Habitats - Isolated and confined environments on Earth and in space

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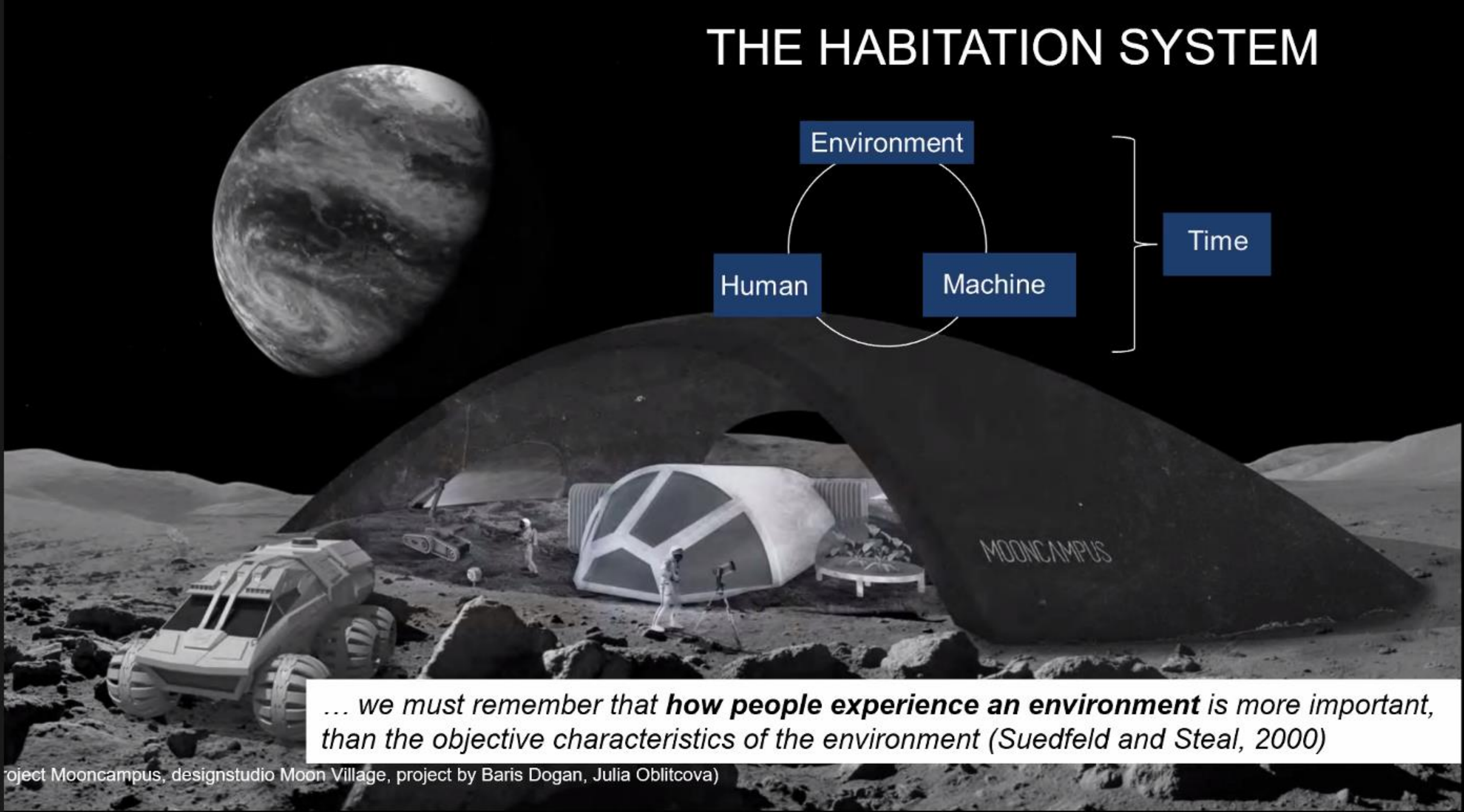
The Multidisciplinary Nature of Habitability Design

If you want to go fast, go alone. If you want to go far, go together. (African Proverb)

- The view from engineering - technological
  - *How do I build the best space for an exterior challenging place?*
- The view from architecture – environmental
  - *What is the best interior space for the place?*
- The view from psychology - human
  - *Who are the best people for a space in a particular place?*
- What is needed– technological + environmental + human
  - *HOW do we make the best space for the people who will be in that particular challenging place?*


THE HABITATION SYSTEM
Environment
Human
Machine
Time
MOONCAMPUS
… we must remember that **how people experience an environment** is more important, than the objective characteristics of the environment (Suedfeld and Steal, 2000)
oject Mooncampus, designstudio Moon Village, project by Baris Dogan, Julia Oblitcova)

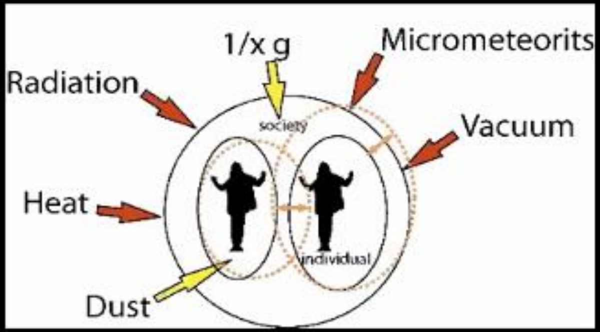
Integrating Environments and Humans

1. What are the effects?
2. Do they impair functioning?
3. Are they self-limiting or progressive?
4. Are they reversible and when?
5. What are the countermeasures?

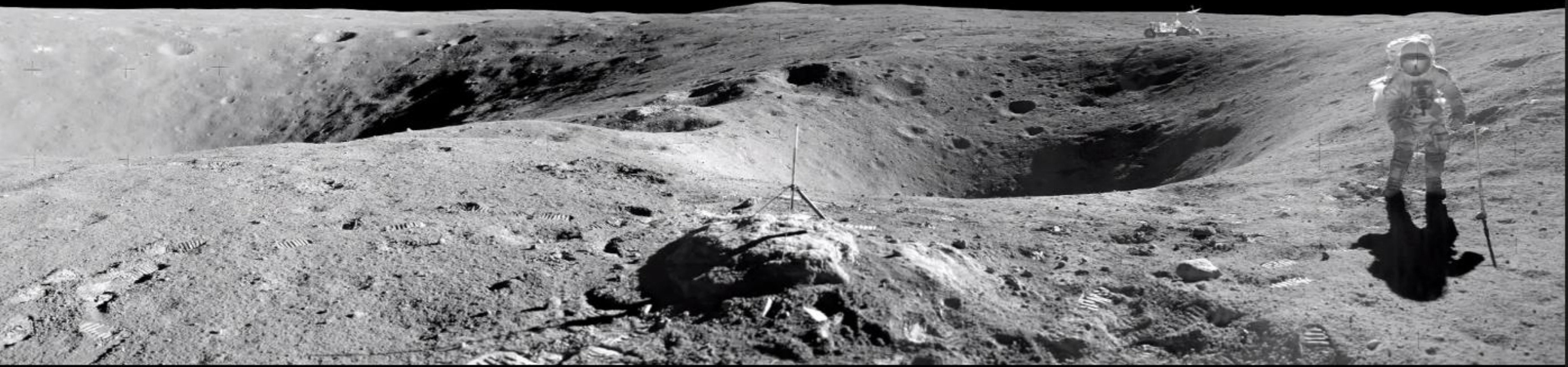
Apollo mission (NASA)

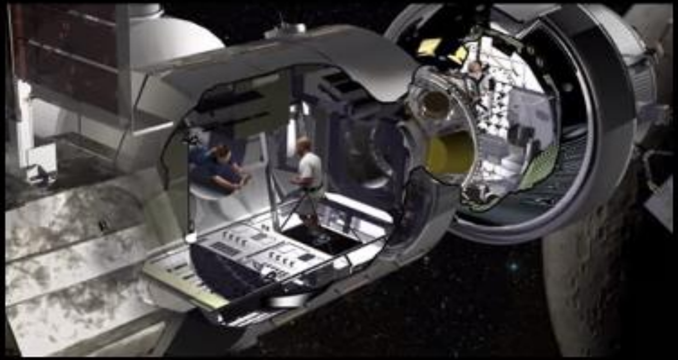
The Unforgiving Environment

Extra-terrestrial Environments= Extreme Environments (EE)

