ELEMENTS FOR A SUSTAINABLE LUNAR COLONY IN THE SOUTH POLAR REGION

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Abstract

Some elements for building a sustainable lunar colony in the South Polar Region are presented. Two areas of interest are the near Earth facing Malapert Mountain ranges at 85 degrees parallel and 0 degrees longitude and the Shivashakti-Saraswathy Plateau emanating from the west-southwest rim of Shackleton crater at the South Pole. It is suggested that the first colony projects be initiated at Malapert in direct visual contact with the Earth and that the second phase of development be carried out around Shackleton crater located at the South Pole.

Site-specific systems studied include the development of cis-lunar logistics and communications and a global as well as a local environmental and regional master plan for lunar development with particular attention paid to the impact of developmental activity on the fragile lunar surface environment. Architectural concepts for facilities and interiors for crew are addressed. They include large spaces for work and recreation as well as private quarters for single and family dwellings. Elements are based both above and below the lunar surface. A concept for building a dual use solar storm shelter and emergency cache facility is included.

Long term missions in space have yet to be undertaken. All analogous evidence from deep isolation facilities here on Earth indicate that human beings are indeed the fragile, weak link in the otherwise resilient hard technology driven architectures that are proposed for such activity.

Cultural and religious activity may offer yet another avenue to relieve the stress associated with isolation and the fear of being in an extremely constrained, alien environment. An architectural concept for a lunar mosque is presented.

Fig 1. USC Space Architecture Team at Calearth Institute Lunar Colony Site In Hesperia, California.

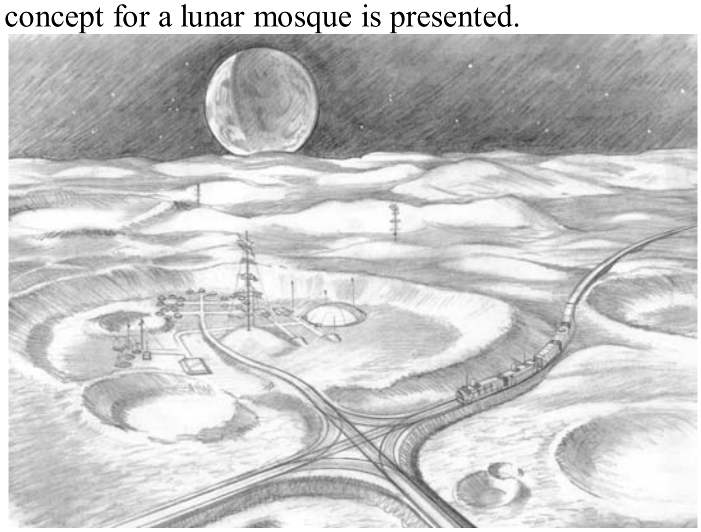

Fig 2. A South Polar Lunar Colony

[1-8]Arch 599-Seminar student in Extraterrestrial and Extreme Environment Habitat Design Team Project, USC Architecture, Spring 2001. Fig. 1.

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Lunar Environmental and Regional Planning

Planning of human settlements on the Moon must involve considerations that are novel to Earth-based models.

Particular attention must be paid to sunlight exposure and direct visual contact with the Earth. Certain high elevation sites in the lunar polar regions offer almost continuous access to sunlight(power) and a direct line of sight of planet Earth as well. Furthermore, the region also presents permanently shadowed “cold trap” areas that might harbor diffuse water-ice, possibly deposited there through natural cometary bombardment over geological time. The combination of above resources, if proved conclusively, would make the polar regions a choice location for early lunar settlements. A lunar colony in such a setting is depicted in Fig. 2.

The South Polar Region around the Aitken basin also offers rugged terrain with dramatic vistas that are peculiar to the southern lunar highlands. The contrasting relief seen in peaks and valleys there would be ideal for locating broadband laser communications equipment and relay stations, allowing the development of a reliable network with minimum physical infrastructure. Fig. 3 shows a mosaic of the region.

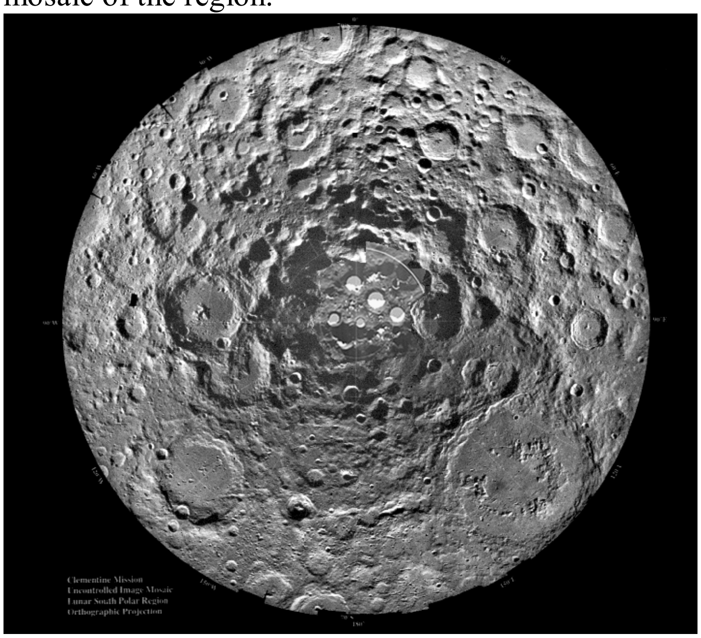


Fig. 3. Lunar South Polar Region Mosaic

Lunar regional and site planning and land management program must also consider issues such as topography, zoning for spacecraft landing and lift-off operations and base fly-over trajectories, annual surface insolation, diurnal temperature variations and effects on structures, waste management, lunar base operations ecological environment impact studies and environmental conservation.

