I, Jeffrey R. Badger, hereby submit this original work as part of the requirements for the degree of Master of Architecture in Architecture (Master of).

It is entitled:
Designing for Space, on Earth: Creating More Livable Extraterrestrial Habitats Through Architectural Design

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University of Cincinnati
Designing for Space, On Earth

Creating More Livable Extraterrestrial Habitats Through Architectural Design

A thesis submitted to the Graduate School of the University of Cincinnati in partial fulfillment of the requirements for the degree of Master of Architecture in the School of Architecture and Interior Design of the College of Design, Architecture, Art, and Planning

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B.S. University of Tennessee, June 2008

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June 2012
Traditionally, space exploration and habitation have existed primarily within the domain of the engineering field. This has proven sufficiently effective for space-related design challenges, most of which rely on technology and rigorous testing. The short duration and small crew numbers of past missions, along with the ability of the human body and mind to tolerate extreme conditions, have permitted designers to focus on the most immediate and necessary concerns of putting humans into space. But decades of focused research and engineering in space programs, combined with inconsistent budget decisions, have led to a design status quo that is remarkably entrenched and unimaginative. Of particular concern are the limited resources applied toward the design problems of human factors in space.

On Earth, architects constantly address these human factors, usually within the built environment. Despite the obvious environmental distinctions between Earth and space, analogous building/user interactions occur for Earth dwellers and astronauts alike. And going beyond architects’ collective experience and facility at human-centered design, extraterrestrial design problems could potentially derive solutions from innovative or previously disregarded works of architectural theory. With an analysis of existing extraterrestrial designs’ deficiencies in human factors and applicable architectural solutions, we can develop principles for the effective synthesis of engineering and architectural responses in future projects.
ACKNOWLEDGEMENTS

I am deeply grateful to Jeff Tilman, Brian Davies, John Hancock, and James Eckler for the wealth of knowledge and experience contributed to this project.

To my classmates, thank you for your companionship, critique, and beverages during all the reviews and late nights.

I am indebted to my parents, David and Sherry Badger, both literally and figuratively. Without your love, support, and guidance, I could not be where I am today.

And to my wife Elizabeth: thank you for tolerating me through these four years of school—your patience, love, and support have been my lifeline.
# Table of Contents

Chapter One: Introduction 1  
Chapter Two: Existing Precedents 7  
Chapter Three: Simulations & Analogs 17  
Chapter Four: Architectural Synthesis 29  
Chapter Five: Conclusions 45  
Bibliography 50  
Appendix A: Client / Institution / Cultural Situation 55  
Appendix B: Site Context 59  
Appendix C: Programming 63
1.01  Apollo 11 Launch (S69-39961), NASA, 1969
http://history.nasa.gov/ap11ann/kippsphotos/apollo.html

1.02  Ham, NASA, 1961

1.03  Mercury Capsule, Boeing, 1960
http://www.collectspace.com/ubb/Forum38/HTML/001302.html

1.04  Alien film poster, 1979
http://www.imdb.com/media/rm267684864/tt0078748

1.05  Apollo 8 Crew (S68-54520), NASA, 1968

2.01  ISS and Endeavour seen from the Soyuz TMA-20 spacecraft, NASA/Paolo Nespoli, 2011
http://commons.wikimedia.org/wiki/Category:STS-134_docked_to_the_International_Space_Station

2.02  Skylab Station Viewed by Skylab 2 Command Module, NASA, 1973
http://commons.wikimedia.org/wiki/File:Skylab_Station_Viewed_by_Skylab_2_Command_Module_-_GPN-2000-001709.jpg

2.03  Showering on Skylab, NASA, 1973

2.04  Diagram by Author: Design Consideration for Long-Term Extraterrestrial Habitats

2.05  Temporary Sleep Station, NASA, 2002
http://commons.wikimedia.org/wiki/File:Temporary_Sleep_Station.jpg

2.06  Illustrated view of Mars Habitat Unit on Martian surface
http://www.hudsonfla.com/spaceviewinner.htm

2.07  Diagram by Author: Design Deficiencies

2.08  Diagram by Author: Design Approaches

3.01  Amundsen-Scott Mars Station, Chris Danals, 2005
http://commons.wikimedia.org/wiki/File:Amundsen-Scott_marsstation_ray_h_edit.jpg

3.02  Vomit Comet, NASA
http://commons.wikimedia.org/wiki/File:Vomit_Comet.jpg

3.03  Mars Desert Research Station, McKay Salisbury, 2004
http://commons.wikimedia.org/wiki/File:Mars_Desert_Research_Station.jpg

3.04  Aquarius External, NASA, 2006
http://commons.wikimedia.org/wiki/File:Aquarius_external.jpg

3.05  Photograph by Author: Biosphere 2, 2011

3.06  Amundsen-Scott South Pole Station, U.S. Antarctic Program, 2007

3.07  USS Dallas Prepares to Get Underway, US Navy/Nicole Hawley, 2002
3.08 Diagram by Author: Design Requirements within Non-Extreme, Earth-Based Context
3.09 Diagram by Author: Deficiencies/Benefits of Simulations & Analogs
4.01 Photograph by Author: Arcosanti, 2011
4.02 Diagram by Author: Architectural Synthesis
4.03 Diagram by Author: New Building Typology
4.04 *Villa Rotonda*, Andrea Palladio, 1570
4.05 *Pompidou Centre*
   http://www.photoeverywhere.co.uk/west/paris/slides/pompidou_centre2966.htm
4.06 Brand, 13
4.07 *Nagakin Capsule Tower*, Yu Sun Kwon, 2007
4.08 *Nagakin Capsule Tower*, Chris 73, 2004
   http://commons.wikimedia.org/wiki/File:Nakagin_Capsule_Tower_03.jpg
4.09 *Meteora Agios Triadas*, Dido3, 2007
   http://commons.wikimedia.org/wiki/File:Meteora_Agios_Triadas_IMG_7632.jpg
4.10 Diagram by Author: Practices & Concepts/Design Principles
   http://commons.wikimedia.org/wiki/File:US_Navy_110706-N-HW977-253_Samuel_Lam,_left,_and_Steven_Foust_assemble_prototype_retractable_metal_framework_supporting_photovoltaic_panels.jpg

5.01 *AS04-01-750*, NASA, 1967
5.03 *Spirit’s Destination (panorama)*, NASA/JPL/Cornell, 2004
5.04 *Aldrin Apollo 11*, NASA/Neil Armstrong, 1969
   http://commons.wikimedia.org/wiki/File:Aldrin_Apollo_11.jpg

B.01 Diagram by Author: Figure-Ground Site Plan
B.02 Diagram by Author: Site Restrictions Plan
B.03 Diagram by Author: Site Restrictions Section

C.01 Diagram by Author: Programmatic Inventory
C.02 Diagram by Author: Programmatic Adjacencies
C.03 Diagram by Author: Flexibility Types
C.04 Diagram by Author: Flexibility Responses
In the past century, we have begun to do amazing things in space. Over 500 individuals have traveled there, some of them multiple times. And while NASA is presently in a phase of lessened activity (in terms of the manned space program), planning has begun for new ways to take humans into space. And perhaps more importantly, private companies have been developing at an exponential rate, with the free market beginning to drive and fund new avenues for space exploration.

With our species’ innate need to move and explore, habitation of other planets is a near certainty—the only question is how soon. Immediate, worldly concerns often trump those of the future, but planning and experimenting for future needs remains a logical necessity. At the moment, extraterrestrial buildings remain principally a concern for the engineering community. But there does now exist an increasingly active and relevant discourse as to how we can
best address these issues in a multi-disciplinary fashion. One of the important questions that we can ask within this dialogue is how we to develop principles for the effective synthesis of engineering and architectural responses in future projects both on Earth and in space.