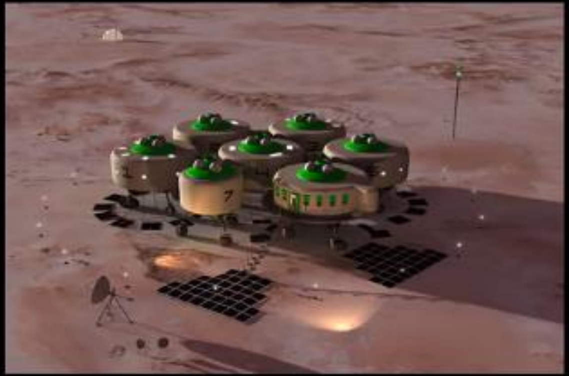


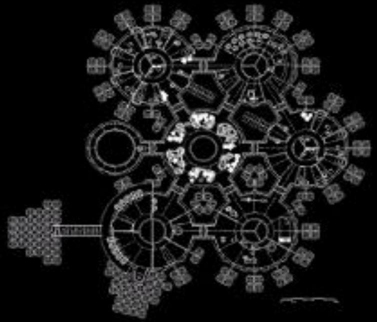
- Not naturally liveable for human beings
- Lack of critical resources
- Hostile environmental challenges





Human Factors and Requirements (in Extreme Environments)

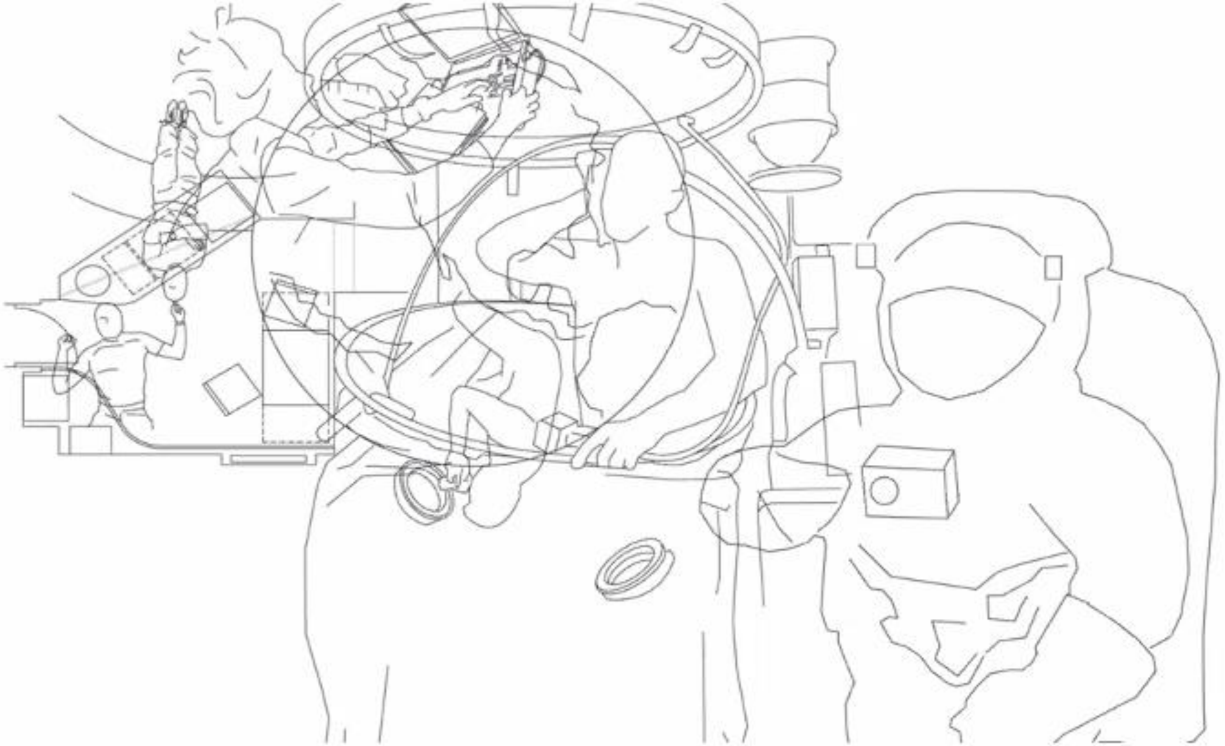




Project Boreas Project Boreas: A Station for the Martian Geographic North Pole, Editor C. S. Cockell, British Interplanetary Society, 2006

Key Factors

1. Reliance on technology
2. Physical/social isolation & confinement
3. High risk & cost of failure
4. High physiological, psychological, psychosocial & cognitive demands
5. Need for human-human, human-technology & human-environmental interfaces
6. Need for team coordination, cooperation & communication



Human Factors and Design

Common challenges in extraterrestrial habitation	
Common challenges **to the built structure**	Common challenges **for the inhabitants**
Microgravity, radiation, extreme temperatures, vacuum or caustic atmosphere, limited possibilities to repair and adapt, abrasive or caustic soils/dust, micro meteors, solar flares …	Microgravity, limited space, isolation, confinement, risk, micro-society, sleep disruption, gastrointestinal disturbances, and somatic complaints as well as psychological reports of boredom, restlessness, anxiety, anger, loss of motivation, temporal and spatial disorientation, interpersonal conflict, homesickness, irritability, difficulties in concentration and deficits in task performance over time; monotony …

Table 3.6 Common challenges in extraterrestrial habitation from Space Habitats and Habitability: Designing for Isolated and Confined Environments on Earth and in Space, Haeuplik-Meusburger & Bishop, 2021, Springer. p. 34.

Human Factors / Behavioral Issues

SLEEP
rest, relaxation, sleep and storage

HYGIENE
PERSONAL HYGIENE
full and part body cleansing, clean and change clothes and storage
SHOWER, TOILET
HOUSEKEEPING

FOOD
store, prepare, grow, consume and storage

WORK
operations, worktasks, experiments, communication, education, training and storage

LEISURE
free-time activities, exercise, intimate behaviour and storage

Relevant issues potentially addressed through Design

- The Physical Environment (Interior Space, Food, Hygiene, Temperature and Humidity, Décor and Lighting, Odor, Noise), Health and Leisure (Recreation, Exercise), Privacy (Crowding, Territoriality), Complex Effects. Connors et al. (1985)
- Including habitable volume, crew quarters, leisure applications, décor, and windows. Kanas and Manzey (2003)
- Outside Communication, Group Interaction, Recreation / Leisure, Sleep, Food (Top 10 of 24 issues); Clothing, Exercise, Medical Support, Personal Hygiene, Habitat Aesthetics, Privacy Personal Space, Waste Disposal and management, Onboard training, Simulation and task preparation. Stuster (2010)
- Sleep (rest, relaxation, sleep and storage), Hygiene (personal hygiene, shower, toilet, housekeeping), Food (store, prepare, grow, consume, and storage), Work (operations, experiments, communication, education, training, and storage), Leisure (free-time activities, exercise, intimate behavior, and storage). Häuplik-Meusburger (2011)

