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MOON CAPITAL Competition
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Program

Deadline: Friday, September 3rd, 2010

Final Architectural Design Program for

Moon Capital

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Marc M. Cohen, ArchD[1], Michael A. Fox, B.Arch, SMarchS[2], Madhu Thangavelu, B.Sc.Engg, M.Arch[3].

1. *Licensed Architect, Associate Fellow, American Institute of Aeronautics and Astronautics, (AIAA), Palo Alto, CA.*

2. *California State Polytechnic University Pomona, Assistant Professor, Department of Architecture.*

3. *University of Southern California, Lecturer, Department of Astronautical Engineering, Viterbi School of Engineering and the School of Architecture, Los Angeles CA.*

Moon Capital consists of the planning and design of a Second Generation Habitation on the Moon to support a resident staff of 60 people. The groundbreaking on the Moon will occur July 20, 2069, to mark the 100th anniversary of the Apollo 11 landing. *Second Generation* means that a prior lunar base exists that can serve as the construction camp and the assembly point for building Moon Capital.[1] [2] This assumption means that the project designers do not need to address the means of delivering materials and construction equipment to the site; the technology and transportation capability exists to assure these deliveries proximate to the construction site.

The primary purpose of Moon Capital is to provide a permanent commercial, science, and technology development facility on the Moon. Up to now, scientists and engineers have conducted lunar research almost exclusively from Earth. Certainly, the Apollo Astronauts returned over 300kg of lunar materials to Earth, which have provided a subject for study for over 40 years. However, lunar science goes far beyond picking up rocks for return to Earth; and lunar technology development has barely begun. The scientific and technological disciplines have matured to where they can be far more productive and serendipitous if these professionals can do their work directly on the Moon.

Lunar Habitation – Moon Capital arises from a concept of the evolution of lunar Habitation and Space Architecture. The *First Generation Habitation* will take the form of a lunar base that currently seems to appear on the exploration timeline for a construction start circa 2030. This base will provide habitation elements that include rigid, pre-integrated modules, deployable or inflatable structures, and the reuse of lunar lander parts. This First Generation base will focus on the traditional space exploration domains of science, engineering, and technology, and each part of it will be owned and operated by the national space agency that builds it. The first generation base can provide some manufacturing and assembly of modules and components for the *Second Generation Habitation:* Moon Capital. However, mass delivered out of the gravity well of Earth is always at a premium in space, so any design decisions that reduce landed payload-mass and mass that the construction process must move will contribute to the success of the project.

As the *Second Generation Habitation*, Moon Capital represents an international effort to build a permanent human community on the moon. This community intends to achieve a much broader scope of endeavor than the First Generation base. It will support an entrepreneurial and commercial activity that can become the forerunner of a true in-space economy. Moon Capital will be much more advanced in achieving self-sufficiency such as food production and regenerative life support. By placing the Habitat Core underground, Moon Capital will provide superior protection from the extreme and unforgiving lunar environment.

Second Generation also means that Moon Capital will serve a multigenerational population; the staff can come with their families. Co-locating children with their parents at a lunar base is an essential step toward truly breaking the bonds of Earth and becoming a space-faring species.

Scope -- The scope of this project encompasses the complete pressurized living and working environment and essential unpressurized functions proximate to the Habitation on the surface. It includes the systems for transiting the "Delta-P" (the change in pressure) to access the vacuum of space, including airlocks, suitports, and pressurized rovers. This approach assumes the existence of an International Lunar Surface Operations Suit along with the

[1] Bodkin, David K.; Bocam, Kenneth J. (2006 September). A Human Lunar Surface Base and Infrastructure Solution (AIAA 2006-7336); also Belvin, W. Keith; Watson, Judith J.; Singhal, Surendra N. (2006 September). Structural Concepts and Materials for Lunar Exploration Habitats (AIAA 2006-7338).

[2] Thangavelu, Madhu et al (2009, September). Return to the Moon: Looking Glass 204, AIAA 2009-6612, http://astronautics.usc.edu/concepts-studio/lookingglass.htm.

potential for modifications to enable optimal adaptation to the airlocks, hatches, and pressure regimes. Thus, the project involves both underground and surface elements. The placement of underground elements may presume excavation, regolith-moving, and tunneling equipment with sufficient power to operate them.

