Intersect, Vol 16, No 2 (2023)

Home Far Away from Home: Spacecraft Interior Design for Human Well-being

Helen He
Stanford University

Abstract

Today's spacecraft are equipped to sustain human physical well-being beyond Earth. Yet, when it comes to less-quantifiable health factors, such as mental and emotional well-being, there is limited research on how those are influenced long-term by a spacecraft's physical environment.

Currently, maintaining well-being in space is not a major difficulty. Rigorous astronaut selection processes and training ensure the physical and mental fortitude of each human who flies to space. Residents keep up morale with crew gatherings and holiday celebrations. Proximity to Earth allows a constant view of the planet, regular payload gifts, and reliable communication with friends and family, keeping home close by.

Yet, as we aim beyond Earth and the moon, missions will increase in distance and duration. Payload deliveries will be less frequent, and Earth communication will lag. As space travel durations and distances increase, it becomes even more important to shape healthy outer space experiences for astronauts. A spacecraft's internal environment will play a major role in that experience, especially if it is the same environment travelers will live in with the same fellow travelers for months, even years.

Using a framework adapted from the International WELL Building Institute, this paper explores basic principles that form the foundation for a healthy spacecraft interior. Its vision: to help guide engineers and designers in creating outer space living environments where humans can not just survive, but also thrive.

1. Introduction

Today's spacecraft are sufficiently equipped to sustain human physical well-being beyond Earth. Yet, when it comes to less-quantifiable health factors, such as mental and emotional well-being, there's limited research on how those are influenced long-term by a spacecraft's physical environment.

1.1 Current State of Art on Spacecraft Interiors

Currently, maintaining well-being in space is not a major difficulty. Rigorous astronaut selection processes and training ensure the physical and mental fortitude of each human who flies to space. Most health problems that arise are gravity-related “space adaptation syndrome” symptoms, such as vertigo and nausea, which are short-term and easily remedied with onboard medications (David, 2005). Additionally, residents aboard the International Space Station keep up morale with crew gatherings and holiday celebrations. Proximity to Earth allows a constant view of the planet, regular payload gifts, and reliable communication with friends and family, keeping home close by (Kobie, 2019).

1.2 Increasing Importance of Spacecraft Interiors

However, as we aim beyond Earth and the moon — SpaceX aims to send crewed round-trip missions to Mars by 2024, with total space travel times of up to 1.5 years — missions will increase in distance and duration (Wall, 2020). Payload deliveries will be less frequent, and Earth communication will lag. As space travel durations and distances increase, it becomes even more important to shape healthy outer space experiences for astronauts. A spacecraft’s internal environment will play a major role in that experience, especially if it’s the same environment travelers will live in with the same fellow travelers for months, even years.

1.3 Influence of Earth Interiors on Mental and Physical Health

Currently, there’s limited research on how wellness in outer space is influenced by spacecraft interiors. Yet on Earth, research has already shown that details of physical spaces can impact people’s emotions and behaviors, especially spaces where people live or work regularly. In a 2010 study, when given a demanding cognitive task, participants who worked in an office setting with plants did better in attention and performance than those who worked in the same setting without plants (Raanaas et al., 2011). In another study on college students and dorm wall colors, researchers found that students preferred to live in dorms with blue walls. Students associated the color blue with calmness and studied better in blue environments (Costa et al., 2018). As long as we retain our human senses, built environments will influence us off Earth just as they do on Earth.

1.4 Applying Earth Interiors to Create a Framework for Spacecraft Interiors

Building off the environmental design framework of the International WELL Building Institute, a global organization dedicated to promoting healthy interior environments and communities, this paper aims to develop a foundation for healthy spacecraft interiors. Its vision is to help engineers and designers build outer-space living environments not just for human functioning, but also for human flourishing and well-being.

2. Creating a Framework for Spacecraft Interior Design

This paper will first build a design principle framework to guide what makes a healthy spacecraft interior for living and working in. The framework will be derived from the WELL Building Standard, which is created by the International WELL Building Institute (IWBI).

2.1 What is WELL?

Readers may be familiar with the LEED (Leadership in Energy and Environmental Design) building certification, the most widely-used standard in the world to rank green buildings (USGBC). Similar to LEED, IWBI is a global organization focusing on places and spaces, with a different lens: a focus on human health and well-being. Clients include not just buildings, but also companies, organizations, and communities. Each quarter, IWBI releases the WELL Building Standard (also simply known as WELL), a set of research-backed guidelines gauging the well-being and health of buildings, organizations, and companies. This paper uses the latest version of WELL, version 2 (v2), which was released in April 2021 (see Appendix for the full list of features).

2.2 Building Off WELL

WELL v2 is composed of over 120 features, which are individual guidelines organized into the following categories: Air, Water, Nourishment, Light, Movement, Thermal Comfort, Sound, Materials, Mind, and Community. To create a framework for spacecraft interior design, I've filtered out irrelevant features, since they fall into one of the following categories:

- Expected to already be covered by general space mission logistics
- Not applicable to space missions
- Beyond the scope of interior design
- Any combination of the above

The remaining features are applicable to spacecraft interior design. These features are listed in Table 1.

The filtered features are then reorganized into **three main principles** that make up the spacecraft interior design framework, which this paper uses (see Table 2).

Category	**Feature name**
Light	L03 - Circadian Lighting Design
Light	L06 - Daylight Simulation
Light	L07 - Visual Balance
Light	L09 - Occupant Lighting Control
Thermal Comfort	T04 - Individual Thermal Control
Sound	S03 - Sound Barriers
Sound	S05 - Sound Reducing Surfaces
Sound	S06 - Minimum Background Sound
Mind	M02 - Nature and Place
Mind	M07 - Restorative Spaces
Community	C13 - Accessibility and Universal Design

Table 1. A list of WELL features selected as relevant to spacecraft interiors (International WELL Building Institute, 2021). For the full list of WELL v2 features, please see Appendix.

Features	**Common principle derived**
• L09 - Occupant Lighting Control • T04 - Individual Thermal Control • S03 - Sound Barriers • S05 - Sound Reducing Surfaces • S06 - Minimum Background Sound	*Principle 1: Design for agency and order*
• M07 - Restorative Spaces • C13 - Accessibility and Universal Design	*Principle 2: Design for comfort amid constraints*
• L03 - Circadian Lighting Design • L06 - Daylight Simulation • L07 - Visual Balance • M02 - Nature and Place	*Principle 3: Design for beauty*

Table 2. The features from Table 1 are sorted into groups, thus deriving the three main principles that form this paper's framework for spacecraft interior design.