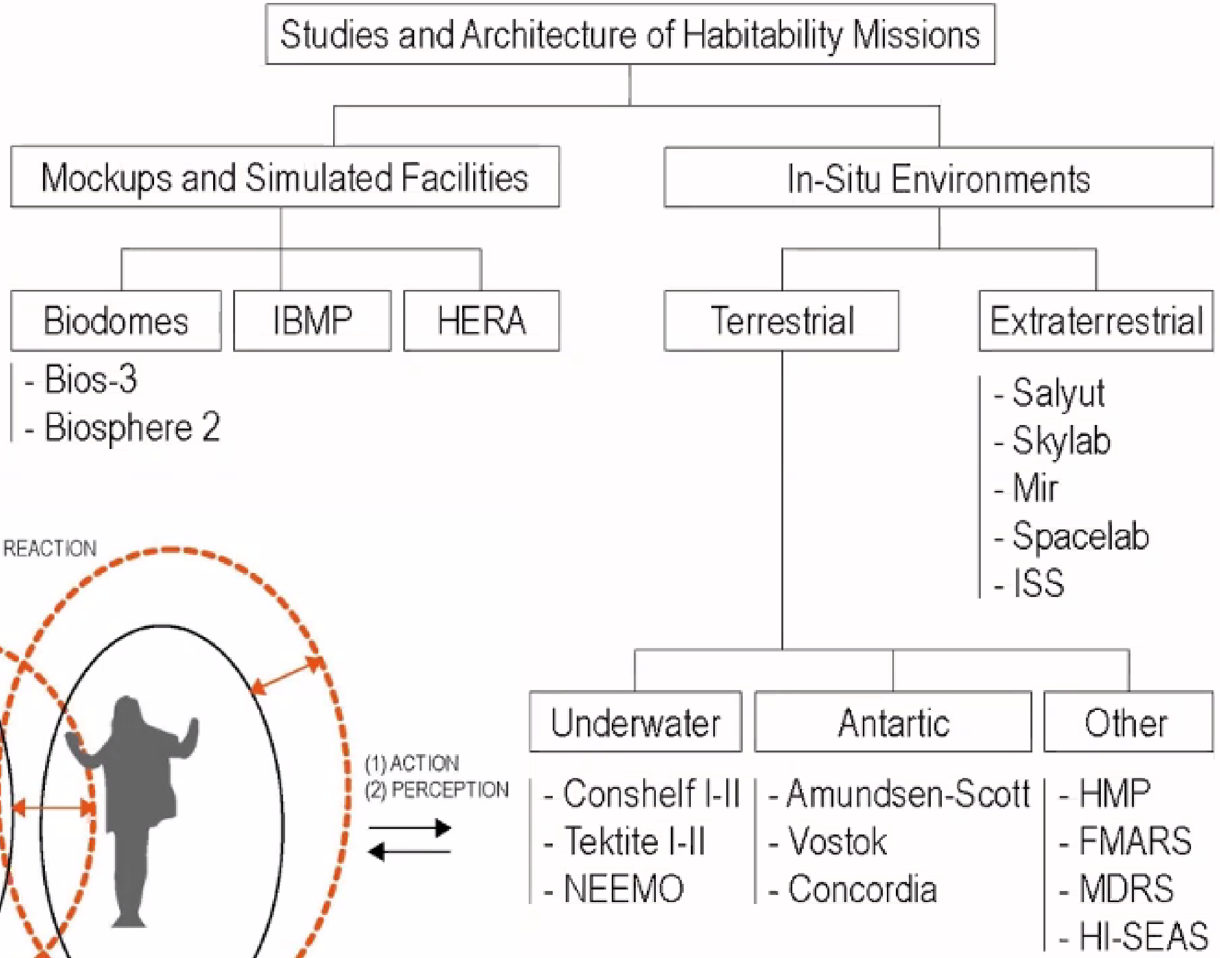
Table 3.10 Habitability Design. Relevant Issues identified in Human Factors Research, that can be potentially addressed through design and architecture (Sources: As in table)

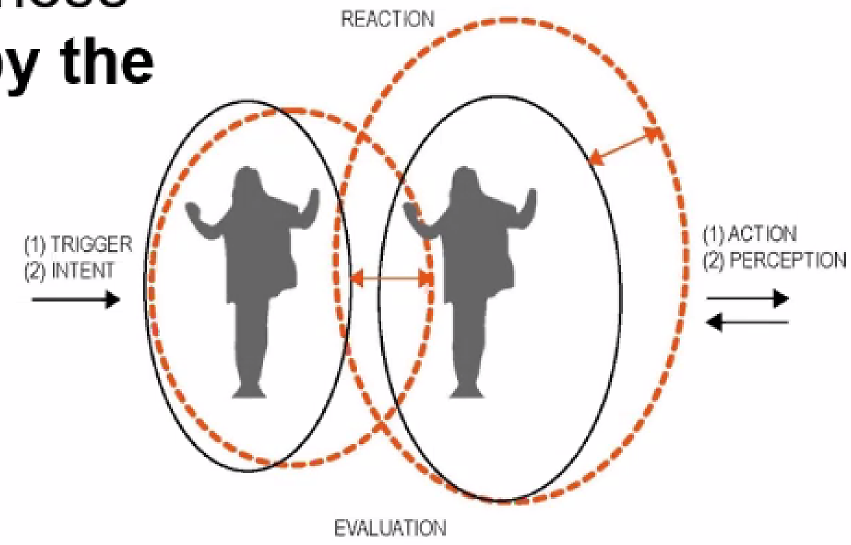
Human Factors and Behavioral Research

Findings for future habitation:

(1) There are **basic human commonalities**

(2) Human adaptation (to these environments) **is affected by the living spaces**





Habitation Readiness Requirements for Habitation Systems

Technology Readiness Level Definitions (NASA)

TRL	Definition
1	Basic principles observed and reported
2	Technology concept and/or application formulated
3	Analytical and experimental critical function and/or characteristic proof-of concept
4	Component and/or breadboard validation in laboratory environment
5	Component and/or breadboard validation in relevant environment
6	System/subsystem model or prototype demonstration in a relevant environment (ground or space)
7	System prototype demonstration in a space environment
8	Actual system completed and "flight qualified" through test and demonstration (ground or space)
9	Actual system "flight proven" through successful mission operations

Habitation readiness levels and its relation to technology readiness levels (Connolly et al. 2006)

Habitation systems research	Research and design levels	Habitat subsystem technologies should have the following TRLs
Habitation systems research (Level 1)	Level 1: human factors, crew systems, and life support research related to habitation systems	Any TRL
Conceptual and functional feasibility of the technology (Level 1–4)	Level 2: habitation design and concepts, functional and task analysis	Any TRL
	Level 3: internal configuration, functional definition and allocation, use of reduced scale models	TRL 6 or higher
	Level 4: full-scale, low-fidelity mockup evaluations	
Demonstration of the technology (Level 5–6)	Level 5: full-scale, high-fidelity mockups, human testing and occupancy evaluations	TRL 6 or higher
	Level 6: habitat and deployment field testing	TRL 7 or higher
Testing of the technology and technology operations (Level 7–8)	Level 7: pressurized habitat prototype testing	TRL 8 or higher
	Level 8: actual systems completed and "flight qualified" through test and demonstration	
	Level 9: actual system "flight proven" through successful mission operations	

RELEVANT PSYCHOLOGICAL AND SOCIO-SPATIAL PHENOMENA

"One important fact, which has emerged during decades of research, is that in the study of capsule environments there are few main effect variables. Almost every outcome is due to an interaction among a host of physical and social environmental variables and personality factors. Thus, although we conceptually deconstruct the situation into particular sources of variance, we must remember that how people experience an environment is more important than the objective characteristics of the environment." (Suedfeld and Steel 2000, pp. 227–253)

Designing for the best fit person

First, we thought there was a ‘Right Stuff’ … but …. the same places affected different people differently…and the same people responded differently in different places … WHAT WAS GOING ON?

NASA

Inspiration 4 crew (space-x)

The MISSION made a difference!

→ There are consistencies in the personality of functional and dysfunctional teams across environments that produce similar experiences &

→ Characteristics of the mission define and necessitate very different personalities.

What you take is what you have: Limited space, limited resources and limited people!

'The Golden Rule of Space Architecture'
Making Use of WHAT you HAVE

Making use of every **ITEM**
- Multipurpose
- Or produce locally

Making use of every **SPACE**
- Flexible for reconfiguration
- Multipurpose
- Repurposed upon demand

Making use of every **CREW**
- One crew for all
- No escape

Making do without OR making do with some kind of substitute

What you take is what you have or what you can create!

