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SELENIA: A HABITABILITY STUDY FOR THE DEVELOPMENT OF A THIRD GENERATION LUNAR BASE

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INTRODUCTION

When Apollo astronauts landed on the Moon the first generation of lunar bases was established. They consisted essentially of a lunar module and related hardware capable of housing two astronauts for not more than several days.

Second generation lunar bases are being developed, and further infrastructure, such as space station, orbital transfer, and reusable lander vehicles will be necessary, as prolonged stay on the Moon is required for exploration, research, and construction for the establishment of a permanent human settlement there. Human life in these habitats could be sustained for months, dependent on a continual flow of life-support supplies from Earth.

Third-generation lunar bases will come into being as self-sufficiency of human settlements becomes feasible. Regeneration of water, oxygen production, and development of indigenous construction materials from lunar resources will be necessary. Greenhouses will grow food supplies in engineered biospheres. Assured protection from solar flares and cosmic radiation must be provided, as well as provision for survival under meteor showers, or the threat of meteorite impact. All these seem to be possible within the second decade of the next century. Thus, the builders of Selenia, the first of the third-generation lunar bases are born today.

During the last two years students from the School of Architecture of the University of Puerto Rico have studied the problems that relate to habitability for prolonged stay in extraterrestrial space. An orbital personnel transport to Mars developed originally by the Aerospace Engineering Department of the University of Michigan was investigated and habitability criteria for evaluation of human space habitats were proposed. An important finding from that study was that the necessary rotational diameter of the vessel has to be on the order of two kilometers to ensure comfort for humans under the artificial gravity conditions necessary to maintain physiological well being of passengers, beyond the level of mere survival.

A THIRD GENERATION LUNAR BASE

"Selenia" is derived from Selene, the name of the Greek goddess who personifies the Moon (Fig. 1). Our lunar settlement is named Selenia in recognition of the mythologic notion of the kind of experience to be encountered as humans actually populate Earth's closest neighbor, the Moon.

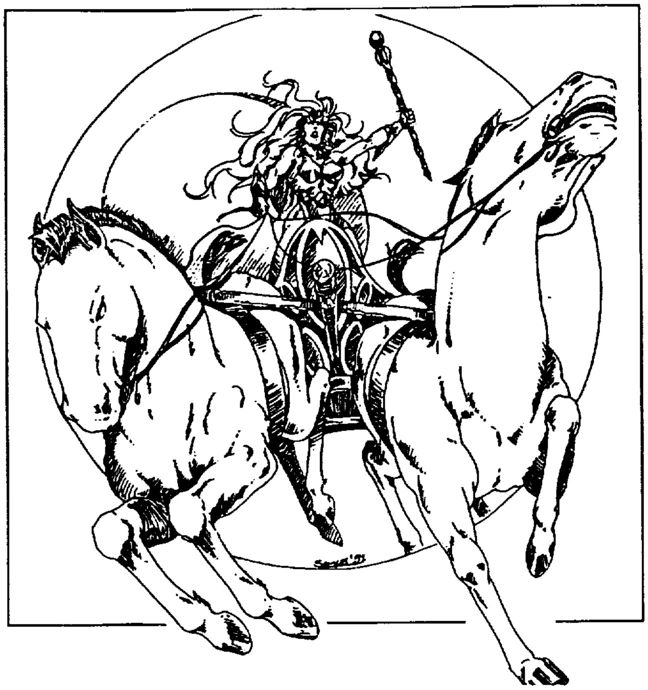

Fig. 1. Selenia, a Greek Goddess.

Selenia is a settlement of one hundred inhabitants working on lunar exploration, indigenous materials development for the sustenance of the settlement and for export, astronomical observation, and general research under reduced gravity conditions. Located at Lacus Veris on the Mare Orientale region,[1] its appearance is like a bullseye (Fig. 2) because of the presence of several large concentric crater rims at the very edge of the nearside of the Moon.

Selenia, a self-sufficient human settlement, will produce enough revenue to make it economically feasible by exporting products in addition to the production necessary for its own sustenance from lunar resources and recycling.

It consists of a 120-ft-diameter craterlet covered by a geodesic structure with tunnels to house underground personal quarters (Fig. 3). Three Social Nodes will be located at the juncture of the tunnels, each containing a lobby-lounge, a gym, a galley, a dining-conference-library area, an infirmary, a chapel, and a

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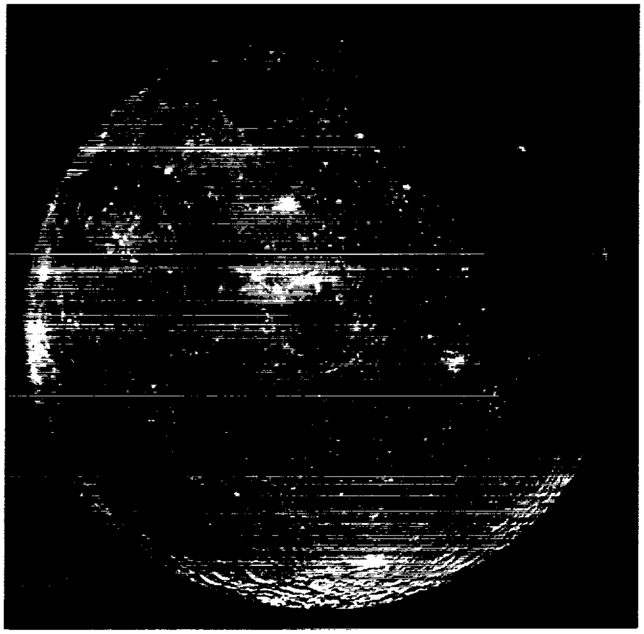

Fig. 2. NASA Photo 37327.

