50th International Conference on Environmental Systems
12-15 July 2021

ICES-2021-23

Habitats for Our Future Extraterrestrial Homes – Lessons from Terrestrial Analogues and Our First Habitats in Space

Dr. Sandra Häuplik-Meusburger[1]
TU Wien, Institute for Architecture and Design, Department Hochbau 2, Vienna, Austria

Dr. Sheryl Bishop[2]
University of Texas Medical Branch, Galveston, Texas USA

The social, psychological and spatial significance of living in an extraterrestrial environment places unique demands on the living spaces to support human habitation in such environments. One of the critical requirements for successfully living and working in such environments – and thus mission success – is to fully address the dependency on the habitat, its technological capability as well as the capacity to counteract the stresses of a closed loop, extreme environment. Historically, such habitats have lacked all but the merest attention to such details with a focus primarily on surviving rather than thriving. This is changing and the built environment is slowly becoming an important factor to ensure both physical and psychological wellbeing.

The authors have explored various concepts of the term Habitability for isolated, confined, extreme (ICE) environments from the perspectives of the inhabitants as well as the planners and social sciences. In their upcoming new book, they reviewed an exemplar selection of ICE habitats from the earliest exploratory missions, to the first mockups and simulated habitats, and to terrestrial in-situ facilities as well as human operated space habitats (Häuplik-Meusburger and Bishop, 2021).

This paper summarizes the historical emergent process of development and integration of habitability issues into the design of terrestrial and extratererestiral ICE facilties. Using exemplars from in-situ facilities in both terrestrial and extraterrestrial environments, this paper highlights various current and future concepts of 'habitability' and their translation into design appropriate for future design consideration for extraterrestrial habitats.

Nomenclature

EE = Extreme Environment
EVA = Extra Vehicular Activity
ICE = Isolated, Confined, and Extreme [Environment]
ISS = International Space Station

I. Introduction – The Unforgiving Environment

When we talk about the environment of *outer space* or *extraterrestrial environments*, we refer to a natural environment that is beyond Earth or not from Earth. According to our current knowledge there is no extraterrestrial environment that is naturally livable for human beings as they lack critical resources

---

[1] Senior Lecturer, TU Wien, Institute for Architecture and Design, Department Hochbau 2, Karlsgasse 5/3, 1040 Vienna, Austria

[2] Professor Emeritus, School of Nursing, University of Texas Medical Branch, 301 University Blvd, Galveston, Texas, 77517, USA .

Copyright © 2021 Haeuplik-Meusburger and Bishop

(e.g., breathable air, water) or involve hostile environmental challenges (e.g., microgravity, high radiation). As such extraterrestrial environments are categorized as *extreme environments* (EE).

The social, psychological and also spatial significance of living in an extraterrestrial environment has become more explicitly characterized by a further refinement of the term to incorporate the extraordinary isolation and confinement found in all extreme environments, commonly referred to as ICE *(isolated, confined extreme)* environments. Such environments are those in which "*physical parameters […] are […] outside the optimal range for human survival […] and which conditions […] deviate seriously from the accustomed milieu of most [and further] involve physical remoteness […] and a circumscribed spatial range*" (Suedfeld and Steel 2000, p. 228).

One of the critical characteristics for living and working in ICE environments – and thus mission success – is an extraordinary dependency on the habitat, its technological capability as well as the sociospatial framing, i.e, the elements of the built environment that form the boundaries for the social and individual activities taking place within the habitat. Inhabitants not only must overcome the physical and psychological challenges posed by the dangers and limitations imposed by the particular environment itself, but may also experience significant distress from being confined indoors and isolated from civilization and social contact. All of these factors and their associated stress responses (Table 1) must be taken into consideration when designing livable space or habitats for ICE environments, as the built environment can either mitigate or excerbate those factors. Historically such ICE habitats have lacked all but the merest attention to such details with a focus primarily on surviving rather than thriving. This is changing and the built environment is slowly becoming an important factor to ensure both physical and psychological wellbeing.

