BEYOND EARTH: LANDSCAPE ARCHITECTURE ON THE HIGH FRONTIER

by

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CHAPTER I
INTRODUCTION

Earth is the cradle of the mind, but one cannot live in the cradle forever - Konstantin Tsiolkovsky

INTRODUCTION

For centuries humans have gazed into the night sky in earnest, pondering their role in the universe. Did humans have a place among the stars, and, if so, how could they survive? Is it possible to construct habitats in space capable of sustaining human life? The answers to these questions have only just begun to be formulated.

The Concept of Space Colonies

During the past thirty years, space technology has been increasing literally at the speed of light, enticing scientists to use what it had to offer to develope a means of travelling and living in space. Many nations of Earth are accepting the challenge and have been devising life support structures, or space stations, that are capable of enclosing an environment suitable enough to enable humans to live in space for short periods of time (Harrison, Akins and Conners, 1985).

Can people actually live in space? That is, can environments off the earth be built and inhabited as permanent communities? The concept of an extraterrestrial community is intriguing. The existence of such a colony will enable people to conduct research into subject areas that they currently do not have the capability of studying (NASA, 1972). People will be able to test their capacity to achieve a certain degree of autonomy from earth. They will also be able to study their ability to exist in an inhospitable environment while providing food and life-support systems from available space resources. In addition, people will be able to examine their capability to create and nurture a living landscape such as exists on Earth.

A short time ago these questions and comments would not have been taken seriously by anyone except an avid science fiction reader, or visionary individuals ahead of their time. These inquiries are presently being entertained, not out of curiosity, but because the advancements that have been made in science and space technology have revealed that the potential benefits that space colonization has for the ever-increasing and enclosed population of planet Earth are unlimited.

Given that it is technically feasible to construct a settlement in space, why should the effort be made to do so? Are there sound reasons why such an endeavor would benefit more people than just those directly involved? Precisely because there are sound reasons for permanent space communities, the effort should be made to design and construct them, and the landscape architectural profession can be significant contributors to this venture.

The last two hundred years has seen the human race become dominant over the Earth's natural systems. The discoveries in medicine, advances in chemistry, biology, and genetics all have helped control fatal diseases in most countries of the world. The result of this is a population increasing with such rapidity that soon the Earth may not be able to support the associated increase in the needs of the population.

Without question, man has expanded his control over the natural environment in order to satisfy his needs. The results have not been positive. An escalation in all types of pollution, destruction of wildlife, serious depletion of the Earth's irreplaceable natural resources, and most recently, dissipation of the ozone layer are but several examples of mans' mindless assault on the environment. The environmental revolution that took place during the past two decades has begun to strike an awareness on the part of humanity that the landscape called Earth is truly a limited resource, and that immediate steps must be taken to insure its survival.

As "stewards of the land", the landscape architectural profession has a deep and abiding interest in all of these environmental issues. As concerned professionals, landscape architects must respond to the challenges that these environmental issues offer. Robert Ross, Jr., Chief Landscape Architect of the U.S. Forest Service, and Vice President of the American Society of Landscape Architects, (ASLA), stated that, "stewardship of the landscape is not some sacred duty of landscape architects, but a professional responsibility" (Ross, 1989).

Indeed, it is the responsibility of the landscape architectural profession to contribute their expertise in finding solutions to the environmental problems facing mankind. At the same time, it is the responsibility of the profession to remain on "the cutting edge" of current technology. Both responsibilities can be accomplished provided the landscape architecture profession can make valuable contributions to, and be a viable member of, multidisciplinary space facility design teams.

Scope of Study and Objectives

This study responds to the need for participation by the landscape architectural profession in being an active and valuable contributor to the conceptual design of extraterrestrial communities. At the present time, there is no immediate requirement for large-scale implementation of man-made "natural" habitats in a space station environment. However, there is a need for basic research with respect to the design of the physical elements that will be necessary to create these habitats. It is within this context that the knowledge and expertise of the landscape architectural profession can be most influential.

The purpose of this study is to develope an understanding and appreciation of the significant contributions the landscape architectural profession can make to the design of large-scale living environments for human habitation off the Earth, specifically, the design of space station habitats.

Research Format

Chapter II provides the background information for this study. Included in this chapter are:

a) the history and current concepts of space station alternatives
b) a case for the building of space stations
c) a brief description of an overall first system
d) the properties and dangers of space
e) human needs in a space environment
f) a discussion of space station habitability design requirements.

Chapter III provides the study intent, the methodology and implementation procedures. Chapter IV examines the study and finds. Chapter V will provides an evaluation of the study, as well as observations, and conclusions.

Chapter VI suggests future research needs brought about as a result of this study, as well as the need for new skills and education for the landscape architect planning to work in space environments.

CHAPTER II
BACKGROUND

History of an Idea

The First Visualizations

No one can say with any accuracy how long man has been dreaming of travel into space. Visions of settlements in space stretches back into the myths and legends of ancient times. However, the suggestion of permanent habitats in space is relatively new. Isaac Newton mentioned the potential for artificial satellites in 1687, barely three hundred years ago. The first written account of a space colony appeared in 1869 in a novel by Edward E. Hale, entitled Brick Moon. In this account, a brick sphere, built as a navigational aid for ships at sea, was to be catapulted into an orbit above the Earth. As workers were putting the finishing touches on the inside of the sphere, it rolled onto the catapult too soon, which activated the release mechanism, and the result was the launching of the first space colony (NASA, 1977).

Forerunners of the concept of actual self-contained habitats in space appeared in the writings of Jules Verne in 1878, and those of Kurd Lasswitz in 1897 (Salkeld, 1975). Verne was perhaps the most prolific of the early science fiction writers. Many of his predictions of future flights from the Earth into the realm of space were quite accurate, even though another century would pass before space travel became a reality. For example, in his book *Trip to the Moon*, Verne states that the launch will take place in Florida, there would be a 3-man crew, they would orbit the moon, and land again on Earth by splashing down into the ocean (O'Neill, 1981).

Twentieth Century Thinking

The idea of actual colonies in space, where people could live out their lives, was first written about in 1903 by the Russian science fiction writer Konstantin Tsiolkovsky. He was convinced that humans could construct man-made environments somewhere in space. Tsiolkovsky described the station from a technical viewpoint, and he was the first individual to perform mathematical calculations involving the principles of spaceflight (Golden, 1977). Tsiolkovsky proposed that liquid oxygen could be used as a rocket fuel, that the space habitats would rotate to simulate gravity, make use of solar energy, and that there would be a "greenhouse" that would operate on the principle of a closed-loop ecological system in which waste products would be recycled (Starchild, 1979). These systems defined the idea of a space station habitat in very basic terms (NASA, 1977).

According to Salkeld (1975), the next fifty years saw interest slowly rising in the notion of space stations orbiting the Earth. There were a few individuals like

Oberth, who suggested in 1923 that space stations could serve as scientific platforms. In the 1920's J.D. Bernal, working independently and unaware of Tsiolkovskys' works, duplicated some of his work, and suggested that a sphere could contain a habitat suitable for human living. In 1928 Guido von Pirquet recommended that refueling operations for deep space flights could be carried out on orbiting stations. And in 1929 Potocnik suggested that a station thirty meters in diameter, which he named a "Wohnrad", or living wheel, could be placed in geosynchronous orbit about the Earth (Salkeld, 1975). In World War II Germany considered the military uses a space station might have to offer.

In the 1950's and 1960's the concept of larger space stations was made popular by Wernher von Braun, who suggested a larger "wheel"; Arthur C. Clarke, who published *Islands in the Sky*, a novel about large space stations, suggesting the use of asteroids and the moon as consumable resources; and Darrell Romick, who proposed a space station of cylindrical shape three hundred meters in diameter and one kilometer long, to be inhabited by 20,000 people (Salkeld, 1975; O'Neill 1981).

An Accidental Discovery

In 1969 a professor of physics at Princeton University, Dr. Gerard O'Neill, analyzing the results of an class assignment he had given his students, came to the startling conclusion that a small, enclosed colony, orbiting around the Earth in space, could provide humans with practically all the abundance that life on Earth could offer, and possibly more (Golden, 1977). According to O'Neill, what began as a joke had to be taken seriously when the numbers began to come out right.

O'Neill also discovered that, given the technology of the 1970's, it was possible to construct a prototype space station capable of permanently supporting a population of 10,000 people in orbit around the Earth. O'Neill continued his research into the feasibility of constructing such a station. The results of that study indicated the following (O'Neill, 1974):

1. Space can be colonized.
2. Nearly all industrial activity could be moved away from the fragile atmosphere of Earth during the next century.
3. Colonies in space could achieve autonomy from the Earth and establish a self-governing, and culturally diverse population.
4. Space can support a population many times that of Earth.

Interest in the possibility of colonies in space grew even though O'Neill could not find a publisher for his research in any scientific journal (in spite of O'Neills' distinction among the scientific world as the author of the classic study; *Elementary Particle Physics: An Introduction*). At the suggestion of friends, O'Neill took his ideas "to the people" in the form of physics lectures at colleges and universities throughout the United States. The response was overwhelming, and his ideas were enthusiastically accepted by his audiences. As the questions from his audiences grew more provocative, O'Neill began to look in even more detail at what a space colony would be like. Could the colony survive a direct meteor hit? What food resources would the population require?

Enter the Experts

In 1974 O'Neill staged the first formal conference on space colonization. He was so persuasive with his concepts that officials at NASA attended the meeting, in spite of the possible scorn they faced from their colleagues. Soon after this conference was held the distinguished journal *Physics Today* agreed to publish a short description of O'Neill's idea of colonies in space (O'Neill, 1974).

Thanks to O'Neill's dogged persistance, the concept of space colonization was receiving the attention and serious consideration it deserved. Soon O'Neill was a celebrity of sorts, and spoke about space colonies on radio and television, as well as writing magazine articles. He eventually testified before a Congressional subcommittee on space. In 1975, O'Neill arranged for an even larger conference at Princeton University. Over 100 scientists, engineers, physicists, agricultural experts, architects and lawyers participated. All the experts agreed that, whatever obstacles space colonization entailed, they could be overcome.

In the following year, O'Neill and twenty-eight experts in the field of space science, met at the NASA-administered Ames Research Center in Sunnyvale, California. NASA, Stanford University, and the American Society for Engineering Education (ASEE) co-sponsored and participated in a unique study. This group worked to construct a convincing and accurate picture of how people would live and maintain life in large space settlements (NASA, 1977). The goal of this study was to design an initial system that would be viable for the colonization of space.

The study states that "it is not the best system for the colonization of space that can be devised; nor is it complete...not all questions have been posed...not all questions have been answered...(however) it is the most thorough and comprehensive (study) made to date." (NASA,1977). The conclusion of the group was that "space colonization appears to be technically feasible...the obstacles are... principally philosophical, political, and social rather than technological. Permanent communities can be built and inhabited off the Earth" (NASA, 1977).

Space Stations and the Future of Earth

The Primary Enigmas

As the requirements for life of the inhabitants on Earth continue to increase with the population explosion and resulting consumption of resources, O'Neill (1976) recognized four problems, all of which correlate to the limited size of Earth. They are:

1) energy
2) nourishment
3) sufficient space for living
4) population

Population has a direct relationship to the other three concerns. That is, as the population escalates, so does the need for energy, food, and shelter.

Energy, the Foremost Concern

To provide for those basic human needs, even energy, requires energy. Growing food efficiently demands expending energy to manufacture chemical fertilizers. Homes, industries, and commercial businesses are heated, cooled, lighted, and powered by consuming energy. Transportation systems depend on enormous amounts of fuel to convey travellers to their destinations.

Not all of that expenditure of energy is necessary. For instance, in the United States during the "energy crisis" in the mid-1970's, the 10 to 20 percent reduction in energy usage required significant restrictions in the freedom of movement via the automobile so enjoyed and endeared by many Americans. For a time, Americans were keenly aware of the need for conserving energy, and the increase in consumption slowed. As the 1980's draw to a close, America is once again taking energy resources for granted, as evidenced by the increase in maximum interstate highway speed limits.

If the entire population of the Earth used energy at the same rate as the United States and other developed countries, no doubt the world's total proven oil reserves would be depleted in a very short time. The industrial revolution in the United States has relied on abundant and inexpensive sources of energy. As energy costs continue to rise sharply, the results are inflation and a drop in the economic vitality of the more "affluent" nations.

Further, as the world continues to utilize energy, many types of gases, such as bromochlorodifluoromethane and chlorofluorocarbons, are released into the stratosphere layer of the atmosphere. For many years, researchers at the National Atmospheric and Oceanographic Administration (NOAA) have been monitoring these and other trace elements present in the atmosphere at the most remote NOAA monitoring station on Earth - the Amundsen-Scott South Pole Station in Antarctica.

Because Antarctica is such a great distance from the source of the manmade pollutants the global increases of long-lived trace gases can be accurately estimated from the measurements taken at the South Pole (Khalil and Rasmussen, 1985). Khalil and Rasmussen's observations showed that manmade compounds were present at the time of the measurements, (1984), in small concentrations. But the researchers found that the rate of increase is "rapid" and that the gases were increasing in the Earth's atmosphere.

Hofman and others, (1987), stated that the stratosphere had an ozone total loss of 50% in the spring, and up to 75% loss (of ozone) in the 12 - 20 kilometer range of the stratosphere. These scientists soon discovered that this loss produces an "ozone hole" above the South Pole (Khalil and Rasmussen, 1985, 1987; Hofman et al, 1987; Oltmans et al, 1987; Zafra et al, 1987). As this rise in atmospheric pollution decreases the ozone, it increases the temperature of the Earth's surface. Even an increase as small as one degree centigrade can cause dramatic changes in the world's climate, and water levels of the oceans.