2.3 The Proposed Framework

Thus, below is the proposed framework:

- ***Principle 1: Design for agency and order.*** Spacecraft inhabitants should feel familiar and at home with their surroundings. Works paces should be clutter-free, easy to organize, and easy to navigate. Living spaces should be easy to customize and personalize according to individual preferences.
- ***Principle 2: Design for comfort amid constraints.*** Through innovative use of materials, manufacturing methods, and spatial illusions, spacecraft interiors can be comfortable, welcoming spaces, while also meeting spacecraft safety requirements.
- ***Principle 3: Design for beauty.*** Last but not least, spacecraft interiors, especially interiors for unwinding such as sleep and social quarters, must also have beauty: the beauty of Earth, and the beauty of outer space. People need both. Beauty can balance the negative feelings of space travel, like homesickness and fear of the expanse outside. It can make astronauts more prepared and ready to embrace the nature of space travel.

It's important to establish that this framework does not advise sacrificing practicality for comfort. The number one priority of human space travel is to get humans to space — and for two-way missions, back — alive. The reason why space travel today poses so many constraints on design is mainly due to:

- Extreme external environment
- Confined internal environment
- The need to support a wide variety of human tasks and functions (e.g. research, work, bathing, exercise, relaxation, cooking, eating, sleeping, spacewalks, communications, etc.)

I do believe that in the near future, we will be capable of achieving comfort and beauty in spacecraft, in addition to functionality and survivability. There are already places on Earth that achieve this goal, and this paper will next explore these examples. Case studies include four-star micro-hotels and Antarctic research bases: Earth spaces that also are located in extreme external environments, have limited space, and/or need to prioritize function over form. These unique places prove that practicality and comfort can co-exist.

3. Exploring the Framework with Earth Examples

3.1 Principle 1: Design for Agency and Order

Spacecraft inhabitants should feel familiar and at home with their surroundings. Workspaces should be clutter-free, easy to organize, and easy to navigate. Living spaces should be easy to customize and personalize according to individual preferences.

We humans are naturally inclined to desire agency over our surroundings. In a 2010 study, office employees were happier and up to 30% more productive when allowed to customize their workspaces by rearranging plants and artwork (Knight & Haslam, 2010). Additionally, the WELL Standard acknowledges individual control of temperature and lighting as desirable building traits. We feel more comfortable and familiar in spaces that we can personalize to our own comfort.

Another human tendency is the desire to exert order in our surroundings. A Princeton study revealed that participants did worse on computer screen tasks when there was visual noise displayed, such as extra shapes and colors (McMains & Kastner, 2011). Another downside of cluttered workspaces is spending valuable work time searching for items. According to a 2012 McKinsey report, high-skill knowledge workers spend about 1.8 hours per week searching and gathering information (Chui et al., 2019). Disorganized work environments make it more difficult to find the proper tools and documents to get things done.

However, spacecraft interiors have a long way to go in terms of being comfortable, pleasant environments. With a single glance at photos of today's spacecraft, it's not an uncommon sight for interiors to be crowded with dangling cables and exposed equipment: not the best setting for organization or personalization. There are good reasons behind this arrangement. In outer space, interior space is limited. Every available surface must be optimized to store equipment and supplies. Plus, as a former operations support officer explained in response to a Quora question regarding tidiness aboard the International Space Station, "there just isn't enough time in crew members' daily schedules" (Anonymous, 2016). With mission and research goals as top priorities, efficiency and easy access to equipment precede tidiness.

This paper will next analyze two precedent examples of how agency and organization are possible in confined spaces: luxury vehicles and micro-hotels.

3.1.1 Luxury Vehicles: Designed for Agency

It may seem strange for a spacecraft interiors paper to include luxury vehicles, but Earth luxury can teach a lot about feeling at home in unlikely settings: in this case, that setting being on the road.

A major part of "luxury" in these vehicles stems from their high levels of comfort and personalization. For example, British car manufacturer Rolls-Royce, which has been specializing in personalized luxury vehicles for over a century, works one-on-one with clients to refine details, from paint jobs to interior lights. Functionalities also include sound-proof panels, dimmable windows, and acoustics: the typical Rolls-Royce experience looks, feels, sounds, and smells like home.

Luxury vehicles emphasize personalized comfort, but it’s not comfort just the sake of comfort. It's comfort for enhancing human capability and performance. For vehicle clients — typically high-level figures such as executives, celebrities, and government officials… people who do intense, important work, where even a single off day can cost a company millions or disrupt an economy — the vehicle is more than a space to just spend a ride in, but to also host phone calls, answer important emails, or relax and prepare for an upcoming important event. In other words, the vehicle is an extension of the home or office.

A strong example of home or office on the road is the vehicles of the Rolls-Royce Phantom Limelight collection (Figure 1a), a cutting-edge limousine line designed for “powerful people who operate in the public eye and move swiftly from engagement to engagement as part of their daily life” (Chakravarty, 2015).

Here, customization of the physical interior is key to a quality ride experience. One of the unique design highlights of the Limelight vehicles is the door compartments. Clients can select from compartments of a variety of shapes and sizes to accommodate specific, personal luxury items, from watches to pens to fragrance bottles (Figures 1b & 1c). Small but important possessions, whether it be a pen to jot down crucial meeting notes or a perfume to finish off the perfect look for a major awards ceremony, are located in familiar spaces within arm's reach. Passengers don't have to worry about remembering item locations or moving around the vehicle to access items, and they can focus instead on the more important happenings of the moment.

Figure 1a. Exterior (left) and interior (right) of a Rolls-Royce Phantom Limelight vehicle. Reprinted from Rolls-Royce, 2015.

Rolls-Royce shows that a comfortable, customizable space doesn’t require custom interior lights or massage seats — high-tech or high-volume features — though the car manufacturer does support those; sometimes, all it takes is thoughtful physical design. In this case, convenient storage for passengers to store important items while on the road.

Figures 1b & 1c. A custom-built door compartment shows the variety of hyper-specific luxury items that it can be tailored to hold. The leftmost custom-built compartment is designed to hold a client's watches, sunglasses, and ties. The rightmost compartment holds fragrance bottles and shirt pins. Reprinted from Rolls-Royce, 2015.

Space inhabitants will benefit greatly from a similar variety of tailorable, small storage spaces in both habitation and workplaces. Such a variety of storage will allow astronauts to organize and arrange personal living and work spaces according to configurations that they personally are most comfortable and familiar with. When spaces are familiar and items are easy to find, people can stress less about losing important items, and turn their attention to more important tasks at hand.

3.1.2 Micro-hotels: Designed for Organization

The rooms of Arlo SoHo (Figure 2), a boutique hotel located in the Hudson Square neighborhood of New York City, are another example of how efficient tidiness and a comfortable user experience are possible in confined spaces. Called the "first micro-hotel in the United States with four-star design," Arlo has an average of 15 square meters per room, roughly half the size of a standard US hotel room, but the quantity of space does not correlate with the quality of experience (McKnight, 2017). Guests describe the rooms as "very small" but also "comfortable," and "don't let the 'tiny' fool you" (Rob's Realm, 2020; Gab's Visual Diary, 2020).

