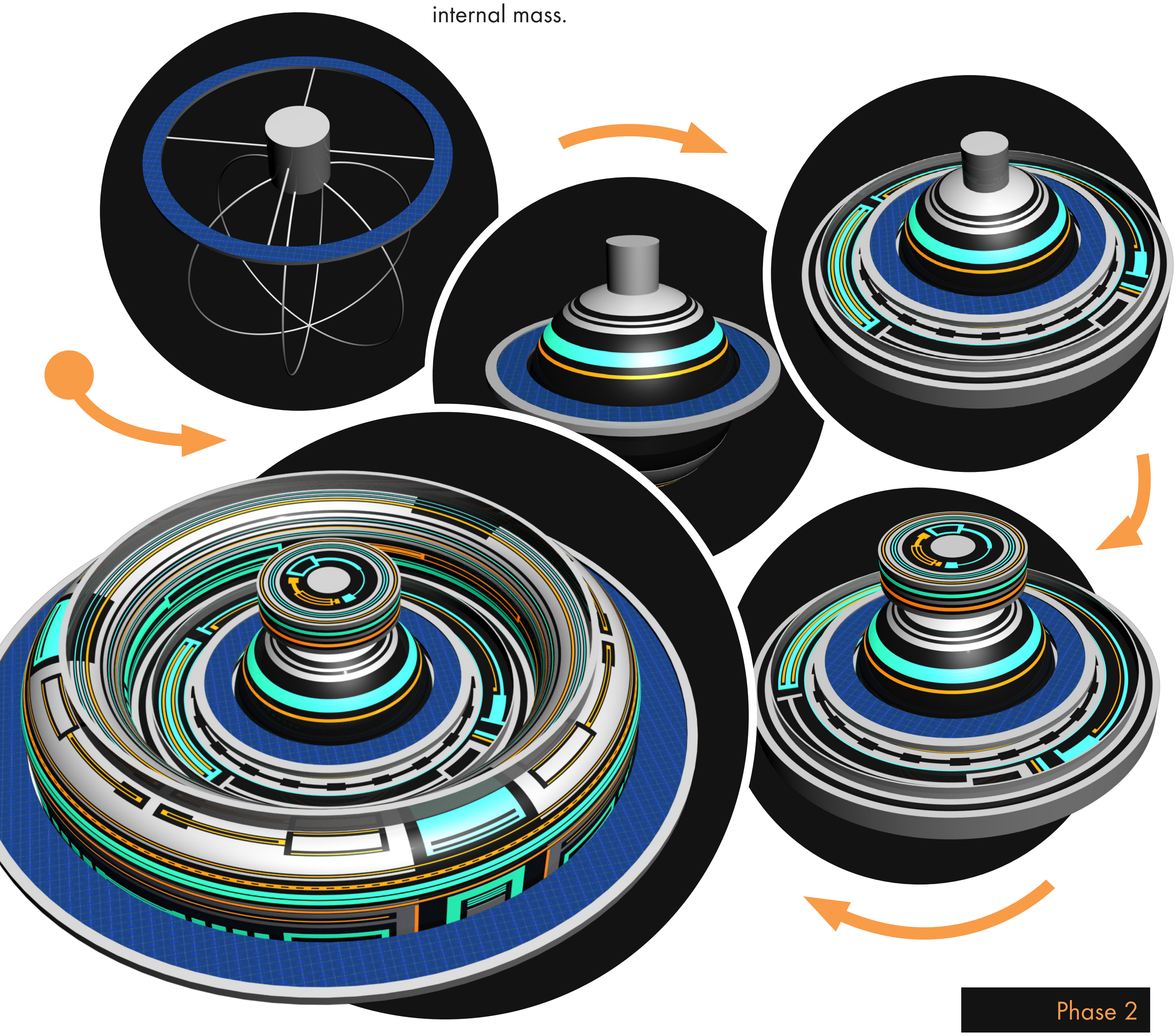
Approximately 7 launches would be needed to build the central sphere (table 5.14), along with the components of the Maglev rotation mechanism and the complete central solar array. The materials needed to build the intermediate double cylinder can be brought into orbit after roughly 11 launches (table 5.11); at this stage, a larger crew can start inhabiting the settlement, given that artificial gravity will be present. 3 additional launches are required to add the dock to the construction. Finally, as the major component of the habitat, the hybrid torus will require 39 launches (table 5.14). Launches required to build a certain component may overlap with others, since they represent approximate values. Thus, the sum of these values may be higher than the required number of launches for the entire first part of the settlement.

8 launches are required to transport gas tanks into orbit, for the pressurized modules. As far as the internal mass is concerned, phase 1 will be separated into 2 stages of construction; Cicada will reach the end of the first stage of construction once it is able to accommodate 200-220 inhabitants (this stage of construction corresponds to the construction of Agon, the first out of the three hotels, presented in Sub-chapter 3.3, Section 3.3.2). This requires 169 launches, in total. The second stage of construction, with a maximum and final capacity of around 600 inhabitants) will be completed after 177 additional launches (table 5.15) and will be finalized once the other two hotels, Alea and Ilinx, are built. Time periods for these two stages are difficult to predict, because they are easily influenced by a multitude of factors. Profits obtained during stage 1 will indicate the beginning of stage 2. Technical development for reusable launch vehicles and other space-related technologies should also be taken into account.