Obviously, the world is in great need of an unlimited energy source, one that does not produce atmospheric pollutants. Nuclear power was once envisioned as the answer, but safe disposal of nuclear wastes remains an unsolved dilemma. In addition, major accidents at Three

Mile Island and Chernobyle have made the public aware of the potential catastrophes these nuclear facilities are capable of generating. At present, no new nuclear power plants are being considered for construction in the United States.

Solar energy could be the solution to our energy problems, population, and food production. Solar energy would indeed be a suitable energy source if it were available twenty-four hours per day. But, due to clouds, the rotation of the Earth, and attenuation by the atmosphere, the majority of the Sun's energy does not reach the surface of Earth. In addition, photovoltaic cells have an energy conversion factor, at best, of only fifteen percent, equating to a very inefficient and expensive method compared to conventional forms of energy generation currently in use. To date, and for the foreseeable future, solar energy produced on Earth is not a viable alternative for supplying the copious amounts of power required by humanity.

The Requirements for Living in the Future

To maintain the standard of living on the Earth, and have an opportunity to solve the problems of energy, hunger, and create living space for an ever-increasing population, the following requirements would be necessary (O'Neill, 1976):

1. Unlimited low-cost energy, available to every nation.
2. Unlimited new lands, to provide living space of higher quality than most of humanity now possess.
3. An unlimited source of raw materials, acquired without harm to Earth's environment.

The Viability of Planetary Bodies

Where, if not on Earth, will mankind be able to live comfortably with sufficient energy, land, and a bountiful supply of resources? Humans are content living on Earth. Most people find it difficult to even consider living on another planetary body. Nevertheless, with the ever-increasing demand on the Earth's resources, consideration needs to be given to establishing bases, or settlements, away and separate from the Earth.

The human race has reached the point in time where they have the technology to explore the depths of space. It has been two decades since man have taken "one small step" on the lunar surface. They have since acquired the technology to carry out industrial activities in space (Compton, 1983). Current plans are for many experiments of industrial application to be performed in the International Space Station in the mid-1990's. Should the next higher level of space bases be on the surface of a planet? O'Neill (1976) suggests that we should exercise the use of "comparative planetology" - i.e., is the best site for an expanding industrial society the Earth, the Moon, Mars, some other planet, or somewhere else entirely?

Establishing an industrial society on the surface of other planets is not a practical solution. First, Mars and the Moon have a land area only equal to that of Earth - too small in the long run. Neither planet has an atmosphere or sufficient gravity for sustaining human existance of the long term. Venus is an inferno, due to its close proximity to the Sun, and Mercury is even closer, and hotter (Carr, 1984). Any planet beyond Mars is unfeasible due to long travel time.

Consider for a moment that a base was established on the Moon or Mars. Just leaving the surface of these planets would require high amounts of propellant for thrust, somewhat analogous to standing in the bottom of a deep hole. For example, to leave the surface of Earth and enter into free space (where gravity has no effect), is comparable, in terms of energy usage, of trying to climb out of a hole 4,000 miles deep, as illustrated in Figure 1. Once out of the "hole", it is prudent to stay "out" rather than land on another planet equating, in fact, to dropping into another "hole", and having to generate the energy to once again "climb" out of that "hole". Using space stations as bases significantly reduces the amount of energy required to gain entry into space compared to the utilization of planets as primary bases.

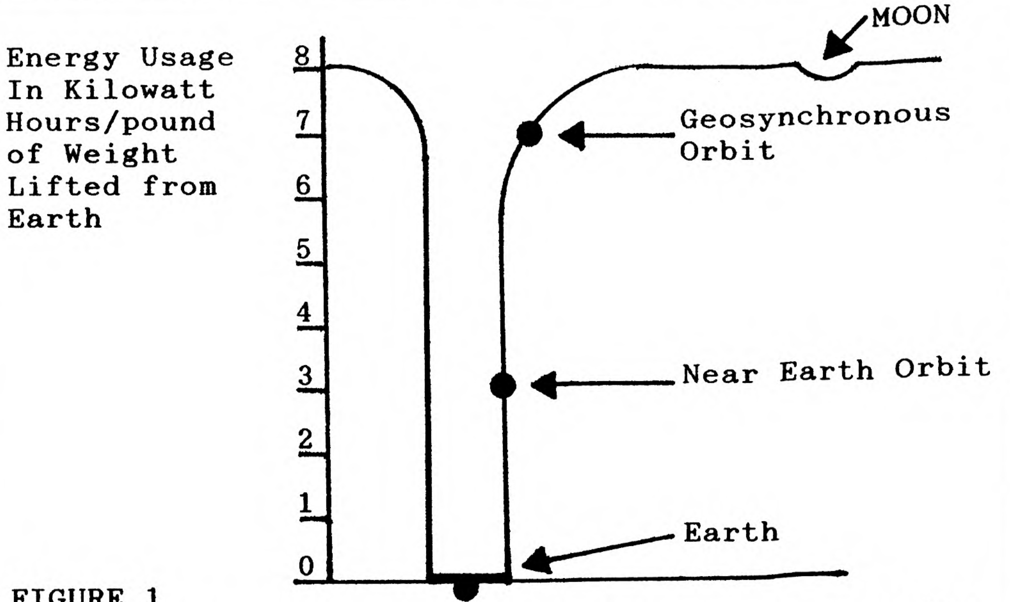


FIGURE 1
Gravity Well of Earth (adapted from Trefil, 1981)

There are other drawbacks of establishing industrial bases on planetary bodies (O'Neill, 1976):

A. Solar Power is more readily available in free space. The Sun's energy is available full time in space at the rate of 1.4 kilowatts/10 ft$_2$, which is approximately ten times higher than at Earth's surface (.18 kw/10 ft^2).

B. Travel and shipping is cumbersome and consumes high amounts of energy resisting the drag of gravity and the atmosphere.

C. Gravity restricts easy movement of materials, and prohibits new industrial technologies from developing. Many industrial products, (for example, crystals), can be made stronger if they are manufactured in zero gravity. In addition, heavy industry requires the use of large cranes, etc., to maneuver heavy objects. These objects are more easily moved in zero gravity. This increases the safety factor, and decreases the need for complicated manufacturing infrastructures.

The Viability of Space Stations

It is possible to construct an environment off the Earth in the form of a space station that will (Grey, 1977):

1. Support light and heavy industrial manufacturing.
2. Enable high-yield agriculture to operate on a continuous basis at all times.
3. Provide a relatively effortless means of transportation to any point.
4. Have an unlimited and universally available source of high energy.
5. Support a human population in a quality living habitat.

Given that Earth will outgrow its sustainability in the future, and close-by planets offer no viable solution at this point in time, then "somewhere else entirely" is the only alternative. It is possible to design such an environment, not on a planet, but in free space, in the form of a space station (O'Neill, 1976; NASA, 1977; Grey, 1977).

Constructing such a station is now achievable using current technology, and by intelligently utilizing the natural resources of space and planetary bodies.

A General Description of an Overall Space Station System

The first colony in space is a proposed space habitat supporting a community of 10,000 people, known as Bernal Sphere One. These people will be employed, have families, and live out normal lives in the same manner as the inhabitants of Earth. The illustration in Figure 2 depicts the sphere and torus arrangement of the proposed station, in a scale comparison to another large man-made structure, the Empire State Building.

Bernal Sphere One will orbit the Earth in the same orbit as the Moon in a stationary attitude that is equidistant from both the Earth and the Moon. This point in space is called the Lagrangian libration point, L_5, (a detailed description of L_5 is discussed in the following section).

The sphere habitat consists of a pressurized aluminum sphere 500 meters, (1680 feet), in diameter, with a circumference at the equator of 1575 meters (approximately one mile, see Figure 3). On either end of the sphere are the agricultural areas. These are located in a series of sectional rings (tori), which are connected side by side and form large fields at the same level.

The entire habitat rotates at 1.85 revolutions per minute about a central axis. This will provide Earth-normal gravity at the equator.

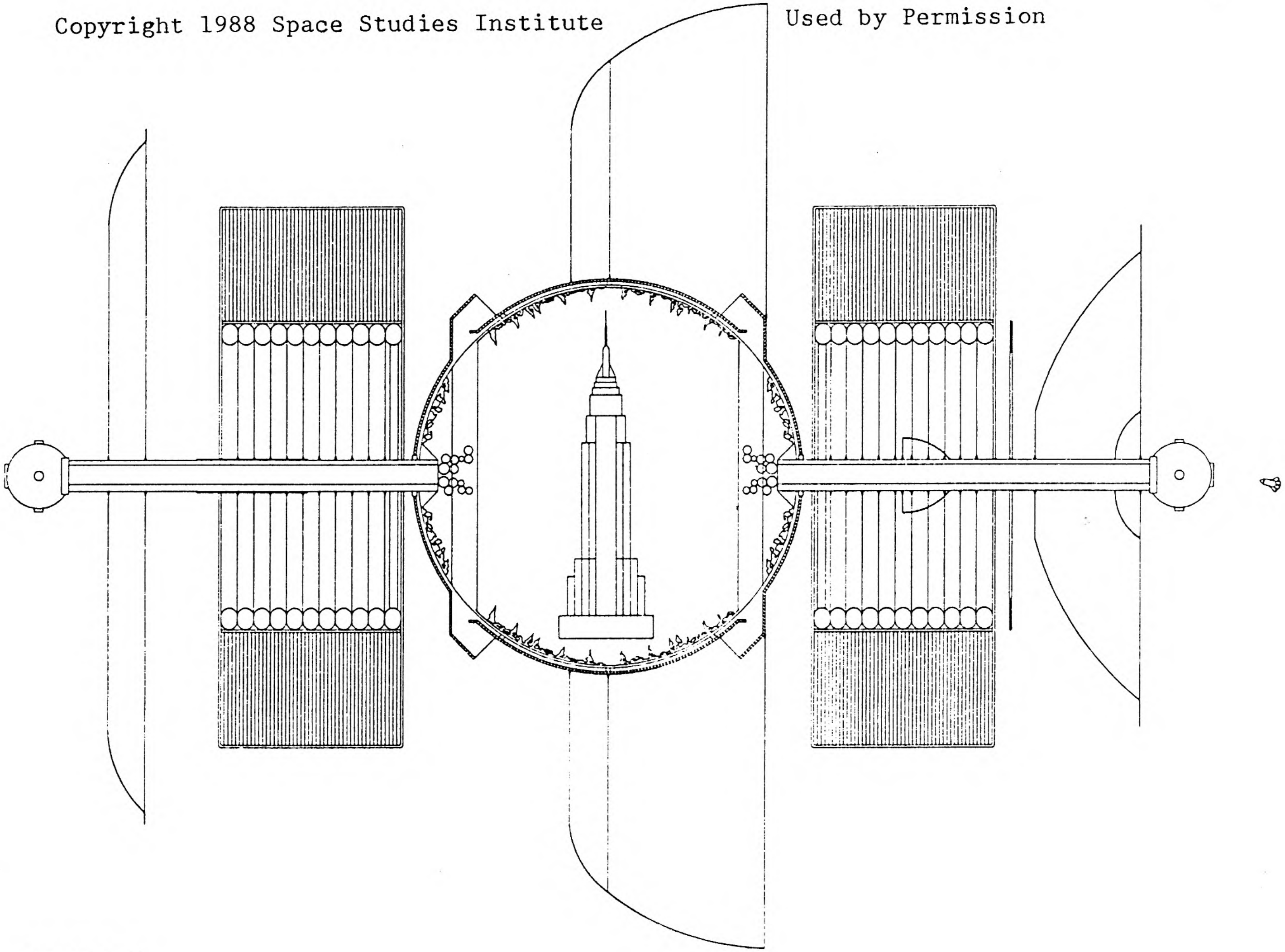
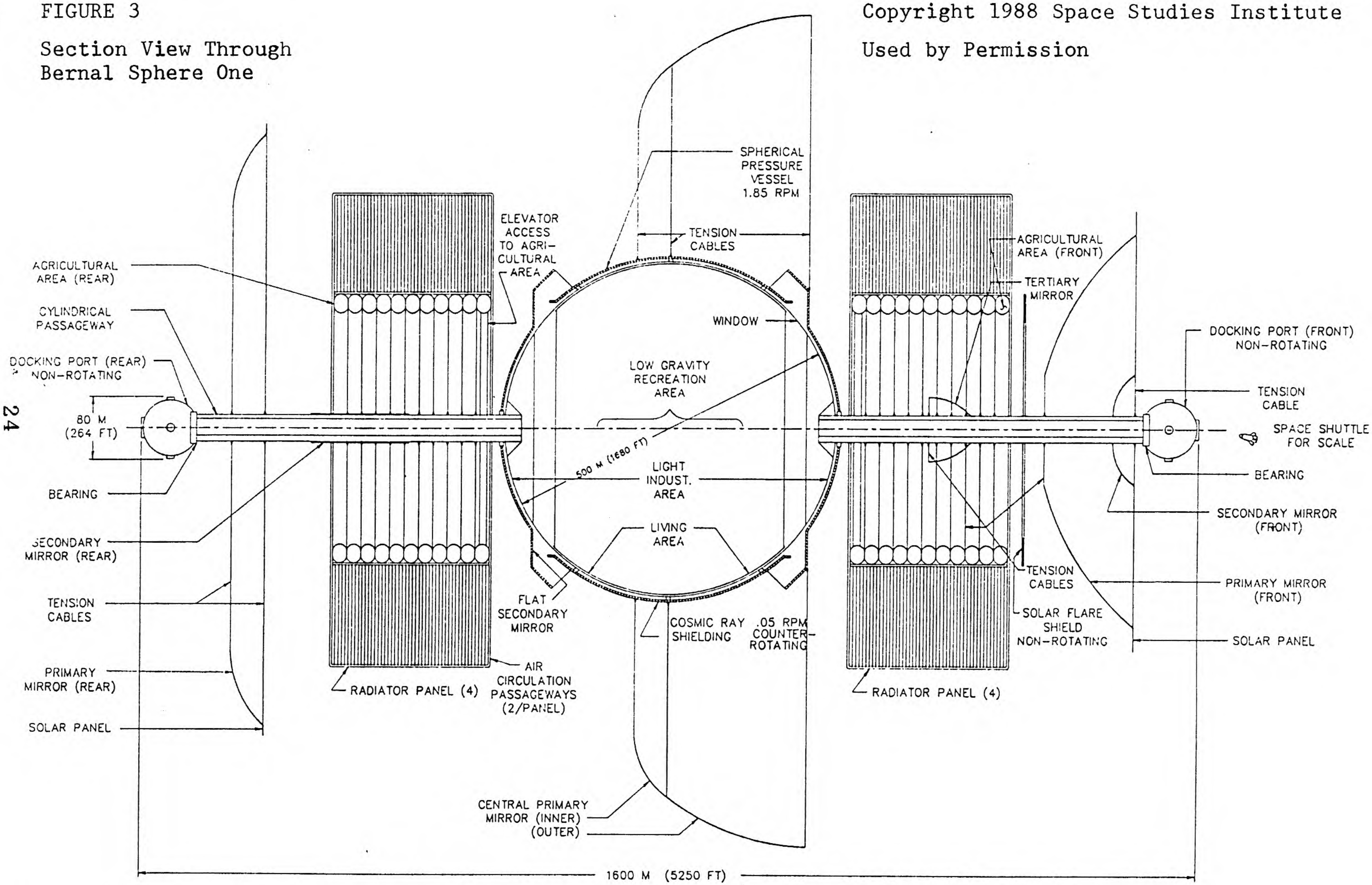


