45th International Conference on Environmental Systems
12-16 July 2015, Bellevue, Washington
ICES-2015-156

From Hostile to Hospitable: Changing Perceptions of the Space Environment

Elizabeth Song Lockard, M.Arch, Ph.D.[1]
Chaminade University, Honolulu, Hawaii, 96825

The next generation of Space exploration will see the first humans traveling to Mars, and eventually establishing permanent outposts there. As human voyages extend in duration to years and decades, the scope of human factors research must expand accordingly. The success of the seminal settlements will depend on a comprehensive understanding of the full range of needs for psychological adaptation. Research on psychological adaptation has tended to focus mostly on social dynamics and variables, but very little on the design of physical habitat itself and its the relationship to the exterior surroundings. One of the needs that can be addressed through the habitat architecture is the ability to feel at home in the unfamiliar environs of Mars—but this will first entail a fundamental shift in our current attitude of apprehension towards the Space environment to one of affinity. This paper will discuss why changing those unfavorable perceptions is important; namely that psychological adaptation is premised in part on the formation of positive perceptions of one's immediate environment, and that those perceptions powerfully inform the development of the habitat architecture. Human prosperity in Space will ultimately be linked to a cosmological view of our solar system not as hostile, but as hospitable. In order to better insure the crew's ability to acclimate to the conditions of Mars, three possible means by which perception can be altered will be explored: language, interaction, and technology.

Nomenclature

The language of architecture and the language of astronomy both include the word 'space' in their respective lexicons; while there is some overlap in their meaning, there are also some critical subtle differences. Since I refer to both meanings in this paper I have elected to make the distinction by capitalizing one to indicate a proper name, and the other in small case to indicate a simple noun:

Space = astronomy: the cosmos, the Universe, the heavens, the void between celestial bodies
space = architecture: the general condition of emptiness, absence, or void; the absence of materiality

I. Introduction

OVER the course of manned Space exploration, the scope of human factors research has expanded considerably. In the earliest missions to the Moon, the human needs addressed in the design of the Apollo spacecraft were limited exclusively to physiological issues of survival: insuring that air pressure, oxygen levels, thermal factors, etc., were maintained within somatic limits of its crew. In the more recent generation of Space exploration—which involved not just travel into low-Earth orbit, but also working and living on Space stations—the scope of human needs expanded to include both functional components such as labs and workspaces, as well as practical concerns such as places for sleeping, exercise, and hygiene. Driven by stringent economic and engineering considerations, the design of the spacecraft focused predominantly on meeting only the essential bodily needs; other human factors beyond those requirements played only a nominal role, if any. However, as the objectives of Space exploration shift from short-term scientific missions to long-term human habitation—and especially as we prepare to establish human outposts on Mars within the next decades—a more comprehensive analysis of the needs of the crew must be undertaken; if not fully understood, the consequences for the stationed crew could ultimately be as disastrous as any life-safety or mechanical systems failure.

[1]Associate Professor, Department of Environmental + Interior Design , 3140 Waialae Avenue, Honolulu, HI 96816.

To better assess the broadest range of human needs, Maslow's hierarchy [see Figure 1] provides a reference: At the base of the pyramid are needs required for survival (physiological); built upon those are the needs required for well-being and quality of life (physiological, psychological, sociological); and at the pinnacle are the needs associated with purpose and fulfillment (spiritual). The lowest-tier needs have been rigorously studied in the human factors research, while some middle-tier needs—such as privacy, meals, social rituals, communications, crew interaction, etc.—have begun to be seriously addressed. But some of the elevated needs, such as aesthetic experience, or a sense of belonging and home, have yet to be considered. This paper will argue that in order to address those elevated needs, we must first change the way we think about the Space environment, and transform our disposition towards it from one of hostility to one of hospitability. Successful long-term habitation of Mars will hinge upon how the crew perceives their extraterrestrial surroundings.

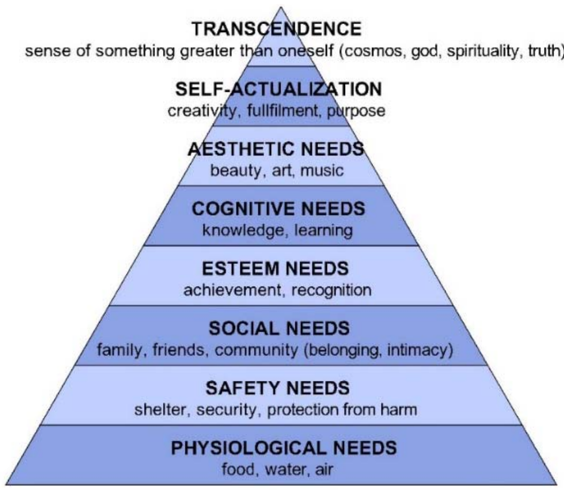

Figure 1. Maslow's Hierarchy of Needs

II. Expanding Criteria for Long-Term Habitability

Habitability, as defined by NASA, is "a measure of the degree to which the environment promotes productivity and well-being".[1] Within this definition are three progressive levels.[2] The first level encompasses the requirements for health, safety and security of the crew. This criterion takes the highest priority and must precede all other considerations. In its nascence, the Space program addressed only these physiological necessities in missions of short duration. The second level, expanding on the first, entails criteria for functional and task performance. This level of habitability received more attention when scientific research and experimentation became a more integral component of the mission. Mission durations also increased from days in orbit to weeks or months on the Space stations. As missions to Space transform into long-term voyages and human outposts on other planets, the third level of habitability, which emphasizes comfort and satisfaction, will become of paramount importance.