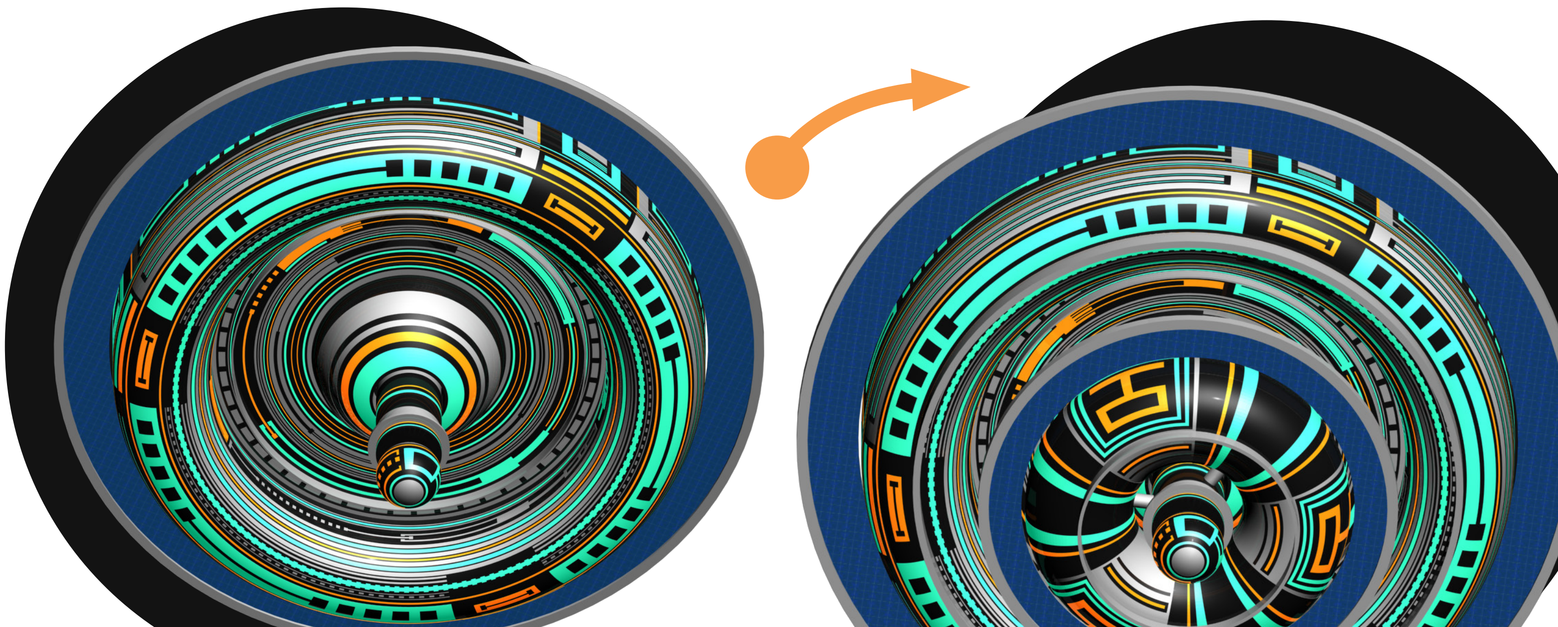
5.4.2. Phase 2

The second part of the settlement will be built during phase 2: the column, the small sphere and the torus. Whether phase 2 will take place in the near future or somewhere further along the line depends on the profits obtained during phase 1, but also on technological progress. Around 35 launches are required for phase 2 to reach completion, if internal mass is taken into account. The construction of the column requires roughly 2 launches for its shield and rear wall, as well as the atmosphere inside. For the same purpose, the small sphere only requires one launch and the torus (together with its spokes) requires around 13 launches. The remaining 19 launches for phase 2 (table 5.15) are for the internal mass.

Phase 1



Phase 2



5.5. Financial aspects

5.5.1. Population

As the arrangements for the hotel and employee dormitory are discussed in Sub-chapter 3.3, we may conclude that an estimate for the population would be around 604 inhabitants (468 tourists and 136 members of staff; we consider this value to be approximate, because apartments in the employee dormitory are able to accommodate 2 people, however, not everyone with would to live with a roommate; other ideal scenarios which may or may not take place were taken into account for the hotel rooms). The purpose of this section of the project is to determine whether or not the available area is able to accommodate this given population (note that we only take into account the construction of the first part of the settlement, that is the central sphere, the dock, the intermediate double cylinder and the hybrid torus, since the second part of the settlement may or may not be a feasible future prospect, depending on the profits earned during phase 1 and the willingness of our investors to further reinvest in this line of business).

Table 5.1 was made in accordance with the information given in Space Settlement: A Design Study [12] (page 26), though many values are approximate and offices, schools, animal areas, churches and community halls were not applicable to our settlement and thus not taken into account. Total available areas were calculated in regard to the allocations given in 3.2 (though the sphere and the dock were not taken into account). We notice that many of the values of the available area are rather close to the values given in [12]. Great differences are eye-catching in the case of the residential and entertainment areas. Firstly, the unusual value for the residential area is due to the fact that Cicada is mainly a touristic destination and therefore mainly populated by tourists; residential area allocations for tourists are incomparable to those of permanent residents. As far as the apartments in the residential area are concerned, 28,5 m^2 should be enough, since members of the staff would work monthly shifts and could not be classified as permanent residents. Secondly, it is only natural that the entertainment area would greatly exceed a normal value for a colony, since the main purpose of a hotel and amusement park is related to entertainment (note that additional entertainment and recreation areas can be calculated for the torus).

Population	604		
Area allocation			
Destination use	Required projected area/person (m^2)	Available projected area (m^2)	Available projected area/person (m^2)
Residential	49	11775	19,495
Restaurants	4	2400	3,974
Storage	5	2846,933	4,713
Waste/water treatment, food processing	16	6484,746	10,736
Plant growing area	44	29.074	48,135
Entertainment and recreation	12	22300	36,92
Miscellaneous (green space, transport routes, electrical supply and distribution and others)	13	8000	13,245
Medical facility	0,3	1350	2,235
Total	143,3		139,454

Table 5.1. (area allocations for the first part of the settlement, in accordance with [12])

5.5.2. Internal mass

Non-structural mass per person (t)	
Plants (for food, recycling air, water, etc.)	2
Water (for drinking, hygiene, recycling)	1
Water (for recreation and aesthetics)	0,5
Furniture and fixture	0,5
Lightning and equipment (plumbing, power, cooling)	1
Paper, plastic, textiles	0,35
Agriculture and recycling overhead and equipment	1,25
Total	6,6

Table 5.2. (non-structural mass per person, in accordance with [11] (page 40))

The internal non-structural mass per person and the total internal mass were calculated in accordance with the information given in [11] and [12]. However, values may vary, since we considered that the allocations for a space hotel would be different than those for a colony. For instance, not that much furniture would be required for tourists and short-term residents and almost no paper will be needed on the settlement. The published literature suggests that this mass varies between 3,5 and 14 tonnes per person. For a settlement of reduced dimensions, that is meant to function as a touristic destination, we regard 6,6 tonnes per person as a reasonable value. Also, in order to determine the total internal mass for the torus, there were cases when we took into account values that are less than those for the internal mass for the hybrid torus (for example, the structures and the non-structural internal mass per person; table 5.3).

Internal mass	
Hybrid torus	
Soil (dry) (t): 3.000 ($A_{1P}^{\#}$)+5.000 ($A_{2P}^{\#}$)+agricultural area* 0,2 m thick*721 kg/m^3	5.346,01
Water in soil (10% soil) (t)	534,60
Non-structural internal mass per person (from table 5.2)	3.986,40
Biomass people (t) (70kg*population number)	42,28
Structures (t) (5t*population number)	3.020,00
Substructures (20% of structures) (t)	604,00
Utilities (t) (1t*population number)	604,00
Miscellaneous: solar panels, radiators (1t*population number) (t)	604,00
Total internal mass hybrid torus IM_{ht} (t)	14.741,29
Torus	
Non-structural internal mass per person (0,5t*population number) (t)	302,00
Biomass people (t)	42,28
Structures (0,5t*population number) (t)	302,00
Substructures (20% of structures) (t)	60,4
Miscellaneous: solar panels, radiators (1t*population number) (t)	302,00
Total internal mass IM_t (t)	1.008,68

Table 5.3. (total internal mass, in accordance with [12] (page 95))
#we calculated the green areas for the first and second floor of the hybrid torus

5.5.3. Shield mass

Shielding configuration 1					
Material	Thickness (cm)	Density (g/cm³)	Areal density (kg/m²)	Price $/kg	Price $/m²
Aluminum 6061-T6	0,250	2,700	6,75	2,00	13,500
Beta cloth	0,013		0,25		80,000
MLI-Aluminized Mylar	0,018	1,390	0,25	1,50	0,375
Open cell foam (polyamide AC-550)	15,000	0,007	1,07	1,20	1,278
Nextel AF-10	0,060	2,800	1,68	250,00	420,000
Kevlar KM2	0,069	1,000	0,69	1,50	1,035
Spectra 1000 style 952	1,000	0,970	9,70	0,80	7,760
Total	16,410	0,124	20,39		523,948

Table 5.4.

Shielding configuration 2					
Material	Thickness (cm)	Density (g/cm³)	Areal density (kg/m²)	Price $/kg	Price $/m²
Aluminum 6061-T6	0,250	2,700	6,750	2,000	13,500
MLI-Aluminized Mylar	0,018	1,390	0,250	1,500	0,375
Open cell foam (polyamide AC-550)	15,000	0,007	1,065	1,200	1,278
Nextel AF-10	0,030	2,800	0,840	250,000	210,000
Kevlar KM2	0,069	1,000	0,690	1,500	1,035
Spectra 1000 style 952	1,000	0,970	9,700	0,800	7,760
Total	16,367	0,118	19,295		233,948

Table 5.5.

