Urban Design Guidelines for Human Wellbeing in Martian Settlements

Matthew Donoghue

A thesis in partial fulfillment of the
requirements for the degree of
Master of Urban Planning

University of Washington
2016

Committee:
Rachel Berney
Branden Born

Program Authorized to Offer Degree:
Urban Design and Planning

University of Washington

Abstract

Urban Design Guidelines for Human Wellbeing in Martian Settlements

Matthew Donoghue

Chair of the Supervisory Committee:
Assistant Professor Rachel Berney
Urban Design and Planning

Although various engineering, economic, and medical aspects of Mars habitation have received close attention from space agencies, far less attention has been given to the role of human dynamics in a Mars mission.

This study outlines the relationship between human wellbeing and the planning and design of a Martian settlement. It draws from environmental psychology and urban planning to define a set of criteria for human wellbeing with respect to the built environment. Through the review of analogous habitats including Antarctic research bases and the International Space Station, the study analyzes the specific impacts that a Martian settlement will have on individual and societal wellbeing. These impacts, which include monotony and interpersonal conflict, present major long-term habitability concerns that have a strong relationship to the built environment. Unmitigated, they may induce depression, anxiety, hostility, violence, suicide, boredom, and psychological withdrawal.

The study concludes with comprehensive design guidelines that range from community scale spatial organization to site scale details. These guidelines mitigate negative impacts to wellbeing through conceptual strategies that can be applied to future designs. They seek to balance the physical constraints of a Martian settlement with the need for a complex, rich, active, and rewarding built environment.

Acknowledgments

Many thanks to Prof. Rachel Berney for chatting about, reading, re-reading, editing, re-editing, and critiquing my thesis. And re-re-reading it one more time. This entire project has been a fairly seamless process and I owe that to her continuous involvement.

Thanks to Prof. Branden Born for his thoughtful contributions and ability to connect an out-there topic like Mars to everyday urban planning. And stellar drawings of alien saucer ships.

Thanks to Prof. Don Miller for being the first person very early on to encourage me to pursue this topic. His insight helped form the process for the entire study.

Special thanks to my classmates Cheryl, Max, and Nico for letting me bounce ideas off of them.

Figure 1: *This hub module illustration is a conceptual application of the design guidelines. In addition to serving as a key landmark, the space offers a diversity of restorative settings, positive distractions, and choices.*

Table of Contents

List of Figures

*Figures produced by Author.

TABLE OF CONTENTS

INTRODUCTION

CONDITIONS

WELLBEING CRITERIA

IMPACTS

DESIGN GUIDELINES

CONCLUSION

Acronyms

ICE	Isolation, confined, and extreme environments
ISS	International Space Station
ISECG	International Space Exploration Coordination Group
LMLSTP	Lunar-Mars Life Support Test Project
NASA	National Aeronautics and Space Administration

Terms

Analogous habitat	A habitat that shares similarities to a Martian settlement, including isolation, confinement, and location in an extreme environment.
Directional space	A space for pedestrian movement. Common examples include streets, corridors, and paths.
Escape facility	Destination spaces that are physically and psychologically separated from primary sources of stress.
Function	A specific activity in a space. In a Martian settlement this extends to dining, cooking, researching, or socializing, to name a few.
Hygiene facility	A bathroom.
Locational space	A traditionally defined occupiable space that is a destination and serves one or more activities. Most functional spaces fall under this category, including parks, bedrooms, workplaces, and restaurants.
Socio-petal	Arranged to encourage and facilitate social interaction.
Socio-fugal	Arranged to discourage social interaction.
Space	An occupiable volume.
Third place	Nodes of informal and unorganized social interaction that exist outside of the residence and workplace.
Transect	Distinct groupings of functional spaces in a Martian settlement, typically defined by a dominant use. Among others, the list includes work, residence, domestic, social, medical, and utility.
Transitional space	A space in-between locational and/or directional space that help gracefully shift between functions or atmospheres.

Executive Summary

Once relegated to science fiction, human settlement on Mars has become a realistic goal in the 21st century. However, current plans for Mars undervalue the role that human factors and habitability will play in the long-term success of a mission. Specifically, the design of the built environment on Mars will play a huge role in mitigating the negative impacts to individual morale and societal cohesion.

Process

This study asks: How can planners and designers design for human wellbeing in a Martian settlement? A four-step process was utilized to produce the design guidelines. First, anticipated living conditions on Mars were compiled from a review of space agency planning documents, Mars environmental literature, and extra-terrestrial habitat design studies. Second, wellbeing criteria were developed based on a comprehensive review of environmental psychology and urban design literature, and served as the critical lens for the remainder of the study. Third, impacts to wellbeing on Mars were derived from psychological analyses of analogous habitats such as Antarctic research bases and the International Space Station. Lastly, the wellbeing criteria and impacts to wellbeing were analyzed for their spatial context, and translated into physical design guidelines.

Conditions

A settlement of 30 to 60 people won't be the first development on Mars, but it will be the first scale to accommodate long-term human occupation. A 20-minute communication delay will force the crew to be semi-autonomous from Earth. New crews may be sent up every 26 months, with missions lasting a minimum of 1,100 days. The exposed surface of Mars features freezing temperatures, a deadly atmosphere, and constant exposure to solar radiation, forcing residents to live in an isolated and confined built environment. This habitat will be efficiently designed using some combination of prefabrication on Earth, assembly on Mars, and use of local resources. Ultimately, every facet of daily life must exist within a hermetically sealed structure.

Wellbeing

Human wellbeing is integral to mental health and group cohesion. It is defined as a complex combination of individual and societal needs that are relevant in any physical context. This complexity simplifies into nine wellbeing criteria: personal space, crowding (or lack thereof), territoriality, privacy, choice, sense of place, restoration, social support, and self-expression. Each criterion further breaks down into objectives for the design of the built environment. These objectives, 38 in total, provide the nexus between human wellbeing and the built environment.

Impacts

The living conditions on Mars present specific negative impacts to wellbeing, to be considered alongside the criteria in the previous section. Without mitigation

through design, these impacts may induce an array of issues including hostility, violence, depression, anxiety, boredom, withdrawal, and extreme stress. Impacts to wellbeing are the result of isolation and confinement, interpersonal interactions, disrupted sleeping conditions and circadian rhythms, inadequate privacy, monotony and lack of stimulation, inadequate facilities to relax, stress from mission objectives and tasks, uncomfortable facilities, a lack of identity and control, and extreme removal from Earth.

Design Guidelines

The design guidelines are conceived as two scales: community and site design. Community scale addresses high level conceptual master planning, programming, layout and form, circulation and legibility, and overriding settlement characteristics. Site design scale provides guidelines for specific functional typologies, internal spatial dimensions, and small scale design features such as views and furniture.

Wellbeing in the built environment is less about bold design moves and more about a simple organization of space. The design guidelines, 28 total, are conceptual and adaptable to a variety of mission-specific goals, architectural styles, and construction methods. They are intended for use and critique by designers and planners of Martian settlements. They provide a first step in better understanding the built environment on Mars and the ways it can be molded to promote long-term success. For long-term mission success and habitability on Mars, wellbeing needs to be holistically integrated into space agency goals alongside physical health, efficiency, research objectives, and technological innovations. Design guidelines would be most effective as part of Mars mission policy documents and design manuals in order to ensure that the ideas permeate all facets of design and planning.

Applications on Earth

The study is relevant here on Earth as well. The design guidelines for Martian settlement are highly relevant for design and planning of any isolated and confined environment (ICE) on Earth, including research bases and prisons. The basic principles can be considered for any self-reliant, contained, or isolated community plan, including retirement communities, disaster relief, and refugee camps. Similar to a Martian settlement, individuals living in these environments are incredibly vulnerable and are subject to high levels of stress.

Additionally, rapid urbanization, shifting cultural values, and ethical commitments to social justice require creative solutions to inadequate urban conditions. Wellbeing as an applied concept helps ensure that cities of tomorrow are desirable places to live. The nine wellbeing criteria have lasting applications in community health, urban planning, and design. Modified and simplified into policy statements and goals, the criteria can be considered alongside health impact assessments (HIA) traditionally concerned with physical health. Similarly, they can be adapted for municipal design review boards in the form of site-specific evaluative criteria for planning and design. Lastly, each abstract criterion can be extrapolated as physical indicators in the built environment that can be mapped and integrated alongside traditional spatial analyses of communities.

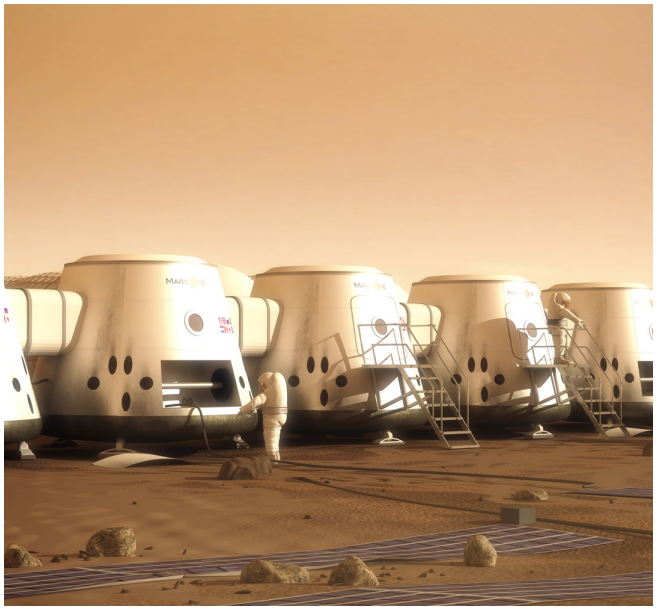


Figure 2: *Preliminary renderings of Mars One habitat modules. Mars One, a Dutch non-profit, has plans to venture to Mars by 2025. (Mars One/ Bryan Versteeg, space.com)*

Introduction

Why Mars Matters

In 2015, NASA published their vision for going to Mars during the 2030s. Stated in the first lines of the report, "Like the Apollo Program, we embark on this journey for all of humanity. Unlike Apollo, we will be going to stay."[1]

Going to Mars has long been an ambition for dreamers and explorers on Earth. In 1953, a German SS officer by the name of Wernher von Braun published Das Marksprojekt (The Mars Project).[2] Inspired by rocket engineering advances of WWII, this book became the first coherent plan for inhabiting the red planet and envisioned sending 10 space shuttles and 70 men to Mars.

Fast forward to 2016. The red planet dreamers remain and a space race has begun. Space agencies NASA and the ISECG (International Space Exploration Coordination Group) have created roadmaps to guide the next 15 years of space travel innovation with the explicit goal of reaching Mars.[3] Private corporations Space X and Blue Origin are engineering innovative and practical rocket systems that will be able to not only get to Mars, but to come back. Even non-profits are getting in on the game. Dennis Tito, a billionaire who once paid $20 million to ride in a space craft, has backed a mission to send a married couple on a fly-by of Mars. And perhaps the most ambitious is Mars One, a Dutch nonprofit with goal of permanent colonies on Mars by 2025.

Are we ready to put humans on Mars? In 2016, Astronauts Scott Kelly and Mikhail Korniyenko returned from the ISS (International Space Station) after a record breaking 340 days. But this pales in comparison to a mission to Mars which could last a staggering 1,100 days.4 And as we establish a continued presence there, more and more people will be staying longer and longer. Buried in both NASA and ISECG plans for Mars is a poignant subplot: the human factor. While the short term success of a Mars mission is focused on technological and transportation innovation, the long-term success is hinged upon the crew's ability to function and thrive.

In the spirit of human exploration, this study asks: How can planners and designers design for human wellbeing in a Martian settlement? The conclusions are presented in the form of conceptual design guidelines that provide simple spatial recommendations to maximize individual morale and societal cohesion. Through the unique lens of wellbeing, it is the intent of this study to insert itself into a growing body of research on the design of Mars habitats. Additionally, the design guidelines presented have broader use for extreme habitats and self-reliant communities here on Earth. The concept of wellbeing is increasingly relevant for urban communities, and has

1 NASA, "Journey to Mars" (NASA, October 2015). 1.
2 Stephen Petranek, *How We'll Live on Mars* (Simon and Schuster, 2015). 7-14.
3 Ibid.
4 NASA, "Journey to Mars." 11.

01 **Conditions**: *What are the anticipated living conditions on Mars?*

02 **Wellbeing Criteria**: *What are the wellbeing criteria for humans and the built environment?*

03 **Impacts**: *How will the living conditions on Mars negatively impact human wellbeing?*

04 **Design Guidelines**: *How can planners and designers mitigate the challenges identified in the prior sections through the design of a Martian settlement?*

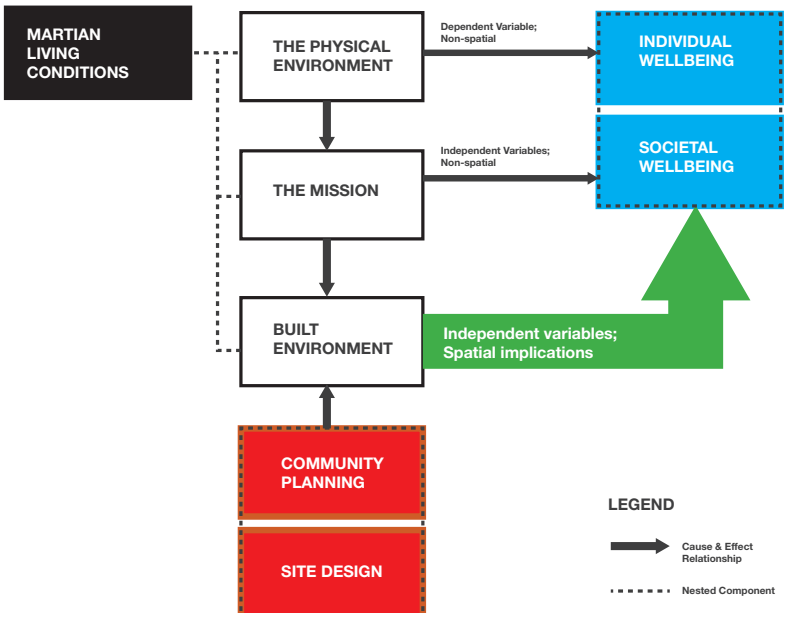


Figure 3: *Process model for this study, illustrating the relationship between the four primary sections of this document.*

direct applications in the fields of community health, urban planning, and design.

Using this Document

This document is a guidebook for planners and designers of Martian habitats. The first three sections lay the groundwork for understanding wellbeing in the Martian context, while the fourth section provides design guidelines for a growing settlement of 30 to 60 people. Together, these four sections present a logical nexus illustrated in the figure above. Independently, each section targets a specific question while building upon the knowledge of the previous sections.

Section 1: Conditions. *What are the anticipated living conditions on Mars?* This section weaves together three interrelated threads. The first thread looks into the mission itself, including the timeline, population size, demographics, and governance of the settlement. The second thread introduces the baseline environmental conditions on Mars, including factors of orbit, time, gravity, light, atmosphere, and terrain. The third and final thread provides the baseline constraints of a Martian built environment, including the scale of the settlement and the basic architectural requirements.

Section 2: Wellbeing Criteria. *What are the wellbeing criteria for humans and the built environment?* This section is detached from Mars and explicitly focused on understanding human dynamics. It categorizes attributes of wellbeing that exist at individual, group, and societal scales. The resulting nine criteria present objectives for the built environment to foster positive mental health and group cohesion. In addition to being relevant to this study, these criteria represent basic human requirements that are transferable to any physical context.

Section 3: Impacts. *How will the living conditions on Mars negatively impact human wellbeing?* This section reveals how human wellbeing will be compromised for those living on Mars. It pulls evidence from studies of analogous habitats, including polar research stations, the International Space Station (ISS), NASA research modules, and historic expedition parallels. Integrated throughout, these impacts ground each potential issue in a spatial context that can be used in design. With respect to the entire study, this section illustrates how the conditions from section 1 will impact the wellbeing criteria from section 2, and provide a logical nexus for the design guidelines in section 4.

Section 4: Design Guidelines. *How can planners and designers mitigate the challenges identified in the prior sections through the design of a Martian settlement?* The design guidelines are bisected into two scales. The first scale is at a community scale, concerned with the overall organization and conceptual design of the settlement. It considers overarching spatial arrangements and patterns that help foster a positive and cohesive experience in the Martian settlement. The second scale is of site design, concerned with the character of individual spaces and human-scale design features. Together, these two scales

of design guidelines provide a toolkit that can be applied to most physical facets of a Martian settlement. They are conceptual and can be adapted to a variety of mission-specific goals, architectural styles, or construction methods.

Audience

There are two primary audiences for this topic. First, the organizations and researchers studying the feasibility of extraterrestrial habitation, including NASA, associated institutes, and researchers in the related fields of environmental psychology, health, architecture, and urban planning. Second, architects, urban designers, and planners of Martian cities. For this audience, it is critical that the guidelines are accessible and practical to incorporate into a plan and design.

Data Sources and Process

This study is reliant on secondary source data gathered from existing literature. The literature pulls information from diverse fields including environmental psychology, physical sciences, landscape architecture, urban planning, and architecture.

The first section (conditions) is informed by current scientific data, space agency plans for Mars settlement, and studies of architecture for Mars. Understanding of the mission is largely drawn from work by astrophysicist and Mars visionary Robert Zubrin in combination with NASA's 2015 "Journey to Mars". Data compiled by scientific journalist Stephen Petranek and recent research from NASA and space scientists was used to illuminate the environmental conditions of Mars. Literature by architects Vera Martinez, Joanna Kozicka, and NASA engineers, as well top designs from the NASA 2015 3D-printed design challenge, helped build an understanding of the built environment constraints on Mars.

The second section (wellbeing criteria) is woven from a variety of definitions of wellbeing established in environmental psychology and urban planning literature. Assessments of wellbeing by environmental psychologists Robert Gifford and Gary Evans, among others, were compiled to build an understanding of baseline human needs in the built environment. This was supplemented with social-spatial urban design literature by Kevin Lynch, Christopher Alexander, and various other architects, landscape architects, and planners. From this literature, a preliminary wellbeing criteria was established, and strengthened with design literature on restorative environments and spiritual places. A large list of definitions of wellbeing from these diverse sources were cross-referenced for overlap and inconsistency, and merged to provide a single list that captured a range of scales and factors of individual and group wellbeing. Once the nine criteria were established, each one was analyzed for its relationship to spatial patterns and the built environment. These relationships were translated into four or five objectives per criterion. Though overlap between criterion and objectives exist, steps were taken to avoid redundancy in order to present a complete list of discrete objectives.

The third section (impacts) used studies of analogous Mars habitats to build an understanding of the challenges facing Martian settlers. Studies of isolated and confined environments (ICE), including reviews by environmental psychologist Peter Suedfeld, provided evidence of the impacts to human wellbeing by a restrictive built environment. Studies and books on space and Antarctic station psychology provided valuable data and anecdotal evidence of anticipated issues as well. Descriptions and plans of analogous habitat designs were analyzed by the author to contrast successful and unsuccessful designs. The full range of issues presented in the literature were further synthesized into major impact categories that were unique to the conditions of a Martian settlement. These impacts were refined and cross-referenced with the wellbeing criteria in section 2 in order to illuminate the most prevalent barriers to wellbeing on Mars. Research revealed that impacts and wellbeing criteria did not have a one-to-one relationship, as a single impact could affect many facets of wellbeing.

The fourth section (design guidelines) was developed from the prior sections. Conclusions from the wellbeing criteria and impacts section were evaluated for their spatial context, and organized by relevant scale (community and site design). These data points were then sorted by a relevant theme, for example spatial organization, circulation, or design features. The themes were then simplified into design guidelines (three to five per theme) that could be described by straightforward spatial objectives. In sum there are two scales, eight themes, 28 design guidelines, and over 60 specific design objectives.

Assumptions & Limitations of Data

A number of assumptions were made to help focus this study. These include:

- The timeline, governance, and population of a Mars settlement. Based on credible theories and plans, this thesis is focused on a settlement of 30 to 60 people with high levels of autonomy and self-governance.
- The mission goals for a Mars settlement. The success of exploratory phases as well as the continued

economic backing for extraterrestrial exploration will shape future missions.
- The development of building systems and materials to buffer the Martian environment. Considering baseline technological constraints, this study assumed that engineering innovations will keep pace with the goals of the habitat designers.

The study also revealed the following data limitations:
- Wellbeing literature regarding workplaces was far less developed than for domestic or recreational life. Analogous studies similarly breezed over workplace conditions as realities of the habitat. As a result, the design guidelines offer fewer recommendations for the design of workplaces. This is a topic that requires future research and a specific understanding of mission goals.
- Many studies of analogous habitats frequently discussed relevant wellbeing issues without regard to the spatial context, making it challenging to reveal cause-and-effect patterns to inform the design guidelines.
- Many of the environmental conditions identified in section one have yet to be evaluated with regard to human experience. Many questions remain regarding the wellbeing impact of factors including Mars time, low gravity, low light levels, and long seasons. Other impacts are clearly identified yet purely hypothetical and untested, such as Earth-out-of-view phenomenon.
- There were challenges with applying design cues from analogue habitats to a Martian settlement. Though representative, these habitats differ slightly in scale, age, and function.
- The wellbeing criteria are organized to provide a clear list and hierarchy of findings. In reality, each wellbeing criterion may overlap considerably with others and all may be interrelated. They should be considered alongside physical health criteria for maximum effect.

CONDITIONS

What are the anticipated living conditions on Mars?

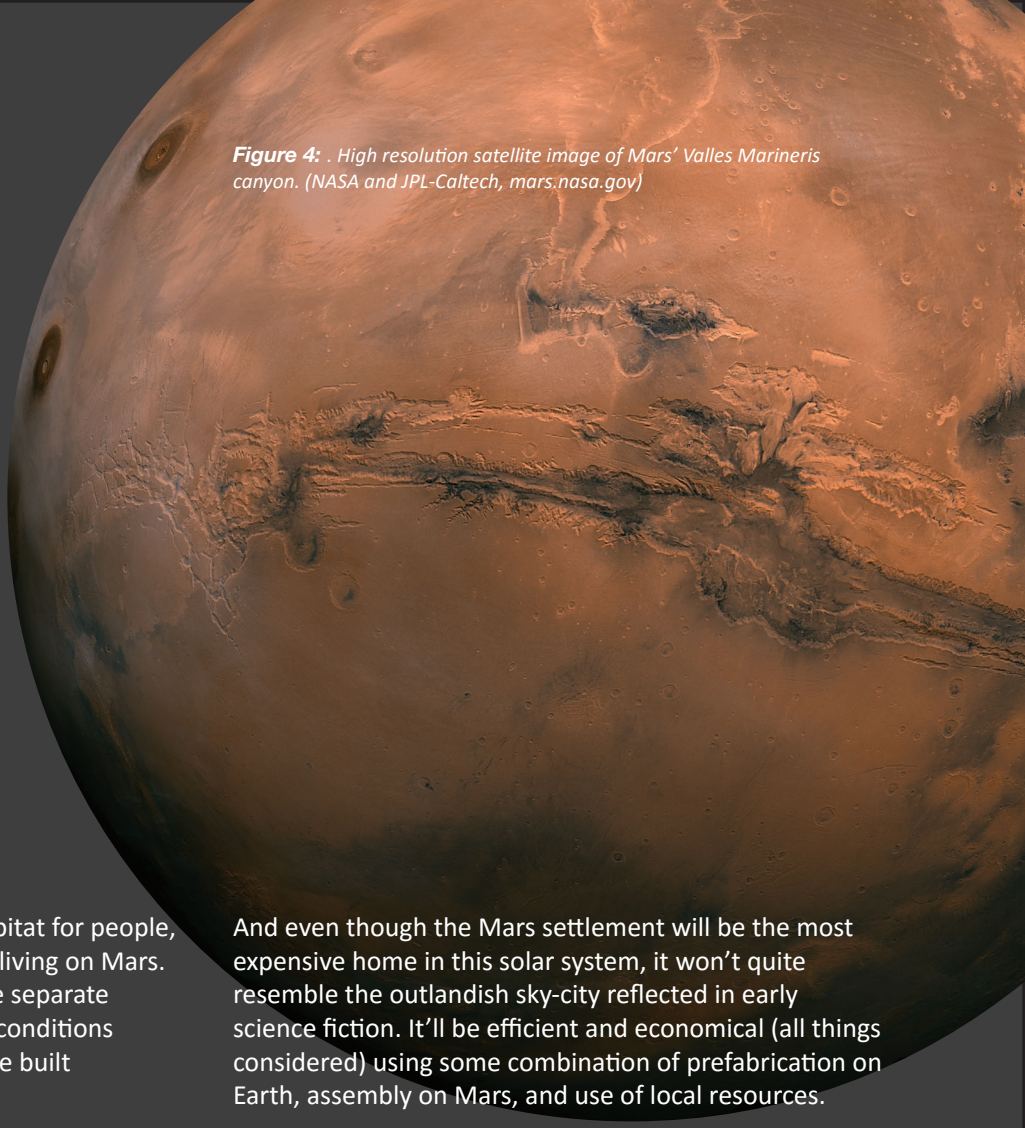


Figure 4: *. High resolution satellite image of Mars' Valles Marineris canyon. (NASA and JPL-Caltech, mars.nasa.gov)*

Introduction

To understand how to design a better habitat for people, we must first understand the context for living on Mars. The living conditions are defined by three separate threads: the mission, the environmental conditions of Mars, and the unique constraints of the built environment.

The mission of humans on Mars is for the pursuit of science, to expand our knowledge of not only Mars but the extents of human innovation and knowledge. A settlement of 30 to 60 people won't be the first development on Mars – early single crew expeditions will be – but it will be the first scale to accommodate long-term human occupation. And the crew will be largely self-reliant and autonomous from Earth, comprised of adventure-minded and highly-educated individuals from diverse international backgrounds.

Mars is hardly a paradise destination. First off, at its closest it is 50 million miles from Earth and the journey will last over half a year. The gravity is so low that a person's muscles may go into atrophy over time. The atmosphere which is 95 percent carbon dioxide is deadly to breathe, and the extremely low atmospheric pressure will dehydrate the human body. Despite the weak sunlight, constant solar radiation bombards the planet, increasing human risk for cancer. And hopefully the habitat is insulated, because while a nice day can be a balmy 70°F, at night the temperature will drop to -100°F.

And even though the Mars settlement will be the most expensive home in this solar system, it won't quite resemble the outlandish sky-city reflected in early science fiction. It'll be efficient and economical (all things considered) using some combination of prefabrication on Earth, assembly on Mars, and use of local resources.

There is a lot we don't know. And plenty we won't know until we get there. But starting here, we can paint a basic picture of a population, a place, and a habitat.

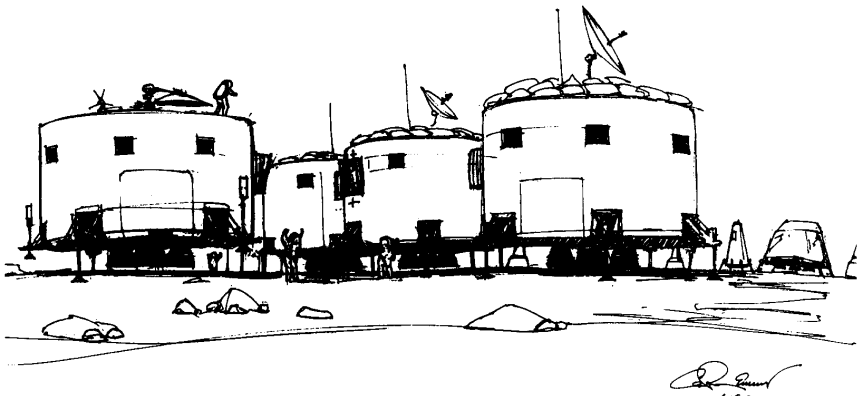


Figure 5: *A sketch of the Mars Direct habitation system. (Robert Zubrin, "Mars Direct: Humans to the Red Planet by 1999")*

Mission

Phases of human settlement on Mars

The allure of traveling to Mars has been imagined and re-imagined through folklore, science fiction, and most recently through scientific exploration. There are numerous reasons people dream of going to Mars: search for extraterrestrial life, astronomical research, mineral extraction, scientific and technological innovation, and as a secondary habitable planet. After all, Mars is the viewed as the most likely place for life and the most habitable planet beyond Earth. In his 1990 paper *Mars Direct,* astrophysicist and Mars visionary Robert Zubrin proposed a preliminary timeline for human habitation of the red planet.[1] Building on his template, plans for Mars exploration and colonization can be conceived along a five-phase spectrum of time and scale: exploration, settlement, colonization, urbanization, and terraforming. This thesis addresses the scale of phase II (settlement).

Exploration is the preliminary stage of discovery and includes the first manned missions to Mars, such as NASA's proposed 2035 "Journey to Mars". Based on NASA plans, this will be characterized by four to six person crews sent for durations of 1,100 days.[2] The human habitat will likely be a singular or small complex of modules either prefabricated on Earth or built by robotics prior to human arrival. It is likely that space agencies will use the relative mobility of these early missions to scout for ideal locations for more permanent settlements, to conduct detailed scientific exploration, and to test long duration habitation systems.

Settlement is an intermediate phase, but a critical one. Following initial exploration, a more permanent site will be selected with the expectation of repeat journeys, international co-occupation (similar to the ISS), longer stays, and eventually the establishment of a small semi-permanent population. Zubrin theorized that 25 years after the first Mars exploration, a settlement could grow to support a population of 48 individuals.[3] As it grows, the settlement will shift from solely exploratory research to a more diverse community of scientists, explorers, farmers, engineers, and innovators, all honing and developing their respective industries.

Colonization builds upon the emerging permanence of the initial settlement and the developing industries. While people during this phase could return to Earth, the focus would be on continued permanent developments and a growing population. Zubrin's model conceives parties of 24 people arriving annually beginning in year 26 and increasing with each year.[4] The base ceases to be a singular community and grows rapidly into an increasingly autonomous, diverse, and complex habitat that begins to conceptually resemble a town or city on Earth. This phase is difficult to predict; depending on economic, political, and environmental factors on Earth

1 Robert M Zubrin and David A Baker, "Mars Direct: Humans to the Red Planet by 1999," *Acta Astronautica* 26, no. 12 (1992). 899-912.

2 NASA, "Journey to Mars" (NASA, October 2015). 21.

3 Zubrin and Baker, "Mars Direct." 906-908.

4 Ibid. 908-911.

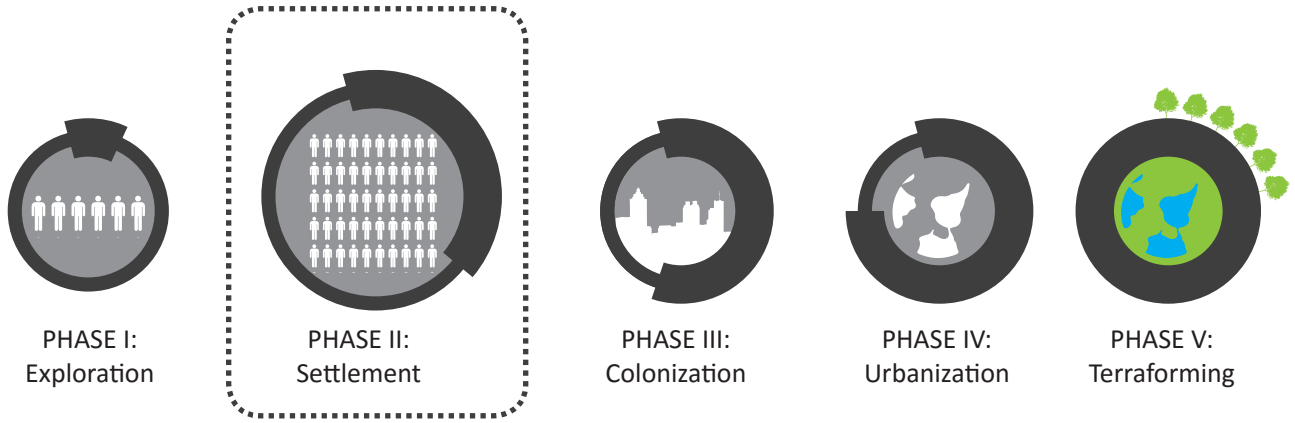


Figure 6: *Representation of the proposed five phases of humans on Mars. This thesis provides design guidelines for phase II, settlement.*

as well as conditions on Mars, growth could be rapid or gradual. Additionally, the design of the built environment will cease to replicate Earth practices and will begin to reflect a Martian vernacular and culture. As identified by NASA, this shift is recognized as a transformation from "Earth-Reliant" to "Earth-Independent".[5]

Urbanization builds upon the theoretical growth of the colony into a dense and heavily populated city with autonomous systems of infrastructure, economy, politics, and culture. It may also result in emergent political boundaries on Mars, multiple cities, habitable territories, and regional transportation systems. Zubrin's "Mars Direct" envisioned Mars with a population of 80,000 by year 100.[6]

Finally, terraforming is a final foreseeable stage of human occupation on Mars, centered on the development of functioning ecological and natural systems that alter the atmosphere, temperature, and surface conditions to a point where it is habitable beyond hermetically sealed environments. In a nutshell, making Mars like Earth.