Figure 2. Exterior and interior photos of the Arlo hotel. Reprinted from Uniq Hotels.

Matt Goodrich, chief creative design officer of AvroKO, the design firm behind the hotel's interior design, explains, "We created spaces where guests' needs are anticipated, quality is prioritized, and self-reliance is encouraged" (Itzkowitz, 2016). Rooms are built with custom furniture that is "thoughtfully designed to maximize space without sacrificing comfort" (McKnight, 2017). Foldable desks and self-adjustable hanging pegs allow guests to interact with and personalize their rooms (Figure 3a). Small, recessed shelves of various dimensions are built into the bed and walls (Figure 3b). This allows flexible, personal storage for items and luggage of all sizes, letting guests customize their rest and work spaces to their own liking. Similar to those of the Rolls-Royce Phantom Limelight limousines, the compartments' recessed design prevents storage from taking up volume, yet an open design easily allows guests to see what they have stored and, perhaps more importantly, prevent leaving items behind when checking out.

Figure 3a. Standard hotel room features include folding desks (left) and customizable pegs (right). Reprinted from Arlo Hotels.

Figure 3b. In these photos, we also see recessed shelves built into walls (left) and under beds (right). Reprinted from Arlo Hotels.

Additionally, customizable pegs, though they protrude more than the shelves, add a pleasant, playful surprise of living in an otherwise cramped space. Bright colors and simple shapes make the pegs resemble a game; guests can't resist using them to organize. At Arlo, tidying isn't just an arduous chore. It's something that can be fun, refreshing, and brighten up a traveler's day.

It may seem counterintuitive to use play when it comes to motivating people to do tidying tasks quickly and efficiently. Yet, playfulness and functionality do not have to be trade-offs. According to the book *Understanding Industrial Design* by Simon King and Kuen Chang (2016), both former directors of the renowned design firm IDEO, functional products can use playfulness to improve the user experience. This technique is used by world-famous houseware companies like Kohler, where interactive, sensorial products attract and delight customers. At the Kohler Design Center in Wisconsin, USA, customers can interact with houseware products, such as sink faucets and showerheads with flowing water, in a purchase-free environment. A 2012 study found that customers were more likely to experiment with sink faucets and showerheads that had more user interaction built into their usage. Examples of popular products included the Kohler Karbon faucet, which is shaped like a speaker and has more flexibility than other faucets, and the Kohler Flipside, a showerhead with a flippable head. Survey interviewees in general rated these products higher in terms of motivation for usage and ease of usability (Hong, 2012). Designs like Karbon and Flipside add unexpected joy to daily tasks such as washing the dishes and showering.

Though Arlo's pegs consume more space than Rolls-Royce's door panniers, these types of storage add a tangible, customizable aspect of controlling one's environment and making it feel like home. Thoughtfully designed organizational furniture pieces, though they require more resources to create, they bring more value and benefits. They make everyday tasks like organization no longer a chore or afterthought. They can be fun, joyful, and easily integrated into daily routine, making spacecraft interiors more organized and comfortable to live in long-term.

3.2 Principle 2: Design for Comfort Amid Heavy Design Constraints

Through innovative use of materials, manufacturing methods, and spatial illusions, spacecraft interiors can be comfortable, welcoming spaces, while also meeting spacecraft safety requirements.

In the previous section, we explored how the controllability of our environment can make us feel at home even in car seats and micro-hotel rooms. One common thread among these examples is physical materials for comfort. Limited space doesn't limit designers from using soft Nappa leather for seats in the Rolls-Royce Phantom vehicles, or custom-made foldable furniture for Arlo Grey's rooms.

However, such design features for spacecraft can be difficult. Technical practicalities such as budget, payload limits, and material safety pose many constraints (Hale & Lane, 2010). We now turn to how aircraft approach these issues using material technology and sensory illusions while adhering to strict air safety standards.

3.2.1 Materials in Aircraft

Not unlike spacecraft, aircraft must be deemed "airworthy" before taking off (SKYbrary). Designers must take into account safety standards such as weight, material flammability, and seat sturdiness (Anderson, 2011). Here, practicality often conflicts with comfort, particularly with the design of seats, which compose the majority of a passenger's flight experience. Seats must be sturdy and fit within limited cabin space. Yet passengers also desire seats that are large and comfortable, requiring more weight and volume. This demand for quality air hospitality has been fueling competition among airlines in engineering and design innovation to produce the most comfortable yet also safe travel experience (Barranco et al., 2020).

Pushes in material technology have given rise to airplane seats that are both cozy and practical. Textile manufacturer Acme Mills assembles seats with its Dymetrol fabric. The fabric acts as a "suspension membrane" (Figure 4) sturdy enough to eliminate bulky foam and heavy seat pans, saving an average of over 1,500 pounds in commercial airlines. The fabric's suspension properties also reduce pressure points, providing a more comfortable flight experience (Acme Mills). Similarly, Mirus Aircraft Seating's "Hawk" economy seat (Figure 5) uses pressure point mapping to maximize seat comfort. In addition, its internal frame is made of a combination of carbon fiber and aluminum. This makes frames not only sturdier but also slimmer and more flexible to shape, saving space and increasing legroom (Mirus). A seat's usage experience depends on not just its materials, but also its fabrication method. Using 3D scanning, a group of researchers was able to create an airplane seat designed to fit the contours of the human body: the form increased body contact and provided a sitting experience just as comfortable as regular airline seats while taking up less mass and volume (Hiemstra-van Mastrigt et al., 2019).

Figure 4. Above is a seat model built with the Dymetrol suspension membrane, which eliminates the need for additional seat pans and saves volume.
Reprinted from Acme Mills.

Figure 5. Above is the Mirus Hawk aircraft seat, which has a sleeker and slimmer profile compared to traditional aircraft seats, thanks to pressure point mapping, carbon fiber, and aluminum. Reprinted from Mirus Aircraft Seating.

Investing in these innovative uses of materials and manufacturing will greatly benefit spacecraft too. This will create living and work spaces that are not only safe, durable, and easy to maintain, but also add joy and comfort to outer space living. This is important, especially if these spaces are to be used in passengers' daily lives for long periods.

3.2.2 Sensory Illusions in Aircraft

The way a space is perceived *visually* is just as important as how it's perceived physically. In aircraft, when designers are dealing with small spaces, they often use visual illusions to compensate for the lack of physical spaciousness. These illusions will highly benefit spacecraft too. Though such interior features require careful design and planning, the cost, payload, and resources they conserve can be refocused toward more important mission assets. Visual illusions are more practical than the real deal since they have lower costs, weight, and energy to implement. The following examples include using light instead of physical space, and stick-on mirrors instead of wall-mounted mirrors.