Shielding configuration 3					
Material	Thickness (cm)	Density (g/cm³)	Areal density (kg/m²)	Price $/kg	Price $/m²
Aluminum 6061-T6	0,550	2,700	14,850	2,000	29,700
Open cell foam (polyamide AC-550)	15,000	0,007	1,065	1,200	1,278
Total	15,550	0,102	15,915		30,978

Table 5.6.

Mass and price for shielding configuration 3		
Segment	Mass (kT)	Price ($M)
Unpressurised portion of the double cylinder	0,060	0,117
Central sphere	0,232	0,039
Unpressurized portion of the column	0,017	0,033
Dock	0,055	0,117
First segment	0,015	0,029
Total	0,379	0,334

Table 5.7.

Mass and price for shielding configuration 1		
Segment	Mass (kT)	Price ($M)
Hybrid torus A_{oht}	0,740	19,027
Torus A_{ot}	0,238	6,130
Small sphere	0,026	0,658
Total	1,004	25,815

Table 5.8.

The tables in this section illustrate the mass and price for each one of the three shielding configurations. Like the internal mass, the mass of the shield is essential in calculating the costs for the construction of the settlement. We determined the areal density as the product between thickness and density. The areal density for beta cloth is 0,25 kg/m^2 [13].

Most prices can be found on https://www.alibaba.com. However, compared to the enormous launch costs, the required cost to purchase the materials needed for the shield is insignificant and was mainly calculated to prove this point. For instance, for the first shielding configuration, which is also the most expensive one, the price is approximately 26 dollars per kilogram. That is approximately 0,015 of the launch cost per kilogram (approximately $1700 for reusable launch vehicles). Thus, when calculating the costs, we do not take into account the cost to purchase the materials, but only that to transport them from the Earth to the Equatorial Low Earth Orbit.

Mass and price for shielding configuration 2		
Segment	Mass (kT)	Price ($M)
Hybrid torus A_{iht}*	0,461	0,294
Torus A_{it}	0,117	1,415
Double cylinder**	0,254	3,079
Column***	0,040	0,485
Spokes	0,005	0,066
Total	0,877	5,339

*Table 5.9. (*without the common area with the double cylinder; **without the common area with the hybrid torus and the unpressurized portion; ***without the unpressurized portion)*

5.5.4. The required thickness of the settlement's hull

We will begin by calculating the thickness of the hull for the intermediate double cylinder. We will approximate it to a cylinder, since the distance between the radii is quite significant, and follow the reasoning discussed in [Al Globus, S. Covey, D. Faber, 12]. Thus, the shell mass is given by the following formula:

$$\text{Shell mass}_{\text{double cylinder}} = \frac{2\pi(R_c + t_{s2})^3 \rho_{s2}(1 + h_c/R_c)d_s}{\sigma_{w2} - \rho_{s2} g_{max}(R_c + t_{s2})},$$

where σ_{w2}, ρ_{s2} are the allowable working stress and the density for the structural material (in this case Aluminum 6061 – T6) and t_{s2} is the thickness of shield configuration 2.

Double cylinder	
Major radius R_c (m)	60
Minor radius r_c (m)	25
Height h_c (m)	8
g_{max} (m/s^2)	3,92
Aluminum 6061-T6 density ρ_{s2} (kg/m^3)	2700
Atmospheric pressure p_a (kPa)	51,7
Aluminum 6061-T6 (hull material) σ_{w2} (allowable working stress for the structural material) (kPa)	270000*
Thickness of shielding configuration 2 t_{s2} (m)	0,164
Design stress d_s (t/m^2)	22,274
Shell mass$_{\text{double cylinder}}$ (kg)	346047,143
Thickness of the wall t_{dc} (m)	0,006

*Table 5.10. (*source: http://asm.matweb.com/search/SpecificMaterial.asp?bassnum=ma6061t6)*

The design stress was calculated using the following formula:

$$d_s = (1+3)\left(5,27+0,02+\frac{IM_{ht}}{5\sum_{k=1}^{4}A_{kP}}\right)$$

The 3 in the parenthesis represents the design structural strength margin of 300%, according to [Al Globus, S. Covey, D. Faber, 12]. 5,27 is the atmospheric pressure converted from kPa to tonnes per square meter. The approximate mass of the shield is 0,02 tonnes/square meter (the two shielding configurations don't differ much in terms of mass). Also, we consider that the internal mass for the intermediate double cylinder is a fifth of that for the hybrid torus.

In order to determine the thickness of the wall, the following formula was used:

$$t_{dc} = \frac{\text{Shell mass}_{double\ cylinder}}{\text{Shell area}_{double\ cylinder}\rho_{s2}}$$

Double cylinder	
Shield mass (t)	253,98
Shell mass (t)	346,05
Air mass (t)	40,12
Total mass (without internal mass) (kt)	0,64

Table 5.11.

Hybrid torus	
Maximum radius R_{max} (m)	90
Minimum radius R_{min} (m)	60
Aluminum 6061-T6 density ρ_{s2} (kg/m^3)	2700
Titanium-6Al-4V density ρ_{s1} (kg/m^3)	4429
Atmospheric pressure p_a (kPa)	51,7
Aluminum 6061-T6 (hull material) σ_{w2} (allowable working stress for the structural material) (kPa)	270000
Titanium-6Al-4V (hull material) σ_{w1} (allowable working stress for the structural material) (kPa)	900000
g_{max} (m/s^2) hybrid torus level 1 (floor)	5,88
g_{min} (m/s^2) hybrid torus level 2 (ceiling)	3,92
Thickness of shielding configuration 1 t_{s1} (m)	0,164
Density of shield1 ρ_{sh1} (kg/m^3)	124,224
Thickness of shielding configuration 2 t_{s2} (m)	0,163
Density of shield2 ρ_{sh2} (kg/m^3)	117,89
Thickness of the outer wall t_{ht1} (m)	0,0052
Thickness of the inner wall t_{ht2} (m)	0,0037

Table 5.12.

The formulas used to calculate the thickness of the outer and inner walls of the hybrid torus are given in accordance with [16, page 46] (the notations are the same as in table 5.12):

$$t_{ht1} = \frac{R_{max}}{10^3\sigma_{w1} - \rho_{s1}g_{max}R_{max}}\left[10^3 p_A + \frac{\rho_{sh1}t_{s1}g_{max}(R_{max}+t_{s1}/2)}{R_{max}} + \frac{2g_{max}r_{ht}IM_{ht}}{V_{ht}}\right]$$

$$t_{ht2} = \frac{R_{min}}{10^3\sigma_{w2} + \rho_{s2}g_{min}R_{min}}\left[-10^3 p_A + \frac{\rho_{sh2}t_{s2}g_{min}(R_{min}-t_{s2}/2)}{R_{min}} + \frac{2g_{min}r_{ht}\text{Total mass}_{double\ cylinder}}{V_{ht}}\right]$$

The outer wall cylindrical is the one that has to sustain the greatest load. Had we used Al 6061-T6 for the rear wall, the required thickness would have been around 2,5 cm, which is why we used a titanium alloy, Titanium 6Al-4V, with a thickness of 6 mm; the material is heavier than aluminum, but has a much greater allowable working stress. Essentially, the outer straight wall of the hybrid torus is made out of titanium, instead of aluminum.

The pressure exerted by the intermediate double cylinder on the inner wall of the hybrid torus is greater than the atmospheric pressure and helps prevents the buckling of the hull; as it is suggested in [12, page 40], the gravity load is greater than the load imposed by the atmospheric pressure.

Torus	
r_t (m)	15
R_t (m)	30
g_{max} (m/s^2)	2,94
$R_t/2r_t+0{,}5=a_r$ (aspect ratio)	1,5
Shell design structural margin	300%
Design stress d_{st} (kg/m^2)	21.080,08
Shell mass$_{torus}$ (kg)	244.239,63
Thickness of the wall t_t (m)	0,005

Table 5.13.