FIGURE 2

Scale comparison of Bernal Sphere One to Empire State Building

FIGURE 3

Section View Through
Bernal Sphere One



The interior of the Bernal Sphere habitat is illuminated with natural sunshine. The Sun's rays are deflected by mirrors on either end of the sphere, and reflected inside through louvered "windows", which act as a baffle to suppress dangerous cosmic radiation (see Figure 3). With the assistance of the natural sunshine and regulated farming methods, the colonists are able to grow enough food for themselves within the tori on approximately 200 acres.

Plentiful solar energy and massive quantities of regolith (lunar soil) are the key ingredients to establishing a community in space. Lunar soil is used for:

1) shielding from cosmic radiation
2) raw material for industrial manufacturing
3) as a source for space station construction materials.

The Sun accomplishes several tasks for the space facility. Two of the most important are: a) promoting agriculture of unusual productivity, and b) providing unlimited energy for industries essential to the success of the colony. The colony will use solar energy for the generation of electricity, and to power solar furnaces. With this solar energy supply the colonists will refine aluminum, titanium, and silicon from lunar ores shipped from the Moon.

Using these refined elements, the fabrication of materials for the construction of new colonies and the creation of satellite solar power stations is possible.

The power stations are placed in geosynchronous orbit above the Earth where they will then will generate enormous quantities of electricity and transmit this energy, via microwave, to Earth receiving stations. The economic and environmental value of the solar power stations will more than support the initial investment costs of constructing the colony, justifying the existence of the colony, and promoting the construction of additional, larger colonies.

The primary elements of the overall space colonization system and their relationships are illustrated in Figure 4.

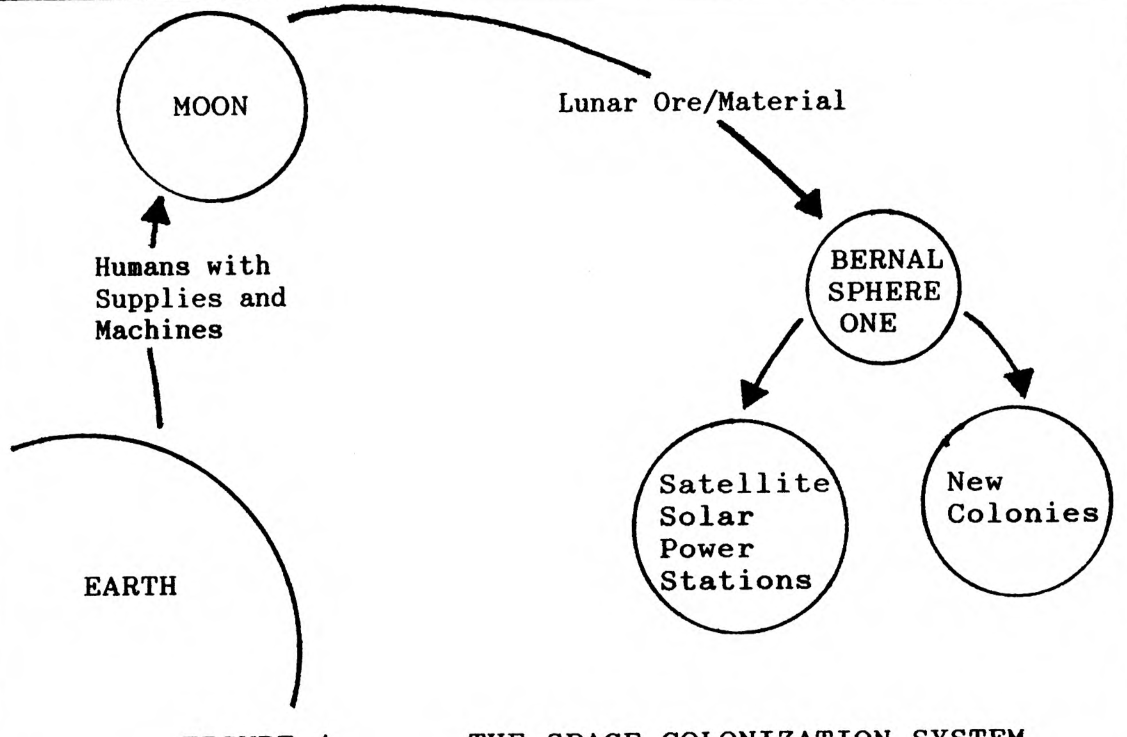


FIGURE 4 THE SPACE COLONIZATION SYSTEM (adapted from NASA, 1977)

Properties of Space

It is very important that landscape architects have a working knowledge of the site environment in any project they undertake, and space is no exception. As Lynch (1986) states, "Every site, natural or man-made, is unique (it) imposes limitations and offers possibilities... understanding a site demands time and effort". Just as sites on Earth must be understood, if landscape architects are to be involved in the design of space habitats, they must be familiar with the properties of space.

Contrary to popular belief, space is not an environment void of matter, rather it contains many valuable resources of energy and matter, in addition to hazardous fluctuations of solar radiation. Space also has topographical features in the form of gravitational fields of ridges and valleys. Space is also a vacuum and therefore offers no resistance to moving objects. Thus, space offers ease of transportation.

If the natural resources space has to offer are to be used safely and efficiently for the benefit of the colonists, the elements and characteristics free space must be understood. Following is a brief explanation of the physical properties of space that dictate essential physical design criteria, of the proposed space station facility. This information, along with the physiological, sociological and community requirements of human beings in space, constitutes the quantitative and qualitative principles that will be used to establish a space colonization facility master plan.

1. Topography

The property that produces ridges and valleys in space giving it "contours" is gravitation. The gravitational contours in space are as important to space settlers as the contour of the lands were to the early settlers in the United States. As stated earlier, to escape into space from the surface of a planetary body, such as the Earth or Moon, requires enormous amounts of energy because both bodies sit at the low point of a gravity valley (Figure 1).

The larger the mass of the body, the deeper will be the gravitational valley. Compared to the Moon, the Earth's gravitational valley is 22 times deeper. Therefore, matter can be transported from the surface of the Moon with much less energy compared to transporting the same amount of matter from the Earth's surface. The lessor gravitational pull of the Moon will be of primary importance in allowing the space colonists to obtain the majority of their resources from the Moon.

L_4 and L_5

In addition to the valleys of gravity surrounding each planetary body, there are other, more subtle, gravitational properties that merit consideration. For example, as shown in Figure 5, the Earth-Moon system has shallow gravitational valleys that surround what are known as Lagrangian libration points.

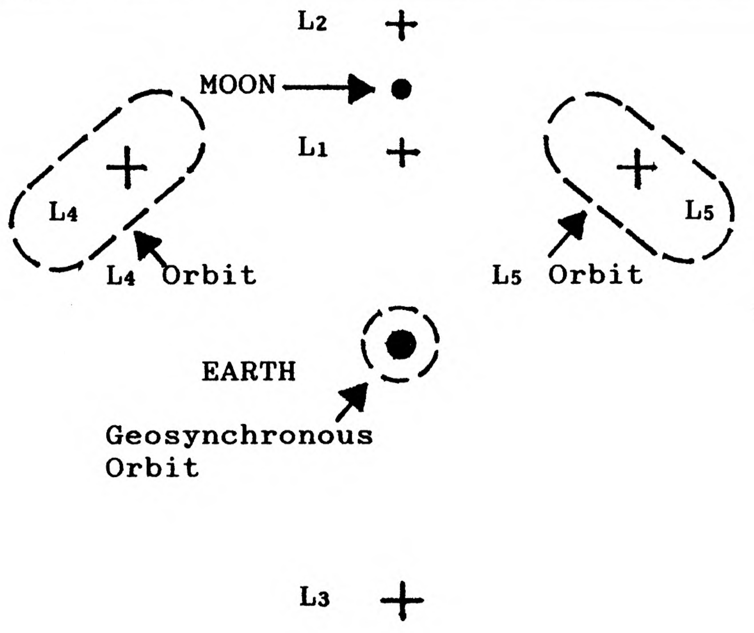


FIGURE 5 Earth - Moon Lagrangian libration points (adapted from NASA, 1977)

These five points were discovered in the eighteenth century by the mathematician-astronomer Joseph-Louis Lagrange, as he was trying to solve the "three-body problem" (Golden, 1977). This problem involved answering the following question: If there are three bodies, in this case the Earth, the Moon, and an asteroid, in orbit around one another, what effect will the gravitational and centrifugal forces have on each body, and how would these forces act on one another? Lagrange found that if the asteroid, (or space station), were constantly travelling in the same orbit as the Moon around the Earth, at a distance of approximately 248,000 miles from the Moon, either ahead of the Moon or behind it, the asteroid would be trapped, and remain in the same position, due to the balance of the gravitational and centrifugal attractions of the Earth and the Moon (NASA, 1977; Golden, 1977).

As illustrated in Figure 5, the site ahead of the Moon is known as L_4, and the site behind the Moon, L_5. There are three other sites, L_1, L_2, and L_3 where bodies could be trapped for a time, but these are not as stable as L_4 and L_5, and an object trapped at those points would eventually leave orbit, especially when the gravitational pull of the Sun is taken into account.

When the Sun's gravitational effect is considered, objects placed at L_4 and L_5 will not remain rigidly in place. Instead, they will move in a long elliptical orbit thousands of miles in length, around L_5 (or L_4), as indicated by the dotted lines in Figure 5. Golden (1977) compares this phenomena to a ship circling its mooring with the changing tides. The basic conclusion, according to NASA (1977) is that massive objects placed in the vicinity of L_4 and L_5 would orbit these points with a period of about one month while accompanying the Earth and the Moon around the Sun. This phenomena has distinct advantages because these regions could contain thousands of space station colonies before the area becomes a victim of "space urbanization".

2. Natural Resources

Solar Radiation

Space is not "empty" as it would appear, and in fact it is filled with radiant energy from the Sun. Beyond the confines of Earth's atmosphere, the Sun's energy is very intense. According to NASA (1977) ten square feet of space that is facing the Sun has 1390 watts of sunlight passing through it. At the surface of the Earth, this total is only 185 watts. Not only is there approximately 7.5 times more energy available in space, but there are also many wavelengths of light energy obtainable not attenuated by the Earth's atmosphere (NASA, 1977).

If humans are to live in space for any amount of time, they must have protection from the intense radiation. At the same time, however, this energy is a valuable resource for the space settler and those inhabiting the Earth. The ceaseless supply of energy will make the venture in space a success by converting solar energy to electrical power for use in the space colony habitat, and industrial applications. As can be delineated by the proposed space station plans (Appendix A) parabolic mirrors would capture enough light to heat industrial furnaces to 5000 degrees Celsius for use in melting lunar materials. The Sun will also supply the needed light for plant propagation and crop production, as well as natural light for the inhabitants of the colony.

Vacuum of Space

As noted heretofore, the vacuum of space is a resource in its own right. It will permit many manufacturing and industrial processes that are impossible on Earth. In addition, many new industrial processes and new products as yet unknown will become available for use.

Sources of Matter

Matter is evidenced throughout the void of space comes in a variety of shapes and sizes. The largest masses are the planets and accompanying satellite bodies. Asteroids, meteoroids, interplanetary dust, and finally submicroscopic particles of ionizing radiation round out the family of space matter.

Planets could be the primary locations of material resources for the construction of space stations, but their distances and gravitational valleys dictates their availability as a source of raw material unfeasible.

The Moon, with its relatively shallow gravity valley, or gravity "dimple", and its close proximity to L_5, is a very attractive source of raw materials. The lunar soil composition has such elements as oxygen, aluminum, titanium, silicon, iron, and magnesium as observed from lunar samples brought to Earth by the manned American Apollo missions, and the unmanned Soviet Luna missions (Taylor, 1975; Cherkasov and Shvarev, 1975; French, 1977).