The main technique behind increasing the perception of space, without adding physical space, is to increase the amount of light. Lighter wall colors brighten empty spaces while masking confining features like corners and edges (Atelier Akuko). This explains why it's common for airplanes like Boeing's 787 Dreamliner to use creme or light-gray-colored interiors for their cabins (Kepler22b, 2016) (Figure 6a). Another common technique is to add reflective surfaces such as metal finishes and mirrors. By bouncing around lighter, these surfaces make spaces appear to double in size (Mandell, 2016). Due to higher costs and heavy mounting, such surfaces are more common in private aircraft, where designers have more flexibility with weight constraints and budgets. More practical options include stick-on mirrors and metallic decor: while just as reflective as the real thing, these are lower in cost and weight, and can also be used in spacecraft (Wright, 2020; Wayfair).

Another common principle in increasing spatial perception is emphasizing long, continuous lines. In an article on the lifestyle blog *Bustle*, an interior designer says: "Shelves, decorations, all that stuff, hang it higher than normal... This helps to draw the eye upward toward the ceiling. In a way, it also literally adds more space" (Grant, 2018). Similarly, at the Boeing Customer Experience Center near Seattle, Washington, interior models feature lines running vertically along cabin walls. Cabin experience designer Dr. Rachelle Ornan-Stone explains that this draws the eye upwards and makes the cabin stretch taller. This is why Boeing planes have lighting concentrated upwards along cabin walls and along the ceiling (Figure 6b). Additionally, overhead storage bins are installed high above passengers' heads to draw the gaze upwards, and shallow indentations in the walls subtly attract passengers to gaze toward windows; these details also make the cabin space feel larger (Dominguez, 2016).

Figure 6a. Interior of the Boeing 787 Dreamliner interior. White walls make the interior feel more spacious. Reprinted from United Airlines.

Figure 6b. Another interior of the Boeing 787 Dreamliner interior. Here, we see running ceiling lights, curved walls, and continuous lines that make the interior space seem to stretch and expand. Reprinted from United Airlines.

3.3 Principle 3: Design for Beauty

Last but not least, spacecraft interiors, especially interiors for unwinding such as sleep and social quarters, must also have beauty: the beauty of Earth, and the beauty of outer space. People need both. Beauty can balance the negative feelings of space travel, like homesickness and fear of the expanse outside. It can make astronauts more prepared and ready to embrace the nature of space travel.

It may seem odd to discuss designing spacecraft interiors for beauty when already a huge design effort is (importantly so) dedicated to the functionality of everyday space life — supporting rest, hygiene, meal prep, exercise, research, etc (May; Grush, 2019). As former NASA astronaut and Johnson Space Center director Ellen Ochoa explained in an email interview regarding her experiences aboard the Discovery space shuttle, "the shuttle was designed for short flights — most were five to 15 days, so comfort wasn't a big consideration. It was more about being able to get the work done and the ability to carry up equipment and supplies" (Ochoa, 2021).

In the future, however, spacecraft interiors must become more comfortable. Especially as journeys grow longer, everyday lifestyle activities aboard spacecraft, such as relaxation and socializing, will become just as prominent as work and research activities. Spacecraft will continue to have areas designated for equipment and research work, spacecraft will also have spaces for rest and recharge: think private crew quarters, cafeterias, and social gathering spaces. Details of these interiors become even more salient, especially if they're the few spaces that the crew can retreat to for privacy and unwinding. These spaces must be designed for beauty and comfort, and not just by any design. There are specific human needs that design must accommodate. Particularly as space travel increases in distance and duration, two aspects intensify: distance from home and proximity to outer space.

Previous space missions have shown the profound impacts of both being so removed from the familiarities of Earth and being so close to the unknown void of space. These circumstances have two main negative impacts on astronauts: yearning for home, and intimidation by the vacuum outside.

Homesickness is a concern in aerospace travel, especially as missions are expected to go further and longer. Though homesickness is not often expressed explicitly by space visitors, it's a common experience. Gazing at Earth is the most common free-time activity among astronauts, and one of the most popular rooms aboard the ISS among visitors is the Cupola, famous for its panoramic views of Earth. The omnipresent sight of Earth is a poignant psychological anchor among astronauts: a reminder that home is not too far (Tolley, 2020). In fact, in 2014, NASA invested $1.6M to develop virtual reality headsets for travelers to simulate the experience of home while on long missions (Melanson, 2014).

In addition to homesickness, the high-risk nature of space travel and the dangers of the space vacuum are also profound psychological stressors. The current astronaut selection process ensures that those who go to space can maintain calm, capability, and confidence in zero gravity. Ask any astronaut about how they felt about going into space, and they likely won't outright admit feeling scared. Yet, no astronaut lacks at least some degree of apprehension. When asked about being afraid of going to space, former European Space Agency astronaut Luca Parmitano said in his blog: "The temptation to answer simply 'no' is great, everyone would breathe a sigh of relief and go on knowing that there are out of the ordinary men and women in the world who work without fear: astronauts. But superhumans do not exist — and it is better this way. My humble opinion is that only fools say they are never afraid — and they are lying when they say it" (Eveleth, 2013). In such a high-risk environment where only a few inches of metal separate astronauts from a deadly vacuum, such feelings are expected. These will most likely grow for longer missions going further from Earth, particularly for space tourists and first-time travelers.

Similar to astronauts, scientists staying at the Halley VI British Antarctic Research Station are often confined indoors for long periods, some residing through the entire eight-month winter season. With -60°F temperatures, 100 mph snowstorms, and 24/7 darkness, winters in Antarctica are the most brutal on Earth (Australian Antarctic Program). Residents must deal with homesickness, yet also face the harsh environment outside. This section discusses how the Halley base accommodates homesickness and acknowledges the extreme, hostile setting.

3.3.1 Halley VI: Designed for Homesickness

Despite being located in one of the harshest environments in the world, Halley VI aims to feel like home to guests. According to Hugh Broughton Architects, the firm behind Halley VI's interior, the design is meant to be "uplifting" and "inspiring," particularly during dark winter seasons when Seasonal Affective Disorder is common (Hugh Broughton Architects). Labs and equipment rooms have functional, sterile interiors, typical for spaces of research and technical work (Figure 7). Things change in the residential or the main gathering modules (Figure 8). Interiors are filled with bright, vibrant colors and plush modern furniture: a casual, relaxing balance to workspaces.