The design stress for the torus is:

$$d_{st} = (1+3)\left(5,27 + 0,02 + \frac{IM_t}{A_{ot}}\right)$$

IM_t is given in table 5.3. Otherwise the formula is similar to that of the double cylinder. According to [Al Globus, S. Covey, D. Faber, 12], the formula for the shell mass is:

$$\text{Shell mass}_{torus} = \frac{4\pi^2 \rho_{s2}(R_t + r_t + t_{s1})^3 (2/a_r) d_{st}/4a_r}{\sigma_{w2} - \rho_{s2} g_{max}(R_t + r_t + t_{s1})}$$

Finally, the thickness of the wall is given by:

$$t_t = \frac{\text{Shell mass}_{torus}}{\text{Shell area}_{torus}\rho_{s2}}.$$

The other components are either unpressurized or characterized by very small values of artificial gravity. Thus they do not require a thickness of the hull equal to that of the torus, the hybrid torus and the intermediate double cylinder. However, a thickness of 5 mm was still chosen for the psychological comfort of the inhabitants. Note that the dock is entirely made out of titanium alloy 6Al-4V for the rear wall (also with a thickness of 5 mm).

The shell masses of the torus and intermediate double cylinder were calculated before. For the others, the shell mass was determined as the product between the thickness of the wall, the density of the material it is made of and the area of the component (or that of a portion of it).

	Hybrid torus	Central sphere	The dock	The column	Small sphere	Torus (+spokes)	Total mass (without internal mass) (kt) phase 1	Total mass (without internal mass) (kt) phase 2
Shield mass (t)	1.201,03	232,37	55,07	39,99	26	360,64	1,74	0,43
Shell mass (t)	861,25	118,27	76,63	25,43	16,96	247,59	1,4	0,29
Air mass (t)	381,52	0,00	0,00	5,45	2,60	82,79	0,42	0,09
Total mass (without internal mass) (kt)	2,44	0,35	0,13	0,07	0,05	0,69	3,57	0,81

Table 5.14.

Table 5.14 indicates the total masses of each of the components, if we do not take into account the internal mass. The mass of the intermediate double cylinder was calculated before, because it was needed to determine the thickness of the hybrid torus' wall. As it is discussed in Sub-chapter 5.4, phase 1 is represented by the construction of the central sphere, the dock, the intermediate double cylinder and the hybrid torus. Phase 2 consists of the central column, the torus (and its spokes) and the small sphere.

5.5.5. Cost estimate

Phase 1	
Phase 1-1	
Shell, shield and air mass (kt)	3,57
Internal mass (kt)	5,369
Total mass (kt)	8,94
Required launches	169
Total launch cost ($B)	15,17
Materials cost ($B)	6,36
Engineering cost ($B)	9,53
Total cost Phase 1-1 ($B)	31,06
Phase 1-2	
Internal mass (kt)	9,37
Required launches	177
Total launch cost ($B)	15,91
Materials cost ($B)	5,42
Engineering cost ($B)	8,135
Total cost Phase 1-2 ($B)	29,47
Phase 2	
Shell, shield and air mass (kt)	0,81
Internal mass (kt)	1,01
Total mass (kt)	1,82
Required launches	35
Total launch cost ($B)	3,15
Materials cost ($B)	1,8
Engineering cost ($B)	2,7
Total cost ($B)	7,65
Total cost (phase 1 and 2) ($B)	68,19

Table 5.15.

As it is discussed in Sub-chapter 5.4, the construction of the settlement is divided into two phases, one for the central sphere, the dock, the intermediate double cylinder and the hybrid torus, and one for the column, the torus and the small sphere. Phase 1 is separated into 2 stages; one hotel will be built during stage 1 and the other two during stage 2.

Therefore, during phase 1-1, the settlement will be able to accommodate around 150 tourists and 70 residents, thus a total population of around 220 inhabitants. The internal mass for this stage was calculated as 220/604 of the total internal mass of the hybrid torus (table 5.3). If we consider that 53 tonnes can be transported per launch (http://www.spacex.com/falcon-heavy), the required launches to transport the total mass (for phase 1-1) from the Earth to ELEO would be 169. The total launch cost can be determined as the product between the required launches and the cost per launch (around 90 million dollars). Following the ideas presented in [12], we consider an additional cost for the materials used for the shield and for the internal mass (from which we subtracted the soil, the water in soil and the people biomass); we estimate this additional cost as 1000 dollars per kilogram. For the same materials, another additional cost is the engineering/manufacturing cost; we estimate that the this cost is 1500 dollars per kilogram.

For stage 2 of phase 1 and for phase 2, all values were calculated in an identical manner with those in phase1-1.

5.5.6. Unit price

In what follows, we try to estimate the unit price for a night of accommodation at a space hotel, keeping in mind that it should offer a rather satisfactory return on the enormous investment that was required to build the settlement. We regard the unit price as the price a tourist has to pay in order to spend a night on the settlement; this price includes accommodation at one of the hotels and any other tickets for entertainment facilities in the park (excluding restaurants and shops). Renting a single room is equal to the unit price; however, double rooms and suites are two, respectively three times the unit price. It is also noteworthy to specify that each of the tables in this section is concerned with yearly costs, revenues or profits. These tables are not concerned with launch costs. We hope to rely on partnerships with companies that design launch vehicles, both for human transport and resupplies.

Tables 5.16 and 5.17

Tables 5.16 and 5.17 show that we also value investments in research, by offering scholarships and participating in exchange programs, in external services, like marketing and legal representation, and

Activities		Factor1	Factor2	Value ($B)	Factor3		Multiplying factor (years or months)	Total ($B)
Settlement cost phase 1-1	Shield, hull, buildings, plants etc.	Fixed	Annual cost	30,66	Depreciation	0,03	1	1,022
Publicity and research	Scholarships, campaigns etc.	Fixed	Monthly cost	0,001			12	0,012
Maintenance	EVA repairs etc.	Fixed	Monthly cost	0,0015			12	0,018
Consumables		Fixed	Annual cost	0,09			1	0,09
Salaries	Non-productive	Fixed	Monthly cost	0,0001	Number of employees	8	12	0,0096
Other costs	Insurances, licenses etc.	Fixed	Annual cost	0,001			1	0,001
Total fixed cost (TFC_{11}) ($B)								1,153
Salaries	Productive	Variable	Monthly cost	0,00005	Number of employees	70	12	0,042
Supplies	Supplies from the Earth	Variable	Monthly cost	0,01			12	0,12
External services	Juristic, marketing etc.	Variable	Annual cost	0,00001	Number of employees	10	12	0,0012
Environmental protection	Removing orbital debris from LEO	Variable	Monthly cost	0,001			12	0,012
Total variable cost (TVC_{11}) ($B)								0,1752
Total cost phase 1-1 (TC_{11}) ($B)								1,3279

Table 5.16.