Issues such as lunar landscape preservation areas, orbital pollution and both immediate and cumulative effects from logistics support vehicles operation and their mitigation, cislunar and lunar orbital debris management, dust and off gassing contamination need to be addressed. Plate on following page shows location of Phase I Malapert Base and Phase II Shackleton Ridge Colony. Schematic facilities layout at Malapert Mountain is also shown. It is planned to use the tallest peaks at both sites for solar photovoltaic power generation. Options include crowning the peak with blankets of amorphous silicon solar panels or erecting imposing, kilometer tall conical tower structures for hanging curtains of high efficiency solar arrays. See next page.

Solar Observatory System(S.O.S.)

The S.O.S. framework will be represented by a series of Radio and optical telescopes connected together with reliable communications links as an “observation system”, including interferometric instruments, as needed, which will alert the Moon Colonists to react on short notice in case of imminent dangerous solar particle events or hazardous micro meteoritic activity.

<u>The Components:</u>

1) Stationary Radio telescopes and Optical telescopes: Earth based, Moon Based, and on and around other celestial bodies
2) Orbital Radio telescopes and Optical telescopes: Spacecrafts in different orbits in order to cover a wide range of observation, this can include Earth, Moon and other Solar System orbits.

In this phase 1 study, the first Lunar Based Solar Telescope is presented as a spacecraft that is remotely landed in a 100 ft. diameter crater, close to the Colony Site in the Malapert / Shackleton Area at the South Polar Region of the Moon.

A folded optics reflecting telescope, with a stationary 24” aperture primary mirror is placed within the spacecraft at the end of a deployable light structure truss. A heliostat deployed on the other end of this truss /extendable boom tracks the sun. The instrument uses laser beams and microwave radio communication devices to hook up to the base and the other SOS elements. See Fig. 4.

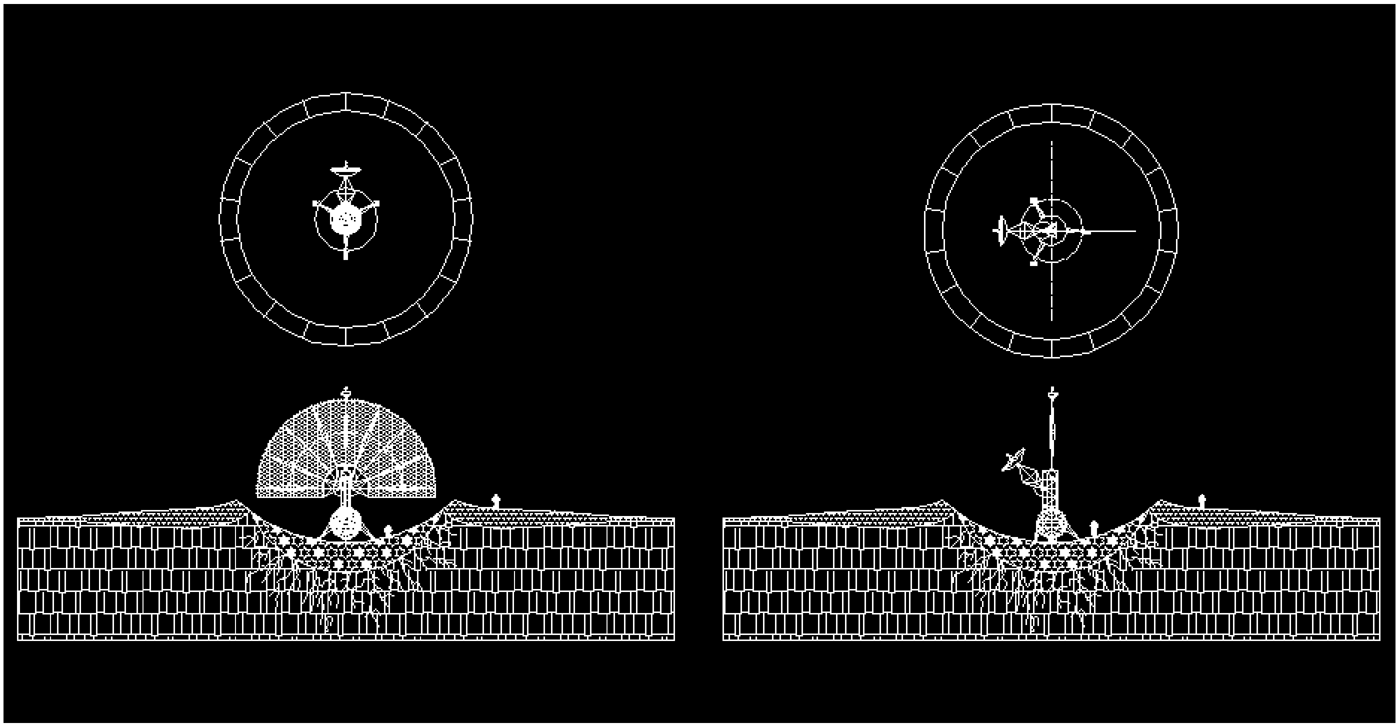


Fig.4. Phase I Solar Observatory System Elements Deployed at Shackleton Base in the lunar South Pole contains a solar telescope and a micro meteoritic early warning device.

A Lunar Colony Concept

The lunar environment poses unique challenges for architectural design of large, fully enclosed spaces. The vacuum of space is compounded by large temperature variations, lethal radiation and micro meteoritic activity.

However, the rugged terrain, the contrasting relief presented by the very deep valleys and peaks of the lunar South Polar Region offer unique exciting possibilities to build structures upon.

The aim of our design is to keep the inhabitants as comfortable and productive during the long periods associated with extended duration missions – more than a year at a time. Since such missions have not yet been attempted, we can only speculate on what these habitats and spaces might look like. We hope that a new rationale for lunar settlements might evolve from these studies.

Based in analogous experiences here on Earth including those in the Antarctic and on deep-sea oil rigs, we attempt to derive some patterns that may be applied to lunar dwellings. Conceptual design, construction methods merits and limitations are discussed. Several alternative concepts were explored and results presented. Fig.5. depicts the exterior massing of a lunar colony that relies heavily on in situ resource utilization(ISRU) for construction materials and methods.