In meeting successive new goals, the expansion in scope of human factors—reflecting a bottom-up approach—has been incremental and quantitative. But are the current habitability criteria sufficient for a crew stationed on Mars for 10-20 years? What other considerations can better insure that they will adapt to their remote and unfamiliar environs? Adopting a top-down perspective reformulates the question: what is needed for comprehensive *adaptation* and how does it differ from, or build upon, the criteria for *habitability*? While comfort, leisure, recreation, and quality of life, are indeed indispensable conditions for well-being, they also imply a state of passivity; a disengagement from the resistances and challenges of daily life. But psychological well-being cannot be satisfied by the provision of creature comforts; it also implies positive interactions and an *active* engagement with the physical environment.[3]

Adaptation, in contrast, is characterized by robustness and resilience—all the necessary attributes for prosperity, longevity, and subsequently evolution of our species. It cannot be achieved through passive means. Adaptation is defined as "the adequacy of an organism to cope with the conditions of its natural environment".[4] To adapt means to grow accustomed to the immediate world that we inhabit. There are several mechanisms by which an organism can adapt,[5] but any process of adaptation—whether physiological, psychological or sociological—requires a degree of negotiation with the environment; it cannot occur in a vacuum, or through the avoidance of hazardous environmental conditions.[6] In evolutionary history, species have endured or became extinct, depending on their ability (or inability) to adapt to new or changing environmental conditions. On the one hand, exposure to extreme conditions that exceed our somatic capacities can be detrimental and threaten our very survival.[7] On the other hand, avoiding potential environmental risks at all costs does not provide the opportunity for an organism or species to grow hardier and more resilient when faced with adversity.[8]

To better improve humankind's chances to prosper over the span of their lives on Mars, and eventually to evolve in the environments of other planets, we need to introduce interactions with those environments that will help us become more robust over time. Therefore, in order to adapt both physically *and* psychologically, there must be confrontation with those very resistances and challenges of daily life.[9,10,11,12,13,14] Studies show that when subjects are better adapted to their environments, not only do stress levels decrease, but that crewmembers are more productive and perform their tasks more safely.[15] Understanding stress related to the perception of adversity is key to facilitating psychosocial adaptation.[16]

In the body of research literature on human factors however, adaptation to the environment has been mostly limited to the physiological issues: adaptation to micro-gravity, adaptation to diurnal cycles, adaptation to diet, etc. But the psychological dimension is equally important: adaptation to life in social isolation, adaptation to physical confinement, or adaptation to the remote and extreme conditions of Mars. Numerous studies have proposed possible strategies to solve the problems associated with isolated and confined environments, primarily focusing on crew variables (i.e., dynamics, composition, number, etc.)[a] To a lesser degree, how psychosocial adaptation can be addressed by the habitat interior has also been examined,[b] but the research in this area has generally overlooked the aspect of interaction with our exterior environments and how the habitat architecture can serve as an interface to that end.

One of Maslow's higher-order needs is a sense of belonging to something outside of ourselves—be it to the social realm or physical realm. The feeling of being "at home" where we dwell is the most fundamental way in which we experience belonging. The question of how to instill a sense of home on Mars should become a central consideration in human factors research.[17] This is not simply satisfied by the provision of the physical habitat structure alone. The habitat as *house* is merely a tectonic construct (objective), but the habitat as *home* is a phenomenological one (subjective). Home is our locus of empathy and identity, the reference by which we categorize and interpret domains of belonging.[18,19] Entailed by a sense of home is the intimate connection to landscape and a sense of where we are (phenomenal location[c]), through which we develop empathy with our surroundings. However, we cannot develop attachments to people or places that we view as hostile; they must be grounded in a disposition of kinship or resonance. Moreover, thinking of our surroundings as hostile intensifies feelings of isolation—one of the major obstacles in long-duration Space travel. But if instead, the way we view and interact with our environment focuses on its positive attributes, then feelings of alienation are likely to be diminished.[20]

This raises the question of how humans can develop a rapport with an environment in which they did not evolve. Ironically, it does not matter that the conditions of Mars do not support human life. There are countless examples of "hostile" regions on Earth that many populations call their home. History has shown how people have formed enduring attachments to their homes despite harsh climates and conditions, exposure to physical danger, destruction by natural events, and even the ravages of war. In fact, often to the contrary, hardship can actually serve to reinforce one's sense of home.[21] The greater the obstacles to overcome, the greater sense of affiliation and appreciation we may feel towards it. Despite living in what is commonly characterized as "hostile" conditions, polar workers stationed in Antarctica reported developing strong bonds with their frigid and desolate surroundings.[22] Subjective perceptions of home do not necessarily correlate with the objective circumstances of the environment. It is not necessary that the conditions of Mars be temperate, sunny, wet, or even conducive to life in order for it to be thought of as home one day. While physiological factors for safety and survival are contingent upon actual physical conditions, psychological aspects of adaptation are not; they are dependent upon how we *perceive* those conditions. In addressing the wider range of needs of its human occupants, the design of the habitat must respond both to the subjective perceptions of its surroundings as well as to the real and concrete conditions of the physical environment.[23,24,25]

---

[a] Researchers who have written on crew dynamics include: Marilyn Dudley-Flores and Thomas Gangale, Sheryl Bishop, Kim Binsted, Jim Pass, Gary Evans, Daniel Stokols, and Sybil Carrere.

