# Mutopia


DESIGN TEAM: Penn State Engineering, NYU-Poly Social & Behavioral, and Georgia Tech Center for Biologically Inspired Design

CONCEPT: The proposed Mutopia Village involves a full scale community with a built out capacity of 500 people in permanent habitation on a moon base centered around artificial gravity moontrifuges in a covered moon crater valley, with self-sufficiency in power from solar windmills, and high efficiency food, water, and waste recycling systems. The research will address habitability issues on multiple levels in order to assure productivity and performance; comfort and satisfaction; and physical and mental health of the villagers. There is abundant evidence, largely from earth-based environments, that attest to the importance and power of these issues as they affect perception, behavior, and emotional well being.

## I. Engineering Design, Penn State

Gravity is a most significant issue for Mutopians. The Moon has one sixth the gravity of earth. Current research on health risks living in no gravity for months (Russian Space Station) indicates severe irreversible health problems. Given the uncertainties of humans living for long periods of time on the moon, a requirement will be that earth gravity be available through artificial means for some or all of the time in the village. Artificial gravity can be obtained by rotating a habitat to produce sufficient centripetal forces. NASA sponsored research experiments simulating a rotating habitat established that a speed of 10 rpm caused Coriolis sickness in most humans; while at a speed of 4 rpm some will have motion sickness but will adapt after a few days. Using the centripetal acceleration produced by rotation equation, and given that the Moon will supply 17% of the gravity at a rotational speed of 2 PPM, the diameter of the centrifuge would need to be approximately one-hundred meters (15). It would be a very much enlarged Gravitron amusement park ride. This Moontrifuge will be a centerpiece of Mutopia

STRUCTURE: Building the structures at least partially underground will provide protection against radiation, solar winds and extreme temperature differentials. A major concern during construction and the life-span of structures are moon dust and moonquakes. The lunar surface has a layer of fine particles that consist of pulverized regolith. The dust is jagged and electrically charged, and clings to any type of material. Also, shallow quakes on the moon have the potential to cause great damage. Moonquakes, which occur very close to the moon's surface register up to a 5.5 on the Richter scale and last up to ten minutes long. Seismic design and the use of appropriate building materials will limit the negative effects of potentially destructive moonquakes. Stabilized permanent magnet suspension (SPM) is the magnetic levitation technology for the moontrifuge. SPM suspension uses opposing sets of rare earth magnets, typically neodymium alloys placed in Halbach array. These magnets, within the track and on board the vehicle create a permanent, passive levitation. Energy would be needed to move the centrifuge,, but the absence of current in this type of maglev technology eliminates electromagnetic drag in the SPM system. Because the SPM system requires no energy to levitate the moontrifuge or overcome electromagnetic or air drag forces, this would be a very efficient way to operate the moontrifuges. Problematic conditions when facing excavation of the lunar surface are: porous regolith, compacted dry regolith, regolith containing water ice, and rock. By using vibratory mechanical equipment to excavate the lunar surface has greatly decreased the efforts needed to remove regolith. The materials on the lunar surface are very conducive to producing a brick, which is useful in the structure and protection of the community, against asteroids and radiation. Moonbricks will also be useful as an insulator to maintain a survivable temperature or as an outer shell of the community. The moontrifuge can be constructed from materials extracted from the lunar regolith. Aluminum oxide (15 wt. %) and iron oxide (10.2 wt. %) are constituents in the regolith.

ENERGY: Harnessing the Sun's solar wind as a power source by a solar windmill is a novel concept to be researched and expanded as a viable option. The process of harvesting solar wind as a power source will be similar to wind turbines on Earth, but propelled by the bombardment of ions in the solar wind, or an absorbing collector shield similar to solar panels. Also, biological fuel cells will produce a constant source of energy.Helium-3 fusion is a possibility in powering Mutopia, as it is a great source of renewable energy. Helium-3 is an abundant element on the lunar surface, located in the mature mare regolith. There is also a high content of titanium being exposed to high solar winds. Helium-3 is available on approximately 75% of the lunar surface; the remaining 25% is the near side of the moon and it is magnetically shielded from Earth (20). The helium-3 fusion also has the potential to power spacecrafts. Since helium-3 is non radioactive; therefore, the spacecrafts will not require as much radioactive shielding, leaving the spacecraft much lighter (22). Fusion of helium 3 is non radioactive unlike other elements that are used in fusion. It is clean nuclear energy; unlike current fission that uses hydrogen but produces problematic radioactive waste. The gases released during the mining of helium 3 will have no adverse effects to the Moon as it has no atmosphere (21).