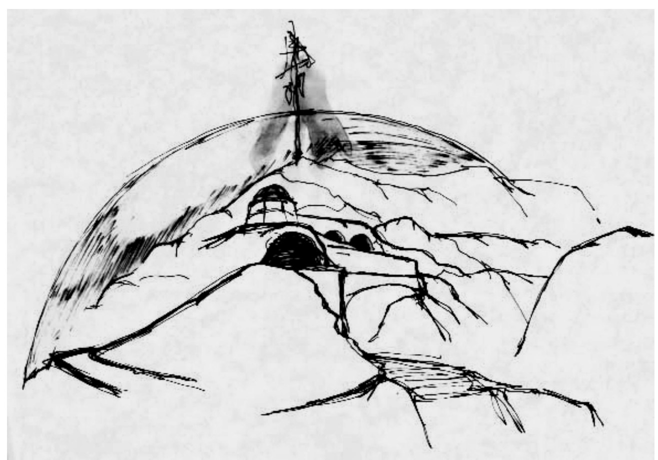


Fig. 5. A concept for a south polar highlands lunar colony

The First Mosque on the Moon

Architecture and engineering of structures to be built in space often confines its emphasis to the physical and scientific needs of the human inhabitants. A critical element of long term human survival and well being is the need to nourish and nurture the human soul and spirit. Faith, worship and prayer are inseparable values and beliefs associated with humanity, culture and civilization.

This study assumes that a portion of the proposed lunar colony is set aside for religious buildings. It addresses the rationale and the programmatic, functional, architectural and structural requirements of an extraterrestrial Mosque for Islam and Muslims.

We examine the design of a lunar mosque that will use the classical elements of Islamic design consisting of a dome for worship and an adjoining tower, the Maa'thanah. The dome rests on the lunar surface and uses a gimbaled floor plate to resolve the issue of allowing worshippers to face the exact direction of Mecca, the Islamic holy city, for prayer. Extensive, water filled view windows are incorporated to give worshippers a sense of connections to the heavens. Associated facilities are subterranean. The Maa'thanah protects the Mosque and its water ice radiation shield from the sun by moving along the circular track surrounding the dome. Thus it would follow the sun, creating a constant shadow. The Maa'thanah also provides ample power for the facility with a curtain of adjustable solar photovoltaic panels.

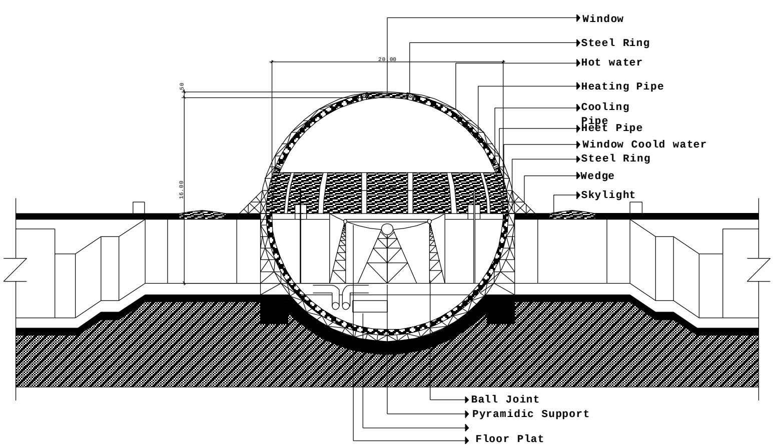


Fig. 6. Section through Lunar Mosque Dome shows Mecca tracking gimbaled floor plate.

The study proposes the use of lunar surface derived structural materials that can survive the extreme environmental conditions of the lunar surface including the lack of an atmosphere, micro meteoritic activity, galactic cosmic radiation and intense solar electromagnetic and particle radiation, reduced gravity and diurnal temperature fluctuations of 300 degrees Celsius or more. This In Situ Resource Utilization(ISRU) technology is being pursued at CALEARTH Institute in Hesperia, California, where a variety of structures are being hand-built and tested and a lunar colony simulator is planned. See Fig.8.

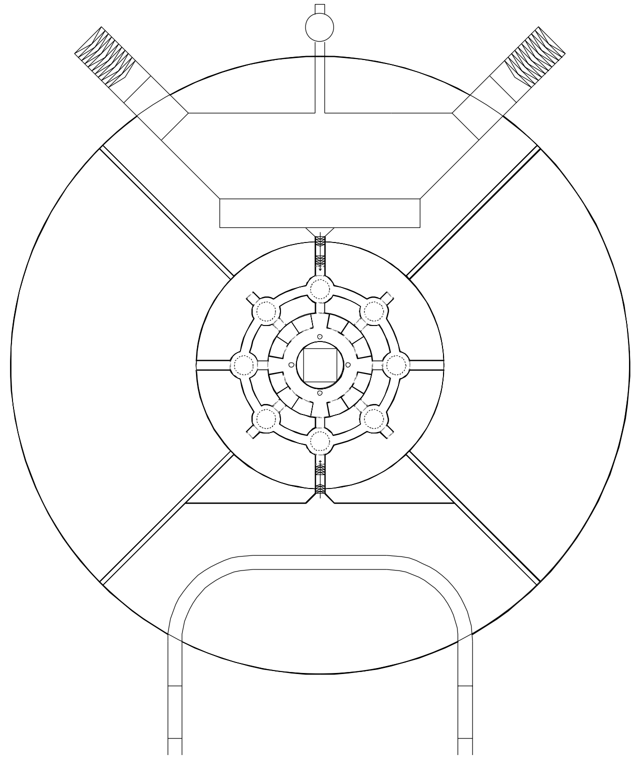


Fig.7. Plan Of Subterranean Level shows Rover Entrance and Light Rail Transit Stations. The segments also house large botanical gardens and parks. The core has facilities for recreation and formal ceremonies and meetings. Particle radiation free daylight is piped into this level.