These phases represent a very linear approach to inhabiting Mars. While phase I is anticipated and well supported in NASA plans, phase II is reliant on the successes of phase I. A number of factors, including technological failures or future economic support, could end human occupation on Mars after a single trip. While it is anticipated that these missions are international, there is the potential for a competitive space race. Multiple non-cooperative settlements may then evolve in completely different ways. It is also conceivable that for cost or ideological reasons, phase III colonization never occurs, and instead a disaggregated world of smaller-scale settlements emerges.

The prospect of colonizing other planets has major ethical considerations that are beyond the scope of this study to fully analyze. With no indigenous human population on Mars, there appear to be fewer ethical violations as compared to colonization throughout human history. However, it is worth noting that only countries with affluence or connections will be able to send people to Mars. Though a scientifically driven mission is anticipated, a for-profit venture seeking the extraction of minerals has environmental and economic ethical considerations as well. Lastly, it is presently unknown whether or not microbial life exists on Mars. Contamination of microbes from Earth could kill off any native species before discovery, while microbes from Mars could pose major health risks to the human habitants.

Population size & demographics

Using Zubrin's model of a settlement phase, this thesis assumes a growing community of 30 to 60 individuals. It is expected that they are not the first people to live on Mars for extended periods of time, but they will be the first settlement large enough to be considered a community. The size and growth of this population is significant for two reasons. First, it is large enough that complex social interactions exist on a variety of scales, from individual to sub-group to community wide. Second, the habitat shifts from a shorter-term, singular module to a differentiated complex. Whereas a module represents an extreme

5 NASA, "Journey to Mars." 7.
6 Zubrin and Baker, "Mars Direct." 911.

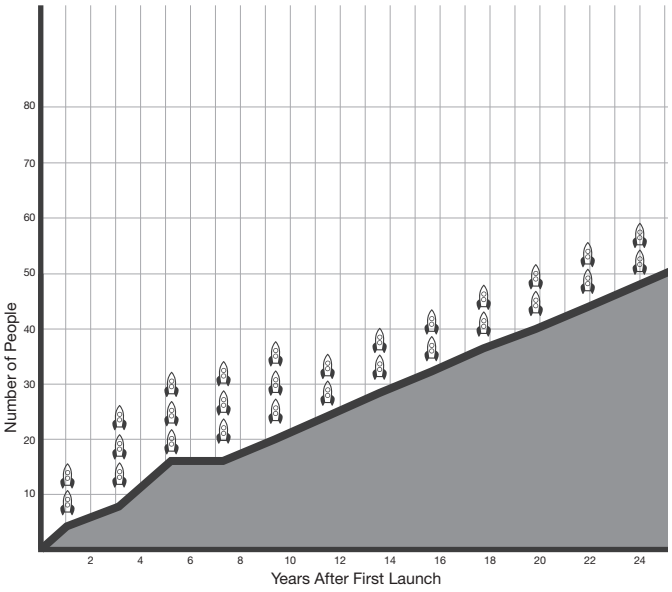


Figure 7: *Projected growth of phase II settlement, based on Zubrin's estimates. This thesis assumes a growing population of 30 to 60 people.*

architectural and engineering challenge, an entire complex taps into principles and theories of urban planning and urban design as well, and has the capability to fulfill a richer and more diverse experience than a module can.

A Martian settlement will require international cooperation. The ISS, for example, is a $100 billion dollar habitat built and occupied by the United States, Russia, Japan, Canada, and the European Space Agency (Belgium, Denmark, France, Germany, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland and the United Kingdom).[7] It can be assumed that any community will be drawn from many countries and will lack a singular ethnic, cultural, or religious heritage. It will be multi-lingual, but for the sake of the mission a dominant language (or languages) may be adopted for mission activities.

Selection criteria for individuals are critical, and as is done currently, an extensive screening process will attempt to identify preferred skills and personalities. Age may not be as important as health and personality. NASA astronauts have ranged from 26 to 46, and most space agencies do not have an upper age limit. Preferred candidates are goal oriented, driven by challenge, personable, sensitive, and motivated by a strong work ethic.[8] Undesirable attributes include arrogance, interpersonal competitiveness, hostility, interpersonal insecurity, complaining, nagging, and fussiness.

Inhabitants of Mars will have been trained extensively in preparation for their mission. Currently, selected NASA astronauts spend 10 years in training prior to any spaceflight. Despite their different backgrounds and personalities, it can be assumed that all individuals will be self-selected and motivated by scientific discovery and a lifelong passion for living on Mars. This passion will come with a strong understanding of challenges and risks involved.

Mission objectives

Early Martian settlers will be both researchers and research subjects. The majority will likely be made up of natural scientists (biologists, horticulturalists, geologists, physicists, chemists), engineers (mechanical, aerospace, electrical), and medical professionals. Other individuals may be social scientists, psychologists, therapists, administrators, farmers, builders, and designers. As the compound grows, the need for diverse and cross-disciplinary skills will emerge.

There are three objectives of the mission. The first objective is to explore the Martian surface. This includes collecting samples, testing prototypes, and expanding knowledge of surrounding regions. Early missions will establish exploration zones (EZs), a radius of nearly 62 miles that NASA expects astronauts will be able to explore comfortably.[9] This may include exploratory resource extraction. However, a majority of longer distance missions will be carried out by robotic vehicles and human missions will be restricted due to cost and safety concerns. The second objective is scientific discovery and technological innovation. The diverse skill set of the community will be put to work to search for extraterrestrial life, develop a better understanding of Mars' natural systems, and to develop industries and technologies for Mars. The third objective is to study human habitability, health, and behaviors. Since this phase represents the first community on Mars, all future developments will be based extensively on the knowledge learned from it.

Duration

Settlement represents a transition from long-duration missions to semi-permanent residence. Crews will spend a minimum of 1,100 days away from Earth, the anticipated duration of initial NASA explorations. As the base grows and habitation systems are tested/adapted, more people will be able to stay for extended periods of time. Barring a revolutionary discovery in spaceflight technology, the cost, time, and risk of transporting

7 Karl Tate, "The International Space Station: Inside and Out (Infographic)," *Space.com*, 2012, http://www.space.com/3-international-space-station.html.

8 Lawrence A Palinkas, "Psychosocial Issues in Long-Term Space Flight: Overview," *Gravitational and Space Research* 14, no. 2 (2007). 26-27.

9 Mike Wall, "Permanent Mars Colony Is 'Long Way Down the Road,'" *Space.com*, accessed April 3, 2016, http://www.space.com/32325-nasa-mars-colony-crewed-mission-outlook.html.

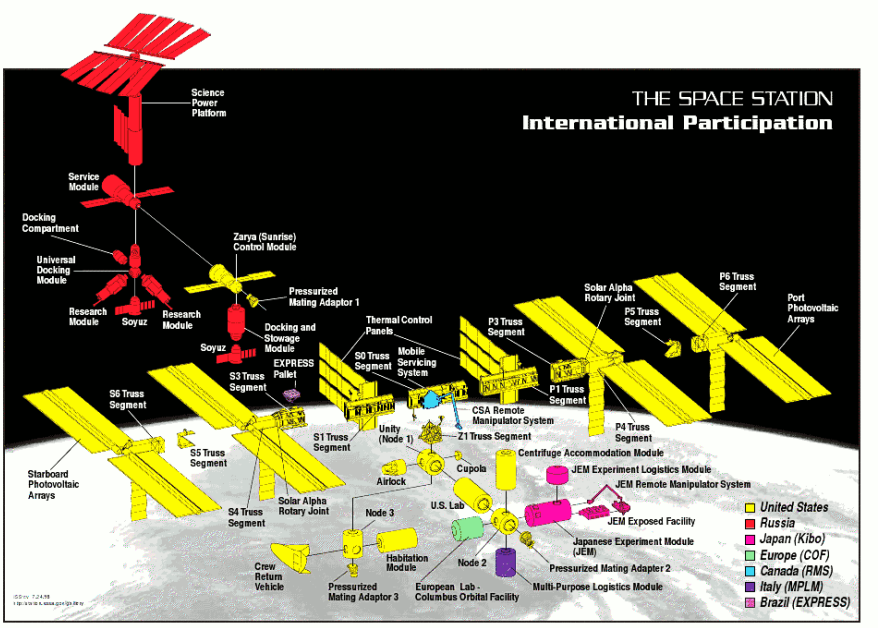


Figure 8: The nations of the International Space Stations (ISS).
The international cooperative precedent of the ISS suggests a major Mars mission would be culturally diverse and democratically governed. (planetpailly.wordpress.com)

people between planets is extremely high and there will be a preference to minimize transport.

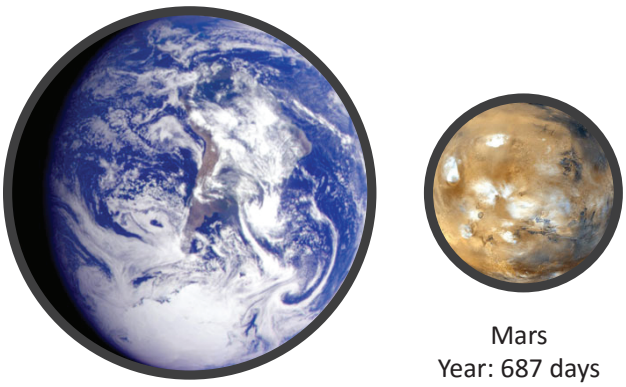
It can be expected that new crews will arrive every 26 months. The arriving population may vary in size, depending on available spaceflight technology and the number of shuttles sent. Current NASA plans are for crews of four at a time, although other plans and agencies suggest nine people may work better for team cohesion.[10][11]

Governance structure

A Mars settlement will be more autonomous than any previous spaceflight mission. Mars has a 20-minute communication delay with Earth, meaning information will be shared but a strong independence from Earth will govern most day-to-day decisions and emergency situations.[12] Real-time communications will be impossible, and delayed communications will have limited value in many situations. As Mars progresses from a settlement to a colony or city, there is a high likelihood that it will establish its own governance entirely autonomous from Earth politics.[13]

Internal governance of a Mars settlement could exist along a wide spectrum of possibilities. The proposed Mars One mission suggests that decisions will be collective and require unanimity, while the population is relatively small.[14] It acknowledges that as the community grows, a more complex governing system will need to be developed by those on Mars. There may be need for a hierarchical command of the base, akin to the ISS, that rotates periodically with changing crews and missions. Since the mission will be based on international cooperation, there is a strong likelihood it will be highly democratic with no single entity wielding unilateral power.

10 NASA, "Journey to Mars." 18-20.
11 Joanna Kozicka, "Architectural Problems of a Martian Base Design as a Habitat in Extreme Conditions" (Gdansk University of Technology, 2008). 83-84.
12 NASA, "Journey to Mars." 7.
13 Declan J. O'Donnell, "Mars Governance," in *The Founding Convention of the Mars Society*, ed. Robert Zubrin and Maggie Zubrin (San Diego, Calif: Published for the Mars Society by Univelt, 1999). 873.
14 Mars One, "What Governmental System and Social Structure Will Be Implemented on Mars?," *Mars One*, accessed March 2, 2016, http://www.mars-one.com/faq/mission-to-mars/what-governmental-system-and-social-structure-will-be-implemented-on-mars.



Earth
Year: 365 days
Day: 24 hours

Mars
Year: 687 days
Day: 24.7 hours

Figure 9: *Relative days and years between Earth and Mars. Days are nearly the same, while Martian seasons last nearly twice as long.*

Martian Environment

Orbit, Time, & Gravity

Mars has a longer and more extreme elliptical orbit than Earth. As a result, a year on Mars is 687 days with seasons that last nearly twice as long as they do on Earth.[15] Meanwhile, a day on Mars is 40 minutes longer than a day on Earth, a relatively insignificant difference. At their closest, Mars and Earth could theoretically be 33.9 million miles apart, yet the closest recorded distance has never been less than 50 million miles. These closest distances or "oppositions" occur every 26 months. Given the high fuel costs and time of travel, all launches to Mars are expected to coincide with the opposition.

Mars is half the diameter of Earth and has 38 percent its gravitational force.[16] Such an extreme decrease in gravity will give humans greater physical reach, but will have significant physiological effects as well. Human bone density will likely decrease and risk of atrophy is especially high. Due to the relative difference to 0-gravity, it will be easier to adjust to Mars gravity after long-duration spaceflight than it is on Earth.

Atmosphere & Pressure

Humans on Mars will be unable to survive without an artificial atmosphere. The Martian atmosphere is 95 percent carbon dioxide, 2 percent nitrogen, 2 percent argon, and less than one percent oxygen.[17] For reference, Earth's atmospheric composition is 78 percent nitrogen, 21 percent oxygen, and less than one percent argon. Even if oxygen levels were high enough for human needs, the carbon dioxide would need to be displaced with an inert gas that does not interact with our bodies, such as nitrogen.

Atmospheric pressure, which is the pressure exerted by the weight of the atmosphere, is roughly 0.6 percent of Earth's at sea level.[18] In comparison, the relatively low pressure at the summit of Mt Everest is only 33 percent of sea level pressure. The effects of the Martian atmospheric pressure on the human body would be immediately deadly without an artificially pressurized spacesuit or habitat.

Light, Radiation, & Temperature

Despite sharing a sun, Earth and Mars have drastically different exposures to sunlight. Mars is 50 percent further from the Sun than Earth, and as a result experiences 56 percent less sunlight than Earth. There are significant geographic and seasonal variations in solar gain as well. Similar to Earth, Mars has two polar caps (N and S) that both feature extremes in sunlight during summer and winter months. On the Mars equator, sunlight is comparable to mornings in high latitude cities (Chicago, Seattle) or to midday sunlight in extreme latitude locations (Antarctica, Arctic Circle).[19]

15 Stephen Petranek, *How We'll Live on Mars* (Simon and Schuster, 2015). 39-54.
16 Ibid.
17 Kozicka, "Architectural Problems of a Martian Base Design." 18-19.
18 Ibid.
19 Petranek, *How We'll Live on Mars*.

Figure 10: *A Martian sunset over Gale Crater. The thin atmosphere and layer of particulate matter renders sunsets a blue-ish hue. (NASA/JPL-Caltech/MSSS/Texas A&M, jpl.nasa.gov)*

One of the biggest concerns on Mars is harmful solar radiation, in the form of high-energy subatomic particles such as ultraviolet light.[20] Due to a weak magnetic field and relative lack of atmosphere, cosmic radiation is 100 times more powerful than on Earth, creating a high-risk environment for cancer or acute radiation sickness. Solar flares, which are sporadic but detectable in advance, can cause extreme and deadly spikes in radiation. One of the primary engineering challenges will be to devise materials or shields to protect inhabitants from radiation.

The orbit and lack of atmosphere also affect the way light hits the Martian surface. The sun will appear five-eighths the size it does on Earth and will have less of an opaque glow around it. Light on Mars is far less dispersed and makes the surface reflect brighter – consider the difference between a frosted and clear light bulb. Due to the thin atmosphere and unique dust particles, the color of the sky on Mars varies as well.[21] During mornings and evenings it is blueish, at sunset and sunrise it is pinkish, and during the day it is yellow-brown, pinkish, and occasionally violet. Additionally, the two Martian moons, Phobos and Deimos, are visible from the surface. Phobos will appear less than half the size of the sun while Deimos will be little more than a dot.

Without an insulating atmosphere like Earth, Mars is cold and extreme. The average temperature on Mars is -80°F, with a low at the poles of -195°F.[22] Summer temperatures near the equator on Mars range from 70°F during midday to -100°F at night.[23] These daily fluctuations are far too drastic for human exposure and the Martian habitat will need to be heavily insulated and heated.

Winds

Surface winds on Mars are common and extremely high speed, and due to the low atmospheric pressure can change rapidly.[24] However, due to a very thin atmosphere, the force felt by the winds is much less than similar winds on Earth. Winds can induce extreme dust storms that deposit large quantities of mineral particles, which could block out communication devices, cause minor damage, and blacken the daytime sky. However, structures of considerable height will be able to withstand the weak force of the Martian winds.

Terrain & Surface

The surface area of Mars is only 28 percent that of Earth, yet it is comparable to the amount of dry land found on Earth.[25] The surface is largely covered by a thin dust layer of rust (iron oxide) which gives Mars its classic reddish color.[26] The terrain is diverse, including giant extent volcanoes (Olympic Mons, three times larger than Mt Everest), deep rifts, and sand dunes. There are polar ice caps that contain frozen carbon dioxide and potential

20 Kozicka, "Architectural Problems of a Martian Base Design." 15-16.
21 Ibid. 15-16.
22 Ibid. 19-22.
23 Stephen Petranek, "Infographic: How We'll Live on Mars," *Ideas.ted.com*, July 7, 2015, http://ideas.ted.com/infographic-how-well-live-on-mars/.
24 Kozicka, "Architectural Problems of a Martian Base Design." 23-25.
25 Petranek, *How We'll Live on Mars*. 40.
26 Kozicka, "Architectural Problems of a Martian Base Design." 28-29.

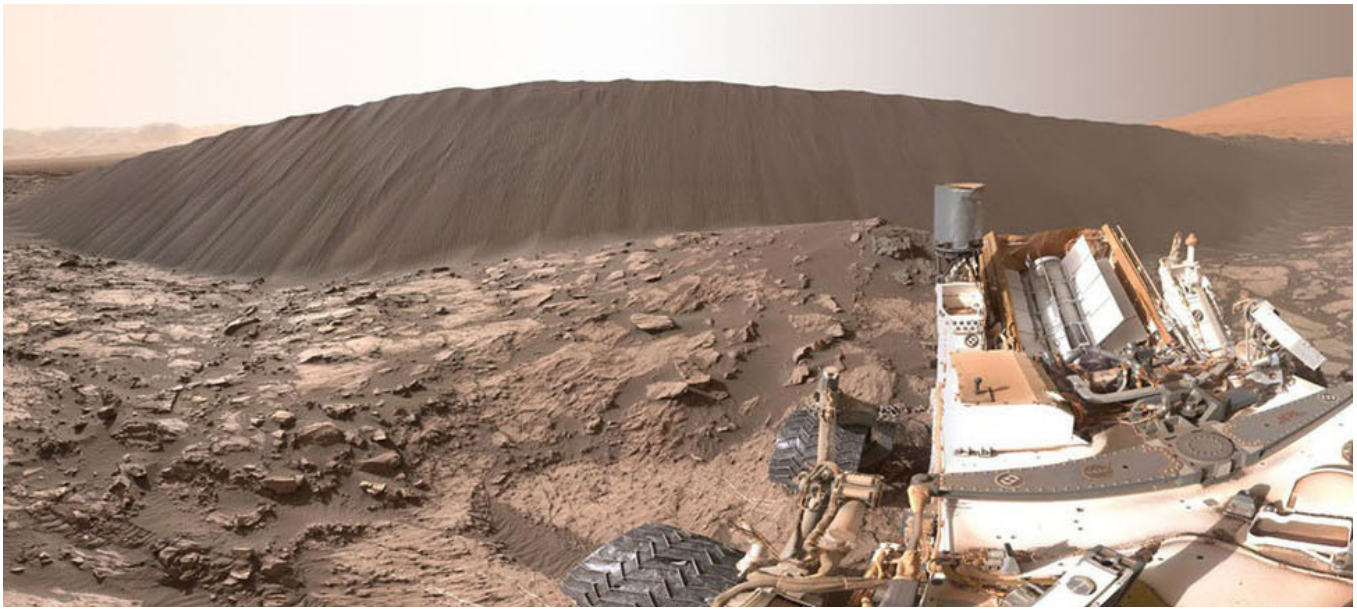


Figure 11: *A "selfie" by NASA's Curiosity rover shows coarse regolith in the foreground, a large dune, and Mt. Sharp rising back right in the distance. (NASA/JPL-Caltech/MSSS, jpl.nasa.gov)*

large quantities of ice.[27] Due to a thin atmosphere, Mars is covered in impact craters and lacks the weathering of Earth to erode its dramatic geographic features. Additionally, there is evidence of large quantities of water ice frozen throughout the Martian surface. Recent satellite imagery has also confirmed that ice in the soil seasonally melts and flows along the surface in select locations.[28]

27 Petranek, *How We'll Live on Mars*. 39-42.

28 Gina Anderson, "NASA Confirms Evidence That Liquid Water Flows on Today's Mars," Text, *NASA*, (September 28, 2015), http://www.nasa.gov/press-release/nasa-confirms-evidence-that-liquid-water-flows-on-today-s-mars.

Figure 12: *A rendering of pneumatic structure, by Bigelow airspace, attached to the International Space Station. (Bigelow Airspace/NASA, space.com)*

Built Environment

Structure Scale

The anticipated scale of a settlement on Mars varies considerably by design. For a population of 48 people, Zubrin allocated 25 habitation modules, combined to form a continuous pressurized volume of 284,000 cubic feet (just under 6,000 per capita).[29] An independent study at the University of Texas A&M proposed a habitat module for 20 people with a volume of 275,000 cubic feet (13,700 per capita).[30] Current plans for Mars One provide 35,000 cubic feet for four people (8,800 per capita).[31] Comparatively, NASA currently requires a mere 883 cubic feet per person for spaceflight operations.[32] While these examples provide an order of magnitude, they should be considered a best approximation.

Any space settlement, due to cost and logistics, will start out as a dense population with minimal spatial excess.[33] What can be anticipated is that a Martian settlement will build incrementally over time. Its rate of growth will be based on every 26 month cycle of new arrivals. The sheer cost of transporting materials prohibits a one-and-done construction method and instead favors built environment growth that parallels population growth. First, critical support systems will be established, along with laboratory and living spaces for the initial missions. This stage may mirror the scale of exploratory missions, represented by an all-in-one module design. Second, successive transports will add additional and more complex research areas, expanding residential capabilities. Third, the level of complexity and scale will force an increase in diversified work and laboratory spaces, expansion and subdivision of residential areas, and the provision of basic community amenities, such as dining and entertainment areas.

Constraints on the Built Environment

The first and largest constraint is the factor of transportation. You can only build what you can reasonably ship or mine from the surface. This greatly reduces the scale and complexity of the structure. It will also need to be easily assembled or deployed, either upon arrival or by robotics prior.

Additionally, any habitat needs to be hermetically sealed with an artificial atmosphere. It will have closed loop systems, not just for breathable air, but for water, waste, and food. It needs to be artificially pressurized with ample insulation to protect people from the freezing Martian nights. A critical design challenge is shielding habitants from radiation. The structure needs to protect from constant bombardment of solar rays, through protective barriers such as regolith, water, gas, or ice.[34] For the rare event of solar flares, which are potentially

29 Zubrin and Baker, "Mars Direct." 907.

30 Ikhlas Sabouni and Marshall Brown, "Mars Habitat: Special Topics in Architecture 1990-91" (Prairie View A&M University, 1991). 12-15.

31 "How Much Living Space Will the Astronauts Have?," *Mars One*, accessed April 4, 2016, http://www.mars-one.com/faq/health-and-ethics/how-much-living-space-will-the-astronauts-have.

32 Alexandra Whitmire et al., "Minimum Acceptable Net Habitable Volume for Long-Duration Exploration Missions," (NASA, 2015). 3.

33 A Scott Howe and Brent Sherwood, *Out of This World: The New Field of Space Architecture* (AIAA, 2000).

34 Petranek, *How We'll Live on Mars*. 51-54.

Figure 13: *A proposed four-person habitat design that uses a pneumatic prefabricated core covered with mined Martian regolith. (Team Gamma/ NASA, architectmagazine.com)*

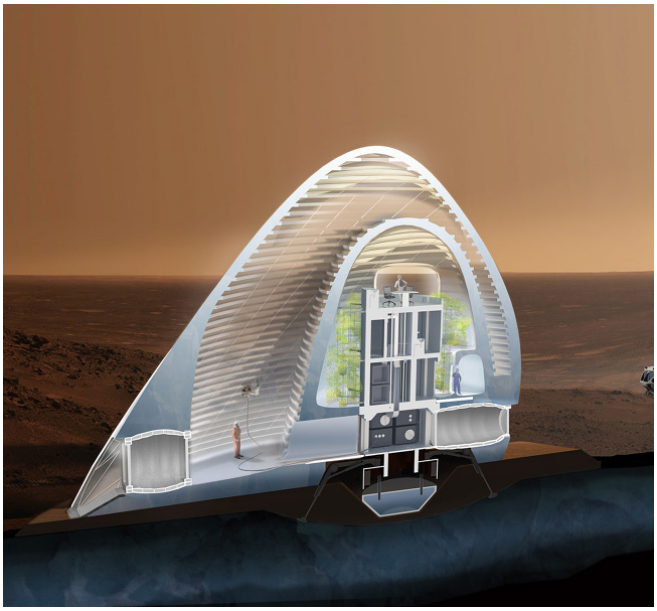


Figure 14: *Mars Ice House is a proposed design with a 3D printed outer shell of ice to protect against radiation. (CloudsAO, cloudsao.com)*

deadly, there will need to be a secure sub-surface bunker to shield from extreme levels of radiation.

Construction Methods

There are four methods of Mars habitat construction: 1) prefabricated modules, 2) in-situ structures, 3) pneumatic structures, and 4) 3D-printed structures.

Prefabricated modules are self-contained units built to completion on Earth prior to launch. Most NASA proposals and test modules fall into this category. While they are easiest to build and test, there are numerous drawbacks. The sheer mass adds considerable difficulty and costs to transportation.[35] Modules have more airlocks and connection points, thus a higher risk for leakage. Perhaps most critically, they provide adequate short term habitability but due to their confined nature are less adaptable to long term growth.

Pneumatic structures are pressurized volumes that attach to a simple frame and are inflated upon arrival to Mars.[36] Like modules they can be tested and prefabricated on Earth, yet unlike modules can be transported with relative ease. They can easily be constructed to exceed the volume constraints of the space shuttle, and offer greater variety in scale and arrangement of spaces.[37]

In-situ structures utilize local materials and geography for construction. This relates to site location as well as converting surface regolith to a buildable material. For example, proposals have looked to utilize carved out sub-surface lava tubes. While this presents the smallest burden on transporting materials, it is reliant on a process that cannot be accurately tested on Earth.[38] In addition, it forces subsurface structures with minimal solar access, and presents issues of leakage and maintaining a sterile environment.

3D printed habitats have emerged only recently as a viable option for construction. A 2015 NASA competition yielded ICE House, a robotically printed ice structure with an internal pressurized volume.[39] Though much is unknown regarding the feasibility of large-scale 3D habitat printing on Mars, it presents a unique opportunity to utilize robots to build highly customizable structures prior to the arrival of any people.

A hybrid building approach to a Mars settlement is likely, considering the varying needs and extensive time-frame for growth. Utilizing advantages of each method would enable long term flexibility. A conceivable strategy may be to begin with prefabricated modules and pneumatic structure and advance with 3D printed and in-situ methods as more can be tested on Mars.

35 Sabouni and Brown, "Mars Habitat." 4-6.

36 Janek Kozicki and Joanna Kozicka, "Human Friendly Architectural Design for a Small Martian Base," *Advances in Space Research* 48, no. 12 (2011). 1998-1999.

37 Sabouni and Brown, "Mars Habitat." 4-6.

38 Kozicki and Kozicka, "Human Friendly Architectural Design for a Small Martian Base." 1998.

39 SEArch and Clouds AO, "Mars Ice House," *Mars Ice House*, accessed April 5, 2016, http://www.marsicehouse.com/.

From Hard to Soft Science

These conditions represent the knowledge at a moment in time. Discoveries that take place over the next several decades will refine the base context of living on Mars. The discovery of extractable water and the technology to effectively remove it will be a primary limiting factor for when and where we can establish a semi-permanent base. The continued advancement of building materials and ongoing study of radiation impacts to humans will dictate the extent of enclosure or potential burying of the settlement. The advancement of rocket programs will determine how much and how often we can feasibly send people and cargo to Mars, while the testing of robotic construction and 3D-printing may open up a door to spacious and luxurious habitats never before thought possible.

As in any design project, the existing conditions of a site present challenges that may be ameliorated through design. Many of these challenges are purely technological: the development of radiation shielding materials is well beyond the scope of this research. Others are economic or political, while others still – such as the selection of a crew or the mission goals itself – are subject to the scientific community and the governing body at NASA and similar organizations.

The conditions outlined in this section provide the legs to this entire study, yet only skim the surface of decades of groundbreaking research. NASA has poured billions of dollars into rovers, probes, and research studies that have shaped our understanding of the mission, the Martian environment, and the technological components of the built environment. Only a fraction of this research has focused on the human experience, and even less on human wellbeing. The next section, outlining criteria for wellbeing, is intentionally detached from the Martian context but provides a definition and framework for considering the human factor in the built environment.

Figure 15: *Two kids having a good time. (Vachara Chulapanichakam, flickr.com)*

WELLBEING CRITERIA

How does the built environment support individual and group wellbeing? How do these criteria govern individual behavior and interpersonal interactions? How do these criteria support needs and aspirations over a day, a week, or a year?

A Human Constant

The prospect of living on Mars, as identified in the previous chapter, offers many unknown variables. Changes in technology are rapid and many Martian conditions require further verification. The people going are unknown at this point, although we have some indication of general attributes. Given all this uncertainty, how can we anticipate and design for any concept of wellbeing on Mars at this point?

The one constant is humans. Within us, there are fundamental needs and desires. Whereas traditional design disciplines respond to specific users and design challenges, the field of environmental psychology has studied the relationship between humans and their built environments. This has enabled an understanding of general human wellbeing regardless of context.

Wellbeing has emerged as a major concept in urban planning and design literature as well. This came out of movements that linked physical health and chronic diseases such as obesity and diabetes to inadequate city design.[1] Changing conceptualizations of medical professions elevated mental health to a level comparable with physical health, enabling concepts such as wellbeing and happiness to integrate into planning practice. However, contemporary health impact assessments (HIA) are geared more towards attributes of physical health than mental health.[2] In addition to its relevance on Mars, a better understanding human wellbeing will play a major role in evaluating the health of communities on Earth.

Wellbeing will be challenging to achieve on Mars. Studies of prior year-long spaceflight missions have indicated that for the first six months, astronauts are fully able to adapt and compromise to less than desirable conditions.[3] However, beyond six months there are major issues with duration, discomfort, and discontent. This has jeopardized group cohesion, mission objectives, and individual safety.

This section provides an overview of nine identified wellbeing criteria, beginning at the most measurable (personal space) and ending at the most abstract (self-expression). Each criterion contains specific objectives for the built environment that relate to interpersonal interactions and individual mental health needs (outlined on next page). This entire section is detached from Mars, and rooted purely in human need and expectation. Subsequent chapters will apply these criteria to the Martian context.

1 Jennifer L Kent and Susan Thompson, "The Three Domains of Urban Planning for Health and Well-Being," *Journal of Planning Literature* 29, no. 3 (2014). 239-240.

2 CDC and NACCHO, "Protocol for Assessing Community Excellence in Environmental Health" (CDC, 2000).

3 Dietrich Manzey, "Human Missions to Mars: New Psychological Challenges and Research Issues," *Acta Astronautica* 55, no. 3 (2004). 783-784.

Wellbeing Criteria & Objectives

Personal Space

Objective 1: Provide an adequate amount of space for each setting and task
Objective 2: Reduce demand for personal space
Objective 3: Prevent loss of personal space due to incidental violation
Objective 4: Balance socio-fugal and socio-petal environments

Crowding

Objective 5: Reduce perception of crowding
Objective 6: Provide alternates to avoid crowded spaces
Objective 7: Regulate access to limited resources
Objective 8: Adapt space for time of day and seasonal needs

Territoriality

Objective 9: Provide three degrees of territoriality
Objective 10: Embrace personalization and marking
Objective 11: Minimize infringement of territory
Objective 12: Maximize defensible space

Privacy

Objective 13: Provide a private space network
Objective 14: Provide every individual with a personal hub or home
Objective 15: Mitigate complete isolation
Objective 16: Ensure a privacy gradient
Objective 17: Enable modification of privacy thresholds

Choice

Objective 18: Provide multiple space and route options
Objective 19: Enhance legibility
Objective 20: Provide adaptable environments
Objective 21: Enable individual and group modification of space

Sense of Place

Objective 22: Choreograph desirable public spaces
Objective 23: Embrace the uniqueness of a place
Objective 24: Support a human scale
Objective 25: Provide a diversity of behavior settings
Objective 26: Maximize accessibility and appeal of pedestrian circulation

Social Support

Objective 27: Provide formal and informal social opportunities
Objective 28: Enable individuals to mediate social interaction
Objective 29: Promote a diverse social network
Objective 30: Provide opportunity for chance encounters

Restoration

Objective 31: Provide a diversity of escape facilities
Objective 32: Integrate a restorative spatial network into daily routine
Objective 33: Provide positive distractions
Objective 34: Provide moments of challenge

Self-Expression

Objective 35: Provide opportunity for self-expression
Objective 36: Engage all five senses
Objective 37: Promote system-wide harmony
Objective 38: Enhance ecosystem connectedness

Figure 16: *A very literal interpretation of a socio-petal space. It encourages many people to feel comfortable in close proximity. (University of Sheffield School of Architecture, flickr.com)*

Wellbeing Criteria

Personal Space

Objective 1: Provide an adequate amount of space for each setting and task
Objective 2: Reduce demand for personal space
Objective 3: Prevent loss of personal space due to incidental violation
Objective 4: Balance socio-fugal and socio-petal environments

Personal space refers to the interpersonal bubble that envelops each individual. The bubble changes size based on our gender, culture, surroundings, and mood. The dimensions of personal space govern most interactions we have, and in turn dictate the space needed to feel comfortable. Environmental psychologist Edward Hall defines four general zones of personal space: 0 to 18 inches for intimate interactions, 1.5 to 4 feet for personal interactions (such as with friends or family), 4 to 12 feet for social or business interactions, and larger than 12 feet for public interactions (such as speakers and audiences).[4] These zones provide rough guidelines, yet vary based on individual characteristics and cultural differences. Extroverted individuals require less personal space than those that are introverted.[5] Men traditionally require larger personal spaces than women. People from Asia and Latin America tend to require smaller personal spaces than those from America or Western Europe.