Looking back at the history of space exploration, we can see a clear progression in the priority of human factors. The earliest satellites carried no living occupants at all, and thus required little of the protections that human occupants require—pressurization, radiation shielding, etc. And it is not entirely appropriate to use the term human factors for the first living space explorers, who were not human at all. Unfortunately for these first intrepid animals (dogs, chimpanzees, rats, and frogs, among other creatures), their earliest spacecraft only included the most basic necessities for brief survival in space, and initially lacked even the ability to return the animals to Earth. The Soviet dog Laika, who in 1957 became the first animal to achieve orbit in outer space, died after overheating due to mechanical malfunctions in her Sputnik-2 spacecraft. Had the dog not succumbed to the heat, there were still no plans to return her to Earth; she would have been euthanized in space. Later Soviet and American flights proved more successful, launching and safely returning animals like Ham the space chimp. The first humans to fly in space (to be clear, both orbital and suborbital trips)—the Soviet Yuri Gagarin and American Alan Shepard in 1961—spent their short flights in claustrophobically small spaces. For American astronauts of Project Mercury, so goes the joke, the capsules were “worn, not ridden.”

For the longer trips of later missions, interior comfort would increase, but only slightly. The primary concern for designers of second and third generation vessels
like the Gemini and Apollo capsules was simply to keep the astronauts alive. A number of fatal accidents had occurred on Earth and in space during the early years of the Space Race, and engineers had to constantly maintain a delicate balance of safety and utility within their increasingly complicated spacecraft. Astronauts now needed to move around freely in their capsules to accomplish tasks, exit and enter while in space, dock with other modules, and even land on the moon, while simultaneously avoiding the innumerable ways in which a human can die in outer space.

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The bodily dangers of outer space are numerous, usually fatal, and often fascinatingly unique. The most obvious risks stem from space’s almost entirely airless vacuum, which requires a strong spacecraft hull with hatches and windows able to withstand the forces of a pressurized interior. The gaseous makeup of this artificial atmosphere must be closely considered, lest flash fires break out in an oxygen-rich environment. This reinforced hull must also shelter occupants from missile-like projectiles both natural and man-made (space garbage). And without the protective atmosphere of Earth, there must be insulation from the extremely hot and cold temperatures of alternating shade and direct sunlight, as well as harmful UV radiation and cosmic rays.¹ Zero gravity environments present other unexpected challenges. For example, the natural convection currents of a room’s air do not occur without gravity; sleeping astronauts require artificial air movement to avoid asphyxiating in a cloud of their own carbon dioxide. Liquids float and form spheres rather than spilling to the floor, with surface tension becoming a more dangerous force than on Earth. Water can quickly coat a person’s face and flow into the nose, and

¹ Planel, 23
foods tend to hang in the throat without gravity’s pull.² In the long-term, microgravity relieves the daily stresses on our skeletal system, resulting in weakened bones and joints. And these are only the risks once in orbit—the dangers of launching humans into space on rockets and landing them in the ocean or on a landing strip include incredible g-forces, explosive fuels, parachute malfunctions, and the intense heat of re-entry, among others. But despite a number of tragic accidents that have occurred over the past few decades (the Apollo 1 fire, Soyuz 1 and 11 accidents, and the Space Shuttle Challenger and Columbia disasters), a solid majority of space missions have been successful. Not accounting for multiple trips into space by a single person, manned space missions have launched 513 individuals into space, with 18 deaths, with a 3.5 percent fatality rate. Adjusting for multiple trips, that number drops below two percent.

With an understanding of these hazards, one can begin to understand the cramped, uncomfortable compartments. With each additional complexity in a spacecraft’s design come exponential increases in risk and financial cost. But for missions of longer durations, user comfort becomes critical for efficient performance. Uncomfortable, stressed astronauts can experience negative mental and physical effects that influence their abilities to perform tasks essential for research and survival. Even in the more adequate and relatively luxurious conditions of contemporary spacecraft, the stresses of astronauts work, environment, and (probably most importantly) sleep deprivation can contribute to a condition of temporary cognitive impairment known more briefly as the “space stupids.”³
Once familiar with overall challenges for design in the extreme environment of space, we can then analyze specific examples to ascertain their distinct design considerations, successes, and failures. These precedents consist of both constructed and planned space exploration precedents. The most relevant examples are those spacecraft and space stations that have either attempted or succeeded in housing individuals and groups of people for substantial amounts of time. While the fundamental requirements for keeping humans alive do not change, the rapid evolution of spacecraft and habitats presents a progressively complex array of design challenges and responses.
The first significant design consideration for human comfort coincides with the first long-term habitats: space stations. The earliest, Soviet Salyut modules (in orbit 1971-1991), initially allowed only modest gains in livability, mostly due to increased space for movement. Private space for astronauts was introduced in Skylab (1973-1979), the United States’ first space station. Skylab astronauts could find visual privacy in small compartments (though with sound and light isolation), along with improved lighting, food, and hygiene facilities. They still slept in the standard wall-mounted sleeping bag, but they could do so within a space of their own. Many of these improvements came as the result of collaboration with industrial designers at Raymond Loewy/William Snaith, Inc. (As an aside, it is interesting to note the initial disagreements between the project’s engineers, and the consulting designers—many engineers, and even some the astronauts themselves, felt that recommendations for lighting, partition arrangements, and color schemes were not worthy of detailed analysis.4) Salyut 6 (1977-1982), one of the later Salyut missions, followed suit with the addition of kayutus, or small individual crew cabins. These suffered some of the same thermal and acoustic limitations as Skylab’s version, but are noteworthy for including an individual window for each occupant. Similar configurations would be used, and only slightly updated, in the Soviet/Russian Mir space station (1986-2001), within its core module.5 Mir also featured a similar shower setup to those on Skylab and the later Salyut stations, none of which proved very successful, due to the inherent properties of liquids in space. Cosmonauts chose to use snorkeling gear in the shower, while most American astronauts skipped the showers and returned to the more proven method of cleansing wipes (which now remain the preferred method on contemporary missions).

4 Benson and Compton
5 Howe and Sherwood, 45
Design Considerations for Long-Term Extraterrestrial Habitats

Physical:
- Vacuum: - Internal pressurized/breathable atmosphere
  - Reinforced hull, hatches, windows
- Micro/low-gravity: - Appropriate interior proportions
  - Countermeasures (ventilation, velcro, etc.)
- Radiation: - SPE/GCR shielding
- Debris: - Shielding
- Dust: - Dust cleaning/filtering strategies

Organizational:
- Structure/enclosure
- Life support systems
- Thermal systems
- Power supply
- Data management
- Communications
- Research facilities
- Storage
- Radiation shelter

Personal:
- Primary considerations: - Sustenance
  - Rest
  - Work
  - Hygiene
- Resultant considerations: - Acceptable food/beverages
  - Odor & noise control
  - Lighting
  - Views
  - Leisure activities
  - Exercise
  - Medical care
  - Privacy
- Additional considerations: - Sufficient interior space
  - Comfortable furnishings
  - Cleaning/washing
  - Aesthetics
  - Interpersonal dynamics
  - Various psychological concerns
The International Space Station (ISS) represents the most recent example of long-term human space habitation. Occupied since 2000, the space station has housed almost 200 individual visitors, for an average duration of six months each. The ISS is composed of a diverse array of internationally designed and constructed modules, from NASA (USA), RKA (Russia), JAXA (Japan), ESA (Europe), and CSA (Canada). This collaboration represents both a relatively successful and efficient partnership of nations, as well as the inherent weaknesses of the station’s segmented overall design. The station is a composite of individually designed space stations and modules, including the cancelled American Space Station Freedom and the Russian Mir-2, as well as Japanese and European science modules.6 This modular system affords some benefits of efficiency and flexibility, especially for a bureaucratic design environment—where objectives and funding are constantly changing and engineers must adapt older products and designs for use in new projects. A modular system also presents the most directly feasible solution for the international, collaborative nature of the space station.

