Making Mars Home:

Considerations From Earth When Designing Spacefaring Communities

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Dedication

To My Advisors, Thank you for your wealth of knowledge, support, and spirit. You've made this project so fun.

To My Younger Self, You did it! Your dreams of space become more of a reality every day.

To My Parents,

Thank you for believing in me, no matter what. You taught me to shoot for the stars. So this thesis is for you.

01

Abstract

This thesis examines architecture and its ability to affect how humans might live on Mars, specifically using design to mitigate psychological and social problems between humans. How can design improve the lives of spacefarers in the creation of a permanent settlement on Mars? This research synthesizes and analyzes information across architecture, space, and psychology in order to understand areas where design intervention is needed.After analysis, design considerations are identified, and they are placed in a matrix using the sociological methodology of Grounded Theory. All of these outputs contribute to considerations for designing in space, providing considerations for the improvement of the community and psychological health through a non-technical lens. These considerations include clear wayfinding, programmatic elements, and variation in public and private spaces. This research will provide great value to the growing space industry as well as in extreme environments on Earth.

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Introduction

Going back to ancient times, humans have been fascinated with stars and the world above; constellations were named, telescopes were created, and astronomy was developed (Evans 1998). As humans have been drawn to finding and conquering new lands throughout history (Beazley 1906), the new place to be conquered is not on Earth, but rather, on Mars. Propelled by increasing interest in space exploration, the human race is bound to become an interplanetary species in the near future, as The National Aeronautics and Space Administration (NASA) plans to have humans on Mars within twenty years (Daines 2015). Currently, the space industry is valued at approximately $424 billion, projected to reach $1.4 trillion by 2030. This means that fiscally the space industry would be roughly the same size as the current global tourism industry (Sheetz 2020). This suggests that understanding how to design for human habitation in space is becoming as essential as knowing how to design a resort on Earth.

This thesis addresses the need for understanding interplanetary design by creating a summary of considerations for establishing best Architectural practices for establishing a settlement on Mars. In particular, the thesis focuses on mitigating social and psychological hurdles when creating interplanetary settlements.

Current science has the technical ability to provide astronauts with food, water, air, and shelter, but the community and mental health, as well as architecture, have not been as thoroughly integrated or prioritized in space habitation due to astronauts having been

trained to live in these extreme conditions and the focus being on the scientific mission rather than comfort.

However, when it can take months just to arrive at your mission, like Mars , comfort becomes incredibly important. More so, with space tourism becoming more popular, tourists will be expecting the comforts of home, making these elements far more important than in the past (Harrison 2010). Without these social elements, human habitation on another planet may experience long-term adverse effects (National Academies of Sciences, Engineering, and Medicine et al. 2020).

This research will examine if architecture can be a bridge between what we have done in space and future ideas for permanent habitation, specifically the psychological hurdles, which are necessary and desired.

Figure 1. SpaceX Falcon Heavy Launch. (Photograph by SpaceX. 2018.)

Living in an extreme environment already pushes our bodies to their limits. For example, the cardiovascular and muscular systems are required to work harder. Due to the different environments, these body systems must adapt and function differently than the body is intended to in normal conditions (Gunga 2020). Still, the long-term social connection becomes even more complicated with social isolation -as it adversely affects your psyche- making it even more critical that each member's mind is in the right place for the community to survive (Perez 2020). This thesis begins by looking through the lens of neuro-architecture, which is how architecture impacts the human psyche and behaviors (Eberhard 2009), to examine a series of Earth-based precedents selected for their similarities to space, such as extreme environments, isolation, and community similarities. The Grounded Theory Methodology is then used to categorize and identify relationships between elements that impact the individual, social relationships, and community connections.

Through this methodology, this research outlines critical considerations for Architectural space design in order to help mitigate the challenges of living in space.

06

Research Question

How can neuro-architecture mitigate the challenges humans face when living in a permanent settlement on Mars?