Though humans are adaptable, they can only tolerate minor levels of compromised personal space.[6] The critical discomfort region, theorized by John Aiello, suggests that too much intrusion is irreparable and renders lasting negative consequences. Personal space can be physically violated or actively enlarged by nuisance activities of others. Typically this arouses irritation, tension, stress, and may force an individual to relocate themselves. In most circumstances this is minor and avoidable as general social rules support the notion of respecting personal spaces. But if it is routinely violated, a person may become chronically distracted, anxious, hostile, and depressed.

While the built environment is not directly the perpetrator, personal space has a strong spatial relationship. Inappropriate adjacencies and inadequate space allocation can decrease functional space. For example, a study of libraries found that if two-thirds of seats are occupied, individuals will perceive it as full.[7] To counter this phenomena, specific design strategies can reduce the demand for personal space. Personal space is generally smaller in denser, better lit, and more spacious places. Conversely, negative stimuli such as noxious noises, unpleasant lighting, and overly warm temperatures increase demand.

Much of the way we interact in a space is dictated by built environment cues that manifest along a spectrum

4 Robert Gifford, "Environmental Psychology: Principles and Practice," 2002. 123-125.
5 Ibid. 127-128.
6 Ibid. 138-139.
7 Ibid. 141-142.

Figure 17: *Author's representation of Edward Hall's four zones of personal space. The nature of an interaction dictates the required physical space.*

from socio-petal to socio-fugal spaces. Socio-petal spaces are designed to encourage social interaction while socio-fugal spaces are designed to discourage it.[8] We tend to let our guard down in socio-petal spaces and require less personal space. There is a place for both types of space, and our ability to interpret the setting as one or the other (or some combination) will influence how we interact with others. For example, a cluster of chairs facing inwards clearly indicates a space for socializing, while a single occupancy table tucked away indicates the opposite. A supportive built environment not only provides social cues but avoids repetitious circulation patterns that force individuals to intrude upon another's space. Consider the effect of having noisy traffic that runs adjacent to a bedroom window or a work desk that fronts a busy public space.

Crowding

Objective 5: Reduce perception of crowding
Objective 6: Provide alternates to avoid crowded spaces
Objective 7: Regulate access to limited resources
Objective 8: Adapt space for time of day and seasonal needs

The terms "crowding" and "density" are often used interchangeably but represent very different phenomena. Density refers to the quantifiable amount of people in a given area whereas crowding refers to the perceived overabundance of people in a given area.[9] This is an important distinction – since crowding is strictly perceptual, it is subject to change despite a constant density. For this reason crowding is only experienced at interpersonal scales in space, meaning that at a non-perceivable community scale there is no notion of crowding. Whereas high density has no inherently negative impact on wellbeing, crowding is a situational circumstance that leads to a loss of control. This leads to a variety of detrimental impacts: personal goals (movement, task) are blocked, critical resources (space, accessibility, quiet) become increasingly limited, and negative responses are activated, including rushing, psychological withdrawal, immediate physical withdrawal, or assertiveness.[10]

The design of places can positively mitigate crowding with settings that extend space and minimize perceived over-crowding. Crowding is often exacerbated by long open corridors, short ceilings, and low natural light levels.[11] Higher density areas require more transitional spaces and architectural depth to control the patterns of large quantities of people.[12] Cluttered large objects in space increase crowding – in a tactical response, Japanese and Dutch cultures have historically utilized smaller objects of personal affection such as bonsai and miniature paintings to increase the perception of scale in their homes. In addition to the design of space, the

8 Ibid. 141.

9 Ibid. 174-176.
10 Ibid. 176-177.
11 Gary W Evans, "The Built Environment and Mental Health," *Journal of Urban Health* 80, no. 4 (2003). 544.
12 Gifford, "Environmental Psychology." 184-199.

Figure 18: *A crowded public space, but with a variety of options. The dual utility of the stairs as seating and movement expands its time of day function. (azoghbi, flickr.com)*

Figure 19: *Community mural building represents a form of community territory marking. (Dave Loewenstein, arts.gov)*

provision of alternative routes helps mitigate crowding. If an individual is given multiple options, even if all are subjectively crowded, the action of choosing a "better" option provides satisfaction.

In addition to design itself, crowding can be mitigated through regulated access and flexible space. Crowding is the result of a resource of public good (typically space) being over-utilized such that it diminishes the quality of the resource for everybody. With a fixed quantity of people and space, you can modify access to space. Consider a restaurant at capacity – at this point, no more people are seated or the quality of service will diminish for everybody. A more passive way of controlling access is by minimizing entry points into a space and separating crowd-prone spaces from active circulation routes.

Lastly, crowding is not a fixed situation – it fluctuates based on patterns of people over a day or a season. A highway that always seems crowded is only crowded during major commute hours. Repetitive crowding like this will over time diminish individual and group wellbeing. A built environment that can expand or rearrange to accommodate fluctuations of people will be better equipped to control crowding.

Territoriality

Objective 9: Provide three degrees of territoriality
Objective 10: Embrace personalization and marking
Objective 11: Minimize infringement of territory
Objective 12: Maximize defensible space

Territoriality is the perceived control over a space, and is closely tied to our sense of security and identity. Whereas personal space is an interpersonal bubble, territoriality is the personal claim of distinct spatial areas. Consciously and subconsciously, we claim a hierarchy of space on a daily basis: primary, secondary, and public territories.[13] Primary territories are private, self-owned, and of utmost importance, such as our home or bedroom. Secondary territories are seldom private but are important to our sense of control, such as desks at work or a gym locker. Public territories are available to anybody yet can be occupied and controlled for short periods of time before being claimed by others, such as a seat in a coffee shop or basketball court. Secondary and public territories extend our personal realm and make it easier to claim space in varied settings. An individual with a small sphere of territoriality will be handicapped to venture beyond their primary territory, and a disproportionate imbalance of territoriality will render a select few with extreme control.

In addition to occupation, we claim space via personalization and marking, the placement of identifiers to notify others.[14] We personalize walls, desks, rooms, homes, and even public spaces with artifacts and memorabilia that signify individual or group ownership of space. A step further, we deliberately mark territories to ensure that others know it is ours – consider the role of a community welcome sign or the way a café patron

13 Ibid. 150-152.
14 Ibid. 160-161.

Figure 20: *High Line park is by most metrics extremely crowded. Yet the design successfully creates transitional spaces and compartmentalized nodes for seating. (berk2804, flickr.com)*

Figure 21 : *Residential stoops represent a semi-private territory and add a level of natural surveillance to public streets. (Matt, flickr.com)*

leaves their hat on a table when they go to the restroom. An environment that stifles these expressions prevents us from exhibiting the control over our territories that we desire.

Territories are vulnerable to three types of infringement: invasion, violation, or contamination.[15] Invasion is a deliberate and aggressive breach of territory, such as breaking into another's bedroom. Violation is not deliberate yet still intrusive, such as walking through a private conversation. Contamination involves the unintentional spoiling of space through non-physical intrusion, such as introducing noxious noise, light, or smells that diminish the quality of another's territory. Violation and contamination of territory are typically the result of poor circulation and spatial adjacencies, and can be mitigated through design.

Even if our territory is not directly threatened or violated, a poor design of space can induce sensations of fear. Studies by Oscar Newman revealed that residents sharing a common entrance and long hallway with many others had higher levels of detachment due to a perceived lack of safety and community monitoring.[16] People feel more secure in defensible spaces that have visual access and natural surveillance.[17] Clear sight lines across and between spaces ensure that an individual can scan their environment for threats. This works in tandem with natural surveillance, the arrangement of space that is self-protecting.[18] By having a diversity of activities that front a critical territory, the natural flux of individuals will monitor shared and individual territories.

Privacy

Objective 13: Provide a private space network
Objective 14: Provide every individual with a personal hub or home
Objective 15: Mitigate complete isolation
Objective 16: Ensure a privacy gradient
Objective 17: Enable modification of privacy thresholds

Privacy is not a luxury; it is one of the most fundamental principles to our wellbeing. It is a primary territory, an assurance of personal space, a place for complete control, and an escape from crowding. Most importantly, we can control access to private spaces.[19] This provides a place to withdraw to be alone without the threat of being observed by others.[20] This enables emotional release, personal contemplation, completion of sensitive tasks, and intimacy. Despite being social creatures, without this capability we have little control and are prone to over-stimulation.

15 Ibid. 152.
16 Annette Chu, Alice Thorne, and Hilary Guite, "The Impact on Mental Well-Being of the Urban and Physical Environment: An Assessment of the Evidence," *Journal of Public Mental Health* 3, no. 2 (2004). 24-26.
17 Gifford, "Environmental Psychology." 157-159.
18 Chu, Thorne, and Guite, "Mental Well-Being of the Urban and Physical Environment." 25-26.
19 Gifford, "Environmental Psychology." 211-212.
20 Sybil Carrere and Gary W Evans, "Life in an Isolated and Confined Environment: A Qualitative Study of the Role of the Designed Environment," *Environment and Behavior* 26, no. 6 (1994). 710.

Figure 22: *Roll doors and moveable seating enable this business to expand their semi-private space as needed.*

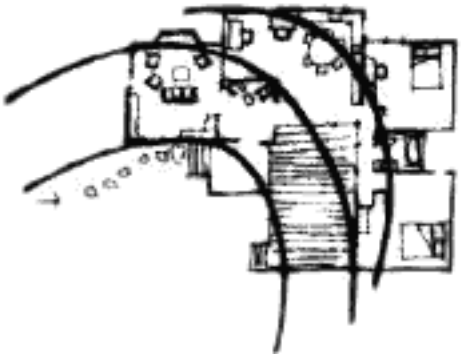


Figure 23: *The original privacy gradient, from Christopher Alexander's a pattern language. The interior sequencing progresses gracefully from a more public foyer to a fully private bedroom. (Christopher Alexander, A Pattern Language)*

These spaces should provide a network of privacy that extends beyond a primary territory. Private spaces can be customized for individuals, groups, or personal goods (a locker or safe). They should exist throughout our daily occupied worlds – for home, work, restrooms, leisure, and secure communications. However, most critical is a home or personal refuge. This seems obvious, but is more integral to our wellbeing than meets the eye. A home represents the physical manifestation of our personal identity. It functions as a critical hub in our daily routine, a stable point from which we begin and end each day. It is storage for our most personal and valuable belongings. By allowing us to retreat, this space strengthens our connectedness to ourselves and others by enabling regulated interactions. A home can vary in size from great estates to a single bedroom, but all should be secure and safe for the individuals or groups that occupy it.

Getting away from others is important, but complete withdrawal into the private realm leads to alienation and isolation.[21] Isolation, the forced or voluntary occupation of one's entire routine in privacy, has immense social consequences. Studies of separated suburban communities revealed that individuals experienced unwanted isolation, loss of community identity, and weakened social support.[22]

Private spaces exist along a spectrum including private, semi-private, semi-public, and public. A degree of transition is needed to pass from each phase to the next. Consider the bedroom, the living room, the foyer, the stoop, the block, the park, and the city. Each represents a different degree along the privacy gradient that strengthens the relative privacy of the adjacent space. We often choose to modify privacy thresholds to situationally adjust the privacy gradient. For example, a college student can leave their dorm door open to invite people to visit. Similarly, a front porch allows communication across private realms between neighbors. Subtle ways to customize thresholds in the built environment enables a greater functional use and user preference.

Choice

Objective 18: Provide multiple space and route options
Objective 19: Enhance legibility
Objective 20: Provide adaptable environments
Objective 21: Enable individual and group modification of space

Choice in the built environment is the ability to pursue goals multiple ways. This may relate to our daily commute (to take the highway or side streets), transit options (bus, car, walking), where we live, how we arrange a room, what activities we can do at park, or who we want to interact with. Choice gives us control over our personal environment, our routine, and our interactions. It enables us to avoid undesirable situations

21 Gifford, "Environmental Psychology." 229-230.
22 Kent and Thompson, "The Three Domains of Urban Planning for Health and Well-Being." 245.

Figure 24: *A street in Chinatown, New York. A diversity of shops, public spaces, and transit options help make New York City a choice-full place. (Mobilus In Mobili, flickr.com)*

(traffic, unwanted contact) and empowers us to select our preferred option.

Without choice and control, humans can descend into helplessness.[23] Helplessness is a condition in which a negative stimulus cannot be controlled or mitigated, leading to reduced persistence and giving up. An extreme choice-less environment is one with fixed routes and single destinations for each required daily activity. A choice-full environment has a diversity of opportunities that manifest as networks of circulation and settings. Settings can vary in location, scale, and adjacency. This enables an individual to select a preferred atmosphere and to control interactions with others. For circulation networks, every intersection of routes is an opportunity node to change directions. Having a network of opportunity nodes allows each user to customize daily routes and chain tasks together.

While choice is a positive attribute, it also increases the complexity of space. Our sense of choice and control is increased by our ability to identify and navigate an environment. A consistent and legible wayfinding system needs to inform and assist navigation regardless of a user's ability, language, or culture. One interpretation of legibility, as identified by urban designer Kevin Lynch, is through the demarcation of distinct landmarks, districts, nodes, edges, and paths.[24]

Since human needs are seldom static, the built environment should be adaptable and customizable. The more adaptable an environment is, the more readily it provides the spatial arrangements we desire. Consider an office building with an interior structural layout that can easily accommodate future residential use – this type of foresight extends the building use when the market for residential far exceeds office. At a smaller scale, people prefer to be able to customize their environment.[25] We can modify environments to adapt to group sizes, to control environmental conditions, to adjust the level of privacy, or to reflect our changing personality or mood. At a practical level, this includes closing window blinds, rearranging furniture for a party, or painting a wall.

Sense of Place

Objective 22: Choreograph desirable public spaces
Objective 23: Embrace the uniqueness of a place
Objective 24: Support a human scale
Objective 25: Provide a diversity of behavior settings
Objective 26: Maximize accessibility and appeal of pedestrian circulation

Sense of place is one's attachment of their physical surroundings into a larger concept of self.[26] Our relationship to place is strengthened by its unique qualities and ability accommodate our ambitions and desires. We place meaning into our built environment, through such things as heritage, loss and destruction,

23 Evans, "The Built Environment and Mental Health." 544.
24 Kevin Lynch, *The Image of the City*, Publication of the Joint Center for Urban Studies (Cambridge, Mass.: MIT press, 1960).
25 Chu, Thorne, and Guite, "Mental Well-Being of the Urban and Physical Environment." 19-21, 28.
26 Gifford, "Environmental Psychology." 272-273.

Figure 25: *A classic place-less environment that could exist anywhere in America. It does not tap into the uniqueness of its context nor provide a human scale environment. (Ryan, flickr.com)*

Figure 26: *Occidental Park, Seattle. Seattle's Pioneer Square historic district has a strong identity of early 20th century brick buildings and towering London planetrees. (SolDuc Photography, flickr.com)*

ownership, and memories. The stability of that meaning is incredibly valuable. As we return to places over time and embed them into our daily expectations, they become an extension of the home and the individual.[27] Conversely, a placeless place is one that lacks the diversity, character, or compatibility needed to connect to us.

Without a positive experience and sense of place, an individual can feel uninspired and isolated. Their ability to care for their surroundings is limited and can contribute to a place's state of disrepair. A person may choose to avoid civic function, distance themselves from their community, and even leave. With a strong sense of place, there is increased sociability, trust, activity, and community identity. Cities and communities need to satisfy two types of spaces: necessary and optional.[28] Necessary spaces are for basic function (places to sleep, eat, and move) while optional spaces round out the breadth of people's desires. It is the provision of optional activities that elevates a high-quality urban experience.

At a community scale, sense of place is strongly associated with public space. A packed pedestrian plaza is seldom the result of density alone. A high quality public space has a draw, be it shops or nature or the ability to watch other people.[29] It needs to support a flow of people and accommodate a range of opportunities that activate it throughout a day. [30] Its design should appeal to the community that uses it and it should have an overriding concept, cohesion, and attention to detail. In addition, a successful place taps into the uniqueness of its context and embraces it. It could not be "anywhere", rather it is inspired and molded by its history and surroundings. This urban narrative unfolds in the built environment through local materials, vernacular architecture, native plantings, historic markers and artifacts, public art, local businesses, and unique views. And structurally, a built environment needs to respond to the human body. It needs to reflect our physical abilities to perceive at eye level and use our whole scope of human senses.[31] Spaces that are over-scaled are often devoid of human experience and connection.

Public space should be an integrated network of behavior settings and pathways that can accommodate our diverse individual and societal goals.[32] Behavior settings refer to the diverse ways in which people use space – sitting, socializing, exercising, observing, eating, or gardening. They can be considered for both individuals and a variety of group sizes. In addition, the built environment should encourage people to move

27 Iain Butterworth, "The Relationship between the Built Environment and Wellbeing: A Literature Review," *Prepared for the Victorian Health Promotion Foundation*, 2000. 6-8.

28 Jan Gehl, *Cities for People* (Island press, 2013). 13-17.

29 William H Whyte, *The Social Life of Small Urban Spaces* (Washington, D.C.: Conservation Foundation, 1980).

30 Gehl, *Cities for People*. 19-21.

31 Ibid. 33-39.

32 Ibid. 21-23.

Figure 27: *A social coffee shop. A diversity of seating options and arrangements allow people to socialize in a variety of group sizes. (Jim Damaske, tampabay.com)*

Figure 28: *A frame from William Whyte's "The social life of small public spaces." Here, a variety of human scale edges and walls provide a plethora of informal social opportunities. (William Whyte, citylab.com)*

and engage in space. Public spaces need to be accessible regardless of an individual's physical ability, gender, language, or culture.[33] Walkways should be rewarding via a rhythm of stimulating eye-level focal points, such as views or activities.[34]

Social Support

Objective 27: Provide formal and informal social opportunities
Objective 28: Enable individuals to mediate social interaction
Objective 29: Promote a diverse social network
Objective 30: Provide opportunity for chance encounters

Humans are social creatures. We identify not only as individuals but as members of groups and communities. Engagement in community decisions and process allows us to make productive contributions to society and empowers our sense of belonging. Being part of a larger community provides us a reliable social network for engagement, support, and spontaneity. This social network supports a variety of our needs including compassion, humor, stimulation, camaraderie, and relaxation. The ability to exchange stories from the day or complain about work increases problem solving and decreases the internalization of stress. Interaction with others provides a level of unpredictability and spontaneity that we enjoy as chance encounters and tangential conversations. Without access to social support, individuals can develop distrust and social isolation.[35]

The built environment should enable individuals to mediate social interaction. People need to find social interaction when they want to and be able to avoid it when they don't.[36] Two separate studies of prisons and psychiatric institutions revealed that scenarios of forced socialization counterproductively increased social withdrawal.[37] At its core, the negative factor is a lack of control. Studies of college dormitories indicated that long corridors induced social interaction that was both undesirable and uncontrollable.[38] Students living in suites, with a stronger hierarchy of control points, were able to avoid or seek out social interaction with relative ease.

The range of ways to socialize varies greatly by individual, time of day, and mood. A greater diversity of social spaces provides a higher likelihood that an individual's desired social environment can be realized.[39] These spaces range from intimate spaces and private small-group spaces (for controlled interaction) to public plazas and forums (for spectacle and spontaneity).

33 Butterworth, "The Built Environment and Wellbeing." 10-11.
34 Gehl, *Cities for People*. 38-41.
35 Chu, Thorne, and Guite, "Mental Well-Being of the Urban and Physical Environment." 26.
36 Evans, "The Built Environment and Mental Health." 545.
37 Ibid. 539-540.
38 Ibid. 539.
39 Ibid. 543.

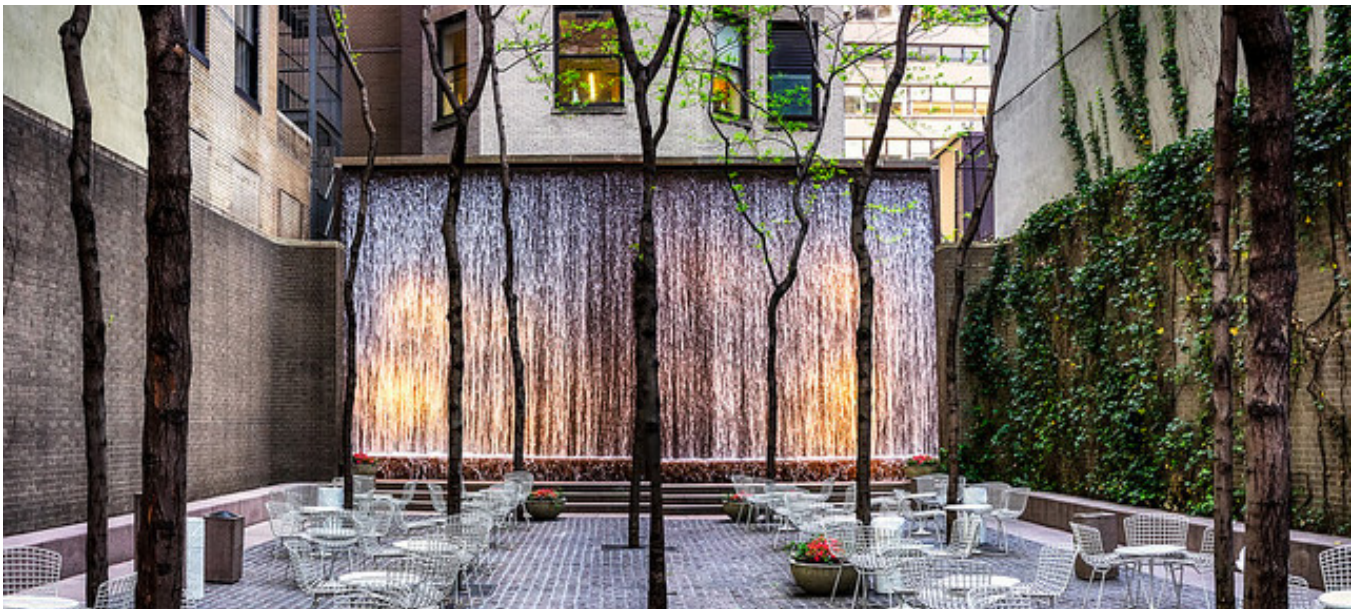


Figure 29: *Paley Park in New York City is a classic escape facility, offering access to natural elements with a degree of psychological separation from the urban Manhattan surroundings. (Roman Kruglov, flickr.com)*

They also exist as a blend of formal and informal spaces. Formal social places are designed specifically for interpersonal interaction. Spaces such as plazas or parks offer reliable social opportunities that individuals can seek out. In contrast, informal social spaces have an alternate primary function. Studies of elderly populations in Montreal revealed that streets that encouraged leisurely strolling increased social participation on a daily basis.[40] In general, informal social opportunities are focal points or corridors that have unique views, neutral territoriality, conducive seating arrangements, and activity generators.[41] The most informal spaces are third places, locales that provide unorganized and spontaneous social interaction.[42] They are small nodes throughout a community that increase connectedness, such as community gardens, bus stops, or hair salons. Third places are not deliberately programmed for being social spaces yet can emerge as a very important hubs.

Restoration

Objective 31: Provide a diversity of escape facilities
Objective 32: Integrate a restorative spatial network into daily routine
Objective 33: Provide positive distractions
Objective 34: Provide moments of challenge

Why do we at the end of a long day go to the park, see a movie, or grab a drink with friends? These actions are forms of restoration. Restoration enables cognitive freedom and temporary detachment from stressful situations.[43] It engages passive attention as opposed to active attention, and mitigates the effects of over-stimulation. Overall this increases concentration, lowers rates of depression, decreases mental fatigue, and improves relationships.[44]

Restorative environments manifest as escape facilities such as natural areas, social hangouts, or movie theaters. Escape facilities are locations physically and psychologically separated from primary sources of stress, such as work or domestic responsibilities.[45] They are often coupled with leisure, recreation, and nature, and have been shown to reduce the impacts of crowding and density.[46] In addition to mitigating mental fatigue, they often provide opportunities for physical activity, entertainment, leisure, spirituality, and social support. For escape facilities to properly function, they need to be accessible and desirable to a broad population.

Beyond dedicated escape facilities, restoration can be embedded in our daily routine – consider the value of a lunch break, a peaceful morning commute, or the ability to look out a window from a work desk. This is

40 Kent and Thompson, "The Three Domains of Urban Planning for Health and Well-Being." 245.
41 Evans, "The Built Environment and Mental Health." 543-545.
42 Kent and Thompson, "The Three Domains of Urban Planning for Health and Well-Being." 245-246.
43 Gifford, "Environmental Psychology." 387-390.
44 Evans, "The Built Environment and Mental Health." 545-546.
45 Chu, Thorne, and Guite, "Mental Well-Being of the Urban and Physical Environment." 23-24.
46 Ibid.

Figure 30: *Light tunnel at Chicago O'Hare Airport. This tunnel of changing light and ambient noise provides a fascinating positive distraction to stressed travelers. (Scott Wilton, flickr.com)*

of critical importance to individuals with health issues or high-stress occupations. At best, a built environment can provide restorative elements that permeate the entire community.[47] Traditionally this approach implies integrating nature into the built environment.[48] Contemporary approaches to restoration are less prescriptive and focus on creating a continuous network of restorative spaces, such as human scaled promenades or integration of public art. Urban space theorist Gordon Cullen abstracted this further by stressing the importance of the human spatial experience and the ability to achieve a heightened awareness of your surroundings.[49] This emphasizes an urban form that utilizes rhythm, contrast, and spatial transition to help achieve strong sensations of here, there, and in-between.

Restorative environments have four characteristics: separation from sources of fatigue, indeterminate boundaries that offer breadth of possibility, compatibility with an individual's desires and expectations, and fascination through positive distraction or challenge.[50] Positive distraction is supported by the attention restoration theory which posits that we become fatigued as the result of chronic active attention. We utilize active attention while completing necessary tasks and meeting work deadlines. The goal of attention restoration is to activate our involuntary attention with activities and settings that are inherently captivating. These positive distractions allow us to digest a scene through minimal effort, blocking out taxing active attention and refreshing our cognitive ability. Positive distractions take many forms including unique architectural features, art, other people, and entertainment.

In tandem with positive distraction is challenge.[51] Physical and mental challenges consume our attention, counter boredom, and can stimulate growth and sense of achievement. Any challenge must be considered in harmony with available resources: too few resources, and challenge becomes an unwarranted obstacle. Challenges achieved in groups render stronger sense of appreciation and camaraderie.[52] Consider the effects of specific triumphs solving a puzzle, reading a new book, learning to build a shelf, or climbing a rock wall. Less deliberate triumphs can be embedded into daily experience, such as stair climbs that reveal views.

Self-Expression

Objective 35: Provide opportunity for self-expression
Objective 36: Engage all five senses
Objective 37: Promote system-wide harmony
Objective 38: Enhance ecosystem connectedness

47 Kevin Thwaites, E Helleur, and IM Simkins, "Restorative Urban Open Space: Exploring the Spatial Configuration of Human Emotional Fulfilment in Urban Open Space," *Landscape Research* 30, no. 4 (2005). 530-533.

48 Evans, "The Built Environment and Mental Health." 545-546.

49 Thwaites, Helleur, and Simkins, "Restorative Urban Open Space." 535-536.

50 Ibid. 528-529.

51 Rachel Dodge et al., "The Challenge of Defining Wellbeing," *International Journal of Wellbeing* 2, no. 3 (2012). 228-229.

52 Peter Suedfeld and G Daniel Steel, "The Environmental Psychology of Capsule Habitats," *Annual Review of Psychology* 51, no. 1 (2000). 229-230.

Figure 32: *The Bullitt Center, Seattle. This "green" building exposes people to its functional systems through visible solar panels, plantings that filter stormwater, passive heating and cooling, and on-site waste treatment. (Bullitt Foundation, bullittcenter.org)*

Early environmental psychologists identified the need for humans to express themselves. This takes numerous different labels: purpose in life, realization of potential, the ability to achieve both happiness and satisfaction.[53] Renowned psychologist Abraham Maslow identified both self-actualization and self-transcendence as part of a human needs hierarchy, to be considered alongside physiological, safety, belongingness, and esteem needs.[54] Others have interpreted these same ideas as spirituality, creativity, and expressiveness. These divergent yet intertwined concepts point to two overriding themes: access to individual self-expression and unity with the surrounding world.

Self-expression manifests in different ways for each person. Every individual has creative outlets, be it art, reading, or sports, to name a few. A successful built environment will not only consider these space types, but should be adaptive enough to accommodate unforeseen pursuits. It is also strongly linked to the ability to lead a spiritual life. While this is often associated with a house of worship or nature, the specific spatial needs for spiritual life vary greatly by individual.

Unity with the surrounding world relates to stimulating all five senses, a harmonious built environment, and ecosystem connectedness. Built environments tend to place supreme value on visual characteristics. Yet anthropologically it has been shown that engaging all five senses is linked to spirituality and culture, and provides more opportunity for individuals to connect to their environment.[55] This functions to increase our perception and engage all of our capabilities to their fullest. This relates to the provision of a harmonious environment where no single entity or faction dominates.[56] This includes balancing competing forces of light and shadow, built and natural, and domestic and occupational functions, to name a few. This harmony helps showcase the range of sensations that a built environment offers, providing more opportunity for an individual to realize their preferred niches.

Lastly, humans better comprehend themselves when they understand their place within a larger system. This originates from the concept of biophilia which argues that "human beings have an inherent need to be close to and integrated with nature."[57] Biophilia extends to our ability to immerse ourselves in the functional systems of both natural and built environments.[58] This enables us, through truly understanding our place in a larger context, sensations of contentment and humility.[59] In practice, this can translate to heightened exposure and understanding of energy, water, and urban ecological systems.

53 Dodge et al., "The Challenge of Defining Wellbeing." 222-225.
54 Robert Birch and Brian R Sinclair, "Spirituality in Place: Building Connections Between Architecture, Design, and Spiritual Experience," 2013. 81-82.
55 Ibid. 85-86.
56 Ibid. 83.
57 Ibid. 86.
58 Gifford, "Environmental Psychology." 389-390.
59 Birch and Sinclair, "Spirituality in Place." 86.

Applying Wellbeing

Historically, psychologists have struggled to apply a single definition to wellbeing. The nine criteria outlined in this section reflect an analysis and synthesis of studies and definitions that have grounding in the built environment. Through the objectives outlined, each can be applied to spatial, material, aesthetic, and character features of any built environment, including one on Mars. And they can all be considered at multiple scales – for example, the provision of territoriality or sense of place has strong groundings in a comprehensive layout as well as site details at a fine grained level.

It is important that all nine be considered with relation to each other, as they are inherently linked. Access to privacy affects the ability to escape which affects ones attitude towards social support which can change their needed personal space…and so on and so forth. There is considerable spatial overlap as well – for example, a secure bedroom can satisfy needs of privacy, territoriality, crowding, and self-expression. While most people can have their wellbeing compromised to minimal effect in the short-term, it becomes far more critical for the long-term dynamic of individuals and groups. These criteria are easily overlooked because they are subtle and at times abstract concepts, yet they can be severely compromised by an inadequate built environment, as is illustrated in the next section.

Figure 32: *Halley VI Research Base in Antarctica. The extreme physical environment and isolation from other people make it analogous to a habitat on Mars. (Thomas Welsh, blogs.discovermagazine.com)*

IMPACTS

What are the impacts of the conditions of a Mars settlement on human wellbeing? How will living on Mars impact the crew as individuals and as a cohesive society? What are the spatial implications for each impact?

Introduction

The early Martian pioneers will face extreme situations on a daily basis. Peter Suedfeld, an environmental psychologist whose work has been dedicated to studying habitats that are analogous to a Martian settlement, offers a best guess for some of the earliest pioneers.

Despite training and maintenance tasks, there will most likely be stretches of empty time punctuated by bursts of hard, intense work. The crew will be cooped up in a small and probably not very comfortable capsule for two very long voyages with few opportunities for diversion. Between those voyages, they will spend more months living in such a capsule on the planet and exploring a harsh, unfamiliar, and potentially lethal natural environment. Emergence from the capsule, either in space or on Mars, will require the cumbersome donning and later doffing of complicated and clumsy, but crucial, mobile life-support ''clothing.'' Exploring the Martian environment will demand physical strength, courage, and energy; the crew will experience fatigue, frustration, and uncertainty. During the entire mission, they will be much further from home than anyone in human history had ever been, and will not have the comfort of seeing the blue globe of Earth that earlier space voyagers found so reassuring. Danger will be constant. The crew will always be aware that there is no chance of outside help or rescue in case of emergency and that (as a recruiting advertisement for Shackleton's Antarctic crew supposedly stated), ''safe return [is] uncertain.'' As constant background, this awareness is stressful enough; when actual emergencies occur, it will loom even more intensely.[1]

This section discusses the ways in which conditions of Martian living will negatively impact the wellbeing of the settlers. The 10 simplified impact categories discussed in this section represent a range of issues that are prone to occur in Martian settlements – from the monotony of a capsule habitat to the lack of escape from stressors. Each impact left unmitigated presents a major obstacle to long-term habitability of Mars, and can result in major mental health issues and a breakdown of team cohesion. The takeaways from this section will provide the major design challenges that will inform the final design guidelines

While this section is dense with negative effects of living on Mars, it is worth noting some immensely positive impacts as well. Residents on Mars will revel in mission accomplishments that render a strong sense of appreciation for colleagues.[2] They will experience a tremendous sense of adventure and accomplishment, with peaks of jubilation that may be unparalleled on Earth.