[b] Research who have focused on the habitat architecture include: Angel Seguin; Janek Kozicki and Joanna Kozicka; C. Burattini, F. Bisegna, F. Gugliermetti, and M. Marchetti.

[c] Phenomenal location, unlike absolute location, is not determined by measurements or mapping, but through human presence and experience.

While the actual physical conditions do not necessarily hinder psychological adaptation, negative perceptions of them do, and therefore we must first consciously cultivate a favorable view of the non-Earth landscape. Change in perception however, cannot be expected from the mere acquisition of information of environmental conditions alone, no matter how detailed or abundant; it must be supplemented by visceral experience. There is a world of difference, for example, between understanding the physical principles behind ocean currents, and actually negotiating its forces when swimming in the sea. Creating this phenomenological relationship to the external environment of Mars—one based on quality of *experience* rather than quantity of *data*—should be an integral aspect of the habitat design. By designing for experience, we can facilitate a deeper and more meaningful relationship to the Martian environment.

Three ways by which to alter perception will be discussed: the first must begin with language (to reflect and inform the way we think about our environments); second is interaction (to become more familiar with our environments), and the third is technology (to mediate our experiences with our environments).

III. Means by which to Alter Perception: Language

The language we use to talk about Space both reflects and informs our attitudes towards it. This is evident in the way various cultures depict Space; the terms that we apply say much about the degree of affinity or alienation we feel towards Space. Culturally ingrained attitudes also profoundly influence both the collective disposition to adapt to new and strange environments, as well as the design of our habitats and other environmental interfaces. Four cultural memes capture the range of attitudes towards Space:[26]

Americans—whose history and cultural spirit are founded on pioneerism—tend to conceive of Space as something to be exploited and conquered. The use of the term 'outer space' in the English language clearly indicates that Space is viewed as an external and foreign entity, distinct from Earth and remote from our cognitive sphere in its 'otherness'. The language of conquest so often associated with exploration reflects attitudes of imperialism and manifest destiny. We see this even in how NASA names their spacecraft after fearsome Greek or Roman gods, like Mercury, Apollo, Gemini, Saturn, Jupiter, Orion, and Titan.[27]

In contrast to the American cosmological view, Japanese culture sees the human species as an integral part of the Universe, not removed from it. Their term for Space—'uchuu'— reflects a view of the cosmos as if from the inside rather than from the outside, as a constituent rather than as an observer. This sensibility is evident in traditional Japanese architecture, which strives for harmony and integration in its surroundings. The Japanese teahouse serves as a metaphor for the Universe, in which the physical structure coupled with the social ritual of the tea ceremony symbolize the realm of Nature and the human interaction within it. This architectural metaphor is derived from an ethos of empathy and connectedness with the cosmos. As opposed to images of power or might, JAXA references folklore and elements of Nature in naming their spacecraft, such as Kibo (hope), Kizuna (wind), Kiku (chrysanthemum), Hinode (sunrise), and Kodama (spirit).[28]

In Chinese the term for Space is 'tiān kōng', which literally translates as 'empty sky', signifying that Space is nothing more than a container, devoid of any presence within it. (Similarly in Vietnamese, the word 'không gian' equates Space with nothingness.) These metaphors represent the abyss, the void, a state of 'nowhereness', and are rooted in feelings of alienation, reflecting both trepidation and anxiety towards Space.

Finally, for the Russian-born Tsiolkovsky—the father of modern rocket science—traveling to Space was not at all a threatening prospect; on the contrary, he imagined zero gravity as a liberating condition, one in which humanity would not only evolve to insure its own survival, but also ascend to greater happiness. His attitude towards the cosmos in his writings is almost euphoric; for him, Space was the ultimate symbol of emancipation from the constraints and limitations of Earth.[d]

In addition to reflecting our attitudes, language—and the ideas it expresses—can also actively shape the way we perceive the world around us. We should abolish descriptors like "hostile" or "inhospitable" when referring to non-Earth venues because they tend to reinforce already negative dispositions.[29] Instead of language that exclusively focuses on the perils of living on Mars, we should consciously incorporate language that positively acknowledges and emphasizes the ways in which the planetary conditions of Mars support human life, and why the Red Planet is the ideal location for our first extraterrestrial outpost. Some of those reasons include the following:

- The partial gravity of Mars provides a vertical orientation that is absent in microgravity
- The terra firma of Mars helps to establish proprioception and facilitates wayfinding
- Partial gravity attenuates the myriad physiological problems associated with microgravity (e.g., Space sickness, facial edema, muscle atrophy, bone decalcification, digestive disorders, etc.)