Table 1 Examples of stressors associated with habitability for long-term human spaceflight and potential architectural countermeasures (cf. Dudley-Rowley et al. 2004)

Stressors	Effect on human behavior	Architectural countermeasures
Volume limitations	Feelings of claustrophobia, lack of privacy	Interior layout and zoning, windows (real and virtual), virtual or mixed-reality measures
Confinement, isolation and separation	Feelings of claustrophobia, lack of motivation, "cabin fever", degraded performance	Layout (social events, visitors, private communication with family and friends)
Noise, vibrations	Sleep disturbances, poor communication and misunderstandings	Vibration, isolation and control, spatial and temporal zoning of activities
Lighting, illumination	Fatigue, irritability, blurred vision	Lighting design (mix of natural and artificial light, ambient light and task-specific lighting), choice of materials

Using exemplars from in-situ facilities in both terrestrial and extraterrestrial environments, this paper highlights various current and future concepts of 'habitability' and their translation into design appropriate for future design consideration for extraterrestrial habitats.

II. Defining Habitability

Embedded into the broader discussion on human factors integration, habitability plays an important role in the design of any built structure. However, in extraterrestrial and isolated and confined environments, habitability plays a far more crucial role in the physical and psychological wellbeing of the inhabitants as well as mission success. It is important to understand that in extraterrestrial environments and most of the environments characterized as ICEs, the basic requirements of human existence can only be secured by an additional technical envelope, such as the habitat or a space suit. Isolated from the Earth, astronauts must live for long durations within a compact and confined environment, completely dependent on mechanical and chemical life support systems. This building type must be subject to careful design, planning and construction that incorporate both elements for surviving as well as those for thriving.

Today, the term, **habitability,** is understood to be an umbrella term that describes the suitability and value of a built habitat for its inhabitants in a specific environment (cf. Häuplik-Meusburger 2011). It is a complex system related to the individual as well as society in relation to the (built) environment. Components of this system include (cf. Häuplik-Meusburger and Bishop, 2021):

- the Setting (the actual environment, mission length, tasks, type of habitat, and others),
- the Individual (physical and psychological conditons, experience, and others),
- the Group (composition, culture, and others), and
- Time (length, scheduling, and others).

With historical missions of short duration, the integration of habitabitability was seen as 'nice to have' and usually was related to achieving more comfort. When planning long-duration missions, habitability design with all its components (Setting, Individual, Group, and Time) becomes vital for crew interaction and overall mission success (Table 1). As exemplified by Frances Mount (Mount 2002, p. 87): "*The impact of a poorly designed switch or lack of stowage area is different for a mission of six months compared to a mission of one week.*"

III. How to Evaluate and Prove Effectiveness – Operational versus Research Simulation Facilities

As long duration missions are most relevant to extraterrestrial habitability issues, scrutiny of existing long duration facilities highlight why advancement of habitability research in ICEs has been so agonizingly slow as the overriding focus has been on *survivability*. Existing facilities currently vary widely in their existing structures as well as their purpose. For instance, in Antarctica, widely acknowledged as one of the best analogue environments for long duration space missions due to the extensive duration of winter isolation, there exists only one pure research facility, Concordia. Participants at Concordia are true research subjects existing solely to provide data on human adaptation to ICE environments. Most long duration facilities in Antarctica are compromised by their involvement with various non-research priorities, such as meeting the logistic challenges involved in maintaining a national presence in Antarctica as in the case of Mc Murdo Station which involves both civilian and military personnel. For such facilities, there are substantial difficulties in implementing scientific protocols to test human adaptation or to make station modifications to test habitation configurations.

At the opposite extreme to facilities located in actual extreme environments are the laboratory simulation chamber facilities like those found at NASA-JSC (HERA) and the Russian Institute of Biomedical Projects (IBMP) which lack real danger and risk. A compromise between the simulation chambers and the operational facilities in real environments eventually emerged that took the form of habitats built specifically for research purposes situated in moderately challenging or isolated locations in which more experimental control could be implemented as well as moderate confinement and isolation, aka in-situ research stations. Chamber facilities and the in-situ simulation habitats utilize minimalist spartan chambered structures in which to simulate the confinement and limited isolation of missions of varying durations (Table 2). These facilities only loosely mimic protocols for EVA egress/ingress, communication delays, the employment of space suits and other factors that would be in place in an actual extraterrestrial environment. Most are not situated in places characterized by significant environmental risk as with Antarctica. They do, however, provide the opportunity to be somewhat modified in order to target specific design parameters of interest and, thus, offer opportunities for assessing efficacy and effectiveness of different design implementations. Efforts to test various components of habitability and human adaptation in these modular structures has generated growing interest in the construction of new research facilities that can be more easily modified to accommodate a wider range of interior design elements under conditions of varying complexity to test efficacy and effectiveness.