Fig.8. EVA Simulation at CALEARTH

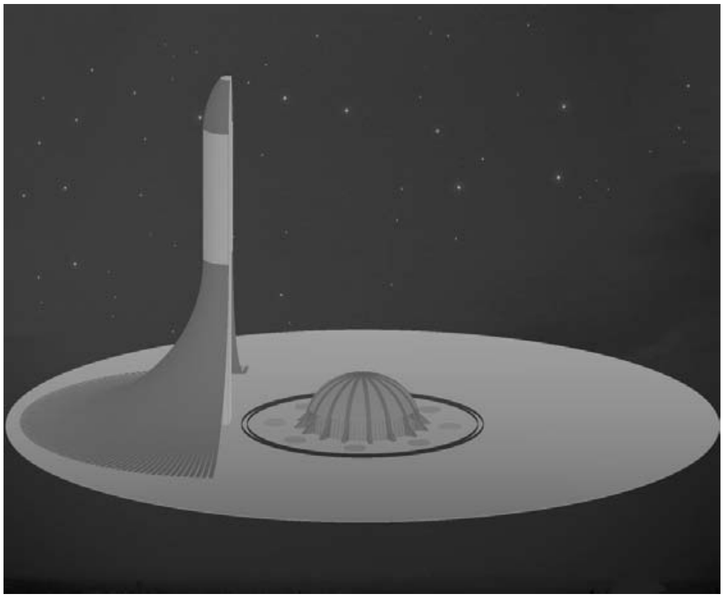


Fig . The Mosque Dome and solar power generating Maa’thanah(tower).

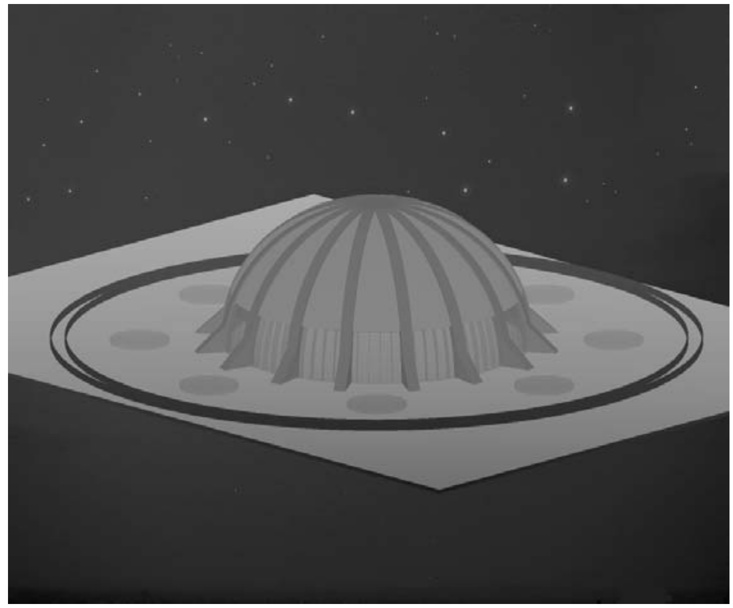


Fig. 8. The Mosque Dome uses water ice to shield against solar particle radiation. The circular track guides the Maa’thanah that casts a continuous shadow over the dome to preserve the integrity of the ice radiation/micrometeoritic shield.