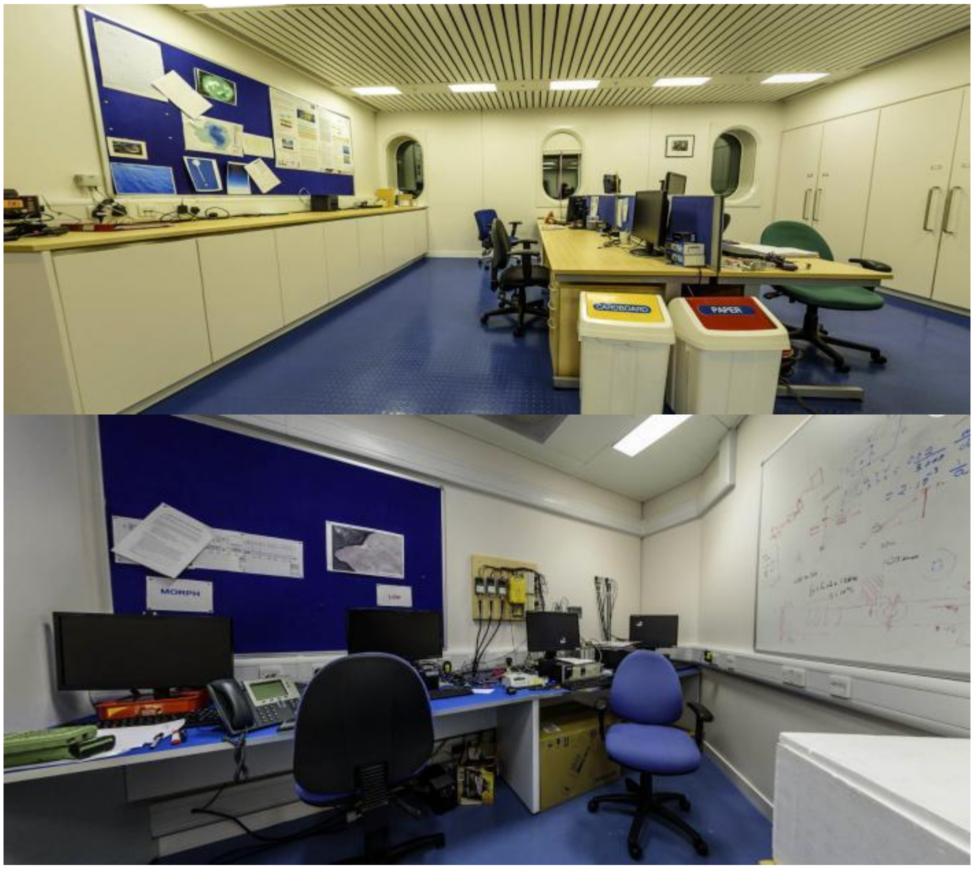

Figure 7. Halley VI workspaces, featuring science offices (top) and balloons room (bottom). Furniture includes standard desks and chairs. The floors, boards, and chairs add some pops of bright color, but otherwise, these spaces overall have a sterile palette. Reprinted from Halley VI Research Station 360° Virtual Tour, 2016.

Figure 8. Halley VI's social and relaxation spaces, including the quiet room (top), TV room (middle), and bar area (bottom). These rooms have much brighter splashes of color compared to those in Figure 7. Rooms also have plenty of rounded, plush furniture, and soft surfaces to physically and mentally soothe inhabitants. Reprinted from Halley VI Research Station 360° Virtual Tour, 2016.

Living experiences at the base have so far been positive. Pat Powers, base commander, complimented the main pod as being "a lot more social" than the previous pod (Moore, 2013). In his blog, British Antarctic Survey research engineer Mike Rose described the space as "really impressive… seems far more homely [sic],” with the lounge area being “very comfortable” (Rose, 2013). Despite being located in such a harsh environment, Halley VI provides a comfortable home for researchers to not just survive the Antarctic’s sub-zero temperatures, but also thrive in.

Additionally, it’s not enough for a space to feel like home, but to also bring in a bit of home planet Earth itself, literally. The practice of designing interiors inspired by Earth's nature is known as biophilic design. The term “biophilic” derives from the Greek word *biophilia*, literally meaning “love of life” (Browning et al., 2014). Research has shown how people benefit when in interiors with natural features, both *direct* (e.g. living plants, fountains, natural light) and *indirect* (e.g. artificial plants, sounds of nature, simulated light) (Kellert et al., 2008). In this paper, I’ll focus mainly on indirect natural features. Direct features like real plants except for food and research purposes, real fountains, and natural light will probably be difficult to achieve in outer space.

As seen in Figure 9, Halley VI uses cedar wood paneling in one of its main rooms, with the wood selected specifically for its natural cedar scent. In addition, the interior colors are from a “spring color palette” selected by a color psychologist (Figure 10) (Moore, 2013). Halley VI’s design brings a warm meadow to an environment where plant life is otherwise impossible.

In outer space, where people will be further than before from plant life (or any life in general), biophilic design elements will play an even greater role in adding beauty and comfort to the journey experience.

Figure 9. One of the most notable biophilic features in Halley VI is its naturally scented wood panels in the history corridor, bringing hints of forest to the Antarctic snowscape. Reprinted from InteriorDesign.net, 2013.