[d] From Tsiolkovsky's treatise, *Free Space*

- Partial gravity may render the need for artificial gravity devices unnecessary
- Martian structures could be more lightweight and have larger spans than buildings on Earth
- Mars has a similar diurnal cycle to Earth
- Mars has the theoretical potential to be partially terraformed to support plant life, and could eventually create enough atmosphere that humans would no longer need to wear pressurization suits[30]
- Mars is only nine months away under optimal conditions
- Communications, although not instantaneous, are possible between Mars and Earth
- Water (in the form of water ice)—an essential element for all life—is in abundant supply on Mars

In its capacity to both mirror and inform our values, the power of language to change our perception of Space should not be underestimated. If effectively implemented, it can help humans in making the psychological transition to a new extraterrestrial venue.

IV. Means by which to Alter Perception: Interaction

All new encounters with the foreign and unknown initially arouse feelings of trepidation and anxiety, as is expressed in the following passage:

> *"Imagine if you can, a mass of canyons, ravines, ridges, gullies, chasms, and mountains, piled one above another in inextricable confusion…no vegetation anywhere to be seen, nothing but stones around us…this black yawning abyss just before us…The gloom increases with every step. The walls assume in the darkness a thousand grotesque and misshapen forms. The obstacles in our pathway become more frequent and dangerous; the darkness more and more intense…We go on, hesitating, doubting, fearing, until after hours of tedious toil such as I hope never again to experience, we finally reach the bed of the river that has worn this mighty wrinkle in the face of Mother Earth."*

This is an excerpt from the travel journal of nineteenth-century pioneer Samuel Woodworth Cozzen, dramatically titled "Journey of Death", which documented his impressions upon discovering the Grand Canyon while trekking through the southwest.[31] One might expect a similar reaction by the first pioneers to Mars, had they never seen or expected such a landscape before. Even landscapes that today we find magnificent were probably at one time perceived as threatening and treacherous. It is only through prolonged exposure and repeated encounters that we become more familiar and comfortable in exotic environments; and as they become more mundane, our attitudes towards them naturally change.[32,33] Where it once induced terror, the Grand Canyon today is oft described as spectacular and wondrous, and has become one of the most popular geological destinations on the planet, drawing visitors from all over the world. As Mars becomes more familiar to its inhabitants over time, Valles Marineris may likewise one day become a similarly awe-inspiring tourist attraction [see Figure 2].

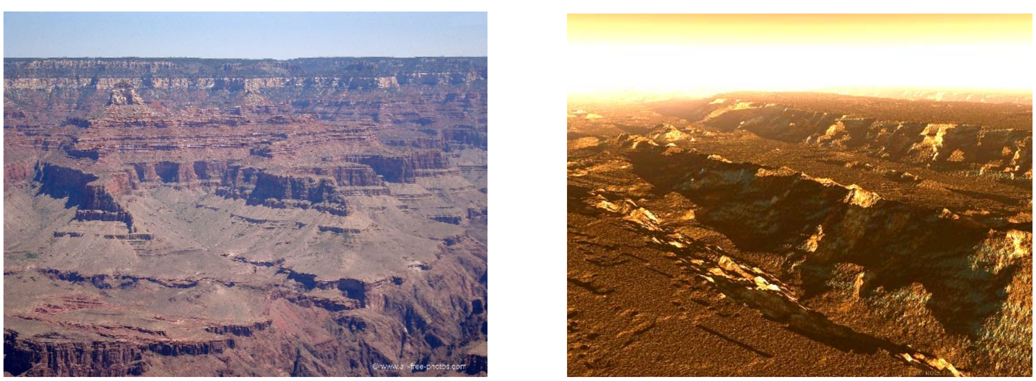

Figure 2. Grand Canyon, Earth (left) and Valles Marineris, Mars (right)

Through the series of reconnaissance missions of the Mars Curiosity and Rovers, which send back high-resolution images of the planet's surface for all the world to see, the process of familiarization has already begun prior to any human having actually travelled there. But in any location, establishing a sense of place—as somewhere real and not imagined—requires actual human presence.[34] The Moon, for example, was merely an abstract visual entity until Neil Armstrong took the first televised steps on the lunar surface. With only that brief human presence, the Moon had been transformed from a conceptualized space to a lived space;[35] it now had human history. It took only the images of footprints in the lunar dirt to change how we perceived the Moon in a way that all the data amassed could not do.