In terms of human habitability, the ISS demonstrates significant gains since the early days of space exploration, but still relatively little planning for longer-term human necessities. Many of the station’s weaknesses in this area (very limited bathing facilities, few comfortable sleeping compartments, poor environmental lighting conditions, etc.) can be attributed to the limits of technology and available space, but must still be addressed eventually for future projects. Interestingly, astronauts in the ISS have established the usefulness of flexible spaces, especially for personal needs. With ever-fluctuating crew numbers and nationalities, astronauts often set up their own personal

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6 Kitmacher, 23
areas within lesser-used areas of the station, attaching their sleeping bags and personal storage to the walls.

• • •

Moving forward, we can also consider the design challenges for future space exploration and settlement, a blend of existing and future issues. The most likely location for a long-term extraterrestrial colony is on Mars: of the planets and moons in our solar system, Martian surface conditions are the most similar to Earth. But as Carol Stoker (a planetary scientist at NASA’s Ames Research Center) notes in Strategies for Mars, most of our collective research has focused on the “getting there,” at the expense of planning for the “being there.” A permanent Martian colony will present design considerations at multiple levels, including basic physical conditions, overall configuration feasibility, and personal/community needs. In order to develop any new strategies for addressing these considerations, the necessary research and testing must first be conducted here on Earth.

NASA and other organizations have already devoted a significant body of research and thought to possible transportation and habitation strategies, with a focus on the most critical concerns. One product of these investigations is the hypothetical Mars Direct model for initial exploration and habitation on the Martian surface. Originally developed in 1990 by NASA engineers Robert Zubrin and David Baker, the Mars Direct plan incorporates multiple stages: launch, transit, landing and settlement, and a return to Earth. A central component of this scheme is the Mars Habitat Unit, a cylindrical module for housing the crew both during the voyage, and once on the planet surface. Unlike the long and thin shapes of most contemporary space station modules,
designed to fit within the cargo area of the (now-defunct) Space Shuttle, the Mars Habitat Unit is shaped like a “tuna-can.” This wider spatial format would make full use of an Ares rocket’s massive dimensions, and allow for more efficient utilization of interior space. Beyond the established standards of orbital habitation, this scheme’s initial planning for human comforts has been mostly cursory. In theory, though, the Habitat Unit is certainly more comfortable than previous orbital units, if only due to the benefits of gravity. Not only does gravity facilitate healthier astronauts, and a more familiar environment, it permits the feasible and authentic use

8 Zubrin and Wagner, 62
of other human comforts and rituals: sitting around a kitchen table and eating a cooked meal with companions, sleeping on a horizontal bed, placing personal effects on a desk, or taking a real shower with hot water. Astronauts are tough, driven people, but these daily comforts provide important physical and psychological benefits for any human being in a strange environment, especially over longer mission durations.

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Looking at these specific examples of past, current, and planned extraterrestrial habitats, we have begun to discern some of the design requirements for human survival and comfort. But we can also identify specific deficiencies and shortcomings that must be addressed. These design deficiencies often fall into categories similar to those design requirements: systems deficiencies (having to do with the physical systems and utilities of a spacecraft or habitat) and personal deficiencies (those relating to livability, or human factors).

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**Systems Deficiencies**

Rigid systems: modules can permit some overall external flexibility, but limited individual control & future-proofing

Poor integration of mission- and human-centered systems: issues of light, noise, personal space, etc.

**Personal Deficiencies**

Inadequate facilities: hygiene, sleep, etc.

Lack of privacy

Lack of individual control over immediate environment

Neglect of personal habits & rituals: cooking, housekeeping, etc.

Little sense of place
Furthermore, we can analyze and classify the existing design approaches and determine which methods are more successful than others, for our particular area of interest. Though these often opposing categories of design approaches can be much more nuanced than a simple diagram might suggest, identifying them will still be useful for choosing modes of ongoing design. The simplest dichotomy might be engineering efficiency vs. human comfort, or “man in a can” vs. “quality of life.”  

This will likely remain an enduring tension to be resolved in every future design—the human body will always be messier and more needy than machines and computers. (This somewhat unsettling tension also underlies the effectiveness of films like The Matrix and The Terminator.) The nature of this requisite interaction between man and machine introduces another dichotomy: one of clinical and humanistic interactions. In its most extreme manifestation, the former technique approaches a spacecraft’s human operator as simply another component in a larger machine, albeit a wasteful component necessitating the majority of the machine’s resources. In this case, little thought to the human component’s comfort is required, as long as it remains alive and functional. In contrast, a humanistic approach considers the man-machine/environment interaction on more levels than efficiency. Prioritizing the human user as a distinct and served entity may result in less efficiency by some metrics, but ultimately facilitates more effective users and more efficient human operation.

In a paper presented at The Case for Mars IV Conference in 1990, architect and aerospace engineer Marc M. Cohen looks at the ways in which one can problem-solve, particularly in the case of exploring Mars. He identifies systems engineering as a traditional, and professionally ingrained means of solving well-defined problems. In the
case of Mars exploration, however, the problem is much more complex than anything previously encountered, and much of it remains indefinite. Compared to the Moon, for example, a mission to Mars involves many more initial unknowns. Cohen suggests an alternative participatory planning method.\(^\text{10}\) In the standard systems engineering method, design problems are always assumed to be well-structured, and work is precisely divided for efficiency. This can result in decisions being constantly revisited, and creative ideas along the way (ostensibly slowing down the process) being eliminated rather than considered and tested. In a participatory approach, all involved parties build consensus on design problems and strategies for solving them. Similar design work and testing by multiple interested and invested parties is encouraged in order to foster new ideas. Both of these approaches have their merits, but the participatory approach might prove more useful for the development of innovative design solutions, especially here on Earth.

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10 Cohen, *Participatory Planning Alternative for Mars Mission Design*
Since opportunities for research and experimentation with actual humans in outer space are extremely limited, the vast majority of research is performed here on Earth. These examples tend to fall within two general categories: *simulations* and *analogs* (these are by no means rigid classifications, and these terms are often used interchangeably). For the sake of this analysis, we will consider simulations to be facilities and studies constructed with the explicit—and primary—intent of reproducing extraterrestrial conditions (i.e. spacesuits, sealed compartments, freeze-dried or liquid foods—the whole nine yards). Analogs, on the other hand, include a broad variety of facilities with environmental aspects comparable to those in space, or on other planets (isolation, extreme thermal conditions or altitude, etc.).

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11 Howe and Sherwood, 331
Simulations can range from very specific tests to long-term, comprehensive isolation experiments. We can simulate some of the physical conditions of space, namely microgravity and extreme g-forces, only through very specific procedures. Microgravity can be simulated by putting a person or object in freefall. The best way of accomplishing this is by flying an airplane in parabolic arcs—up at around 45 degrees, and then back down, repeatedly. Around the plane’s crest, anything inside experiences around 20 seconds of microgravity, followed by a period of 2g hypergravity. Experiments in the “Vomit Comet” must be kept short, and preferably waterproof (the plane’s nickname is no joke; many people become nauseous and vomit repeatedly during the flights’ often 20-50 parabolas). Underwater conditions can also approximate reduced gravity, thus astronauts often practice spacewalks in the Johnson Space Center’s pool. And for specific tests, even more contrived simulations can be utilized, like bed rest trials of a month or longer.\(^\text{12}\) For truly accurate conditions, however, there is no substitute for outer space. Ultimately, the difficulty in replicating the dangers and physical forces of space, and the strict engineering tolerances required, make such experimental aims unfeasible for most simulation facilities on Earth.

In addition to physical condition simulations, NASA and other organizations have long tested human responses to a number of other situations, including isolation. Researchers have isolated test subjects at existing facilities like the Ames Research Center, in deserts, at the poles, and underwater. Long-term experiments like Biosphere-2 in Arizona, NEEMO’s underwater Aquarius station in the Florida Keys, and the Mars Society research stations in Utah and the Canadian Arctic have gathered a wide range of information on the performance of habitats in extreme environments, as
well as the complex nature of individual and interpersonal human behavior in isolation.