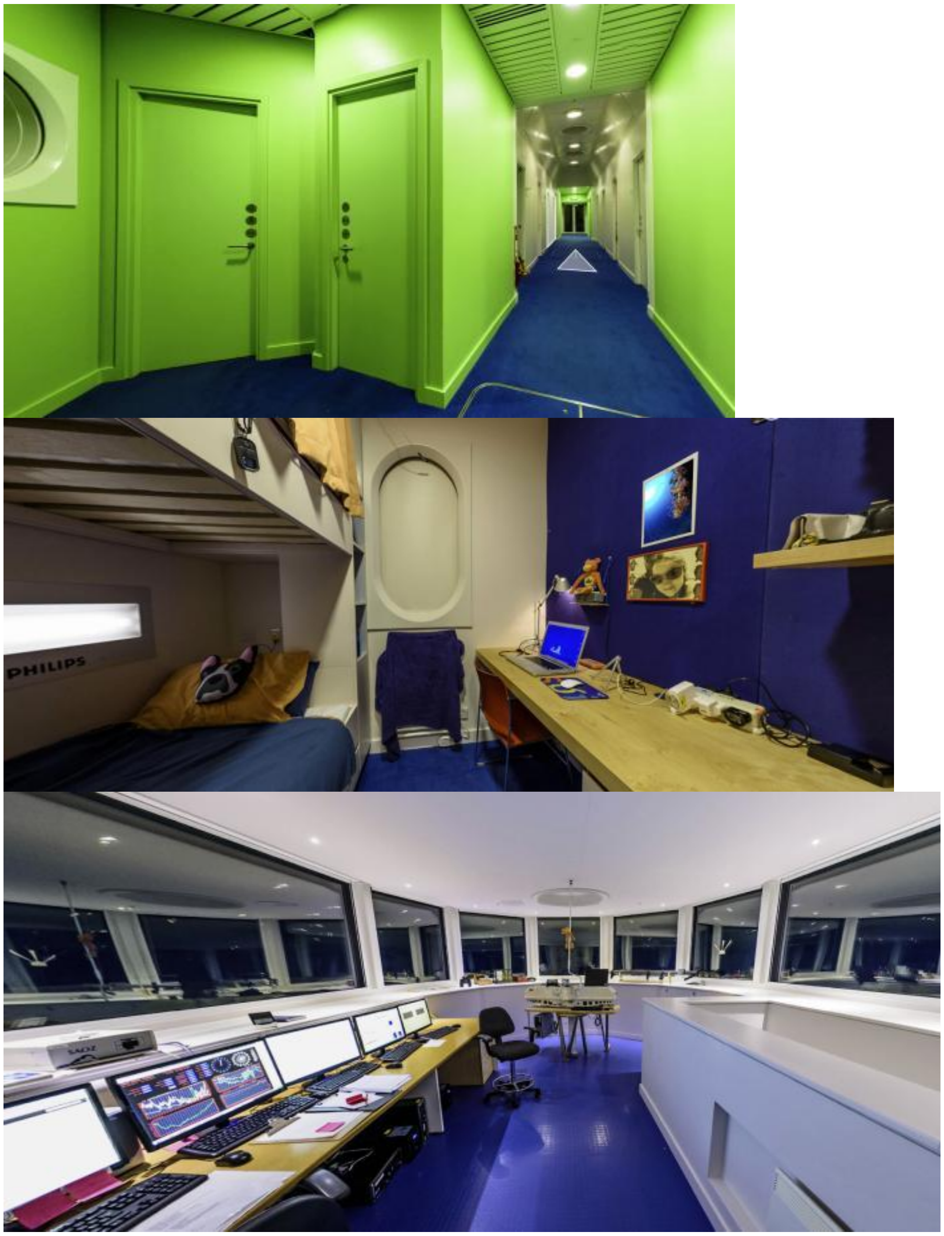

Figure 10. Interiors featuring the spring color palette that was curated by a color psychologist. Here, bright hues of green and blue add everyday vibrancy throughout Halley VI, including the residential corridors (top left), dorms (top right), and even some workspaces (bottom). Reprinted from Halley VI Research Station 360° Virtual Tour.

3.3.2 Halley VI: Designed for Anticipation of the Unkown

Though the Antarctic tundra isn't as deadly as the space vacuum, it's still not exactly a place where one can simply stroll out for some fresh air. Not unlike astronauts gearing up with EVA suits and oxygen for a spacewalk, Antarctic expeditioners must prepare freezer suits and plenty of thermal layers (Mahoney, 2019). Outside, potential hazards include hypothermia, frostbite, and sweat freezing (Australian Antarctic Program). Additionally, the fact that below the base is the cracking Brunt Ice Shelf isn't exactly comforting either (Amos, 2021).

Thus, it's easy for the design team at Hugh Broughton to mask Halley VI from the extreme environment outside and to keep the indoors a year-round spring paradise. Yet, the design doesn't hesitate to address the Antarctic environment's duality — the lethal cold, yet also the setting's beauty — with a simple feature: windows. Particularly in the main base, one of the most salient features is a giant window (Figure 11) taking up an entire wall. While the views of blizzards and 24/7 dark skies may not be the most ideal during the winter season, during the summer season, windows allow in plenty of natural light, thanks to Antarctic snow being among the most reflective materials on Earth (Hall & Martinec, 1985). Also during summer, windows provide spectacular views of the *aurora australis* at night (Moore, 2013). As shown in Figure 12, other spots to take in the landscape include the social module's "quiet room," with its views letting residents "contemplate the majestic icescape outside," and the skylights in the TV room (SpaceArchitect).

Figure 11. Below are the exterior (left) and interior (right) of Halley's main module. The giant window of Halley's main module allows plenty of natural sunlight to illuminate the space. Reprinted from InteriorDesign.net.

Figure 12. The quiet room (top) and TV room (bottom) also have expansive window views, allowing residents to appreciate the Antarctic beauty outside, day and night. Reprinted from Ice Cold Blog, 2014.

Similarly in space, the expanse of the universe has never failed to amaze astronauts despite its deadliness. One of the most popular modules aboard the ISS for relaxation is the Cupola, famous for its 360-degree panoramic view. Regarding the interior of the Discovery shuttle, Ochoa mentioned: “It’s very important to have windows, for both science and for the experience and mental health of astronauts.” In addition, she mentioned the view as one of the main highlights of a day in outer space, saying “it was always a treat to be able to look out the window, generally after dinner and before going to bed” (Ochoa, 2021).

Future spacecraft design should emphasize ample accessible windows. Though heavy, windows add an invaluable psychological benefit to travelers that will benefit the mission in the long run.

Like that of the Antarctic, the extreme nature of outer space is dualistic. It has beauty, and wonder, yet also the ugly: danger, inhospitality, and inhabitability. Interior design can help us embrace the outside’s beauty and be prepared to face its ugliness. Future spacecraft interior design should balance home and the stars. Earth-inspired, biophilic design brings security, and groundedness, and keeps a bit of home close to travelers. Ample windows that open up to the outside environment keep alight excitement and wonder of the expanse beyond. Both lead to psychological preparedness that's crucial to mission success.

4. Conclusion

It has always been human nature to explore the space around us, from land, to sea, to sky, and more recently, to the stars. We will continue to push exploration further into the cosmos: missions with more distance, with more people, where anyone who looks at the night stars and wishes to fly among them, can. And no doubt, also part of human nature: human emotions. Joy, frustration, loneliness... These emotions go wherever we go. In a high-stakes environment like outer space where even the slightest off-day can spell disaster, never has it been more important to design spaces that nourish the ups of being human and accommodate the downs. On or off the planet, the built environment will shape us as much as we shape it. With the framework that it establishes, this paper hopes to guide current and future designers in creating healthy, comfortable homes beyond Earth, where humans can not just live, but also thrive.

References

Acme Mills. *Dymetrol*. Acme Mills. Retrieved from https://acmemills.com/dymetrol/.

Amos, J. (2021, Janurary 7). *Antarctic Base Opens Briefly as Berg Watch Continues*. BBC News. Retrieved from https://www.bbc.com/news/science-environment-55573397.

Anderson, A. (2011). *Aviation Safety: Evolution of Aircraft Interiors.* AERO Magazine. Retrieved from https://www.boeing.com/commercial/aeromagazine/articles/2011_q4/2/.

Anonymous. (2016). *Will they ever make the interior of the ISS look tidy?* Quora. Retrieved from https://www.quora.com/Will-they-ever-make-the-interior-of-the-ISS-look-tidy. Question answered by NASA operations support officer Robert Frost.