A sense of place—the affective bond we have with our environments—is one of humankind's fundamental needs.[36] The attachment we develop to a place cannot be established only through the acquisition of information—knowledge we acquire through our intellectual faculties.[37] It requires an empathetic connection that can only be derived through the experience of one's surroundings—knowledge we acquire through our sensory faculties. In order to develop the kind of intimate connection to the Martian landscape like the attachment we feel towards our terrestrial homes, inhabitants need to receive as much sensory input of their environs as possible. Specific sensory experiences of the Martian landscape should capture various environmental conditions and phenomena, such as: the topography of the terrain and the firmness of the ground underfoot; the tactile character of the regolith (roughness, dryness, texture, hardness, etc.), the faint winds and fine dust in the atmosphere; the changes in ambient temperature from daytime to nighttime; the range of movement under reduced gravity conditions; and also any sounds or smells in the Martian atmosphere. Although these experiences may not seem vital compared to the conditions required for survival, for a crew living years, decades, or perhaps the rest of their lifetimes on Mars, both the feeling of being at home there and the opportunity for aesthetic experience—especially of their extraterrestrial venue—will be crucial to their long-term adaptation.[38]

V. Means by which to Alter Perception: Technology

Examining how the more esoteric needs beyond shelter, safety, and security can be met through the habitat design and technology calls for an architectural perspective over an engineering approach. While both fields are concerned with the functional and quantitative aspects of the physical structure, an architectural perspective also addresses the qualitative aspects of human occupancy—in particular, the ways in which we perceive and experience the physical spaces we inhabit.

To illustrate the difference in these approaches, let's take a window, for example: an engineer would design the opening to meet quantifiable physical criteria—interior and exterior pressure differential, structural reinforcement to span the opening, expansion and contraction coefficients of the glass, etc. An architect on the other hand, would design the window with an understanding of the subjective component—the impact of natural light and exterior views on mood and behavior, the sense of security afforded by visual awareness of one's surroundings, the feelings of vulnerability of being viewed from the outside, and so on. The window is not simply a transparent surface or an aperture in an otherwise solid wall. On an experiential level it also represents a penetration of barrier, a threshold between domains of interiority and exteriority, and a cognitive portal to a world beyond.[39,40] The window may be a successful feat of engineering and yet still fail miserably from the user's perspective if these phenomenological aspects are not taken into account.

Technological interventions that mediate the physical obstacles of our world can either enhance the experience of the environment or can inhibit them. These interventions can be tectonic, virtual, prosthetic, or robotic in nature. As we develop spacecraft geared towards long-term human habitation—designing for greater human comfort as well as increased safety—supplemental technologies will emphasize leisure and protection. But technologies intended to buffer occupants from the hazards of the immediate environment (such as regolith shielding) also eliminate, or drastically reduce, the possibilities for any positive interaction with the surroundings. The assumptions upon which these types of technologies are based emanate from a view of the foreign and unknown as intrinsically hostile[e], and therefore as such, we should isolate ourselves from those potentially dangerous conditions without having considered potential benefits of interaction. Likewise, technologies of convenience associated with comfort and leisure aim to maximize efficiencies by bypassing obstacles that we would otherwise have to contend with. These 'obstacles' are not valued as an experience in themselves, but rather are seen as something to be avoided. Elevators are an example of a technology of convenience; stairs take effort to ascend, whereas elevators render the arduous effort unnecessary. However, there is a range of sensory experience in climbing stairs that is not afforded by the elevator: a proprioceptive sense of location within the building, the vertical distance traveled, and information of changing conditions along the way. None of these are experienced in the elevator. These types of devices that minimize resistances and sever us from our environment can be characterized as technologies of expedience.

Moreover, should our habitats be designed to exclusively shield its crew from the exterior conditions, it will only exacerbate feelings of confinement and immobility within the enclosure. There are other psychologically detrimental consequences of withholding experience of the outdoors. The activities of the crew will tend to be more introspective,

---

[e] "Hostile" implies an unfriendly, antagonistic, or malevolent disposition—traits that cannot properly be ascribed to entities without agency. "Hazardous" on the other hand—which simply implies a high degree of risk—is a more appropriate term to describe the Martian environment. For example, the ocean can be hazardous but is not considered hostile.

and in the extreme can lead to a state of quasi-solipsism in which what is perceived as real shrinks to only the domain of what can be confirmed directly through sensory input.[41] In addition, denying the members of the crew stationed at a Martian outpost the opportunity to acquire corporeal knowledge of their surroundings will serve to perpetuate any disposition of hostility towards it. Without visceral experience, the crew will not be able to establish a larger sense of place, much less a favorable sense of their habitat as home, which in turn will only impede their ability to adapt psychologically. Sequestration from the exterior environment is therefore not the long-term answer, no more than sequestering crew members from each other would be the ideal solution to avoid social conflicts.

However, the first humans to migrate to Mars will not be able to simply open the door of their abode and take a walk outside. Given the hazardous conditions of the Martian environment, creating opportunities for interaction will not be without intensive technological intervention. Here on Earth, humans have been able to explore extreme environments employing a range of devices that allow discovery of places that were previously impossible to access. For example, prosthetic apparatus such as scuba gear and pressurized vehicles such as submarines have introduced humans to ocean depths that could never have been experienced without some type of equipment. Such interventions do not necessarily dilute the experience if they permit or even encourage increased interaction with the environment.

In contrast to technologies of expedience, these are technologies of experience, the nature of which encourages greater engagement with our surroundings and does not merely strive for efficiencies.[42] The purpose of technologies of experience is precisely to encounter such environmental resistances. They make possible what was previously impossible. They enhance, enrich, enable or supplement relationships to our environments. Negotiation with environmental resistances—be they benign or hazardous—are fundamental to developing intimate connections to the physical world around us. The invention of the sailboat for example, allowed humans to traverse the seas. Its navigators developed a deeper knowledge of the water through negotiating wind velocity and direction, waves, ocean currents, changing tides, weather, and so on. Navigation of a sailboat is challenging and often hazardous, but in spite of this people choose to sail because of the visceral experience it offers of the sea. In comparison, traversing the water by hydrofoil is a completely different event. It is built for high speeds and efficiency in order to minimize the resistances of the sea [see Figure 3]. It is a faster means to a destination in which the ocean is hardly perceived at all, nor do its occupants gain a better understanding of the physical forces of the ocean or its properties.