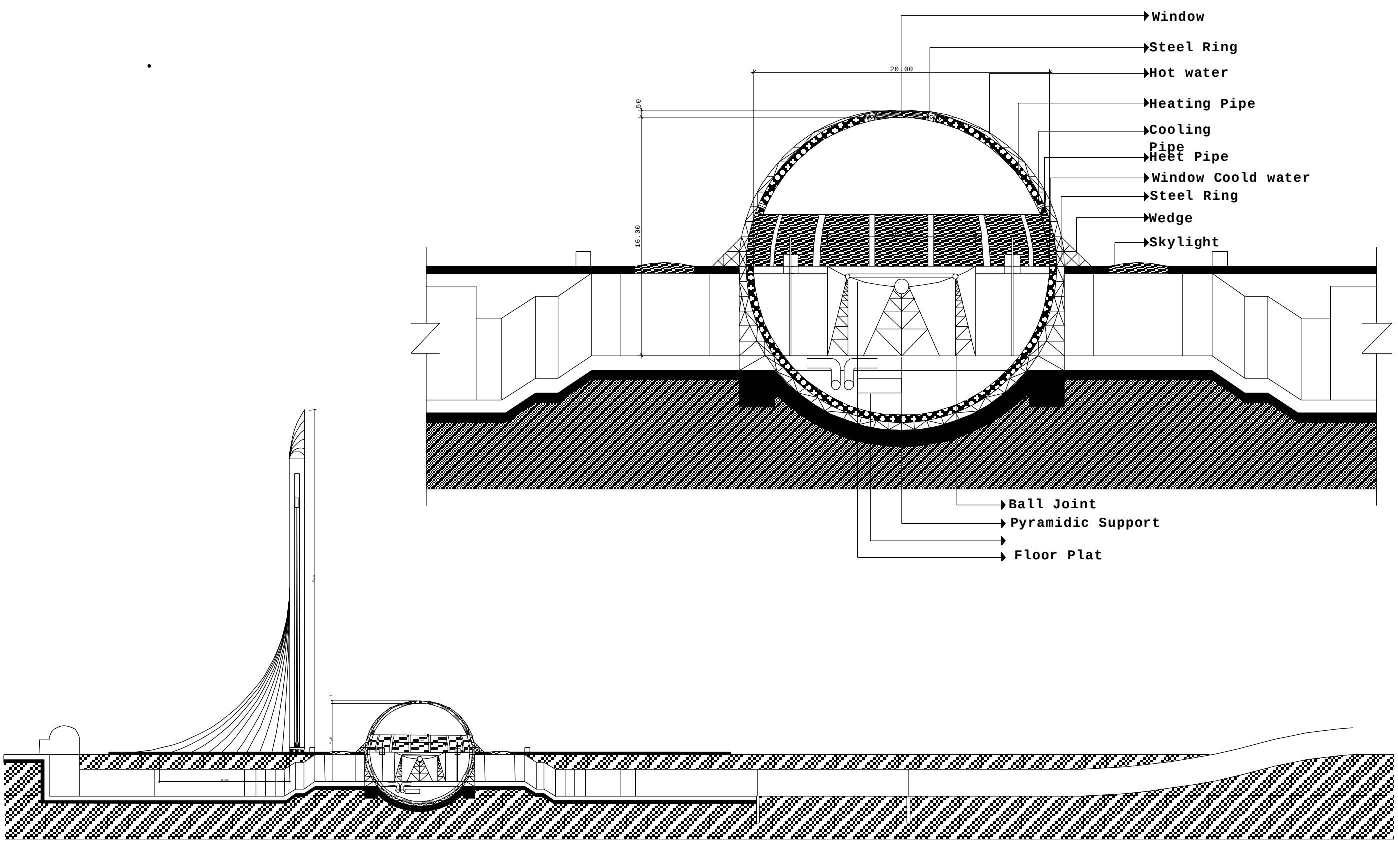


Fig. 9. Sections through the Lunar Mosque Complex show spherical pressure vessel, water-ice radiation/micrometeoritic shield, Maa’thanah and subterranean spaces that house social and cultural gathering facilities, greenhouses, parks and passageways. Filtered Daylight is piped into the facility.

Lunar Colony Private Quarters

In the alien, extremely hostile and abnormal environment of the moon, the crew of the first and subsequent colonies will need extra support to maintain their health and psyche. Extreme care must be paid to the design details for these places to make their surroundings habitable and their work more productive.

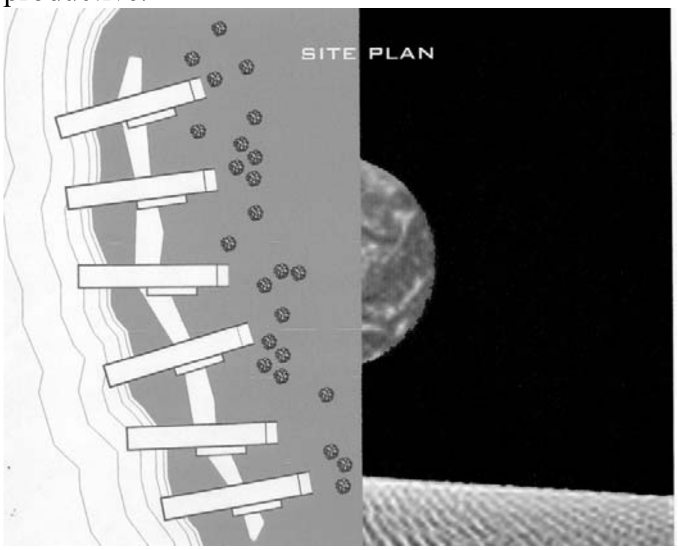


Fig 10. Site plan of Earth-facing crater slope habitat cluster at Malapert

While a large proportion of envisioned activities during the initial phases of establishment require team-work and group interaction in public spaces, dealing with the construction and buildup of the colony, the need for privacy and personal space becomes even more important. A refuge from the stress of hard technology intensive surroundings is needed to maintain a healthy balance of crew life style and psyche.

Personal living spaces for a variety of purposes include single, double and family dwelling typologies tailored for the lunar environment. The evolving nature of the lunar colony program must be addressed. Commercial activities like lunar tourism and retirement facilities for the elderly offer potential to create a very unique architecture on the moon.

In the 1/6th Earth's gravity environment of the moon, the Earth facing inner slopes of craters may allow the construction of "extreme cantilevers", only dreamed of on Earth. Sturdy box structures, partially buried through deliberate landslides caused by regolith movers on crater rims, would create controlled "regolith avalanches" and subsequent radiation protection for habitats within these structures.

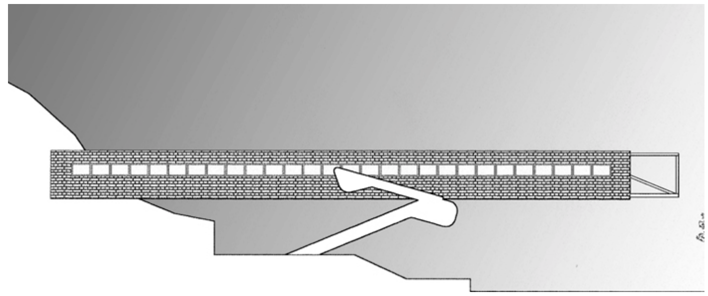


Fig. 11. Lunar Colony Habitats on Crater Slopes would project extreme cantilever structures while a large part of the structure would be buried under lunar soil using controlled "regolith avalanches".

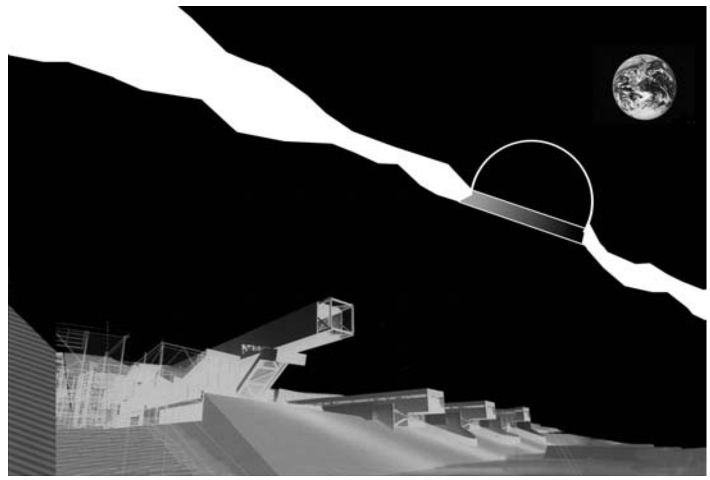


Fig.12. A view of Malapert Habitat Cluster from Crater / Valley Floor

Advanced Tools and Concepts For Lunar Extravehicular Activities

Extravehicular Activity(EVA) – any human space activity or operation performed outside the protective environment of a spacecraft or space habitat – is a vital operation for lunar colonization. It is clear that the most effective construction and operations will synergistically employ human-robot buddy systems. While robots work best under highly predictable conditions, humans are able to adapt better to an unpredictable environment.