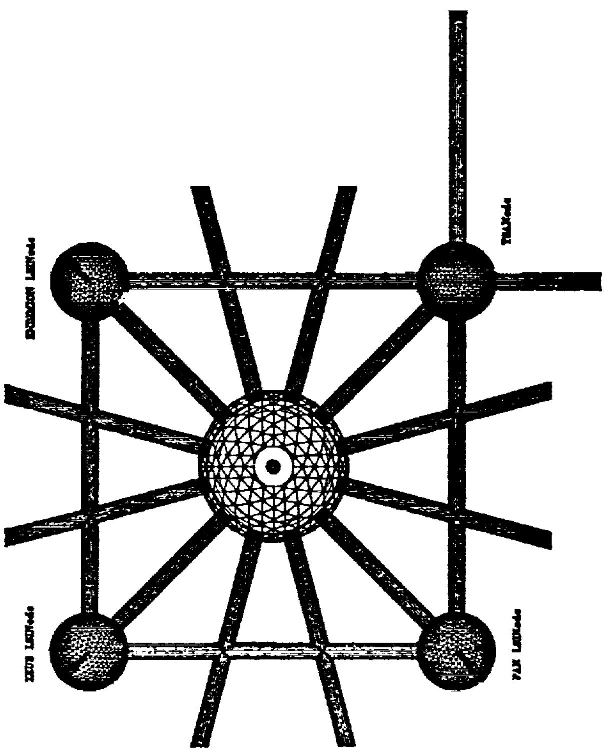

Fig. 3. Floor plan of Selenia.

surface-access igloo. A Transportation and Surface Access Node is located at the juncture of the surface-access tunnels, completing the square and housing equipment and parking spaces for pressurized surface transports. The northward surface access tunnel points toward the takeoff and landing facility two and a half km away, and the tunnel going east leads toward the energy field.

The heart of Selenia is the four-level craterlet (Fig. 4). The lower level houses a "lung" system for storage, regeneration, and odor control of the air supply. The second level is for water recycling and by-product extraction. The third level will hold the food production facility that requires protection from solar flare radiation. Above will be the food production facility that requires less protection, and over it, a park-like common, that will house communal activities and will provide facilities for recreation, lunar sports, and artistic performances. There will be a centralized elevator for access to all levels and the Observation Tower to monitor nearby surface operations and to enjoy the sights.

Anthropometrics for low-gravity lunar habitation were studied, and color schemes, illumination patterns, and interior decoration considered, aiming to fulfill the habitability criteria developed earlier for the NASA/USRA project[(2)].

HABITABILITY CONCEPT DEFINITION

Habitability, as defined earlier by University of Puerto Rico students could be summarized as "that state of equilibrium, which results from the interaction between components of the Individual-Architecture-Mission Complex; which allows a person to sustain psychological homeostasis, adequate performance, and acceptable social relationships."[(2)]

A diagram was developed to communicate the interdependence of the three parts of the complex (Fig. 5). Individual stress due to isolation, interpersonal stress due to confinement, and impersonal stress induced by a totally artificial or alien environment may cause a person to suffer psychological impairment, which may hinder the fulfillment of the mission or even the individual's motivation for survival in such an

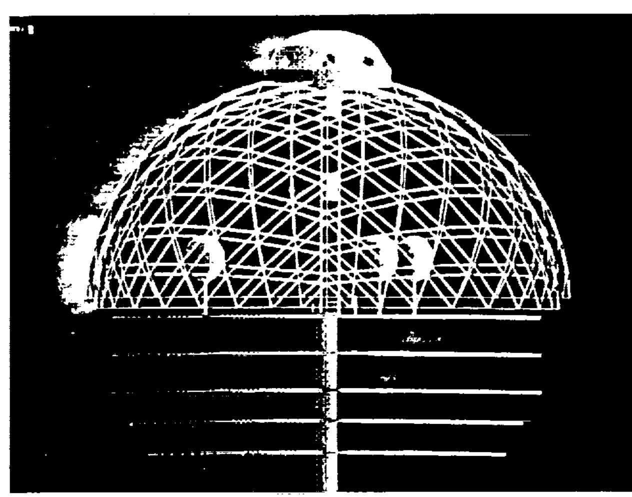

Fig. 4. Cross-Section of Main Craterlet Dome.

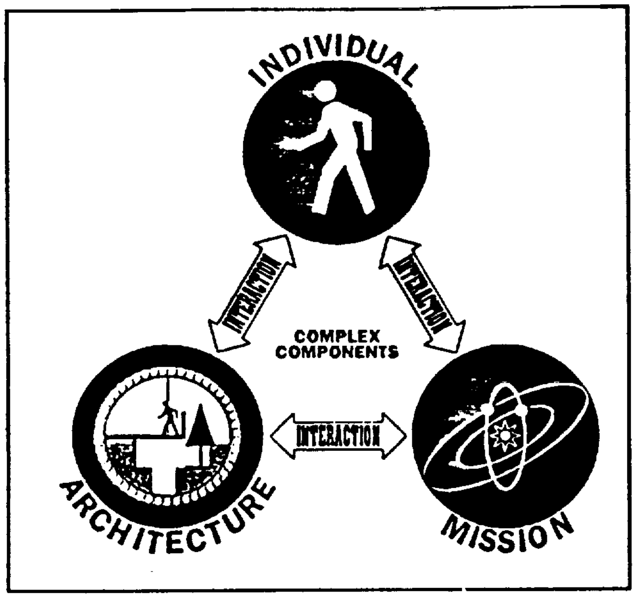

Fig. 5. Habitability Concept Diagram.

environment. The mission, together with the individual's values can provide the proper motivation and drive for striving to accomplish expected goals. But since psychology is shaped by physicality, it is the architecture that is the key to providing quality of life. Sights, motions, and sounds, as well as careful consideration of all sensory stimuli must be envisioned and provided for before we can design an appropriate environment for human inhabitants in extraterrestrial space.