Figure 3. Crossing the ocean:
Technologies of experience (sailboat) v. technologies of expedience (hydrofoil)

Technologies of experience should be integrated in the Mars habitats, not for any explicit scientific purpose, but so that the crew can learn about their environs through sensory interaction, in addition to opportunities for aesthetic experience. Windows on the ISS were not installed for reconnaissance purposes, but instead at the behest of the astronauts who wished to have a view of the 'world' beyond the enclosure of the module. They served a purely phenomenological purpose, not a scientific one. Crew members reportedly spent 80% of their leisure time gazing out the window.[43] The anecdotal psychological benefits, which came to be known as the Overview Effect, are well-documented and substantiate the need for the crew to establish connections beyond their immediate habitat.[44,45]

Determining the degree and nature of interaction will depend in part on the degree of acceptable risk. Of the possible options that could be explored, incurring the least risk would be the use of virtual reality technologies which can create non-physical, real-time interfaces with the exterior environment. The broadest definition of virtual technologies (VTs) includes any device that either offers an experience of a remote physical environment through extending an individual's sensory or cognitive capacities, or otherwise creates non-physical, digital cyberspaces. Some mundane examples of VTs are the telephone (the former) and the television (the latter).

More recent generations of VTs allow for a greater degree of interactivity and engagement. Skype software, for example, intensified the sense of the caller's presence—previously only aural—by adding a visual component in which faces, bodies and the spaces they inhabit are synchronized with the voice. The crossmodal effects of the visual and verbal dimension brings us a little closer to the *feeling* of actually being there.[46] However, only a critical mass of sensory input is necessary to induce experience; not all senses must be fully stimulated. In the future it is foreseeable that we will achieve a fuller telepresence in a remote planetary setting through an interactive medium that engages all the senses—not just sight and sound, but also smell, taste, and touch, as well as a haptic dimension.[47]

More sophisticated virtual technologies, such as remote sensing and teleoperation through robotic devices have already been deployed to furnish operational interfaces between the crew members and the extraterrestrial environment. Several generations of Mar Exploration Rovers have been utilized for scientific research (e.g., reconnaissance of the planetary topography and geotechnical analyses) through the use of semi-autonomous robotic rovers, sending back images that allow humans to experience the Martian landscape vicariously. The rovers effectively act as extensions of their operators' visual, tactile, motile, and cognitive abilities. But VTs used only for collecting data about the climatic and geophysical properties of a planet is not sufficient alone to foster a bond with the remote landscape. Interface technologies must have an experiential or phenomenological component.

A new generation of virtual technologies will be pivotal to the long-term adaptation process, but their effectiveness will be highly contingent upon how, and for what purpose, they are implemented. If we gear the habitat technologies towards integrating the crew with their surroundings, the perception of the Space environment will shift from one of alienation grounded in the notion of conflicting interests, to one of affinity based on the recognition of common interests. Integration strategies, as opposed to avoidance strategies, are more conducive to establishing empathetic connections and increasing familiarity through perceptual engagement with the exterior conditions. An integrative approach is derived from, but also cultivates, respect for life and all of Nature, valuing both benefits to the human colonists as well as to the environments they inhabit.

One obvious application of VTs would be re-creating familiar places on Earth for which the crew is nostalgic. These re-creations could undoubtedly be beneficial in providing short-term comforts and alleviating immediate psychological or social stresses. However, if used solely for this purpose, VTs could also become a mechanism for maladaptation in the long-term. But if complemented by devices like remote vision goggles or self-controlled rover cameras that can better explore the Martian landscape, then more intense connections to the local surroundings can be forged, thereby reducing the need to recall familiar scenes of Earth for comfort and stimulation [see Figure 4].

Figure 4. "Walking" through the Martian landscape

When we think of 'being in Nature' on Earth, we think of experiencing a place that is not mediated by gadgets, machines, or other devices. In fact, technology is often thought to undermine humankind's connection to Nature. But VTs do not need to be antithetical to the experience of the natural world; on the contrary, they can help us develop more comprehensive and meaningful sensory relationships with the great outdoors. 'Being in Nature' on Mars or on the Moon is not possible without extensive intervention, but how we employ technologies should be thoughtfully considered. VTs can positively frame and shape our interpretations of these encounters—or they can negate them. It becomes even more critical—especially if the primary purpose of the built habitat is to keep its occupants safe by buffering them from the 'hostile wilderness' of Space (cosmic radiation, solar flares, dust storms, frigid temperatures, etc.)—that VTs establish an experiential connection to the extraterrestrial landscape through enhancing our sensory relationships with it. VTs can instantiate conduits not only to *gain knowledge* about the quantitative properties of the environment, but also to *viscerally experience* its qualitative properties in ways the body cannot do so directly. At its best, they have the capacity to bring us even closer to the extraterrestrial environment.