What Is Neuro-Architecture

Neuro- architecture in plain terms is really how architecture and the built environment impacts the human psyche including how we feel and behave. It is an interdisciplinary idea, crossing between architecture and psychology. Neuro-architecture functions based on the assumption that our environment directly impacts our behavior. The goal of neuro-architecture is to understand architecture and its impact on behavior.

07

Literature Review

Introduction

Neil Armstrong and Buzz Aldrin ventured onto the moon just over fifty years ago, making them the first humans to step foot on another terrestrial (rock-based) body (Canright 2009). NASA plans within the next twenty years to have humans on Mars, making the reality of becoming an interplanetary species increase (Daines 2015). To understand how humans have begun the design work to become an interplanetary species, this chapter will cover human sociological needs within the context of architecture, design for wellbeing, and previous space station design.

Psychology Of Space Exploration

Being in a new environment is strenuous, but when it is as extreme as space there are additional factors fighting against you including isolation, radiation, gravity changes, and distance from Earth. Isolation and stress adversely affect the mind and increase one's risk for numerous diseases (National Academies of Sciences, Engineering, and Medicine et al. 2020), while space radiation can cause cancer-related health risks and loss of function (Nelson 2016). Furthermore, gravitational changes cause loss of bone and muscle mass and hormonal changes (Clément, Bukley, and Paloski 2007).

Additionally, social isolation is a crucial factor that comes into play with how you feel, when in such extreme and far away location, such as Mars. Being so far away from our home, and on a completely

new world people may experience social isolation. Social isolation, which involves emotional isolation, means lacking social connections, including friends, co-workers, or daily interaction with others. Social isolation is related to loneliness, but they differ because you can be lonely and still have social interaction. Loneliness is the feeling of isolation, not necessarily meaning you are isolated. Isolation can significantly affect mental, physical, and cognitive abilities. More specifically, ***according to Hawkley, an analysis of recent studies on varying social species "shows that socially isolated housing… results in altered behavior (e.g., anxious, depression-like, aggressive, passive, cognition/memory), physiology (e.g., changes in basal or stress-reactive corticosterone, blood pressure, inflammation, immune responses, hippocampal function) and mortality (e.g., post-stroke outcomes)" (Hawkley and Capitanio 2015).*** The connection between isolation and poor health can alter your quality of life throughout your life span, increasing the risk of dementia by 40 percent ("Understanding the Effects of Social Isolation on Mental Health" 2020). Research shows the importance of social connection, ***as the adverse effects of isolation cause an increase in premature death from every cause, regardless of sex or race (Alcaraz et al. 2019).*** Not much is known about how isolation causes these adversities; so far, research suggests it results from an increase in the "fight or flight" response, an evolutionary trait in animals to either flee or fight in order to stay alive, weakening one's immune system (Novotney 2019). It is vital

that humans are healthy to survive on Mars; therefore, socialization is important and a priority when designing.

From the beginning, psychologists and others emphasized how psychological stressors should be considered a risk factor for worsened health that will only increase with the duration of exposure to the stressor (Vakoch 2011). Astronauts are specially selected and trained for this mental challenge, including going through many psychological and physical screenings, water, equipment, and weightlessness training, as well as training in various atmospheric pressures for emergency situations (NASA n.d.b.). However, even those individuals trained for space exploration re-enter Earth with difficulty (Jordan 2016). Complications include the inability to form sleep patterns and walk independently; astronauts, including Christina Koch, who holds the record for the longest continuous time in space by a woman, note they feel different after their time in space (Garcia 2020). Both one's body and mind change in space, leaving many mental hurdles to overcome once the astronauts return to Earth. Health professionals today acknowledge mental health as incredibly important, but this was not always the case - especially in space. Prior to and during the Space Race, psychology and mental health were put on the back burner of concerns at NASA (Harris 1991). This was until the 1960's when Walter F. Grether, an early pioneer in both space and psychology, pointed to four areas for research in the future: 1) "moving about the interior of spacecraft (once they became large enough for this to

occur), 2) conducting extravehicular activities (EVAs) or ‘spacewalks,’ 3) performing rendezvous, and 4) living and working under conditions of prolonged isolation and confinement” (Vakoch 2011). His recommendations highlighted a new area of research that began the connection between space and psychology. Grether’s ideas of space psychology were what is now known as ergonomics or human factors (Vakoch 2011).