Table 2 Exemplars of past and current chamber facilities and simulation habitats. The facilities simulating long-term human space missions exceeding 6 months are underlined and those in realistic environments are noted with an asterisk. (updated list from Häuplik-Meusburger et al. 2017)

Past Simulators and Simulation Missions	Current Simulators & Simulation Missions (as of 2021)
Regenerative Life Support Study by NASA Langley Research Center	Aquarius and NASA Extreme Environment Mission Operations (NEEMO)*
Apollo Ground-based Tests	Mars Desert Research Station (MDRS)*
MOLAB	Flashline Mars Arctic Research Station (FMARS)*
Skylab Medical Experiments Altitude Test (SMEAT)*	Concordia Research Station in Antarctica*
Skylab Mobile Laboratory (SML)*	NASA Fast Track Horizontal and Vertical Mock-Ups for lunar habitation
Ben Franklin Underwater Research Laboratory*	Environmental Habitat (EnviHab)
Tektite I and II Underwater Research Laboratories*	European Mars Analog Research Station (EuroMARS)*
BIO-Plex (Bioregenerative Planetary Life Support Systems Test Complex)	Australian Mars Research Station (MARS-Oz)*
BIOS-3 (Institute of Biophysics, Krasnoyarsk, Russia)	Virtual Simulators located at Industries, such as TAS-I VR Lab
Biosphere-2*	IBMP (RSA and ESA)
Lunar Mars Life Support Test Project (LMLSTP)	Human Exploration Research Analog (HERA)
Closed Ecology Experiment Facilities (CEEF)	HI-SEAS Hawaii Space Exploration Analog (long-term 2013-2018*; short-term 2018-ongoing)
Jules Verne Underwater Facility*	Haughton Mars Project (HMP) Devon Island
	Lunar Palace – Yuegong-1
	Lunares

III. Habitability Studies in In-Situ Environments

A subset of the examples listed in **Table 2** reflect those in which involve either long duration missions or habitats located in environments in which the hab was essential as protection from the extreme environment. Expeditions, simulations without a habitat, and very short simulations missions were not included. The variability across these facilities in both their physical configurations as well as their mission characteristics is huge which complicates comparisons in the search for commonalities across facilities. The facilities listed in **Table 3 and 4** descriptively highlight exemplary characteristics from both terrestrial analogues as well as space facilities that have contributed to the knowledge on habitability in extreme environments. Before our built environments can be improved, we have to understand where the gaps between need and what is available lies.

A. In-Situ Terrestrial and Extraterrestrial Facilities

How a space is experienced defines how well that space provides for human wellbeing. **Table 3** shows a comparison of some of the terrestrial in-situ analogue habitat characteristics. For instance, the HI-SEAS Facility has a dome structure, and the underwater facilities feature cylindrical ceilings, both of which present different ceiling heights. HERA, MDRS and FMARS feature cylindrical walls but uniform ceiling heights yet different in shape for each floor (i.e., flat ceilings on the first floor but domed ceiling on the second floor). Spatial and structural characteristics such as these not only influence the interior outfitting and integration options (it can be quite a challenge to furnishing spaces) but also represent different perceptions and experiences of the space.

Table 3 In-Situ Terrestrial Facilities: Habitation volume, duration and crew of historical terrestrial facilities. Source: Häuplik-Meusburger and Bishop (2021)

IN-SITU TERRESTRIAL FACILITIES: Habitat Features

Name of Facility	Module type	Environment	Total Area	Simulation duration	Features
TEKTITE I & II Ended 1970	2 vertical cylinders, 2 stories, connected by tunnel	Underwater	~48 m2 + tunnel	10, 20, 60 days	Total dependency on life support; experiments focus on ecology, biology, decompression sickness, microbiology, mycology, isolation, confinement.
AQUARIUS/ NEEMO	Horizontal cylinder, one-story	Underwater	41 m^2	7, 14 days	Total dependency on life support; experiments focus on isolation, confinement, communications, telemedicine, and remote health care technologies.