ARCHITECTURAL DESIGN CONCEPT DEVELOPMENT

In the next century, we will be exploring farther in the Solar System. It will be more economical to base such operations on the Moon than on Earth, because of reduced gravity that will require less energy to assemble hardware and gather mineral resources. By that time the Moon could be providing fuel to power the Earth. Helium-3, which the solar wind has deposited in the lunar regolith over millennia, could be collected and transported to fusion plants on Earth. According to the NASA Lunar Helium-3 Fusion Power Workshop, of April 1988, one ton of helium-3 could meet the U.S. annual energy needs by the year 2015[3]. Thus the Moon could become the future substitute for the oil-producing countries of today as an energy supplier.

Infrastructure will include launch systems capable of transporting passengers to a space station, transferring to a lunar transportation node, or Orbital Transfer Vehicle, which will carry them on to lunar orbit; and a lunar landing craft capable of maneuvering from orbit into the landing and takeoff facility of the base. From such a port, several kilometers from the base, lunar rovers will provide transportation for people and cargo.

As the rover approaches Selenia, little will be seen apart from the lunar landscape, since most of its architectural features lie under the surface or will be covered under a 3′-6′ layer of bagged regolith for shielding (Fig. 6). Only the antennae, the surface access igloos, and the micrometeorite shields at the entrance would stand out. The rover will enter through tunnels carved out of the rock and built under the regolith to a Transportation and Surface Access Node.

Selenia will have to generate its own foodstuffs, recycle its own water and oxygen, and maintain its own ecological balance. Its main feature will be a domed craterlet that contains a Closed Environmental Life Support System (CELSS), which will house several biomes, biomachines, and agroindustrial features, protected to ensure survival of the colony. The rest of the social life of the lunar settlers will take place in their work, rest, and leisure places around the CELSS.

LACUS VERIS LOCATION

The site selected was one of a group recommended by the Solar System Exploration Division of the NASA Johnson Space Center in the northwest quadrant of Mare Orientale at 87.5°W, 13°S, a multiring crater structure. At the limb of the nearside of the Moon the Earth sinks below the horizon for eight Earth days for every lunar day, giving it some of the advantages of a farside site location. Many topographical and geological features can be observed within a relatively short distance on the lunar surface.

INHABITANT DESCRIPTION

The success of any mission depends to a great measure on the dynamic interaction among participants and Earth support. It is very important to analyze the characteristics of these people and ensure that the architectural design of the habitats take into account factors such as age, sex, physical conditioning, interests, and purpose to contribute positively to the development of good group dynamics.

There are three Leisure and Social Interaction Nodes called Endymion, Zeus, and Pan. Thirty-three inhabitants will be associated with each LSINode as a subcommunity, sharing leisure activities and meals, and will have coinciding work and rest schedules. The following classification or distribution is deemed optimal: 27% of the population will work in mining related endeavors (e. g., materials engineers, explorers, etc.); 21% will work on astronomical observations and research; 33% will work on exploitation or production of prime material for export to Earth and the Solar System; and 15% will work in administration of the base, physical, social, and health maintenance.

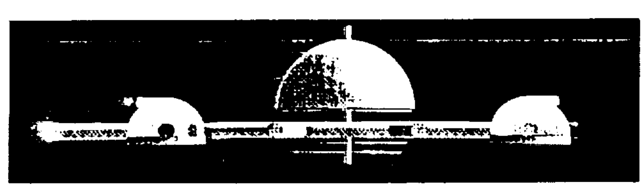

Fig. 6. A Cross-Section through Selenia.

LIFESTYLE ANALYSIS

An important aspect of the social, scientific, and economic development of the base is the lifestyle of its inhabitants. Living conditions should not be limited to mere survival, but should include quality and style within a Selenite society. Life in Selenia will follow a terrestrial calendar and will accommodate the human circadian cycle. Selenia will have a 365.25-day year, 24-hour day, with the difference that weekdays will be displaced one third, that is, eight hours difference among the different LSINode subcommunities. This will make possible a three-shift work schedule so that all operations may be uninterrupted. This schedule seeks to conform to the needs of the base dwellers, except that it makes it impossible to have total community reunions. To eliminate this drawback weekends could alter the schedules to allow for total community sharing. In Pan, the weekend takes one third of Saturday, and one third of Monday. In Endymion, two thirds of Monday, and in Zeus, two thirds of Saturday. All LSINode subcommunities will coincide one and a third day on part of Saturday and Sunday. Schedules for the weekend will allow for general assemblies, festivities, and sports tournaments. In addition this would be an appropriate time for departure of personnel and arrival of new dwellers with reception from the Selenite community.

The lunar month is a little over twenty-eight days. For convenience they have been grouped into four weeks of seven days each. There will be eight days in which the Earth will be just below the horizon. Therefore one of the weeks of the month and its corresponding weekend will be significantly different than others in Selenia. For optimum conditions at arrival and departure times, as well as the communal celebrations, position of Earth and Sun in relation to the base must be considered.

Of all these conditions (sunrise, Earth-rise and sunset) Earth-rise seems to be the most appropriate for arrival and departure of dwellers because of good communications and visibility. The days in which Earth falls below the horizon will be the most appropriate for astronomers to make observations that are not possible from Earth, seeking more answers and questions about our universe.

PERSONNEL CATEGORIES

Work will be generally classified in four categories.

Mining-exploration: These will be mostly engineers who will be studying the geology, topography and resources available on the Moon to pave the way for future extraction, resource utilization, and export. They will develop and test new construction techniques in a reduced gravity environment.

Astronomy-astronautics: Research and observations in the reduced gravity, airless, and slowly rotating environment of the Moon can accomplish feats impossible on Earth.