Despite these strides in researching the mental implications of space travel, NASA was reluctant to study or release information on the psychological impacts of space flight, possibly due to confidentiality or the potential downfall of the agency (Santy 1994). As NASA overall had reduced psychology’s role in space exploration, a gap spanned over thirty years where NASA continued with psychology in this reduced capacity.

The attitude toward space psychology began to change as The Committee on Space Biology and Medicine in 1987 recognized this gap and urged more studies, only for nothing to happen until the issue was reaffirmed with urgency ten years later by subsequent committee membership. The Committee then addressed the problem quickly as they acknowledged the benefits of addressing psychological needs.

> Predicted from controlled simulation studies, the history of space exploration has seen many instances of reduced energy levels, mood changes, poor interpersonal relations, faulty decision-making, and lapses in memory and attention. ***Although these negative psychological reactions have yet to result in disaster, this is no justification for ignoring problems that may have disastrous consequences.***
>
> -Committee on Space Biology and Medicine, 1998

Psychological effects noted by the Committee included the inhabitant's mood, understanding of time, perceptual and motor skills. Environmental issues included the confinement, isolation, and habitability of the spaces. From the cultural perspective, the relationships between people, sense of self, and connection vastly changed. While some of these can happen anywhere, some issues can be alleviated through other methods, such as crew cohesion and decision-making authority. Which are ideas the Committee urged people and other psychologists to consider when making our next space station (Vakoch 2011).

Sense Of Self In Space

The psychological effects when traveling to a new planet and living there are vast, affecting our sense of self, relationships with others, and community as a whole (Harrison 2010). To stress this importance, imagine you go outside to look at the sunset, walking out to a deep dark blue sky, and instead of seeing your normal view, it's completely different. You're gazing at the bright stars of the Earth and the Moon instead, which would be a rather jarring experience (Malik 2014). Individuals' psychological health dramatically impacts their adaptation to their isolation, extreme environment, and harsh demands. (Vakoch 2011).

These effects are apparent in a 520-day artificial reality simulation of the European Space Agency's crew voyage to Mars. This study placed a crew of six healthy men from around the world in a

small 550m³ capsule for over a year in a high-fidelity simulation of Mars (Poláčková Šolcová et al. 2016).

The crew wore wrist trackers to gain data about their sleep, rest, and work cycle. Part of the data gathered included mental health screenings everyone took weekly, along with conflict screenings, a "psychomotor vigilance test (PVT-B), and a series of visual analog scales on stress and fatigue" (Basner et al. 2014). One of the six members reported an onset of depression symptoms, and depression rose amongst the entire crew through the second half of the mission. Throughout the mission, low levels of stability for the crew members' mood regulation are shown through self-reported ***symptoms of depression, fatigue, confusion-bewilderment, total mood disturbance, unhappiness, sickness, mental fatigue, and stress.*** Furthermore, crew members who experienced the most negative mood problems throughout the mission also accounted for the ***highest amount of communication errors through commission and omission specifically.*** Throughout the mission, these crew members' sleep decreased in quantity and quality. Overall, the whole crew became more sedentary over time (Basner et al. 2014). The study is a good indicator of how an individual's mental state is affected on long-term missions and how vital mental health is to mission success.

Relationships In Space

In the same way, as our health and sense of self change in space, our relationships and interactions with others also change (Vakoch 2012). While the crew is carefully selected to handle these psychological challenges in missions to space, they still run into problems. This raises a large area of concern within our space agencies, and in space tourism or a permanent settlement, as the same rigorous selection and training an astronaut goes through will not be the same for the everyday spacefarer.