With no current habitat on Mars, this study relies on analogous habitats to provide insight into the effects of Mars habitats. These habitats include polar research stations, Mars test capsules, the international space station, and historic exploration parallels. While none perfectly represents the conditions on Mars, in the aggregate they parallel the breadth of challenges that can be anticipated. The first part of this section introduces the range of habitats considered in the analysis.

1 Peter Suedfeld, "Historical Space Psychology: Early Terrestrial Explorations as Mars Analogues," *Planetary and Space Science* 58, no. 4 (March 2010). 640-641.

2 Peter Suedfeld and G Daniel Steel, "The Environmental Psychology of Capsule Habitats," *Annual Review of Psychology* 51, no. 1 (2000). 229-230.

Impacts to Wellbeing

Isolation & Confinement
- *Isolation from civilization and support systems on Earth*
- *Confinement in a sealed habitat*

Interpersonal Interaction
- *Inadequate social support and lack of group cohesion*
- *Social monotony and lack of spontaneous interactions*
- *Social conflict over uses of limited space*

Sleep & Circadian Rhythms
- *Sleep disruption as a result of noise and adjacencies*
- *Inadequate environmental time cues and desynchronized circadian rhythms*

Privacy
- *Lack of personal privacy and inadequate personal refuge*
- *Lack of compartmentalization to accommodate levels of privacy*
- *Over-compartmentalization leading to complete withdrawal*

Monotony & Sameness
- *Monotonous routine and lack of diversity of activities*
- *Monotonous built environment in terms of form, color, and materiality*
- *Static built environment and lack of spatial adaptability*

Escape
- *Lack of escape facilities*
- *Contamination of escape facilities by workspaces*
- *Inadequate exercise facilities*
- *Contamination of leisure activities by inappropriate adjacencies*
- *Inadequate space to lead a spiritual life*

Mission & Communications
- *Periods of high-stress workloads punctuated by stretches of empty time*
- *Autonomy from and strained relationships with Earth brought on by 20-minute communication delay*
- *Lack of privacy for personal communications to Earth*

Comfort
- *Lack of ergonomic furniture options*
- *Insufficient storage and presence of clutter*

Identity & Control
- *Inability to customize arrangement and environmental conditions of spaces*
- *Inability to personalize individual or group spaces*
- *Inadequate space to practice cultural customs*

Mars Deadly, Earth Distant
- *Earth-out-of-view phenomenon and lack of connection to Earth*
- *Constant threat of the deadly Martian environment*

Figure 33: *The Columbia Laboratory Module of the ISS. Note the complete usage of surface area to take advantage of the zero gravity. (NASA, nasa.gov)*

Analogous Habitats

International Space Station (ISS)

The ISS is a microgravity research laboratory in Earth's orbit. Since its first occupation in 2000, it has continually grown to become the largest orbital body, roughly the size of a football field. It is designed for six people to live and work for durations of up to one year, and has housed over 220 people from 18 countries. Its core consists of 12 pressurized modules funded by 15 different nations, with a total habitable volume of 13,600 cubic feet. These modules provide sleeping quarters, research laboratories, storage, and docking ports. The modules interconnect and attach to a primary truss that forms the backbone of the structure. Over an acre of solar arrays with a wingspan of 240 feet attach to the truss.

NASA has billed the ISS as an important testing ground for Mars. The base has been utilized to debut advanced technologies, including shuttle transport, communications, and habitat equipment. Recently NASA has partnered with commercial spaceflight pioneer Space X to provide a real-world application for their new rocket technology. This represents an important step for a new type of public-private partnership that may come to define the next generation of spaceflight. NASA has also used the ISS to test the effects of prolonged space flight on humans, monitoring the effects of zero gravity on astronaut's muscles, vision, height, immune system, and more. They collect the journals of astronauts to study the psychological effects of isolation and confinement.

In many ways, the ISS provides the best information for understanding a habitat on Mars. It is the furthest human habitat from Earth, is fully isolated and confined, serves an international crew, and experiences communication delays (albeit far less than Mars would). The lack of gravity provides insight to Mars' low-gravity while EVAs (extra-vehicular activities including spacewalks) parallel aspects of terrestrial exploration on Mars. Additionally, there is no safety net. Once there, you largely are reliant on your habitat, yourself, and your crew for survival and wellbeing, knowing that any form of rescue is far off.

Polar Research Stations

Similar to the ISS and Mars, polar research stations are physically isolated from civilization and exposed to extreme environmental conditions. Most research stations operate year round with a smaller population that stays over winter. Winter weather conditions can prevent emergency rescues while freezing temperatures confine residents to the interior habitat. During this period, these habitats are most like a Mars colony – isolated, confined, and self-reliant. For decades, environmental psychologists have studied the effects of overwintering and ICEs at bases including McMurdo, Halley VI, and Palmer in Antarctica and Haughton Mars on Devon Island in North Canada. Devon Island is regarded as the most similar environment to Mars due to its remoteness, freezing temperatures, extreme sun cycles, and a dry and barren terrain. For this study, data from Palmer Station (built 1968) and Halley VI

Figure 34: *Palmer Station, Antarctica. (Bob DeValentino, palmerstation.com)*

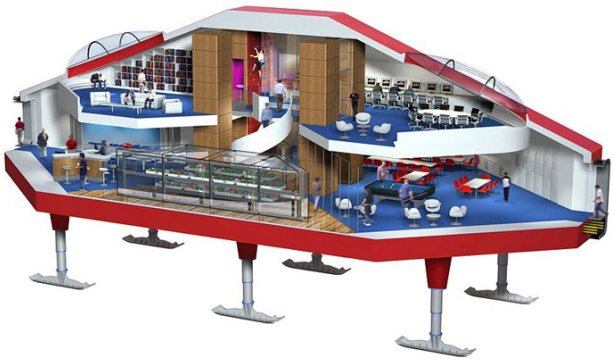


Figure 35: *Halley VI Research Station is a series of interconnected modules. The central module, shown here, is larger with separated levels for diverse social settings. (Hugh Broughton Architects, hbarchitects.co.uk)*

(built 2012) provided a contrast in eras of design and habitation.

Palmer Station is one of the oldest and northern-most research stations in Antarctica.[3] Though it is designed to exceed 40 people in the summer months, it only houses 10 over winter. It is built on a rocky peninsula that protrudes from a glacier covered island, consisting of two primary buildings a series of scattered structures for ancillary activities that include a boat shop, aquarium, and sauna. The two primary buildings, known as the biology building and GWR (garage, warehouse, and recreation), are centrally located and connected with elevated walkways. The Biology Building is a three story structure that separates laboratories and machine shops (1st floor), dining and miscellaneous offices (2nd floor), and bedrooms and bathrooms (3rd floor). The GWR is a two story structure that includes heavy equipment and the station power plant (1st floor) and recreation areas (2nd floor).

In contrast to Palmer Station, Halley VI represents a modern chapter of polar research station design. It is one of the southern-most bases, located on the floating Brunt Ice Shelf which moves over 400m/year.[4] In 2004 a design competition was held to design a replacement for Halley V, after predications of future ice sheet calving demanded a more flexible and relocatable habitat.

The resulting design was grounded in modularity and habitability.[5] Completed in 2012, the structure is a linear alignment of elevated modules on skis. The modules are organized by function, separating science, power plant, operations, living, and sleeping functions. The standard module is a single level and has an implied grid but no internal structure, enabling easy reconfiguration and partition based on use. The sleeping areas are subdivided into ergonomically designed private rooms, each of which has a window. A central module for living is the largest, providing two levels that include spaces for dining, socializing, reading, and recreation. Moveable acoustic partitions allow the space to radically reconfigure from summer (60 people) to winter (16 people).

Mars Simulation Capsules

NASA and similar organizations have been testing the habitability of capsule environments since before the 1990s. Early capsules were located in aerospace hangars and featured crews of four living in simulated isolation for up to 90 days. Intensely studied from 1995 to 1997, the Lunar-Mars Life Support Test Project (LMLSTP) was a retrofitted 20 foot diameter vacuum chamber divided into 3 levels.[6] The lower level provided “public space”

3 Sybil Carrere and Gary W Evans, “Life in an Isolated and Confined Environment: A Qualitative Study of the Role of the Designed Environment,” *Environment and Behavior* 26, no. 6 (1994). 714-717.

4 A Scott Howe and Brent Sherwood, *Out of This World: The New Field of Space Architecture* (American Institute of Aeronautics and Astronautics, 2000).

5 Ibid.

6 Helen Woods Lane, Richard L Sauer, and Daniel L Feeback, *Isolation: NASA Experiments in Closed-Environment Living*, vol. 104 (Amer Astronautical Society, 2002). 59-77.

Figure 36: *The 3-tiered Lunar Mars Life Support Test Project. (NASA, dvidshub.net)*

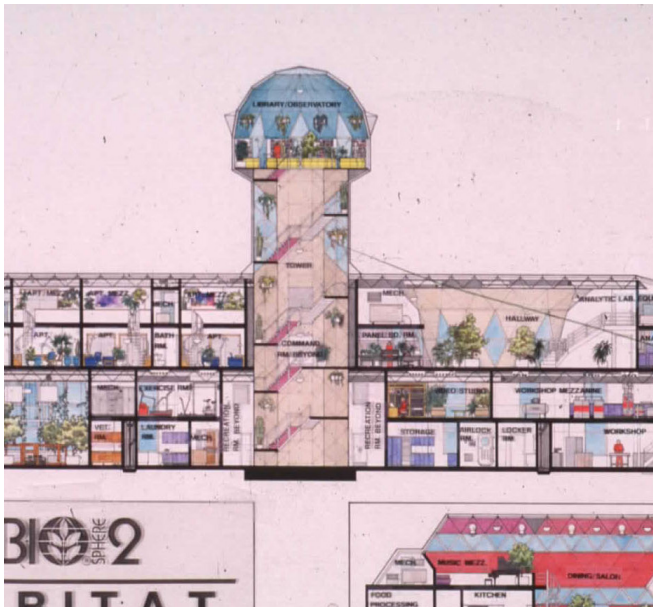


Figure 37: *A schematic section of the Biosphere 2 habitation and laboratory unit. (patrickmccray.com)*

for group activities, the second level contained critical equipment, storage, and exercise equipment, and the third floor provided a separated space for sleeping and crew privacy. An "airlock" to the outdoors was located off of the first floor.

These habitats provide a highly controlled laboratory to test closed loop systems and human habitability. The earlier trials have gone on to inspire numerous international tests over the past 10 years. Among these, Mars 500 was a simulated habitat in Moscow that featured an international, six-person crew living in confinement for 520 days.[7] The habitat was four hermetically sealed and interconnected modules designed to simulate the experience of traveling to and from Mars. Other tests have been established by the non-profit Mars Society including the Flashline Mars Arctic Research Station (FMARS) on Devon Island and the Mars Desert Research Station (MDRS) in Utah. There are plans for additional modules to be built in Europe and Australia. Lastly, the Hawaii Space Exploration Analog and Simulation (HI-SEAS) is a habitat located at 8000 feet above sea level, organized by Cornell University and the University of Hawaii at Manoa.

Other Sources

While Antarctic research bases, the ISS, and simulation capsules are the most accurate sources of evidence, a variety of non-traditional sources provide surprising insights. Historic parallels, articulated by Peter Suedfeld, focus less on conditions of a habitat but more on the psychological states of early colonists and explorers.[8] These expeditions, including Lewis and Clark and polar explorers such as Fridtjof Nansen parallel the extreme isolation, social support, and self-reliance of a Mars mission. Submarines provide a more militaristic habitat that reveal extreme aspects of confinement and compact living with a large population. Lastly Biosphere 2, a hermetically sealed ecosystem in the Arizona desert, was inhabited for two multi-year missions and presents a case study for living in a closed-loop ecosystem.

7 Carole Tafforin, "The Mars-500 Crew in Daily Life Activities: An Ethological Study," *Acta Astronautica* 91 (2013). 1-2.

8 Suedfeld, "Historic Space Psychology." 641-644.

Figure 38: *The Cupola module in the ISS. Views of the outside environment are important for combating the oppressive confinement of ICEs. (NASA, spaceflight.nasa.gov)*

Impacts on Wellbeing

Isolation & Confinement

Any settlement on Mars will be an isolated and confined environment (ICE). While this indirectly impacts most facets of wellbeing, this first impact is dedicated to the direct effects of both isolation and confinement on individuals. The sensations of both relate to prison, submarine, or ISS psychology, although the extreme distance of Mars will amplify these feelings.

Isolation refers to physical and psychological distance from any other humans. Inhabitants will understand that while on Mars there will be no escape, help, or rescue in case of emergency.[9] There will be an intense remoteness from any preconceived notion of home or family. As a result of a 20-minute communication delay, synchronous ties to critical social networks on Earth will be largely disabled and may induce the sensation of being "alone" on Mars. There will be no opportunity to meet new people or to explore at whim as all surface travel will be highly regulated. Additionally, studies have shown that those who live or work in isolation require more personal space to feel comfortable, a luxury seldom afforded by ICE habitats.[10] These factors may induce neurotic reactions, sleep disorders, stress, intense loneliness, anxiety, and depression.[11]

Confinement refers to the inescapable physical encapsulation by the habitat. Confinement tends to exacerbate crowding, negative adjacencies, and an inadequate supply of private spaces.[12] Reviewers of the ISS critiqued the adjacency of an exercise machine to the dining area, suggesting that this combination of incompatible activities would induce tensions between people. Users in confined environments often rely on views to the outside to psychologically extend their limited spaces and to provide a welcome departure from the walls that hold them.[13] As well, negative interactions or relationships with other people in the habitat will exacerbate the sense of confinement. Common effects of confinement include sleep disorders, depression, psychosomatic problems, and compulsive behavior. Studies of research crews that overwintered at Antarctic stations have observed major cases of withdrawal, apathy, neglect of hygiene, big eye (chronic polar insomnia), and long eye (a fugue state in which thoughts drift between reality and absence). Additionally, Russian cosmonauts recognize hypodynamia, a state of insufficient motor activity leading to atrophy brought on by long-term confinement.

Any habitat on Mars will need to mitigate the effects of isolation and confinement through large scale spatial

9 Ibid.

10 Robert Gifford, "Environmental Psychology: Principles and Practice," 2002. 130-131.

11 Suedfeld and Steel, "The Environmental Psychology of Capsule Habitats." 230-231.

12 Robert Gifford and Cecile Lacombe, "The Habitability of Spacecraft: Assessments of a Virtual Reality Simulation of the ISS Across Cultural, Personality, and Individual Differences" (Saint-Hubert, Quebec: Canadian Space Agency, 2006). 20-29.

13 Suedfeld and Steel, "The Environmental Psychology of Capsule Habitats." 234.

organization of a habitat complex. Namely, it should maximize the perception of space, minimize negative adjacencies, reduce sensations of being trapped, foster positive social interactions, and provide access to high quality views. To whatever extent possible, it should also promote a strong communal self-reliance and maximize personal communications and relationships with Earth.

Interpersonal Interactions

Interpersonal interactions in a Martian habitat will be more sensitive and extreme than on Earth. ICE habitats have a tendency to amplify emotions and interactions, inducing major highs and major lows. Upon arriving and integrating, self-evaluation and self-esteem will be tested and compromised, and each individual will settle into a new social role that fits them best.[14] In this unique environment, there is an increased sense of intimacy and depth of self-disclosure. Rumors may circulate at much higher rates with immensely detrimental effects. The success of the community will hinge on its ability to remain cohesive and maintain positive relationships, with worst case scenarios leading to social isolation, hostility, violence, suicide, competing factions, disorder, and anarchy.

Similar to Earth, scales of social interaction will occur. People will congregate in pairs, small groups, larger clusters, and occasionally as a habitat-wide community. Micro-cultures will inevitably develop with individual and small group ideologies, allegiances, and customs, potentially leading to closed loops of communication based on profession, gender, race, or religion. In general, previous ICE habitats have failed to accommodate the diversity of behavior settings and variety of group sizes in space. The ISS has been critiqued for not providing an adequate setting for group dining, an important daily social opportunity that can unite the entire crew.[15] In contrast, the Halley VI research station was designed with space for a large dining table that could accommodate the entire population, which was well received by the inhabitants.[16]

Spending every day in the same social routine will become incredibly monotonous.[17] This monotony will be interrupted by the biannual arrival of others which will provide a spark of enthusiasm but will challenge pre-established social norms. Monotony combined with a static built environment has the potential to lead to sensory deprivation, chronic boredom, nuisance

Figure 39: *The dining space at Palmer Station provides valuable team bonding and social support for the entire crew. (Linnah Neidel, antarcticsun.usap.gov)*

behaviors, and disputes. ICEs lack sufficient diversity of social opportunities to prevent static routines, and lack the flexibility to create new settings for interaction. This increases the value of any opportunity for spontaneous interaction. Studies at Palmer Station successfully noted how small nodes outside of bedrooms functioned as a hotspot for chance encounters for pairs or small groups.[18] Similarly, a study of LMLSTP revealed how smaller areas outside of rooms provided highly casual interactions for two or three members of the group, but never more.[19]

Interpersonal conflict exists along a vast spectrum ranging from irritation to homicide. Many conflicts will inevitably arise based on diverse factors of personality, culture, and mission stress, but each of these can be mitigated partially by the built environment. In the Mars settlement, trivial habits will become maddening if unavoidable. Without having opportunities to escape the situation long term, the nuisance actions of others may lead to rash behaviors. A lack of choices and escape facilities will exacerbate these tensions. Similarly, group uses of social spaces tend to take priority over solitary or small group activities. The inability to reconfigure or subdivide space renders large social spaces and lounges mono-functional at times. Unlike Antarctic research stations, people cannot simply use the outdoors for solitary or small group activities. Instead, public spaces

14 Ibid. 235-236.
15 Gifford and Lacombe, "The Habitability of Spacecraft." 74-75.
16 Howe and Sherwood, *Out of This World*.
17 Suedfeld and Steel, "The Environmental Psychology of Capsule Habitats." 234-235.
18 Carrere and Evans, "Life in an Isolated and Confined Environment." 722.
19 Lane, Sauer, and Feeback, *NASA Experiments in Closed-Environment Living*. 172.

Figure 40: *The proposed Mars One habitation units feature a public lounge directly adjacent to a bed, potentially competing usages of space. (Mars One/Bryan Versteeg, dailymail.co.uk)*

need to maximize diverse social opportunities and minimize conflict between users.

A Martian settlement will need to provide a plethora of social spaces that accommodate a variety of behavior settings and group sizes. The layout of space should provide adequate visual and acoustic buffers between non-compatible spaces. Circulation patterns should maximize opportunity for spontaneous interactions at critical nodes. And given the realistic constraints of an ICE, it is critical that large social spaces can be reconfigured into subspaces to accommodate the changing needs of the community. Overall, the strength of the social network will be in the physical density, multi-functionality, and adaptability of social spaces.

Sleep & Circadian Rhythms

In addition to all the psychological factors of isolation and confinement that can impact sleep patterns, both the built environment and the natural environment will make Mars a challenging place to sleep. The two primary causes are sleep disruption due to noise and desynchronized circadian rhythms. Easily overlooked, lack of sleep can lead to lead to moodiness, depression, hallucinations, cognitive dysfunction, and decreased awareness/increase of accidents.

The closed-loop systems of ICEs operate continuously and often produce mechanical noises that permeate the sleeping quarters at night. In addition, the different schedules of individuals coming and going will compromise sleep without adequate privacy and compartmentalization. Adjacent activities that create noise in the evening will create tension with sleeping areas. Prior studies have indicated how detrimental loud equipment and noise/light distractions have been on sleep patterns, and recommendations have stressed the importance of acoustic insulation between sleeping areas.[20] It is critical to provide individuals personal control over sleeping quarter light, noise, and temperature levels in order to customize their ideal sleep conditions.

Circadian rhythms will be severely compromised on Mars. Low light levels, longer days, extended seasons, and inadequate interior lighting all negatively contribute. Simply put, the Martian environment does not provide the range and acuteness of environmental cues that humans use to wake up, fall asleep, and maintain an internal clock. Lack of time cues can lead to an internal desynchronization where the body's systems become poorly timed with each other.[21] Homogeneous interior lighting lacks the appropriate wake-up and wind-down sequences that natural light provides. The design of the settlement can integrate cues into the built environment that showcase the natural light cycles on Mars. Where

20 Ibid. 132.

21 Suedfeld and Steel, "The Environmental Psychology of Capsule Habitats." 238.

that is not enough, artificial day/night lighting can support circadian synchronization.[22]

The habitat design will need to promote a positive sleeping environment by separating bedrooms from loud machinery, minimizing noxious adjacencies, and providing individual sleeping quarters with adequate visual and acoustic barriers. The entire habitat will need to replicate circadian rhythms on Earth (set to Mars time) by building in environmental time cues throughout.

Privacy

As identified in the wellbeing criteria, privacy is of utmost importance to long-term habitability. Conditions in ICEs can range from separated and insulated bedrooms to shared bunks with no barriers. On the early 20th century ship *Belgica*, one crew member journaled, "If we could only get away from each other for a few hours at a time, we might learn to see a new side and take fresh interest in our comrades; but this is not possible."[23] Contemporary ICEs such as the ISS suffer from many of the same ailments where true privacy seldom exists but for a few fleeting moments.

A Martian settlement will need to first address personal privacy. On Earth, we define our private realm through our homes and apartments, and further still with bedrooms and beds. More than just a secure location to leave personal belongings, a private space generally functions as a personal refuge to be away from others. When we lose that refuge, we lose our sense of control, ability to escape, and aspects of our personal identity. "Hot bunking", the practice of rotating beds based on shifts in submarines, has been discontinued as it compromised privacy and personal space too greatly.[24] Interviews with astronauts in Skylab revealed that better defined sleeping quarters would have helped with irritability and overall camaraderie. One astronaut bemoaned being "forced to listen to one crew member's classical music selections."[25] The lack of adequate private refuge and escape facilities forces tiny sleeping quarters to become critical territories for leisure, a function they aren't generally designed for. For example, private areas on the ISS lack basic features of a refuge, such as windows and control over the interior environment.[26]

Analogous habitats illustrate that the most effective means of providing privacy is through compartmentalization. In Halley VI, this takes the form of semi-private modules subdivided into private bedrooms.[27] The effects of subdivided spaces extend beyond just residential areas. Fridtjof Nansen, an Arctic sailor during the 19th and 20th centuries, built egalitarian crew quarters on his vessel *Fram* that were shared and prevented individual refuge.[28] However, the highly specialized crew were able to isolate themselves within their respective workspaces across the ship as needed. Though degrees of compartmentalization provide adequate space separation, they can enable individuals to slide into complete isolation from others – a very dangerous prospect for a Martian settlement.[29] Antarctic winter crews have observed cases of "cocooning", a condition by which withdrawal can becomes pathological for an individual.[30] This can be exacerbated by a lack of facilities that require group interaction.

A habitat on Mars will need to first address personal privacy of the sleeping quarters. At a minimum, they need to provide an individual with the ability to periodically withdraw from the group and to be shielded from noxious behaviors. Private space needs to offer a level of control and predictability, and cannot be subject to intrusion. Holistically, the design should balance ample compartmentalization and periodic interaction to mitigate the potential for cocooning.

Monotony & Sameness

Will Mars be boring? Quite possibly. Suedfeld's characterization of a day-in-the-life at the beginning of this section suggests "stretches of empty time punctuated by bursts of hard, intense work." The empty time is necessary to combat fatigue, yet without stimulation it presents a major challenge that is unique to living in an ICE.

The routine of being a pioneer in a restricted environment has roots in early explorers. Historical accounts of the Lewis and Clark mission revealed that the crew struggled with long periods without mental stimulation.[31] Trapped on a boat with nothing more than basic survival tools often led to low morale. In similar seafaring missions, the leaders took it upon themselves to counter the apathy of inactivity. During his expeditions, Fridtjof Nansen recognized the importance of stimulation and provided his crew with books, games,

22 Sheryl L Bishop, "Here to Stay: Designing for Psychological Well-Being for Long Duration Stays on Moon and Mars," *Lunar Settlements*, 2010. 269.
23 Jack Stuster, *Bold Endeavors: Lessons from Polar and Space Exploration* (Naval Institute Press, 2011). 273.
24 Carrere and Evans, "Life in an Isolated and Confined Environment." 710.
25 Ibid. 711.
26 Gifford and Lacombe, "The Habitability of Spacecraft." 107.
27 Howe and Sherwood, *Out of This World*.
28 Stuster, *Bold Endeavors*. 272.
29 Bishop, "Here to Stay." 269.
30 Stuster, *Bold Endeavors*. 274.
31 Suedfeld, "Historic Space Psychology." 642.

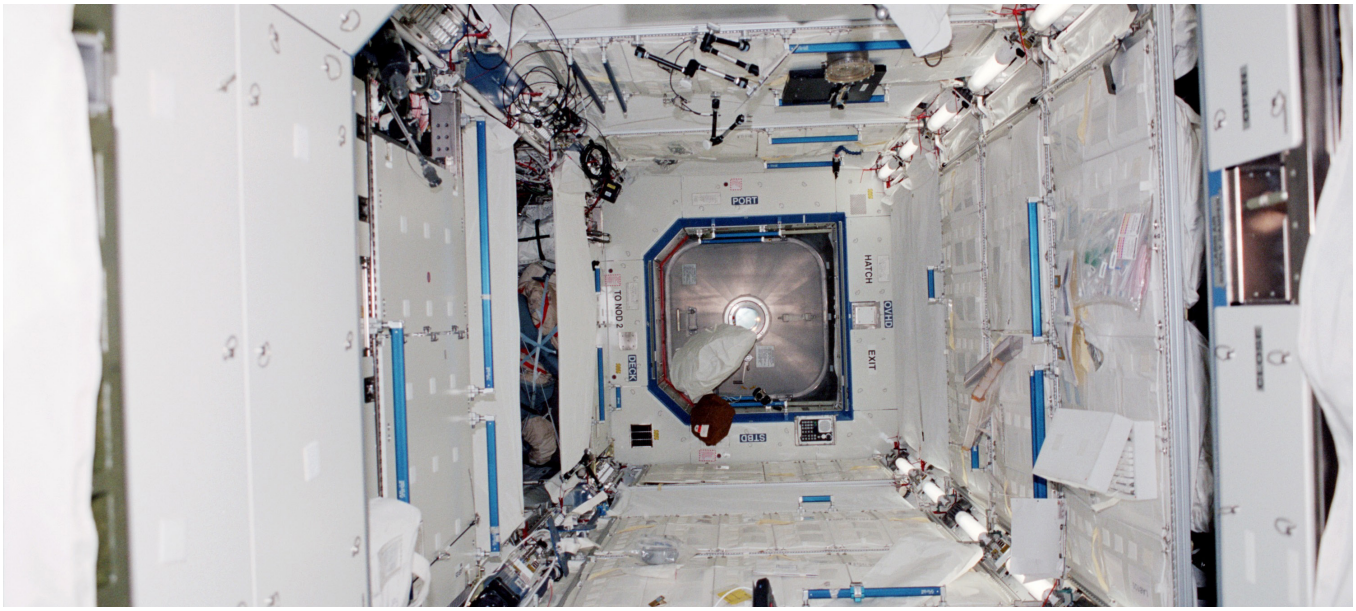


Figure 41: *The interior of the ISS is a prime example of a monotonous habitat. The primary deviation from the module is afforded through small windows. (NASA, spaceflight.nasa.gov)*

and musical instruments to help pass the time.[32] Modern explorations and research stations seek to provide a range of leisure and recreation activities. Diversified entertainment options that allow individuals to interact individually or as groups in different capacities helps to stimulate an otherwise predictable routine.[33] Antarctic research stations punctuate annual schedules with momentous celebrations, such as for a holiday or the rising of the sun after a long winter.[34]

On Earth, our environment is kinetic. Over a year seasons change bringing new climates and colors. Rotating billboards flash colorful displays while a new restaurant offers up fresh culinary opportunities. Over a day we observe a diversity of people traversing public space and experience a variety of settings. According to space architect Vera Martinez, "architecture alone has to substitute the diversity of the natural environment that the human being is used to, on the face of the Earth."[35] Confined habitats commonly lack sensory variety, which has been linked to decreased concentration, performance, mood, abject boredom, and restlessness.[36]

Simple remedies have been proposed for Antarctic research stations such as decorating space and wearing colorful clothing. But often times these issues are rooted in the built environment design.

The interior and exterior environments of analogous habitats are largely static in both space and time. Monochromatic and repetitious complexes are commonplace, lacking in both variation and novelty.[37] The artificial interior climate of spacecrafts including the ISS feature static temperature and air-flow, presenting a deficiency of sensory stimulation.[38] A singular, smooth, off-white material can be found covering all walls, ceilings, and floors. And a series of interconnected modules ensure that every space has similar dimensions, access, and form.

A Mars settlement could easily become a static experience. Same people, same confined place, same environment. Even consider a Martian view – the lack natural ecosystems and atmosphere renders it relatively unchanged year round. Success stories have pointed to the need for environments to change over time. In Palmer Station, past crew members have thematically painted doors to add a layer of whimsy and stimuli to the environment.[39] Larger scale temporal change is rarer;

32 Ibid. 643-644.
33 Joanna Kozicka, "Architectural Problems of a Martian Base Design as a Habitat in Extreme Conditions" (Gdansk University of Technology, 2008). 92.
34 Suedfeld and Steel, "The Environmental Psychology of Capsule Habitats." 244.
35 Vera Martinez, "Architecture for Space Habitats. Role of Architectural Design in Planning Artificial Environment for Long Time Manned Space Missions," *The 15th IAA Humans in Space Symposium* 60, no. 4–7 (2007). 590.
36 Bishop, "Here to Stay." 262.
37 Suedfeld and Steel, "The Environmental Psychology of Capsule Habitats." 234.
38 Gifford and Lacombe, "The Habitability of Spacecraft." 69-70.
39 Carrere and Evans, "Life in an Isolated and Confined Environment." 728-731.

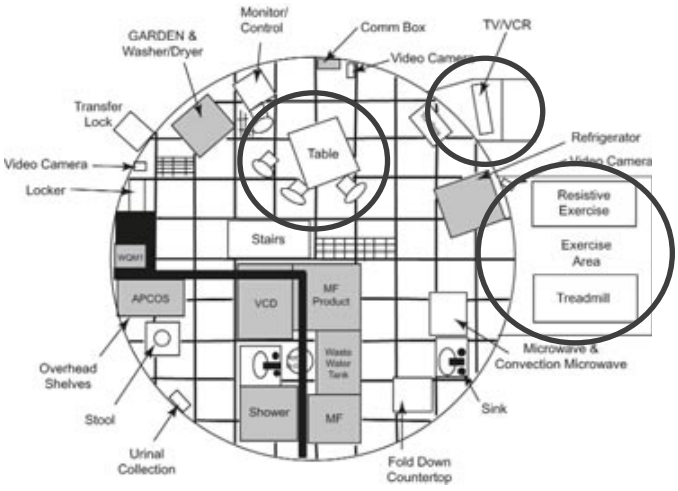


Figure 42: *The floorplan of the LMLSTP. Negative adjacencies between social and exercise facilities (circled above) compromise the restorative value of both functions. (Lane/Sauer/Feeback, "Isolation: NASA Experiments in Closed-Environment Living")*

Figure 43: *A hot tub at Palmer Station in Antarctica is a valuable source of restoration and relaxing social opportunity. (Domi Paxton, antarctica.blogs.wm.edu)*

most stations are fixed and do not have the capacity for widespread reconfiguration or alteration.

No Escape

Most ICEs lack adequate escape facilities, as their design is highly utilitarian and task-oriented. For many space missions, the ISS included, a small window was the most valuable form of escape – a visual portal that extended beyond the habitat and enabled deep reflection. For the Mercury Capsule, a 1960s orbital mission, the astronauts fought with the engineers and demanded they design in a window. To quote one astronaut from that mission, "None of us wanted to die of claustrophobia out there in space, and none of us could see any point…if we were half blind."[40] In submarine environments, windows are far less important for restoration, in part because the view of the ocean is unnerving. Crew members preferred films with "sweeping vistas and scenes of open country" to contrast the capsule environment's lack of views further than a couple yards.[41]

One of the biggest challenges is the contamination of escape facilities by work. When asked what they missed most about Earth, two former astronauts from SkyLab noted the inability to simply sit down, reflect, and relax.[42] For them, the mission dominated in both time and space, and the ability to detach from it proved challenging. In the ISS, semi-enclosed sleeping quarters front a shared workspace module, an arrangement that challenges one's ability to escape work.[43] Even where work and leisure spaces are separated, the intense proximity and lack of "free space" encourages a spillover of workplace activities.