Studies of projects such as the construction of solar power satellites indicate that for a large-scale operation, it is feasible to acquire the resource capacity of the Moon to compensate for the high Earth-to-orbit transportation costs of initial facilities (Mendell, 1985). The Moon can supply practically all of the elements necessary to sustain human life and technology in a space station (NASA, 1977; O'Neill, 1977).

Asteroids offer such elements as hydrogen, carbon, and nitrogen (NASA, 1977). They also have shallow gravitational wells, move in well-determined orbits, and could be reached with relative ease. Asteroids can be very valuable resources, especially if they are composed of large amounts of water ice and carbonaceous chondrite (NASA, 1977).

3. Dangerous elements

Solar Radiation

As mentioned earlier, inhabitants of any space facility will need protection from the ionizing radiation of the Sun. Solar flares and cosmic rays are direct and profound hazards to life in space. When violent eruptions, or flares, occur on the surface of the Sun, high energy protons are released. These elements are capable of distributing extreme doses of radiation. Because this radiation travels at speeds approaching that of light, and takes only minutes to journey from the Sun, humans will have to be constantly protected.

Meteors

Meteors represent another potential hazard to a space colony. A meteor as little as one gram can shatter a window pane in space. Meteors as large as one meter in diameter can cause major structural damage. Two effects of a meteor direct hit are loss of atmosphere, and damage due to shock waves. Shock waves of only 5 psi overpressure can knock down buildings and kill an average human being (NASA, 1977). The general rule of thumb is; the larger the space station, the less effect a direct meteor hit will have. The chances of a meteor one meter in diameter or larger colliding into a space station are 1:1,000,000. According to NASA (1977), the hazards of meteoroids pose little danger to kilometer-sized habitats. Regardless, emergency survival shelters for inhabitants should be given consideration in the design of the habitat.

Human Needs in a Space Environment

Man is an animal. He retains, and is substantially stimulated by, his animal instincts. Man requires an environment that offers optimum development. All of us are animals of the field, the forest, the ocean, and the plains. Since birth, we have the love of pure air, a dry place to walk and sleep, and need the warmth of the sun on our bodies. We instinctively love the feel and smell of freshly turned earth, the taste and twinkle of a clear mountain stream, the coolness under a wooded canopy, and the puffs of white clouds in a bright blue sky. Simonds (1983) stated that all things being equal, a truly happy person is one who lives in closest and fullest harmony with nature.

The human being is the most unique among the animals because of our desire for order and beauty. It is uncertain whether any other creature so relishes a view, can see the grandeur of a large Sequoia, or is fascinated with the splendor of a rocky shoreline. An environment of perfect order and beauty can never be created, or maintained, because an ecosystem of any kind is always changing and expanding.

As landscape architects who, as defined by Newton (1971), "arrange land, together with the spaces and objects upon it, for safe, efficient, healthful, and pleasant human use", we strive toward the creation of this ideal environment. Simonds believed that it is not enough to fulfill the instincts of the physical animal alone, we must satisfy the requirements of "the complete being".

These basic concepts hold true for Man as he currently exists on the planet Earth. They also apply to places off the Earth to which man may travel and live. When man establishes permanent settlements in orbit above the earth, or on planetary bodies, he will have to manage the hostile environment that is unique to space. If the people that populate these colonies are to lead happy, productive, "normal" lives, they will require a habitat - wholly man-made - that can sustain them and fulfill the requirements of "the complete being".

As in the Earth environment described above, the human population within a space colony will require the same elementary essentials such as shelter, air, food, water, and gravity. In addition to the basic requirements of life the needs of space colonists must also be addressed. Certainly, psychological needs will be directly impacted by the space station environment; an environment to which the landscape architect can make meaningful contributions.

The space station habitat will obviously be significantly impacted by the selected design team members and their associated bias as a master plan concept for the space station community is evolved. Exactly what are the needs required in space environments, and how would these differ from needs required on Earth?

This is a question that cannot yet be fully answered. Man can live in space environments that deviate from Earth, but the physiological and psychological effects of an appreciable deviation are unknown at this time. Therefore, with respect to human safety and health, the living conditions in the first space dwellings should be designed similar to what one would find on Earth. A list of the more basic needs required by the inhabitants of an initial space community can be found is Table 2-1. A brief description of each physiological need, along with other considerations, follows (from NASA, 1977; Trefil, 1981):

TABLE 2-1 SUMMARY OF PHYSIOLOGICAL DESIGN CRITERIA (adapted from NASA, 1977)

Pseudogravity	1g
Rate of Rotation	1.85 rpm
Maximum Safe Radiation Exposure for General Population	5 rem/year
Temperature	21.5°-26.5° C (70°-80° F)
Atmospheric composition	
Oxygen	100-170mm Hg
Inert gases (Nitrogen)	590mm Hg
Carbon dioxide	3mm Hg
Water/water vapor	5-7.5mm Hg

A. Pseudogravity

Gravity, as we know it on Earth, provides continuous and uniform weight to all objects. All plant and animal life has genetically adapted to the effects of gravity. Exactly what effects prolonged exposure to zero gravity, (zero g), as found in free space, would have on human physiology is not known.

Results of medical investigations into man's ability to adapt to zero g conducted during the Skylab missions were not encouraging. All extended space flights have provided evidence that a loss of calcium occurred, which, in turn led to a loss in structural material in weight-bearing bones. Other medical problems came to light such as hormonal imbalances, circulation problems, hypoglycemia, and electrolyte imbalances due to decalcification (Compton, 1983).

Medical problems also were associated with readaptation to Earth gravity, (one g). Astronauts experienced increased heart rates, muscular reflex changes, venous pooling, and leucocytosis (increased white blood cells) (NASA, 1977).

This knowledge of the effects of weightlessness on physiology acquired during the Skylab missions indicates that it would be necessary to have some measure of gravity in the first space colony environments. However, given the continual advancement of medical technology the possibility remains that medical discoveries offering the potential of maintaining bone strength and eliminating other associated medical problems could become reality without artificial gravity. With experience gained, and the advent of technological advances certain in time, flexibility in the design of space station environments would be a wise approach.

The most feasible way to generate Earth-like, or pseudogravity, in the space colony is by rotation of the station, in this case, a sphere. Thus, as the sphere rotates at approximately two revolutions per minute, (rpm), centrifugal force is provided which in turn provides pseudogravity. Certainly, the utilization of pseudogravity, (1g), should obviously be required design criteria, until more medical information becomes available.

B. Atmosphere

The atmosphere in the sphere must be of acceptable composition and pressure, capable of supporting human life. Most of the population on Earth is accustomed to living near sea level, where the atmosphere is about 14.7 pounds per square inch. In contrast, mountainous regions at higher altitudes from 5,000 to 11,000 feet typically encounter atmospheric pressure 2 psi, plus or minus. The pressure provided in a space habitat will probably reflect that of mountain regions. O'Neill (1977) suggests a pressure in the sphere equal to that of Denver, Colorado, about 2.5 pounds per square inch.

The gaseous composition of the atmosphere in a space colony will have, of course, oxygen. Other gases, such as nitrogen, are required to maintain growth development in plants. Carbon dioxide levels will be maintained at a level high enough to permit plant photosynthesis. Inert gases, such as helium, will be present to assist in fire suppression.

Temperature within the space station habitat will be a comfortable range of from seventy to eighty degrees. Higher or lower temperatures can be created for various human activities if the need arises. The relative humidity will be maintained at forty percent.

C. Food and Water

Permanent populations living in space must have a continuous and readily available food supply. No longer will space food that resembles "coarse granulated rubber with a sausage flavor" made famous by the Apollo missions, be tolerated (Compton, 1983). Instead, abundant food will be grown in special tori, or rings, attached on either end of the sphere.

This agriculture area, in a completely controlled climate, will be staggered in growing climates that are unique to each tori. In this manner, a variety of crops will be under cultivation at any particular time, (O'Neill, 1977). For example, bananas can be harvested along with wheat. This is impossible to do on Earth, but relatively simple to accomplish in space.

Clean, fresh water in a space habitat must be plentiful enough to sustain life and support sanitation requirements. For a community of 10,000 inhabitants, water will also be used as a source of recreation. Once water is introduced into the habitat, it will be recycled indefinitely in a closed-loop ecological cycle.

D. Shelter

Certainly structures that resemble houses or apartments will be the living units for the colonists. But the entire sphere habitat will also require shelter from cosmic ray activity, and solar radiation. To accomplish this end, the sphere will have a skin several feet thick that will block radiation, in addition to providing protection from meteoroids. The agricultural portion of the habitat will not need this protection, because the radiation will not be harmful to plant life. In fact, the crop production will be quite high, due to abundant energy from the Sun.

E. Industry

If a successful, economically viable colony is to be founded in space, the people living in that colony must perform specific tasks as contributions toward that viability. For the well-being of the inhabitants, they must have a purpose; some tangible, valuable, product of their labors that will deliver a return on investment of the space station, and establish the community as a viable economic asset to Earth. That is, the space station community must be justifiable. There must be a worthwhile product manufactured that will benefit planet Earth, and at the same time institute economic development and provide permanent employment to the station population.

The primary product of the first space settlement will be satellite solar power stations. These power stations will be built in an industrial facility located outside, but in close proximity to, the sphere habitat. Upon construction, the power stations will be placed in geosynchronous orbit above the Earth, where they will collect and convert solar radiation to microwave energy. This energy will then be sent from the power stations via transmitters in a microwave beam to receiving stations on Earth, where it will be converted to electricity for use (O'Neill, 1977, 1975).

Basic Environmental Design and Habitability Considerations

A space station may take on a variety of configurations. However, in addition to the physiological considerations, the station configuration has to be designed around certain environmental criteria. The criteria for environmental design are both qualitative and quantitative. The quantitative requirements are listed in Table 2-2, and the qualitative criteria are presented in Table 2-5 (NASA, 1977).

A. Quantitative Space Requirements in a Space Colony

Habitats for humans in space must be designed to provide comfortable living, service, social, and recreational facilities. Criteria must be determined for area available, that is, the amount of area per person, (see Table 2-2). This calculated space is important for two reasons: 1) it determines the population density, and 2) limits services and utilities that will need to be provided for the inhabitants.

According to NASA (1977), there should be at least 430 ft^2 of living area per person. Therefore, a two-story house with 430ft^2 of floorspace would occupy only 215ft^2 of projected area. The area actually used can be made to be larger than projected area by constructing several stories within a building.

TABLE 2-2 SUMMARY OF QUANTITATIVE ENVIRONMENTAL DESIGN CRITERIA (adapted from NASA, 1977)	
Population: men, women, children	10,000
Community and Residential (projected area/person, ft^2)	505
Agriculture (projected area/person, ft^2)	215
Community and Residential (volume/person, yds^3)	1100
Agriculture (volume/person, yds^3)	1200

Most cities in the United States have considerably more than 430ft^2 per inhabitant, but several cities outside of the U.S., such as those in France, have less (see Table 2-3). It will be the task of the space station design team to minimize the feeling of crowding by conscientious organization of these spaces, while still maintaining essential services.

TABLE 2-3 AVAILABLE LAND PER CAPITA IN SELECTED CITIES AND TOWNS (adapted from De Chiara, 1982)

Location	Per capita living area ft^2/person
Boston, MS	2000
Chicago, IL	1850
El Paso, TX	10230
Jersey City, NJ	1600
New York, NY	1100
Manhattan Island, NY	400
San Francisco, CA	1770
St. Paul, France	290
Vence, France	500
Rome, Italy	430
Columbia, MD	5400
Bernal Sphere One	430

Land use plans must be developed for a space colony of 10,000 inhabitants in a process similar to that of planning cities on Earth, with quantitative calculations of the volumes and areas required. The types of spaces that need to be provided are:

1. Residential - dwelling units, private outdoor space, pedestrian access points.
2. Commercial - retail businesses, office space, outdoor areas,
3. Public and semi-public enclosed space - government buildings, hospitals, schools, churches, recreation and entertainment.
4. Public open space - parks, outdoor recreation: swimming, golf, playgrounds, zoo.
5. Light industry - personal services, etc.
6. Transportation - bike paths, pedestrian walks.
7. Utilities - electrical, communications, air distribution, sewage, water treatment (recycling).
8. Agriculture - located in tori.
9. Heavy industry - will be located outside sphere.

In order to estimate the amount of area and volume required for these spaces, analogies can be made to the organization and distribution of these spaces on Earth. Sufficient open space must be provided for the psychological health of individuals, that is, these types of spaces are as important in space as they are on Earth.

Allocation of space among the assorted community institutions such as schools, residences, hospitals, commercial, etc., is determined by estimations of allocations of land use, as shown in Table 2-4.

TABLE 2-4 SUMMARY OF COMMUNITY SPACE AND AREA ALLOCATIONS (adapted from NASA, 1977)

Type of Space	Surface area (ft^2) required /person	No. of levels	Projected area (ft^2)/ person	Estimated height (feet)	Volume (Yds^3)
Residential	530	4	130	10	5190
Business					
Shops	25	2	10	15	325
Offices	10	3	3.5	15	140
Public & Semi-Public:					
Schools	10	3	3	12	135
Hospital	3	1	3	16	5.5
Assembly (churches, halls, etc.)	16	1	16	32	530
Recreation & Entertainment	10	1	10	103	105
Public Open Space	110	1	110	165	17660
Service Industry	45	2	20	20	850
Storage	55	4	10	10	565
Transportation	130	1	130	20	254
Mechanical Utilities (Sewage, water, electric, etc.)	47	1	47	15	585
Agriculture Spaces					
Crop areas	475	3	160	50	2330
Animal areas	55	3	18	50	2650
Food processing (collection, storage, etc.)	45	3	14	50	2130
Drying areas	90	3	30	50	4240
TOTALS	1656		714.5		37,694.5

B. Qualitative Space Requirements in a Space Colony

As noted heretofore, paralleling the major physiological needs above are the equally important psychological and aesthetic needs of the space station inhabitants, (see Table 2-5). Addressing these needs through conceptual designs, development and implementation is the area in which the landscape architecture profession can make its greatest contributions. As Stuster (1986) states:

> "It is imperative that we design truly functional habitats--environments that routinely support life and encourage productivity--if the full potential of the space station is to be achieved."