Take what you know you will need and design for the capability to make everything else as it becomes known!

3-D printing for dental needs: Häuplik-Meusburger, Meusburger, Lotzmann,IAC-18,A1,4,18,x43890

Sample printed parts from the Made In Space 3D printer, like the type that could be created on the space station. (Image credit: Made In Space)

Apollo 13 crew improvised to adapt the CM's lithium hydroxide canisters for use in the LM (NASA). Skylab 4 astronauts Gerald P. Carr, left, and Edward G. Gibson trimming their homemade Christmas tree

Christmas trees in Antarctica sculpted by Nander and Sainan (Photo Nander Wever)

Camping versus Residing

It was a little bit cramped, we had to sleep in small places; it was a little bit like camping and,of course for eight days on board the ISS you can for sure do that. (Frank de Winne,interview, 2009)

Sleeping bunks, space shuttle flight (STS-99)

- → Staying in a place for a short period of time is transitory = **camping**
- → Staying in a place for an extended duration is residing = **habitation**

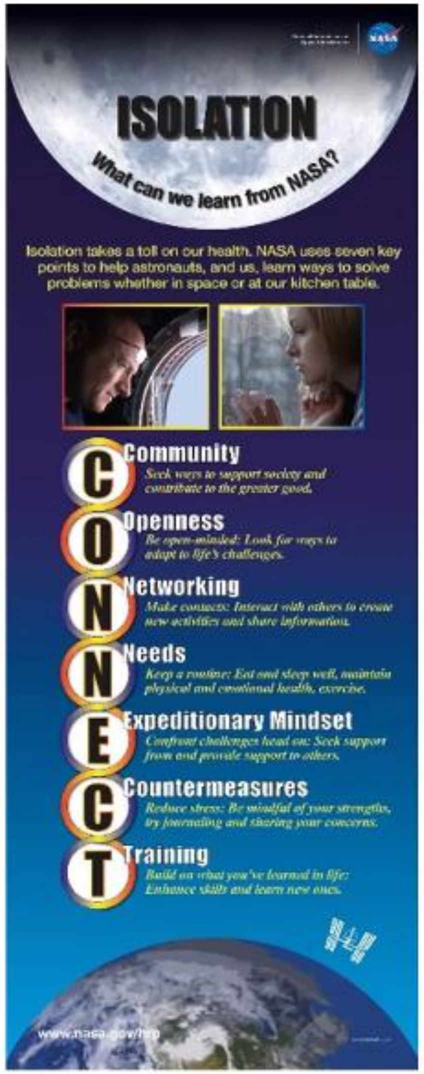
- → Transitory spaces are felt to be temporary and only address survivability concerns.
- → Spaces that have feelings of permanence are perceived as ‘homes’ and address issues of thriving.
- → Thriving is the ultimate goal…not merely surviving.

Space Roommates – Social Logic of ICEs

ATTENTION must be paid:

→ Isolation from family, friends, the familiar social environment and alternative others

→ Limited and forced social contact with a small group

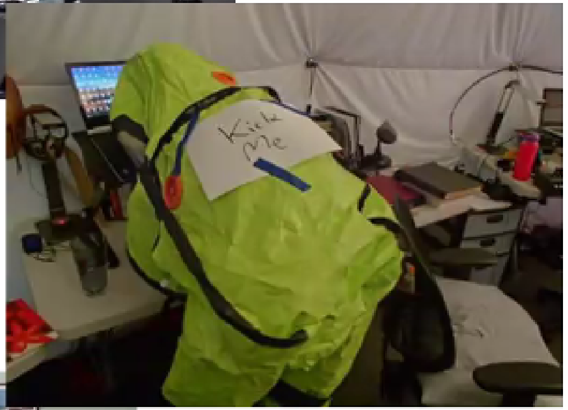


NASA Human Research Program
Lessons on Isolation (NASA)

The Apollo 11 crew relaxes in the Mobile Quarantine Facility after returning to Earth on July 26, 1969. (NASA)

Astronaut Scott Kelly training for his year in space (Photo: Bill Ingalls/NASA/Getty Images)

Space Roommates – Social Logic of ICEs



HI-SEAS V, simulation mission

Apollo mission (NASA)

When the need for privacy becomes a territorial issue

- We NEED personal space – to be alone, to not be heard, smelled, seen, or with.
- Personal space is defined as 'mine'.

Zoning out social conflicts -When Little Things become Big Things

- Conflict is inevitable. Mitigation should seek to minimize incidents (workstations with adequate resources, private areas for social distancing, automation for minimizing burdensome tasks, areas for relaxation) as well as provide for means to countering rising tensions (play, leisure, exercise, sports, social activities).

Love goes through the stomach, fine manners help

- Sharing food and meals provide opportunities for social gatherings, links pleasure from satisfying hunger and taste with others and cooperative mutually beneficial activities.

Friendship, Intimacy and Sex

- Humans need touch. Relationships will happen regardless of rules, policies, laws or prohibitions. Social structures (and habitat design) should plan for the existence of relationships and provide flexibility to accommodate these normal human needs.

Looking out and looking in: What makes us feel confined?

Crowdedness = too much! Too close!
Violations of personal space; spaces perceived as inadequate

2001

Image of the Destiny Laboratory (NASA)

→ Lack of stimuli: Monotony and Boredom: Complexity is good; complicated is bad
→ Extreme artificiality and visual complexity of built environments leading to attentional fatigue

Bringing our own green - lack of natural elements

Multiple lines of independent inquiries from architecture, evolutionary and environmental psychology, biology and computer imaging indicated that natural elements provide neural efficiencies, restoration or rest directed attention that are countermeasures to stress. Somehow, we must translate

THIS:

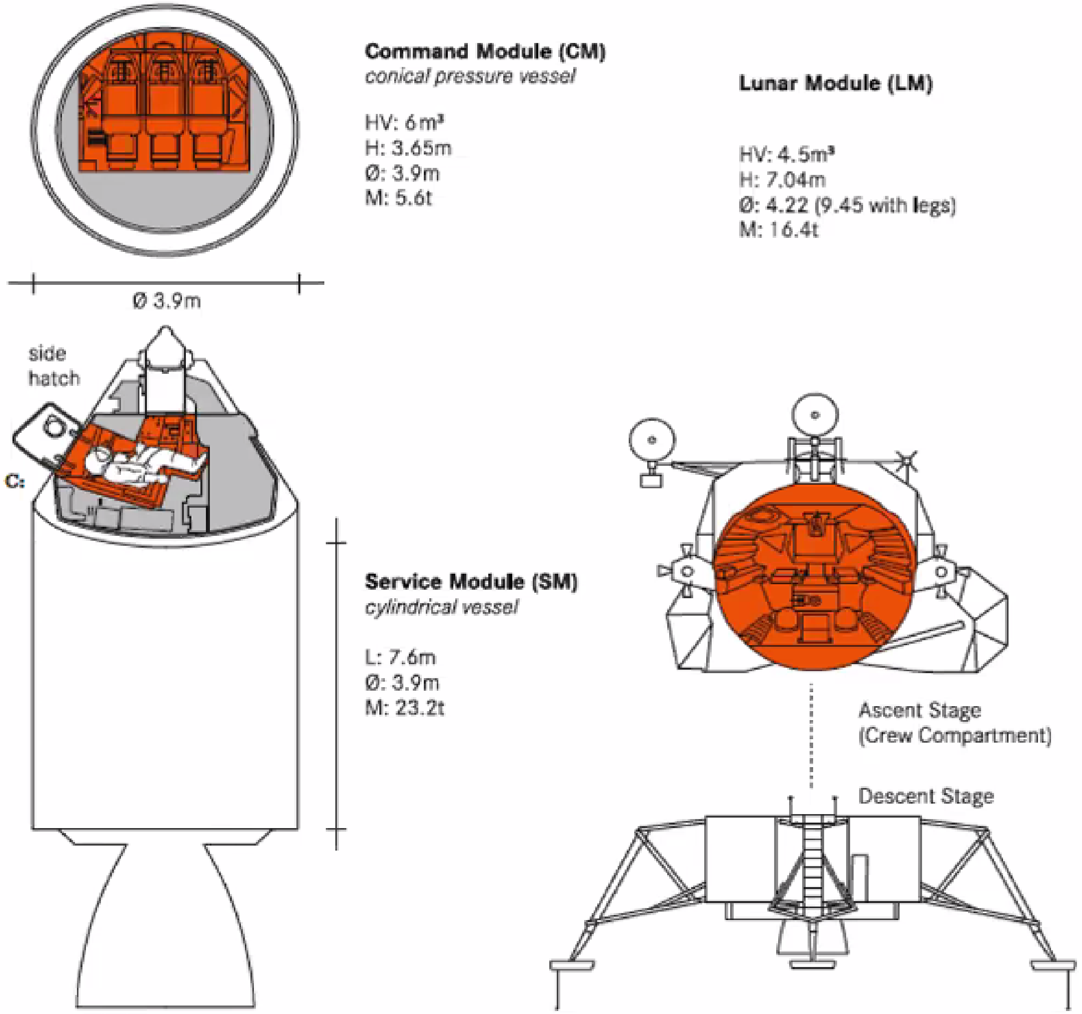
Into far more effective forms than THIS…