Sponsorship – The sponsoring and governing body for Moon Capital will be an international consortium of space agencies (CSA, ESA, RSA, JAXA, NASA, etc). The Consortium supports the general planning and design effort and the construction capability. The Consortium owns collectively the power, air, and water supply, life support (including waste disposal) systems, the underground core habitat, common laboratory and workshop, and surface access capabilities. Individual space agencies, corporations, NGOs, and universities may additionally provide their own private laboratories as surface elements. These surface labs may connect directly to the surface access units or be freestanding with their own separate airlocks and rover access hatches.

Demographics – Given that the sponsoring Consortium is international, so will be the crewmembers and visitors. Of this crew population, up to 30 can be scientists, engineers, entrepreneurs, scientists, and technicians, and up to 20 are support staff. Up to 10 may represent the arts, humanities, and journalism. Of the total resident population of 60, about 15 to 20 may be children from kindergarten through high school age.

TABLE 1. Moon Capital Crewmember Demographics

Role	Tasks	Number	Employer	Comments
Engineering and Science	Engineering, Resource Extraction, Industrial Production, Science Technology	Up to 30	Academia, Commercial, Entrepreneurs, NGOs Space Agencies	This role is the basis of productivity.
Support	Administration, Communications, Education Maintenance, Operations, Reliability, Safety, Service.	Up to 20	The Consortium	This role is the basis of habitability in the living and working environments and safety in operations.
Arts & Humanities	Art, Dance, Entertainment, Journalism, Literature, Music, Philosophy, etc	Up to 10	Independent or Media	This role helps extend the totality of Earth culture to the Moon for the crew and to help express the human experience on the Moon.
Children	Learning & Growing up	15 to 20	All have chores and responsibilities	The number of children is included with their parents in the three rows above.
Visitor	Varied	Up to 10	Varied	Longer term visitors staying in the habitat core.

A major objective of Moon Capital is to begin the creation of a “normal” human life off the Earth, including spouses, families, and children. Both spouses must qualify professionally to engage in the work of the Moon Capital.

The support staff includes systems, maintenance, medical, food service, and educational professionals, plus spiritual leaders. The members of Moon Capital will enjoy regular voice, video, and cyber communication with their colleagues, relatives, and friends on Earth. The nominal tour of duty will be one year with options to extend up to three years. Some members may elect to serve longer on the Moon; others may serve shorter- tours according to the scope of their missions.

Living Environment – The living environment provides the complete habitation accommodations for Moon Capital crewmembers: life support, food growth, water, hygiene facilities, private quarters, cooking/dining, recreation, exercise, group activity, and quiet areas. Each crew member is entitled to a private cabin, including children. The intermediate partition walls may be dismounted or slid away to create larger, shared private spaces for couples and families. Because there is great potential variability in the familial connections among the Moon Capital crewmembers (or the lack thereof), the living quarters must afford flexibility and reconfiguration.

One surface expansion option in the Entrepreneurial Zone may include "hotel rooms" for short term visitors (three months or less). In the event of a solar storm or high micrometeoroid flux, these visitors will retreat to the underground habitat core where they will stay in the common areas for the duration of the threat (typically not more than 72 hours).

Working Environment -- The science includes but is not necessarily limited to chemistry, geology, planetology, meteoroid studies and meteoritics, life science, gravitational biology, radiation measurement and studies, astronomy, and Earth observations.[3] The engineering studies include but are not limited to in situ resource extraction and utilization, power development, construction techniques, and reuse of landed assets. All these disciplines will use Intra-vehicular activity (IVA) laboratories and workshops. Excellent design for Space Human Factors will be an important part of developing Moon Capital. Good human-system interfaces reduce risk and improve safety and efficiency. Many crewmembers will engage in extra-vehicular activity (EVA) work on the surface. Some technology development activities (e.g., materials and construction engineering) may require large facilities.

Planning – Site selection and planning constitute an essential aspect of Moon Capital. The location of the Moon Capital is the South Pole Region because of the presumed availability of recoverable water ice, the persistence of light for nearly all the lunar month, and the relatively temperate climate compared to the Moon's equator. Because the best sunlight for production of photovoltaic power arrives at the highest points and the best accumulations of water ice occur at the lowest points, the choice of site must consider an intermediate location between the two extremes. The planning of Moon Capital shall include planning for expansion, up to an increase of 4x or 5x in pressurized volume and area, with corresponding increase in amenities.