Activities		Factor1	Factor2	Value ($B)	Factor3		Multiplying factor (years or months)	Total ($B)
Settlement cost phase 1	Shield, hull, buildings, plants etc.	Fixed	Annual cost	59,79	Depreciation	0,03	1	1,7936
Publicity and research	Scholarships, campaigns etc.	Fixed	Monthly cost	0,001			12	0,012
Maintenance	EVA repairs etc.	Fixed	Monthly cost	0,0025			12	0,03
Consumables		Fixed	Annual cost	0,09			1	0,09
Salaries	Non-productive	Fixed	Monthly cost	0,0001	Number of employees	8	12	0,0096
Other costs	Insurances, taxes etc.	Fixed	Annual cost	0,01			1	0,01
Total fixed cost (TFC_{1}) ($B)								1,9452
Salaries	Productive	Variable	Monthly cost	0,00005	Number of employees	136	12	0,0816
Supplies	Supplies from the Earth	Variable	Monthly cost	0,03			12	0,36
External services	Juristic, marketing etc.	Variable	Annual cost	0,00001	Number of employees	10	12	0,0012
Environmental protection	Removing orbital debris from LEO	Variable		0,001			12	0,012
Total variable cost (TVC_{1}) ($B)								0,4548
Total cost phase 1 (TC_{1}) ($B)								2,4

Table 5.17.

Number of tourists	150
Days (one year)	365
Price per unit Pu_{11} (one night per person) ($)	85.000
Total fixed cost TFC_{11} ($B)	1,153
Total variable cost TVC_{11} ($B)	0,175
Total cost TC_{11} ($B)	1,328
Quantity of output Q_{11} (total number of tourists*)	54.750
Average total cost $ATC_{11}=TC_{11}/Q_{11}$ ($)	24.254,563
Average fixed cost $AFC_{11}=TFC_{11}/Q_{11}$ ($)	21.054,563
Average variable cost $AVC_{11}=TVC_{11}/Q_{11}$ ($)	3.200
Contribution per unit $Cu_{11}=Pu_{11}-AVC_{11}$ ($)	81.800
Break-even Point (sales units) $Bp_{11}=TFC_{11}/Cu_{11}$	14.092
Break-even Point (percentages)=Bp_{11}/Q_{11}	25,7%
Total revenue TR_{11} ($B)	4,654
Profit $P_{11}=TR_{11}-TC_{11}$ ($B)	3,326
Profit after taxes ($B)	2,328

Table 5.18. (phase 1-1)

Number of tourists	450
Days (one year)	365
Price per unit Pu_1 (one night per person) ($)	50.000
Total fixed cost TFC_1 ($B)	1,945
Total variable cost TVC_1 ($B)	0,455
Total cost TC_1 ($B)	2,4
Quantity of output Q_1 (total number of tourists*)	164.250
Average total cost $ATC_1=TC_1/Q_1$ ($)	14.611,957
Average fixed cost $AFC_1=TFC_1/Q_1$ ($)	11.843,007
Average variable cost $AVC_1=TVC_1/Q_1$ ($)	2.768,950
Contribution per unit $Cu_1=Pu_1-AVC_1$ ($)	82.231,05
Break-even Point (sales units) $Bp_1=TFC_1/Cu_1$	23.655
Break-even Point (percentages)=Bp_1/Q_1	14,4%
Total revenue TR_1 ($B)	8,213
Profit $P_1=TR_1-TC_1$ ($B)	5,812
Profit after taxes ($B)	4,068

Table 5.19. (phase 1)

**the quantity of output refers to the number of tourists in sort of an ideal scenario, where suites accommodate three people, double rooms accommodate 2 people and single rooms accommodate one person (costs are directly proportional to the number of people the room is designed to accommodate); however, for instance, it is possible for a single customer to rent a suite and pay a triple price, which will still count as three tourists;*

environmental control, by participating in campaigns whose purpose is to rid ELEO of orbital waste. Average salaries for employees and managers are also shown in these tables.

The first factor in the first two tables refers to the type of costs. Variable costs depend on the quantity of output; fixed costs do not. In the case of many types of costs, however, this classification is arguable and may depend on each company's choice.

Particularly in the case of materials needed to build the settlement and buildings inside, the third factor is depreciation. Depreciation can only be applied to certain fixed costs and is used to show that the price of an asset suffers from a certain reduction over time, due to the fact that the particular asset is used and begins to gradually wear off. Depreciation helps us asses the decreasing value of an asset after each year of usage. In the case of our settlement, we consider a depreciation period of 30 years and apply a linear depreciation (meaning that it is constant each year). Even after usage, however, the price of an asset usually still amounts to something and it cannot be considered null; the asset is still worth something and a part of the investment can be recovered. This is why the use of a salvage value is required, which is subtracted from the cost of the asset. In the case of buildings and materials needed for construction, we consider a salvage value of 400 million dollars for phase 1-1 and 750 million dollars for phase 1 as a whole.

Tables 5.18 and 5.19

The break-even point shows when revenues and costs are equal, which means that no profits are obtained, but there are no losses either. Thus, the break-even point in sales units represents the quantity of output that is needed for equality between cost and revenue. The break-even point expressed as a percentage shows what fraction of the maximum quantity of output is represented by the break-even point in sales units. Our break-even point is 25% of the maximum quantity of output for phase 1-1 and 14% at the end of phase 1.

What can be noticed is that, compared to the average cost (which represents the cost of production of one product), the price per unit is extremely high, though it decreases by a certain amount during the second part of phase 1. Thus, as both tables show, for a tourist, a night of accommodation has the price of 85.000$ during phase 1-1 and 50.000$ at the end of phase 1. Firstly, such a great difference between the average cost and the unitary price is justified by the fact that we wish for returns on investments not to be too delayed. Secondly, we are aware that launch costs will significantly drop over time, due to technological progress, and small unit prices might not allow us to retrieve our investment in due time. If we were to stop at phase 1-1, investment could be fully recovered in approximately 15 years; if we also enter phase 1-2, this period is reduced to approximately 9 years. Also, we consider that taxes are 30%. However, we hope that governments will choose to encourage space tourism and grant tax incentives to enhance its development, at least during early stages. This would also ensure a faster return on investment.

5.6. Inhabitants

5.6.1. Staff members

	Phase 1-1 (156 tourists)	After Phase 1-2 (468 tourists)
General manager	1	1
Administrative manager	1	1
Hotel general manager	1	1
Receptionists	2	6
Housekeeper	2	6
Bartender	1	3
Electrical engineer	4	10
Civil engineer	3	6
Mechanical engineer	8	12
Agronomist engineer	1	2
Chemical food engineer	2	2
Database administrator	1	1
Systems developer	1	1
Network engineer	1	1
Worker	16	28
Psychologist	1	1
Doctor/nurse	4	6
Restaurant staff	8	15
Scientist	8	15
Park staff	4	8
Total	70	126

Table 5.20.

Though many work procedures on Cicada will rely mostly or entirely on computerization and mechanization (agriculture or the selling of goods in shops, for instance), trained staff are still needed to oversee these activities and ensure the well-functioning of the settlement, as well as attend to the customers. In general, staff members are responsible for the safety and comfort of the tourists, as they will have to undergo medical examinations and thorough training sessions.

It is noteworthy that the increase in staff members from phase 1-1 to the end of phase 1-2 is not directly proportional to the increase in tourists, since many jobs do not depend that strictly on the number of tourists and hotels, like the number of housekeepers does, for instance.

Most of the jobs in table 5.20 are self-explanatory. The term *worker*, however, is more of a generalization and refers to those that supervise agriculture, those that work in the food processing or water-waste treatment centers and those that work in maintenance.

Staff will generally work between 3 and 6-month shifts or may even go as far as one year, if that is their choice.

Though the number of workplaces should be 136 or more, at least 10 will be left open for invitations from the Earth to the settlement or for exchange programs. Also, additional staff on Earth will be represented by 5 other managers and 10 employees working in design, marketing and as legal representatives.