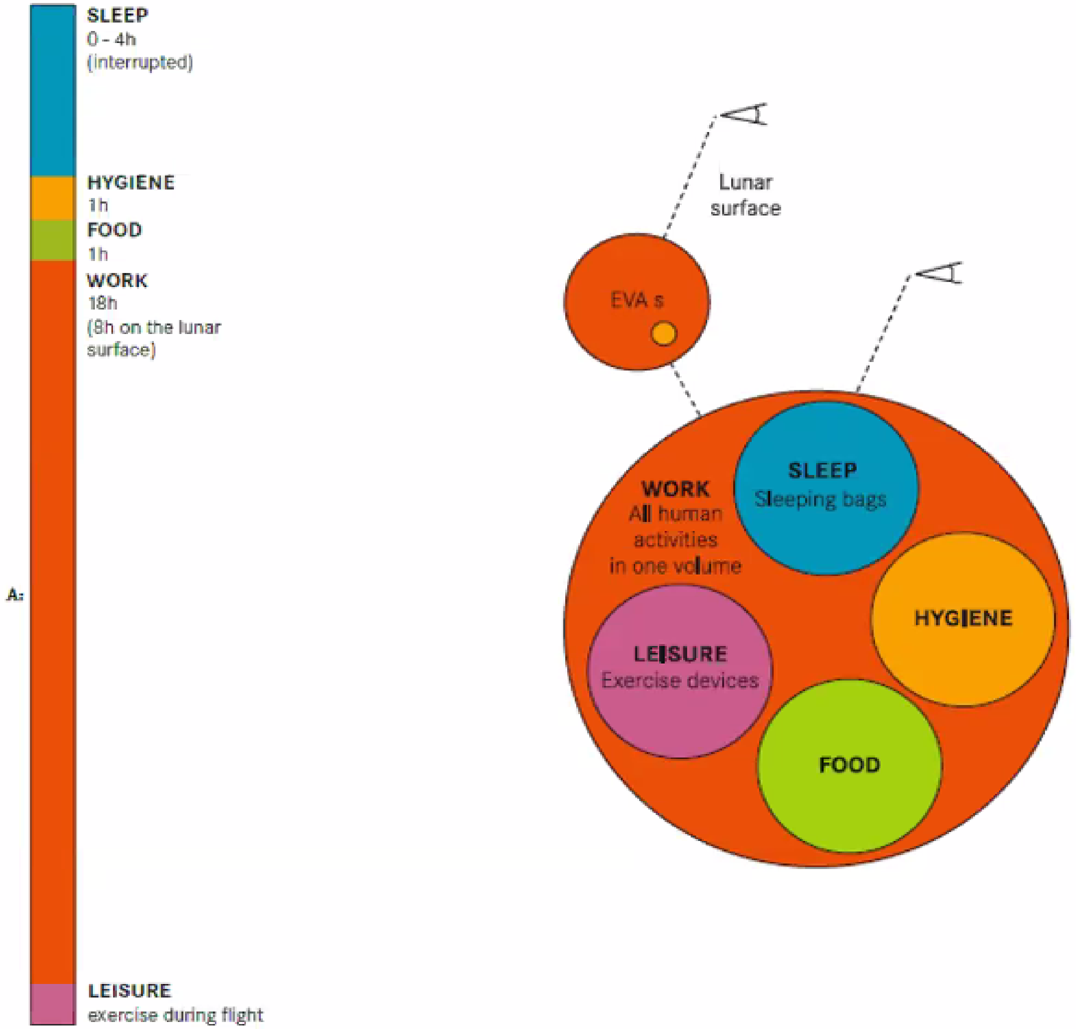
Pictured: Yusuke Murakami during MARS 160 during plant and sun therapy [FMARS 2017]

Expedition 5 cosmonaut Victor Savinykh with 'his' plants on Salyut 6 (image credit: TASS, courtesy V. Savinykh)

EXAMPLES OF HUMANS AND ENVIRONMENT INTERACTION

Human Activities during Apollo





Graphics from Architecture for Astronauts (Häuplik-Meusburger, Springer, 2011)

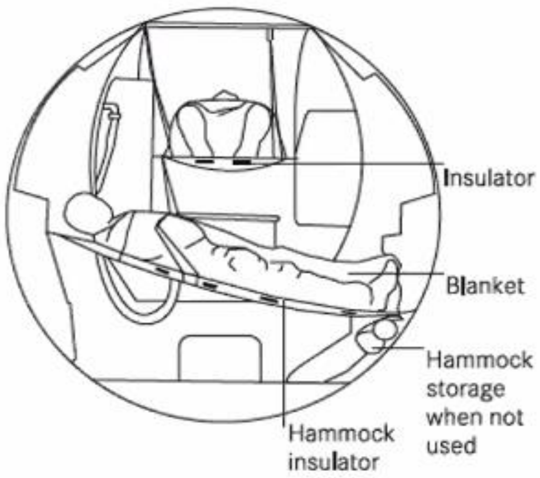
Human Activity-SLEEP during Apollo

SLEEP
rest, relaxation, sleep and storage

- Two sleeping bags and insulated hammocks with Apollo 12 (additional heater and insulated base)
- Earplugs (high level of noise)
- Window shades

Gene Cernan (Apollo 17): *"**What a waste of time**. My mind whirls as I lay in the hammock, wide awake. I was mentally and physically whipped, but felt I should not be loafing around in my underwear while there was a whole Moon to explore just beyond that little hatchway. We only had about sixty hours left, and time had warped. When we were outside, the hours just galloped away, but inside the spacecraft, the clock didn't seem to move at all, and our rest period passed with agonizing slowness. Eventually, we slept."* (Cernan, et al., 1999 p. 330)

C:



D:

Gene Cernan, Apollo (NASA)

→ Private sleep facilities for all crewmembers
→ Separate sleep from other activities
→ Allow reconfiguration and adjustment by design

Human Activity-HYGIENE during Apollo

HYGIENE
PERSONAL HYGIENE
full and part body cleansing, clean and change clothes and storage
SHOWER, TOILET
HOUSEKEEPING

- Personal hygiene equipment
- Apollo bag, UTS, UTA, UCTA, diaper
- Urine on the clothes an couches
- Lunar dust caused problems
- Loss of little tools

Neil Armstrong (Apollo 11): "***Our cockpit was so dirty with soot,*** that we thought the suit loop would be a lot cleaner."

Astronaut Dick Gordon [about the EVA undergarment] "*after a few days it got so clogged with urine and so dirty, that you just hated to put the thing back on*" (NASA [Debriefing A12], 1969).

A:

A:

B:

A:

→ Integrate easy-to-use full body cleansing
→ Integrate redundancy
→ Easy housekeeping
→ Hygiene activities are private activities

Urine collection and transfer assembly (NASA), Urine transfer system with roll-on cuff (NASA), Urine collection and transfer assembly worn over the liquid cooling garment NASA), Apollo 10 Commander shaves in the CM (NASA) – all images as published in Architecture for Astronauts, 2011.