Architecture -- ***All habitable Space Architecture is pneumatic.*** All habitable elements of Moon Capital must hold an atmosphere of 101.35kPascal (14.7psi)[4] in an Earth-normal gas mix at sea level. It is feasible to vary the atmosphere pressure and gas mix for operational purposes in the agriculture modules, airlock, EVA access facilities, rovers, and the surface laboratory modules. To ensure safe conservation of the atmosphere, all Moon Capital pressurized volumes will be contained in engineered pressure vessels. It will not rely upon tunnels or other excavations in regolith to hold the atmosphere because of the difficulties of ensuring and verifying a pressure seal. Therefore, the construction of the underground base will comprise primarily the placement of rigid or inflatable

[3] Budden, Nancy Ann (Ed.) (1994 August). *Catalog of Lunar and Mars Science Payloads* (NASA RP-1345

[4] Please note that a pressure of 101.35kPa (14.7psi) exerts a surface pressure of 101.35kNewton/m^2 (2116 pounds/$foot^2$) outward in all directions against the walls of the pressure vessel.

modules in tunnels or excavations where they can benefit from a protective cover of lunar material. The minimum required thickness of regolith above the modules is 3m.

Moon Capital consists of four main architectural parts:

1. Surface Access Unit,
2. Entrepreneurial Surface Labs and Workshops,
3. Core Habitat protected from the surface environment, and
4. Agricultural Zone.

Egress to the surface and ingress from it serve as primary considerations for the location of the airlock system for crew and lunar terrain vehicles. The underground habitat shall have two complete surface access units. The project designers are responsible for the sizing of the pressurized elements. In theory, it would be possible to accommodate all underground functions in one large inflatable pressure vessel or in a variety of pressure vessels of diverse sizes and materials.[5] However, dividing the project into multiple self-sustaining units or clusters improves safety and reliability of the whole enterprise. All pressurized connections require berthing or docking ports, connecting nodes or tunnels, and hatches that provide safe and separate containment of atmospheres.

The selection and use of materials is constrained seriously by limitations on flammability and toxic out-gassing. “Green” construction is desirable in theory so long as the materials do not contribute flammable fuel or produce smoke in excess of spacecraft safety standards.

Utilities -- The Consortium provides life support, power, communications, and data connectivity as a common utility system to all pressurized volumes and functions. Life Support constitutes a decentralized function throughout the underground habitat and surface elements. The Life Support functions are packaged into self-contained, pre-integrated units. These pods are substantially larger than the equipment they accommodate to allow maintenance – including teardown -- in place, side-by-side installation of spares and removal of old equipment from service. The Life Support pods provide:

- CO_2 removal and recovery.
- Air Revitalization – O2 replenishment, with emergency storage of O_2.
- Buffer gas management for N_2 and any artificial atmosphere constituents such as He.
- Temperature and humidity management and control
- Zoned heating, ventilating, and air conditioning (HVAC)
- Trace Contaminant detection, removal, & control
- Odor control and removal
- Particulate contaminant (including lunar dust) removal and filtration, cleaning of filters
- H_20 polishing and reserve water tank.
- Grey water primary reprocessing
- Solid waste primary processing

Grey water and solid waste flow or are otherwise transported to the Agricultural area for secondary and tertiary processing. Completely processed water is returned to H_20 reservoirs. Water extracted from ice on the surface is also processed to remove contaminants and then added to the reservoirs.

[5] Cohen, Marc M. (2002 October). Selected Precepts in Lunar Architecture (IAC-02-Q.4.3.08).

In contrast with the decentralization of Life Support, the power, communications, habitat system health monitoring, and data connectivity are a distributed, centrally controlled utilities. Data management and communications are also centrally controlled and distributed as services throughout Moon Capital. There is a local electrical breaker panel and a local data and communication bus in each of the sub-sections described above.