Some of the most ambitious and holistic simulations currently in operation are those of the Mars Society, a space advocacy organization that performs both private and collaborative testing. The Mars Analog Research Station Programme consists of multiple simulation facilities operated by the Mars Society. Currently, there are two stations in operation: the Flashline Mars Arctic Research Station (FMARS) on Devon Island in the Canadian Arctic, and the Mars Desert Research Station (MDRS) in the Utah desert. European and Australian installations have been planned, but not built. The buildings themselves are based on the previously mentioned Mars Habitat Unit, a potential housing and laboratory unit proposed by Dr. Robert Zubrin as a part of the Mars Direct plan for Martian exploration and colonization.

The units themselves consist of 25-foot-tall cylinders (27-foot diameter) designed for compatibility with existing and proposed rocket technology. There are two levels: the lower level houses open workspace and bathroom facilities, while the top contains crew cabins and cooking/dining space. The “Hab,” as it is called, is only moderately self-sufficient at present, due to site and financial restrictions. Water is collected from nearby streams (FMARS) or delivered (MDRS) and stored within external and internal tanks; diesel generators provide electricity. Greywater is used for toilet flushing. The MDRS does also feature a “GreenHab” unit, which encloses a greenhouse and greywater processing equipment. Researchers at the stations perform experiments under realistic conditions whenever possible. Crew makeup is relatively diverse—most crews include college and graduate students in addition to other researchers. NASA often collaborates with the Mars Society in order to run their own
tests and simulations, most often at the Arctic Flashline site.

Like smaller-scale spacewalk simulations in swimming pools, the Earth's oceans create an analogous environment to that of space and facilitate realistic simulations. One such simulation is the Aquarius module, an underwater habitat located in the Florida Keys and operated by the NASA Extreme Environment Mission Operations (NEEMO). Researchers here utilize the undersea conditions to simulate an isolated, low-gravity, and oxygenless environment. Crews rotate in similar fashion to the Mars Analog Research Station, living and working in isolation for shorter one to three week periods. Owing to a demanding environment and short habitation periods, the crew comforts are sparse (personal areas are similar to bunks found in nuclear submarines).

Simulations can be performed in less challenging environments, of course, with varying degrees of realism. Biosphere 2, located in the Arizona desert, could very well be constructed anywhere (though the intense desert sun is beneficial in this case). Initially constructed and used as an extensive isolation experiment, Biosphere 2 is a completely self-contained habitat, housing an array of different biomes like deserts, jungles, and oceans. The facility is perhaps best known for a two-year-long experiment from 1991 to 1993, in which eight researchers lived in almost complete isolation. Aside from a brief atmospheric complication due to El Niño, they grew their own food and breathed oxygen produced by plants in the biosphere's various miniature biomes. Though initially panned as a partial failure, the experiment resulted in new information on isolated group dynamics, and the viability of enclosed natural biomes for future space colonization.

Another example recently concluded in Moscow—the Mars 500 experiment. Devised as a complete simulation of a mission to Mars, the most substantial stage of this experiment
included a simulated Martian landing and 520 days spent in isolation. Due to the location, the replication of environmental conditions was limited, but other considerations were extensive, including lags in communication links to the outside, and limited, self-contained stores of food and other resources. In addition to support facilities, the simulation areas themselves included realistic modules for Martian habitation like a primary habitat module, a medical module, a landing simulator, and a utility/storage module. Attached to the contained living spaces was a replicated Martian surface for outside experiments. Experimental goals ranged from group dynamics observation (the simulation group was composed of international crew members) to analysis of human and systems performance under different conditions.

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The second category we can examine—analogs—can include a wide variety of precedents, depending on the scope. For this analysis, we will limit this range to a few particularly relevant examples. While their locations may vary drastically, these precedents share common qualities like isolation, harsh environments, and stressful situations.

Some of the best analogs on Earth for outer space conditions can be found in the icy desert of Antarctica. The continent is the site of numerous relevant analogs, from many different nations. One of the most isolated is the Amundsen-Scott South Pole Station, an American Antarctic research facility located at the Geographic South Pole. It has been continuously occupied since its original construction in 1956 and 1957. Temperatures here can range on average from -80° to -15° F, at an elevation of 9,301 feet. Though covered in ice, humidity is extremely low. The buildings themselves have changed over time—the original wood and canvas building
was replaced by a geodesic dome in 1975, and finally a newer, elevated building in 2003. This newest structure is elevated on adjustable jacks in order to mitigate previous issues of snow burial and drifting. Electricity is generated mainly by diesel generators, supplemented by photovoltaic panels during the summer. Owing to its location, the facility receives six straight months of low-elevation angle sun, from March to September, and complete darkness during the other six months.

The majority of activity at Amundsen-Scott occurs during the summer, when temperatures are warmer. Summer occupancy averages around 200 people. A smaller staff remains to “winter-over” in higher isolation, usually around 50 people. This staff is mostly made up of maintenance personnel, with some researchers. Due to the relentlessly hostile conditions, many of the daily activities for residents center on keeping the station operational (i.e. thermally survivable, and above the snow), especially during the harsh winter. Machinery breaks down constantly, and water collection means gathering snow with bulldozers before melting it down—showers are accordingly short and infrequent.13

For occupants of Antarctic stations, isolation can induce anxiety, and exacerbate existing sources of stress. These can manifest in psychological and physiological effects. Physical stressors include those of the outside environments, and aspects of the buildings themselves—poor lighting and ventilation, noise, sterile environments, and crowding. Some of the most helpful alleviators include aspects of both novelty and routine. Special events break up monotony, while preparations for these events can distract from daily tedium. The ability to perform daily, personal rituals, can

13 Harrison, Clearwater, and McKay
also be very helpful for stress relief (much like a basketball player’s personal pre-free throw routine—bouncing the ball a set number of times, or wiping the face in a particular way), especially if these ritual can help an individual connect consciously or subconsciously with memories of less stressful places and situations.

Submarine missions (particularly on military nuclear submarines) can provide a unique analog for outer space habitats. When submerged, sailors live and work in isolation for long periods, usually two to three months at a time. Due to their nuclear power source, these “habitats” are theoretically limited only by the food stores for the crew (a reactor supplies energy without any need for oxygen; breathable air and drinking water can be extracted from seawater). As an enlisted crew, individual sailors form a distinct user type: somewhat like future space colonists, they live and work under the constraints of a specific mission, though eventual colonists will likely have a less homogeneous makeup.

The design of an Earth-based facility necessitates a reordering of the design considerations for extraterrestrial habitats. Strict design necessities for outer space must be balanced with the range of requirements for Earth-based buildings in different environments. The utility of architectural principles must be considered for a similar range of situations. Some structures and systems required for survival in space can be discarded or reduced in functionality when built on Earth, while design considerations pertaining to individual users may gain importance for a project’s research goals.
## Design Requirements within Non-Extreme, Earth-Based Context

