1 OBJECTIVES AND PROCEDURE

Genesis II, a second generation, or advanced, lunar outpost provides housing, research work space, mission control space, and all amenities for a permanent lunar settlement of 11 astronauts and mission specialists to live on the moon for durations up to 20 months. As well as providing the first or second permanent settlement on the moon, *Genesis II* is planned to serve as an evolutionary testbed for all materials, processes, and development strategies to be employed in a more mature lunar colony for the next 20 years, and as a testbed for procedures to be employed in the exploration and eventual settlement of Mars.

1.1 PROJECT GOALS

Genesis II is an advanced lunar base with anticipated construction commencing in the year 2005. *Genesis II* includes base master planning and design for a mission focused on five experimental systems:

a. lunar mining and analysis for lunar oxygen and helium$_3$

b. lunar construction technology test-bed,

c. a closed system ecological life support facility (biotron),

d. a lunar far-side observatory, and

e. a human factors and environment-behavior research.

Design development focused on the division of work and rest environments. To provide continuity within the base master plan, an integrated, modular component system was developed to be applicable throughout the base.

Design issues considered included base master planning and phasing, human factors, psychological and social reactions to long-duration space missions, high-tech materials and construction technology, lighting, and mechanical systems, heating, ventilating, air conditioning, and environmental control life support systems (HVAC/ECLSS), energy systems, and overall design aesthetics.

1.2 OBJECTIVES OF AN ADVANCED LUNAR BASE

A mature base will benefit from previous, initial experimentation in living and technology. With a continuing commitment on behalf of government and industry, the base has the groundwork emplaced for advancement.

1.2.1 NASA LUNAR MISSION OBJECTIVES

The goals of the space program are clearly defined in the 1990 Report of the Advisory Committee on the Future of the U.S. Space Program (NASA, 1989). The basic imperatives of today's national civil space effort are, therefore, to:

-sustain our heritage to learn, explore, and discover;
-maintain our technological competitiveness in global markets;
-enhance the quality of life for all people on Earth.

In general, the definition of the human exploration initiative includes: to enrich the human spirit, to contribute to national pride and international prestige, to inspire America's youth, to unlock the secrets of the universe, and to strengthen our Nation's technological foundation. Human exploration of the Moon and Mars will fulfill all these aspirations. A permanent outpost on the Moon will support human presence for science and exploration (NASA, 1989).

Specifically, a lunar outpost will challenge technological and human capabilities, with advances in those areas being the goal. There will be research to counter the effects of reduced gravity, design of self-sufficient life support systems, development of hardware and software to engage and monitor the experiments, systems designed to lessen the differences between the atmospheres, and research to address the deep cold and radiation hazards.

In the area of human needs, the health, productivity, and safety of the crew members must be met. The outpost will increase the comprehension in the way humans adapt to the space environment. An important feature will be understanding of behavior, performance, and human factors in extraterrestrial situations.

Geology and geophysics, astronomy and astrophysics, human and plant biology, and evolutionary biology will all be advanced. Understanding the present as well as the past of planetary bodies will lead us to a knowledge of the origin of our own planet. The lunar base will utilize nuclear power systems, explore in-situ resource utilization, develop radiation protection systems, and advance automation and robotics. All these endeavors will inevitably lead to beneficial spin-offs for humans on Earth.

1.2.2 KEY RESEARCH AND DESIGN ISSUES

Based on a self-critique of the 1989-1990 UW-Milwaukee design work on *Genesis I*, and with the very helpful suggestions of James Burke, NASA-Jet Propulsion Laboratory, and Stephen Paddack, NASA-Goddard Space Flight Center, areas of detailed investigation included the following issues:

a. Character of the lunar environment with design studies on implications of the lunar topography, atmosphere, radiation levels, solar flares, power sources, temperature extremes, and in-situ materials.

b. Long-term effects of reduced gravity and design studies on different approaches to creatively design for 1/6th gravity.

c. Extraction of design-relevant implications from previous space experience, analogous situations, and simulations, e.g., Mir and Skylab, Antarctica and Navy submarines, and Tektite.

d. Space allocation studies including human factors analysis of minimum space required for different lunar habitation and research functions.

e. Design trade studies of all different areas of a lunar habitat, e.g., health maintenance facility, exercise facility, crew quarters, air locks, workstations, etc.

f. Design studies of different ways of getting natural light into a regolith-covered lunar habitat without admitting gamma ray particles, including partially covered cupolas, flexible light pipes, periscopes, etc.

g. Secondary research and habitability design study of the short and long-term effects of underground, windowless architecture.

h. Design replacement studies of how to replace/renovate/expand parts of a habitat without disturbing ongoing functions.

i. Studies of alternative construction technologies including prefabrication modules, rigid structures, inflatables, and in-situ resource utilization.

j. Design studies of the implication of new, high-technology materials especially elastomers and thin films, e.g., Kevlars, Mylars, Spectra, Nomex, aluminums, titaniums, rigidizing foams, and in-situ resource utilization of lunar regolith.

k. Regolith depth studies of the minimum depth of regolith to protect lunar habitats from radiation and micrometeorites, and design studies of regolith containment systems, second-generation regolith bagging machines, and processes (including sequences) of habitat construction.