Exercise is one of the most valuable forms of escape and is built into most missions. These opportunities are critical to physical health, yet they commonly suffer from being un-motivating, poorly located, and insufficient for the population size of the mission. On the ISS, space constraints forced a treadmill to be located next to a dining area, a less than desirable adjacency. This decreases the restorative value of both activities.[44] The lack of privacy while exercising can make it more of a chore than a leisure activity. While for some exercising is a social endeavor, for many it is self-conscious activity better enjoyed in privacy or anonymity. Additionally, the provided exercise machines - almost always a modified treadmill or cycle machine - oftentimes cannot accommodate the entire crew over the course of a day and become undesirable after repeated use with no alternatives.[45]

Leisure activities are always popular among crews. Reading, listening to music, and watching films are among the most popular activities in ICEs.[46] For nuclear

40 EK Eric Gunderson et al., *From Antarctica to Outer Space: Life in Isolation and Confinement* (Springer Science & Business Media, 2012). 351.
41 Stuster, *Bold Endeavors*. 241-242.
42 Ibid. 237.
43 Gifford and Lacombe, "The Habitability of Spacecraft." 86-90.
44 Ibid. 62-63.
45 Stuster, *Bold Endeavors*. 68-70.
46 Ibid. 233-236.

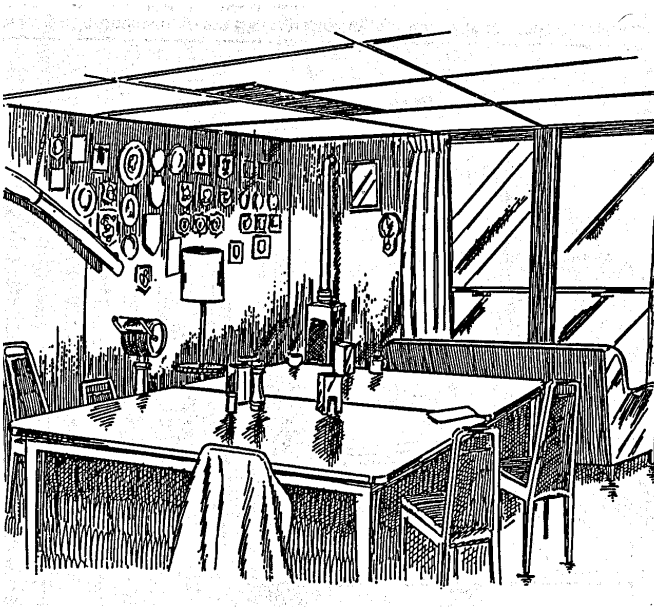


Figure 44: *Sketch of the Palmer Station dining room. Residents periodically reconfigured the furniture and personalized walls as a group. (Sybil Carrere/Gary W Evans, "Life in an Isolated and Confined Environment")*

Figure 45: *The interior of a Halley VI bedroom, equipped with ample desk space, shelves, personalizable walls, and window with adjustable blackout shade. (Michal Krzysztofowicz, antarcti.co)*

submarines and Antarctic research stations, daily film viewings are a popular activity that bring people together. Even with the advent of personal video players, group film events serve to mitigate social withdrawal of select individuals. Trends from research stations note that upon arrival, crew members come prepared with personal hobbies or studies, yet in relatively short time they are abandoned in favor of more passive, social activities. Studying and reading are also quite common and in early expeditions it proved challenging to provide crews with a great enough diversity of books. While digital libraries will reduce these limitations, there remains a limited capacity for physical amenities. Irritating noises from machinery and other activities can degrade the quality of one's personal leisure. In early Antarctic stations, playing music was contentious and led to a variety of interpersonal conflicts.

Lastly, spirituality has proven challenging in ICE habitats. Reviewers of habitability on the ISS noted that there was not enough space to practice a religion or have a quality spiritual life.[47] Private quarters suffered from a lack of both privacy and the reflective capacity of a viewing window. Without an adequate private space, religious practices get pushed to multipurpose spaces. This can lead to conflict based on individual beliefs, and the infliction of personal preferences on those who do not identify with it.[48] However, the celebration of religious holidays with the entire crew provides opportunities for cross-cultural understanding and team bonding.

Escape in the Martian habitat correlates to the separation of work and domestic space, as well as the provision of diverse exercise and leisure spaces. More than most spaces, escape facilities are sensitive to adjacent activities and can be spoiled by noise and lack of privacy. Lastly, personal refuges and escape facilities should offer opportunity for spirituality and reflection.

Identity & Control

Most ICEs lack customizable environments. Many private spaces cannot be adjusted for temperature, light, and noise, attributes that enable daily comfort and increase the escape value of a bedroom. For example, a senior Antarctic crewmember described turning up his space heater while flipping through photographs to stimulate memories of a California vacation with his family.[49] In addition to internal atmosphere, bedrooms are oftentimes so compact that the prefabricated layout prevents periodic reconfiguration of the space. Similarly, public spaces seldom account for divergent personal preferences and task-specific needs, instead opting for a fixed internal atmosphere and layout. In the laboratory, shared workspaces prevent control over personal space and can result in conflicting territorial claims.

Repeated studies of Antarctic bases have shown how extensive and critical personalization is. The inability to

47 Gifford and Lacombe, "The Habitability of Spacecraft." 61-62.
48 Stuster, *Bold Endeavors*. 242-244.
49 Ibid. 274.

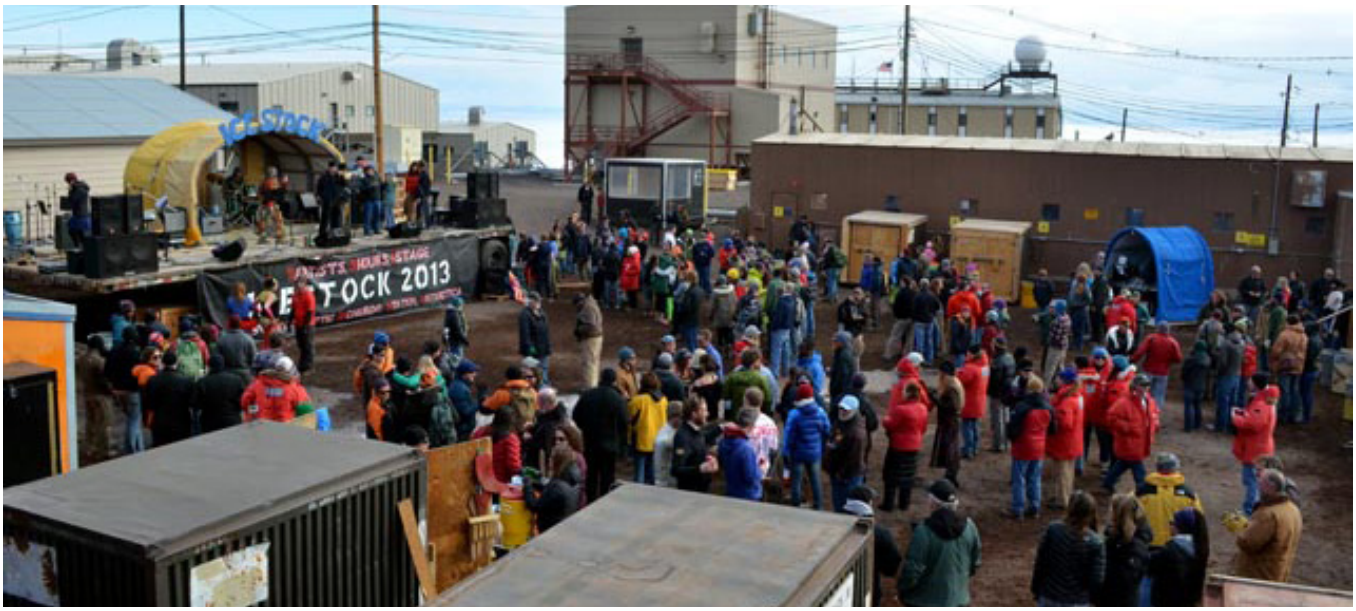


Figure 46: *McMurdo Base, Antarctica. Every new years, McMurdo Base hosts IceStock music festival. These celebrations require a large-scale temporary repurposing of space. (Peter Rejcek, antarcticsun.usap.gov)*

personalize a space can affect self-awareness, morale, and sense of ownership. In personal spaces, individuals cover walls with photos, mementos, and art to heighten nostalgia and strengthen their personal identity. In public spaces, group personalization provides a sense of collective ownership and can heighten group morale. Antarctic stations have accomplished this in different ways. In Halley VI, the interior walls of bedrooms were covered with peg board to encourage frequent redecoration. At Palmer Station, doors of bedrooms were periodically re-painted by a resident artist who consulted with each resident.[50] Group photos and hobby creations during isolation were hung on walls to celebrate individual and group achievements.

In addition to personalization, cultural customs such as food preparation or practicing religion also root people in their traditions and heritage. In the ISS, a reliance on prepared meals and lack of kitchen space removes the "event" of preparing foods.[51] Insufficient dining areas minimize social eating and remove community bonding opportunities. To counter this, the design of the dining area in Halley VI is intentionally large enough to accommodate the entire crew in summer months and is reconfigurable to the scale of the population in winter months.[52]

A unique and positive impact of the habitat is a heightened connectedness to the built environment. Personnel in Biosphere 2 remarked how being confined enhanced their sense of connection to their artificial world and to systems on Earth.[53] They noted that every action had a profound impact in a closed environment with impressive feedback loops and oftentimes instantaneous results. In essence, they were aware of their place as integral cogs in a sensitive ecosystem. Induced by factors of isolation and confinement, this sensation has to potential to be exponentially greater in a Martian settlement.

Attributes of identity and control are strongly linked with providing customizable territories. In addition to being reconfigurable, private spaces need ample surface area for personalization. Group spaces need to accommodate cultural customs and community identity-building activities. Lastly, the habitat should capitalize on a heightened connectedness with the built environment and provide ample opportunity to experience positive feedback loops.

Missions & Communications

Studies of analogous habitats have observed how duration of a mission effects the crew, a pattern referred to as the Third Quarter Symptom. At the beginning of missions, motivation, morale, and team bonding are high. At roughly the third quarter of the

50 Carrere and Evans, "Life in an Isolated and Confined Environment." 728-731.
51 Gifford and Lacombe, "The Habitability of Spacecraft." 73-74.
52 Howe and Sherwood, *Out of This World*.
53 Mark Nelson and William F Dempster, "Living in Space: Results from Biosphere 2's Initial Closure, an Early Testbed for Closed Ecological Systems on Mars," vol. 1, 1996. 20-21.

mission, motivation begins to drop rapidly and the extended impact of all other factors begin to wear on the inhabitants. During this period, decreased morale induces extreme fluctuations in mood and increases anti-social behaviors. As the crew enters the fourth quarter, the anticipation of returning home brings on a final sensation of euphoria which lasts until return. Exactly how this translates to Mars is unknown, as the durations and impacts are far greater, but it hints at the possibility of major fluctuations over the duration of the mission.

The mission schedule itself is a balance between work and leisure, a balance that has in the past been difficult to hit. Over-working leads to stress and conflict between crewmembers, and jeopardizes relationships between the crew and Earth support. The only opportunity to leave the habitat exists as surface missions that involve donning heavy life-support gear. These surface missions will be exhilarating, yet simultaneously physically and mentally exhausting. For all residents, pressures brought on by the intensity and the expectations of the work may lead to periods of low morale. In the rare occasion of equipment or habitat failures, every resident of the habitat may be called upon to act very quickly under extreme stress.

As mentioned before, communications to Earth will have a 20 minute delay. With real time communication unavailable, the mission will be forced to preserve its autonomy. The relationship between crew and Earth may become strained if it feels like ground control is micro-managing. Historically, personal communications to family and friends have been incredibly important for morale.[54] However, ICE habitats seldom provide ample privacy for these infrequent conversations to occur. Early analogous missions relied on physical mail and later a singular ham radio for communications.[55] As communication technologies improved, the provision of semi-private communication areas were made available. Communications to home are among the most intimate and emotional activities, and should be coupled with the highest degree of privacy available. Most modern facilities recognize this importance and hardwire every bedroom with internet and phone capabilities. The downside is the risk of communication obsession by which an individual may become preoccupied with issues on Earth to the detriment of the mission. Extreme cases have been noted amongst oil divers, submariners, and Antarctic researchers.[56]

54 Suedfeld and Steel, "The Environmental Psychology of Capsule Habitats." 236-237.
55 Stuster, *Bold Endeavors*. 203.
56 Ibid. 207-208.

The built environment cannot eliminate the effects of mission duration or stress. However, it points to the need for the habitat to adapt to changing social dynamics that may occur during the mission. In periods of low morale, it will be especially critical to find ways to energize and motivate the crew. Additionally, communications to Earth will need to be accommodated within each person's living quarters. Balancing that with a high degree of daily social support among the crew can help prevent pathological communication obsession.

Comfort

Habitats designed for brute survival often overlook comfort. Critique of the ISS illustrated a variety of ergonomic concerns not addressed by the design.[57] The usage of homogeneous "Walmart-style" lighting is abrasive and challenges one's ability to relax.[58] Humming of equipment is pervasive and distracts during time off. Furniture options are few and spaces are so constricted that a reorganization of space to user preferences is limited. Similarly, crew members of the LMLSTP found their habitat to neglect basic comfort needs.[59] The furniture options were moveable but limited, and crew members strongly desired more places to relax. A steep staircase that wound through the site was a nuisance to climb multiple times a day while a lack of natural light and windows further decreased the desirability of space. A lack of electrical outlets made seating options even less practical.

One of the most challenging aspects of ICE design is the mitigation of clutter. Open storage facilities are often integrated into multi-use spaces, leading to the contamination of functional space with visible clutter. Narrow corridors, common in module design, further induce sensations of clutter.[60] The narrow modules of the ISS have equipment on almost every surface which hinders comfort and navigability.[61] The clutter of group space activities is often poorly separated from individual areas, leading to a spillover effect of both physical and visual clutter.

At a large scale, these issues are a matter of providing a range of ergonomic options, a surplus of storage areas, and mitigating spillover effects of group activities. To preserve use for everybody, corridors and confined spaces need to be kept clear and accessible. At a smaller scale, equipment and furniture should be moveable or stowable to mitigate visual clutter.

57 Gifford and Lacombe, "The Habitability of Spacecraft." 65-66.
58 Ibid. 65.
59 Lane, Sauer, and Feeback, *NASA Experiments in Closed-Environment Living*. 83-84.
60 Bishop, "Here to Stay." 268.
61 Gifford and Lacombe, "The Habitability of Spacecraft." 53-55.

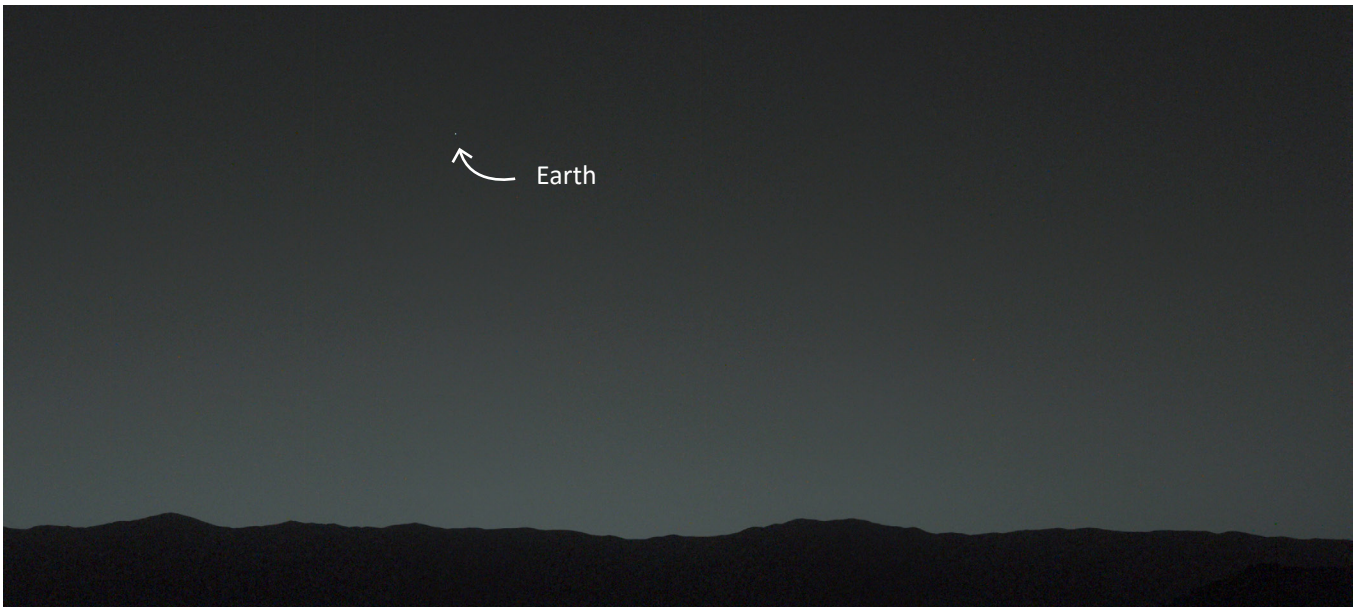


Figure 47: *A view of Earth from Mars. At most, it is a tiny blueish dot in the sky. (NASA/JPL-Caltech/MSSS/Texas A&M, jpl.nasa.gov)*

Mars Deadly & Earth Distant

While analogous habitats provide numerous parallels to Mars, the fact remains that no population has even been so removed from Earth and so reliant on the long-term security of their habitat. Without precedents we can only speculate. How will people react to not seeing planet Earth? Will the image of Mars be a terrifying reminder of the risk they face? Or will the surface of the red planet be a constant motivator?

Early Martian settlers will be the first human beings unable to see their home planet. When visible from the surface, Earth will appear as a small blueish dot in the sky. Other times, it will be completely obscured from view. Though "Earth-out-of-view phenomenon" is purely hypothetical, researchers have noted how important the views to Earth have been for all previous spaceflights. To quote astronaut Suni Williams, the window portal onboard the ISS is "one of those places you find yourself all the time because all you want to do is look back at our planet."[62] Space psychologists have major concerns that losing this connection will have drastic effects on wellbeing.[63]

Though beautiful and fascinating, the Martian outdoors are imposing and deadly. Every crewmember will keenly understand that their life depends on the integrity of their habitat and clothing.[64] The comfort in views has varied amongst missions. While ISS crewmembers covet their views of Earth, submariners often find their ocean views unnerving.[65] Given that Martians will be self-selected and driven by exploration and science, one may speculate that fascination will triumph over fear, so long as they trust the integrity of their habitat.

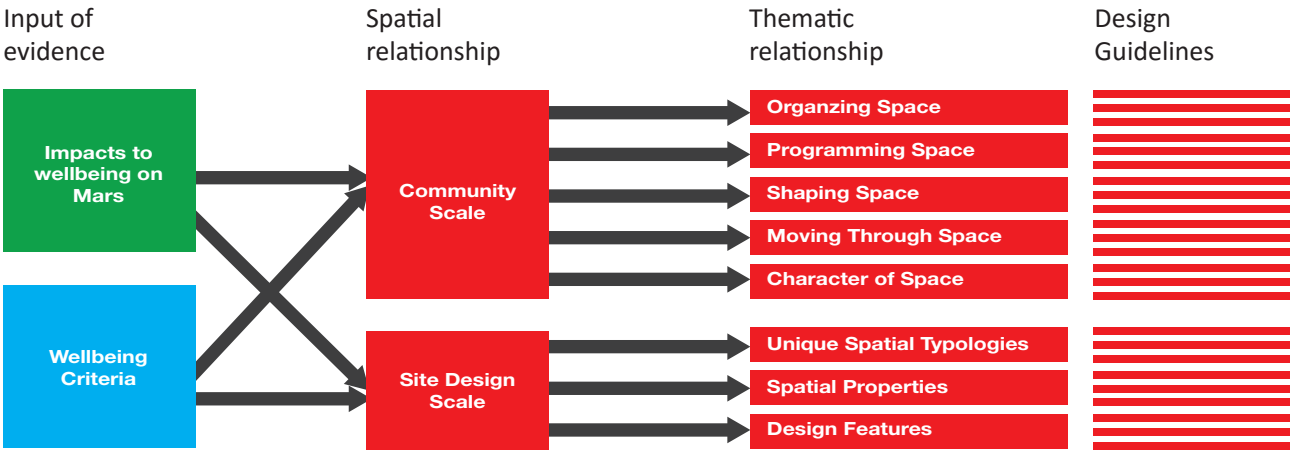
Research of the preliminary human missions to Mars will be needed to reveal the psychological toll of this far-removed world. It can be presumed that Martian settlers will have a strong nostalgia for planet Earth and will develop coping mechanisms to deal with the Earth-out-of-view phenomenon. In this respect, the built environment will play an important role by providing crewmembers with a level of trust and familiarity lacking on Mars.

62 NASA and Sunita Williams, *International Space Station Tour* (International Space Station, 2003), http://www.nasa.gov/mission_pages/station/main/suni_iss_tour.html.

63 Nick Kanas et al., "Psychology and Culture during Long-Duration Space Missions," *Acta Astronautica* 64, no. 7 (2009). 661.

64 Suedfeld, "Historic Space Psychology." 642.

65 Stuster, *Bold Endeavors*. 241-242.



Spatial Considerations

Figure 48: *Diagram of author's process of transitioning from human-centric evidence to spatial design guidelines.*

The previous two sections – wellbeing and impacts – are phrased as effects of the built environment on humans. The upcoming section rearranges this logic to provide responsive and pragmatic urban design recommendations, organized by community and site design scales. Each design guideline contains a logical nexus woven from multiple impacts and multiple criteria of wellbeing in order to mitigate the realities of being a resident on Mars.

Each impact in this section has a spatial relationship specific to the two scales of design guidelines. To illustrate this, let's consider the impact of "Sleep & Circadian Rhythms". The disruption of sleep correlates to the lack of separation between sleeping quarters and non-compatible uses. It can be considered at a community scale as the relationship between residential areas and machinery. It can also be considered at a site design scale as the transition and buffering between sleeping quarters and public spaces. Meanwhile, circadian rhythms are related to daily exposure to environmental cues. At a community scale this correlates to the settlement's relationship with the sun and an internal configuration that provides visual access of natural light. At a site design scale it is pertinent in details such as lighting design, bedroom configuration, surface colors, and more.

Like the conditions section, the impacts section is limited by the knowledge to date. Ongoing studies at the ISS and in test modules around the world continue to reveal valuable information about a Martian habitat's effect on humans. The exploration stages of humans on Mars will provide the first real world scenarios and may reveal a host of new impacts not discussed here.

Figure 49: *A photo from NASA's curiosity robot of the Martian surface. Future Martian settlers may wake each morning to a similar view. (NASA/JPL-Caltech/MSSS, photojournal.jpl.nasa.gov)*

DESIGN GUIDELINES

How can planners and designers mitigate the challenges identified in the prior sections through the design of a Martian settlement? How can spatial patterns and arrangements influence wellbeing that serves the needs of both the individual and the collective society?

A City within a Building

On Earth, a building is a building. A diversity of buildings, serving residential, employment, and civic functions, comprise a city. This city is connected through a diversity of exterior spaces, including streets, parks, plazas, intersections, and natural areas.

On Mars, a building is a city. There is no “outdoor space” to connect or access. Surface walks require full suits and will be strictly regulated for mission purposes only. The interior environment alone must provide the range of functions and benefits that a city offers.

This illuminates a great challenge: How can we ever build a structure large enough to accommodate this diversity? By breaking down our needs into social and psychological notions of wellbeing and applying them to the constraints of a Martian settlement, we can create constrained environments that approach the range of settings and characteristics that we need. In the guidelines, this range is simplified into “transects”, distinct groupings of functional spaces. Though at times addressed independently, each transect has considerable overlap with others. The different transects include:

- Work: laboratories, conference spaces, equipment rooms, and associated storage
- Residential: sleeping quarters and private refuge
- Domestic: kitchens, dining, laundry, hygiene facilities, and living spaces
- Social: lounges, activities, and entertainment
- Escape: leisure, spiritual, and restorative environments
- Agricultural: food production
- Medical: isolation wards, laboratory space, and storage
- Utility: power generation and closed-loop systems
- Communications: internal command center

The design guidelines that follow are a toolkit of conceptual and at times abstract concepts to help enhance wellbeing in the design of a Martian settlement. They are non-prescriptive in nature, and can be applied to any general form, building practice, or population. They are strengthened with simple objectives that can be adapted to meet the severe economic and technological constraints that are anticipated.

The guidelines break into two large categories based on scale. The “Community” section provides guidelines that consider the settlement in the aggregate, as a complex series of interconnected functions, spaces, and opportunities. The “Site Design” section dives into physical characteristics of spaces, with attention to dimension, detail, and user experience.

Community Scale Design Guidelines

Organizing the Plan

1. **Configuration**
   - *Embed an overall wayfinding logic*
   - *Enable adequate physical separation of different uses*
   - *Accommodate long-term growth*
2. **Orientation**
   - *Maximize daily sunlight exposure*
   - *Maximize viewshed diversity*
3. **Privacy Gradient**
   - *Provide a privacy gradient along functional transects*
4. **Spatial Relationships**
   - *Separate non-compatible transects*
   - *Maximize overlap and adjacency where beneficial*

Programming Space

5. **Bedroom, Suite, & Cluster**
   - *Provide private, individual bedrooms*
   - *Cluster residential units*
   - *Develop a hierarchy of residential scales*
6. **A Social Network**
   - *Provide a hierarchy of social spaces*
   - *Include a primary hub, secondary social spaces, and third places*
7. **A Restoration Network**
   - *Provide escape facilities separate from domestic and workspaces*
   - *Provide formal and informal exercise spaces*
   - *Provide restorative environments along passive/active and solitary/group spectrums*

Shaping Space

8. **Bulk & Scale**
   - *Support a dense habitat of mid-rise structures*
9. **Diversity of Spaces**
   - *Provide a diversity of volumes, forms, colors, and materials throughout*
10. **Perception of Scale**
    - *Maximize net-perceivable volume*
    - *Utilize permanent and temporary internal compartmentalization*
    - *Prevent closed loop compartmentalization that will allow complete withdrawal*
11. **Defensible Spaces**
    - *Maximize defensible spaces and natural surveillance*

Infusing Legibility

12. **Districts, Nodes, and Landmarks**
    - *Clearly demarcate and define districts, nodes, and landmarks*
13. **Glorious circulation**
    - *Delineate a hierarchical network with primary routes*
    - *Provide choice through alternate routes*
    - *Provide stimulating nodes along routes*
14. **Sequencing of space**
    - *Seamlessly connect directional, transitional, and locational spaces*
    - *Provide a high degree of transition throughout*

Providing Character

15. **Flexibility vs. Permanence**
    - *Enable annual and daily reconfiguration of space to maximize utility*
    - *Allow rooms to be internally reconfigurable or moveable*
16. **Accessibility vs. Challenge**
    - *Integrate rewarding mental and physical challenge into the built environment*
17. **Connectedness**
    - *Expose facets of the internal habitat "ecosystem"*
18. **Earth Normal & Mars Awesome**
    - *Provide an Earth-normal layout*
    - *Provide views and cues to the Martian environment*

Configuration

- *Embed an overall wayfinding logic*
- *Enable adequate physical separation of different uses*
- *Accommodate long-term growth*

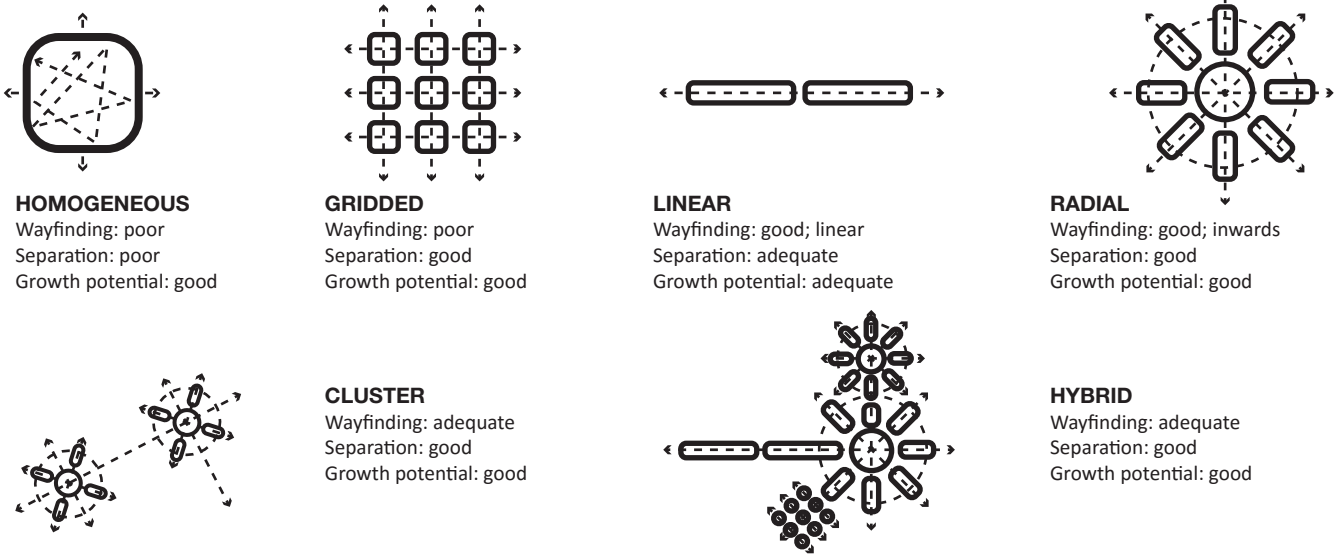
Configuration refers to the conceptual physical layout of inhabitable volumes. This layout impacts every wellbeing criterion and sets the stage for the long-term human experience on Mars. At its core the configuration needs to achieve three primary goals: 1) embed an overall wayfinding logic, 2) enable adequate physical separation of different uses, and 3) accommodate long-term growth.

A review of analogous habitats reveals five common configurations: 1) homogeneous, 2) gridded, 3) linear, 4) radial, and 5) a network of clusters. Homogeneous, gridded, or linear modules have great potential for a small population. They are efficient, organized, and easily reproducible. However with upwards of 30 people the settlement becomes increasingly complex. A homogeneous habitat no longer provides enough capacity for differentiation and buffering, a gridded habitat lacks legibility and promotes sameness, and a linear habitat cannot accommodate the complexity of spatial relationships that need to happen.

A radial configuration assumes a center (likely the social heart of the settlement) and expands outwards. It can adequately separate uses via different “wings” and has a built in wayfinding system as any space can relate back towards the center. An expanded network of clusters similarly provides opportunity to control internal spaces, but with an increased degree of hierarchy. However, if not adequately planned for, a complex network could lack legibility and overly isolate uses.

For these reasons, a configuration should start conceptually with a radial form, and as it grows should transform into a network of radial clusters. As the settlement grows, additional modules can extend the radius in multiple directions corresponding to specific functional transects (residential, laboratory). At the point where a growing radial network becomes too stretched out, a network of clusters should be implemented by establishing a secondary or tertiary radial hub.

A hybrid approach, combining aspects of radial and network configurations with gridded or linear may be situationally appropriate. Research wings may have value as highly structured grids, while a greenhouse may become a linear sequence of spaces. Within a central configuration, a diversity of sub-configurations should be considered to maximize the utility and quality of subareas.