Agriculture – A key feature of Moon Capital is that it will be capable of growing a significant fraction of its own food. It is desirable to provide fresh produce at least three times per week to the members. The agricultural zone is nominally divided into ten growing modules or sections or a larger structure. Each module has its own specialized life support pod that provides the optimal (and variable) gas mix with elevated partial pressure of CO_2 for the crop. The lighting for agriculture will be the largest single consumer of electricity and the largest producer of waste heat in the habitat. The design of the lighting should minimize this demand. For example, the lighting arrays may consist of multi-color LEDs that are tuned to the growth phase and height of the plants. The planting, trimming, and harvesting may be done robotically because the high density of the crops and the elevated CO_2 atmosphere is toxic for humans. These conditions make it inadvisable for people to enter the growing modules under normal operating conditions, but if ways can be found to let people safely spend some time in or near the agricultural chambers, they might enjoy doing so as a relief from the stark external environment on the lunar surface.

Design Integration – An intrinsic goal of a this competition for Moon Capital is to advance the discipline and practice of design integration, meaning the coordination and design for control of complexity in the total built environment.[6]

Modularity – The ways that the Space Community knows to reduce and control costs are:

1. Reduce launch mass,
2. Reduce complexity, for which the first order indicator is to reduce the number of unlike (different) parts,
3. Achieve economies of scale, and
4. Rely on mass production of similar elements rather than the production of few or singular elements.

The successful implementation of modularity can help to achieve ways 2, 3, and 4, although these savings may occur at the expense of reducing launch mass in space in the interest of more economical production. Many of the recurring elements in this project may benefit from modularization and mass production. These elements include but are not limited to the life support pod, the hygiene facility, the private sleep cabin, the EVA Suitport airlock, the farm module, and the cluster laboratory. The modularization of these functions and the logical potential combinations of them are a key to the success of this project.

[6] Cohen, Marc M. (1998 July). Space Habitat Design Integration Issues (SAE 981800).

Functional Requirements

The Architectural Design Program for Moon Capital appears below. It states the required architectural functions in area. It is the responsibility of the designers to determine the appropriate "ceiling height" and sub-floor height, and the pressure vessel geometry, thereby calculating the pressurized volume for each function. . Because many of these functions are specialized, the table provides reference sources. These sources and the footnoted references are all available for free download as from http://www.spacearchitect.org. Click on Publications then click on Bibliography.

The design of the Second Generation Lunar Science and Technology Base shall be dimensioned entirely in SI units. The use of some imperial units in this program is for illustrative purposes only and does not imply that they may be used in the design.

Function	Area m^2	Number	Press. Area Sum	Units	Total	Suggested Sources
Moon Capital					7486	http://www.spacearchitect.org
SURFACE ACCESS UNIT (2)			510	2	1020	
Surface EVA Systems			285			Hoffman, Stephen J. (2004 April). Advanced EVA Capabilities: A Study for NASA's Revolutionary Aerospace Systems Concept Program (NASA TP-2004-212068).
Cargo Bay/Airlock with Rover Port accommodates palletized cargo.	12	1	12			Cohen, Marc M. (2000 July). Pressurized Rover Airlocks (SAE 2000-01-2389).
Garage/Airlock for Rover Servicing	30	1	30			
Electric Power Servicing Workshop & Supplies	30	1	30			
ISRU Support and Servicing Workshop & Supplies	30	1	30			
Suitport Airlocks, each with 4 suit interfaces (2).	4	2	8			Cohen, Marc M. (1995 April). The Suitport's Progress (AIAA 95-1062).
Rover Docking Ports with interior vestibule (2)	12	2	24			
EVA Prep and suit maintenance Area for each Suitport Airlock	8	2	16			Cohen, Marc M.; Bussolari, Steven (1987 April). Human Factors in Space Station Architecture II: EVA Access Facility – A Comparative Analysis of Four Concepts for On-Orbit Space Suit Servicing (NASA TM-86856).
EVA Equipment Spares, Parts, Repair	20	1	20			
EVA Suit Loop for all airlocks – Supply and Regeneration (2), includes thermal control internal loop, distributed.	12	1	12			
Circulation area as needed	50	1	50			