5.6.2. Preparing for the trip

The first space tourists will require both physical and mental strength. A harmonious combination of the two is essential to ensure collaboration between passengers/tourists and crew/staff members in cases of emergency and to reduce any long-term consequences which may arise as a result of the trip. Detailed medical examinations and complex training ought to be undergone by those who wish to experience an orbital flight and/or stay at a micro-gravity (rotating) space hotel, but also by those that choose to work in this domain. Providers have to turn safety into their top priority, offer services of the highest quality and be transparent in their relations with customers, in order for their business to thrive, especially when it comes to this emerging, yet unknown industry. It is only natural for customers to show willingness and responsibility and hold their end of the bargain, by being prepared and not putting themselves and others in danger. It is expected that the selection criteria for staff will be stricter and training periods will be longer.

Firstly, meticulous medical examinations will be performed as part of the selection process. In early development, space tourism will sadly not be accessible to those with psychiatric disorders, type 2 diabetes, a recent history of drug abuse and untreatable cardiovascular conditions (high blood pressure and irregular pulse rates could, in some cases, be treatable; however, candidates who are suffering/suffered from coronary heart disease, myocardial infarction or cardiac valve replacement and those who underwent a heart transplant will be ineligible) [32]. Customers ought to be assured, yet at the same time truthfully informed in regard to health concerns involved in orbital tourism. Loss in bone strength is among the main concerns, alongside increased heart rates and exposure to radiation, which should not hold too much significance, if adequate radiation shielding is provided and the exposure period is reduced.

As a follow-up to the medical examination, a training period will be required. The first space tourist, Dennis Tito, spent 6 months in training [26]. Training sessions will be time-consuming and demanding, yet still not an obstacle to those that truly wish to embark on this journey. Modules should naturally be separated into theory and practice. Theoretical modules will likely contain courses about the space environment, emergency procedures and orientation in a rotating environment. Practical modules may be concerned with maintaining physical condition in space, centrifuge simulations, 0 g maneuvers, water landing simulations and becoming familiar with the effects of Coriolis forces and accelerations in a rotating habitat [20][26]. Hopefully, training periods will be reduced as a result of the development of space tourism.

Space tourists or staff members will have to spend at least 10 days in quarantine before their journey; viruses might be very dangerous if released in a confined space such as a settlement. Trips to space will also come with periods of accommodation, both for tourists and for staff members.

5.7. Market research

In early development, space tourism is an business domain that is certainly not easy to market. On the one hand, this is likely caused by lack of awareness, which leads to lack of interest. The general public perceives the dangers of space travel and tourism in an exaggerated manner; for many, a trip to space is a distant and vague concept. While it is undoubtedly clear that such risks do exist, it is also important to acknowledge that space tourism may not be as out of the ordinary and hazardous as many might think. On the other hand, extremely high prices in the beginning of space tourism create a rather small target market. This is inevitable, given the enormous costs, and will assuredly become a problem of the past once space technology reaches upper stages of development and prices for tickets begin to drop.

One aspect is clear, however; works of literature, art and movies/TV shows, even cartoons, have often portrayed lush and astonishing surroundings to accompany the idea of space tourism or space habitation. It is undeniable that these are tempting to many. A luxurious future that represents a devoted image of perfection and the peak of evolution, with a much higher standard of living, is an ideal almost everyone wishes to be part of. However, opinions change when reality settles in; Cicada's aim is to help change this reality, to provide high comfort standards for space tourism. The world will learn to travel to outer space, as it learned to travel across lands and across the oceans and even far above.

Knowledge is born from the unknown. Since the beginning of humankind, exploration has always had a price. Space exploration is no different. And, just like all we have done until modern times, it comes with a great reward.

5.7.1. The target market

The Futron/Zogby Survey

Originally conducted in 2002 and renewed in 2006, the Futron/Zogby Survey was realized by Futron Corporation and consisted of interviewing 450 participants over the phone, in order to determine possible characteristics of the target market for orbital and suborbital flights. Aside from criteria such as physical condition, each interviewee needed to have a net-worth in the order of millions. Around 18% of them expressed interest in orbital flight, out of which 22% would pay for a ticket with a price ranging from $20 million to $25 million [26]; the average age for this portion of respondents was 55. Zilliotto [27] predicts that, by 2021, there will be around 13.000 potential customers with net-worths higher than $600 million.

The Adventurers' Survey of Public Space Travel [28]

Incredible Adventures conducted a survey in 2006, using their website as a method to reach potential respondents; since not all of those who completed the survey were part of a certain target market, some aspects regarding the survey might be inaccurate. Despite that, the 998 responses (out of which 14% came from millionaires) were still able to somehow convey how the general population might feel about orbital and suborbital space travel. Since Cicada is more strongly related to orbital flights than suborbital ones, we will mostly refer to those portions of the survey concerned with orbital flights (and sometimes even space hotels; note that the survey refers to 0 g hotels, where there is no artificial gravity). When asked about the time period they are willing to spend in training before their trip (which would include either an orbital flight and a stop at a space hotel or just an orbital flight), 51% of respondents indicated a 3-month session as an upper limit, whereas the other 49% agreed to take part in a training session of 6 months or more. In regard to the time spent in orbit, 70% of respondents suggested they would be satisfied with 2 weeks or less; the others opted for 1 month and longer. As far as a stop at a space hotel is concerned, 79% indicated that, for them, such a stop would not be necessary; 29% of the remaining ones would be willing to pay an additional 10% for such a stay, while 15% would even go as far up as 50%. For a ticket to a lottery that offers the winner a $10-milion trip to the orbit, with a duration of 2 weeks, 9% would go as far as $1000, while the majority, 52%, would pay $10 or less. 83% of respondents agreed that an orbital flight should not exceed the price of $5 million; only 8% were willing to pay $20 million and 10% were willing to pay $10 million; it is expected that the number of potential customers will increase once orbital flight and habitats in LEO reach an upper stage of development and prices decrease. It is noteworthy that the majority of respondents held safety issues in high regard and wanted to be assured that orbital/suborbital flights are completely secure before starting their trip.

The EADS Astrium survey

In collaboration with Ipsos SA, EADS Astrium conducted market research in order to determine the target market for suborbital flights. The research was divided into two parts: a qualitative part, which consisted of 12 face to face interviews with potential wealthy customers, and a quantitative part, which analyzed the opinions of 1850 respondents with high net worths through an online survey. Though the study was concerned with suborbital flight, the insight it provides is still somewhat relevant to orbital travel as well, to a certain degree. Overall results show surprising levels of interest and willingness to purchase tickets for a suborbital flight; many interviewees and online respondents were enthusiastic to embark on such an extravagant journey, which gave them a sense of pride, and were also looking forward to meeting other passengers and taking pictures of the wonderful view to commemorate their trip.

As discussed in [29] and [26], respondents for the EADS Astrium survey could be separated into 5 categories, which are relevant to the characterization of the target market:

- **the enthusiastic elite,** representative for individuals with considerably high net-worths that are most eager to take part in a suborbital flight;
- **the blasé group,** which includes individuals with similar net-worths, yet a more apathetic mentality towards suborbital flights;
- **the adventurers group,** passionate about suborbital tourism, though not as wealthy as those that are part of the enthusiastic elite;
- **the risk averse group,** willing to purchase a ticket only if they have great certainty that the flight is safe;
- **the low end high-net individuals,** that showed no interest in suborbital tourism.