AMUNDSEN-SCOTT SOUTH POLE STATION	Modular 2-story, adjustable, elevated	Antarctica	7400 m^2	9 m	Bioregenerative life support technology and recycling systems, human health and performance, adaptation to extreme isolation and confinement.
VOSTOK STATION	5 aluminum frame buildings	Antarctica	unknown	12 m	Ice core drilling and magnetometry, actinometry, geophysics, medicine and climatology.
CONCORDIA	2 elevated towers with 3 floors each	Antarctica	1500 m^2	9 m	Studies psycho-social responses to extended isolation and confinement, crew cohesion, task performance.
FMARS	2 story cylindrical	Arctic	8.81 m diameter	2-4 w, 1 & 4 m	Studies psycho-social responses to extended isolation and confinement, crew cohesion, task performance and food study.
MDRS	2 story cylindrical	Desert	10 m diameter	1-2 w, 80 d	Studies psycho-social responses to extended isolation and confinement, crew cohesion, task performance, use of VR in maintaining social connections, and food study.
HI-SEAS	Dome, two story interior structure; Attached shipping container for storage	Volcano	145.8 m^2 / 1462 ft^2 usable	4, 8, and 12 m	Studies psycho-social responses to extended isolation and confinement, crew cohesion, task performance, use of VR in maintaining social connections, and food study.

Overall, the use of terrestrial in-situ analogue simulation environments has provided the bridge between purely operational environments with all the extraneous uncontrolled elements and the overly controlled laboratory and capsule habitats. As such they have helped advance habitability research from humans-in-the-loop studies (i.e., human factors research) to evaluations of human response to the habitat itself. This shift has far-ranging effects.

For instance, human factors studies wherein the human is simply providing assessments of some aspect of the environment (where the environment is the 'subject' of focus; e.g., how appealing, how comfortable, how spacious) have largely not been considered human research (where the human response is the focus). Therefore, those assesments have not been routinely required to undergo review and approval by Institutional Review Boards (IRB) or Ethics Committees. This has generated a number of 'studies' in which extrapolation of human response to environmental characteristics has been approached with a predominantly engineering perspective.

Once the human impact of the environment upon the human becomes the focus, such research meets the criteria as human research and such review is mandatory. It also requires the incorporation of behavioral scientists with expertise in the human side of the equation. This fine line between human factors/engineering design and human subject research has not been well defined nor widely appreciated in the architectural and engineering community. Such regulatory review is frequently experienced as intrusive and stifling in a field which has, heretofore, been able to design with a free hand. However, to develop living spaces that serve human needs, the research into human responses to various habitability factors must be the next central focus in that journey.

Similarly, **Table 4** shows a comparison of some of the extraterrestrial in-situ habitat characteristics. For instance the early space stations are all single element modules. Mir was the first modular space station and with the ISS the first inflatable module was tested. The spatial orientation is mainly horizontal and work oriented. A different orientation has only been accepted for non-working activities, such as sleeping, hygiene and exercise.

Table 4 In-Situ Extraterrestrial Facilities: Habitation volume, duration and crew of historical space habitats and the International Space Station. **Sources: Cohen (2009) and Häuplik-Meusburger (2011)**

EXTRATERRESTRIAL FACILITIES: Habitat Features

Name of Facility	Module type	Spatial Orientation	Habitable Volume [m³]	Mission duration	Features
Apollo CM (with LM) Ended 1972	Single elements; Command Module, Service Module, Service Module, Lunar Module, Lunar Roving Vehicle	CM: horizontal and vertical LM: horizontal	10 (6)	12d 12m (Apollo 15); On Luanr Surface: 3d 2h 59m (Apollo 17)	11 missions, 6 lunar landings; almost constant communication (line of sight) with delay

Salyut 7 Ended 1984	Single element space station with docking possibilities	Horizontal; exceptions: exercise equipment, windows; use of colour code	90	16-237	One resident crew /2-3) and visiting crews (2-3); space station series with gradual change of hardware
Skylab Ended 1979	Single element space station with multiple docking adapter	Mainly horizontal: upper deck: free space; Exceptions: toilet	320	28, 59, and 84	Three crews (3CM); used once; converted rocket; testbed for a number of restraints
Mir Ended 2001	Modular space station; Automated launch and configuration	Similar to Salyut stations	380 (core module: 90)		First international space station, with an original design life of five years, inhabited 1986 – 2000, constantly occupied from 1989 – 1999, Valeri Polyakov spent 438 days at once; Limited communication with mission control
Spacelab Ended 1998	Single module; science extension to fit the Shuttle's cargo bay	horizontal	75 (4.1x7)	8 – 10d Shuttle missions With 12 hour shifts	Was flown on 16 Space Shuttle misisons; reusable laboratory module; multi-configurable
International Space Station (ISS)	Modular space station with truss-backbone structure; Shuttle and robotic arm needed for configuration in orbit	Mainly horizontal	1200	Varies, 180-340;	Inhabited since 2000, since 2009 by a permanent crew of six; Recyling of air, wastewater, urine and production of oxygen; Expandable concept with inflatable modules; constant communication and monitoring via telemetry