VI. Conclusion

The imperative to alter perceptions of Space should not be dismissed as a marketing strategy to promote the industry or to hype Mars as an attractive tourist destination. The arguments for shifting from negative perceptions to positive ones are grounded in the tangible benefits to a Mars-stationed crew, in that such a shift will fortify their capacity to adapt to a non-Earth environment—and to ultimately survive in the long-term. Moreover, negative characterizations of the Space environment can have significant detrimental psychological effects that may undermine the prospects for a successful human outpost. The perception of Space as "hostile":

- Induces feelings of fear, alienation, trepidation, anxiety, and increased isolation and confinement
- Cultivates a sense of otherness, not of belonging
- Fosters an antagonistic relationship with the environment, and an attitude of conquest towards Space
- Perpetuates an adversarial and segregative disposition
- Focuses on unfavorable conditions in which only dangers are recognized
- Results in treatment of the environment as an obstacle to overcome and exploit
- Views humans as contaminants or trespassers
- Favors the development of technologies of expedience in order to avoid environmental challenges
- Influences habitat architecture to serve exclusively as protection, barrier or shield
- Constricts our sphere of empathy

Conversely, there are many potential advantages when Space is viewed in a positive light. The perception of other planets as "hospitable" environments:

- Induces feelings of wonder, beauty, appreciation, awe, interconnectedness and unity (i.e., aesthetic experience)
- Cultivates a sense of belonging, not of being an outsider
- Fosters ameliorative relationships and an attitude of cooperation and reciprocity
- Focuses on favorable conditions, and recognizes its assets and potentials
- Treats the environment as a realm of possibilities and something to be nurtured
- Views humans as benevolent participants, and as part of the natural environment
- Favors development of technologies of experience for the purposes of greater interaction
- Gives rise to architecture that creates a sense of place and of being "at home"
- Expands our sphere of empathy

This paper has proposed three means by which perception can be altered; the first step is to recognize the crucial role of perception in psychological adaptation. Second is to understand that the language we use in reference to Space informs those perceptions as well as influences how we design and apply habitat technologies (in other words, what we invent and why we invent it). The third step is to maximize opportunities for interaction with, and the acquisition of knowledge about, the environment in order to promote greater familiarity, which in turn reinforces positive attitudes. And finally, allow positive perceptions to inform a new approach to designing human-environment interfaces in the first outposts on Mars. These first outposts are going to be especially critical, as the habitat architecture must do much more than our dwellings on Earth; they will constitute the crew's entire world and realm of experience, and therefore will have to provide for the broadest range of needs and experiences possible. Habitats should not only be designed to keep its occupants safe and secure, but also to enrich the experiences of their new planetary home.

Acknowledgments

This research is supported in part by NASA Grants NNX11AE53G and NNX13AM78G.

References

[1] Preiser, W. (1991). Environmental design cybernetics: A relativistic conceptual framework for the design of space stations and settlements. In A. Harrison, Y. Clearwater, & C. McKay (Eds.), *From Antarctica to outer space* (pp. 147-160). New York, NY: Springer-Verlag.

[2] NASA STD-3000 Volumes I-III. Retrieved from www.standards.nasa.gov/documents

[3] Harrison, A. A. (2010). Humanizing outer space: architecture, habitability, and behavioral health. *Acta Astronautica*, *66*(5–6), 890–896.

[4] Steiner, D. F. R. (2002). *Human ecology: Following nature's lead*. Washington, DC: Island Press.

[5] Moran, E. F. (2000). *Human adaptability: An introduction to ecological anthropology*. Boulder, CO: Westview Press.

[6] Margulis, L. (1998). *Symbiotic planet: A new look at evolution*. New York, NY: Basic Books.

[7] Kelly, K. (1994). *Out of control: The new biology of machines, social systems, and the economic world*. New York, NY: Basic Books.

[8] Margulis, L. (1998). *Symbiotic planet: A new look at evolution*. New York, NY: Basic Books.

[9] Tuan, Y. F. (1977). *Space and place: The perspective of experience*. Minneapolis, MN: University of Minnesota Press.

[10] Ihle, E. C., Ritsher, J. B., & Kanas, N. (2006). Positive psychological outcomes of spaceflight: An empirical study. *Aviation, Space, and Environmental Medicine*, *77*(2), pp. 93–101.

[11] Hillis, K. (1999). *Digital sensations: Space, identity, and embodiment in virtual reality* (1st Ed.), Minneapolis, MN: University of Minnesota Press.

[12] Hayles, N. K. (1999). *How we became posthuman: Virtual bodies in cybernetics, literature, and informatics* (1st Ed.), Chicago, IL: University Of Chicago Press.

[13] Gallagher, W. (2001). *The power of place.* Cambridge, MA: Harvard University Press.

[14] Hooks, B. (1991). Homeplace: A site of resistance. In *Yearning: Race, gender and cultural politics* (pp. 41-49). Toronto: Between the Lines.

[15] Ritsher, J., Kanas, N., Ihle, E., Saylor, S. (2007). Psychological adaptation and salutogenesis in space: Lessons from a series of studies. *Acta Astronautica 60*, 336-340.