The lunar EVA spacesuit should provide good mobility, dexterity, tactility, ease of donning and doffing and comfort during long tasks. To this end, hard suit technology is a versatile choice for the lunar colony-building environment.

Hard suits, like the NASA ARC AX-5 and the Mark III eliminate the need for lengthy preparation like pre-breathing and allows for more EVA time with less risk of bends incidents.

Emergency procedures for lunar EVA and local transportation are also essential.

Accordingly, the use of safety pods, Oxygen / Battery recharging stations and a Lunar Escape Maneuvering Unit(LEMU) will be implemented as emergency aids, and modified versions of the Apollo unpressurized lunar rover and the Nomad Explorer Rover with EVA Bell attachment will be used for transportation and colony buildup operations.
See Fig. 13.
Lunar EVA activities are inherently dangerous, and their use is a hazardous procedure that should be minimized because of radiation and micrometeorites. Nonetheless, EVA is an essential and versatile part of human activities on the lunar surface for efficient colony buildup on the Moon.

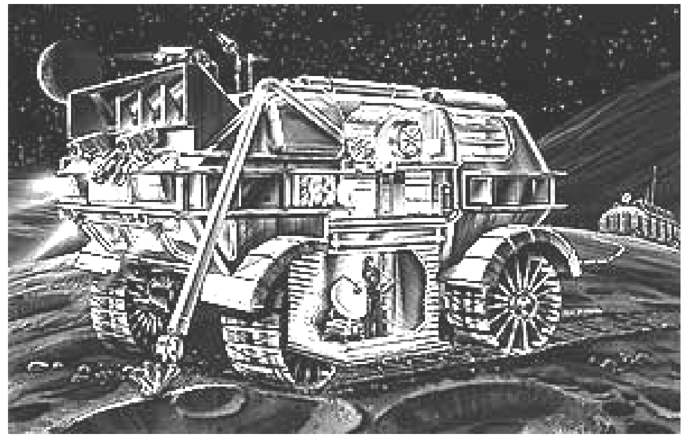


Fig.13. Nomad Explorer's EVA Bell system would simplify EVA by providing shirt sleeve environment.