Atrerlier Akuko. *The Psychology Of Space: Perception.* Akuko Studio. Retrieved from https://atelier.akuko.studio/psychology/the-psychology-of-space-perception.

Australian Antarctic Program. (2020). *Antarctic Weather.* Australian Antarctic Program. Retrieved from https://www.antarctica.gov.au/about-antarctica/weather-and-climate/weather/.

Australian Antarctic Program. *Clothing - What Do You Wear?* Australian Antarctic Program. Retrieved from https://www.antarctica.gov.au/about-antarctica/people-in-antarctica/clothing.

Barranco, V., Cameron, S., & Narishkin, A., dirs. (2020, February 27). *How Airplane Interiors Are Designed* [Video]. Business Insider. Retrieved from https://www.businessinsider.com/how-airplane-interiors-are-designed-delta-777-2020-7.

Browning, W., Ryan, C., & Clancy, J. (2014). *Fourteen Patterns of Biophilic Design.* Terrapin Bright Green, LLC. Retrieved from https://www.terrapinbrightgreen.com/reports/14-patterns/.

Chakravarty, S. (2015, April 24). *Rolls-Royce Phantom Limelight Collection, a Bespoke $650K Luxury Limo for the Rich and Famous.* Luxurylaunches. Retrieved from https://luxurylaunches.com/transport/rolls-royce-phantom-limelight-collection.php.

Chang, K. & King, S. (2016). *Understanding Industrial Design.* O'Reilly Media.

Chui, M., Manyika, J., Bughin, J., Dobbs, R., Roxburgh, C., Sarrazin, H., Sands, G., & Westergren, M. (2012, July 1). *The social economy: Unlocking value and productivity through social technologies.* McKinsey Global Institute. Retrieved from https://www.mckinsey.com/industries/technology-media-and-telecommunications/our-insights/the-social-economy.

Costa, M., Frumento, S., Nese, M., & Predieri, I. (2018). Interior Color and Psychological Functioning in a University Residence Hall. *Frontiers in Psychology, 9.* https://doi.org/10.3389/fpsyg.2018.01580.

David, L. (2005, November 21). *Nauseating News About Spacesickness.* Space. Retrieved from https://www.space.com/1792-nauseating-news-spacesickness.html.

Dominguez, T. (2016). *How Airplanes Are Designed To Feel Bigger On The Inside* [Video]. Discovery Channel. Retrieved from https://www.youtube.com/watch?v=imzDk6dfP54.

Eveleth, R. (2013, September 10). *Yes, Astronauts Are Afraid to Go to Space.* Smithsonian Magazine. Retrieved from https://www.smithsonianmag.com/smart-news/yes-astronauts-are-afraid-to-go-to-space-5249261/.

Gab's Visual Diary. (2020). *User review of Arlo SoHo.* Google Reviews. Retrieved from https://www.google.com/travel/hotels.

Grant, E. (2018, October 24). *13 Things That Make Your Space Look Smaller.* Bustle. Retrieved from https://www.bustle.com/p/13-things-that-make-your-space-look-smaller-12588263.

Grush, L. (2019, February 1). *Better Interior Design Might Keep Astronauts Healthier and Happier in Deep Space.* The Verge. Retrieved from https://www.theverge.com/2019/2/1/18205506/nasa-mars-mission-spacecraft-interior-design-astronaut-behavioral-health.

Hale, W. & Lane, H. (2010). *Wings in Orbit: Scientific and Engineering Legacies of the Space Shuttle,* 200–225. NASA. Retrieved from https://www.nasa.gov/centers/johnson/wingsinorbit/.

Hall, D. & Martinec, J. (1985). *Remote Sensing of Ice and Snow.* Chapman & Hall.

Hiemstra-van Mastrigt, S., Smulders, M., Bouwens, J., & Vink, P. (2019). Designing Aircraft Seats to Fit the Human Body Contour. *DHM and Posturography,* 781–789. https://doi.org/10.1016/B978-0-12-816713-7.00061-1.

Hong, Z. (2012). *A Study for Playful Product Design* [M.A. Thesis]. Department of Industrial Design, Auburn University.

Hugh Broughton Architects. (2013). *Halley VI British Antarctic Research Station.* Hugh Broughton Architects. Retrieved from https://hbarchitects.co.uk/halley-vi-british-antarctic-research-station/.

International WELL Building Institute. (2021). *Welcome to WELL.* International WELL Building Institute. Retrieved from v2.wellcertified.com.

Itzkowitz, L. (2016, October 6). *Would You Stay in a High-Design Micro-Hotel in New York City?* Architectural Digest. Retrieved from https://www.architecturaldigest.com/story/arlo-hudson-square.

Kellert, S., Heerwagen, J., & Mador, M. (2008). *Biophilic Design: The Theory, Science and Practice of Bringing Buildings to Life.* John Wiley & Sons, Inc.

Kepler22b. (2016). *Why are passenger cabins white?* Aviation Stack Exchange. Retrieved from https://aviation.stackexchange.com/questions/25665/why-are-passenger-cabins-white.

Knight, C. & Haslam, S. (2010, June). The Relative Merits of Lean, Enriched, and Empowered Offices: An Experimental Examination of the Impact of Workspace Management Strategies on Well-Being and Productivity. *Journal of Experimental Psychology Applied, 16*(2), 158-172. https://doi.org/10.1037/a0019292.

Kobie, N. (2019, January 8). *The design secrets NASA's using to keep astronauts happy in space.* WIRED UK. Retrieved from https://www.wired.co.uk/article/space-travel-design-mental-health-interiors.

Mahoney, E. (2019, October 4). *Spacewalk Spacesuit Basics.* NASA. Retrieved from https://www.nasa.gov/feature/spacewalk-spacesuit-basics.

Mandell, L. (2016, May 10). *How to Make a Small Room Look Bigger: Design Experts' Secrets.* Realtor. Retrieved from https://www.realtor.com/advice/home-improvement/how-to-make-a-small-room-look-bigger/.

May, S. *A Day in the Life Aboard the International Space Station.* NASA. Retrieved from https://www.nasa.gov/audience/foreducators/stem-on-station/dayinthelife.

McKnight, J. (2017, December 21). *AvroKO Creates "Micro-hotel" in Former Industrial Neighbourhood in New York.* Dezeen. Retrieved from https://www.dezeen.com/2016/12/21/avroko-arlo-hudson-square-micro-hotel-manhattan-new-york/.

McMains, S. & Kastner, S. (2011, January 12). Interactions of top-down and bottom-up mechanisms in human visual cortex. *Journal of Neuroscience, 31*(2), 587-597. https://doi.org/10.1523/JNEUROSCI.3766-10.2011.