Lunar resource exploitation: This is the most important personnel category on the base from the commercial point of view. It will include engineers, physicists, chemists, biologists, and ecologists, who will be producing prime material for export to enhance quality of life on Earth, to sustain life on the Moon, and to further exploration of the Solar System. Many will be concentrated in the CELSS, and the biomes of Selenia's main craterlet for production of food, recycling of air and water, and essentials such as clothing and medicines. Some will be gathering energy-rich materials such as helium-3, searching for life-sustaining substances, such as trapped water and oxygen, and producing hardware in reduced gravity for base operations and export.

Maintenance-administration: These will be people employed in the LSINodes, CELSS, and TSANode, taking charge of kitchen-galley, medical center-infirmary, and general physical, social, and health maintenance. People involved in government will generally be from this group, but participatory democracy should incorporate others to represent all sectors and categories of dwellers.

GOVERNANCE

Life in Selenia will require a system of government to supply the needs of the people and to maintain an orderly way of conducting affairs. This special kind of community of gifted and educated individuals of different nationalities, would require that they agree to abide by an established system and to strive to work for its improvement in harmony with each other.

Participatory democracy is based on the people as the source of power delegated to elected authorities that make decisions on their behalf. In Selenia such decisions cannot be taken in complete isolation from Earth. A system should include an economy in which private enterprise, property, and work remuneration are agreed upon by the Selenite community. There should be a willingness to surrender individual freedoms and afford a greater degree of central control as long as this represents a guarantee for community and personal survival.

Individual dwellers would be classified in two groups: those who intend to go back to Earth and those who intend to remain permanently on the Moon. The first group might insist that their remuneration for work on the Moon be transferable back to Earth. The latter group could develop a different sense of remuneration and private property. Wealth will still be related directly to power and influence, but mutual help will be the norm to insure communal subsistence.

Property ownership on the Moon is a similar problem to that place in Antarctica, which lawyers refer to as *res nullius*(4). Is the Moon like Antarctica, a place whose ownership is to be claimed by those who have been there, or have settled there? Or should it belong to no one, and therefore to all humanity? Nations that have established Antarctic bases have agreed to terms of mutual cooperation, without resigning to their claims to sectors of the land. Could we envision this as the proper model for dealing with lunar property claims, or should we assume that because one nation got there first and planted its flag, the Moon is already part of that nation's territory? What will happen when another power contests such a claim and arrives to start exploiting lunar resources for its own benefit? Could an international body such as the U.N. or some other alliance of space-faring nations intervene to see that the interests of all humankind are upheld as potential conflicts arise? Can the U.S. act as a benevolent leader in this endeavor, incorporating the efforts of other nations to widen the base of human and material resources available?

Governance of Selenia must take into account these factors, and provide a system of checks and balances to prevent greedy, ambitious, corrupt, or dictatorial leadership from taking over.

SOCIAL WELFARE

It is unrealistic to assume that social ills such as crime will never reach our Selenite community. An effective judiciary system should be in place, capable of swift action in agreement with all national jurisdictions involved. Habicapsule confinement, movement monitoring using electronic devices, financial sanctions, and extradition to nation of origin, are some of the measures that could be used in Selenia to enforce the law.

Accidents and emergencies could happen, but preventive measures must be taken, since in some instances they could be devastating and could place survival in jeopardy. Epidemics, fire, air leaks, malfunction of life support systems, falls, injuries, or meteorite collisions could happen, and plans of action should be in place before the emergency occurs. The following are possible ways of dealing with these emergencies.

Shielding: A 3′-6′ bagged regolith shield will cover all vital structures of Selenia and would protect it from small meteorites and thermal, cosmic, and solar flare radiation. Compartmentalization, as in submarines, and redundancy of life support systems will increase possibilities of survival in case of impact by more massive bodies. For micrometeorite collision protection a thin metallic membrane would suffice over the sensitive part, since they tend to vaporize on contact (Fig. 7).

Evacuation and air lock systems: In case of fire, malfunction of life support systems, or atmospheric depressurization, sensing devices will automatically activate air lock systems to insure survival. They could be locally overridden to allow for the evacuation of individuals.

Medical emergencies: Each LSINode contains an infirmary, which serves as a medical center, where physicians and paramedics provide health services to each subcommunity, monitoring the effects of reduced gravity on the dwellers, prescribing pharmaceuticals and exercise regimes to maintain muscle tone and bone strength. In case of epidemics, selected habicapsules or even one of the LSINode infirmaries could be quarantined. In case of death, provision to return a body to loved ones on Earth should be made, but dwellers should be encouraged to donate their bodies for scientific and medical purposes.

NORMS AND VALUES

Cultural diversity among inhabitants of the base may bring also norm and value clashes. Behavior that may be perfectly acceptable in one society may be offensive in another. Religion, language, race, nationality, and other cultural traits of the individuals in the Selenite community will influence their norms and values.

Religion: Christians, Buddhists, Muslims, Jews, and non-believers could coexist in Selenia, as long as there be no fanatic proselytizing or coercion from one to the others. Spiritual welfare can add to the quality of life of the Selenite community and fulfillment of individuals. Thus, a chapel is provided in each LSINode for private meditation, as well as for group worship.