HOMOGENEOUS
Wayfinding: poor
Separation: poor
Growth potential: good

GRIDDED
Wayfinding: poor
Separation: good
Growth potential: good

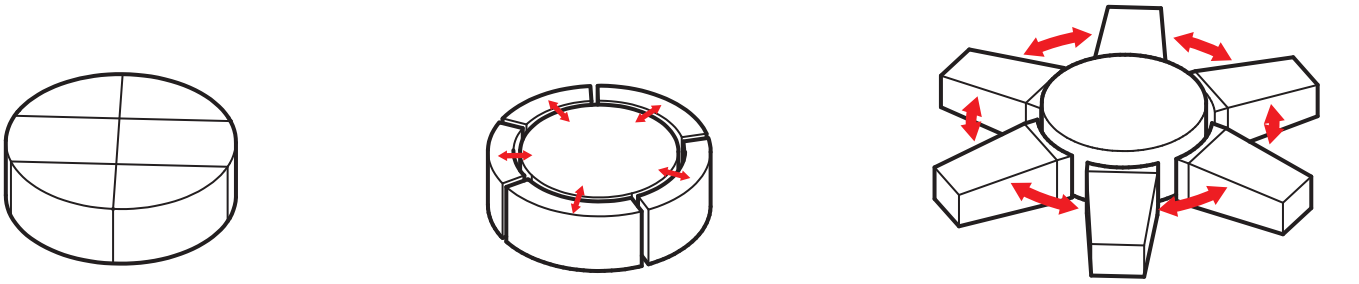
LINEAR
Wayfinding: good; linear
Separation: adequate
Growth potential: adequate

RADIAL
Wayfinding: good; inwards
Separation: good
Growth potential: good

CLUSTER
Wayfinding: adequate
Separation: good
Growth potential: good

HYBRID
Wayfinding: adequate
Separation: good
Growth potential: good

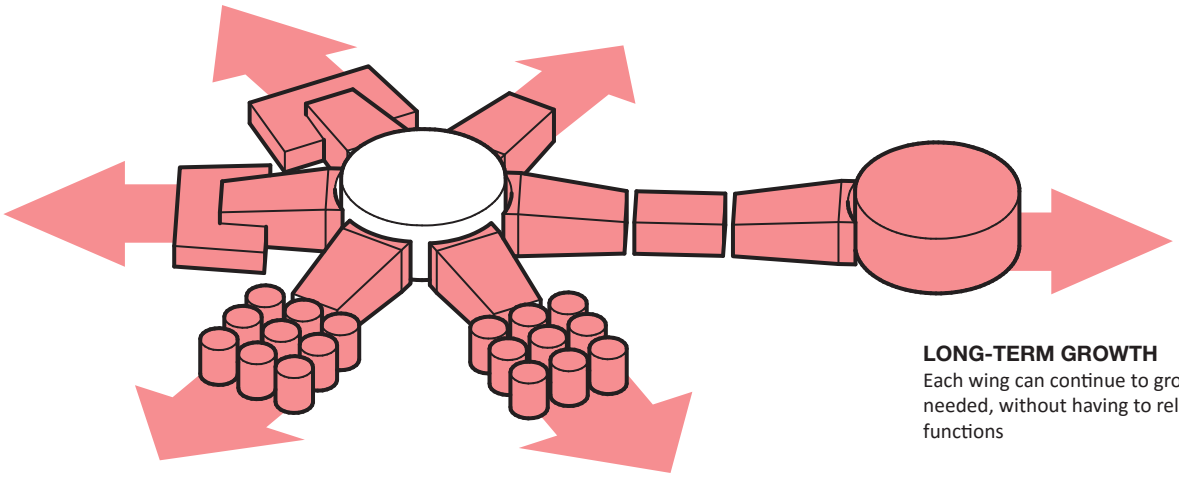
Figure 50: *Examples of different configurations commonly found in ICEs, evaluated for wayfinding, separated uses, and capacity for long term growth.*



A DIVERSE PROGRAM
First, consider the complexity of diverse functions in a limited space

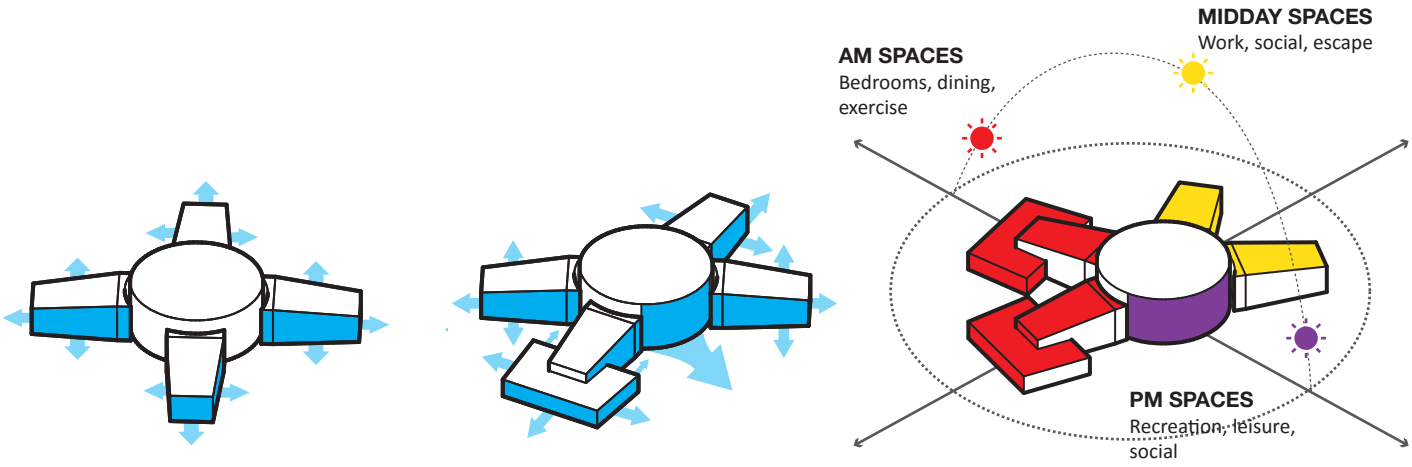
EMBEDDED WAYFINDING
A radial development can always orient back towards the center

SEPARATE USES
Distinct "wings" allow for adequate separation of non-compatible uses.



LONG-TERM GROWTH
Each wing can continue to grow outwards as needed, without having to relocate existing functions

Figure 51: *The configuration should accommodate three distinct goals, as illustrated using the example of a radial settlement.*



VIEWS AND SUNLIGHT
A rectilinear settlement has only four distinct view directions and lacks a relationship to the arc of the sun.

MAXIMIZE VIEWSHED
A better alternative has a variety of unique perspectives and creates a hierarchy of views.

MAXIMIZE DAILY SUNLIGHT
The internal program should locate interior functions such that they correlate with the temporal arc and exposure of the sun

Figure 52: *A settlements orientation should maximize a diverse array of views and maximize habitants daily access to sunlight.*

Orientation

- *Maximize daily sunlight exposure*
- *Maximize viewshed diversity*

Whereas configuration is specific to the spatial organization of the habitat, orientation refers to the habitat's relation to the rest of Mars. Specific site selection will remain unknown until further exploration, so the thrust of this guideline is to identify predictable qualities of a site and how to maximize their benefit.

A buried Martian settlement should be considered a worst case scenario. While radiation is deadly, the quest should be for an innovative material response to the problem, not the consolation of sub-surface living. Prior habitats, such as Mars Ice House, have found creative ways to justify surface-level living.[1] While artificial lights and views can trick our bodies they cannot trick our minds. Humans have evolved to respond to natural light cues and we utilize views of our built environment for wayfinding, restoration, and even spirituality.

Light levels are low on Mars, making it is critical to maximize the daily solar gain. The experience of light hinges on where people are at different times. To help with circadian rhythms, the configuration and orientation should enable daily routine to "follow" the light. Morning places (sleeping spaces, dining) should open up to the rising sun, evening spaces (escape, restoration, social) should showcase the dramatic Martian sunset, and workspaces should seek to maximize sunlight throughout the afternoon. While few spaces fall into a discrete time-of-day category, general routine schemes can be predicted and supported.

In maximizing viewshed diversity, the orientation and configuration of the settlement need to work together. Viewshed diversity is achieved by having sight of the surface from a variety of heights and angles. While view preferences are subjective, the impact of monotony and sameness suggests the need for complex views. The central social and leisure spaces should be aligned towards premier view areas (towards mountains, valleys) or views that change (dunes). Any sites of historical significance (launch or landing pads, iconic first steps, towards a mission destination or goal) should also be considered as valuable.

1 SEArch and Clouds AO, "Mars Ice House," *Mars Ice House*, accessed April 5, 2016, http://www.marsicehouse.com/.

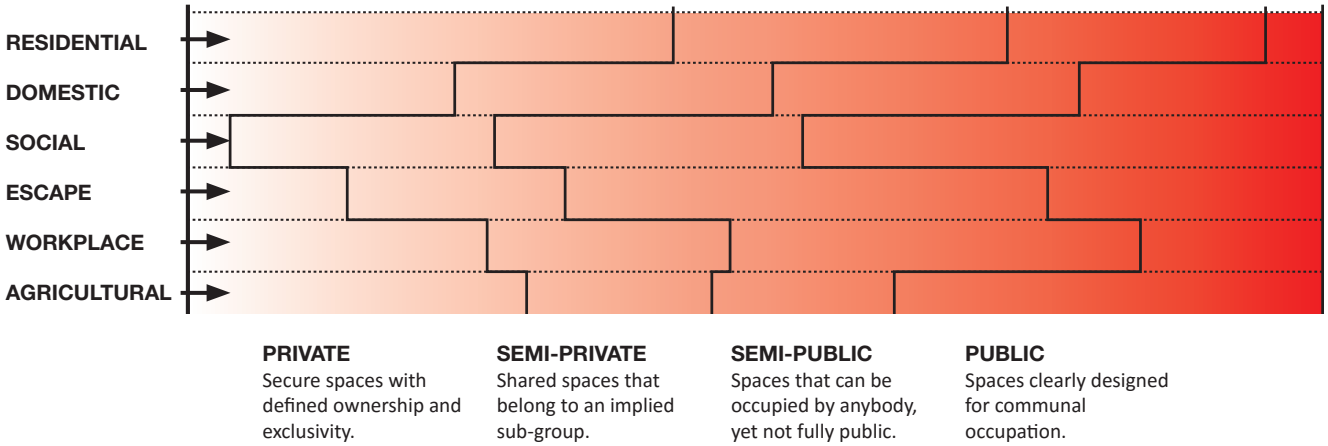


Figure 53: *The settlement contains a gradient of private, semi-private, semi-public, and public spaces. Each functional transect has a unique distribution along the privacy gradient.*

Privacy Gradient

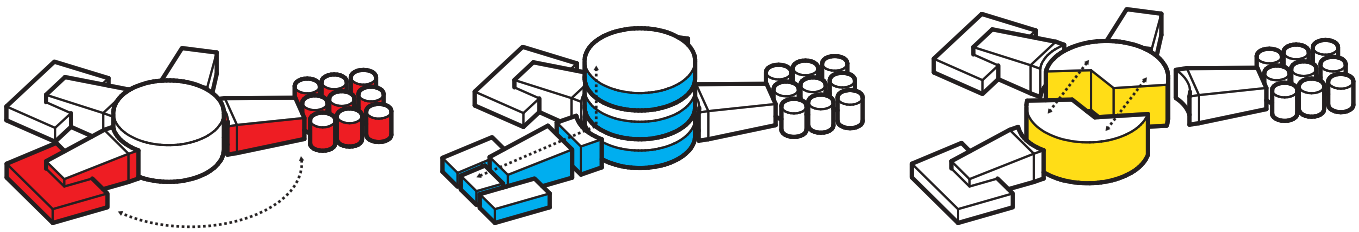
- *Provide a privacy gradient along functional transects*

Access to and control of privacy is more than the provision of private spaces. A locked bedroom that opens onto a crowded dining hall or personal work desk that fronts a major circulation route is hardly private.

A privacy gradient should be employed across the entire complex. Each transect in the settlement needs to transition gracefully from public to semi-public to semi-private to private. Jumping abruptly between public and private produces a tension and diminishes the quality of each space. An adequate gradient helps foster privacy, territoriality, and sense of place.

Consider the following example, starting the gradient from the most public point such as the primary social hub. As it transitions towards the workplace wing it may first go through an intermediate transitional space towards a semi-public workplace foyer that doubles as small social lounge. From there, divisions of laboratories are separated by use; a wing for geological research may be a semi-private space for a geologist but not for a mechanic who works in a different wing. Within the sub-wing, there may again be another transitional space in the form of a small conference room that doubles as a team lunch room. From there a corridor extends to specific laboratories, intended only for those who are directly involved with that research. Within each, there exists a central shared workspace with rotating technical station as well as individually defined personal workstations.

While this reflects an overly prescriptive example of what the privacy gradient achieves, it illustrates how it can be considered at a variety of scales. It should be considered for any and all functional transects in the settlement (residential, workplace, escape).



BUFFER
Utility versus Residential
Work versus Escape versus Residential
Exercise versus Dining

ADJACENCY
Social to Domestic
Dining to Kitchen
Exercise to Hygiene

OVERLAP
Social with Dining
Greenhouse with Leisure
Bedroom with Private Refuge

Figure 54: *Non-compatible functions should be fully buffered, sequential functions should feature adjacencies, and mutually beneficial functions should overlap.*

Spatial Relationships

- *Separate non-compatible transects*
- *Maximize overlap and adjacency where beneficial*

Space in a Martian settlement will be cramped, and as a result not every function will have its own discrete space. As a result, spatial relationships will be a delicate art of cost-benefit analysis. There are three conditions of spatial relationship for different functions to be strategically applied: overlap, adjacency, and buffer.

Overlap (or multi-use) should be considered in situations where the two functions are mutually beneficial or at least non-detrimental to each other. Overlap functions may be simultaneously compatible functions or occupy different times of day. A few example of overlap include dining and social spaces, greenhouse and restorative spaces, and bedrooms and private refuge spaces.

Adjacency should be considered where the two functions may be related or part of series of activities, but their immediate overlap would be to the detriment of one or the other. This exists along a spectrum, from physical barriers to psychological separation techniques. At a high level, this includes the sequential transition between social and residential spaces. More specific examples include the adjacency of dining to food-prep, exercise to hygiene facilities, and bedrooms to local lounges.

Buffers should be considered when one function is inherently detrimental to the vitality of the other. This detriment can take the form of invasion (the intentional intrusion of space), violation (the inadvertent intrusion of space), or contamination (noxious spillover aspects of a function such as noise or vibration). Buffers can be considered as 1) physical, sensory, and psychological barriers or 2) complete separation and isolation. Functions that need to be buffered include work and escape, utilities and residential, and exercise and dining.

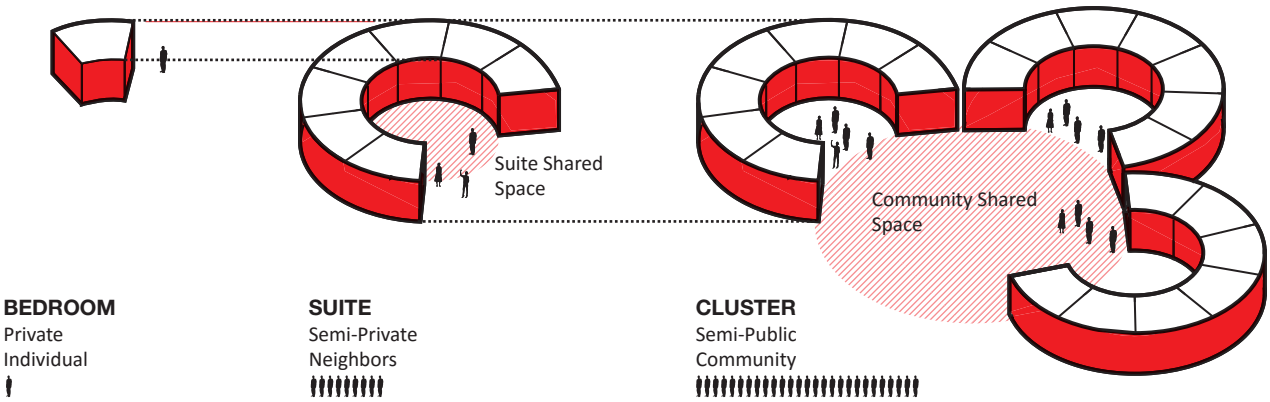


Figure 55: *Residential areas need to provide degrees of privacy and community, by lumping private bedrooms into "neighborhoods" of suites and "communities" of clustered suites.*

Bedroom, Suite, & Cluster

- *Provide private, individual bedrooms*
- *Cluster residential units*
- *Develop a hierarchy of residential scales*

Home is the most important space for individual wellbeing. In addition to being sleeping quarters, it functions as the primary refuge, storage for ones most valuable possessions and memories, a place to escape from social interaction, and a territory completely controlled by the individual that occupies it.

For these reasons, bedrooms should generally be single-occupancy private spaces that can be locked. Short hallways on approach or suites are permissible, but long, uninterrupted hallways should be avoided.[2] Logistically bedrooms should be clustered to avoid lengthy and unnecessary circulation.[3] Given the scale of the complex, multiple clusters should be utilized to create manageable sub-communities.

A successful hierarchy of residential scales begins to emerge. A wing of residential or living use may center on a leisure space, small dining area, or relevant amenities (such as bathrooms). It branches off into residential several clusters of bedrooms, each of which has its own smaller social space or community washroom.

It is worth noting that prevailing best practice in communities on Earth in the 21st century leans towards mixed-use living. For a settlement of 30 to 60 people on Mars, this is a negligible concept. Everything will be in close proximity, and the ability to separate uses becomes far more critical than maintaining a true "mixed-use" typology. As Mars develops beyond settlement towards scales of colonization and urbanization, a "mixed-use" approach becomes more relevant.

2 Gary W Evans, "The Built Environment and Mental Health," *Journal of Urban Health* 80, no. 4 (2003). 544.

3 Matthew A Simon and Larry Toups, "Innovation in Deep Space Habitat Interior Design: Lessons Learned from Small Space Design in Terrestrial Architecture," 2014. 2-3.

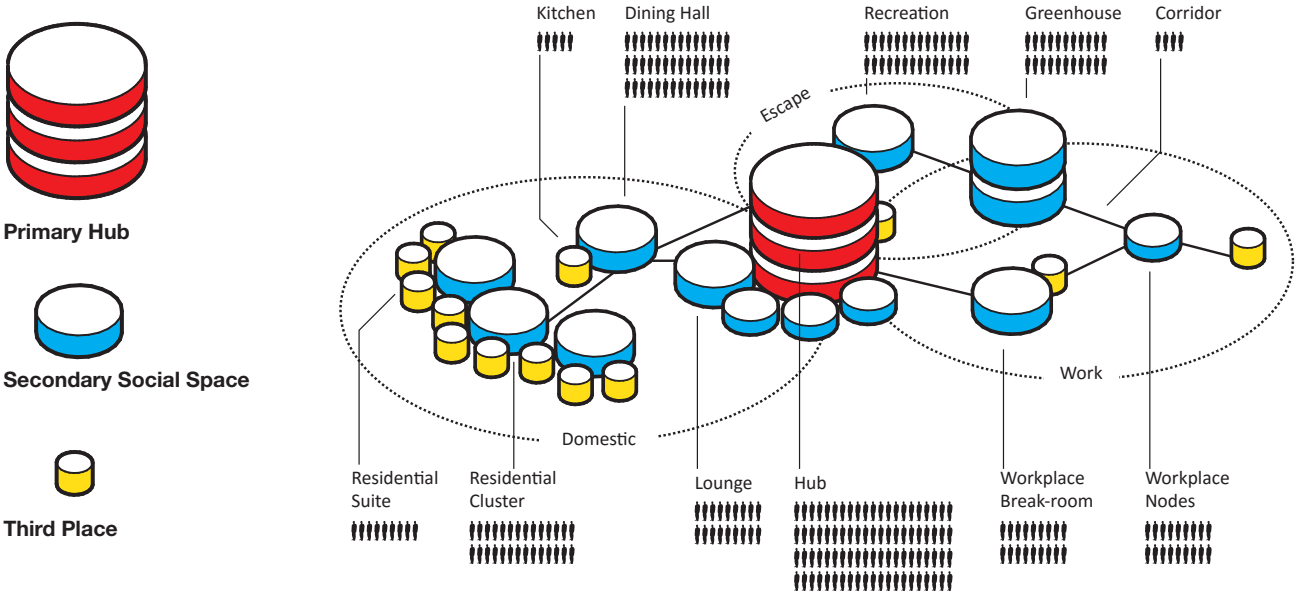


Figure 56: *Three tiers of social space should create a social network that permeates every transect of the settlement.*

A Social Network

- *Provide a hierarchy of social spaces*
- *Include a primary hub, secondary social spaces, and third places*

In addition to all of the spaces required for the mission and survival (residences, work spaces), the settlement must facilitate a civic life. For this reason, the settlement needs a hierarchy of social spaces that represent the range of interpersonal scales in which people interact, and collectively create a vibrant social network.

At its core, the settlement is one community made up of 30 to 60 people. While it is unlikely that a group of this scale will congregate often, it is important that the settlement can on occasion accommodate it for events, announcements, and celebrations.[4] When it is not needed, it can be subdivided or repurposed for more day-to-day functions. A volume of this scale will inevitably be the exception, and should function as the civic center of the settlement.

Secondary social zones represent the primary day-to-day domestic and workplace spaces for interaction outside of mission functions. These not only include obvious spaces such as lounges and dining halls, but should permeate the entire settlement. Lunch breaks at work and small residential lounges help extend social activity and present opportunities for interaction throughout the day. In the aggregate, these social spaces should reflect a diversity of activities and group sizes.

Lastly, third places are nodes of informal and unorganized social interaction, and exist outside of the residence and workplace. They provide opportunity for spontaneous interaction and chance encounters, important in a closed society defined by strict boundaries and routines. They allow for both a sense of anonymity (a rare interaction) and intense familiarity (running into a close friend). They may include a small social gathering space outside the bedrooms, a homey corridor with a view, or the ever important water cooler near the work spaces. Third spaces may emerge in unexpected places such as the greenhouse or exercise area, and should be encouraged so far as they do not disturb others or the mission.

4 Sheryl L Bishop, "Here to Stay: Designing for Psychological Well-Being for Long Duration Stays on Moon and Mars," *Lunar Settlements*, 2010. 271.

Figure 57: *"Escape facilities" exist along a spectrum from active to passive and of group size.*

A Restoration Network

- *Provide escape facilities separate from domestic and workspaces*
- *Provide formal and informal exercise spaces*
- *Provide restorative environments along passive/active and solitary/group spectrums*

On Earth, a stressful day at the office or home can be calmed by a walk in the park, a trip to the bar, or the occasional out-of-town vacation. On Mars, escape is not an option. Escape facilities are a critical part of the Martian settlement, and provide essential opportunities to relax and take a quick physical and mental vacation. They should be separated from work functions and offer differing levels of privacy. Escape facilities exist along a spectrum of activity type (passive to active) and group size (anti-social to social).

Mars' low gravity and, hence, risk of atrophy makes exercise a necessary escape. Due to spatial constraints, past space missions have viewed exercise as a mandate not an opportunity. This makes exercise undesirable and un-motivating for many.[5] A dedicated exercise facility with a diversity of workout options should be provided with a degree of privacy from other functions. It is a valuable third place for social interaction and should accommodate small groups at a time. Where possible, informal exercise areas should be incorporated into a larger network of spaces. These could take the form of wide circulation routes to accommodate jogging or smaller workout spaces in restorative environments such as the greenhouse. They should be located adjacent to hygiene facilities and stimulating interior or exterior views.

A restorative space has two primary characteristics: 1) physical and psychological separation from stressors, and 2) properties of relaxation, fascination, and stimulation. They need to be independent from explicitly social and work environments and have access to high-quality exterior or interior views. They should be considered in tandem with nature, ecosystem connectedness, learning opportunities, creative outlets, challenge, and social spaces. In addition to escape facilities, restorative attributes can be integrated into the entire built environment. Examples of potential restorative spaces include upper decks to observe social spaces, a small study node in the greenhouse, or seating alcoves with views along corridors.

If the settlement represents an urban community, leisure spaces correlate to relaxing domestic activities. These include recreation, hobbies, and entertainment. Leisure spaces can be social or individual, but the primary characteristics are that they are centered on or around activities of choice. They should be specifically programmed for a diversity of activities with differing degrees of flexibility. These include craft workspaces, libraries, TV rooms, game rooms, lounge seating, and more. The specific ambiance of the environment is less critical than it is for restorative environments.

5 Ibid. 270.

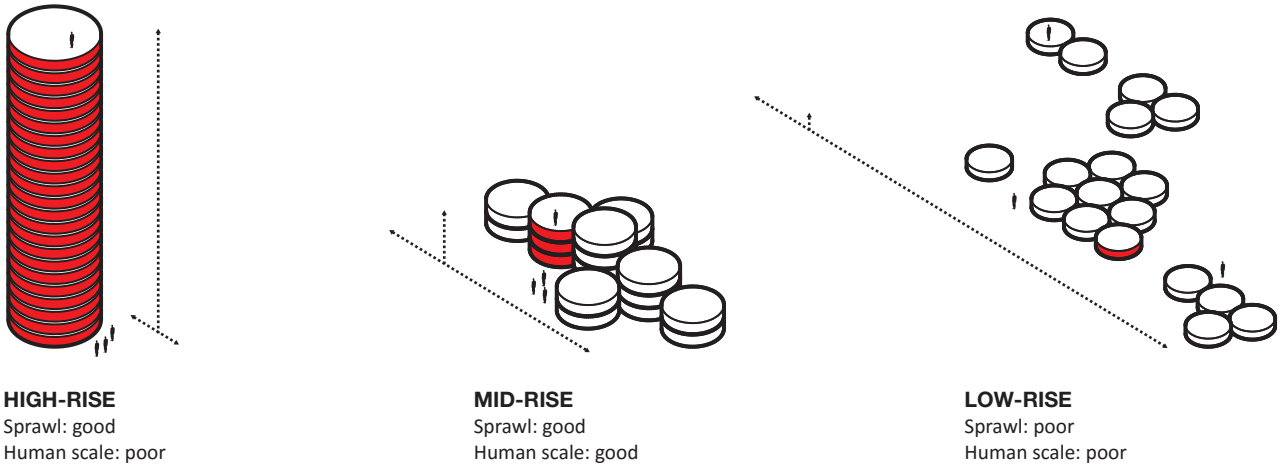


Figure 58: *The height and spread of the settlement are important for creating a human-scale environment.*

Bulk and Scale

- *Support a dense habitat of mid-rise structures*

Due to low gravity, in theory a Mars development could be more spacious and taller than for similar population sizes on Earth. It's easy to get excited about futuristic mega-domes and constrained tubes that traverse a city in the sky. However, rooted in human brains is the notion that we can only trust things we have experienced before, including factors of scale, distance, and form.[6] In such an unfamiliar setting as Mars, building trust into the built environment is paramount.

As mentioned earlier, a Martian settlement is both a building and a public realm. Interior spatial-structural relationships will resemble three patterns that are familiar on Earth: building-corridor (interior), building-street, and building-open space. The latter two relationships provide the opportunity for experiencing both bulk and sprawl.

A Martian settlement needs to minimize sprawl while providing an appropriate density for civic life. Structures should vary between two and four stories tall with floor heights that are relatable to buildings on Earth yet adjusted for the expanded mobility in Mars' gravity.[7] It is important to maintain a height limit particularly along a residential transect. Beyond five floors, an individual begins to lose their connection to the "city" below and can drift into isolation.[8] Bulk exceptions may be made for central social spaces and other functionally unique spaces.

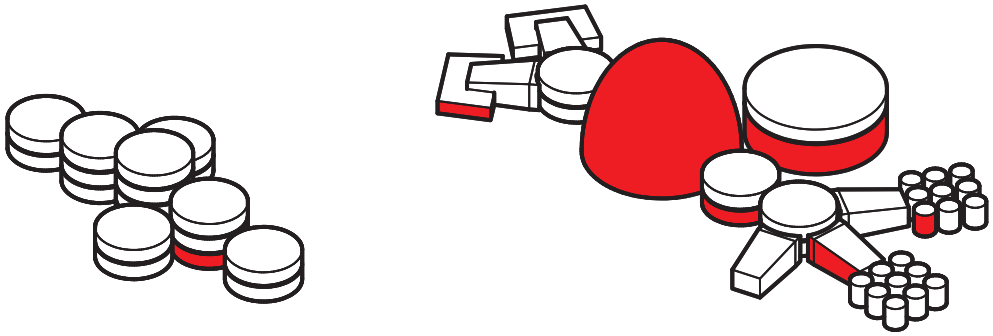
The converse of an oppressively tall habitat is a sprawling one. A sprawling settlement creates an inefficient abundance of circulation space while decreasing choice and capacity for social interaction. Studies of public space have found that two people 25 feet apart can recognize each and communicate whereas two people 100 feet apart will barely be able to recognize each other.[9] In addition, sprawling environments fail to adequately counter the effects of crowding since every person will still seek out the same places at the same times. It increases the likelihood of long corridors which are counter to a positive social field of vision.

6 Robert Gifford, "Environmental Psychology: Principles and Practice," 2002. 25-26.

7 Christopher. Alexander, Sara Ishikawa, and Murray Silverstein, *A Pattern Language : Towns, Buildings, Construction* (New York: Oxford University Press, 1977). 114-119.

8 Jan Gehl, *Cities for People* (Island press, 2013). 41-42.

9 Ibid. 35.



HOMOGENEOUS VOLUMES
The repetitious use of the same form will induce long-term boredom.

DIVERSE VOLUMES
Modulation in form and volume will assist in the creative subdivision of engaging internal space.

Figure 59: *Diverse volumes are preferable to homogeneous ones.*

Diversity of Spaces

- *Provide a diversity of volumes, forms, colors, and materials throughout*

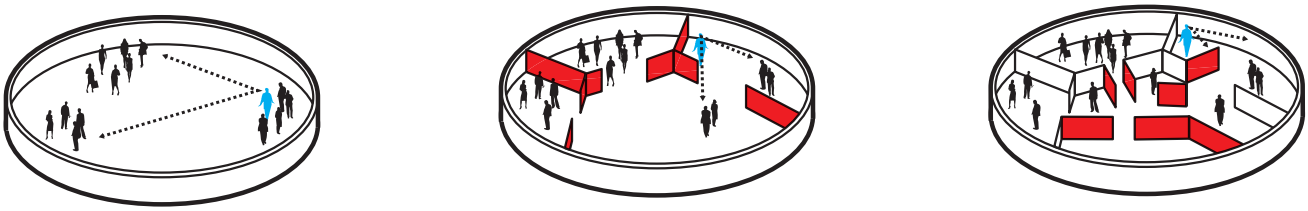
Imagine living in a world where every room is identical, every building is the same exact size, and every park is the same configuration. On Mars, that is a reality that would be far too easy to accomplish using a system of modules, a stark, monochromatic, and overly repetitive environment that could induce boredom, anxiety, and disorientation.[10] For this reason, it is critical that the built environment help provide the spatial diversity that people are accustomed to on Earth.[11] The settlement can achieve this through a diversity of volumes, forms, colors, and materials.

Even with the limitations of a prefabricated module, spatial diversity can be achieved through a flexible design and internal configuration. For a custom built system, designing in diversity should be even easier. For a modular system, multiple modules should be designed that can be flipped or rotated to produce a diversity of spatial dimensions. Landmark spaces may want to be custom modules that differ even more extremely, as done in the design for Halley VI in Antarctica.[12]

10 Peter Suedfeld and G Daniel Steel, "The Environmental Psychology of Capsule Habitats," *Annual Review of Psychology* 51, no. 1 (2000). 243.

11 Vera Martinez, "Architecture for Space Habitats. Role of Architectural Design in Planning Artificial Environment for Long Time Manned Space Missions," *The 15th IAA Humans in Space Symposium* 60, no. 4–7 (2007). 589-590.

12 A Scott Howe and Brent Sherwood, *Out of This World: The New Field of Space Architecture* (American Institute of Aeronautics and Astronautics, 2000).



OPEN
Low Net-Perceived Volume
Low Isolation
High Crowding
Low Utility

COMPARTMENTALIZED
High Net-Perceived Volume
Low Isolation
Low Crowding
High Utility

ISOLATED
High Net-Perceived Volume
High Claustrophobia
Low Crowding
High Utility

Figure 60: *Degrees of compartmentalization can be used to extend the perception of space, although over-compartmentalization may induce withdrawal and isolation.*

Perception of Scale

- *Maximize net-perceivable volume*
- *Utilize permanent and temporary internal compartmentalization*
- *Prevent closed loop compartmentalization that will allow complete withdrawal*

Does the shape and size of a room really matter? As it turns out, yes. Rectangular rooms appear larger than square ones of the same size.[13] Lower ceilings require more personal space per individual and encourage focus whereas higher ceilings create a liberating sensation and alleviate crowding. Circular rooms focus energy inwards whereas long linear spaces are susceptible to crowding. Additionally, curved rooms tend to induce more crowding than rectilinear ones. And space arrangements that partially obscure a portion from view enlarge the overall space in the mind of the viewer.

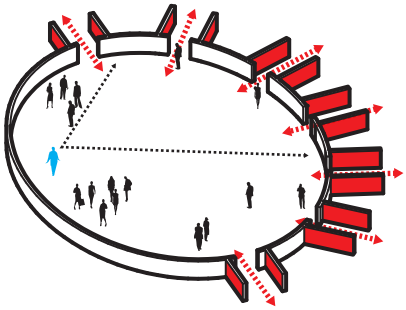
Using this logic, strategically modulate forms, volumes, and ceiling heights to respond to the specific atmosphere being created in that space. With space being a primary limiting factor, the comprehensive planning and design should seek to maximize net perceivable space.

Compartmentalization of large spaces into smaller ones is an easy way to expand perception of space. Used strategically, it segregates uses and mitigates the effects of crowding.[14] However, over-compartmentalization leads to claustrophobic spaces with the potential to induce complete long-term isolation of individuals.[15] The settlement should strategically compartmentalize to maximize functional space while minimizing completely isolated loops. Public spaces should provide a variety of subspaces without enabling individuals to avoid all checkpoints of interaction.

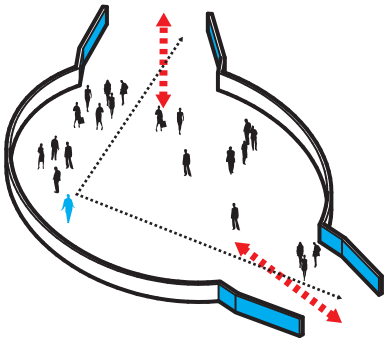
13 Gifford, "Environmental Psychology." 26, 130-131, 184-186.

14 Robert Gifford and Cecile Lacombe, "The Habitability of Spacecraft: Assessments of a Virtual Reality Simulation of the ISS Across Cultural, Personality, and Individual Differences" (Saint-Hubert, Quebec: Canadian Space Agency, 2006). 108-110.

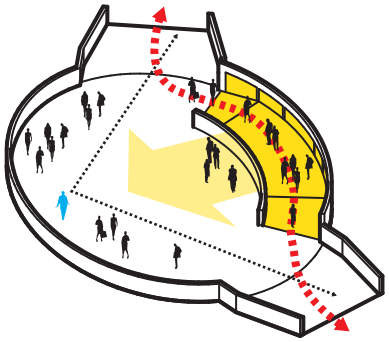
15 Ibid. 110.