Melanson, D. (2014, October 18). *NASA's Latest Virtual Reality Is Designed to Soothe Homesick Astronauts.* VICE. Retrieved from https://www.vice.com/en/article/z4mq4j/virtual-reality-for-homesick-astronauts.

Mirus. *Mirus Hawk.* Mirus Aircraft Seating. Retrieved from https://www.mirus-as.com/the-mirus-hawk/.

Moore, R. (2013, February 10). *Halley VI Research Station, Antarctica – Review.* The Guardian. Retrieved from https://www.theguardian.com/artanddesign/2013/feb/10/halley-vi-base-architecture-antarctica.

Ochoa, E. (2021). E-mail correspondence with author of this article.

Raanaas, R., Evensen, K., Rich, D., Sjøstrøma, G. & Patila, G. (2011). Benefits of indoor plants on attention capacity in an office setting. *Journal of Environmental Psychology, 31*(1), 99-105. https://doi.org/10.1016/j.jenvp.2010.11.005.

Rob's Realm. (2020). *User review of Arlo SoHo.* Google Reviews. Retrieved from https://www.google.com/travel/hotels.

Rose, M. (2013, February 9). *Arrived Halley.* Ramblings to and from Antarctica. Retrieved from https://esorekim.blogspot.com/2013/02/arrived-halley.html.

SKYbrary. *Airworthiness*. SKYbrary Aviation Safety. Retrieved from https://www.skybrary.aero/articles/airworthiness.

SpaceArchitect. *Halley VI Antarctic Research Station.* SpaceArchitect. Retrieved from https://spacearchitect.org/portfolio-item/halley-vi-antarctic-research-station/.

Tolley, G. (2020, October 29). *Homesick for Planet Earth.* Wellcome Collection. Retrieved from https://wellcomecollection.org/articles/X41xTxIAAB0AgqvT.

USGBC. *LEED rating system.* U.S. Green Building Council. Retrieved from https://www.usgbc.org/leed.

Wall, M. (2020, December 2). *SpaceX's 1st Crewed Mars Mission Could Launch as Early as 2024, Elon Musk Says.* Space. Retrieved from https://www.space.com/spacex-launch-astronauts-mars-2024.

Wayfair. *Metal Peel & Stick Backsplash Tile* [Search results]. Wayfair. Retrieved from https://www.wayfair.com/home-improvement/sb1/metal-peel-stick-backsplash-tile-c1864259-a130379~433187.html.

Wright, L. (2020, May 9). *Peel And Stick Mirror*. VisualHunt. Retrieved from https://visualhunt.com/peel-and-stick-mirror.

Appendix

Below is the full list of WELL v2 features from IWBI (International WELL Building Institute, 2021).

Air

- A01 Air Quality
- A02 Smoke-Free Environment
- A03 Ventilation Design
- A04 Construction Pollution Management
- A05 Enhanced Air Quality
- A06 Enhanced Ventilation Design
- A07 Operable Windows
- A08 Air Quality Monitoring and Awareness
- A09 Pollution Infiltration Management
- A10 Combustion Minimization
- A11 Source Separation
- A12 Air Filtration
- A13 Enhanced Supply Air
- A14 Microbe and Mold

Nourishment

- N01 Fruits and Vegetables
- N02 Nutritional Transparency
- N03 Refined Ingredients
- N04 Food Advertising
- N05 Artificial Ingredients
- N06 Portion Sizes
- N07 Nutrition Education
- N08 Mindful Eating
- N09 Special Diets
- N10 Food Preparation
- N11 Responsible Food Sourcing
- N12 Food Production
- N13 Local Food Environment
- N14 β Red and Processed Meats

Movement

- V01 Active Buildings
- V02 Ergonomic Workstation
- V03 Circulation Network
- V04 Facilities for Active Occupants
- V05 Site Planning and Selection
- V06 Physical Activity Opportunities
- V07 Active Furnishings
- V08 Physical Activity Spaces and Equipment
- V09 Physical Activity Promotion
- V10 Self-Monitoring
- V11 β Ergonomics Programming

Sound

- S01 Sound Mapping
- S02 Maximum Noise Levels
- S03 Sound Barriers
- S04 Reverberation Time
- S05 Sound Reducing Surfaces
- S06 Minimum Background Sound
- S07 β Impact Noise Management
- S08 β Enhanced Audio Devices
- S09 β Hearing Health Conservation

Mind

- M01 Mental Health Promotion
- M02 Nature and Place
- M03 Mental Health Services
- M04 Mental Health Education
- M05 Stress Management
- M06 Restorative Opportunities
- M07 Restorative Spaces
- M08 Restorative Programming

Water

- W01 Water Quality Indicators
- W02 Drinking Water Quality
- W03 Basic Water Management
- W04 Enhanced Water Quality
- W05 Drinking Water Quality
- W06 Drinking Water Promotion
- W07 Moisture Management
- W08 Hygiene Support
- W09 β Onsite Non-Potable Water Reuse

Light

- L01 Light Exposure
- L02 Visual Lighting Design
- L03 Circadian Lighting Design
- L04 Electric Light Glare Control
- L05 Daylight Design Strategies
- L06 Daylight Simulation
- L07 Visual Balance
- L08 Electric Light Quality
- L09 Occupant Lighting Control

Thermal Comfort

- T01 Thermal Performance
- T02 Verified Thermal Comfort
- T03 Thermal Zoning
- T04 Individual Thermal Control
- T05 Radiant Thermal Comfort
- T06 Thermal Comfort Monitoring
- T07 Humidity Control
- T08 β Enhanced Operable Windows
- T09 β Outdoor Thermal Comfort

Materials

- X01 Material Restrictions
- X02 Interior Hazardous Materials
- X03 CCA and Lead Management
- X04 Site Remediation
- X05 Enhanced Material Restrictions
- X06 VOC Restrictions
- X07 Materials Transparency
- X08 Materials Optimization
- X09 Waste Management
- X10 Pest Management and Pesticide Use
- X11 Cleaning Products and Protocols
- X12 β Contact Reduction

Community

- C01 Health and Well-Being Promotion
- C02 Integrative Design
- C03 Emergency Preparedness
- C04 Occupant Survey
- C05 Enhanced Occupant Survey
- C06 Health Services and Benefits
- C07 Enhanced Health and Well-Being Promotion
- C08 New Parent Support
- C09 New Mother Support
- C10 Family Support
- C11 Civic Engagement
- C12 Diversity and Inclusion
- C13 Accessibility and Universal Design
- C14 Emergency Resources
- C15 β Emergency Resilience and Recovery
- C16 β Housing Equity
- C17 β Responsible Labor Practices

- M09 Enhanced Access to Nature
- M10 Tobacco Cessation
- M11 Substance Use Services
- C18 β Support for Victims of Domestic Violence