Solar Storm and Emergency Cache Shelters

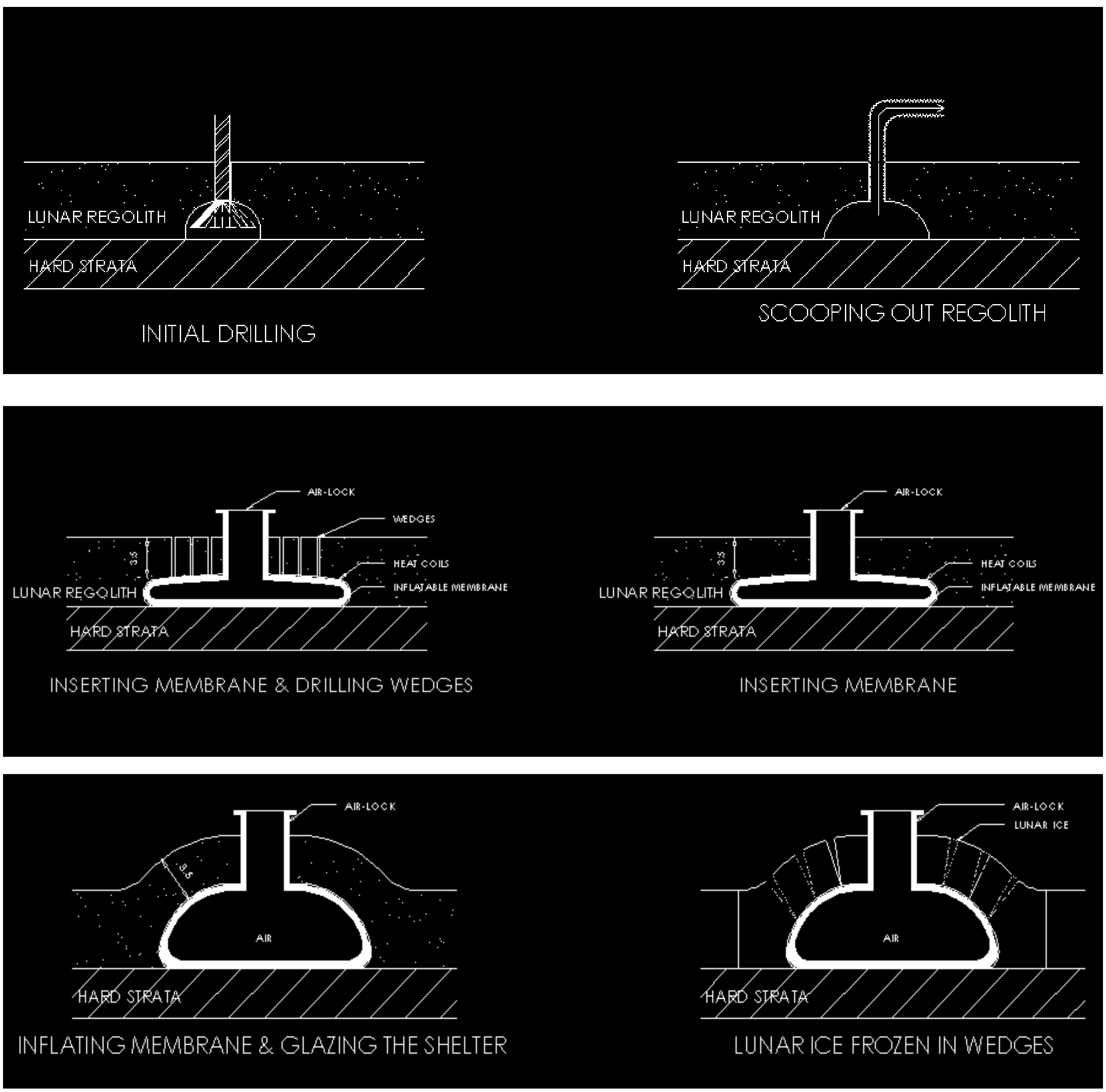


Fig.14. Concept For Creating A Shelter Using Permafrost Layer In The Lunar South Polar Region.

Solar Storm and Emergency Cache Shelters

Solar particle events that occur from time to time can be lethal to human activity on the lunar surface. While it is hard to predict when one might occur, current instruments can provide enough “early warning” of imminent events.

In order to protect crew working at a distance from the colony, it is important to emplace solar storm shelters within effective range so that crew might weather out the storm.

In the Polar Regions, if ground ice is present, a variety of energy efficient methods could be used to build shelters by melting the ice and forming interior spaces.

In one concept, a large diameter borehole is dug to a depth of few meters into the dirty ice surface. A dome shaped underground cavity is then burrowed out using special drilling equipment. An expandable pressure bladder is inserted and then superheated steam under pressure is circulated in the cavity. The system also produces a pneumatic hammer effect. The heat would thaw the surrounding ice and the pressure and vibration would help loosen and plasticize the regolith/ice, expanding the volume, raising the ceiling of the cavity, to form a dome. As the desired volume and ceiling height dimensions are reached, the steam is replaced by cold ambient temperature gases that will set the dome structure in its final configuration. The technology and alternative concepts to accomplish this task is currently under investigation at the USC School of Architecture. See Fig. 14.

Logistics, Transportation and Communications

Several options exist for developing a reliable logistics channel to support lunar colony buildup and operations.

The US Space Transportation System Shuttle and the Titan IV, the Russian Energiya and Proton, the European Ariane are all mature systems capable of delivering substantial payload and cargo to the moon. The Chinese Long March, the Japanese H-2 and the Indian PSLV programs underway can also support lunar colony activity effectively.

Both Piloted and cargo vehicles could use the Earth Moon Lagrangian point L1 as a staging area for servicing a lunar colony in the South Polar Region.
Broadband communication systems are needed to support the lunar colony activities. Direct, line-of-sight laser communications is feasible as the proposed colony is located in the south polar region with the Earth disc visible at all times just over the horizon.

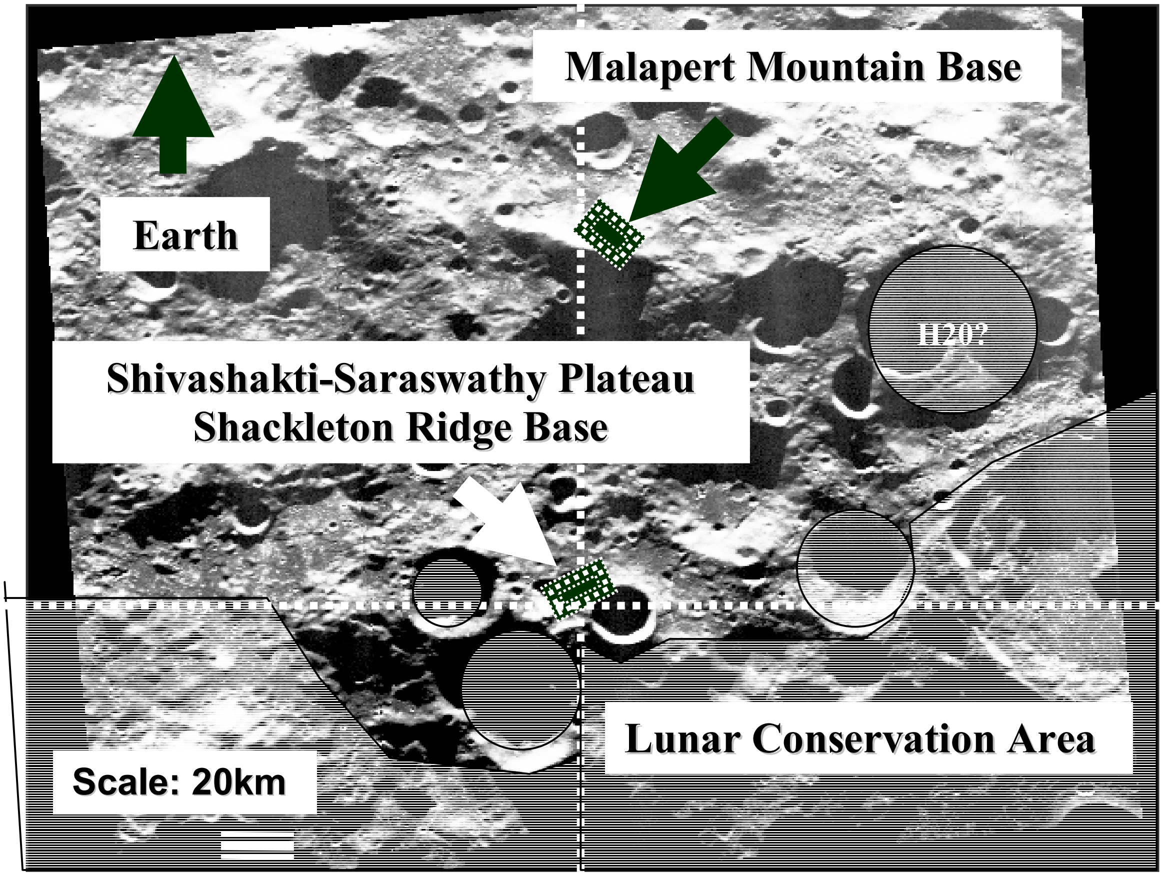
Acknowledgments

This 15 week, 3-unit graduate Architecture Arch599 seminar in Extraterrestrial and Extreme Environment Habitat Design was held in the USC School of Architecture under the umbrella of the Masters in Building Science Program(MBS) in the Spring of 2001. Approximately 45 hours of meeting were equally split among expert lectures, design theory, concepts creation, debate and discussion.