TABLE 2-5 SUMMARY OF QUALITATIVE ENVIRONMENTAL DESIGN CRITERIA (adapted from NASA, 1977)

Long sightlines
Large overhead clearance
Noncontrollable/unpredictable parts of the environment (plants, animals, children)
External views of Earth, Moon, stars, etc.
Parts of interior out of sight of others
Natural sunlight
Method of visiting outside environment of space
Availability of privacy
Good communications, internally and with Earth
Capability of physically isolating certain spaces of habitat
Flexible internal organization
Detail design elements of interior left to inhabitants

The Need for Diversity and Variety

Environmental psychologists and behavioral scientists (Brady, 1980; Proshansky, 1970) have noted that diversity, variety, flexibility, and motivation can make otherwise monotonous environments acceptable to their inhabitants.

When the environment is perceived as different from what one desires or is accustomed, stress results, and that stress, especially in a space environment, can be reinforced by a feeling of total isolation. Stress can be relieved by internal (psychological) adaptation or by external (environmental) changes. The space station environment can be designed to reduce such stresses by the inclusion of specific criteria.

The ideal conceptual design of a space station is to construct a setting that will provide the inhabitants alternate means of fulfilling their goals for an environment, thus giving them freedom of choice. Such a goal is attainable given the large size of the sphere, which frees inhabitants from limitations of present-day space stations.

The interior master plan concept should allow details to be left as choices for the inhabitants themselves. This is analogous to developing a master plan for a planned unit development on Earth, where each homeowner has the opportunity to "fix up" the house and yard to suit their particular tastes. Therefore, the major effort in the design of a space habitat should not be on the specifics, but on the range of options available. The space colonists will require access to large and small spaces, both public and private, and to long and short vistas. However, the land plan and architectural designs must be flexible and manipulative. The inhabitants need to be able to use and change these spaces in harmony with their individual wants and needs. The original basic design of the habitat must permit the inhabitants to be able to reshape the interior by developing and altering the spaces over time.

Another method of relieving environmental stress in a space habitat is to provide large-scale vistas. To produce this effect, the habitat has to be of sufficient space to lessen the sense of its being man-made. To accomplish this, it may also be necessary to limit a view so that the entire space station structure cannot be seen in a single scan by use of broken sightlines and the employment of microenvironments (Klaus, 1987).

Yet another way to provide views is by mirrors to the outside space environment. Regions of zero gravity and views of the Earth, Moon, and stars would provide stimuli by the availability of panoramic vistas, long sightlines, and a perception of reality beyond the human scale.

The artificial habitat can be further reduced by the presence of natural sunlight, vegetation, and animals. The vegetation would be especially necessary to produce an "Earth-like" environment, for both the humans and animals. Plant life be used for both aesthetics and food. The inclusion of natural light from the Sun is also a necessity, because it is required for good health in humans and for plant growth alike!

Landscape Architecture and Contributions to a Space Habitat

When considering the landscape architectural contributions toward space habitats, the questions that most often arise are: In what sense is the function of the environment significant to the total space colony effort? If the difficult technical problems of constructing a large-scale space station, placing it in permanent orbit, and furnishing it with a closed-loop ecological system can be solved, then are not the psychological and aesthetic design considerations less critical?

The impression is given that to determine the landscape architectural requirements of the colony at L_5, all that need be done is to survey the prospective inhabitants as to what kind of environment they would prefer - for example, sub-tropical or Alpine - and then unravel the technical problems of fabricating such desires. The colonists would then have an ideal utopian environment, pollution-free, weather made to order, with landscapes on demand. Even though speculating about such a possibility is appealing, it is far too simplistic a view compared to the actual challenge, (Grey, 1977).

The underlying concern is with the creation of a habitat that is wholly artificial, and therefore certainly more limited than any comparable task on Earth. An environment in space must be able to attract colonists to live in it, and be able to support their existence for many years. Unless such an environment can be provided, the solution of all the other technical issues upon which the endeavors of constructing a permanent settlement in space rests will be in vain.

CHAPTER III
METHODOLOGY AND PROCEDURES

RESEARCH INTENT

This study investigates the contributions that the profession of landscape architecture might offer to the design of space station living environments. It employs two approaches, archival research and focused interviews. These methods are discussed in the following sections.

In addition to providing a basis for this study, the information has also been utilized in the development of a conceptual design study of a space habitat, Bernal Sphere One. This is a first attempt - the initial undertaking - to comprehend the design problems that may be encountered in space station habitat design on a large scale. A brief design intent and graphic illustration for the living environment of Bernal Sphere One is found in Appendix A.

DEFINITIONS

Contributions - The expertise and specialized knowledge encompassed within the profession of landscape architecture that might be contributed toward the development of space station habitat design generated by a multidisciplinary space facility design team.

Habitability - In the context of the space station, habitability is defined as the extent to which an environment promotes the productivity, performance, and well-being of its occupants.

PROCEDURE

Archival Research

Prior to investigating what contributions the landscape architectural profession could make toward the design of space station environments, it was necessary to understand the properties of space, and what constituted a space station environment.

The search was conducted by utilizing card catalogs, computer searches, and inter-library searches. Literature material and graphic illustrations were obtained for Bernal Sphere One from the Space Studies Institute in Princeton, New Jersey; the foremost authority on large-scale space facilities systems.

Focused Interviews

Two types of interviews were conducted during the course of this research:

1) face-to-face personal interviews

2) phone interviews

The purpose of these interviews was to focus discussion on the following concepts:

a) multidisciplinary space facility design teams

b) space stations, (planetary and orbiting)

c) habitability design considerations for environments off the Earth.

d) to gain insight as to how the profession of landscape architecture is viewed by professionals involved with the space station design and space programs in general.

It was not intended for these interviews to be of a highly structured question-and-answer nature. That is, there was not a strict text adhered to. Initiative was taken on the part of the interviewer to allow the subjects freedom to express their views and expert opinions about the subject matter being discussed. Although this manner of data gathering lacks scientific procedure, and fails to produce hard statistical information, it was not intended for the interviews to yield this type of data. Statistical validity was not the important consideration. The questioning was intentionally open-ended and semi-directed, with the aim being to open up avenues that otherwise would not have been found using a more traditional structured format. In addition, the questions that were asked cannot be answered through a selected menu of choices.

If, during the course of the interview, the conversation drifted and the focus of the interview was lost, the subject was exposed to a series of questions used to focus the interview (see Appendix B).

Arrangements were made for interviews with key individuals who were involved in the design of space facilities. These individuals were associated with either government, corporate, or private organizations. Once again, this is a departure from traditional research methods. A significant sample was not used because of the limited availability of experts in the field of space facility design. Therefore, the selection of participants was necessarily restricted. In addition to these individuals, the President of the American Society of Landscape Architects (ASLA) was interviewed. The subjects were told their names would remain confidential, and only their occupations would be listed. A list of the people interviewed appear in Table 3-1. The list is arranged in alphabetical order according to occupation.

TABLE 3-1 LIST OF SUBJECTS INTERVIEWED

PROFESSION	NUMBER
Astronaut (retired)	2
Corporate Principal (aerospace industry)	1
Environmental Psychologist	3
Landscape Architect	1
Physicist/Engineer	1
Private Space Research Institutes	2
Space Architect	2

Twenty individuals were invited to interview. Of these, a total of twelve people participated. Two of the twelve were phone interviews, the remainder were face-to-face interviews. Each interview averaged 10 minutes in length. Phone interviews were recorded, with the subject's permission.

The face-to-face interviews were conducted at two separate conferences. The first eight interviews were conducted in August, 1987 during the conference *Research in Antarctica: Applications to Life in Space*, held at Sunnyvale, CA. This conference was sponsored by NASA and the Division of Polar Programs. The final two interviews were held in October, 1988 during the conference *Designs for the Future*, held at Tulsa, OK, sponsored by the ASLA, and the American Institute of Architects (AIA). The two phone interviews were conducted in November, 1988.

At the commencement of each interview session, the subject read a one page abstract outlining the purpose of this study (see Appendix C). In the case of the phone interviews, a copy of the abstract was mailed two weeks prior to the interview. All of the subjects responded to the study intent statement, and discussed the concepts of space settlements and multidisciplinary space facility design teams with the interviewer. This information is presented in Chapter IV.

CHAPTER IV
RESULTS

The results of the study are presented in two sections. The first section contains an overview of the archival research outcomes. The second section contains the personal interview results.

OVERVIEW OF ARCHIVAL RESEARCH

The intense literature search revealed that available material with respect to space and space station facilities is enormous. However, the majority of the literature available was science fiction. Although this material was useful in organizing a historical review, truly factual material pertaining to the specific design criteria needed for the actual construction of, and the environmental conditions within a space station, was limited.

The most valuable factual information came from research published by the National Aeronautics and Space Administration (NASA), the American Institute of Aeronautics and Astronautics (AIAA), and the Space Studies Institute (SSI). Bibliographies from various studies conducted by these organizations were very valuable. Like a chain reaction, one source after another supplied useful information.

A majority of the literature reviewed pertained to space stations in general, including designs for facilities of varying magnitudes on Mars, the Moon, and in orbit about the Earth. As the review of literature progressed, it became obvious a choice had to be made among these alternatives as to the specific type of space station that would be appropriate for this study, and where such a station would be located.

The choice was made in favor of an orbiting space station because the long-term potential benefits to the environment on Earth that such a facility would generate far out-weighed those offered by Lunar or Martian bases. Another reason for this choice is that such a station is technically feasible to construct, given current technology.

Yet another decision had to be made relative to the type of space station configuration. While several space station configurations have been generated, the Bernal Sphere configuration was selected for consideration since it is the focus of numerous studies currently underway, and as a result, more current data is readily obtainable.

The majority of literature material and graphic illustrations were obtained for Bernal Sphere One from the Space Studies Institute in Princeton, New Jersey. This private organization is the foremost authority on large-scale space facilities systems.

In addition to specific station design and physical requirements, the literature also disclosed that since the beginning of manned spaceflight, the physiological needs of astronauts were of major concern; and yet relatively little planning attention has been given regarding the astronauts' psychological and social well-being. In light of the short duration of the early flights of the Mercury, Gemini, and Apollo missions, the lack of psychological emphasis was justified. NASA held the reasonable assumption that the astronauts would be able to tolerate certain deprivations for these brief periods. However, with the advent of the longer Skylab missions, it soon became evident that a greater variety of human needs would have to be accommodated. Thus, the need for incorporating human "habitability" within space facility interiors has been determined.

PERSONAL INTERVIEW RESULTS

In general terms, the interviews revealed that there are several schools of thought concerning the settlement of space, including:

1) bases should only be established on the Moon.
2) Mars should be the next step, vs the Moon or orbiting space stations.
3) orbiting space stations are the only practical solution for large-scale settlements, but small supporting facilities on the Lunar surface, such as a Lunar mining operation, would be necessary to support orbiting stations.

All of the subjects, with the exception of the landscape architect, are currently participating in research activities complimenting particular schools of thought regarding space habitation. Thus, responses received tended to be strongly biased in favor of, and in reference to, a specific space project associated with the various schools of thought previously discussed. Throughout all of the interviews, each participant agreed that the environment of any large habitat off the Earth would have to be carefully planned by multidisciplinary teams of highly skilled professionals, specifically, engineers and environmental designers.

The term "environmental designer" was a term commonly used by nearly all the interviewed participants associated with space station design. When the subjects were pressed for a definition of "environmental designer", the terms "architect" and/or "interior designer" were usually offered as explanations.

As the interviews progressed, the profession of landscape architecture was introduced as a possible contributor to the proposed space station environmental design team. Of the group interviewed, the environmental psychologists and astronauts tended to associate landscape architects with nurseries, tree services, etc. The remainder of the interview group were more familiar with the landscape architectural profession, but did not consider their potential contributions to be significant. However, when the subjects were informed as to the types of expertise offered by the landscape architectural profession, the majority indicated that landscape architects could be important contributing members of multidisciplinary teams.

The general information of each interview follows:

1. ASTRONAUTS

Two astronauts were interviewed, both of which served on Skylab missions. One astronaut was a pilot, and the other a medical doctor.

The pilot astronaut was very skeptical about the concept of space settlements, particularly large orbiting stations, such as Bernal Sphere One. This subject saw no possibility of the need for landscape architects on a space station environmental design team. However, as stated above, once the subject was aware of the possible contributions the landscape architectural profession might offer in the way of planning facilities, etc., the skepticism subsided. As a former member of Skylab, this subject acknowledged the need for improvement of space habitats.

The medical doctor astronaut was "vaguely familiar" with the landscape architectural profession. This subject was very excited about the possibility of plants in a space environment, if used as a source of psychological well-being as well as a source for food. He went on to suggest that plants as a source of food and plants for well-being should be kept separate. "If I woke up from a nights sleep and discovered someone had eaten my favorite plant, I would be in a foul state of mind". This point was well taken.

2. CORPORATE PRINCIPAL

This subject was the head of a research and design firm specializing in space habitats. He was enthusiastic about large-scale space facilities, and indicated a preference for Lunar bases. He suggested that the landscape architectural profession should become active participants in the conferences encompassing habitat design in space if the profession was to become recognized as a valuable asset to space facility design teams. He went on to state that "landscape architects need to be publicized more - some people are not aware the profession exists, or what the profession does".