How small of a free-space settlement can people be happy living in? [30]

In 2017, Al Globus and Tom Marotta conducted a survey to reflect how the general population might feel about being permanent residents of a small space settlement (more specifically, Kalpana Two, with a diameter of 100 meters); despite the fact that respondents cannot be categorized as part of a determined target market, the results of the survey are still relevant to the construction of our hotel and park. Cicada may not be a space settlement meant to accommodate permanent residents, but it is, nevertheless, a small habitat, with a maximum radius of 90 meters, which will rely on human activity. Out of those that completed the survey, around 78% were older than 25 and almost 95% described themselves as space enthusiasts. Only a little over 3% of the yearly incomes of the respondents were higher than $250.000. Around 8% of respondents stated that they would not be willing to become inhabitants of Kalpana Two; other 16% considered it, but needed more assurance, and the remaining respondents, representing the majority, showed high levels of enthusiasm at the idea of inhabiting such a settlement. To afford living in such conditions, 30% would sacrifice 25% of their wealth; around 60% would be willing to give more than 50% of their wealth, even going as far as their entire income, while the others were completely against paying for it. When asked about the population on the settlement, the option that was mostly selected (by 36% of respondents) was 1 to 500; in total, 80% were satisfied with living in a settlement with a population of under 5000 inhabitants. 38% declared that a space settlement the size of a campus is acceptable for a comfortable lifestyle; 31% would be satisfied with a settlement smaller than a cruise ship, whereas others would wish for a place to live that is bigger than a suburban town. Open ended questions show that respondents are enthusiastic about living in a close-knit community that is different from the ones on Earth, about the many attractions of space (such as the view or the micro-gravity conditions), about their freedom to control their lifestyle and about actively participating in the intellectual development of the human race, along with people that share their way of thinking. These types of questions also show that many respondents are concerned with safety risks (like hazards and high radiation levels) and homesickness, consider the habitat too small and lacking in variety and also believe that the prices of living there might be too high. It is noteworthy to acknowledge that many responses would change in the case of a hotel in space; population, size and homesickness might not be as relevant, however, even higher prices, especially for transport, but also for accommodation, might act as a counterbalance.

In early stages development, we are inclined to believe that the demand for orbital space tourism will be inelastic. An increase in price will likely not cause a proportional decrease in the quantity demanded, because those who can afford and are willing to pay such an enormous amount of money will not dispirited by a 20% increase in prices, especially if competition on the market will be almost inexistent. However, during growth and maturity, the demand will be elastic, though in a different sense. A great reduction in prices will surely increase the target market and thus the quantity demanded.

Conclusions

Certainly, in the beginning of space tourism, the target market will consist of extremely wealthy individuals. What can be concluded from all the surveys is that space tourism is perceived as a great enhancement to the evolution of humanity and is intriguing and fascinating to many; however, not all of these enthusiasts are able to afford such a trip, at least not for the time being. Most of the surveys were mainly concerned with orbital/suborbital flights; in the case of a space hotel, it can be assuredly stated that a great majority of those who are willing to pay for and experience an orbital flight would also be interested in a stay at a hotel, for which the price could be considered an irrelevant addition to the enormous transport cost (especially if artificial gravity is provided). What is also noticeable is an expected recurring concern for safety, which arises from the risks associated with our current means of traveling to space and inhabiting it; many regard absolute safety as currently unrealistic and are willing to wait until this is proven otherwise to even consider embarking on a journey to space. Fortunately, one prediction for the future is that technological development and more experience in this field of industry will cause a significant drop in prices and will provide much safer conditions for trips to space, therefore further enlarging the size of the target market; one of Cicada's main purposes is to act as a starting point and lead us towards a future of that kind and, hopefully, far beyond.

5.7.2. Product life cycle

It is difficult to accurately predict the stages of the life cycle of a product that has never been on the market before, or at least not on a large scale. Though there are many hints which indicate how the target market may perceive orbital space tourism, it is nevertheless a mere assumption to try and give details about consumer behavior in regard to our product in early and advanced stages of development.

Introduction, growth and maturity

As discussed previously, the debut of space tourism will likely be supported by the *"enthusiastic elite"* [29], mostly already aware of the parameters which characterize such a journey. The introduction of a product on the market begins to advance towards growth as a result of market acceptance. This will be achieved through public awareness and publicity campaigns, perhaps documenting the journeys of the first space tourists, but also through a small reduction in price and increase in safety. We predict that growth will be influenced by technological progress, which will hold relevance in regard to a more significant reduction in prices and the development of much safer launch mechanisms and technologies that ensure life support on a habitat in outer space. More categories of consumers will gradually begin to enter the target market: *"the adventurers group"*, *"the risk adverse group"* and part of *"the blasé group"*. Maturity will be reached when space elevators and other more accessible means of transportation will be developed; prices will maintain consistency and the demand will be continuous, going on for a long period of time. Other orbital space settlements, among which there will also be space hotels, will begin to appear in LEO and finally space tourism will become accessible to the general population, as the size of the target market reaches its peak.

Decline or revitalization

Decline will begin to settle in as orbital space tourism becomes an everyday occurrence and competition becomes a threat. However, space exploration offers endless possibilities for revitalization. There will be attractive opportunities for hotels on the Moon, on Mars and for orbital hotels outside LEO. Companies will surely even begin to branch towards asteroid, lunar and Martian mining; exploiting space resources will become an industry with a tremendous potential for financial gain and, if handled correctly, for the benefit of the economy on Earth. Nevertheless, revitalizing our products is not only a matter of evading LEO; many innovative market practices and ideas can be applied in order for us become an unique touristic destination in the eyes of the target market.

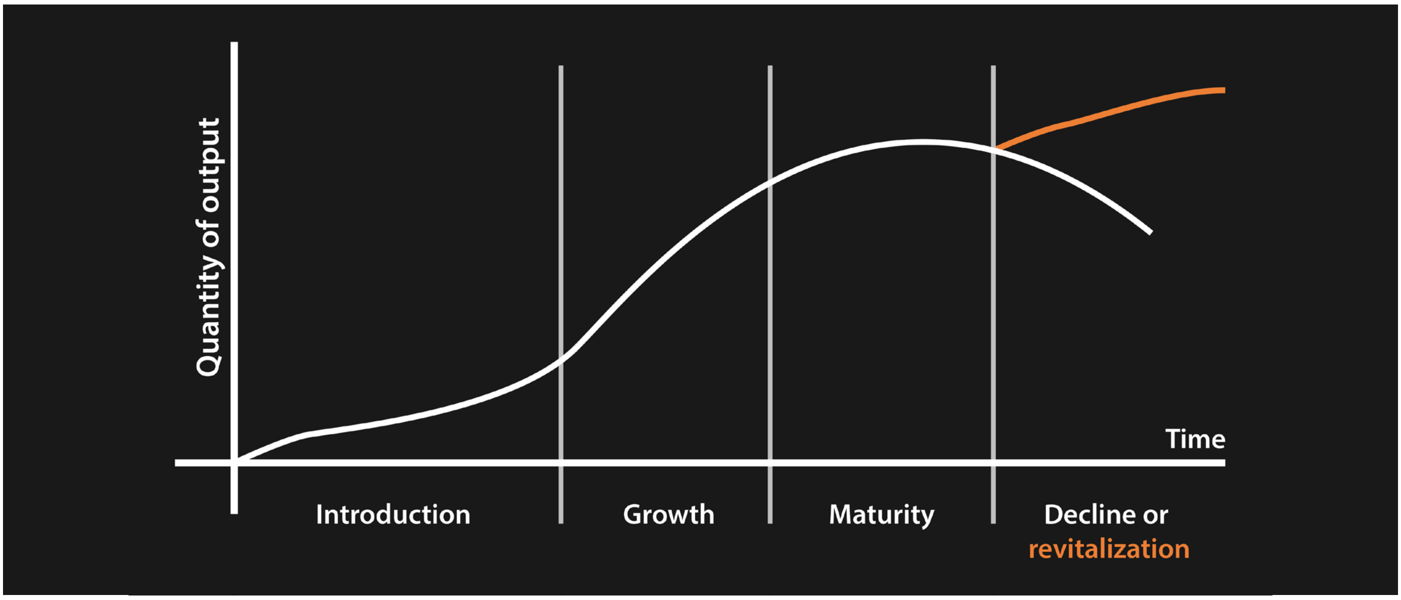


Figure 5.1. (graphic representation of the product life cycle)

What is clear, however, is that our journey to space will become the next major step in the evolution of our species. The future surely holds unimaginable wonders and we cannot even begin to dream of its magnificence. If space tourism conquers outer space, humankind will only continue to lift its eyes up towards elevation.