INDEFENSIBLE SPACE
Too many access points, inadequate visibility between spaces, and no natural surveillance heightens anxiety in non-private spaces



CONTROL PHYSICAL AND VISUAL ACCESS
A hierarchy of access points that are highly visible from the interior space strengthens territoriality



ACTIVATE FOR NATURAL SURVEILLANCE
Functional edges and circulation routes activate space and increase natural surveillance

Figure 61: *Defensible space is created through controlled access, activation, and natural surveillance.*

Defensible Spaces

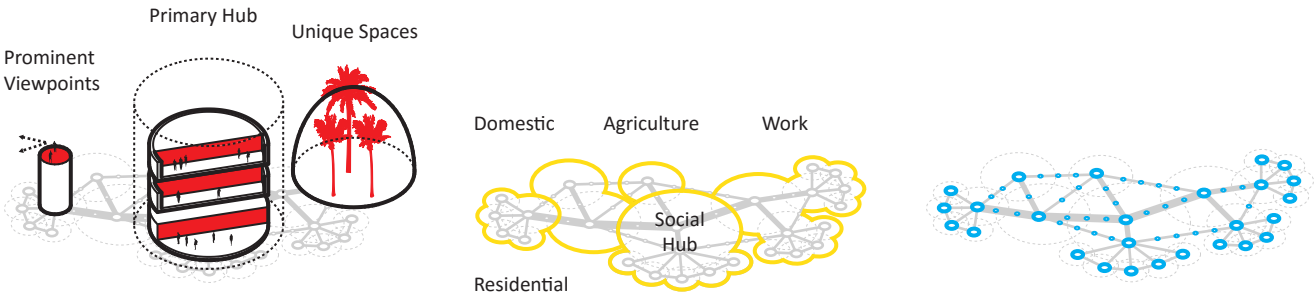
- *Maximize defensible spaces and natural surveillance*

A defensible space is a physical environment that is self-monitoring. This concept explains why people feel more secure in a highly visible plaza than a dark alleyway. An indefensible space triggers an internal fight or flight mechanism that raises stress levels whether or not people are in actual danger. This will be particularly true on Mars, a small society with very little anonymity and tight quarters. In a Martian settlement, defensible space is critical for mediating impacts of density and preserving territoriality.

The master plan should be organized to maximize natural surveillance. Approaching a space, an individual should be able to see into and assess the activities beyond the threshold. Within a space, circulation routes should enter at clearly demarcated points, minimizing surprise entry. A single point of entry into a space can induce the sensation of being trapped, while too many points of entry can be overwhelming and unpredictable. Dead-end corridors and expansive spaces should be avoided completely, while shared spaces should have adjacencies with active circulation routes in order to maintain a natural cross-flow of people. Public spaces should share adjacencies with functions that help to activate space while full-day surveillance should be encouraged with overlapping activities that occur at different times of the day within the same space.[16]

In relation to the "*Privacy Gradient*", semi-private spaces should be monitored by the specific users that occupy it. For example, a residential suite has upwards of eight private residential units that face upon a semi-private shared space. This ensures that as these residents come and go, they will traverse and observe said space. If they are in their rooms, they can watch over the space. It conveys that this space is a shared territory belonging to the residents of these specific units, and that only upon invitation should other people occupy the space. The same logic can be applied to lounges in work wings.

16 Annette Chu, Alice Thorne, and Hilary Guite, "The Impact on Mental Well-Being of the Urban and Physical Environment: An Assessment of the Evidence," *Journal of Public Mental Health* 3, no. 2 (2004). 24-26.



HIGHLIGHT LANDMARKS
Unique spaces and points of reference should be made highly visible and given identifying design features

CREATE DISTRICT IDENTITY
Districts can be defined by dominant use or subarea, and each should have a distinct character and theme.

EMPHASIZE FOCAL POINTS & SOCIAL NODES
Nodes and focal points exist predominantly at intersections and transitions

Figure 62: *Legibility and aspects of identity and wayfinding will be strengthened in a Martian settlement with clear demarcation of landmarks, districts, and nodes.*

Districts, Nodes, and Landmarks

- *Clearly demarcate and define districts, nodes, and landmarks*

A legible environment is easily understood and navigated by the user simply by their own cognition. Legibility increases awareness, decreases confusion, provides orientation, and better enables people to pin-point locations. Pioneered by urban designer Kevin Lynch, mental mapping identifies five elements of a legible built environment: landmarks, edges, nodes, districts, and paths.[17] These five elements should be distinguishable to individuals regardless of language or culture. Since ICEs by nature have clearly defined edges, legibility predominantly hinges on the clarity of landmarks, districts, nodes, and paths. Paths are covered in more depth in "*Glorious Circulation".*

Key landmarks orient people in space as a point of reference for all other spaces. Landmarks include central social hubs, voluminous greenhouses, and distinct architectural features. Externally identifiable features such as launch pads and distant mountains also function as wayfinding landmarks. For example, "look towards Mt Sharp, the bathrooms are down the corridor to the right." Interior and exterior views to landmarks should be highlighted across the settlement. The design of landmark spaces or objects should be amplified to provide a ubiquitous point of reference for the entire crew.

Nodes include focal points, ancillary locational spaces, and intersections. These are junctures that function as a pause in the urban fabric where another decision must be made. Nodes should provide unique social opportunities or moments for rest with design features that provide a positive distraction.

Districts are distinct areas of a similar character, in a Martian settlement likely defined by the dominant uses of residential, social, escape, or work functions. If the complex is a network of clustered sub-developments, each cluster will take on identity as a district. Even a single residential cluster can take on a sub-district identity. Each discernible district should have a unique design language that distinguishes it. This includes any combination of color, elevation change, lighting, views, spatial arrangement, or architectural form.

17 Kevin Lynch, *The Image of the City*, Publication of the Joint Center for Urban Studies (Cambridge, Mass.: MIT press, 1960). 46-49.

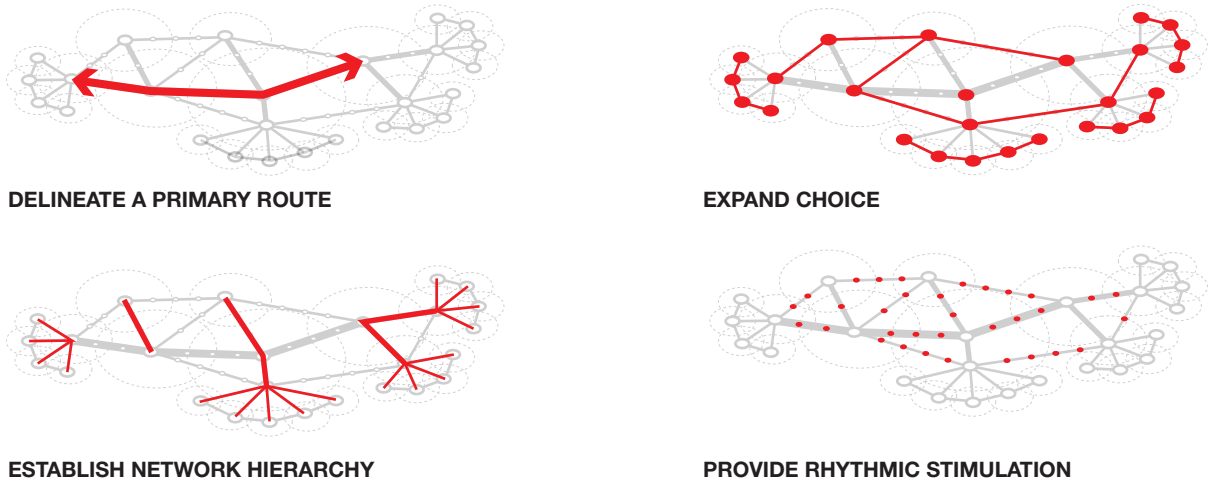


Figure 63: *The circulation network should have hierarchy, choice, and stimulation.*

Glorious Circulation

- *Delineate a hierarchical network with primary routes*
- *Provide choice through alternate routes*
- *Provide stimulating nodes along routes*

A Martian settlement does not have the luxury of sprawling endlessly amongst a sea of roadways and paths. Circulation will need to be compact and efficient, multi-functional, and integrated with spatial planning guidelines. It achieves these goals with a hierarchical network that provides choice and stimulation.

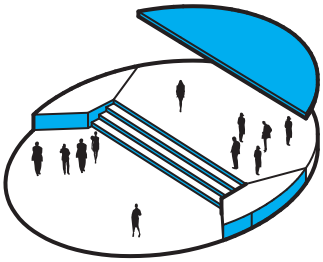
The network should be comprised of major and minor pedestrian flows. Just like the building spaces themselves, the circulation network needs to appropriately respond to spatial relationships. Major corridors should not directly pass private residential areas, and minor corridors should not be expected to handle major flows of people. A logical hierarchy of pathway scales will mitigate the effects of crowding and heighten a sense of privacy. Large public spaces may be bisected by several implied pathways while semi-private spaces may need to be located adjacent to pathways, or in extreme situations require their own segmental separator.

The network should offer multiple route choices without becoming an illegible network of limitless routes. Being able to choose between routes, even just two, will promote a greater sense of control than if forced to take the same route every day.[18] Similarly, the ability to avoid undesirable situations will help mitigate the effects of forced socialization.[19] The ability to selectively walk in loops also provides valuable recreational walking opportunities and expanded emergency routes.

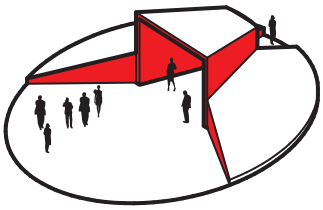
Circulation routes should avoid both long uninterrupted hallways and abrupt turns, both of which reduce the sense of control.[20] Sight lines should be maintained at all times, ensuring that the pedestrian can see into the next space. For this reason, the design should open crossing routes as nodes and avoid acute corners.

Fatigue and lethargy are anticipated symptoms of living on Mars. Circulation should balance accessibility with stimulation, fascination, and challenge. Consider a route not as a single line, but as a series of cohesive segments punctuated by focal points such as social nodes, art, and internal / external viewpoints. Optional challenges such as ramps or stairs, in moderation, help diversify spaces and provide opportunities to experience new perspectives of the same spaces.

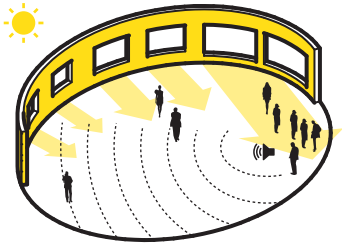
18 Gifford, "Environmental Psychology." 197-198.
19 Joanna Kozicka, "Architectural Problems of a Martian Base Design as a Habitat in Extreme Conditions" (Gdansk University of Technology, 2008). 85.
20 Evans, "The Built Environment and Mental Health." 544.



THRESHOLDS
Transitions between two spaces (locational-locational)



SEGMENTS
Transitions between a space and circulation (locational-directional)



EPHEMERALS
Seasonal or environmental transitions (may coincide with other locational, directional, or transitional spaces)

Figure 64: *Transitions are needed to mediate the extreme compactness of the Martian settlement, to gracefully shift between functional spaces and circulation.*

Sequencing of Space

- *Seamlessly connect directional, transitional, and locational spaces*
- *Provide a high degree of transition throughout*

The sequence of space should be the physical manifestation of daily routines and flows to create a logical pattern of spaces. In order to create a desirable flow and occupation of people in space, each should be identifiably locational, directional, or transitional. These three space typologies overlap considerably, but cumulatively foster sense of here, almost here, and far from here.

Locational spaces are points of activity, such as a laboratory or residence. They represents the most conventional definition of a space.[21] They are centers by which people come to and leave from. Each center can be distinguishable, although some more clearly than others. They are directly connected to routes of circulation yet minimize exposure to stimuli beyond the space in order to foster a sense of "here-ness".

Directional spaces enhance continuity, movement, and future possibility. They often exist at part of a spine along which locational and transitional spaces exist. They are characterized by consistent design features, rhythmic elements, and sense of anticipation through implied views and focal points. Classic examples of these spaces include corridors and walkways.

Transitional spaces help define locational centers, and heighten sensations of change or transformation. They typically adjoin locational spaces along directional routes and can exist at a variety of scales. In a Martian settlement, they become exceedingly important for gracefully approaching, leaving, or connecting locational spaces. As is typical on Earth, dense urban areas require more transition (architectural depth) to help counter impacts to territoriality, crowding, and sense of place.[22]

Transitional spaces exist as three types: thresholds, segments, and ephemerals. Thresholds are spaces that define an area between locational spaces, through distinct changes in direction, level, or form. They may also include likely module features, such as airlocks. Consider the role of stairs in the middle of a social space, a subtle but important way to define two distinct sub-spaces. Segments are transitions between locational and directional spaces. These may include small nodes, arcades, tapering circulation routes, or residential foyers. These provide graceful entry into an important space, a sense of departure or arrival. Ephemeral spaces reflect the transient effects of light, shade, time, and season. They assist in transitioning not spatially, but temporally. They may include changing shadow patterns or sounds (artificial or natural) that alter throughout the day or year.

21 Kevin Thwaites, E Helleur, and IM Simkins, "Restorative Urban Open Space: Exploring the Spatial Configuration of Human Emotional Fulfilment in Urban Open Space," *Landscape Research* 30, no. 4 (2005). 533-536.

22 Gifford, "Environmental Psychology." 185.

Figure 65: *Flexible interiors and movable modules can be used to provide daily, seasonal, and long-term reconfiguration.*

Flexibility vs. Permanence

- *Enable annual and daily reconfiguration of space to maximize utility*
- *Allow rooms to be internally reconfigurable or moveable*

Flexibility and permanence are necessary traits that exist at opposite ends of the same spectrum. Flexibility allows for growth, diversity, and adaptation – all needed in a compact, multi-use, and evolving settlement.[23] It enables stimulating change, periodic repurposing of space, and increased customization.[24] This is all tolerated due to the fact that humans, particularly those who venture to Mars, are incredibly adaptable. Yet in a stressful and foreign environment, it is critical that there exists a level of expectation and reliability in the built environment. Permanence of home features, such as the location and adjacencies of the bedroom are important to our sense of control, privacy, and place. Once altered, a critical leisure or spiritual space may never have the same value again.

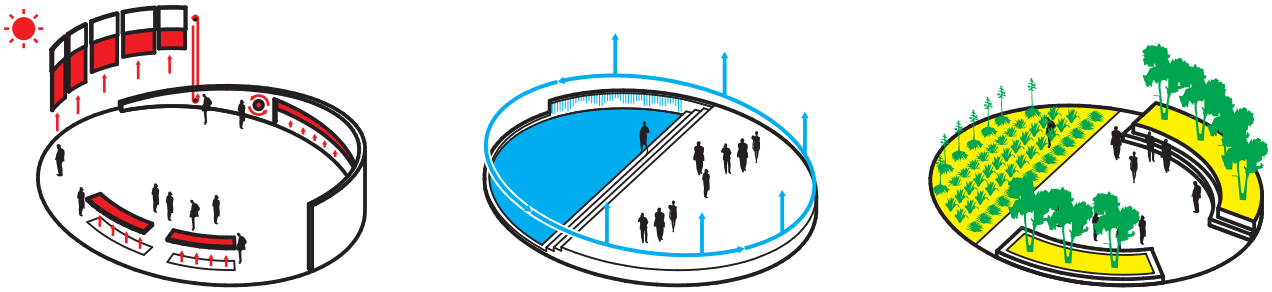
Flexibility refers to the ability of space to change over time and can be considered in two ways: 1) as periodic change before returning to an original state or 2) as permanent change and continuous evolution.

Spaces should periodically reorganize to maximize functional volume over the course of a day, a season, or for a special occasion. For these periodic changes, there are two primary options. First, consider a volume with an interior of flexible divisions that can be easily rearranged. These divisions become thresholds that define the extents of public and private space. For example, imagine a primary hub that can easily configure between a single celebratory space and a series of smaller activity zones. Second, consider a series of modules that can move and realign to respond to the densest areas of people. A module on a track could become a secondary dining room attached to residences in the morning, a conference room attached to workspaces in the afternoon, and a reading room attached to the lounge in the evening.

What happens when a residential area reaches capacity, yet there is new demand? Consider working in flexible spaces that are structurally designed for long-term reconfiguration. For example, a residential cluster may start as five units adjoined to a small lounge. As growth occurs, additional built spaces will grow away from the residential area. At this point, with the advent of new amenities, the lounge can reconfigure as new residential cluster.

23 Howe and Sherwood, *Out of This World*.

24 Sybil Carrere and Gary W Evans, "Life in an Isolated and Confined Environment: A Qualitative Study of the Role of the Designed Environment," *Environment and Behavior* 26, no. 6 (1994). 735-737.



BUILDING FEEDBACK
Responsive built environment to human actions

SYSTEMS
Exposed facets of utility and life-support systems

VEGETATION
Integrated food and oxygen production

Figure 66: *The settlement can foster a sense of connectedness through a responsive built environment, exposed closed-loop life support systems, and integrated vegetation.*

Accessibility vs. Challenge

- *Integrate rewarding mental and physical challenge into the built environment*

The crew of a Mars community will be, for much of its early life, healthy and able-bodied. It is expected that they are adventurous thrill seekers, having already moved to Mars. Integrated attainable challenges will help maintain active minds and enable small accomplishments throughout the day.[25] In addition, they provide opportunities to attain new skills and knowledge. In a Martian settlement, challenges can be used to test Mars' gravity, to incentivize movement, and to stimulate passive attention.

Overall, spaces and pathways should minimize obstacles and inefficient routes. Yet with a third or Earth's gravity, heights and climbs will be far less challenging on the human body.[26] Steep, continuous stairs may be obnoxious but short flights are a welcome climb.[27] Straight paths may be most efficient, but a curving path that provides access to a superior view may be worth the while. While a primary route may want to be more level and universally accessible, alternative routes should engage a playfulness of movement by employing climbing walls, slides, and tracks.

Connectedness

- *Expose facets of the internal habitat "ecosystem"*

Notes from Biosphere 2 revealed that the four inhabitants felt a heightened sense of connection to their built environment, to the larger system, and to the world.[28] Their isolation and reliance on closed-loop systems reinforced their place in the world as critical cogs in a complex ecosystem. This concept evolves from biophilia, the notion that through ecosystem connectedness we better understand our place in the world.[29]

Similar to Biosphere 2, a Martian settlement is more than a building or neighborhood – it is an ecosystem. Both natural and artificial, the habitat should be designed to foster a strong sense of interconnectedness between environment and human. Consider the "natural" systems of the settlement: hydrological, atmospheric, barometric, agricultural, structural, and surface (geographic), to name a few. There is a unique opportunity to remind inhabitants on a daily basis of these support systems that enable their existence. Consider universal and widespread sensory access to oxygen producing plant life and exposed utilities that highlight water and air circulation systems.

25 Rachel Dodge et al., "The Challenge of Defining Wellbeing," *International Journal of Wellbeing* 2, no. 3 (2012). 228-229.
26 Howe and Sherwood, *Out of This World*.
27 Helen Woods Lane, Richard L Sauer, and Daniel L Feeback, *Isolation: NASA Experiments in Closed-Environment Living*, vol. 104 (Amer Astronautical Society, 2002). 73,96,98.
28 Mark Nelson and William F Dempster, "Living in Space: Results from Biosphere 2's Initial Closure, an Early Testbed for Closed Ecological Systems on Mars," vol. 1, 1996.
29 Gifford, "Environmental Psychology." 389-390.

Earth Normal & Mars Awesome

- *Provide an Earth-normal layout*
- *Provide views and cues to the Martian environment*

Humans are creatures of Earth. Every human in an early Martian settlement will have been born and raised on Earth. No amount of research or training can change the fact that their brains and behaviors are shaped by Earth. It is ingrained into their subconscious through a lifetime of exposure to Earth colors, masses, textures, shapes, spaces, layouts, changes in time, and smells.

It is important to maintain aspects of Earth normality.[30] Start simple – up is up and down is down. Cardinal directions should be established. Doors should hold proportion to the body and stairs should be reliably spaced. Walls should be generally straight and meet at right angles where possible. A kitchen is a place to cook food and a dining hall is an area to eat it. The home is separate from the workplace and a weekend vacation is separate from the home. Ultimately, the specific manifestation of Earth normality should be customized the past experiences of the Mars residents.

And at the same time, these residents are explorers and dreamers. They have worked their entire lives to get to Mars, and spent countless years training for, studying, and dreaming about the red planet. They did not move to Mars to live in a place that is a second Earth. They came to be awe-inspired.

The settlement should embody that awesomeness of Mars. Sweeping views should remind users of their context throughout the day. Slightly revised spatial proportions can be imposed to reflect changes in gravity. Airlocks and view portals to the outdoors should not be designed as barriers to certain death but rather the gateways to unrealized potential.

This settlement is a first generation of semi-permanent habitation. As it colonizes and urbanizes, Mars Awesome may become Mars Normal, and Earth Normal may become Earth Foreign. Until that time, however, it is important to remember where we are from and why we are here.

30 Suedfeld and Steel, "The Environmental Psychology of Capsule Habitats." 243.

Site Scale Design Guidelines

Unique Spatial Typologies

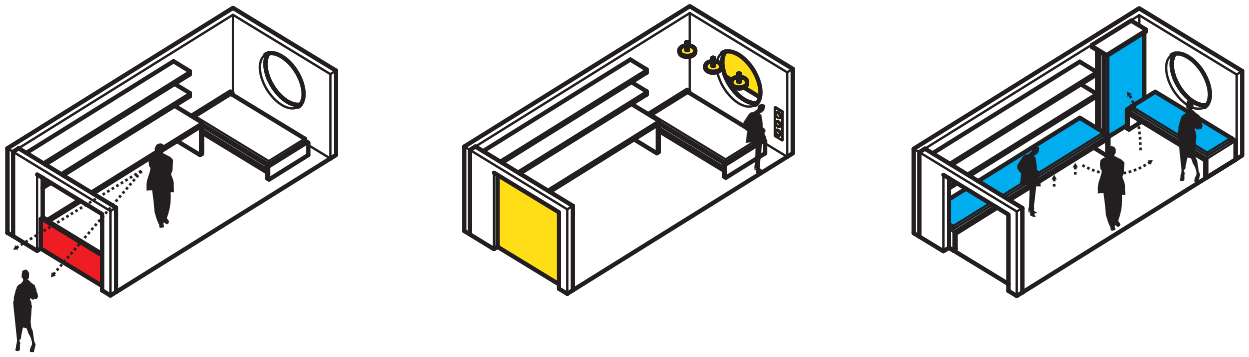
19. **Bedrooms**
    - *Enable modifiable privacy thresholds*
    - *Provide interior environmental control*
    - *Provide a reconfigurable interior layout*
20. **Multi-purpose Space**
    - *Overlay mutually beneficial functions*
    - *Clear demarcate primary and critical functions*
    - *Provide modular functional priority*
21. **Places to Watch**
    - *Provide settings for responsive, observational, and inferential watching*

Spatial Properties

22. **Volumes**
    - *Maximize sight lines, modulate shapes, and adjust ceiling heights to maximize volumes*
    - *Provide a human scale via overhead planes or repetitious site elements*
23. **Divisions**
    - *Situationally use fixed walls, flexible walls, and flexible partitions*
24. **Surfaces**
    - *Use a diversity of colors and textural materials to contrast with the red planet*
    - *Utilize color and material changes to increase legibility*

Design Features

25. **Interior Conditions**
    - *Provide degrees of control to interior conditions that correlate to the privacy gradient*
    - *Modulate lighting based on function and time of day*
    - *Provide a noise-sensitivity gradient*
    - *Provide subtle variations in temperature throughout*
26. **A Room with a View**
    - *Situationally provide exterior, interior, and artificial views*
27. **Personalization**
    - *Provide degrees of personalization that correlate to the privacy gradient*
28. **Stimulation**
    - *Maximize access to natural elements*
    - *Provide design features that stimulate all five senses*
29. **Furniture, Storage, & Clutter**
    - *Minimize sensation of clutter*
    - *Provide deployable or transformable furniture options*



MODIFIABLE PRIVACY THRESHOLD
The ability to modify the front entrance allows the bedroom to undulate between private and semi-private

INTERIOR ENVIRONMENT CONTROL
Attributes of temperature, light, and noise need to be entirely customizable

RECONFIGURABLE LAYOUT
Multiple layout options gives the occupant choice over time

Figure 67: *Bedrooms should enable residents maximum privacy and control, through modifiable thresholds, interior environmental control, and a reconfigurable layout.*

Bedrooms

- *Enable modifiable privacy thresholds*
- *Provide interior environmental control*
- *Provide a reconfigurable interior layout*

Bedrooms are the most important spaces for individual wellbeing and can be expected to be used roughly 40 percent of the time.[31] Each should be dedicated to one individual (or two in the case of partners) and will inevitably be constrained for space. Each bedroom needs to function as a home base, sleeping quarters, an escape facility, and a personal workspace. The design can achieve this through modifiable privacy thresholds, environmental controls, and a reconfigurable interior.

The residences need the capacity to be 100 percent visually and acoustically buffered from other residences and spaces. The doorway should have modifiable positions from locked shut to open to half-open with views out. The status of the front door is a social cue regarding the inhabitant's mood and level of independence desired, and allows for interaction between residences to occur. Additionally, provide moveable walls that can change the distribution of private and semi-private space throughout the day.[32] This periodically exchanges volume between bedrooms and adjacent shared spaces based on times of occupancy.

The residence should provide each individual optimal control over the interior environmental. Each should have a window with blackout shades that enables views from a sitting or lying position. Temperature and lighting should be manually adjusted from the interior. Every surface on the interior should be personalizable and customizable, with wall, ceiling, and shelf space for photographs, mementos, instruments, and personal food storage.

The interior also needs to be flexible to change. Overall, the space needs to accommodate several furniture configurations. This enables the resident to periodically rearrange their own space, giving them control over where they sleep and study. It is advisable to design stowable furniture into the room. Taking cues from micro-housing, a residence with stowable bed, desk, and lounge furniture can take on distinct different functions throughout the day.[33]

31 Carrere and Evans, "Life in an Isolated and Confined Environment." 40.
32 Simon and Toups, "Innovation in Deep Space Habitat Interior Design." 6-7.
33 Ibid. 4-5.

Multi-purpose Spaces

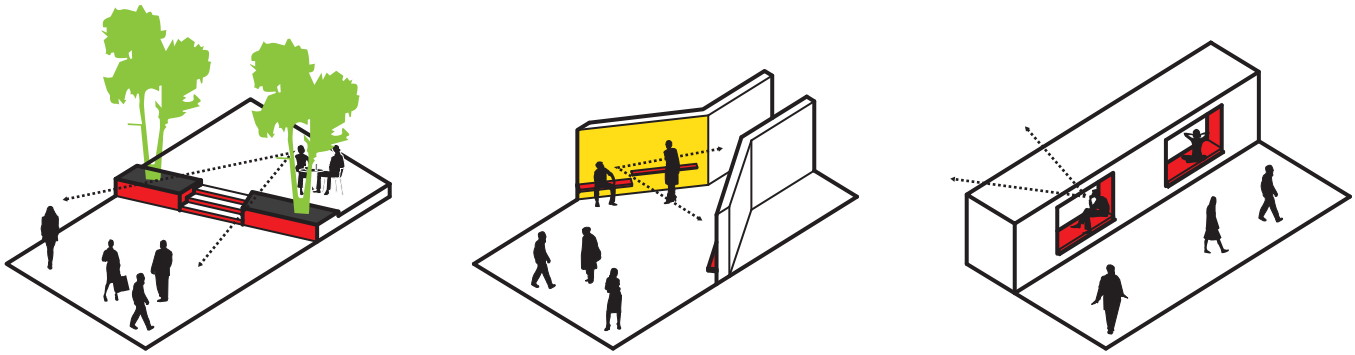
- *Overlay mutually beneficial functions*
- *Clear demarcate primary and critical functions*
- *Provide modular functional priority*

Prior spaceflight designs have relied heavily on dual- and triple-function spaces out of necessity, often to the overall detriment of mission. Yet with volume a critical and limited resource, single use spaces are infeasible and undesirable. In a Martian settlement, efficiency takes the form of multi-purpose and reconfigurable spaces. Multi-purpose spaces rely on mutually beneficial function, clear demarcation of primary functions, and modular functional priority.

Many overlap combinations have major upsides, but are sensitive to cross-contamination. Consider the potential for the following multi-purpose space: a greenhouse for functional food production, a garden plot for hobby gardening, a central workspace that doubles as a secondary social/dining space, edge nooks for passive group activities, a second level with flex-lab space, and a third level with reading rooms and a jogging track. The primary mutual benefit across all of these functions is access to nature, and no function is inherently detrimental to another.

Demarcation of spatial function is critical to protect the integrity of each activity. In the greenhouse example given, the primary function of food production is used during work-hours, while the secondary functions of escape and social facilities are used primarily during the morning and afternoon. Mission critical functions such as food production cannot be jeopardized by other activities, and require physical separation such as low fences or grade change. Others such as laboratory space will have expensive and fragile equipment that is too cumbersome or risky to move or leave exposed to non-work functions.

Multi-purpose spaces require time-of-day modular priority. That is, a space needs to flexibly accommodate the dominant activities for specific times. It can achieve this through stowable and re-arrangeable furniture, flexible walls and partitions, and controlled permission of activities. During work periods, the workspace needs to be the identifiably dominant activity. In the overlap of a social kitchen/dining/social space, the kitchen represents a critical task that must always remain present. However, less critical overlaps such as dining rooms and lounges should be able to modulate their form and arrangement to accommodate temporal needs.



RESPONSIVE
Passive observation,
"people watching"

OBSERVATIONAL
Problem solving, wayfinding

INFERENTIAL
Spiritual, deriving meaning

Figure 68: *There should be moments across the settlement (in circulation or embedded into larger spaces) that afford individuals opportunity to observe their surroundings.*

Settings for Watching

- *Provide settings for responsive, observational, and inferential watching*

Not every activity in space is task oriented. Much of our time we spend enjoying our communities, casually observing or absorbing the settings that surround us. In addition to the variety of passive and active escape facilities outlined in *"A Restoration Network"*, the settlement needs to accommodate a diversity of everyday behavior settings. Most importantly, there need to be opportunities for our favorite human activity: watching.

People have three modes for watching their environment: responsive, operational, and inferential.[34] In the responsive mode, we passively observe the scenes around us as if watching a movie. In the operational mode, we are problem solving, trying to comprehend and make conclusions about our surroundings. Lastly, in the inferential mode, we derive subjective meaning from our surroundings.

These modes can be accommodated at split level overlooks, edges within locational spaces, and nodes within transitional spaces. Vantage points with socio-fugal seating arrangements and views of active public spaces are ideal for responsive watching, such as a seat-wall along the edge of the primary social hub. Here, the user can sit removed from the activity without being disturbed by others. Transitional spaces activate our operational mode as we absorb and interpret a new setting. Since most people can absorb their surroundings relatively quickly, these spaces do not need to accommodate long-term occupancy. Instead, they should be supplemented with short-term seating options or lean rails. Lastly, rewarding focal points that stimulate curiosity and fascination are opportunities for inferential watching, such as a greenhouse overlook or secluded circulation node with a view. Here people may spend extended periods of time placing meaning in their built environment. These spaces are relatively dramatic and should be paired with comfortable seating and overlooks.