LIFE SUPPORT: Evolving from the closed water cycle systems currently used in space operations, such as the International Space Station (16), the lunar water will be an entirely encompassing life system, which finds inspiration in the earth's water cycle. To compensate for the lack of substantial atmosphere and lack of abundant resources, a closed system is required to lay the role of keeping all valuable water within the system from being lost. The closed water orbit will incorporate the latest technology, such as microbial fuel cells, microfiltration and reverse osmosis to purify the incoming waste streams (17). In addition, just as is created on earth, the water orbit will incorporate plant and soil systems to aid in filtration and processing, but also providing valuable plant and agricultural resources. Any needed make-up water will be obtained from the planetary ice sources, which contain an estimated mass of 6.6 billion tons of water (18). Water for the system will be recovered from the polar ice field. In addition, essential minerals such as nitrogen can be recovered by processing of the Moon's regolith.Plant growth and use will be invaluable to the inhabitants of Mutopia. Plants will be utilized in waste water treatment, by means of phytoremediation (19); a food source, mainly grown by hydroponics; an oxygen garden, to naturally enhance the level of natural air and to enhance the living environment, all of which will make the inhabitants feel "at home" on the moon. The settlement will incorporate the creation of artificial gravity, which will be critical due to biological plant's ability to sense gravity through gravitrophism. Efficient and sustainable use of water, along with other life resources, will be taken to a level not imagined on earth. With all resources being limited and the desire to create zero waste, everything will be reused and recycled to its fullest potential. In order to achieve 100% use of the life resources, a complete life cycle plan will be developed that will refine, recycle and reuse all water and wastewater streams. Other innovative community-based living arrangements such as a living buffet "Garden of Luna" will be explored to use centralized life systems to maintain simplicity.

## II. Behavioral and Social Issues, NYU-Poly

A self-sufficient habitat of this scale needs to address habitability issues on multiple levels in order to assure productivity and performance; comfort and satisfaction; and physical and mental health. There is abundant evidence, largely from earth-based environments, that attest to the importance and power of these issues as they affect perception, behavior and emotional response.

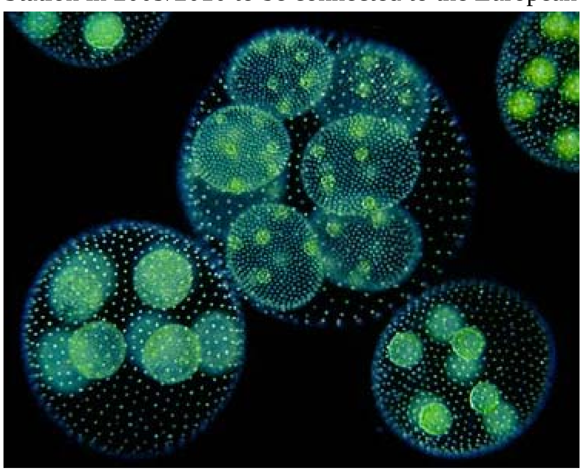
For a habitat of this size these issues will need to be considered on multiple levels. At the macro-scale lay concerns that fall largely into the domain of community design, including the variety and kinds of settings that exist in the habitat, social and designed permeability of borders affecting access and access control, overlap or separation of function, etc. For instance, how will space be organized with respect to industrial, governmental, legal, policing (military?), scientific, commercial, recreational, educational, and residential functions? For a permanent habitat, many or all of these may be necessary. Critical considerations include spatial design – the social and physical organization of space - desired and available for these activities. Cultural aspects include the type of society: totally heterogeneous with an eclectic blend of habitat styles and various cultures, local homogeneous communities with standardized living quarters and mixes of each.

At a micro-level, attention must be paid to interior design as it affects individual, small group and larger group space needs and interactions. Issues include the kinds of space and access control needed for adequate privacy for social, personal and hygiene functions, spaces for professional and social interactions, ability to personalize and territorialize space for greater sense of control and comfort. The number and kinds of spaces available affects the degree of spatial and social variety experienced and hence the ability to avoid monotony and boredom. Other critical needs include the quality of natural and artificial lighting, rhythms of light and dark cycles, and the ability to experience simulations of earth-quality natural settings. Nature scenes have been shown to be relaxing, restorative and important for long term comfort and functioning. Lastly, selection of those who will occupy the habitat, level of cultural diversity, nature of the "local" culture and the organizational structure (military/authoritarian or civilian/democratic) may be critical to the long term success of such a habitat.