1.2.3 PRINCIPLE DESIGN CRITERIA

The Space Architecture Studio set forth a specific group of primary design criteria to guide in the final design of *Genesis II*. These were:

-habitability, human factors, and environment-behavior considerations;
-safety;
-using advanced near-term available technology;
-replaceability and modularity; and
-cost, i.e., minimizing volume and weight at lift-off.

1.3 DESIGN METHODOLOGY

A structured organization is a necessity to the planning process of the lunar base. Evaluation of past efforts was conducted and new topics studied in depth. The following sections review *Genesis I* (see Hansmann & Moore, 1990) and provide synopses of the independent research conducted to assist in the design of *Genesis II*.

1.3.1 *GENESIS I* LUNAR OUTPOST AND CRITIQUE

Genesis I was intended to be an initial outpost for the lunar surface. It was to contain the following components: three domed inflatables, each three floors; four-space station-derived common modules; one heavy life launch vehicle module; nodes; logistics modules and EVA modules.

The base, which housed 12 crew members, was meant to be an experimental test-bed for construction technology, mining, a lunar far-side observatory, experimental materials testing, CELSS (closed ecological life support system), and human factors and environmental behavior research.

The base combined both proven and experimental technologies. Prefabricated modules, transported and landed completely outfitted, made use of already proven technology derived from research on the proposed Space Station Freedom. The inflatable dome structures were suggested to introduce the use of fabric such as Kevlar in the design of living and working areas. By using these fabrics, weight and volume would be saved in the launch process, yet structures with large volumes could be possible on the lunar surface.

One of the important assets the base possessed was the variety of living and working environments. Open floor plans were designed for the group areas, yet personal spaces allowed for flexibility and expression of personality. Work environments were modular or open plan. It also provided for the viewing of the lunar surface from cupolas located in two areas.

One of the limitations was its size. For an initial outpost, the base was far too large. The nodes were found to be too numerous, as were the domes. Generally, there were too many functions dedicated to this base. Habitability should have been a priority for the initial operating configuration phase and sufficiently researched. Later phases could address the mining and far-side observatory objectives.

1.3.2 FALL 1990 INDEPENDENT RESEARCH STUDIES

Three students chose to undertake independent study courses in preparation for the Spring Design Studio. Summaries of these reports follow.

1.3.2.1 Extraterrestrial Habitation: A Quest for Solutions

The purpose of this study was to investigate what has already been learned about human behavior and adaptation to harsh environments and alien conditions, and to design elements that can help the adaptability process. This study focused particularly on studies of analogous situations, previous actual space exploration, simulated situation, and projects under development, in each case to look at their design implications.

In order to conduct this research, over 50 books and 200 journal articles were collected from the Technical Library and New Initiatives Library at NASA's Johnson Space Center, and from the Lunar and Planetary Institute in Houston. Materials were also found in the Space Architecture Design Group's collection of documents. Of these, 62 were found to be especially valuable and were used in the report. Members of NASA Johnson Space Center were also valuable in providing information for this project.

The important of the findings of this report are essential to the future designing of habitats in exotic environments. Stress from confined quarters - similar to that expected in any lunar habitat - was the main problem found in studies such as Space Station/Nuclear Submarine Analogs by B.J. Bluth. Solutions included, for example, a view to the outside, vital to the well being of not only the United States' Skylab crew, but to the Soviet cosmonauts serving on Salyut and Mir. It was found that they spent most of their leisure time gazing out of windows-amazed at the sight. This sets a major criterion for future extraterrestrial habitats. Another crucial finding deals with the need for private quarters where one can "get away" and establish personal territory (Dalton, 1974). Submarine, Antarctic and space crews have expressed their need for personal space. Without this space depression and group dissension will often occur.

In conclusion, it was discovered that of the four topics researched, the analogous situation section proved to be the most insightful. The habitats studied were small and the first exotic environment habitats will initially be small. The traffic patterns, storage compartments, and the dividing of spaces seem more applicable than those in the previous actual space exploration because the latter were designed for zero gravity. Information was found about the crew's reactions to the habitat in which he/she lived. With studies of this kind, the success of future habitat designs will be better designed (Paruleski, 1990).

1.3.2.2 An Investigation of Technological Options in Lunar Construction

The areas of space exploration and research have been dominated by engineers since the space programs beginning. Recently NASA has realized the importance of having architects involved in the design of many of their projects. Architects can add a new dimension in designing habitats to be placed on other moons or planets. Investigated were many previously proposed lunar structures, noting the advantages and disadvantages of each. Design recommendations are included which offer the best options of each of the proposals. The paper can be used as a guide for the non-engineering designer to derive the most useful structure for his or her needs.

While in Houston for an intern position in the summer of 1990, research was gathered from three technical libraries at NASA Johnson Space Center. People at NASA, and its contractors became useful in providing information or in locating needed resources. A small Space Architecture Library and the university library also became useful sources for a total of over 200 reports, articles and publications. These were then searched to find information directly related to the main topic, narrowing the number to approximately 60. These provided a sufficient background and sampling of the many different types of structures which need to be compared to any space architecture application.