Basic Amenities can become Big Troubles

Skylab astronaut using the toilet system (NASA)

Valentin Lebedev (Salyut 7, 1991):
"The toilet – I literally sit on it like a witch on a broom. Everybody runs into some pretty funny problems with this space bathroom. ***It won't forgive mistakes."***

CNN BUSINESS

An alarm went off on SpaceX's all-tourist space flight. The problem was the toilet

SpaceX's private Inspiration4 astronauts had some toilet trouble in space

By Amy Thompson September 20, 2021

In space, even basic amenities are difficult.

Human Activity-FOOD during Apollo

- Rehydratable, bite-sized, ready-to-eat, thermostabilized food
- Food packaging
- No dedicated area

Harrison Schmitt (Apollo 17): *“The food was good (...) It didn’t have much taste (...) but also NASA had decided, they didn’t want to have a lot of spice in the food. They didn’t want to stimulate your intestinal system. You were always looking for something that had a little more taste, and the bacon squares probably had the most taste, so they disappeared quickly.” (Schmitt, 2009)*

FOOD
store, prepare, grow, consume and storage

A:

Apollo 9 commander James A. McDivitt is drinking from a space food pouch (NASA), Apollo Food variation (1968-1972) – images as published in Architecture for Astronauts, 2011

→ Integrate food growing systems
→ Develop cooking devices
→ Separate food preparation from other activities
→ Use plants to increase habitability
→ Integrate personal greenhouses

Human Activity-WORK during Apollo

- Experiments on lunar surface
- Microgravity and 1/6 G
- Extra-vehicular activities
- Space suit gloves development
- Flexible schedule

Gene Cernan (Apollo 17): *"Learning how to walk was **like balancing on a bowl of Jell-O**, until I figured out how to shift my weight while doing a sort of bunny hop."*

Harrison Schmitt (Apollo 17): *"We were busy as explorers (...) You try to take advantage of the time you have." (Schmitt, 2009)*

C:

Apollo 17 scientist astronaut Harrison Schmitt collects lunar rake samples (NASA)

→ Integrate empty (storage) spaces
→ Design ergonomically
→ Integrate personal work areas
→ Integrate standardized interfaces
→ Allow reconfiguration and adjustment
→ Integrate on-going training

WORK
operations, worktasks, experiments, communication, education, training and storage

Human Activity-LEISURE during Apollo

- Music, Exer-Genie
- Unique activities on the lunar surface
- Earth watching
- Played with collected rocks

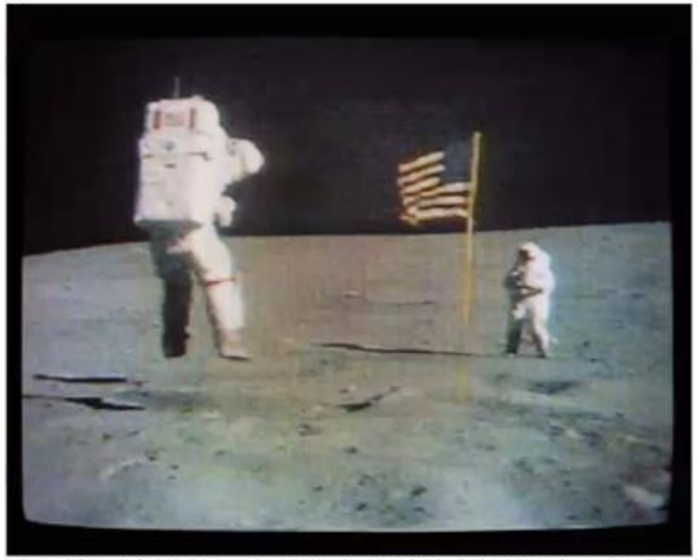
Alan Shepard (Apollo 14): *“What a neat place to whack a golf ball!” (Shepard, 1998)*

Mitchell Edgar (Apollo 14): *“I noticed it [tiring in the legs and back] throughout the flight, diminishing toward the end. (...) It felt good to pull on the Exer-Genie and straighten those muscles out.” (NASA [Debriefing A14], 1971)*

LEISURE

free-time activities, exercise, intimate behaviour and storage

A:



B:

Apollo 16 commander John W. Young leaps from the lunar surface as he salutes the US flag (NASA), “Earthrise” as seen from Apollo 11 mission crew in 1969

→ Unique and Experimental Activities
→ Intimate Behaviors
→ Integrated Real and virtual windows

Human Activities in relation to Gravity

Effects of partial Gravity

- Humans walk and run (40 %) slower on the Moon
- The stepping rate is less than on Earth
- Humans have a reduced abiltiy to change direction quickly
- Stopping and turning are more difficult
- Mobility is challenged by lack of traction

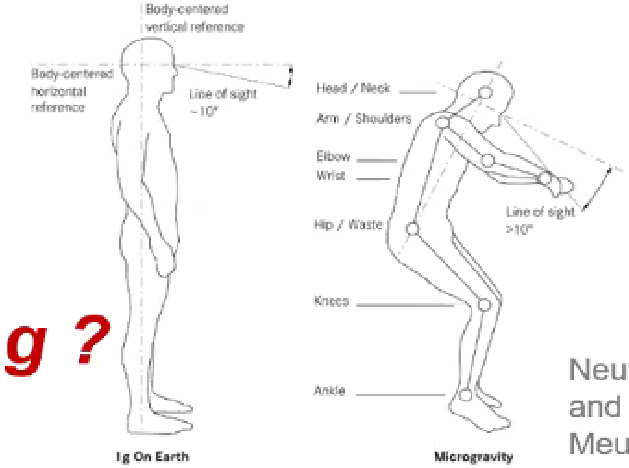
Design Considerations and Consequences

→ Change of ‚reach envelope' leads to new ‚standard dimensions'
→ Design of Stairs and Ramps, translation paths
→ Alternative mobility systems (for lifting and climbing)
→ Choice of materials (floors)
→ Line of sight changes orientation

Comparison of the neutral body position depending on different gravity conditions (image: inside the Kibo module – NASA)

> Adequate gravity regime and ergonomic design is required for living and working spaces

The body posture in 1/6 g ?



Neutral body orientation on Earth and in microgravity (Häuplik-Meusburger, 2011)

Designing for Architectural Countermeasures

Greenhouse design for a lunar research station (TU Wien, project by Alexander Garber and Katharina Lehr-Splawinski);