## III. Biologically Inspired Design, Georgia Tech

Biologically-inspired design (BID) is an emerging field with considerable potential to provide innovative solutions to a variety of problems in human design and engineering (3,4,6.7,8,11,12,13). Biologically-inspired design describes the design technique of looking to biological adaptations to generate new solutions to technical challenges. Evolutionary processes represent millions of years of design concept testing, in which solutions are reached through random genetic mutation and survive only if they are successful. Since many biological adaptations are fundamentally different from human approaches to problems, BID presents rich opportunities for innovative design. By treating nature as a respected mentor, a greater appreciation for the information found in natural systems will promote conservation and sustainability efforts to preserve biodiversity.

Bio-inspired design has been used to enhance space travel in several ways (1). Laminated metals or polymers organized in honeycomb patterns that are used in spacecraft panels provide the benefits of high structural strength with low weight also with the benefit of p crack propagation. Thin wires made of Shape Memory Alloys, artificial muscles, are used in unlocking mechanisms and many other applications. Bio-inspired optimization algorithms (genetic algorithm, particle swarm optimization, ant colony optimization) are currently being used to perform mission analyses and for trajectory design. Large deployable mechanisms such as solar cells, beams, or antenna arrays favor biological folding and deployment mechanisms because of their high packing efficiency. Lobster-ISS, an all-sky X-ray monitor telescope inspired by lobster eye optics, is set to go to the International Space Station in 2009/2010 to be connected to the European Space Agency's Columbus module.



There are many components of the moontrifuge where BID can be utilized to find innovative solutions. The following examples illustrate how inspiration from nature may guide the design of the lunar outpost. In nature there are several organisms that use spherical shapes for convenience of motion and to maximize access to resources. *Volvox* (Figure), a type of alga, form themselves into spherical colonies. The individual algae are connected using cytoplasm and in fact they develop front and rear sides with the front having more developed eyespots. Fire ants form themselves into balls allowing the ants to travel downstream to form a new colony without having any members of their colony drown. Based on the efficiency of these shapes we propose a bio-inspired spherical shape for the moontrifuge. The central rings of the sphere would be used for human habitation due to the amount of gravity that humans need to experience each day. The remaining area would be used for growing plants hydroponically, storage spaces, or other uses. To economize on space, a honeycomb multi-unit system could be utilized.

The folded structure of leaves in bud has been used as a means to transport solar panels in a compact form to 'blossom' when in place in space and provide the large surface area needed to capture the sun's energy. The moth eye is designed to capture light by its nanostructure. Design of the solar collectors utilizing the anti reflective surface of a moth eye for inspiration can improve the efficiency of energy capture (10). Many marine birds, like flamingos, use a counter current exchange system (14) in their legs and feet to enable them to warm the blood coming back into the body and cool the blood entering the portion of the leg that is still in the water. This is a possibility for a bio-inspired heating/cooling system for the moontrifuges and other structures on the moon. Abalone are shelled gastropods that live on rocky shores, battered by crashing waves. Analyses of their shell structure shows offset tiles to prevent crack propagation, transmitting some of the force of impact along the intervening layers (10). The protein in the intervening layer not only provides flexibility but also can be replaced for self healing. Lunar bricks with flexible mortar could strengthen lunar structures against moonquakes. Animals tunnel underground to protect themselves from physical and biological threats. Similarly on the moon it is necessary to protect colonists from radiation, heat, cold, asteroids, and lunar soil while they move from one moontrifuge to another so utilizing underground tunnels similar to those used by ants, moles, etc. is one possible bio-inspired solution. The lunar environment poses significant challenges to sustained human life, where high performance, the usual criterion for earthly products, is not what will attract human habitation. Assurance of robustness (another trait of biological systems) is of utmost importance. A robust settlement maintains the minimal human support in the event of a catastrophe. For the next 10 weeks, our team (Penn State, Georgia Tech, Polytech Institute of NYU) will work together to design the structures and plan the processes needed for sustainable human life in Mutopia.

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