<table>
<thead>
<tr>
<th>High Importance: (Critical)</th>
<th>Medium Importance: (Flexible)</th>
<th>Low Importance: (Optional)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Structure/enclosure</td>
<td>- Thermal systems</td>
<td>- Pressurized/reinforced structures</td>
</tr>
<tr>
<td>- Power supply</td>
<td>- Dust/contamination prevention</td>
<td>- Micro-gravity considerations</td>
</tr>
<tr>
<td>- Research facilities</td>
<td>- Data management</td>
<td>- Radiation shielding</td>
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<td>- Sustenance: food/water</td>
<td>- Communications network</td>
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<td>- Work: exercise, leisure, views, lighting</td>
<td>- Storage</td>
<td>- Extreme temperature insulation</td>
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<td>- Sleep: privacy, odor &amp; noise control</td>
<td>- Psychological considerations</td>
<td>- Auxiliary radiation shelter</td>
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<td>- Hygiene: bathing, clothes washing</td>
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New hierarchies can begin to suggest the significance of individual design requirements and principles. An understanding of such hierarchies facilitates their practical application to a new project’s overall design, and the degree to which they guide the process. The most critical requirements (in the context of a relatively temperate site on Earth, rather than an extreme environment like space’s vacuum), in conjunction with equally essential architectural principles, will shape the building’s fundamental strategies. Moderately important requirements can be adapted for project’s intent and efficiency, while the least important requirements may be rejected entirely. Likewise, architectural principles of moderate, low, or unknown importance will comprise the project’s adaptable, or changing, component. As building elements evolve, a variety of these different ideas can be actualized and tested.
We can also evaluate the performance of simulations and analogs for lessons relevant to subsequent projects on Earth or in space. And despite a wide range of sites and facility types, gaps remain in the experimental situations and data already in existence. Comparatively little research in these facilities has involved larger, more diverse occupant groups. We can identify a need for projects that combine the experimental and observational scientific rigors of simulations with an analog's relatively larger and more diverse group of subjects, within a structure and environment flexible enough to test multiple, evolving design solutions.
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<td>- Narrow research focuses preclude novel, unforeseen output/design implications</td>
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<td>- Narrow occupant age ranges</td>
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<td>- Rigidity of overall designs</td>
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<td>- Rigidity of administrative organization</td>
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<td>- Lack of dialogue/feedback with overall field of research</td>
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<td>- Modular designs allow partial flexibility</td>
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<td>- Collaborative, multicultural teams</td>
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<td>- Specific, relevant research data</td>
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3.09 Deficiencies/Benefits of Simulations & Analogs
After analyzing extraterrestrial precedents and simulations/analogs for useful components and improvable deficiencies, we can begin to establish relevant architectural concepts. These may consist of specific examples, like experimental communities, or general architectural practices and theoretical work. This stage of analysis will identify the relevant architectural principles, and synthesize them with earlier research. The end result will be actionable principles for design in space, and in this case, Earth.

As we have already demonstrated, both existing simulations and analogs contain many intrinsic deficiencies that limit their eventual research output. As is often the case, this is frequently not a significant issue for an individual facility or study, since their particular missions may be very limited in scope. But within a broader context, these various
individual limitations create an ingrained comprehensive research product that results in limited design options. The rigid engineering constraints of outer space and extreme environment locations are the first limiting factor, one that cannot be mitigated without considering less restrictive environments. In order to conceive and test new strategies, perhaps a better site would be located in a more forgiving climate than arctic or desert environments.

In response to the common deficiencies of simulations and analogs, we can identify the need for a new type of research facility—one that combines the useful qualities of both existing types, and rejects any defects. We will consider a project type that can test its users’ ability to live and work closely together, within selected configurations and under certain conditions. The ideal project of this type will be more focused than current analog precedents, while more flexible, accessible, and generative than simulations. One other defining characteristic of this type will be thoughtful consideration, implementation, and testing of appropriate architectural design strategies.

The project’s overall typology will, in one way, consist of a blend of different building types. In the most immediate and practical sense, the project will be a mixed-use housing and research facility (mimicking core activities of extraterrestrial spacecraft and habitats), with self-sufficient and adaptable elements. More essentially, on a general level, the project’s type will be an extraterrestrial simulation/analog test facility. As a result, the project will entail two levels of ongoing research: multidisciplinary research conducted in laboratories (physical sciences, agriculture, etc.), and study of the building’s performance itself.

The proposed building typology for this project will also fall somewhere between two of the types analyzed
earlier: simulations and analogs. As such, the project’s design intent will certainly focus on physical and social environments analogous to those one might find in a future extraterrestrial community, but without the strict tolerances and requirements of an Antarctic or underwater simulation. At a less isolated and extreme site, the project can make use of a wider range of design and construction techniques, with access to larger possible user group. The inclusion of “outsiders” (as opposed to exclusively scientists of astronauts) in the process will generate a somewhat new category within the typology, one with analogous, but also flexible, realistic, and accessible design principles.

The application of architectural thought to the field of extraterrestrial habitats and their analogs on Earth will rely heavily on an existing body of theoretical and built work. Architecture’s utility for this field will derive from specific built and theoretical works, as well as the profession’s
comprehensive body of knowledge and skills as developed from centuries of design challenges and solutions. These precedents range from seminal works—that reveal some of the most basic requirements for good design (especially under difficult conditions)—to increasingly unusual or advanced examples that can help suggest novel approaches for new investigations. The final project itself will also rely on analysis of programmatically specific precedents for more detailed design, but for now we will focus on the most useful examples for the development of this new project typology, along with applicable architectural principles.

Application of essential architectural design principles, as successfully practiced for the entire history of our built environment, will be an underlying prerequisite for this project's conception. The breadth and definitions of architecture's collective theoretical works have expanded over the last century, but certain key precepts can generally be agreed upon as successful. Architects can still usefully cite the Roman Vitruvius' famous declaration of three fundamental commandments for buildings: *firmitas, utilitas,* and *venustas* (strength, usefulness, and beauty). But for most space habitats, the first two qualities have tended to eclipse the third, at the expense of human comfort.

The idea of “beauty” is an inherently subjective one, even more so when it comes to architecture. As a concept, beauty proves difficult to define—is harmonious proportion the epitome of beauty? What about ornament, or details, or pleasing colors? Despite its presence in much of our earthly living spaces, classical visual beauty (generally meaning pleasing aesthetics) can be conspicuously absent in extraterrestrial designs.
Much of the consideration that is given results in only the most basic responses, usually based around the partial covering up of unsightly mechanical systems. Due to these systems’ extensive presence in spacecraft and habitats, we will need to reframe the concept of beauty within a new environment. Peter Eisenman compares classical beauty (things that are good, natural, rational, or truthful) with Kant’s sublime beauty (associated with additional, and sometimes opposing, intangible qualities of uncertainty and the unnatural), a component of which being the grotesque (according to Eisenman). In the context of technologically advanced spacecraft and habitats, the grotesque manifests in mechanical systems and utilities: the pipes, cords, ducts, and switches that occupy so much space while overcoming the natural obstacles to human survival. As with most things, Eisenman goes on to force these thoughts into his arguments on textuality, but he does raise some useful points for further thought. Having established our grotesque systems as part of a more complex beauty, the sublime, we can perhaps develop new ways of creating beautiful spaces within a more challenging framework. For this specific project on Earth, that might mean utilizing design flexibilities for the testing of different types of beauty. Depending on the user, a room’s phenomenological qualities (for lack of a better word here) could be augmented depending on an individual’s own preferences. A living room could embrace one conventional idea of beauty (perhaps a soft carpet, warm wood paneling, and an ornate light fixture), while lab spaces employ a more complex, sublime beauty (fully embracing the utilities and systems for intentions beyond their original mechanical purposes). In either case, the end goal is a more pleasing environment for human occupants, regardless of their individual aesthetic preferences.
Best-practice architectural principles entail careful consideration of multiple factors (many often neglected in the current field extraterrestrial design): necessary building program, occupant comfort, site conditions and context, sustainability, and building longevity, among others. Increased awareness of these issues, with integration of appropriate architectural responses, can only enhance the quality of ongoing extraterrestrial design for actual human use. In his book *How Buildings Learn*, the author Stewart Brand discusses the work of architect Frank Duffy. Duffy’s ideas on “shearing layers” describe a conceptual system for conventional buildings in which components are categorized into distinct layers, depending on their longevity and necessity for maintenance. Brand expand Duffy’s four categories into six: site (longest duration, near-eternal), structure (foundations, columns, beams—lifespans range from 30-300 years), skin (exterior surfaces lasting around 20 years on average), services (mechanical systems: 7-15 years), space plans (interior layouts created by partitions—3-30 years, depending on a building’s program), and lastly, stuff (objects contained in a building that are constantly in flux).\(^{16}\)

For efficient design, according to this system, the basic idea is to minimize the “shearing” of components with different lifespans. For example, if the location of services prevents effective modification of space plans, the shearing results in more difficult and expensive work when things must move or be repaired. Designers can create more efficient and sustainable buildings by permitting ease of access to layers according to their expected lifetime. This idea translates well to the design of complex space habitats, where ease of repair and modifications are a necessity. The same concept should be extrapolated to other areas of these habitats, and our own built project.