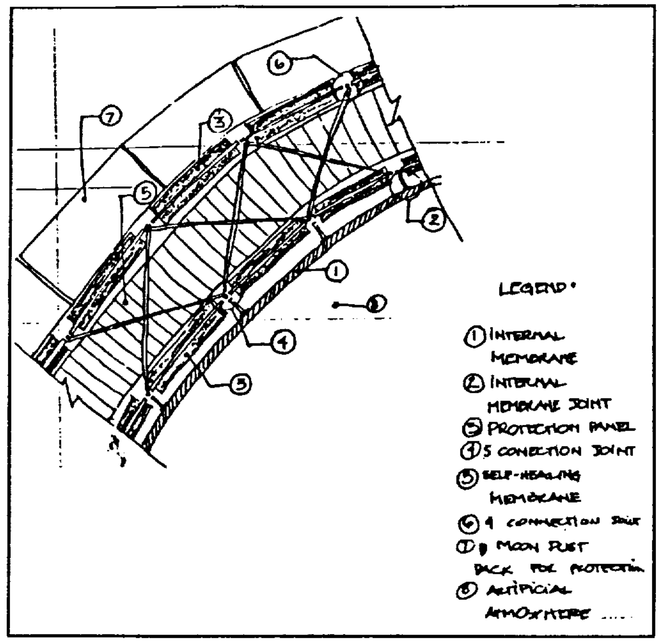

Fig. 7. Section of Shielding and Structure of Main Craterlet.

Language: Each human language has a culturally determined cosmic vision and set of values imbedded in it. Conceivably, languages used in Selenia would be selected on the basis of those spoken by the settlers and their nations of origin, like the United Nations.

Culture, Race and Nationality: Even if the U.S. is to be the leading nation because of its historical role of leadership in the conquest of extraterrestrial space, other nations, races, and cultures must be incorporated if it is to become truly an endeavor of all humankind.

Sex and matrimony: In a conservative western society sex is expected to be confined to heterosexual, monogamous matrimony. In recent times sex has been viewed as a way of enjoying intimate relationships with other persons, who may or may not be of the opposite sex. Traditionally humans have found ways to sublimate sexual drives and channel such a powerful source of energy into creative fulfillment, rather than seeking hedonistic personal satisfaction.

Offspring: In the initial stages at Selenia, there will be no appropriate environment for rearing children. It will not be until humans decide to stay permanently in the reduced gravity environment of the Moon that we will have a first generation of human extraterrestrials. When we can understand the impact of reduced gravity upon reproductive processes we will be able to decide whether or not offspring should be reared in Selenia.

Etiquette: In most societies there are norms for social interaction. In Selenia some of these will be imported from Earth and agreed upon by the dwellers. Others will eventually evolve there as particular Selenite customs and traditions.

Liberals vs. conservatives: In all human societies there is always the tension between those who want to keep the comfort of the known and resist change, and others who boldly want to go beyond experience, seeking innovation. A balance will have to be established to limit personal expression without stifling the enrichment of community mores to maintain quality of life in the Selenite society.

ASSEMBLY PROCESS

On the circumference of the craterlet that will contain CELSS, 12 tunnels will be carved from lunar rock under the regolith. Ten of these will house 18 Habicapsules containing living quarters in an area highly protected from radiation, meteorite impact and major temperature changes, with airlock systems to guarantee survival of major parts of the community in case of failure of life support systems or atmospheric decompression for a period of time. Two of the tunnels will be used for circulation to the core of the Main Craterlet. The advantage of locating these facilities under the surface is that inhabitants could live assured of protection from lethal radiation, meteorite impact, and extreme temperature variations. For the construction of these tunnels we envision that something like the Texas A & M University Subselenian Tunneler Melting Head Device could be used (Fig. 8): "It consists of a tunneler which would melt through the Lunar material, leaving behind glass-lined tunnels. The tunneler uses a nuclear generator, which supplies the energy to thermally melt the regolith about its cone shaped head. Melted regolith is excavated through intakes in the head and transferred to a truck that hauls it to the surface. The tunnel walls are solidified to provide support lining by using an active cooling system about the midsection of the tunneler."[5]

This machine is fast and capable of making 15′-maximum-diameter tunnels, but has the limitation that it cannot make small-diameter curved tunnels. The twelve tunnels made with this device will be transversely connected by four others that form a 230′ square, and will be used for circulation and other community activities. On each of the corners of the square there will be 70′-diameter nodes, three of which will serve as the Leisure and Social Interaction centers of the three subcommunities, and a fourth will house the Transportation and Surface Access facilities. Each will provide a way to the surface. The TSANode will have two additional upward sloping tunnels, one leading eastward toward the energy field, and one leading northward, toward the takeoff and landing facility.

The Main Craterlet, as well as the Nodes are domed by a geodesic structure from which an airtight membrane will be hung to contain the atmosphere, and above which a self-healing protective layer will be placed. Above that, bagged regolith will be placed to create adequate protection from radiation and extreme temperatures. Structural redundancy is employed to insure the integrity of the form in case of local failures. For the regolith bagging system we envision something like the device developed by the Georgia Institute of Technology Textile Engineering Department called "Lunar Regolith Bagging System." (Fig. 9): "This design consists of a rotating brush, protective shroud, metering funnel, prefabricated bags on a roll with built-in drawstrings, a cutter to cut filled bags from the roll, a clutch mechanism to pull the drawstrings closed, and a magnetic control arm to hold the bags open while filling."[6]

This layer of regolith is capable of protecting the dwelling places from lethal radiation, extreme temperatures, and small meteorite impact.

BASE DESCRIPTION

Selenia covers an area of 268,731.83 sq ft and encloses a volume of 1,149,377.70 cu ft. There are four nodes in the corners of the base quadrangle, located in each of the corners, forming something like a baseball diamond.

The Main Craterlet covers an area of 45,238.93 sq ft and a volume of 452,389.34 cu ft, which encloses the 120-ft diameter craterlet found in Lacus Veris (Fig. 10). Except for the upper commons, it will be divided horizontally in 12 almost identical

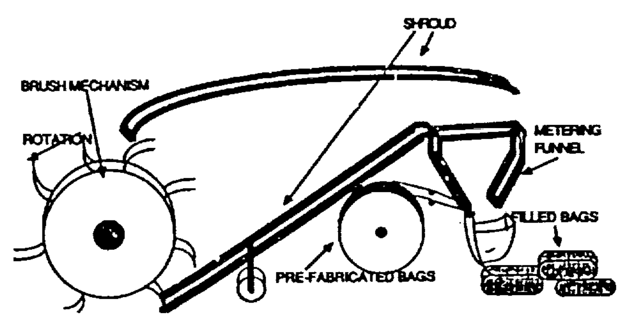

Fig. 9. Regolith Bagging System by Georgia Tech students.