5.8. Cicada's code of ethics

high moral standards for a better future, for the benefit of humankind

how we elevate the meaning of evolution

Cicada stands tall as a gracious symbol of humankind and its journey in outer space; a symbol which conveys its bravery, ambition, ingenuity, perseverance and unity

Brief introduction

30 years ago, in 2040, when the first spaceship to ever bring 25 tourists in the Low Earth Orbit landed on Cicada's docking port, the course of humanity was changed tremendously. By opening the gates towards space exploration, Cicada has revolutionized the image of the earthly world. Humankind's first steps in discovering the mysteries of the Universe have reportedly brought about innovative treatments for formerly incurable diseases, a considerable reduction in pollution, poverty and violence, ever-growing opportunities for employment, the establishment of the first extraterrestrial colony and university, accessible space travel for the general population, numerous alternatives to the Earth's limited resources and an inspiring vision in regard to our cultural values.

Cicada is now a worldwide known brand with a total of two locations in the Low Earth Orbit. The secret to our success lies in our core beliefs: Integrity, Passion, Beauty, Responsibility, Humbleness and Freedom. We treat these values with nothing but the deepest respect and trust them to guide us towards the fulfillment of our purpose: doing everything in our power to cultivate contentment and prosperity for the whole of humanity and to contribute to the realization of a more promising future.

What we believe in

Integrity

we act with honesty and respect, continuously preserving the moral values of our community; together, we create an environment that protects peace, love and harmony

Passion

we dedicate ourselves to our purpose and strive to achieve perfection

Beauty

we have a profound appreciation for art and culture and wish to encourage their evolution in outer space

Responsibility

we act in the benefit of the community and respect our duties as members of it

Humbleness

we acknowledge criticism and value its significance; we constantly seek to improve the quality of our services and create a better future for humanity

Freedom

we maintain a secure environment that protects the comfort and prosperity of our community in outer space

*this code of ethics implies a different time-line; we consider that it was published in 2070 and represents a renowned version of our code of ethics

a positive impact on the

environment

We are actively involved in environmental protection campaigns that seek to rid the Low Earth Orbit of impurities, which may result in detrimental consequences for space habitats and the Earth as well. We avoid the release of orbital debris, by instructing our employees to preserve the natural values of the space environment. We also make it our priority to invest in environmental control through our collaborations with companies whose specializations focus on designing devices that collect and remove orbital waste from outer space.

Contrary to general expectations, the quantity of orbital waste in the Low Earth Orbit has been drastically reduced since Cicada opened the gates towards space exploration. Many private brands that branched towards space-related activities eagerly adopted this approach.

Once again, we chose to believe in the our ability to make a change, for a brighter future for humanity, to believe that the true essence of humankind resides in good intentions... And our beliefs have triumphed!

high moral standards for a better future, for the benefit of our

CUSTOMERS

Integrity

We treat our customers with respect, kindness and patience, regardless of their background. We create a community that is free of discrimination and promotes cultural variety.

Passion

We are passionate about our work. We offer services and products of the highest quality, in order to meet or even exceed the expectations of our customers.

Beauty

Our business tries to encourage customers to rely on artistic expression and to be open about their feelings. We wish for tourists to contribute to the development of space culture.

Responsibility

We keep our promises and hold the trust of our customers in high regard. We are reliable, because we acknowledge our duties and do everything in our power to fulfill them.

Humbleness

We accept opinions that differ from ours. We are very grateful for our customers' suggestions and fully approve of the fact that constructive criticism is the key to improvement.

Freedom

We treat safety with the utmost care. Our goal is to create an environment that ensures high comfort standards, by placing a great deal of emphasis on security and well-being.

We pride ourselves in our straightforwardness in regard to our relationship with our customers. We sincerely value their commitment and trust and wish for nothing more than to repay it with genuineness and transparency. Our top priority is to ensure the safety and well-being of each one of those that choose to place their invaluable faith in our services.
We acknowledge the undeniable significance of honest market practices and are proud to state that we fully meet the standards of the ideal world we promote in our publicity campaigns. We devote ourselves to the truth that gives life in space such a brilliant uniqueness and would never do anything that would betray its virtuous purity. Our greatest and most vivid aspiration is to allow the entire world to experience the wonders of space tourism.
Another top priority of our company is to provide a perfectly safe touristic environment, through which the whole of humanity can prosper and joyfully experience the refined peculiarity and elegance of life outside earthly boundaries. Through our services, we seek to embody the image of an immaculate hotel and amusement park, which radiate a refreshing, natural colorfulness, brightening up the hearts of our tourists.

high moral standards for a better future, for the benefit of our

EMPLOYEES

Integrity

The diversity of opinions and cultures is a truly precious asset to our company. We respect the contribution of our colleagues and try to see the world from different perspectives.

Responsibility

We always act responsibly in our relationships with our colleagues. We are true to our word and analyze the impact each of our decisions might have on those around us.

Passion

Our services and products are a reflection of our soul. We create a amicable work environment which seeks to cultivate and to encourage passionate involvement.

Humbleness

We are never hesitant to admit our mistakes and appreciate the advice of our co-workers. We see this as a way towards self growth and, consequently, the growth of our company.

Beauty

We maintain the image of a workplace in which people can thrive. We are beautiful people, because we value empathy and always act in the benefit of our colleagues.

Freedom

We understand the meaning of freedom. We are all free to make our own choices, as long as they do not negatively affect those around us. The safety of our community is invaluable.

The fact that our core beliefs dictate our decisions is what makes this working environment the embodiment of excellence. As employees of Cicada, we rely on mutual trust to guide us along the right path. Collaboration between colleagues ensures the fluidity of our progress and constitutes the basis of our success.

The presence of diversity in the dynamics of our workplace is a great virtue to our company. To us, variety is delightful and essential. The authenticity, genuineness and quality of our brand are the merits of our employees. Our people are all admirable for their diverse backgrounds and ways of thinking, which help build the pillars of space culture.

Our accountability for our actions and our unequaled, precise and untainted judgment preserve the safety of our fellow co-workers and thus that of the entire community. Our sacred oath is to always act as we are instructed and never to do anything that would put those around us in harm's way.

It is our ideal to be reliable and to always offer our support and protection. We believe in understanding and selflessness, when that is the right decision to make, for the benefit of those around us.

high moral standards for a better future, for the benefit of our

INVESTORS

We are profoundly grateful to those that continuously choose to see the potential of our business and support its development. We hold our promises and acknowledge the significance of transparent investor relations, whose strength comes as a result of mutual trust. Our policy is to conduct business in an ethical manner and to live up to our reputation. We always rise up to a challenge and are confident in our ability to meet or exceeed the expectations of our investors.

Finally,

we believe in

high moral standards for a better future, for the benefit of our

COMMUNITY

Our code of ethics is meant as a starting point to building the pillars of a morally ideal community in outer space. By honoring this code, we offer humanity the opportunity to create its own elevated future outside earthly boundaries, to change the world for the better. We regard morality as the essence of evolution and prosperity. A community that manages to rid itself of the presence of evil and unrighteousness is a community that can thrive.

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I praise evolution and worship the warm, comforting light of creation. I do not believe in endings of any kind. All I see is the eternal world which lies before my eyes.