34 Gifford, "Environmental Psychology." 281.

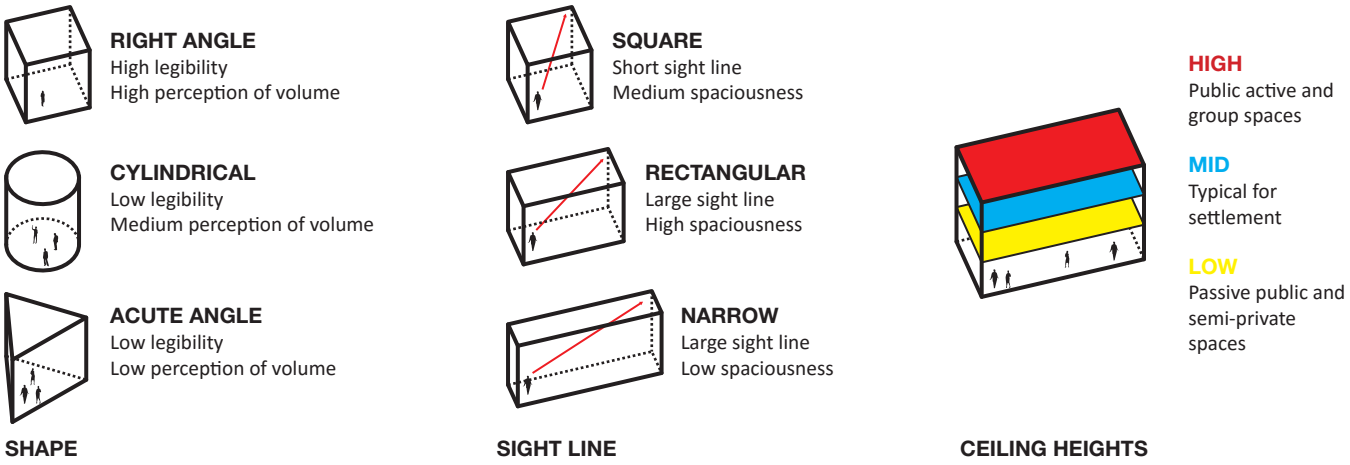


Figure 69: *The shape, sight line, and ceiling height of a space influences its spaciousness and function.*

Volumes

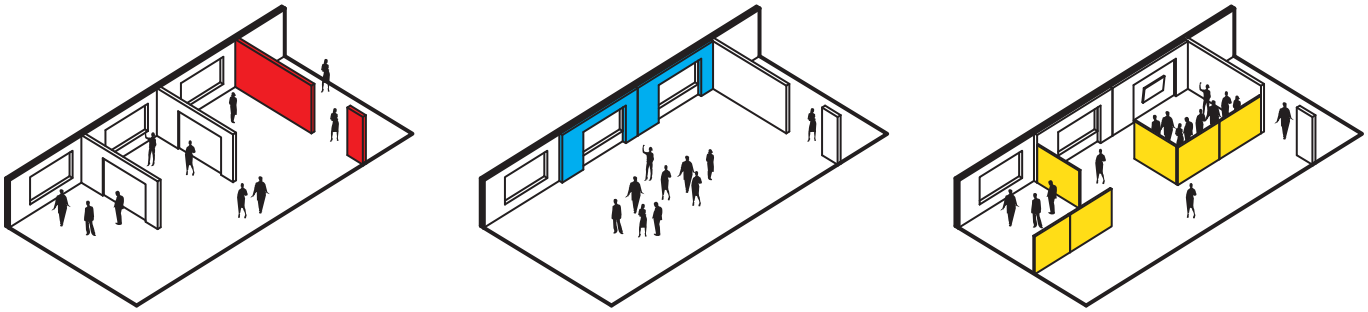
- *Maximize sight lines, modulate shapes, and adjust ceiling heights to maximize volumes*
- *Provide a human scale via overhead planes or repetitious site elements*

As identified in **"***Diversity of Spaces"* and *"Perception of Scale"*, a heterogeneous approach to spaces and volumes is preferred. The volume of space is a critical determinant of a space's function and atmosphere. The following suggestions should be strongly considered for both custom and modular design schemes. In the case of modular designs, careful attention should be paid to how modules can be configured, rotated, and subdivided to create diverse and perceptively spacious volumes.

Shape matters and sight lines are important to the perception of scale. The longest sight line within a volume becomes a focus that determines the perception of scale.[35] For this reason, rectilinear spaces appear larger than square spaces of the same volume. Additionally, cylindrical and spherical volumes decrease legibility and are perceptively less spacious than rectangular volumes. Ceiling heights should modulate based on the task and personal space requirements of a space. Aside from rare circumstances, the height of a volume should not exceed the width. Group or active functions should have higher ceilings, while intimate and passive functions are better suited with lower ceilings.

All spaces should foster a human scale – critical to feeling secure and comfortable in space. For uniquely spacious volumes, such as a greenhouse escape or primary social hub, a human scale can be achieved through hanging light fixtures, trellis overheads along selected edges, or space defining vegetation. Along longer corridor volumes, consider a consistent repetition of human-scaled details including lights, windows, art, and site amenities. Lastly, volumes should reflect attributes of human habitats on Earth with right angles, rectilinear layouts, and standard ceiling heights.

35 Simon and Toups, "Innovation in Deep Space Habitat Interior Design." 5-6.



FIXED WALLS
Permanent boundaries

FLEXIBLE WALLS
Adjustable edges to modulate spaces over time

PARTITIONS
Moveable and removable edges that offer short term divisions of space

Figure 70: *Three types of divisions can be used to ensure maximum utility, efficiency, and desirability of space.*

Divisions

- *Situationally use fixed walls, flexible walls, and flexible partitions*

Despite best attempts to overlap compatible activities and physically separate others, a Martian settlement will be reliant on a diversity of permanent and flexible divisions of space. Divisions needed to satisfy visual, acoustic, and psychological needs. Three degrees of division should be considered: fixed walls, flexible walls, and partitions.

Fixed walls should only be used for fixed spaces that require permanence such as bedrooms, bathrooms, and utility storage areas, to list a few. In all foreseeable instances, fixed walls should be both visual and acoustic barriers. However, given the expected growth and need for long-term adaptation, over-use of permanent walls could impede long-term goals.

Flexible walls provide complete or partial acoustic and visual buffering, but can periodically reconfigure within space. Consider the primary social hub – while this space should accommodate an entire crew, the majority of time will require subdivided spaces. Other applications include for short-term laboratory spaces or modular edges along bedrooms that can shift the balance of public/private space based on time of day. Flexible walls adjust to changing needs for compartmentalization and can be altered after-the-fact to mitigate any instances of isolation.[36]

Lastly, flexible partitions provide varying degrees of short-term psychological, acoustic, and visual buffering. They should be readily reconfigurable by an individual, and be used to create customizable subspaces. Within a reading room, a visual and acoustic partition may be desired for an individual sending messages to their family on Earth. Within a large social space, short term dividers can create sub-rooms for diverse activities or to preserve individual space in the presence of impeding group activities. Within a laboratory, individuals may have different spatial desires for private workspaces, and may need a slight barrier to define their territory.

36 Gifford and Lacombe, “The Habitability of Spacecraft.” 110.

Surfaces

- *Use a diversity of colors and textural materials to contrast with the red planet*
- *Utilize color and material changes to increase legibility*

On Earth, colors and materials differentiate spaces, define design styles, and create unique atmospheres. Compared with Mars, Earth has a truly incredible natural and artificial diversity of surfaces. Buildings in all shapes and sizes display painted adobe to red brick to shiny chrome. Vegetation showcases thousands of shades of green with textures from mosses to great redwoods. People wearing colorful clothing spill out into the streets and businesses with engaging advertising dot the urban landscape. Views of cityscapes, open water, mountains, plains and even desert rotate with the season. On Mars, the exterior will be relatively unchanging and homogeneous in both texture and color. Per writings by Vera Martinez, "architecture alone has to substitute the diversity of the natural environment that the human being is used to, on the face of the Earth."[37]

Utilize a material palette that is familiar to the crew. Consider replicating or transporting Earth materials and textures. In addition to providing a familiar appearance, materials that are stimulating to touch or smell may be valuable in calming and harmonizing a stressful environment. Long term, developing materials from Mars regolith will enable inhabitants to physically interact and connect with Mars within the habitat.

Mars lacks color diversity. Utilize a diverse color palette to contrast and complement the red surface.[38] Lighter colors with dark accents will simultaneously expand the size of the room, reduce crowding, and reinforce natural lights.[39] A diversity of internal colors helps stimulate individuals and ward off effects of monotony.[40] Additionally, colors can be used to heighten emotions of specific spaces. For example, high saturation are perceived as more elegant and comfortable while brighter hues are more active and cheerful.[41]

Both color and texture are integral to the central wayfinding system. The entire settlement should develop and follow a system of color coding for walls, floors, and ceilings.[42] Utilize different textures or colors to identify specific uses, such as walkways or social spaces. Changes in color and material should be used to transition between different behavior settings or districts. Emphasize transitions by using strong and vibrant hues at entries that fade to lighter hues within the volume.[43]

37 Martinez, "Architecture for Space Habitats." 590.

38 Ibid. 592.

39 Simon and Toups, "Innovation in Deep Space Habitat Interior Design." 4.

40 Suedfeld and Steel, "The Environmental Psychology of Capsule Habitats." 244.

41 Gifford, "Environmental Psychology." 247.

42 Suedfeld and Steel, "The Environmental Psychology of Capsule Habitats." 243.

43 Howe and Sherwood, *Out of This World*.

Interior Conditions

- *Provide degrees of control to interior conditions that correlate to the privacy gradient*
- *Modulate lighting based on function and time of day*
- *Provide a noise-sensitivity gradient*
- *Provide subtle variations in temperature throughout*

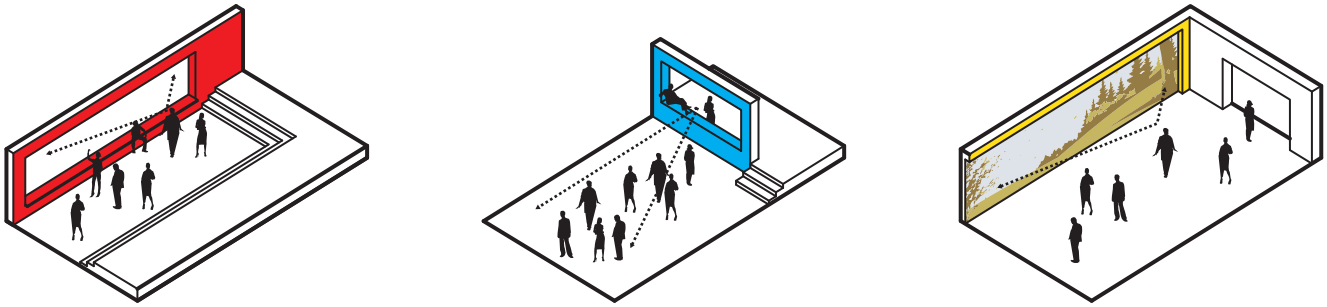
Light, noise, and temperature are the primary interior environmental conditions that dictate wellbeing. These conditions are an issue of personal control and beg the question: who controls them? It depends largely on where the spaces falls on the privacy gradient. For private spaces such as bedrooms or bathrooms, the conditions should be manually set by the individual. For semi-private to semi-public spaces such as small social spaces or workspaces, the conditions should be adjustable but at the discretion of the group. For public spaces or locations reliant on laboratory precision, the design should lean towards automated control. Wherever possible, build small nodes of control into larger, less controllable spaces. Examples include dimmable lighting along seating edges in public spaces, adjustable acoustic barriers in workspaces, and personal heat lamps in a library reading rooms. All three environmental conditions have spillover effects that should be carefully considered as to not become nuisances to others.

Lighting should arc throughout the day to simulate biological circadian rhythms. Full spectrum lighting needs to offset low external light levels and mitigate the potentially severe effects of Martian Seasonal Affective Disorder. While low light levels induce sensations of crowding and loss of territoriality, monochromatic bright lights throughout induce monotony and stress, and poorly accommodate subtleties of specific tasks. Slight differences in light level from space to space can support intended behavior settings – consider brighter direct lights for task oriented spaces such as laboratories and ambient lighting for passive leisure spaces.

Mitigation of noxious noise is dependent upon proper separation of incompatible spaces and use of noise buffering walls and dividers. Utilize non-occupiable spaces (such as storage) as buffers and sequence spaces in order to create a noise-sensitivity gradient. Provide an acoustic threshold to noise-critical spaces and create eddies of acoustic buffering within larger spaces at key locations. Ultimately, noise itself is not a problem – the perceived lack of choice and inability to control it is.[44]

Lastly, temperature is not and should not be viewed as a static condition. Changes in temperature throughout the settlement further sensory diversity. Like light, it should be shaped by individual preferences and behavior settings. Consider varying temperatures between locational and directional spaces, and having escape and social spaces that offer a variety of temperature subtleties.

44 Chu, Thorne, and Guite, "Mental Well-Being of the Urban and Physical Environment." 19.



EXTERIOR VIEWS
Extended views of Martian surface

INTERIOR VIEWS
Views of activity between spaces

ARTIFICIAL VIEWS
Art and digital screens to extend confined spaces

Figure 71: *The limited availability of exterior views may place extreme importance on the provision of engaging interior and artificial views.*

A Room with a View

- *Situationally provide exterior, interior, and artificial views*

Views are positive distractions that reduce stress and illness. When integrated into spaces, they expand the perceived volume and offer moments of psychological escape in daily routine. They can at different times be humorous, reminiscent of home, and awe inspiring. In a Martian settlement, three primary opportunities for views exist: exterior, interior, and artificial.

Exterior views will be a limited resource on Mars. They are high-value edges that need to be accessible to individuals throughout the day – this includes bedrooms, social spaces, escape facilities, and workspaces. Exterior views are most critical for independent and passive group activities. Active group activities are in themselves a positive distraction, and require fewer external stimuli. In most public to semi-private realms, edges should maximize the number of opportunities for an individual to be adjacent to a window. Increase occupiable surface area along these window edges through seating nooks and flexible partitions.

Interior views offer glimpses of activity, nature, and opportunity. The art of people watching is stimulating and restorative by allowing the observer to feel engaged while being removed from social interaction. Offer long views in internal social spaces and between passive and active areas. Provide views from passive to active spaces and from upper level balconies to offer protected covert viewing of voluminous interior spaces. Natural elements, long associated with restorative views, are interior elements on Mars. Provide long views of water or vegetation and short views through a vegetative foreground. Views to nature are especially valuable within bedrooms, escape facilities, or medical wings. Lastly, interior views between directional and locational spaces increase natural surveillance and environmental cognition.

Artificial views are gateways into sights unavailable on Mars. Astronauts have long referenced how important views to Earth and images of hometowns have been in lifting spirits.[45] Images of art, animals, water, and nature have been shown to positively impact health and healing in hospitals.[46] Artificial views on Mars may include digital images of Earth and comforting scenes to remind individuals of home. They are particularly valuable in spaces lacking sufficient interior or exterior views. Digital displays have the advantage of being able to periodically change and to offer an added level of stimulation and unpredictable variety. Consider for small enclosed spaces and corridors.

45 Jack Stuster, *Behavioral Issues Associated with Long-Duration Space Expeditions Review and Analysis of Astronaut Journals* (Houston, Texas: NASA, 2010). 23-25.

46 Gifford, "Environmental Psychology." 410.

Personalization

- *Provide degrees of personalization that correlate to the privacy gradient*

The settlement needs to provide degrees of personalization so that individuals, subgroups, and the collective community can strengthen their identity. This capability should manifest in both private and public spaces.

It is relatively easy to encourage personalization in private realms including bedrooms and personal work-desks, as these are non-disputed territories. In these spaces, surfaces and shelving should be designed to provide maximum personalization by the user. However, it is more contentious for semi-private spaces such as residential suites or specific workspace wings. In semi-private realms, personalization should be determined by the group that occupies the space. The art, photographs, and furniture should be selected to represent the ideologies and character of that subgroup. In doing so, it promotes a patchwork of decoration strategies throughout the complex that give the settlement heterogeneity.

In public spaces, personalization should reinforce the community as a whole. Here, no individual or subgroup should have the capacity to control the look or feel. Instead, preference should be given to rotating displays that highlight shared identities, such as mission-wide accomplishments or photographs of Earth. Smaller areas should be dedicated to highlighting individual or subgroup accomplishments, such as crafts or scientific discoveries. These should rotate in an orderly fashion in an effort to celebrate the entire crew. Additionally, the public spaces should be temporarily redecorated for special occasions, such as holidays or new crew arrivals.

Stimulation

- *Maximize access to natural elements*
- *Provide design features that stimulate all five senses*

The settlement should counter the effects of monotony and sameness by incorporating elements of nature, variety, and activation. This subsection provides a toolkit of site specific strategies can be used throughout the settlement.

Major questions remain regarding how successfully plants will grow on Mars. Despite this, the goal should be to integrate natural elements throughout. Greenhouse spaces are needed for food production, but also provide opportunities for recreational gardening. Public spaces should be complemented with plant species that offer a variety of light and shadow, fragrance, and flavor. Plants with seasonal interest such as fall colors or flowers offer a time of year cue and break from the monotony of the settlement. Herbs and edible plants that are culturally significant to the residents should be grown and used for group meals and special events.

In addition to nature, variety should be accommodated for all five senses in the built environment. Visually, include windows, digital displays, and art to provide stimulation at focal points and nodes. Space windows along corridors to develop patterns of light and shadow. In addition to form, use sequential variation of texture and color to stimulate different emotions and sensations in subspaces. Auditory variety should be used to offset noise from the internal habitat mechanisms and to capture a range of settings not present on Mars. Sounds from Earth, including wildlife, music, and weather could be used to enhance restorative spaces. In corridors, motion activated sounds that periodically change will bring a level of unpredictability to an otherwise mundane commute. Lastly, sensations of touch including materiality, temperature, and humidity should also vary between spaces. Use textures not found on Mars, such as wood grain or tile, to provide elements of nostalgia. Contrast nodes of warmer temperature with corridors of cooler temperature to simulate micro-climates that are present on Earth.

In addition to spatial variety, there should be elements that change over time. These features need to provide a level of unpredictability and spontaneity. For example, digital displays can cycle through nature videos while tickers can keep Martians up-to-date on Earth current events. Lighting effects can be used to alter the hue of a space, which may prove valuable to offset seasonal color changes on Mars.

Furniture, Storage, & Clutter

- *Minimize sensation of clutter*
- *Provide deployable or transformable furniture options*

Storage is of particular importance in a Martian settlement. Every single item needed for survival and mission success needs to be located within the habitat, often resulting in a deficiency of storage space. The resulting impact is physical and visual clutter. The primary goal for storage is to minimize clutter in order to maintain strong visual cues and site lines.[47] Corridors and small spaces are particularly susceptible to clutter and messiness. One strategy is to maintain uncluttered space above waist height.[48] Anything above waist height reduces the perceived openness of a space.

Furniture in a Martian settlement should minimize sensations of clutter and provide choice to individuals. In order to minimize the visual impact of furniture, visually lighter and transparent options are recommended to increase the perception of space.[49] For cramped spaces, such as bedrooms, furniture should be deployable (such as a Murphy bed) or transformable. With a comprehensive design approach, a single kit-of-parts can change between a bed, a sofa, a desk, or a couple or chairs. In public space, a variety of seating options should be provided. Modular furniture that can easily be arranged or stacked to create a variety of seating options is preferred. This enables a space to transform between a socio-petal and socio-fugal arrangement to support to the dominant uses of a multi-purpose space.

47 Simon and Toups, "Innovation in Deep Space Habitat Interior Design." 5-6.
48 Ibid. 5.
49 Ibid. 4.

CONCLUSION

Next Steps

Imagine a day several decades from now. A hundred years and billions of dollars after the idea first popped into Wernher von Braun's head, a group of humans could be arriving on Mars. The residents of this new world will have survived a once impossible 50-million mile journey and will just be getting situated to their new home. During this adjustment period, they will be forging new relationships and establishing their role in this new society. They will be nostalgic about Earth yet fascinated by Mars. Alone on the red planet, these bold pioneers will find every facet of life within their habitat. Their settlement will be their home, their workplace, and their community. It will be designed to mitigate the extreme stressors that each crewmember will face on Mars. The enduring individual and societal wellbeing will help to diminish the loneliness, anxiety, depression, anger, and social unrest that otherwise may plague the mission. And ultimately, the long-term success of not only their mission but all future missions will be dictated by each resident's ability to thrive as part of cohesive whole.

So, how *can* we design a habitat for human wellbeing on Mars? The design guidelines in this study provide a conceptual toolkit of rules, arrangements, and features that can be applied to any design of Martian habitats. There is no single silver bullet – the complexity of this topic requires a holistic approach to design that balances human needs with the extreme conditions of a Martian settlement. The design guidelines serve to advance an emerging discipline of extra-terrestrial planning and design, by building on current goals of space agencies and providing a new lens (wellbeing) as a focus for design. Through this unique lens, the entire study illuminates the immense sensitivity of human needs in a Martian settlement, and yields conclusions that have planning and design applications on both Mars and Earth.

The built environment is only one of many factors that influence wellbeing. For humans to find contentment and cohesion on Mars, wellbeing as a concept cannot exist solely in physical design guidelines. Other factors, such as crew selection, mission goals, mission duration, and communications all play major roles as well. For long-term mission success and habitability on Mars, wellbeing needs to be holistically integrated into agency goals alongside physical health, efficiency, research objectives, and technological innovations.

The design guidelines in this study would be most effective integrated into space agency policy documents and design manuals in order to ensure that the ideas permeate all facets of design and planning. Current NASA spaceflight design standards are driven by utilitarian goals of efficiency and durability. These are exceedingly important values yet lack a necessary human factor. If there can be standards for materials and equipment, there can also be spatial rules that apply concepts of wellbeing. The design guidelines pertain not only to design standards, but also to evaluative criteria that will enable each agency to substantively review and critique proposed Martian habitats. At the very least, the process

Figure 72: *Refugee and disaster relief camps are isolated and largely self-reliant, with a heightened need to foster wellbeing. (Julien Harneis, flickr.com)*

of adopting or adapting design standards for wellbeing will further the discussion and research surrounding habitability on Mars.

This study applies here on Earth as well. The design guidelines for Martian settlement are highly relevant for design and planning of any ICE, such as polar research stations, military compounds, and prisons. However, the basic principles extend beyond a true ICE and can be considered for any self-reliant, contained, or isolated community plan. One major application may be for retirement communities in urban environments. Successful design precedents for previous generations were able provide low density housing in pastoral, suburban environments. However, with a growing number of seniors in urban areas, contemporary retirement communities need to accommodate high densities of people while maximizing wellbeing.

The design guidelines may also apply to temporary settlements including disaster relief and refugee camps. Individuals living in these conditions are vulnerable and subject to high levels of stress. These settlements should be able to support basic human needs such as choice and privacy. Similar to a Martian settlement, the designs need to be resourceful, efficient, and highly adaptable to the changing needs of the population.

Mental health is an emerging topic in urban planning. The current era of mass urbanization is challenging modern cities capacity to provide adequate services and amenities to a growing population. Environmental concerns and shifting cultural values are encouraging municipalities to control sprawl and rapidly densify. New housing booms and community redevelopments in major cities are characterized by big-block apartments and high-rise living. Now more than ever, we need to find creative ways to build efficient cities that can accommodate our diverse psychological and sociological needs.

Beyond the physical constraints of urban design, we have commitment as designers and planners to create more accessible and equitable cities. Social justice concerns can now be viewed in terms of environmental quality, community infrastructure, physical health, and mental health. We need to actively consider how a policy or a plan can impact the wellbeing of members of a community. In providing facilities for disadvantaged or low-income communities, we have just as much if not more responsibility the meet these needs.

Wellbeing as an applied concept helps ensure that cities of tomorrow are desirable places to live. Currently, many cities utilize health impact assessments (HIA) to determine the potential effects a plan or proposal will have on community and environmental health. These assessment protocols, such as PACE EH, are geared more towards attributes of physical health than mental health. The nine wellbeing criteria, modified and simplified into policy statements and goals, would be a powerful asset to improve the quality of life across

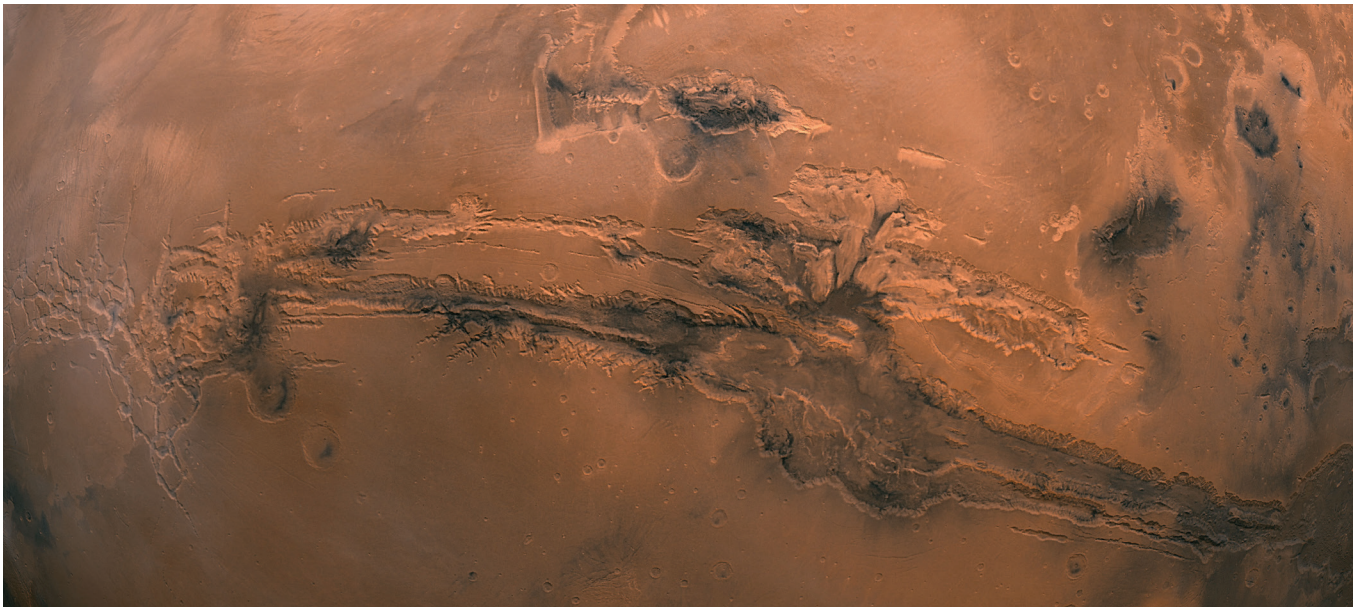


Figure 73: *Mars. (NASA/JPL-Caltech, mars.nasa.gov)*

urban neighborhoods. Additionally, the same approach can be easily adapted for municipal design review boards. Each criteria or objective can be considered for its relevancy to a specific population's needs, leading to the development of site-specific evaluative criteria for planning and design.

Additionally, social sciences, as compared to natural sciences, are more challenging to fully analyze in urban environments. This is the reality for topics that are implicitly more difficult to measure and display spatially, as well as the added challenge of working with human subjects. There is potential to further develop the wellbeing criteria so that they can be quantified and evaluated as one might do for topography or transportation networks. Abstract criterion such as restoration can be extrapolated as physical indicators including tree canopy, architectural landmarks, and "escape facilities". These indicators can then be mapped over a community. This is not a revolutionary approach – it simply involves unpacking physical attributes of communities and repackaging them as characteristics of wellbeing, to be integrated alongside traditional analyses of the built environment.

The assumptions and limitations of this thesis are reflected in the conceptual level of the design guidelines, and provide a first step for future research. As the mission and building systems become more definitive, additional research is needed to refine the design guidelines for a more specific habitat. Major factors such as the objectives, timeline, and governance of the mission need to be better understood for their impact on the built environment. The continued development of closed-loop habitation systems, construction methods, and radiation shielding materials will help inform what the major limitations of the built environment will be. Lastly, the design needs to be specific to a unique population. As the selection of the crew for Mars missions becomes known, it is important to study the specific psychological and social needs for each individual to inform a final design.

Bibliography

Alexander, Christopher, Sara Ishikawa, and Murray Silverstein. A Pattern Language : Towns, Buildings, Construction. New York: Oxford University Press, 1977.

Alexandra Whitmire, Lauren Leveton, Hugh Broughton, Mathias Basner, Anne Kearney, Laura Ikuma, and Michael Morris. “Minimum Acceptable Net Habitable Volume for Long-Duration Exploration Missions.” Subject Matter Expert Consensus Session Report. Houston, Texas: NASA, April 2015.

Anderson, Gina. “NASA Confirms Evidence That Liquid Water Flows on Today’s Mars.” Text. NASA, September 28, 2015. http://www.nasa.gov/press-release/nasa-confirms-evidence-that-liquid-water-flows-on-today-s-mars.

Bishop, Sheryl L. “Here to Stay: Designing for Psychological Well-Being for Long Duration Stays on Moon and Mars.” Lunar Settlements, 2010.

Carrere, Sybil, and Gary W Evans. “Life in an Isolated and Confined Environment: A Qualitative Study of the Role of the Designed Environment.” Environment and Behavior 26, no. 6 (1994).

Chu, Annette, Alice Thorne, and Hilary Guite. “The Impact on Mental Well-Being of the Urban and Physical Environment: An Assessment of the Evidence.” Journal of Public Mental Health 3, no. 2 (2004).

Dodge, Rachel, Annette P Daly, Jan Huyton, and Lalage D Sanders. “The Challenge of Defining Wellbeing.” International Journal of Wellbeing 2, no. 3 (2012).

Evans, Gary W. “The Built Environment and Mental Health.” Journal of Urban Health 80, no. 4 (2003).

Gehl, Jan. Cities for People. Island press, 2013.

Gifford, Robert. “Environmental Psychology: Principles and Practice,” 2002.

Gifford, Robert, and Cecile Lacombe. “The Habitability of Spacecraft: Assessments of a Virtual Reality Simulation of the ISS Across Cultural, Personality, and Individual Differences.” Saint-Hubert, Quebec: Canadian Space Agency, 2006.

Gunderson, EK Eric, Albert A Harrison, Yvonne A Clearwater, and Christopher P McKay. From Antarctica to Outer Space: Life in Isolation and Confinement. Springer Science & Business Media, 2012.

“How Much Living Space Will the Astronauts Have?” Mars One. Accessed April 4, 2016. http://www.mars-one.com/faq/health-and-ethics/how-much-living-space-will-the-astronauts-have.

Howe, A Scott, and Brent Sherwood. Out of This World: The New Field of Space Architecture. American Institute of Aeronautics and Astronautics, 2000.

Kanas, Nick, G Sandal, Jennifer E Boyd, Vadim I Gushin, Dietrich Manzey, Regina North, Gloria R Leon, Peter Suedfeld, S Bishop, and Edna R Fiedler. “Psychology and Culture during Long-Duration Space Missions.” Acta Astronautica 64, no. 7 (2009).

Kozicka, Joanna. “Architectural Problems of a Martian Base Design as a Habitat in Extreme Conditions.” Gdansk University of Technology, 2008.

Kozicki, Janek, and Joanna Kozicka. “Human Friendly Architectural Design for a Small Martian Base.” Advances in Space Research 48, no. 12 (2011).

Lane, Helen Woods, Richard L Sauer, and Daniel L Feeback. Isolation: NASA Experiments in Closed-Environment Living: Advanced Human Life Support Enclosed System Final Report. Vol. 104. Amer Astronautical Society, 2002.

Lynch, Kevin. The Image of the City. Publication of the Joint Center for Urban Studies. Cambridge, Mass.: MIT press, 1960.

Mars One. “What Governmental System and Social Structure Will Be Implemented on Mars?” Mars One. Accessed March 2, 2016. http://www.mars-one.com/faq/mission-to-mars/what-governmental-system-and-social-structure-will-be-implemented-on-mars.

Martinez, Vera. “Architecture for Space Habitats. Role of Architectural Design in Planning Artificial Environment for Long Time Manned Space Missions.” The 15th IAA Humans in Space Symposium 60, no. 4–7 (2007).

NASA. “Journey to Mars.” NASA, October 2015.

NASA, and Sunita Williams. International Space Station Tour. International Space Station, 2003. http://www.nasa.gov/mission_pages/station/main/suni_iss_tour.html.

Nelson, Mark, and William F Dempster. “Living in Space: Results from Biosphere 2’s Initial Closure, an Early Testbed for Closed Ecological Systems on Mars,” Vol. 1, 1996.

O’Donnell, Declan J. “Mars Governance.” In The Founding Convention of the Mars Society, edited by Robert Zubrin and Maggie Zubrin. San Diego, Calif: Published for the Mars Society by Univelt, 1999.

Palinkas, Lawrence A. “Psychosocial Issues in Long-Term Space Flight: Overview.” Gravitational and Space Research 14, no. 2 (2007).

Petranek, Stephen. How We’ll Live on Mars. Simon and Schuster, 2015.

———. “Infographic: How We’ll Live on Mars.” Ideas.ted.com, July 7, 2015. http://ideas.ted.com/infographic-how-well-live-on-mars/.

Sabouni, Ikhlas, and Marshall Brown. “Mars Habitat: Special Topics in Architecture 1990-91.” Prairie View A&M University, August 1991. http://spacearchitect.org/pubs/NASA-CR-189985.pdf.

SEArch, and Clouds AO. “Mars Ice House.” Mars Ice House. Accessed April 5, 2016. http://www.marsicehouse.com/.

Simon, Matthew A, and Larry Toups. “Innovation in Deep Space Habitat Interior Design: Lessons Learned from Small Space Design in Terrestrial Architecture,” 2014.

Stuster, Jack. Behavioral Issues Associated with Long-Duration Space Expeditions Review and Analysis of Astronaut Journals. Houston, Texas: NASA, 2010.

———. Bold Endeavors: Lessons from Polar and Space Exploration. Naval Institute Press, 2011.

Suedfeld, Peter. “Historical Space Psychology: Early Terrestrial Explorations as Mars Analogues.” Planetary and Space Science 58, no. 4 (March 2010).

Suedfeld, Peter, and G Daniel Steel. “The Environmental Psychology of Capsule Habitats.” Annual Review of Psychology 51, no. 1 (2000).

Tafforin, Carole. “The Mars-500 Crew in Daily Life Activities: An Ethological Study.” Acta Astronautica 91 (2013).

Tate, Karl. “The International Space Station: Inside and Out (Infographic).” Space.com, 2012. http://www.space.com/3-international-space-station.html.

Thwaites, Kevin, E Helleur, and IM Simkins. “Restorative Urban Open Space: Exploring the Spatial Configuration of Human Emotional Fulfilment in Urban Open Space.” Landscape Research 30, no. 4 (2005).

Wall, Mike. “Permanent Mars Colony Is ‘Long Way Down the Road.’” Space.com. Accessed April 3, 2016. http://www.space.com/32325-nasa-mars-colony-crewed-mission-outlook.html.

Zubrin, Robert M, and David A Baker. “Mars Direct: Humans to the Red Planet by 1999.” Acta Astronautica 26, no. 12 (1992).