3. ENVIRONMENTAL PSYCHOLOGISTS

Three environmental psychologists were interviewed. All three were conducting research on habitability requirements for small-scale space stations soon to be in orbit. Though they had not considered landscape architects as viable members of a space habitat design team, all three agreed the profession potentially had significant contributions to offer. One subject stated that humans are now at the point that marks the end of their term as visitors in space and are beginning their role as space inhabitants. To acquire the knowledge needed and ease this passage, the thoughtful contributions from many disciplines are necessary.

In addition to expertise currently existing within the profession of landscape architecture, the environmental psychologists suggested that "principles of habitat design" and "human factors research" be incorporated into the basic understanding of those pursuing an interest in space habitat design. As one environmental psychologist stated "this would help in establishing them, (the landscape architectural profession),...giving them more creditability and marketability to the major contractors, and NASA".

4. LANDSCAPE ARCHITECT

Landscape architectural involvement in space station habitat and design was "stretching the bubble in the right direction", according to the subject landscape architect that was interviewed. This person stated that the aerospace industry needs to be made more aware of what the profession of landscape architecture had to offer. Another problem that needed to be corrected was that "the landscape architecture profession needs to be made aware of the opportunities that space design had to offer". One reason there are no landscape architects currently involved in space facility design, according to this subject, is that no one has yet considered, or more likely, no one is aware, of how to use the expertise the profession in the design of space environments. That is to say, the opportunity is there, but no one has considered the possibilities.

In addition, she emphasized that for landscape architects considering this field, the traditional education would have to be supplemented with studies in "habitability" and "environmental psychology".

5. PHYSICIST/ENGINEER

This subject has been on the design team for the international space station, which is scheduled to be placed in orbit in the early 1990's. He is currently a technical assistant working on the design of a Lunar base station. This person stated that, "NASA needs expertise in areas of planning, architecture and landscape architecture to help plan spaces. We realize we (physicists and engineers) cannot know what these people know about space organization. Process is important - we need to understand what we need to do". When asked what landscape architects could specifically contribute, the subject replied "layout of the base station, processing plants, landing pads, and habitats, (on the Moon), this could be the landscape architect's role".

6. PRIVATE RESEARCH INSTITUTES

Two subjects were interviewed under this category. Subject One is Vice President of a private institute that is conducting research into the development of large-scale orbiting space stations. Subject two is currently involved with biospherics research, and is a candidate for a position as a member of a team that will live and work inside a terrestrial space biosphere for two years.

Subject one was "very excited" about the possibility of landscape architects becoming members of space facility design teams. This subject believed that the landscape architecture profession had a lot to offer in creating a high quality of life within a space station environment. He went on to say that not only are landscape architects needed on space facility design teams, but, once the station is constructed and people are living and working in it, "landscape architects would be valuable members of the community in that they could assist in maintaining (the) man-made space habitats".

Subject two stated she had never considered the notion of landscape architects on a design team. The biosphere project she is involved with was designed by architects, engineers, geographers, and biologists. The biosphere is designed to be "very functional in maintaining human needs, and being an efficient closed-loop ecological system". She went on to say if the landscape architectural profession is to be a contributor to the design of space habitats, they would have to "have a basic understanding of how these systems function, and be able to develope conceptual designs with this in mind".

7. SPACE ARCHITECTS

At the time the interviews took place, it was not known that the two architects interviewed were partners in their own firm. Both subjects were from the Lunar school of thought, and did not discuss the possibility of orbiting space stations.

Subject Architect One did acknowledge the need for innovative Earth-like habitats for Lunar bases. He related his belief that architects should be the designers of interior Lunar habitats, and did agree that the landscape architecture profession could eventually be a valuable asset in the design of bases on the Moon, if they acquired new skills and knowledge of the space (Lunar) environment in addition to traditional training.

Subject Architect Two was, at best, tolerant of the interview. He was persistent in his negative attack upon the landscape architectural profession. His chief complaint was that he did not believe the profession was serious enough to be considered for a position on the design team. His belief was that landscape architects would "dabble, and not become true team players". He also related his opinion that environmental psychologists and architects could do the work that may require the skills of a landscape architect.

CHAPTER V
OBSERVATIONS AND CONCLUSIONS

As noted heretofore, the purpose of this study was aimed at addressing what contributions the landscape architectural profession could make to the design of the human habitat within space station environments. Following is an assessment of those findings, more specifically focused on:

1) a post-evaluation of the methodology as initially stated in terms of its success and limitations.
2) a summary of the contributions the landscape architect might advance as a member of the space habitat design team as observed during the course of the study.
3) a summary of significant conclusions established as a result of this study.

EVALUATION

Application

The process of archival research and personal interviews was developed as the foundation of this study in an attempt to obtain useful and accurate information within a reasonable economic and time framework regarding the probable requirements, limitations, and constraints of a space station habitat given the state of technology today. Overall, the process provided a working knowledge of space station habitats as viewed by the various experts and institutions currently investigating space station environments, and appears to have generated acceptable results. In reality, there are few individuals in the world community who are involved in the design of human habitats within the large-scale space facilities.

A majority of the individuals interviewed voiced the opinion that it was encouraging to see other professions, especially those from the environmental design professions, taking an active interest in the development of space station environments.

Limitations

All of those individuals involved in any major capacity within the space program - and specifically the design of space station habitats - are extremely busy, and extremely difficult to contact. Conducting interviews via telephone proved fruitless, even if previous arrangements had been made for appointments. The individuals involved were constantly short of time, or behind in daily schedules. While it would have been helpful to interview others beyond the twelve individuals included within this study, economics would not allow it.

Interviewing key individuals at regional and national conferences proved to be the most fruitful means of gaining the necessary insights and perspective to pursue this study. Secretaries were very helpful in divulging information as to future agendas of key persons. It was in this manner that the subjects were known to be at certain conferences at certain times.

Also due to economic constraints, no foreign space agencies were contacted. This was unfortunate, as a vast resource was left untapped. Future studies could provide a much expanded viewpoint and penetration into the design of space station habitats and should include expertise currently found in countries such as the Soviet Union, France, Germany, England, and Japan.

For example, the Soviet Union has by far the most practical experience living and working in a space station environment. They have continually manned the space station MIR for approximately the past five years. Most of the factual information about stress, medicine, space manufacturing, and a host of other topics has surfaced as a direct result of the Soviet commitment to maintaining a fully manned space station. They are currently developing a rocket apparatus that will carry twelve cosmonauts to the surface of the planet Mars, and return safely to Earth.

There is also an international effort to establish a permanently manned space station in geosynchronous orbit. Led by the United States and the Soviet Union, Japan, England, and the European Space Agency (ESA) are in the final stages of designing the largest space facility ever constructed to be put in orbit. This space station will enable scientists to conduct experiments that would be impossible in an Earth environment. It will also provide an opportunity for important long-term research into human factors and space station habitability requirements.

CONCLUSIONS

Responses to the research abstract, and the six questions (see Appendix B) concerning landscape architecture and space facility habitat design, indicated general agreement among the subjects that the landscape architectural profession did indeed have valuable skills and expertise to contribute to the design of space station environments. As presented in the background section of this study, the skills contributed by the landscape architectural profession should certainly enhance any large-scale space facility environment in terms of human habitability considerations. The following is a limited list of possible contributions:

1. Creation of an Earth-like sustainable landscape within the space station environment.
2. Conceptual design and master planning of "space communities".
3. Minimize the effects of acute and long-duration environmental stresses on human behavior by ensuring a comfortable and nonmonotonous environment.
4. Develop analytical guidelines for the design of habitable, functional and sustainable environments.

5. Develop specialized concepts for the generation of space station habitat design solutions and operational policies.

6. Evaluate evolving design solutions relative to the space station environment.

7. Post evaluation of space station environments once in operation to determine successes and failures of initial design assumptions.

8. Develope and generate computer simulations to aid in the planning and design of space station habitats.

9. Master planning of the base stations, processing plants, landing pads, and habitats, of Lunar stations.

10. Minimize the feeling of crowding by conscientious organization of spaces.

11. Estimate allocations of space station area/volume use including allocation of volume among the assorted community uses such as services, schools, residences, hospitals, commercial, industrial and agricultural areas.

12. Generate conceptual designs that will provide the inhabitants alternate means of fulfilling their goals for an environment, thus giving them freedom of choice.

13. Develop designs for separate pedestrian and vehicular transportation systems within the habitat.

14. Develop guidelines and design concepts for the development of sustainable, closed-loop ecological systems, i.e. biospheres.

15. Analyze, evaluate, and recommend selected plant species that are compatible with specific habitat climates, planting design criteria, and conceptual planting designs.

16. Develop documentation for the construction of "exterior" habitat improvements to be constructed as a part of the space station facility.

17. Develope recreational areas and concepts for innovative low-gravity recreational sports.

18. Establish good working relationships with all members of the multidisciplinary design team.

Additional Observations

The idea of constructing space stations as permanent settlements containing ten thousand inhabitants, in orbit about the Earth seems an impossible feat. However, if the planet Earth is to continue as a enduring entity as we know it today, space station communities will have to become a reality in the near future.

The ever-expanding population, and the exhaustion of renewable resources on the planet Earth demands that new resources, including living spaces and energy sources, be found if mankind is to continue as a species in the centuries ahead. By participating in the design of space station habitats, the profession of landscape architecture could be making a very significant contribution to the people of Earth. Implementing habitats in space would most likely be a beginning to relieving the environmental problems encountered here on Earth. Certainly, involvement by the landscape architectural profession would indeed add credence to the stated purpose of the profession as "stewards of the land" in the fullest sense.

The design and implementation of traditional amenities such as botanical gardens, golf courses, resorts, and planned unit developments are endeavors that improve the quality of life for the inhabitants on Earth; certainly these same proficiencies would be applicable to the design and implementation of permanent space station habitats.

Only by continuing to push at the boundaries of new design technology will the landscape architectural profession become involved in the design and development of space habitats. The future of the profession in the space station endeavor is tied directly to our vision and creativity in responding to the challenges that space offers.

CHAPTER VI
FUTURE RESEARCH NEEDS AND NEW SKILLS IN EDUCATION

The material that was acquired from literature sources gave only a preliminary indication of what elements would make up the interior habitat of proposed space stations. Conceptual drawings undertaken by graphic artists give little attention to the planning or design of the physical environment within the space station. The fact is, to date, consideration of the human living environment has not been a priority given the monumental engineering issues facing the space station challenge.

All of the literature without exception mentioned the need for basic research with respect to the physical elements and environment within a space station. The most important issue this study revealed is that to date no one has completed a design study for the habitat of a large-scale space station. This provides a real opportunity for the landscape architectural profession to undertake a leadership role in developing alternative conceptual design proposals for space station environments.

The landscape architect's ability to seize opportunities offered by membership on the interdisciplinary space design team charged with developing concepts for living environments within space station facilities requires the acquisition of new skills. Not only would landscape architects involved with such undertakings be charged with the comprehension and application of "traditional" design skills, they will also need to have a fundamental knowledge of aerospace technology and the engineering systems required to support such a proposed space station. Special constraints generated by the exotic requirements of a space station will place extensive limitations on conventional design methods and applications. Obviously, in the short term, the most practical method for acquiring these skills is individual research and total involvement as a member of the interdisciplinary design team. Over the long term, in the form of an advanced, intensely focused program, concentrating on space environments - perhaps within a research center directed toward the design considerations of space environments - would be the best approach.

In a special task force report Landscape Architecture into the 21st Century , (Marshall, 1981), The American Society of Landscape Architects (ASLA) identifies "...many new or improved skill needs for the future", that landscape architect students should obtain. The report goes on to state that "...the current core of basic design and technical skills would continue to serve the profession well...", but there are "...other, equally important..." skills that must be emphasized.

Specifically, the expansion of professional skills should occur, according to the ASLA, in computers, energy, communication, business, advocacy, and leadership. The educational skills required by the landscape architect involved in the design of space habitats will have to be expanded far beyond the traditional skills now emphasized. At the same time, the landscape architects pursuing those skills will be very limited in number within the foreseeable future.

Obviously, fundamental knowledge revolving around human behavior and adaptability within isolated environments over the long term would significantly enhance the effectiveness and credibility of the landscape architect as a member of the interdisciplinary team designing space facility habitats.

Knowledge related to closed-loop ecological systems (biospheres) is an absolute necessity to any landscape architect involved in the design of permanent space facilities. Biospherics is itself a relatively new field of study. Much of the understanding and knowledge of our present biosphere, Earth, and its integral parts has only been achieved quite recently. The Soviet Union has pioneered the study of biospherics through the work of V.I. Vernadsky, who coined the term biosphere, and was the first to use it in a scientific sense. At the present time, private corporations in the United States are conducting extensive research in the field of biospherics. The master planning and design of these facilities would go far toward providing a potential means for establishing permanent stations in space. This is an ideal opportunity for the landscape architectural profession to become active participants on the multidisciplinary design teams that create these experimental environments.

New skills and education is the responsibility of the student, educational programs, and the profession of landscape architecture. The success of expanding the profession of landscape architecture depends on these individuals accepting additional educational responsibilities. If landscape architects are to be involved in space facility design, they must be properly prepared in a special educational environment.

One way to accomplish this would be to establish a special design program that would offer courses and research in space architecture. Such a curriculum could provide faculty, staff, and other necessary resources at one location to undertake advanced manned space mission studies. This could be a very innovative, popular, and unique education program.

By continuing to push at the boundaries of new design technology, the profession of landscape architecture will be among the professions leading in the design and development of space station habitats. The economic future of the profession in space is tied to our ability to stretch our vision and creativity to respond to the challenges that space offers.