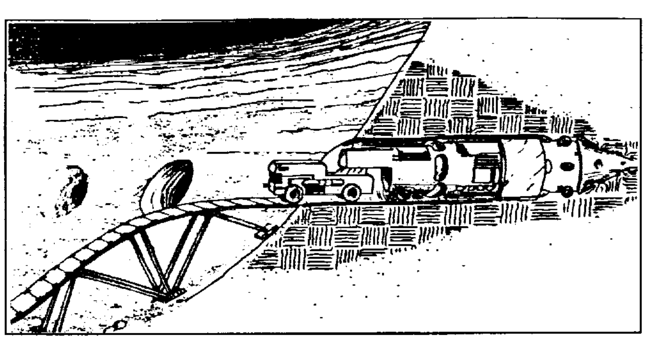

Fig. 8. Subselenian Tunneler by Texas A&M students.

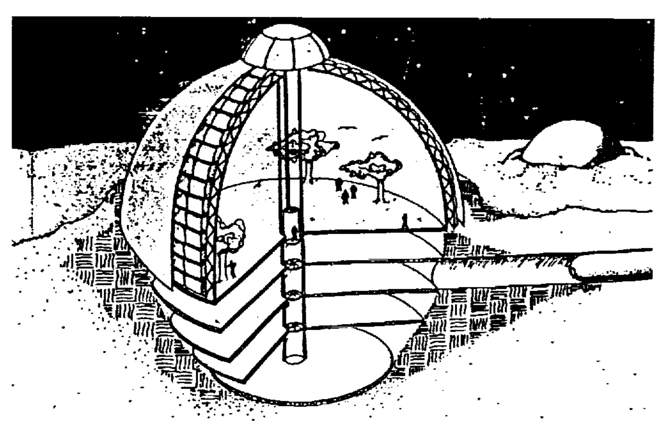

Fig. 10. View of Main Craterlet Levels.

compartmentalized sectors that will contain the following features at each of its levels. The lower level houses air recycling, processing, handling, and deodorizing equipment in 31,415.93 sq ft. We refer to it as a "lung," because of its physiological role in the life of the base. Thus, it is placed in the most protected location on the center of the base. The second level houses water processing and sewer plants in 38,013.27 sq ft. The third level, which is at the Habicapsule tunnels levels, holds a CELSS with animal and vegetable foodstuff producing biomachines in containers that can be transported into the Habicapsule tunnels for protection from extreme solar flare radiation in an area of 45,238.93 sq ft. The fourth level, also of 45,239.93 sq ft serves as a hydroponic and aeroponic greenhouse. The fifth level is covered by the cupola and is a commons for communal and recreational activities in 45,238.93 sq ft. An observatory is located in 615.44 sq ft at the top of this array for monitoring surface operations near the base or enjoyment of the sights. All levels are interconnected by an elevator 6 ft in diameter.

Habicapsules: From the Main Craterlet CELSS, 12 tunnels 141 ft long and 15 ft in diameter will radiate. These will be for circulation, and 10 of them will also hold 18 habitational capsule units, each holding living quarters for 6 inhabitants. Each capsule is 80 ft long, and covers an area of 1902.86 sq ft (Fig. 11). Ten Habicapsules are located inside the quadrangle of the base and eight just outside on the nodule connecting tunnels. Those external connections could be extended for future growth of the base.

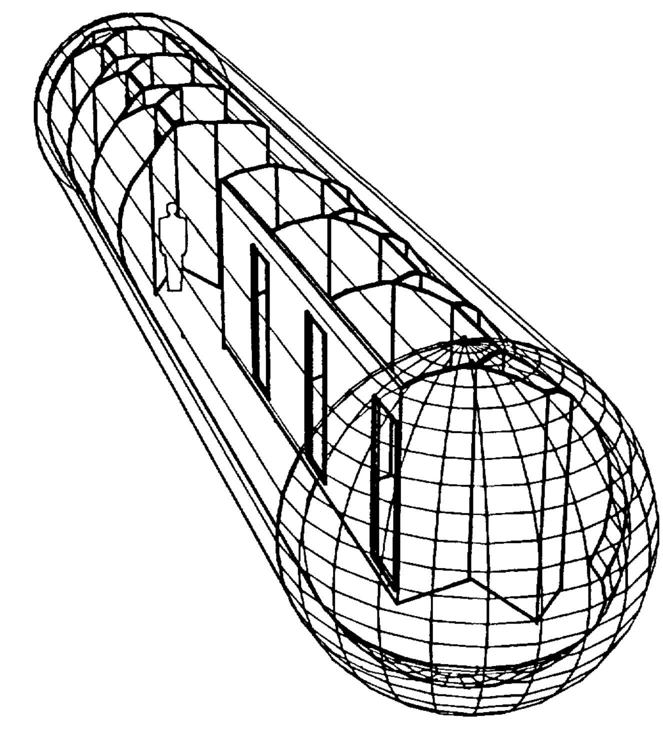

Fig. 11. View of Habicapsules.