Compressor Room (2) to accommodate a high capacity compressor to pump down the airlocks, includes power conditioning and distribution panels, vibration-isolated and noise-insulated.	16	2	32	
Life Support Pod (3) with special lunar dust removal, collection, & disposal	7	3	21	
Exterior "Front Porch" outside each Suitport Airlock, unpressurized `	10	1	n/a	
Atmosphere Storage: High pressure tanks to receive the compressed air output at 10 Bar. Located exterior to the Surface Access Unit. Not pressurized for habitation.	60	1	n/a	
Surface IVA Systems			225	Kennedy, Kriss J. (2002 October). <u>The Vernacular of Space Architecture</u> (AIAA 2002-6102).
Hygiene Facilities (2, unisex) with decontamination showers	4	2	8	
Vertical circulation connection to underground Habitat Core (may include stairs, ramp, elevator, etc)	30	2	60	
Solid waste disposal area	12	1	12	
Equipment recycling area	12	1	12	
Surface observation station with windows, cupola, lounge chairs, lookout	20	1	20	University of Houston, Sasakawa International Center for Space Architecture (2009 January). Report IV: Lunar Module Habitability and Interior Outfitting Considerations and Concepts.
Sample Airlock (for small samples up to 50cm x 50 cm x 100 cm that the EVA crew can pass to the inside without needing to ingress themselves).	2	2	4	
Sample Airlock Receiving Room	10	2	20	
Circulation area provides intake for cargo and an assembly area for EVA/Rover excursions	75	1	75	
Life Support Pod (2)	7	2	14	

ENTREPRENEURIAL ZONE SURFACE LABORATORIES AND WORKSHOPS			200	1	200	Howe, A. Scott (2002 October). The Ultimate Construction Toy: Applying Kit-of-Parts Theory to Habitat and Vehicle Design (AIAA 2002-6116).
Consortium Surface Lab and Workshop			88			Howe, A. Scott (2005 July). Cassette Factories and Robotic Bricks: A Roadmap for Establishing Deep Space Infrastructures (SAE 2005-01-2911).
Exterior pressurized controlled environment for manufacturing/testing materials/structure systems	50	1	50			
Machine & Electrical Workshop	20	1	20			
Life Support Pod (2)	7	2	14			
Hygiene Facility with Decontamination Shower	4	1	4			
Exterior lunar sample storage rack, unpressurized	40	1	n/a			Jones, Rod (2002 October). Observations of the Performance of the U.S. Laboratory Architecture (AIAA 2002-6100).
Expansion Systems			112			
Hatch to private lab connector with vestibule	10	1	10			
Private Lab Connector, inflatable tunnel, with continuation/expansion hatch	20	1	20			
Representative Private Lab Modules (2)	30	2	60			
Life Support Pod (2)	7	2	14			
Hygiene Facility (2)	4	2	8			
CORE HABITAT (UNDERGROUND)			3414	1	3414	University of Houston, Sasakawa International Center for Space Architecture (2008 December). Report I: Figure of Merit Criteria for Evaluating and Selecting Lunar Habitat Module Concepts.

Circulation area as needed	250	1	250		
Administrative			**72**		
Office Areas	20	1	20		
Communications	10	1	10		
Computation (2) including printers & scanners	6	2	12		
Video Conference	20	1	20		
Confidential counseling office	10	1	10		
Operations (2 complete, remotely separated units for redundancy). The Operations Zone requires proximity to the Surface Access Unit.			**150**	**2**	**300**
Electrical Power Conditioning and Distribution (power from photovoltaics and/or fission reactor)	30	1	30		
Water Purification and Distribution (processes water ice from ISRU)	30	1	30		
System Status Monitoring	4	1	4		
Data Systems Management	4	1	4		
Data Servers (2)	6	2	12		
Habitat Health Monitoring System	4	1	4		
EVA Operations Monitoring	4	1	4		
Equipment Stowage	20	1	20		
Supply Stowage	20	1	20		
Hygiene Facility (2)	4	2	8		
Life Support Pod with redundant extra cooling (2)	7	2	14		
Medical/Dental Suite		1	241		

Nealy, John E.; Wilson, John W.; Townsend, Lawrence W. (1988 December). Solar-Flare Shielding With Regolith at a Lunar-Base Site (NASA TP-2869).

University of Houston, Sasakawa International Center for Space Architecture (1989 June 12). Partial Gravity Habitat Study with Application to Lunar Base Design (NASA CR-186048).