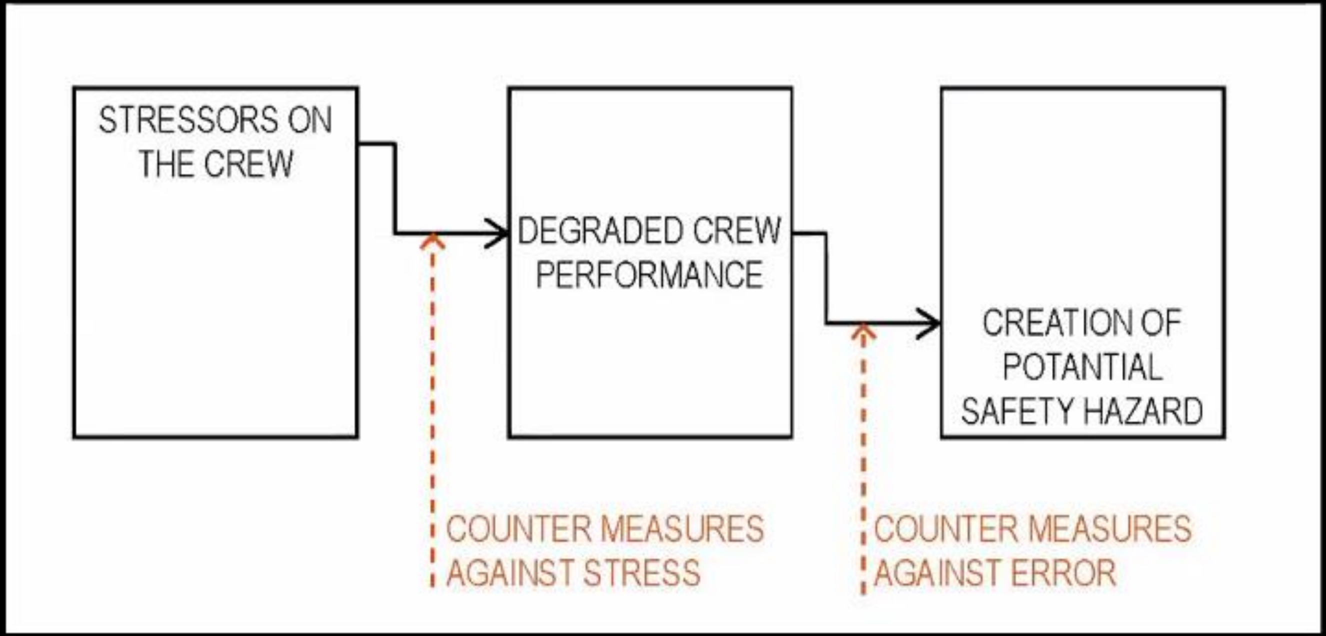


Figure adapted from the Space Station Crew Safety **Human Factors Interaction Model** (Cohen & Junge, 1984)

Lighting

Lunar Base Design (TU Wien, Sabrina Kerber)

Effects on human behavior:

+ Guides and supports functional activities

- Can become a stressor, similar to sound, temperature and humidity

+ can enhance desirable moods

+ can reduce the feelings of crowding

+ promotes physiological synchronization

Architectural design implications:

→ Large spectrum (mix of natural light, color, temperature)

→ Multiple light sources in relation to the activity and area (ambient light, and task specific lighting)

→ Plants need different solutions than Humans

Personal and Social Spatial Space

- Separation of private functions from public is critical
- Need flexible, definable & redefinable interior environments
  - meet needs for solitude, privacy
  - limit social interaction & individual control over amount of contact with others
  - provides for group as well as individual activity
  - moderates feelings of crowding, confinement
  - allows for individual personalization (e.g., decoration) and individual differences

On Mir, "for sanitary and privacy reasons, no one was ever enthusiastic about using a toilet two feet from the dinner table" (Burrough 1999, p. 88).

A Table for All – Social Space for Bonding

It is important that everyone have a ‘place at the table’. It is also important that the table be one that can accommodate everyone.

Skylab 2 crew members eating space food (1973), by NASA

8 Astronauts and Cosmonauts sharing a meal on July 21, 2009 onboard ISS. Image Credit: Canadian Space Agency

Astronauts David Saint-Jacques and Anne McClain prepare pizzas in the ‘kitchen’ onboard the International Space Station during Expedition 59 in March 2019. This is one of the few task-heavy meal options. Image Credit: NASA

Social Space as Sources of Stress

- Social gatherings should be facilitated, not mandated.
- Provide spatial possibilities but don't use space to organize people unless you are prepared for design intentions to be ignored.
- Regulated social space is not perceived as social.
- Make resources available in multiple locations (e.g., entertainment equipment, viewports).
- Provide for different sizes of social space – from all to a pair.

Crew members (STS-131) on the International Space Station (14 April 2010).

Windows – Looking Out and Looking In

“Nevertheless it’s better to see the Moon and the Sun than being in a closed room without seeing anything. Sometimes you need reference. You need something which is natural, not artificial things around you” (Haigneré, 2009).

Lunar Module landing / Valeri Polyakov looking out of Mir space station. Images: NASA | *Astronauts Wilson, Dyson, Yamazaki and Metcalf-Lindenburger float in the windowed cupola module of the ISS. Photo: NASA | Blue Origin*

Windows – An Example of Attention to Details

→ Appropriate design leads to safer, healthier, more functional and pleasant spaces

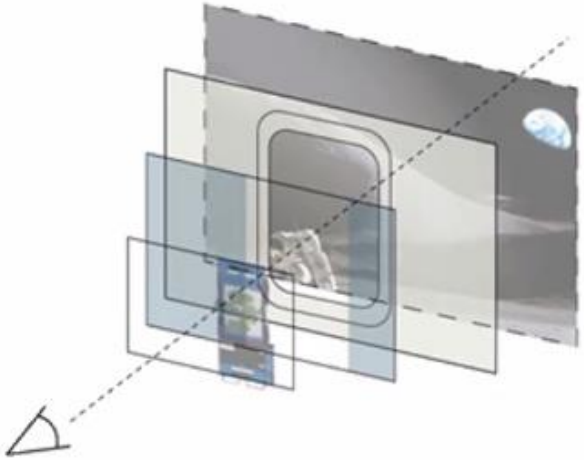
Astronaut Susan J. Helms, Expedition Two flight engineer views Earth from the nadir window of the Destiny module on ISS, before a handhold was installed and before the incident with the broken hose happened in 2001 (credit: NASA). (b) Pilot Stephen N. Frick looks out the same nadir window during STS-110's visit to the International Space Station (ISS). He is holding on the handles that were installed following the incident in 2002 (credit: NASA)

"If something is going to stick out and make a nice handhold, it's going to be used for a handhold"

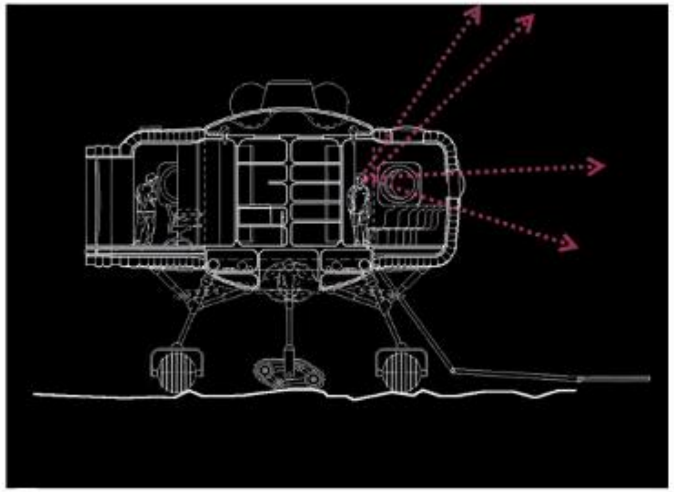
(NASA [Bull.1], 1974 p.76).

SM4 Mission 5/16/2009 Greg Johnson takes pictures through a window at middeck holding on to a control panel (credit: NASA)

Windows – Alternatives



→ Looking in and Looking out is important
→ The human aspect needs to be acknowledged by design
→ Windows can be physical, virtual or surrogated
→ “ Windows to … “ and sightline design integration between functions



Project Boreas, 2006, British Interplanetary Society. Image Credit: Mark Greene | Lunar base Foster + Partners, ESA | Lunar Design, TU Wien, Brock, Elzhaby, Kerber, 2018

Making do with substitutes

(1) Identify relevant habitability issues.
(2) Address negative effects with habitability.
countermeasures.
(3) Find substitutes and surrogates
if not there.
(4) Evaluate and prove their effectiveness
before building and living
In the actual habitat.

Mobile Greenhouse pot design (space-craft Architektur)

Digital Windows (Credit: Sky Factory)

Using Virtual Reality on ISS (credit: NASA)

Greenhouse at Amundsen-Scott South Pole Station, Antarctica

Earth Abides! Replicating our Ancestral Home

- The standard of design practice for most operational environments has been towards minimalistic, patternless interiors where ‘form follows function’; but such environments are not those in which we have evolved to perform at our mental best.
- Growing evidence that habitat interiors might be expressly designed to assist innate natural emotional, cognitive and perceptual processes associated with flexible, creative thought, stress reduction and personal emotional management.

TU Wien, Lunar Oasis Vision, S. Kerber, 2018

Bionomic Design: Integrating Evolutionary Cognitive Processing into Passive Countermeasures

Wise and Rosenberg, 1986

Are natural scenes beneficial?