\(^{16}\) Brand, 12-23
A related example can be found in Metabolism, an architectural movement originating in Japan in the late 1950's and 60's. The focus of the Metabolist group was change and flexibility, influenced by biological processes of dynamic response and regeneration. Architects of the movement produced striking new plans and buildings like Kenzo Tange's Plan for Tokyo and Kisho Kurokawa's Nagakin Capsule Building. At the smallest scale, many of these new designs derived influence from Japanese design traditions, like the *tatami*. But it would actually be their large-scale designs (most unbuilt) that would come to define the movement—megastructures that could change along with a dynamic population.  

In practice, however, most Metabolist work failed to deliver, at least in terms of macro-scale flexibility. For all of their grid systems and plug-in modules, the vast majority of Metabolist buildings remained static after construction, most lacking a feasible system of adaptation, or simply a necessity for one. And even the few buildings utilizing such a system generally lacked flexibility at multiple scales (take Kurokawa's Capsule Building, for example: the residential capsules can be moved, but their interior environments—the most important part of a resident's daily interaction with the building—remain generic and rigid).

Examination of individual precedents in architectural theory and practice can provide a secondary layer of information for distillation of essential principles. In addition to historical analogs cited earlier, we can look at architectural responses to the challenges of comparably isolated, or simply innovative, examples like monasteries and experimental communities. Monasteries present a similar model to future space colonies: a small, dedicated group of people...
living and working in a mostly self-contained community. Though their exact nature depends on characteristics specific to their order (of which there are myriad varieties), we can frequently observe applicable qualities: long-term intentionally isolated living, daily tasks and rituals, strong occupant commitment, and agricultural self-sufficiency. For individual monks, varying levels of individual space allotment and customization can also be found. Additionally, we can find some inspiration in the admirably clear design intentions of monastery construction, where the building’s activities and client are well established. (Our own project will incorporate additional flexibility, in addition to well-planned initial design. The client will also be somewhat less demanding). Monastery designs also took into account every activity of occupants during the day. Translated to our contemporary examples, this means planning not only for seemingly minute known daily activities, but also facilitating future unknown activities as well.

In experimental communities, especially relatively recent ones, we can identify many novel ideas, with both successes and failures. One recent example is Arcosanti, the architect Paolo Soleri’s architectural and social experiment located in the Arizona desert, between Phoenix and Flagstaff. Designed around the concept of an arcology, Soleri envisioned a dense, self-reliant community that could maintain a connection with its natural environment. Core principles included efficient use of resources and marginal land, urban-scale crowding for efficiency and enhanced interpersonal connections, flexible mixed-use planning, hands-on occupant involvement in construction and maintenance, and a balance between efficient planning and spontaneous design processes. In the end, Arcosanti is probably more successful as a theoretical work than as a
successful community. The project’s location and occupant makeup have contributed to an insular, conflicted product. As a proof-of-concept, Arcosanti does succeed in many respects, but future implementation of its tenets must be tempered with realistic strategies.

For the final project’s design, we can also examine more specific precedents, especially as they relate to the programmatic needs of this particular building (beyond the overall characteristics of its typology). As a mixed-use housing and research building, this precedent analysis should focus principally on exemplary buildings of those two types. The most valuable models will be those demonstrating one or more desired qualities similar to those distilled from earlier analysis of simulations/analogs: multidisciplinary use, adaptability, and diverse user groups.

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The project’s next step requires distillation and deliberate selection of guiding design principles. As an addition to the basic typological framework derived from extraterrestrial habitats and Earth-based simulations/analogs, these will assist in both major and minor design decisions alike. These principles will consist of the most useful architectural practices and concepts found in the precedents and theory.

Of the selected precedents, dense massing is one of the two most useful qualities, and one of the most common in successful examples. This is a definite requirement for any pressurized habitat in space or on another planet surface, and is likewise helpful for efficient and sustainable design on Earth. First and foremost, a dense massing occupies a smaller footprint, allowing more open outdoor space to be untouched or used for other purposes. By avoiding sprawl,
this project can lessen its impact on the natural environment and facilitate access and views to that environment for occupants and outsiders. Building materials and systems can be scaled down—this is especially important for a project with resource-intensive research laboratories. With everything close together, residents can easily walk between areas and fulfill many daily tasks without needing to travel elsewhere by car.

The second crucial quality is flexibility, at all scales. Buildings and communities that have allowed for dynamic
evolution in their designs have been able to effectively expand and adapt to changing conditions. Perhaps more importantly, this project cannot test different design solutions without the ability to adjust portions of its configuration. Part of the challenge in existing examples, and in this new project, is achieving a functional balance between planning and adaptability. The building must be able to house specific and intricate systems and components, while allowing them to be used in different ways. We can begin to accomplish this by considering different types of flexibility, in this case \textit{interior} and \textit{exterior}. Exterior flexibility refers here to the
overall massing and arrangement of programmatic spaces in the building. One solution in this type is modular design, by which spatial components can be added, removed, or adjusted after the initial planning and construction. The second type, interior flexibility, entails adaptable spaces within a building’s shell, permitting different configurations for a variety of people, equipment, and tasks. A prime example of this type would be an open floor plan, with movable partitions and components. By combining these two kinds of flexibility, the planned design can account for all the necessary activities and tasks, while facilitating as many different future configurations as possible.

Self-sufficiency—or in this case, partial self-sufficiency—will be fundamental to this new project’s effectiveness as a research facility, as well as its performance as a building on Earth. With a less extreme site, this project does not necessarily have to contain everything, but such a goal will encourage a sustainable building with pertinent and useful research output. As a building, the structure and systems require input and output: electricity, heat, maintenance, etc. Human occupants have similar needs: food, water, light, and other resources. By obtaining internally as many of these resources as possible, the project puts less strain on its environment and existing resource networks. Significant quantities of energy can be generated by various solar and wind collection devices, like photovoltaic panels and wind turbines. The project can mimic more isolated maintenance techniques by housing personnel and their equipment on-site—like other resident workers and researchers, these people will likely become familiar and personally invested in the project. Food production (again, as analogous to long-term needs of extraterrestrial settlements) can be performed on site, in the form of indoor and outdoor agriculture. The building’s dense footprint, located on less agriculturally viable soil, allows as much exterior space as possible (or desired)
to be utilized for food production. Indoor greenhouses can supplement locally viable crops with more exotic options and simultaneously provide opportunities for academic agricultural research. On-site water collection, treatment, and recycling can also reduce the need for outside utilities, as well as the project’s strain on nearby treatment plants. Lastly, the building should include spaces for satisfaction of other human necessities. On-site food production makes the most sense when combined with cooking and dining facilities, and recreation, leisure, and other incidental spaces fulfill at least some other needs. Internally available shopping, in the form of a market, can partially address the need for other outside resources in a modern, non-isolated environment, while mitigating the need for excessive driving (and the associated drains on money, resources, and time).

As we established earlier, addressing individual occupant needs at various scales is an important aspect of designing livable environments for humans in space, and on Earth. The most fundamental of these needs will inform the project’s basic design strategies. Occupants must have sufficient access to necessities like natural light, privacy, views, and thermal comfort, among others. On Earth we don’t have to worry about reducing window sizes for radiation shielding, or planetary orbits and rotations that disrupt natural circadian rhythms. Not being a strict simulation, it would be wasteful for our project to mimic any of these conditions—thus we can make full use of existing building strategies. Sufficient use of well-oriented glazing will permit natural light and views for occupants. A range of open floor plans (with movable partitions) to private modules creates adjustable gradients of visual, acoustic, and spatial privacy. Utilizing compartmentalized areas for living spaces allows residents individual control over temperature, ventilation and light levels.
The importance of this personal environmental control dictates another distinct design principle. The successful long-term housing of a diverse group requires flexibility on a personal scale—occupants must retain a certain level of control over their immediate housing and working environments. Within reason, a user should be able to customize their individual living and working environment to what they think is most functional and comfortable. Having this ability, occupants not only perform more efficiently due to customized settings and interfaces, but also enjoy psychological benefits and an increased investment in (or attachment to) the building and their personal spaces within it. Each resident and worker should be made to feel like an important part of the building and its community.