LSINodes: Leisure and Social Interaction Nodes are 70-ft-diameter hemispherical spaces, covering 3,848.45 sq ft in three levels. The first one houses spaces for recreation and social interaction and includes lobby-lounge, 1,087.68 sq ft, a meeting room for each subcommunity; gym of 728.64 sq ft, a place where physical fitness acquires a new importance if one intends to ever go back to a terrestrial environment; dining-conference in 960.96 sq ft, where meetings, banquets, and other social functions will take place; kitchen-galley, 543.84 sq ft, where meal preparation will take place; and 251.33 sq ft public toilets. Even though the gym is a place for exercising, physical training activities can take place outside it. Monkey bar racing in the circulation tunnels, and Moon-gliding in the commons could be developed to maintain upper body tone. Above the kitchen, there will be a library, which inhabitants can use for research as well as recreational reading.

The highest level of the LSINodes is a surface access igloo of 281.01 sq ft, reached through a ladder or through a 6′-diameter elevator from the interior, and from a "T" shaped access tunnel on the surface. Around the elevator the public bathrooms are located in the first level. The second level houses an infirmary in 610 sq ft, and the third level houses a chapel. Under this array there is a "lung," which serves as part of the life support system of the base, in 3,848.45 sq ft.

TSANode: This is the Transportation and Surface Access Node (Fig. 12). Its 70 ft diameter is derived from the turning radius of the Subselenian Tunneler, and it covers an area of 3,848.45 sq ft. It consists of an open space that serves mostly as a parking place for surface operations vehicles and materials storage. Ten rover vans and two cargo vehicles can be placed there. In addition to the three corner tunnels, which all Nodes have, the TSANode will also have an eastward tunnel leading toward the energy field and a northward tunnel leading toward the landing and launching array.

Energy Field: It is located at least 3 km from the base in the eastward direction (Fig. 13). It contains a solar collector array and fuel cells. Further away is a multimegawatt nuclear power plant to provide energy to the base during the lunar night.

Launching and Landing Facilities: Consists of a main terminal 2.5 km from the base toward the equator, where there are four landing-launching pads. There is also a linear sling mass accelerator 0.5 km away that takes advantage of the lunar rotation and the near-equatorial location of the base.

APPLICATION OF THE HABITABILITY CRITERIA

Personal Identification: Astronauts and cosmonauts have expressed their need to feel that they are not aliens during their space missions, but to feel part of a family of humans who have been privileged to experience an alien environment with adequate protection for survival and with quality of life enhancements. To satisfy this need inhabitants should have the option of individual dwelling quarters, where personal objects could impart a homey character to the living environment. Other areas of the base will also contribute to personal identification by adopting familiar forms, characters, and styles, and where holographic projections will recreate specific reproductions of terrestrial places.

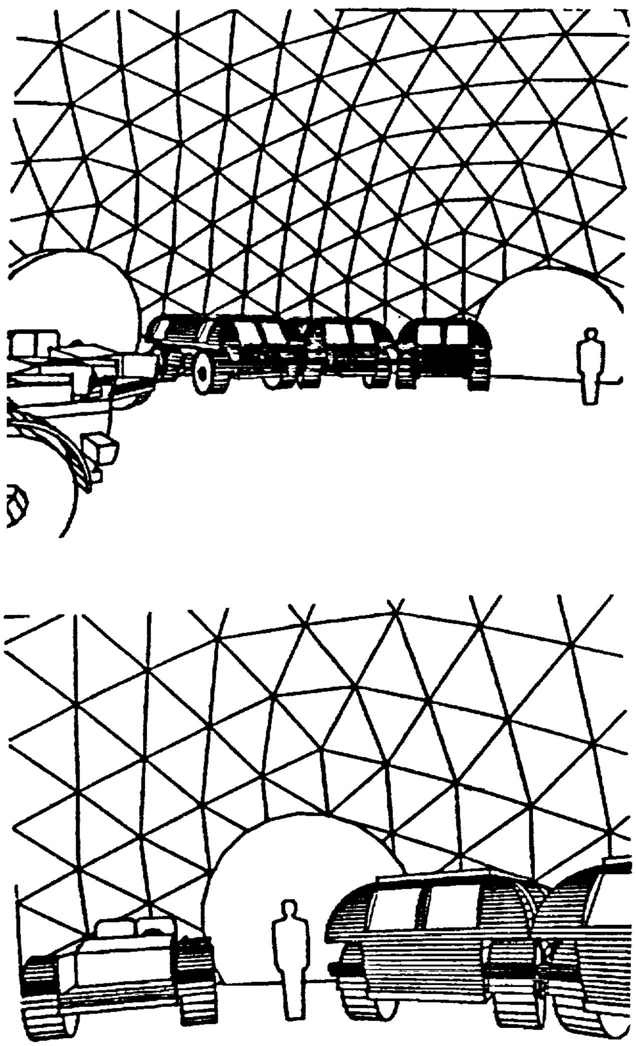

Fig. 12. Views of TSANode.

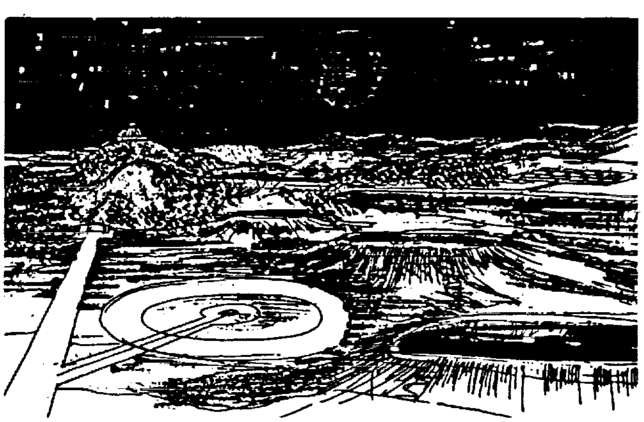

Fig. 13. View of Master Site with Accessory Facilities.

Social Interaction: In prolonged stays in space it seems important for humans to feel the presence of others. Besides company and security, it is necessary to promote positive interpersonal dynamics and good social interaction. Hallways between Habicapsules, and the commons at the Main Craterlet, and spaces at the LSINodes such as the lounges and the dining room will be places designed to promote social interaction.