The problem is even more acute in existing space facilities. Extraterrestrial facilities are more spartan than terrestrial analogues as survivability – within a tight budget range - has been the central driving demand characteristic in design and construction. Whatever is missing in the terrestrial analogue habitats was magnified many-fold in the extraterrestrial facilities. Therefore, identification of successful 'fixes' for terrestrial deficits should similarly increase beneficence when applied to (future) extraterrestrial facilities. The need to identify such countermeasures that facilitate and support wellbeing and thrivability is paramount.

Overall, the use of terrestrial in-situ analogue environments and the existing minimal space facilities have helped advance habitability research from humans-in-the-loop studies (i.e., human factors research) to evaluations of human response to the habitat itself. Once it became apparent that habitability was a critical factor in wellbeing in ICE environments, greater attention to extraterrestrial in-situ habitability factors became the focus.

IV. Exploring Solutions and Experiences

Humans, as individuals or groups, are in constant interaction with the physical and social environment. There have been many theories built on this relationship. Historically, the 'Engineering Control Theory' was predominant, proposing that a trigger, i.e., an event or situation, causes a chosen human action. A newer perspective, the 'Perceptual Control Theory', has experimentally shown that individuals appear to control their perceptions, rather than actions. If the control lies in human perceptions, then effective fixes must address perceptions, not triggers. Although there are multiple efforts to explain this interconnected system through various scientific and mathematical means, this socio-spatial relation is not yet fully understood and cannot be calculated. However, there are two facts that the authors conclude from their research:

(1) There are **basic human commonalities** to adaptation to the kinds of stresses inherent in extreme environments *(trigger – action / intent - perception)* that are characterized by isolation, confinement and extreme environmental risk (ICEs) and

(2) **Human adaptation** to these environments (*reaction – evaluation*) **is affected by the living spaces** in which the inhabitants live and work (either supportive or limiting).

This perspective proposes that spatial design and its concrete form and materiality can have a positive influence or a negative influence on the inhabitants. It also means that there is not just ONE possible solution to a problem, but a variety of possibilities (design, structure, materials, etc.).

In an extensive 2016 NASA review of risk for adverse cognitive or behavioral conditions and psychiatric disorders, Kelley et al. (2016) combined data from both terrestrial analogues as well as extraterrestrial flights regarding probable sources of stress and disfunction for future long duration crews. The impact of isolation, confinement and adjustment to both terrestrial and the unusual environment of space reaffirmed the risk of emotional, behavioral and cognitive impacts found in terrestrial analogues. The report noted that the same types of countermeasures used in ground-based ICE environments were effective for orbital crews as well, e.g., staying connected with family/friends through electronic media, providing a variety of leisure activities and the importance of food. However, they also noted that long duration, more remote bases on the Moon and Mars would pose clear challenges for these traditional approaches to be effectively employed as distance would interject longer time periods between resupply, restrictions in provision of new resources and communication time lags.

Those same caveats for future solutions was reflected in both published research and a worldwide survey of participant experience in ICE environments (Häuplik-Meusburger and Bishop, 2021). In their extensive exploration of the gaps in habitability needs and existing terrestrial analogues and extraterrestrial facilities, the authors repeatedly uncovered the same major overarching habitability issues. It became clear that among the many factors that will compose the future solution(s), some are obvious … some not so obvious. Some solutions address multiple needs and not all solutions can be applied in all instances, e.g., what may work for a planetary base may not be feasible for a transit vehicle. To complicate matters, any exemplary design suggestion today will be based on current imminent or existing technology, of which some will have already matured into practice and new possibilities will have emerged.