[16] Bishop, S. L., Kobrick, R., Battler, M., & Binsted, K. (2010). FMARS 2007: Stress and coping in an arctic Mars simulation. *Acta Astronautica*, *66*(9), 1353-1367.

[17] Carrere, S., Evans, G. W., & Stokols, D. (1991). Winter-over stress: Physiological and psychological adaptation to an Antarctic isolated and confined environment. In Harrison, A., Clearwater, Y., & McKay, C. (Eds.), *From Antarctica to outer space* (pp. 229-237). New York, NY: Springer-Verlag.

[18] Heim, M. (1998). *Virtual realism*. Oxford, England: Oxford University Press.

[19] Hillis, K. (1999). *Digital sensations: Space, identity, and embodiment in virtual reality* (1st Ed.), Minneapolis, MN: University of Minnesota Press.

[20] Seguin, A. (2005). Engaging space: extraterrestrial architecture and the human psyche. *Acta Astronautica*, *56*(9), 980-995.

[21] Hooks, B. (1991). Homeplace: A site of resistance. In *Yearning: Race, gender and cultural politics* (pp. 41-49). Toronto: Between the Lines.

[22] Suedfeld, P. (1997). Homo invictus: The indomitable species. *Canadian Psychology/Psychologie canadienne*, *38*(3), pp. 164–173.

[23] Suedfeld, P. (1991). Groups in isolation and confinement: Environments and experiences. *From Antarctica to outer space: Life in isolation and confinement* (pp. 135-146).

[24] Dator, J. (2012). *Social foundations of human space exploration.* New York, NY: Springer Publishing.

[25] Lockard, E. S. (2006). Habitation in space: The relationship between aesthetics and dwelling. San Jose, California. AIAA 2006-7331.

[26] Lockard, E. S. (2005). Design considerations for long-term habitation in space: The role of aesthetics and human cognition. Presented at the *10th Annual International Symposium on Space Exploration*. International Space University, Strasbourg, France.

[27] Dator, J. (2012). *Social foundations of human space exploration.* New York, NY: Springer Publishing.

[28] Ibid

[29] Ibid

[30] McKay, C. P., Toon, O. B., & Kasting, J. F. (1991). Making Mars habitable. *Nature*, *352*(6335), 489-496.

[31] Gallagher, W. (2001). *The power of place.* Cambridge, MA: Harvard University Press.

[32] Dator, J. (2012). *Social foundations of human space exploration.* New York, NY: Springer Publishing.

[33] McLuhan, M., & Lapham, L. H. (1964). *Understanding media: The extensions of man*. New York, NY: McGraw-Hill Book Co.

[34] Entrikin, J. N. (1991). The betweenness of place. In *The betweenness of place: Towards a geography of modernity* (p. 6-28). Baltimore, Maryland: Johns Hopkins University Press.

[35] LeFebvre, H. (1991). *The production of space*. Oxford: Blackwell.

[36] Tuan, Yi-Fu, *Topophilia: A Study of Environmental Perception, Attitudes, and Values*, Columbia University Press, New York, 1974.

[37] Tuan, Y. F. (1977). *Space and place: The perspective of experience*. Minneapolis, MN: University of Minnesota Press.

[38] Seguin, A. (2005). Engaging space: extraterrestrial architecture and the human psyche. *Acta Astronautica*, *56*(9), 980-995.

[39] Vogler, A., & Jorgensen, J. (May 2004). Windows to the world; doors to space: A reflection on the psychology and anthropology of space architecture. In *Space: Science, Technology and the Arts (7th Workshop on Space and the Arts),* Noordwijk, The Netherlands: ESA/ESTEC (pp. 18-21).

[40] Lockard, E. S. (2014). *Human migration to space: Alternative technological approaches to long-term adaptation*. New York: Springer.

[41] Kanas, N., & Manzey, D. (2008). *Space psychology and psychiatry*. El Segundo, CA: Microcosm Press/Springer.

[42] McCarthy, J. J., & Wright, P. (2007). *Technology as experience*. Cambridge, MA: MIT Press.

[43] Vogler, A., & Jorgensen, J. (May 2004). Windows to the world; doors to space: A reflection on the psychology and anthropology of space architecture. In *Space: Science, Technology and the Arts (7th Workshop on Space and the Arts),* Noordwijk, The Netherlands: ESA/ESTEC (pp. 18-21).

[44] White, F. (1998). ***The overview effect: Space exploration and human evolution.*** American Institute of Aeronautics and Astronautics.

[45] Harrison, A. A. (2010). Humanizing outer space: architecture, habitability, and behavioral health. *Acta Astronautica*, *66*(5–6), 890–896.

[46] Chalmers, A., & Debattista, K. (2009, March). Level of realism for serious games. In *Games and Virtual Worlds for Serious Applications, 2009. VS-GAMES'09. Conference in* (pp. 225-232). IEEE.

[47] Chalmers, A., Howard, D., & Moir, C. (2009, April). Real virtuality: a step change from virtual reality. In *Proceedings of the 25th Spring Conference on Computer Graphics* (pp. 9-16). ACM.