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APPENDIX A

The space station design contained in this paper is a conceptual representation of a space station. The design is intended to be a master plan for Umbriel Station, a sister station of Bernal Sphere One (BSO), the first permanent colony in space. The general dimensions and shape of Umbriel Station are the same as those shown in Figures 1 and 2. The location of Umbriel Station is at Lagrangian libration point five, (L_5), as seen in Figure 5. All other aspects of Umbriel Station are in accordance with all Figures and Tables presented in this study. The following text is printed on the Umbriel Station conceptual plan:

A General Description of the Overall System

This design of Umbriel Station is a conceptual representation of one possible solution. The heart of this system is a 56.65 hectare (140 acre) space habitat where a community of 10,000 people will be the sole occupants of Umbriel Station, the first permanent colony in space. These people will be employed, have families, and live out normal lives in the same manner as the inhabitants of Earth. The illustration in Figure 1 depicts the sphere and torus arrangement of the station, in which the people will live, in a scale comparison to another large man-made structure.

Umbriel Station will orbit the Earth in the same orbit as the Moon in a stationary attitude that is equidistant from both the Earth and the Moon. This point in space is called the Lagrangian libration point, or L_5. An illustration of these locations is shown in Figure 3.

The sphere habitat consists of a pressurized aluminum sphere 500 meters (1680 feet) in diameter, with a circumference at the equator of 1575 meters or approximately one mile, as seen in Figure 2. On either end of the sphere are the agricultural areas. These are located in a series of sectional rings (tori), which are connected side by side and form large fields at the same level.

The entire habitat rotates at 1.85 revolutions per minute about a central axis. This will provide Earth-normal-gravity at the equator. The interior of the habitat is illuminated with natural sunshine. The Sun's rays are deflected by mirrors on either end of the sphere, and reflected inside through louvered "windows", (E), which act as a baffle to suppress dangerous cosmic radiation. With the assistance of the natural sunshine and regulated farming methods, the colonists are able to grow enough food for themselves within the tori on approximately 200 acres.

Plentiful solar energy and massive quantities of regolith (lunar soil) are the key ingredients to establishing a community in space. Lunar soil is used for:

1) shielding from cosmic radiation

2) raw material for industrial manufacturing

3) as a source for space station construction materials.

The Sun accomplishes several tasks for the space facility. Two of the most important are: a) it promotes agriculture of unusual productivity, and b) it provides unlimited energy for industries essential to the success of the colony. The colony will use solar energy for the generation of electricity, and to power solar furnaces. With this solar energy supply the colonists refine aluminum, titanium, and silicon from lunar ores shipped from the Moon.

Using these refined elements, the fabrication of materials for the construction of new colonies and the creation of satellite solar power stations is possible. The satellite solar power stations are placed in geosynchronous orbit above the Earth where they will generate enormous quantities of electricity and transmit this energy, via microwave, to Earth receiving stations. The economic and environmental value of the solar power stations will more than support the initial investment costs of constructing the colony. They will also justify the existence of the colony, and promote the construction of additional, larger colonies.

DESIGN INTENT

The intent of this design is to develop a master plan study for the general development of an orbiting space community. The space habitat, because of its structure, mass, and shape is very sensitive to the choice of design elements. The design of this facility takes into consideration the following elements:

1) Physiological design criteria

2) Quantitative environmental design criteria

3) Qualitative environmental design criteria

4) Community space and area allocations

Some of these are presented in Tables 1 through 3. Although all of the above criteria are extremely important, the quality of the environment is weighed heavily in this master plan. The habitat is composed of four distinct living areas, or neighborhoods, which make up the community. By configuring the units in a stair-step fashion, and arranging the community on two living levels, maximum views and open space are maintained.

The top level is green open space (O) reserved for recreation and relaxation. The lower level contains the shopping, business, research, government offices, schools, hospital, churches, indoor recreation, and other community facilities.

Each individual living unit within a neighborhood is approximately 120 m^2 (1280 ft^2). All of the living units have a semi-private "garden", and a deck area. Long sightlines are strictly maintained for each unit, and no buildings are visible from garden terraces.

Transportation is primarily via walking or bicycle. Thoroughfares follow a serpentine path, allowing access to all locations on both levels. A highlight of the road system are the underwater routes inside glass tunnels that pass under Lake O'Neill, (P). A high-speed emergency transportation system is located below the lower level, as delineated by the letter "j". This route connects all the neighborhoods (A), with the community government center (g), the hospital (f), and the central hub (N). Commuter parking for those working in the space factory is at (M).

Transportation by water is accomplished by accessing the Bernal River, (D). This unique river not only has falls, but "ups" as well. Canoe enthusiasts that float the Bernal will drop down a waterfall and the river will carry them beneath each neighborhood. For example, in each of these subterranean worlds the canoeist will be exposed to environments similar to those found on the Amazon River in South America, or the Klondike in Canada and Alaska. When exiting, the river flows uphill to the top level once again.

The colonists will have a great diversity of unique recreational opportunities. One of the more popular features is the Bike Flight (F). This facility is located at a height of 150 m (490 ft), near the central hub, in zero gravity. Users will ride a device similar to a bicycle. Instead of turning a wheel for movement, the pedals will rotate a propeller, which in turn will provide a modest thrust that will move the user across the sphere.

Other recreational opportunities are:

1) Low gravity mountain bike trails that not only lead over but through the mountain (L)
2) Low gravity mountain climbing. The higher one climbs, the lighter that person is as they approach zero gravity (K). And low gravity diving from cliffs into the pool below (R).
3) Low gravity ballet and swimming (G).
4) Beaches along Lake O'Neill (J). On these beaches are locations for volleyball and OTL (over the line) (I).
5) More traditional recreation such as soccer (H), softball (B), and open space (O, Q) in one gravity and low gravity for picnics, etc.

The lower living level contains the community government, business, and shopping areas. The community government center (g), houses city hall, the fire department, and security services. There are two schools for the children of the community. The grade school (c) includes grades 1-8. The high school (d) are grades 9-12. The hospital has an eighty bed capacity and is located at (f). Low gravity research is accomplished in those areas labeled (b). Offices are contained in buildings (h), and the shops are located in those buildings labeled (i). Open green spaces (m), and a plaza (l) serve to connect the buildings on the lower level.

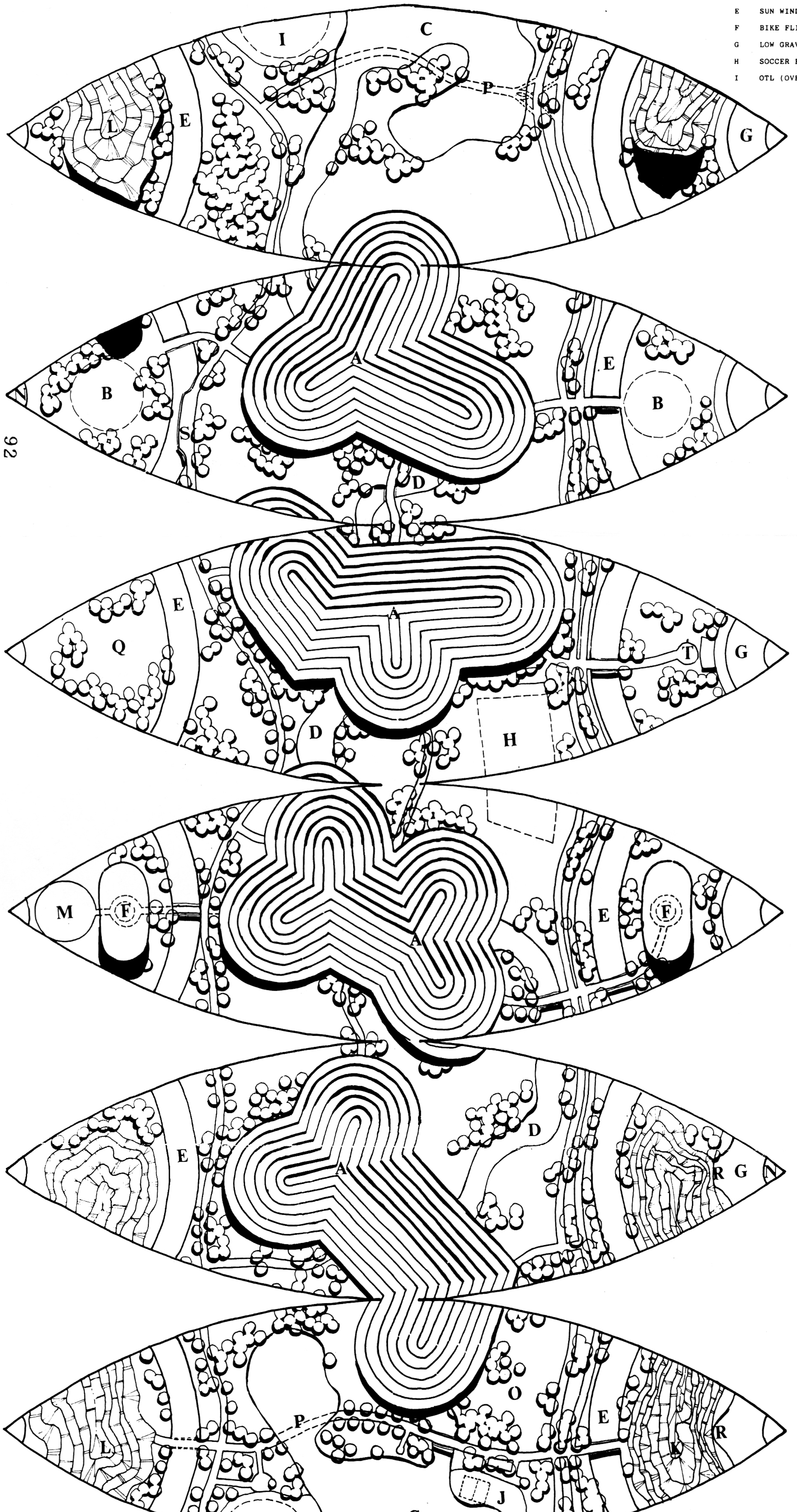
All storage systems are located immediately below the lower living area (n), and mechanical systems are located within the (o) level.

As seen in the section sketch, the colonists will have easy access to all sections of the habitat. It is intended that this design concept provides for an environment that promotes the productivity, performance, and well-being of its occupants.

UMBRIEL STATION

The First Colony in Space PAUL KLAUS LAR 799 INST: BOB PAGE **Scale: 1" = 50m** (164 ft.)

0 50 100 150



Legend

A	LIVING UNITS/NEIGHBORHOODS	J	SUNNY BEACHES
B	RECREATIONAL FIELDS	K	LOW GRAVITY MOUNTAIN CLIMBING
C	LAKE O'NEILL	L	LOW GRAVITY MOUNTAIN BIKE COURSE
D	BERNAL RIVER	M	COMMUTER PARKING
E	SUN WINDOWS	N	CENTRAL HUB ACCESS
F	BIKE FLIGHT FACILITIES	O	OPEN SPACE
G	LOW GRAVITY SWIMMING POOL	P	UNDERWATER GLASS TUNNELS
H	SOCCER FIELD	Q	LOW GRAVITY PICNIC AREA
I	OTL (OVER THE LINE) FIELD	R	LOW GRAVITY CLIFF DIVING

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The Sun accomplishes several tasks for the space facility. Two of the most important are: a) it promotes agriculture of unusual productivity, and b) it provides unlimited energy for industries essential to the success of the colony. The colony will use solar energy for the generation of electricity, and to power solar furnaces. With this solar energy supply the colonists refine aluminum, titanium, and silicon from lunar ores shipped from the Moon.

Using these refined elements, the fabrication of materials for the construction of new colonies and the creation of satellite solar power stations is possible. The satellite solar power stations are placed in geosynchronous orbit above the Earth where they will generate enormous quantities of electricity and transmit this energy, via microwave, to Earth receiving stations. The economic and environmental value of the solar power stations will more than support the initial investment costs of constructing the colony. They will also justify the existence of the colony, and promote the construction of additional, larger colonies.

DESIGN INTENT

The intent of this design is to develop a master plan study for the general development of an orbiting space community. The space habitat, because of its structure, mass, and shape is very sensitive to the choice of design elements. The design of this facility takes into consideration the following elements:

1) Physiological design criteria
2) Quantitative environmental design criteria
3) Qualitative environmental design criteria
4) Community space and area allocations

Some of these are presented in Tables 1 through 3. Although all of the above criteria are extremely important, the quality of the environment is weighed heavily in this master plan. The habitat is composed of four distinct living areas, or neighborhoods, which make up the community. By configuring the units in a stair-step fashion, and arranging the community on two living levels, maximum views and open space are maintained.

The top level is green open space (O) reserved for recreation and relaxation. The lower level contains the shopping, business, research, government offices, schools, hospital, churches, indoor recreation, and other community facilities.

Each individual living unit within a neighborhood is approximately 120 m^2 (1280 ft^2). All of the living units have a semi-private "garden", and a deck area. Long sightlines are strictly maintained for each unit, and no buildings are visible from garden terraces.

Transportation is primarily via walking or bicycle. Thoroughfares follow a serpentine path, allowing access to all locations on both levels. A highlight of the road system are the underwater routes inside glass tunnels that pass under Lake O'Neill, (P). A high-speed emergency transportation system is located below the lower level, as delineated by the letter "j". This route connects all the neighborhoods (A), with the community government center (g), the hospital (f), and the central hub (N). Commuter parking for those working in the space factory is at (M).

Transportation by water is accomplished by accessing the Bernal River, (D). This unique river not only has falls, but "ups" as well. Canoe enthusiasts that float the Bernal will drop down a waterfall and the river will carry them beneath each neighborhood. For example, in each of these subterranean worlds the canoeist will be exposed to environments similar to those found on the Amazon River in South America, or the Klondike in Canada and Alaska. When exiting, the river flows uphill to the top level once again.