A summary of structural layout and habitat design approaches gleaned from experience in terrestrial analogues and extraterrestrial habitats form a core of essential techniques (outlined below). This is not an exhaustive list but one to spark further exploration and elaboration by the worldwide community of engineers, architects, psychologists, sociologists, human factors, and all others and foster collaboration, discussion, dreams, research, experiment and, ultimately, help craft our home among the stars.

- **Maximizing habitable volume with configurations that are perceived as more spacious.** In addition to physically adding to volume, employment of methodologies to expend the experience of existing volume must be incorporated into all designs. Spaciousness can be conveyed through pathing that offers alternatives to travel to the same destination, supporting individual choice, alternatives to use different routes, increasing occasions to expand social distance and privacy as well as opportunities for greater interpersonal interaction.
- **Design of spatial sequences in multi-directions ('up and down') to overview a larger area, provide wider views, visually lengthen the view and enlarge perceived space.** Use of long views should be incorporated inside the habitat. Physically separated and narrow spaces are persistently perceived to be unpleasant and cramped, versus an open floor plan with flexible partitions in relation to human activities are perceived as pleasant.
- **Utilizing multiple compartments, flexible partitions, adaptable furniture and alike to provide for variety and segregated use.** Evidence from the larger facilities (e.g., McMurdo Station) where there were multiple spaces available persistently reinforced the lamations from participants in smaller stations regarding the lack of adaptable space.
- **Using color, lighting, texture and geometry to enhance desirable moods, reduce feelings of crowding and promote physiological synchronization.** In almost all ICE habitats, both terrestrial and extraterrestrial, use of color and architectural features to counter ICE stress has been minimal. Feelings of crowding have been exacerbated by extreme artificiality and visually complicated environments with over-whelming exposed technology, clutter, and functional décor. The psychological experience of too little (perceived) volume, behavioral constraints (e.g., inability to leave) or too much chaos promotes feelings of crowdedness.
- **Using windows, digital displays, greenhouses or art to counter feelings of confinement and monotony and provide visual depth and to temporarily 'be somewhere else'.** Windows and window analogs have long been recognized as effective architectural elements conveying psychological as well as functional benefits in ICEs and space habitats (Al-Sahhaf, 1987).
- **Designing for multiple uses of greenhouses for food production, leisure activities, stress reduction, crafts, gardening, small group interaction, exposure to full spectrum lighting and natural fractals.** The complex properties of nature have been shown to be psychologically restorative in a myriad of studies due to its infinite variability, evolutionary association with beneficial resources, associations with relaxation and stress reduction activities. One key approach to instilling surprise, harmony and complexity could be in appropriating natural design elements for interior habitat environments according to bionomic (the study of the relationship of organisms to their environment) principles. Multiple astronaut reports underscore the importance of plants and living beings during their missions as astronauts persistently created opportunities to interact with natural stimuli in response to the restriction and artificiality of the habitat (cf. Häuplik-Meusburger 2014; Häuplik-Meusburger et al. 2010a, b).

V. Discussion

The intent is to get us all thinking, not only *outside the box*, but outside the confines of our terrestrial mindset. We know that current strategies used to ameliorate stress levels during short-term missions will be impossible during interplanetary voyages and Mars missions. For instance, support strategies that provide ISS crews private family real-time conferences and internet phone facilities will not be possible during a Mars mission. Therefore, telepresence and full fidelity audio/video/3-D communication replay capability will provide for more effective psychological support and interaction for crewmembers and more effective links to families and friends back on Earth.

What is needed is a paradigm shift that expands our understanding of built spaces and encompasses those characteristics that support well-being at the most fundamental level. British-American architect and design theorist, Christopher Alexander, notes that *"many of the [architectural] processes used today sadly are nearly bound to fail. We see the result of this failure all around us."* (p.3). *"Why don't we –why can't we – make places that feel beautiful and alive anymore?"* (Hora, 2020). Alexander argues that it fails because of our conception of order has become almost completely defined by models that describe the world in mechanistic terms. The success of the scientific method in explaining the mechanical aspects of the world has narrowed our viewpoint at the cost of being able to discuss the things that are truly important to us in the world, i.e., life of structure and human feeling. Because the mechanistic approach to explaining the world has been dominant, we, as a society, have become convinced that the mechanistic view is really all there is to the world, and that any value must come subjectively from us, and is not a part of the world around us. Without the existence of external value, *"we have no guide, no basis and no common ground for producing a living world"* (Hora, 2020).