Because all Earth derived materials must be transported to the Moon, with costs of up to $1 million per pound, high strength and low weight are a must. One material that offers these benefits, Kevlar, can have a tensile strength 60% greater than that of steel. Kevlar can be made in thin, cloth-like sheets fabricated to create balloon-like tensile membrane structures which are relatively lightweight, and enclose large amounts of volume. Another material, structural foam, can be transported as a compact liquid which is injected into a form where it expands and hardens into a concrete. This process saves transportation costs and provides an almost endless supply of material.

Lunar structures that were found to be of great use included solid and collapsible options. Structures made of materials such as Kevlar can be compacted to fit in a U.S. Space Shuttle payload bay, and once deployed on the Moon, can be inflated into large enclosures. Metal structures similar in appearance to small submarines can be placed on the Moon with all systems needed to support life already on-board. Lunar forms such as lava tubes can even be used, by sealing them off and pressurizing the enclosures, saving in transport costs and construction time.

Through researching many options among materials and lunar structures, comparisons could be made between those proposed thus far, and conclusions drawn for the best options. In investigating materials, it became apparent that Kevlar and aluminum would be of great value for use in lunar habitats due to their high strength and low weight. Also of great importance will be lunar basalt and lunar concrete, which will save on the need to transport material to the lunar surface.

In comparing proposed lunar structures, best choices were made according to the general time period; initial structure, second generation, or third generation. The best initial structure was found to be the Space Station Freedom derived module, which would arrive fully outfitted. As a second generation structure, the inflatable Kevlar based structure will be large, and require only limited construction. A structure comprised of lunar concrete will be the best choice for a third generation structure, using easily obtainable resources (Fieber, 1990).

1.3.2.3. Environmental Conditions of the Moon and Mars: A Study of Two Worlds and Their Ability to Foster Habitation and Experimentation

There are exceptional environmental conditions that exist on the surfaces of the Moon and Mars. With the increasing participation of professional architects in the space program, the issues of habitability and human factors are being addressed, with resulting design parameters guiding the outcome of the structures. Without a comprehensive understanding of the atmospheric, or lack or atmospheric conditions in which those designs will exist, the architect will be at a disadvantage. This paper attempts to provide an overview of the conditions which will dictate design direction.

To obtain the necessary information, a three-week trip to the NASA-Johnson Space Center in Houston, Texas was taken. In the office of Planet Surface Systems and using the resources of the Technology Library at JSC, trade studies, mission architectures, geologic and geographic surveys were obtained. Several studies from the Lunar and Planetary Institute were rich in detail. In addition, the UW-Milwaukee Library and the Space Architecture Design Group collection provided needed information.

Critical in the design considerations of structures on the lunar surface is the intensity of the radiation due to the lack of a protective environment. Protection of crew and equipment must be obtained using materials which will impede radiation and any micrometeorite impacting, i.e., lunar regolith, regolith bagged within a material system, or burying the structures below the lunar surface.

Another concern is the extreme variation in the temperature of the surface. The range is 500 degrees from daylight to darkness. Structures and systems that can withstand those extremes must be utilized. Along with the temperature variations go the knowledge of the lunar day/night cycle. One lunar day is the equivalent of 14 Earth days. Similarly, one lunar night is 14 Earth days in length. This brings into question power utilization and the storage of backup power for the darker terms.

One unique feature which will be studied in detail is the lunar lava tube. These are natural caverns found in the lunar landscape. The principle interest in these geologic structures is their viability as a site for lunar base construction. The interior configuration of lava tubes on the Moon have yet to be investigated and mapped. If viable, the lava tube could provide excellent radiation shelter for inhabitants, an area preformed for base construction, and an environment where the temperature is fairly stable.

In conclusion, the major considerations for base design include the temperature variations, radiation and micrometeorite impacts, day/night cycles of the Moon, and the presence or absence of naturally occurring features capable of sustaining structures. As well, knowledge of what the surface compositions are may prove valuable for future in-situ resource utilization (Huebner-Moths, 1991).

1.3.2 SPRING 1991 DESIGN STUDIO

The spring design studio was structured into six segments, each providing an opportunity for the students to gain familiarity with the space program, space design, and utilizing the findings to generate *Genesis II.* It evolved in the following:

Part 1. Readings, slide talks, and individual sketch design explorations. Two weeks. Preliminary Design Review (PDR-1) university faculty.

Part 2. Research and design studies of different issues, e.g., lunar site design, 1/6 gravity, workstations, natural light, underground architecture, inflatable dome construction technology, high-technology materials like elastomers and thin films. 3 -1/2 weeks. PDR-II.

Part 3. Preliminary design to develop and explore different parti. 1-1/2 weeks. PDR-III.

Part 4. Design development of different parts of overall lunar base. 2 weeks. Intermediate Design Review (IDR) with NASA scientists and engineers and national guests.

Part 5. Design integration to present final integrated design. 3-1/2 weeks. Not-quite-final Design Review (NQFDR).

Part 6. Presentation. 1-1/2 weeks. Final Design Review (FDR) with university faculty from several disciplines and local architects.