This personal attention during building design extends to the next principle, which calls for consideration of a person’s entire range of likely daily activities. Simply ignoring more private personal activities is unacceptable, especially without the strict spatial constraints of habitats in extreme environments. Planned and flexible interior spaces should include specific areas for smaller human activities: reading and studying nooks, flexible storage options, configurable food preparation surfaces, etc. Here there is overlap with another important design principle, which takes into account the importance of individual and group rituals—both daily and infrequent. These are significant, yet often neglected personal factors. This project should implement and evaluate design-integrated strategies to facilitate their inclusion. Individual spaces should encourage these beneficial personal behaviors, rather than ignoring them and forcing occupants to work against the building’s design.

The project also entails more subtle guidelines. One of these asserts that the building itself should emulate the most successful precedents in establishing a sense of place for its residents and visitors. Elizabeth Lockard notes that while space can be an abstract concept, place is recognized and known through experience. In orbit, astronauts draw connection and comfort from views of planet Earth. Long-term habitation may require a sense of place derived from connections both inward and outward—to an immediate built (and likely enclosed) environment, and to the surrounding environment, be it Earth nearby, a planetary surface, or familiar stars. For our project on Earth, care should be taken to establish meaningful connections.
to the built spaces and the existing site. Being located in a fixed location, as opposed to outer space, should simplify this task at the largest scale. Site-appropriate scale and massing, along with a general respect for the surrounding landscape and context, will all be required. But at a smaller scale, the design should facilitate distinct spaces with strong, appropriate identities. This challenge may at times mimic extraterrestrial situations, since many of these spaces will be located indoors. Modular systems and open layouts can easily fail in this regard, without sufficient care. Homogeneity among interior spaces should be avoided (user-adaptability should help here). Careful choices of room dimensions, material choices, color use, lighting, etc. can all be employed for appropriate and effective spatial differentiation and wayfinding. Views and immediate access to the project's surrounding site can establish a larger scale sense of place.

Consideration of building aesthetics presents a related design principle. Though beauty is a subjective quality, most people can discern enjoyable, aesthetically pleasing spaces from cold, efficiently engineered ones, and prefer them. Within a less rigid context, this project can and should implement aesthetically enjoyable elements into both living and working areas. Careful formal design, with measured, intentional use of color, proportion, and ornament can produce a more pleasant environment for living and working, while more effectively integrating building systems into a less distracting whole.

A final design guideline, though in a slightly different, and less architectural category, requires that the project be fundamentally measurable—analysis and evaluation of the project underlies its entire necessity and utility. The ability of the building to change and adapt goes hand in hand with this requirement, allowing many combinations of planned and unplanned strategies to be implemented and tested. The building's design will incorporate specific spaces and personnel for this particular type of evaluation. With electronic monitoring of buildings systems, researchers will have the ability obtain performance data for analysis. Additionally, interviews and psychological screening of residents and visitors will yield objective information on individual and group dynamics within the facility. The facility's output (research information, agricultural products, collected water, electricity, etc.) can also be measured in order to assess overall building performance.
Skeptics often question the necessity of space exploration, asking instead for tangible plans here on Earth. But the reasons for exploring space are many, with end products crucial to the current and future state of human progress. The results of our space programs, as well as their development programs, have already influenced our technology, environment, and society in numerous positive ways, and will likely continue to do so. Looking right here on Earth—ignoring loftier concepts such as curiosity and the search for knowledge—technology developed by space programs has given us tangible innovations in areas like materials science, technology miniaturization, and wireless systems (along with a host of other tangential developments for everyday products and devices like ).

Barring unforeseen catastrophe, current space
exploration by the human race should gradually progress to colonization of further and further places. The numerical expansion of the human race, as well as its innate need to explore and learn, will necessitate it. In order to get to these places and settle, we will require functional extraterrestrial spacecraft and habitats. But for the most part, we are still thinking short-term. Currently, engineering and cost efficiency trump livability in almost all aspects of extraterrestrial habitat design. This project’s analysis and design response seeks to examine the increasingly important issues of human factors and livability in space, and address them through an architectural lens.
Living in space for longer periods of time, and with more diverse groups of people, will in many respects necessitate habitats more akin to buildings on Earth than space stations. The main difficulty of adapting design principles of the earthly built environment to space habitats stems from the cost and feasibility problems of designing and constructing for extreme environments. The logical response is to begin the adaptation process here on Earth, in a more forgiving environment. The built component of this project will do just that, developing a test facility for extraterrestrial design, and merging the useful aspects of existing Earth-based simulation and analog buildings. With housing and research as the chief components, along with a supplementary focus on self-sufficient agriculture, we can emulate some of the most important characteristics of any future extraterrestrial surface habitats.

The design of the building itself will be guided by architectural principles, and derive insight from the research on existing simulations and analogs. These principles generally coalesce into a few general categories: overall spatial structures and qualities, strategies for satisfying individual user needs, and subtler, less tangible design goals.
Within the first category we can find two of the most critical guidelines: dense spatial massing, and planning for flexibility. Both of these will influence the formal and structural nature of building.

The second category generally entails guidelines at the smaller scale of an individual building user. Following a humanistic approach, the building should facilitate the full range of human needs, regardless of their necessity for basic survival. Design principles call for access to basic things like natural light, nature, and privacy. Furthermore, the entirety of daily activities and rituals for groups and individuals should influence the design of a building that contains and facilitates them. The large-scale flexibility of the building will also extend to adaptable spaces and components for each individual occupant.

Lastly, the project will incorporate subtle principles for effective design. Beautiful spaces, with a distinct sense of place, will be encouraged. Often neglected in high-performance engineering, these are some of the qualities that can enrich a person’s daily interactions with and within a building, and contribute to comfortable, happy, and effective human users.
Astronaut Buzz Aldrin on the moon


Planel, Hubert. Space and Life: An Introduction to Space Biology and Medicine [Espace et la vie.]. Boca Raton: CRC


The typology of any future planetary colonization habitat will ultimately be mixed-use—primarily for housing and research, along with support functions. These will form the critical components for this particular project’s overall building type. Another inevitable quality of extraterrestrial habitats will be an increasingly diverse and “ordinary” group of users (compared to most past and current astronauts, at least) who will occupy themselves with varied types of tasks, activities, and recreation. To simulate this setting will require a facility inhabited by users of different ages, backgrounds, interests, and occupations. Such a building could produce useful output both from the multidisciplinary research performed inside, as well as from performance analysis of the building itself.

The inherently diverse, creative, and multidisciplinary nature of a university environment would be ideal for this project. The University of Tennessee (Knoxville), in particular,
features first-rate research programs in all major sciences, as well as strong ties to the aerospace science field at sites like the Arnold Engineering Development Center (AEDC), the University of Tennessee Space Institute, and the Oak Ridge National Laboratory. As a member of the Universities space research Association (USRA), UT already enjoys a collaboration with NASA and other universities. While possibly creating additional bureaucratic complications, this focus on collaboration and multidisciplinary use should facilitate adequate sources of necessary funding.

In this case, the project's principal client is a university, where the fundamental objectives consist of education and research. In its missions statement, the University of Tennessee states its goals to “move forward the frontiers of human knowledge and enrich and elevate the citizens of the state of Tennessee, the nation, and the world” and to embody “the spirit of excellence in teaching, research, scholarship, creative activity, outreach, and engagement attained by the nation's finest public research institutions.” These are certainly not qualities often associated with government entities.