VI. Conclusion

The future of habitability solutions is pregnant with possibilities! A number of habitability factors can be deliberately employed to enhance coping abilities of those dealing with the extraordinary new living conditions posed by extraterrestrial environments. We are finally at the threshold of a major paradigm shift where the living *space* becomes more important than the living *place*. Enabling technologies involving the use of immersive mixed reality systems and haptic technologies to enhance work and leisure activities as well as provide enriched environmental stimuli are already on the near horizon.

To maximize coping and adaptation, the living space for crews must actively contribute to the process. The best solutions will be those that are passive, i.e., not requiring particular efforts on the part of inhabitants in order to benefit (e.g., one must use the treadmill before gaining any exercise benefit). Embedding the benefit by sheer presence or exposure ensures that inhabitants will be maximizing the potential for effective adaptation. Thus, incorporating facilitative features as part of the habitat seems to be a self-evident win.

At the end, "*it's not how large you make it, it's how you make it large*". [3]

References

Al-Sahhaf, N. A. (1987). Contributions of windows and Isovists to the Juged spaciousness of simulated crew cabins. thesis for the master of science in Engineering, University of 1931 Washington.

Bishop S. L. (2006). Psychological and Psychosocial Health and Well-Being at Pole Station. In C. S. Cockell (Ed.), Project Boreas: A Station for the Martian Geographic North Pole (pp. 160-171). London: British Interplanetary Society.

Bishop, S., Haueplik-Meusburger, S., Guined, J., Peldszus, R. (2016). Bionomic Design Countermeasures for Enhancing Cognitive and Psychological Functioning and Crew Performance in Isolated and Confined Habitats, International Congress for Environmental Systems, Space Architecture,

Vienna, Austria, July 10-14, 2016.Cohen, M. (2009). Testing the celentano curve: An empirical survey of predictions for human spacecraft pressurized volume. SAE International Journal of Aerospace, 1(1), 107-142.

Dudley-Rowley, M., Cohen, M. M., Flores, P. (2004). 1985 NASA-Rockwell Space Station Crew Safety Study: results from Mir. Aviakosm Ekolog Med, 38(1),15-28

Häuplik-Meusburger S., Bishop S., "Space Habitats and Habitability – Designing for Isolated and Confined Environments on Earth and in Space", Springer Nature, Switzerland, 2021.

Häuplik-Meusburger, S., Aguzzi, M., & Peldszus, R. (2010a). A game for space. Acta Astronautica, 66(3–4), 605–609.

---

[3] Jim Wise, private communication with the authors, 2020

Häuplik-Meusburger, S., Peldszus, R., & Holzgethan, V. (2010b). Greenhouse design integration 2019 benefits for extended spaceflight. Acta Astronautica, 68(1–2), 85–90.

Häuplik-Meusburger, S. (2011). Architecture for Astronauts: An Activity-based Approach. Springer Science & Business Media.

Häuplik-Meusburger, S. (2014). Astronauts orbiting on their stomachs: The needs to design for the consumption and production of food in space. Architectural Design, 84(6), 114–117.

Häuplik-Meusburger, S., Binsted, K., Bassingthwaighte, T. (2017). Habitability Studies and Full Scale Simulators: Preliminary themes following HISEAS mission IV. 47th International Conference on Environmental Systems, Charleston, South Carolina, 16-20 July 2017

Hora. Dave. 2020 http://www.archnewsnow.com/features/Feature623.htm

Kelley, S. J., Williams, T. J., Schneiderman, J. S., Whitmire, A. M., Picano, J. J., Leveton, L. B.,

Schmidt. L. L., Shea, C. (2016). Evidence Report: Risk of Adverse Cognitive or Behavioral Conditions and Psychiatric Disorders. https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20160004365.pdf. Accessed 18 May 2020.

Mount, F. E. (2002). Habitability: an Evaluation. In H. W. Lane, R. L. Sauer, D. L. Feeback (Eds.), Isolation: NASA Experiments in Closed-environment Living: Advanced Human Life Support Enclosed System Final Report. San Diego, CA: American Astronautical Society.

Suedfeld, P., Steel, G. D. (2000). The Environmental Psychology of Capsule Habitats. Annual Review of Psychology, 51, 227-253.

.