Clinic – Health Maintenance & Testing	30	1	30
Examining Room (2)	12	2	24
Dental Examining Room with Chair & X-Ray	12	1	12
Surgery (with tele-surgery equipment)	20	1	20
Recovery	12	1	12
Infirmary Beds/Cabins (4)	8	4	32
Supplies	15	1	15
Pharmacy	12	1	12
X-Ray / CAT-Scan with radiation-shielded walls	20	1	20
Circulation/Waiting/Reception	35	1	35
Hygiene Facility with handicap-accessible toilet, sink, shower (3)	5	3	15
Special Life Support Pod (2) to supply medical O2 and hyperbaric chamber	7	2	14
Hyperbaric Chamber & Support Systems to treat crewmembers who may suffer the bends (caisson disease).	20	1	20
Common Areas		1	914
Communal Dining/Recreation	200	1	200
Galley	30	1	30
Food Stowage, refrigerated	15	1	15
Food Stowage, freezer	15	1	15
Food Stowage, dry	30	3	90
Quiet Recreation (movies, games, etc)	30	1	30
Exercise/workout with 1/6 G-adapted equipment	200	1	200
Arts, Humanities, Entertainment	200	1	200
Classroom/Seminar Room (2) with sliding wall between them.	30	2	60

Nixon, David (1986 November). Space Station Group Activities Habitability Module Study (NASA CR-4010).

Vogler, Andreas (2002 May). Modular Inflatable Space Habitats (ESA WPP-200).

Nixon, David; Miller, Christopher; Fauquet, Regis (1989 December). Space Station Wardroom Habitability and Equipment Study (NASA CR-4246).

Laundry	30	1	30			
Hygiene Facility	4	4	16			
Life Support Pod (3) with special processing for soapy grey water	7	4	28			
Children's Zone for 15 to 20 Children			230			
Education, Recreation, and Exercise for Children, Teachers, and Parent "Volunteers"	200	1	200			
Kitchenette	8	1	8			
Hygiene Facility (2)	4	2	8			
Life Support Pod (2)	7	2	14			
Private Living Cluster		1	128	7	896	Harrison, Albert A.; Caldwell, Barrett; Struthers, Nancy J.; Clearwater, Yvonne A. (1988 May 20). Incorporation of Privacy Elements in Space Station Design (NASA CR-182748).
Sleeping Cabin – Each cabin includes a bunk, desk/work-surface, closet, stowage drawers, and ambient & reading lights. One cluster is for short-term visitors and temporary rearrangements	6	10	60			
Hygiene Facility including sink, tub/shower, toilet – not all necessarily in the same compartment. Hygiene facilities are private & unisex.	4	3	12			
Stowage	12	1	12			
Living Room	30	1	30			
Kitchenette	8	1	8			
Janitorial/Maintenance	6	1	6			
Life Support Pod (2) joined into a common manifold with the other Private Living Clusters	7	2	14			
Common Support and Maintenance Services (may be combined or separated at the designer's discretion)		1	97			

Plumbing Shop Area	10	1	10	
Metal and Plastics Fabrication Shop Area	15	1	15	
Computer 3D Printing Shop Area	15	1	15	
Supply/Equipment Stowage	20	1	20	
Machine Shop Area	10	1	10	
Electrical Shop Area	10	1	10	
Hygiene Facility (2), men, women	4	1	4	
Janitorial/Maintenance	6	1	6	
Life Support Pod (2)	7	1	7	
Working Environment: Laboratories		1	414	Cohen, Marc M. (2001 July). Space Laboratories (SAE 2001-01-2142).
Cluster 1 Life Science				
Gravitational Biology Laboratory	30	1	30	
Animal Care Facilities	30	1	30	
Life Science Laboratory	30	1	30	
Agriculture Systems Technology Laboratory	30	1	30	
Stowage	30	1	30	
Supplies	20	1	20	
Hygiene Facility with Decontamination Shower (2), Men, Women	4	1	4	
Janitorial/Maintenance	6	2	12	
Life Support Pod (3) with special animal waste particulate and odor removal	7	3	21	
Cluster 2 Physical-Chemical Science		1	0	Cohen, Marc M. (1999 July). Mars Surface Science Laboratory Accommodations and Operations (SAE 1999-01-2142).
Chemistry Laboratory	30	1	30	
Geology/Planetology/Meteoritics Laboratory	30	1	30	Wilhelm, Don E. (1993). *To a Rocky Moon: A Geologist's History of Lunar Exploration*.