Can we build THE Perfect Habitat?

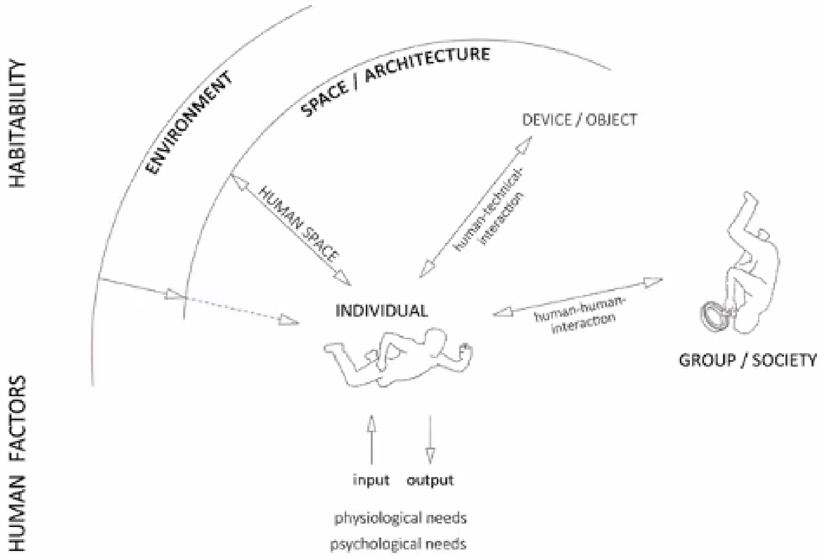
Nine Astronauts from four different Space Agencies, 2019, ISS (NASA)

ISSUES:

1. What we know is based on imperfect terrestrial analogues and a few orbital/transportation vehicles – little ability to generalize.
2. Available participants = small unrepresentative segment of human beings (e.g., well-educated, mainly male adults, etc.)
3. There are few existing opportunities to test new habitat designs
4. All our perceived experiences are deeply mired in cultural practices.
5. There are both individual and group processes that must be addressed in designing functional, supportive facilities. These foci are highly interdependent but different.

Goals for habitability design in space

Structural layout and habitat design can address behavioral issues

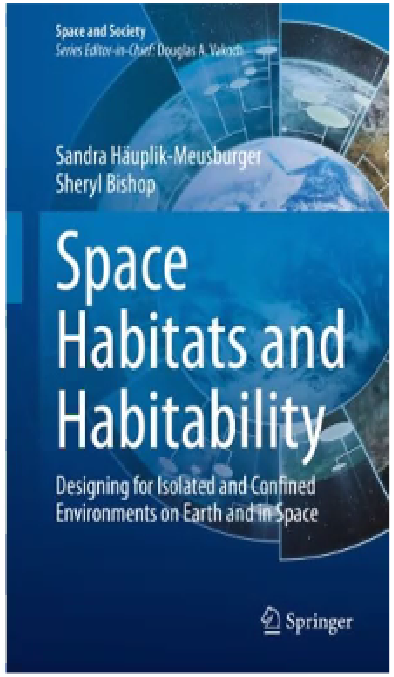


- → Maximize habitable volume with configurations that are perceived as more spacious.
- → Utilize multiple compartments for variety and segregated use.
- → Use color & lighting to enhance desirable moods, reduce feelings of crowding & physiological normality (e.g., entrain sleep cycles)
- → Use methodologies to counter feelings of confinement and monotony, provide visual depth.
- → Multiple uses of plant production spaces: food production, leisure activities, stress reduction, crafts, gardening, small group interaction, exposure to full spectrum lighting, natural fractals.
- → Use of configurations that incorporate open spaces that also support group functions and social interactions;
- → Modular sections that can be differently themed to provide environmental variety as well as provide for multiple pathing options to enable individual control over social interaction;
- → Use of interior design features to visually lengthen the view and enlarge perceived space.
- → Use of color and lighting to regulate mood and attention;
- → Use of windows (either real or surrogate) to provide long views and depth;

Design Check: Rules of Thumb

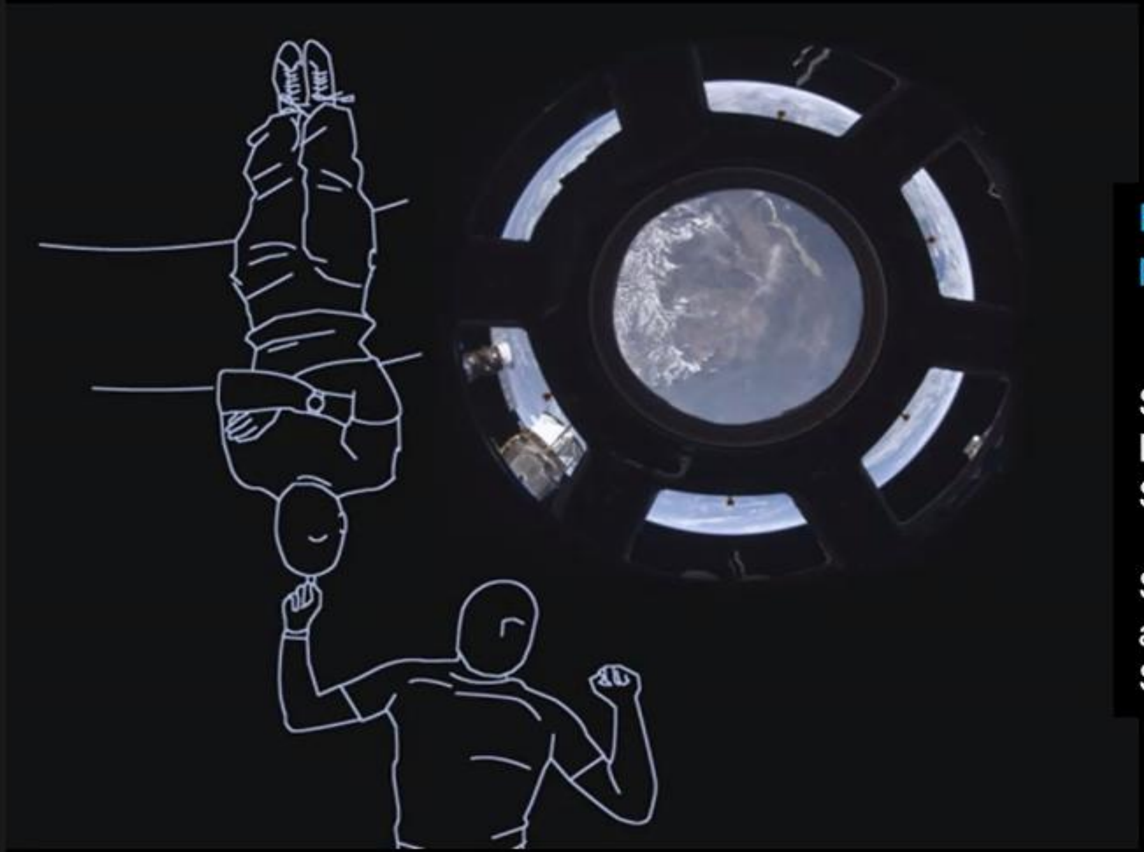
Ten Rules of Thumb for Habitability Design for ICE Environments

1. One solution cannot fit all needs.
2. It takes time to uncover differences.
3. Long term missions have different requirements than short term missions.
4. Everything you are allowed to bring must be a valuable resource.
5. Integrated private, semi-private and social spaces are necessary, not optional.
6. Adequate volume is in relation to how space is perceived by the individual.
7. Spaciousness can be increased by design and geometry.
8. Integrate natural environmental characteristics that support evolutionary derived perceptual processing.
9. New environments offer new challenges and new possibilities.
10. Think transdisciplinary, be creative.



“It’s not how large you make it, it’s how you make it large.”

(Jim Wise, 2020)



For a deeper discussion of the material covered in today‘s webinar, please explore the contents of our book…

SPACE HABITATS AND HABITABILITY
Designing for Isolated and Confined Environments on Earth and in Space

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