The colonists will have a great diversity of unique recreational opportunities. One of the more popular features is the Bike Flight (F). This facility is located at a height of 150 m (490 ft), near the central hub, in zero gravity. Users will ride a device similar to a bicycle. Instead of turning a wheel for movement, the pedals will rotate a propeller, which in turn will provide a modest thrust that will move the user across the sphere.

Other recreational opportunities are:

1) Low gravity mountain bike trails that not only lead over but through the mountain (L)
2) Low gravity mountain climbing. The higher one climbs, the lighter that person is as they approach zero gravity (K). And low gravity diving from cliffs into the pool below (R).
3) Low gravity ballet and swimming (G).
4) Beaches along Lake O'Neill (J). On these beaches are locations for volleyball and OTL (over the line) (I).
5) More traditional recreation such as soccer (H), softball (B), and open space (O, Q) in one gravity and low gravity for picnics, etc.

The lower living level contains the community government, business, and shopping areas. The community government center (g), houses city hall, the fire department, and security services. There are two schools for the children of the community. The grade school (c) includes grades 1-8. The high school (d) are grades 9-12. The hospital has an eighty bed capacity and is located at (f). Low gravity research is accomplished in those areas labeled (b). Offices are contained in buildings (h), and the shops are located in those buildings labeled (i). Open green spaces (m), and a plaza (l) serve to connect the buildings on the lower level.

All storage systems are located immediately below the lower living area (n), and mechanical systems are located within the (o) level.

As seen in the section sketch, the colonists will have easy access to all sections of the habitat. It is intended that this design concept provides for an environment that promotes the productivity, performance, and well-being of its occupants.

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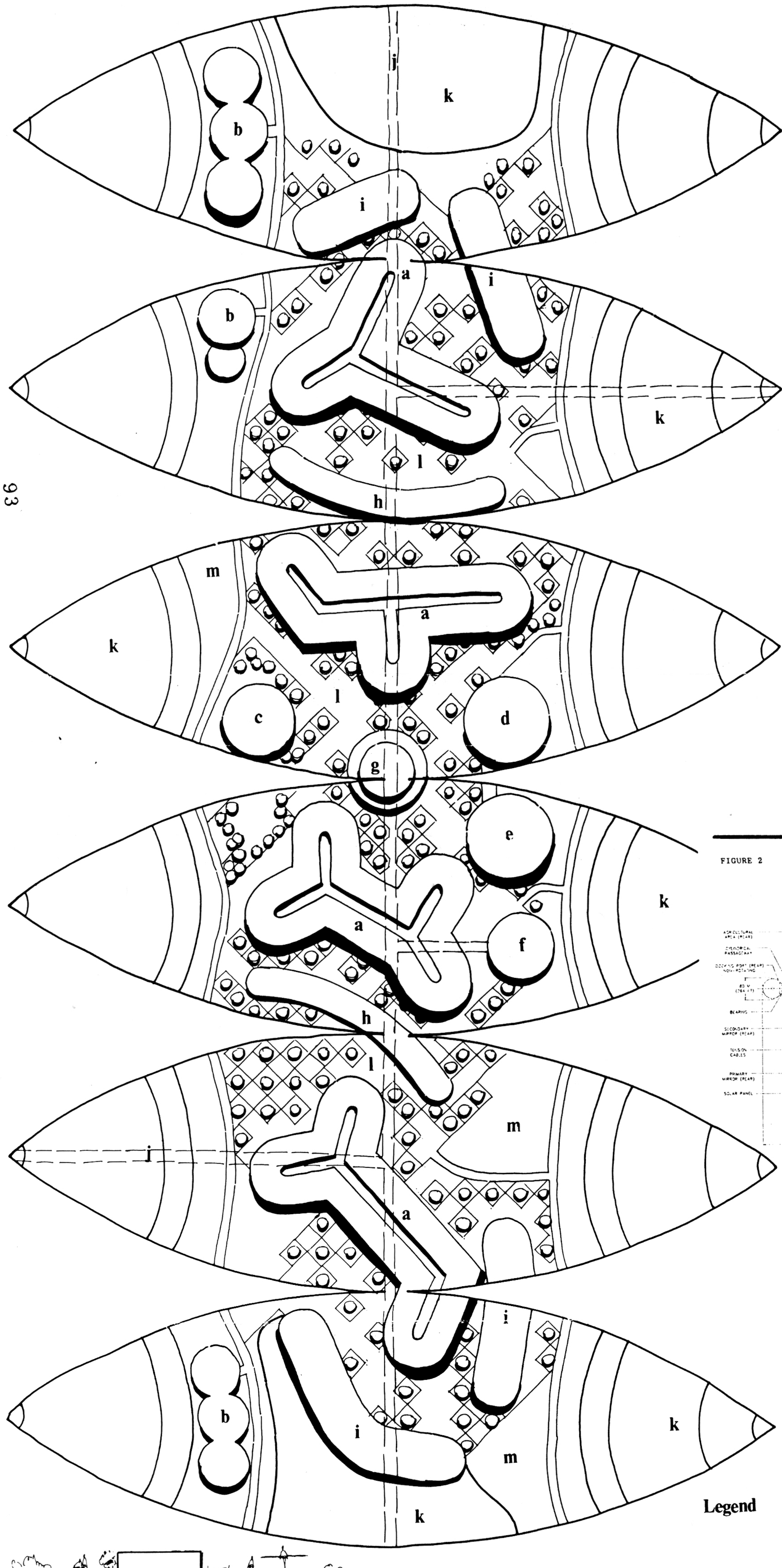


TABLE 1	SUMMARY OF PHYSIOLOGICAL DESIGN CRITERIA
Pseudogravity	1g
Rate of Rotation	.98 rpm
Maximum Safe Radiation Exposure for General Population	5 rem/year
Temperature	21.5°-26.5° C (70°-80° F)
Atmospheric composition	
Oxygen	100-170mm Hg
Inert gases (Nitrogen)	590mm Hg
Carbon dioxide	3mm Hg
Water/water vapor	5-7.5mm Hg

TABLE 2	SUMMARY OF QUANTITATIVE ENVIRONMENTAL DESIGN CRITERIA
Population: men, women, children	10,000
Community and Residential (projected area/person, ft²)	505
Agriculture (projected area/person, ft²)	215
Community and Residential (volume/person, yds³)	1100
Agriculture (volume/person, yds³)	1200

TABLE 3 SUMMARY OF QUALITATIVE ENVIRONMENTAL DESIGN CRITERIA

- Long sightlines
- Large overhead clearance
- Noncontrollable/unpredictable parts of the environment (plants, animals, children)
- External views of Earth, Moon, stars, etc.
- Parts of interior out of sight of others
- Natural sunlight
- Method of visiting outside environment of space
- Availability of privacy
- Good communications, internally and with Earth
- Capability of physically isolating certain spaces of habitat
- Flexible internal organization
- Detail design elements of interior left to inhabitants

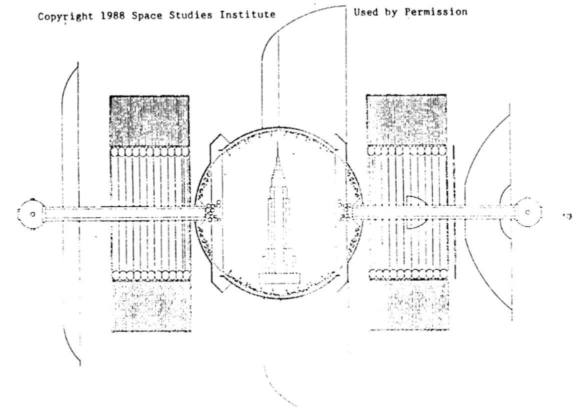
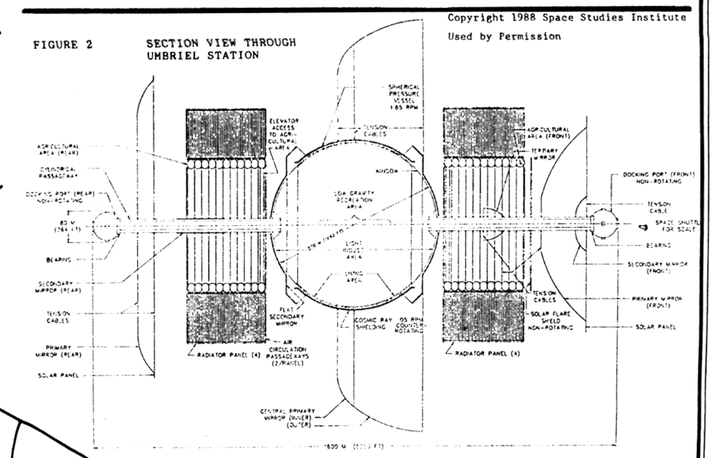


FIGURE 1 SCALE COMPARISON OF UMBRIEL STATION TO EMPIRE STATE BUILDING

FIGURE 2 SECTION VIEW THROUGH UMBRIEL STATION



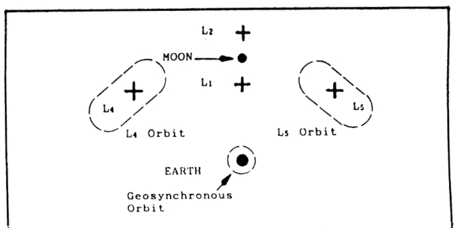
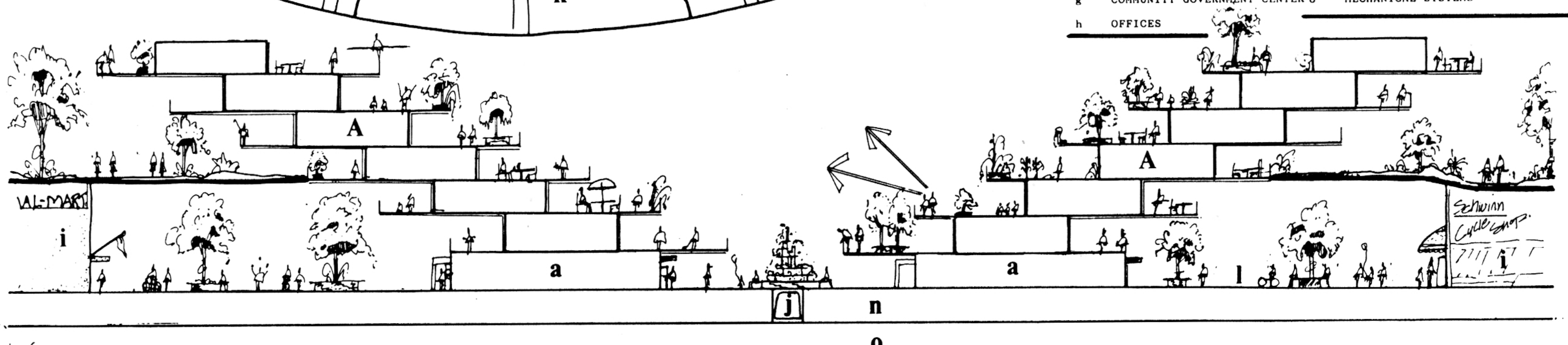


FIGURE 3 Earth - Moon Lagrangian libration points (adapted from NASA, 1977)

Legend

a	INDOOR RECREATION, SHOPS	i	SHOPS
b	LOW GRAVITY RESEARCH	j	HIGH SPEED TRANSPORTATION
c	GRADE SCHOOL	k	SUPPORT STRUCTURES FOR UPPER LEVEL
d	HIGH SCHOOL	l	PLAZA
e	HIGH SCHOOL GYM	m	OPEN SPACE
f	HOSPITAL	n	STORAGE AREA
g	COMMUNITY GOVERNMENT CENTER	o	MECHANICAL SYSTEMS
h	OFFICES		



APPENDIX B

Occasionally, during the course of an interview, the topic of conversation would change direction, or the interview would be interrupted. To keep the interview flowing in the right direction and on track, if the need arose, one or all of the following prepared questions were introduced to the subject.

1. What type of space settlements do you think will exist, that is orbiting, planetary, or both?

2. Do You think earth-like environments will be a reality in space?

3. Have you ever considered landscape architects as designers for space environments?

4. Are you familiar with what a professional landscape architect does?

5. What do you think a landscape architect would have to contribute to be a viable member of a space facility design team?

6. What role do you see the landscape architectural profession playing as designers of space facilities?

APPENDIX C

ABSTRACT: BEYOND EARTH: LANDSCAPE ARCHITECTURE ON THE HIGH FRONTIER

The approach to the conceptual designs of the interiors of space stations to date has not been multidisciplinary. That is, the people behind the scenes that have supplied the ideas, and the technical information to back them, generally have an expertise in either engineering or physics. The designs are analyzed, evaluated, categorized and eventually compiled into a final design intent, and implemented. This process has been quite successful for modest projects like the American Skylab station, the Soviet Mir station, and the proposed international station for the 1990's.

However, as the dimensions of these orbiting stations expand, and the length of time the inhabitants live in space stations increases to decades, it is probable they will require a more Earth-like environment to satisfy the conditions required to support physical and psychological health. Creation of such a habitat can be accomplished by a multidisciplinary team consisting of not only engineers and physicists, but of landscape architects, architects, interior architects, and planners.

This study proposes to investigate the contributions the landscape architecture profession can make to this effort. Included in this study are suggestions pertaining

to the important contributions that the landscape architecture profession could make in the conceptual design, development, and implementation of the living environments in space station habitats.

BEYOND EARTH: LANDSCAPE ARCHITECTURE ON THE HIGH FRONTIER

by

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B.S., University of Missouri, 1985

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MASTER OF LANDSCAPE ARCHITECTURE

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