Mental Landscapes: "Acute Places" are referenced in psychology as enclosed spaces. It is important that they contain symbolic elements that would evoke memories and sensations from previous experiences. These are called "mental gardens." They can help people transcend their immediate physical reality through images, photos, forms, spatial sensations, colors, textures, and materials. The mythology, legends, and decoration in the base should contribute to fulfilling this need.

Privacy: Among inhabitants of the base, social dynamics should be promoted, but privacy or occasions of solitude should also be provided. Their absence has been demonstrated to be an irritant to humans in restricted environments. It seems reasonable to assign each individual a place each can call his or her own.

Contact with Nature: There is great contrast between what we call architecture, and nature. Prolonged stay on the Moon will immerse individuals in the base to a totally alien, artificial environment. The unstabilizing effect that this causes could be offset by gardens and places of contact with animals in the base, such as the Biomes and the CELSS. Habicapsules will have small gardens at the rounded ends. Growing crops and feeding the animals of the CELSS, activities to be shared among all members of the community, will promote a healthy contact with nature, as well as visits to the commons in the upper level of the Main Craterlet.

Equalitarian Conditions: These will promote more relaxed interpersonal relationships among dwellers, making the work on the mission easier and more productive. Arbitrary rank or hierarchical distinctions are not conducive to the best relationships. In architectural terms such equalitarian conditions are reflected in the quality, location, and size of the rooms.

Variety: Psychological studies suggest that similar elements or very repetitive features in an acute place are boring and cause irritability and environmental stress. Habitable places in the base need variety. Decoration at the LSINodes, and rotation of housekeeping tasks should fulfill this criterion.

Aleatoric Conditions: Space travelers have expressed their appreciation for pleasant surprises that depart from daily routine and promote enjoyment of changes. Inhabitants of Selenia will celebrate special events to enhance the routine of ordinary days. The sights of the observatory, the flowering of crops in the CELSS, in the Habicapsule gardens, and in the commons will allow dwellers to enjoy happenings. The lighting of hallways could be programmed to vary aleatorically to simulate weather variation in terrestrial environment or to suit special activities.

Functionality: To be considered habitable, a place must satisfy physical and psychological needs. Also it must house all the hardware necessary to perform the work to fulfill the mission in the base. As an example, the "lungs," the recycling systems, the self-healing membranes, the airlocks, and their redundancy will ensure human life.

Comfort: This includes conditions such as illumination, color schemes, temperature, humidity, pressure, and atmospheric composition that can be accurately determined according to standards, and applied to the design of Selenia.

Stability and Security: Stability refers to inertia that resists forces causing motion or distortion. Human reflexes and muscle tone developed on Earth under a normal 1 *g* will find alien an environment of only 1/6 *g*. The lunar base will offer color coding systems to identify doors, walls, and floors, and different patterns to compensate for the sense of instability or insecurity resulting from such alien conditions.

Sensory Stimulation: It is fundamental that dwellers need as close to normal and as varied as possible a range of stimuli. Sensations are the primary human experience. Surfaces in the lunar base should be treated with color, which will stimulate the visual sense in a meaningful coding system, as well as texture, which will stimulate tactile sense and would help solve acoustic and friction problems in a 1/6-*g* environment. Simulated windows with video showing the exterior of the base will also serve this criterion.

Music and Environmental Sound: The problem of silence in the extraterrestrial environment will be offset by the sounds generated by the life support systems machinery, air handling units, etc.

Sense of Orientation: Characteristics of light can be used to transmit information. Color, as function of wavelength, aids in discerning shapes. Color effects in the interior design of the base are one way to meet the criterion of sense of orientation and also the criterion of comfort. Location of a color stimulus, be it on ceiling, floor, or walls, can make a great difference in the character of a dwelling, its perceived form and size, and its psychological perception.

CONCLUSIONS

Additional questions require further study and research for the continuation of this study, which has tackled many problems but left many questions unanswered. These will constitute an agenda for future years.

Self-healing membrane: The chemistry of fluids, which make membranes self-healing, is known and has many applications on Earth. An example is the kind of substance used in emergency automobile tire repair cannisters. But how would such a substance could perform in the vacuum of extraterrestrial space?

Refinement of the Habitability Criteria: Research underway at Biosphere 2 will help answer important questions such as: What is the volume required for a CELSS per inhabitant? What is the biome composition that more efficiently supports an artificial ecology? What are the empirically tested parameters in reduced gravity anthropometry?

Growth of the lunar base: The question of further growth of the base must be addressed. Is it better to develop other lunar bases in modular stages, or should they be allowed to expand indefinitely, as in the case of terrestrial cities? What is the ideal size for a Selenite community? What are the determinants and parameters that should be considered to reach a conclusion? Is there a critical size at which a self-sufficient community is no longer possible?

Reduced gravity furniture design: Further development of furniture design is necessary, considering the anthropometrics of the lunar environment. The idea of edible furniture materials to ensure survival under catastrophic circumstances is worth exploring.

Illumination and lighting effects: The use of environmental lighting to change the character of an acute place, holography to create environments that evoke mental landscapes, fractals to introduce aleatoric variations in decorative patterns of walls, and photo-sensitive membranes to vary transparency to create a new sense of indoor-outdoor relationships are some of the items that should be explored as resources for the specific design of the lunar base.

New activities: Lifestyle in the Selenite community will create the need for new kinds of sports and new festivities to enhance the routine of ordinary days and new forms of social interaction developed to suit the particular circumstance and inhabitants of the base.

We could be heading toward the development of a design manual for architects of lunar bases. However, our immediate aspiration is to raise consciousness regarding the contribution that architectural designers can make to the conquest of space and to call upon people in that field to reflect upon this new frontier.

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