The primary control of a university will ideally promote the creative research output of the project, coupled with the addition of NASA and other agencies' body of experience, personnel, and (limited, in this case) oversight. For the purposes of an inventive project with new, imaginative results, a university environment should produce a fundamentally different creative climate. The creative flexibility afforded designers and users will presumably yield a uniquely generative model for extraterrestrial human

21 http://www.utk.edu/mission/
Within a wide range of constituent client and institution organizations, the University of Tennessee will retain primary oversight and control of the research facility. The majority of users, both long and short-term, will comprise of local students, teachers, researchers, and support staff. Likewise, the local concerns related to designing and constructing the building will be directed through the university. The standard processes of building university facilities will apply, with the same oversight and regulations for any state funding. Collaborations with government agencies should, however, facilitate greater federal funding, in the form of grants. The project’s multiple fields of research (chiefly aerospace, architecture, and agriculture, in addition to a variety of other sciences) should also establish a larger pool of interests from which to draw funding. By pooling financial and other resources into a shared facility, all parties involved achieve access to innovative and state-of-the-art facilities, as well as increased dialogue and exchange of ideas. This collaboration supports both the multiple levels of research goals inherent to the project, as well as minimizing participatory organizations’ individual funding requirements.

Public relations and promotion are important matters for both government and academic institutions alike. For a governmental organization in constant danger of funding loss, like NASA, the ability to demonstrate tangible benefits and production is vital. Partnership with academic institutions and their students demonstrates farther-reaching goals, and begins to address questions like “couldn’t that money be better spent on Earth?” Additionally, universities rely heavily on self-promotion for funding from student tuition, government, and private gifts. This project has
the potential to physically and symbolically embody UT’s mission statement, while eliciting necessary internal and external press attention.

In the context of shrinking government financial support for the space program, this project’s model presents an additional means of continued national involvement in ongoing research. The proliferation of private aerospace development and tourism companies, and the United States government’s planned reliance on them, has created a simultaneously exciting and worrisome environment for space exploration. The regulatory and academic components of this project’s constituent institutions will hopefully continue to supply a necessary blend of focus, quality control, and creativity.
This project’s site will be located in the East Tennessee city of Knoxville, adjacent to the University of Tennessee. The site is currently part of a university Agricultural experimentation Station. Bounded by a bend in the Tennessee River on three sides, the site is mostly flat open space, with a small wooded area on the eastern, hillier side. The surrounding area is home to a sparse collection of university buildings, including agricultural and energy research buildings, animal care facilities, and a hospital. The site is connected by Alcoa Highway to the main university campus to the north, and a nearby airport to the south.

Knoxville, Tennessee is located in the southeast United States, within a humid subtropical climate. The climate here is mostly temperate, with hot, humid summers and cool winters. Annual precipitation averages 47 inches, most of it
rain. The region’s comfortable period averages 16% of the year; 28% is too hot, and 56% too cold. Annually, there are 3,658 heating degree-days, and 1,449 cooling degree-days.

The majority of buildings near the site fall into one of two types: small, older, utilitarian structures, and contemporary university buildings.
The diagram shown at left demonstrates the figure-ground relationship of buildings/vegetation and open space. A moderate contrast in density can be observed between the east and west portions of the site, with the west half dramatically more open. Outside of the UT Medical center, buildings are still relatively sparse on the eastern half, with more vegetation than buildings. The river itself forms a firm barrier to construction and travel on three sides, while permitting sun, wind, and views to pass. Fences in the site create low permeable barriers, also allowing sun, wind, and views, while serving mostly to confine livestock.

While in recent years, the site has hosted a number of University of Tennessee buildings, most prominently the UT Dairy Farm, the built history of the site goes back much further. Recent archaeological work at the site has uncovered evidence of prehistoric settlements, including Archaic pits, Woodland deposits, Mississippian house structures, and historic cellars, cisterns, and silos. This archaeologically significant zone lies primarily along the river, extending in roughly 300-600’. The project should take care not only to avoid disturbance of these historically important features, but also to facilitate their preservation and study.

In addition to existing buildings, the highway itself presents an important built feature for consideration. The bridge over the Tennessee River is larger than any other buildings nearby, and the highway creates a 400’ vibration zone that can influence sensitive research equipment.
Interestingly, the University of Tennessee has recently planned a campus expansion at the site, with a somewhat similar multidisciplinary research focus. Designs for Cherokee Farm Campus, as it will be known, present both positive and negative examples from which we can learn about our own project's site strategies.

The university’s plan demonstrates respect for some existing features and qualities of the site, and a moderate awareness of environmental factors. It does not, however, show much consideration for some of the more nuanced aspects of the site, filling in nearly all available open space with campus sprawl, and demolishing any trace of the dairy farm and its iconic silos. (The dairy farm itself has been relocated to a nearby, out-of-town location.)

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As it exists, the site presents a unique combination of open possibilities and design challenges. The overall terrain qualities range from nearly flat and clear to very hilly and wooded, with corresponding degrees of visibility, intrusiveness, and design/construction difficulty. The density of surrounding buildings and ground cover is light, with little in the way of distinct vernacular language. Design considerations hinge on the project’s program and client. As likely an iconic university building, a certain degree of visibility will be required. Multidisciplinary research will require intentional yet flexible spaces with both outdoor and tightly contained areas. The facility’s design principles entail a dense massing, along with outdoor agricultural space. And the site itself requires respect for historical features and existing experiential qualities. The resultant design of this project must consider all of these constraints, while thoughtfully maximizing the site’s benefits.
On the most practical level, the project’s primary functions consist of housing and research, with an agricultural component. Many of the users—students, professors, researchers, and staff—will live and work on site. Other facilities will accommodate research-related and general public visitors. The most important organizational principles will be designing high-density spaces, and both interior and exterior adaptability. The building's success will be determined by performance analysis in the form of systems analysis, resident interviews and examinations, and research output quality.

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The next step is to establish the general spaces required for the building's activities, and the individual criteria for those spaces. The first of these spaces is housing, which will consist of variably sized apartments, possibly
Family sizes will likely range from one to five members, with a majority consisting of one or two person units. Each living unit must include living, sleeping, dining, bathing, and storage spaces. Additionally, communal areas will fill the spaces between and around the apartments with such areas as gardens, exercise rooms, laundry rooms, and lounges.

Research is the second major function of the facility, with requisite spaces both indoors and outdoors. The largest space requirements of the project will be the outdoor agricultural research and food production areas--these will range from large open fields to small, contained boxes. Indoors, agricultural research will require greenhouses and laboratories. Additional laboratories will serve other science researchers, both in discipline-specific labs and flex space. Other academic functions like instruction, meetings, and
group study will have a mix of dedicated and flexible rooms. Research on the building itself will take place in a separate lab space, where researchers can collaborate most effectively with building engineers and maintenance personnel (in addition to residents), as well as access data from the building systems themselves. Ongoing building modification work will be performed in a combined design lab/fabrication shop, with access to a loading dock.

Public activities will take place in the facility’s central areas, like the kitchen and dining hall. Nearby will be the front desk and auditorium, in order to minimize travel distance for visitors (and encourage them to stay in public areas).

A service core will contain building systems, delivery areas, and office spaces for maintenance staff. Whatever massing the building may take, this service area should be adjacent to the major systems-demanding areas (laboratories, kitchens, etc.). General parking will likely consist of a large underground lot for long-term parking and events, and a smaller surface lot for daily visitors and deliveries.
The diagram shown above illustrates possible programmatic adjacencies within the building, with individual elements joined by a common service core. At right, diagrams demonstrate potential programmatic strategies for achieving maximum building flexibility at multiple scales.
Flexible / Rigid Spatial Relationships

- Flexible Shell (Modular)
- Rigid Shell

Flexible Interior
- Communal Areas
- Housing Units

Rigid Interior (Core)
- Research Laboratories
- Service
- Auditorium

Possible Spatial Strategy for Flexibility

C.03 Flexibility types

C.04 Flexibility responses
The vastness of space: this 1995 image by the Hubble Space Telescope, called the Hubble Deep Field, encompasses only a very small area within the constellation Ursa Major.