ISRU Materials Processing Laboratory	30	1	30			Taylor, G. Jeffrey; Spudis, Paul D. (Eds.) (1990). *Geoscience and a Lunar Base* (NASA CP-3070).
Environmental Systems Technology Laboratory	30	1	30			
Stowage	30	1	30			
Supplies	20	1	20			
Hygiene Facility with Decontamination Showers (2), Men, Women	4	1	4			
Janitorial/Maintenance (2)	6	2	12			
Life Support Pod (3) with special chemical fume removal	7	3	21			
AGRICULTURE ZONE, in multiple inflatables		1	2852	1	2852	
Farm Module with two remote means of egress	200	10	2000			
Farm Equipment Stowage	20	3	60			
Farm Equipment Repair and Servicing Workshop, radiation shielding	20	1	20			
Farm status monitoring, radiation shielded	8	1	8			
Bioregenerative/Physical Chemical Life Support Interface	20	1	20			
Water secondary and tertiary processing	20	10	200			
Solid Waste secondary and tertiary processing	20	10	200			
Agricultural Robot Repair and Servicing Workshop, radiation shielded	20	1	20			
Circulation in farm areas	150	1	150			
Hygiene Facilities (unisex) radiation shielded	4	2	8			
Janitorial/Maintenance (2) radiation shielded	6	2	12			
Life Support Pod (2) for the Workshop and Monitoring Areas, radiation shielded	7	2	14			
Special Life Support Pods for Farm Modules with variable elevated partial pressure of CO2 (10) and primary water processing	14	10	140			

A Short Annotated Bibliography

Download from http://www.spacearchitect.org

An excellent starting place for lunar architecture is: Duerk, Donna P. (2004 September). Curriculum for Aerospace Architecture with Emphasis on Lunar Base and Habitat Studies (NASA CR-2004-212820).

The lunar science mission provides the basic rationale for the Moon Capital: Duke, Michael B.; Hoffman, Stephen J.; Snook, Kelly (2003 July). Lunar Surface Reference Missions: A Description of Human and Robotic Surface Activities (NASA TP-2003-212053).

Supporting humans in space for long durations is the most challenging aspect of the Moon Capital, especially in terms of human factors: Connors, Mary M.; Harrison, Albert A.; Akins, Faren R. (1985). *Living Aloft: Human Requirements for Extended Spaceflight* (NASA SP-483).

Since all Space Architecture is pressurized, the true currency of design and planning is habitable volume Cohen, Marc M. (2008 June). Testing the Celentano Curve: An Empirical Survey of Predictions for Human Spacecraft Pressurized Volume (SAE 2008-01-2027).

A review of lunar habitat concepts appears in Aguzzi, Manuela (2005 July). BLU (Basic Lunar Unit) for Moon Exploration (SAE 2005-01-3044).

NASA suggested guidelines appear in Allen, Christopher S. et al (2003 January). Guidelines and Capabilities for Designing Human Missions (NASA TM-2003-210785).

For examples of structural approaches see Benaroya, Haym (2002 October). An Overview of Lunar Base Structures: Past and Future (AIAA 2002-6113). 1st Space Architecture Symposium (SAS 2002),

Lunar base engineering, logistics, and operations studies include:

Eagle Engineering Inc. (1987 December). Lunar Base Systems Study (LBSS): Lunar Surface Operations Study (NASA CR-172050).

Eagle Engineering Inc. (1988 May). Lunar Base Systems Study (LBSS): Maintenance and Supply Options (NASA CR-172062).

Eagle Engineering Inc. (1988 July). Lunar Base Systems Study (LBSS): Lunar Surface Transportation Systems Conceptual Design (NASA CR-172077).

Ganapathi, Gani B.; Ferrall, Joseph; Seshan, P. K. (1993 May). Lunar Base Habitat Designs: Characterizing the Environment and Selecting Habitat Designs for Future Trade-offs (NASA CR-195687).

Kennedy, Kriss J. (2002 October). Lessons from TransHab: An Architect's Experience (AIAA 2002-6105).

The dominant aspect of Space Architecture concerns the interior environment, where the crew spends almost all their time except when on EVA or rover missions. References for the quality of the interior environment include:

Durão, Maria Joao (2002 October). Color in Space Architecture (AIAA 2002-6107).

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Stuster, Jack W. (1986 September) Space Station Habitability Recommendations Based on a Systematic Comparative Analysis of Analogous Conditions (NASA CR-3943).

Wise, Barbara K.; Wise, James A. (1988 August). The Human Factors of Color in Environmental Design: A Critical Review (NASA CR-177498).