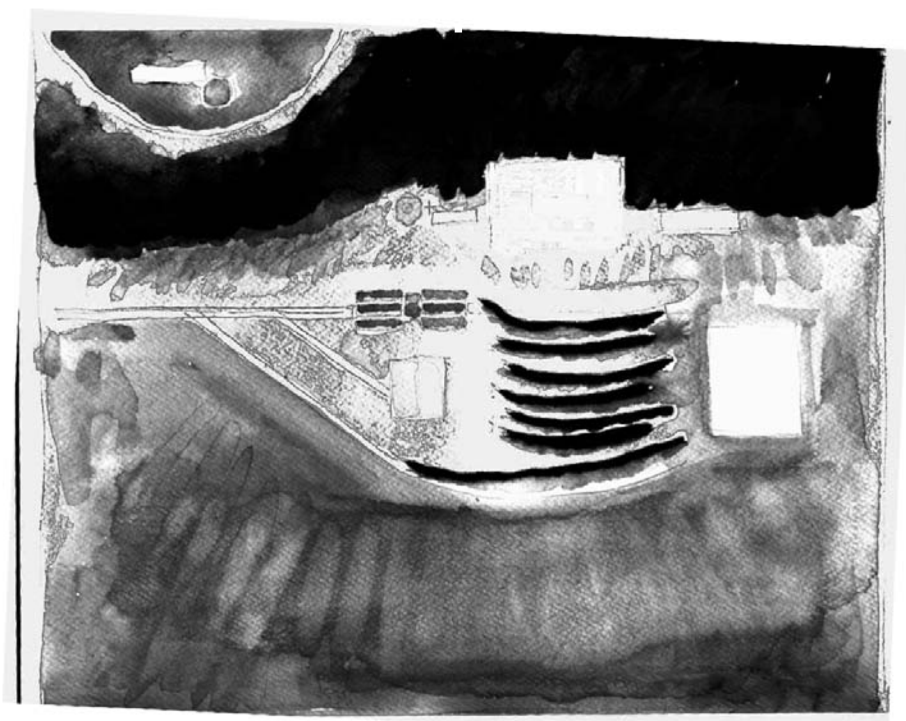
It is an interdisciplinary course and students included those from the Architecture, Building Science and various disciplines of Engineering. Several engineering students are technical staff from the local aerospace industry, working toward an advanced degree in the Graduate Astronautics Program in the Dept. Of Aerospace and Mechanical Engineering in the School Of Engineering.

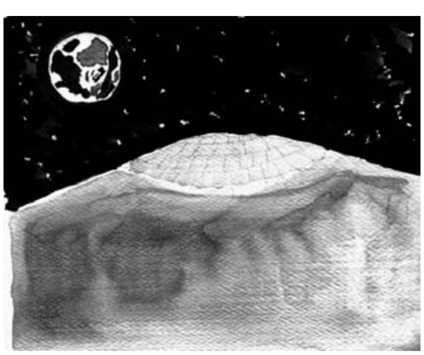
Our aim was to think about new reasons and attempt to conceive new visions for the exploration and settlement of the Moon and beyond. Since this is a top level, conceptual system architecting study, a programmatic, rather than a rigorous engineering analysis perspective was adopted. Each student worked on a particular area and evolved alternative concepts that are included here as sections.

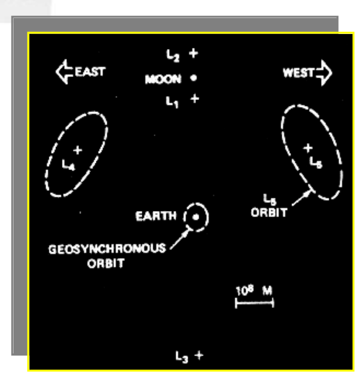
I would like to thank Robert F. Timme FAIA, Dean Of the School Of Architecture for helping realize this course. Thanks are due Prof. Marc Schiler, Director of the MBS Program for assisting with curriculum development and logistics support. Dr. Elliot Axelband, Dean Of Engineering Research, Dr. E.P. Muntz, Chairman of Aerospace and Mechanical Engineering and Dr. Mike Gruntman, Director of the Astronautics Program, Dr. Stan Settles, Chairman of Industrial and Systems Engineering, Dr. Jerry Mendel of IMSC in the Electrical Engineering department were all instrumental in bringing the class to the attention of Aerospace engineering, Electrical Engineering and Industrial Systems Engineering and System Architecture students. I would like to thank also the wonderful visiting lecturers and review panel members including faculty from local universities, visionaries and experts from NASA centers, Caltech-JPL, Boeing Space Systems, the USAF and the AIAA who made this course very interesting. Special thanks to architect Nader Khalili of Calearth Institute, Hesperia, California, for inspiring the students and for the wonderful hospitality during the site tour of the Hesperia Lunar Colony Project. Also commendations to the fine team of interdisciplinary graduate students who were a pleasure to instruct and interact with.



Malapert Mountain Base
Earth
H20?
Shivashakti-Saraswathy Plateau
Shackleton Ridge Base
Lunar Conservation Area
Scale: 20km







EAST
L2
MOON
L1
WEST
L4
L5
EARTH
L5 ORBIT
GEOSYNCHRONOUS ORBIT
L3