Simulations have advanced with the technology of the aerospace industry, minus the sensation of weightlessness, and can be a good indication for long-term habitation in space. In the same 520-day simulation, exhaustion caused a significant amount of conflict (Poláčková Šolcová et al. 2016). “Crew-reported conflicts with mission control peaked during the 30 days of Mars surfacing, were higher in the first half compared to the second half of the mission (23:12), and reported five times more often than conflicts among crewmembers (41:8). Two crewmembers (e, f) reported the majority (85%) of the conflicts (51% and 34%, respectively)” (Basner et al. 2014). This suggests that adapting to the new environment was more difficult than the long-term isolation and that conflict within the isolated group was less significant than conflict between the isolated and non-isolated group.

In a 105-day simulation, they similarly found sleep issues with crewmates. Furthermore, as outside factors, such as schedules from the researchers, decreased, individual differences in the crew grew. The

increase in flexibility resulted in individuals' values and beliefs becoming more forthcoming. As tension grew between individuals, tension among the crew grew and led to an increased amount of conflict with mission control (Sandal, Bye, and van de Vijver 2011).

Overall in long-term simulations and multiple studies, numerous similarities were found including sleep deficits that increased over mission time. As daily task structure decreased, internal tension increased. Individuals' values and beliefs played a prominent role over time due to the loss of structure and increased tension. Due to the growing divides, subgroups based upon these values formed (Vinokhodova and Gushin 2014). These studies demonstrate the importance of interpersonal compatibility among the crew during long-term missions, as without them, cliques form and tensions rise.

Design For Wellbeing

The built environment affects its inhabitants, whether the windows, the amount of light, temperature, accessibility, personal space, or private space—these consciously or subconsciously affect how someone feels within an area. How we live within a geographical region is changed by the home itself and how we live in space. Classic psychology studies demonstrate this importance, where minor environmental differences resulted in significant behavioral changes. For example in Stanley Milgram's (1963) experiment, the presence of an authority figure caused subjects to obey instructions even if the

orders were against their moral beliefs. As Milgram said, “We have seen the cruelties of humans; furthermore, we have seen how the environment impacts behavior, as even small changes to an environment can cause significant impacts on people’s behavior” (Milgram 1963). The Stanford Prison Experiment demonstrates the same idea: that the environment impacts human behavior. In this experiment, normal college students took on the roles of prisoners and guards, resulting in violence, anger, and immorality. Social circumstances could cause many adverse effects to terminate the study (Zimbardo, Maslach, and Haney 1999). These studies demonstrate the impact of one’s social circumstances and how people change their roles to fit their environment. While designing for the whole is important, it is also essential to look at the individual level.

For The Individual

An individual’s physical and psychological health can be improved through better-designed spaces for mental health as mental and physical health is connected. ***The Centers for Disease Control and Prevention (CDC) has found isolation and loneliness to cause a significantly increased risk of heart disease, dementia, suicide, and other health problems (Centers for Disease Control and Prevention 2021).***

Design can help alleviate the mental tolls of isolation because people respond to their surroundings, so designers can shift the setting to garner positive responses and feelings from the inhabitants. Because people respond to their built environment, we see changes

in the choices made for hospital lighting (Dalke et al. 2006), rehabilitation center windows (Raanaas, Patil, and Alve 2016), down to the paint color for prison cells (Genschow et al. 2015).

Investigating health and design for the individual mainly deals with mental health and how spaces make a person feel. In their research, Shepley et al. (2017) found that environmental qualities and features relating to the ambiance and physical interventions improved users' moods. Significant environmental qualities identified were aesthetic practices or feelings that resulted in improved mental health for those who lived in the analyzed spaces. More beautiful rooms, including quality lighting and restrooms, appropriate furniture, and positive distractions, positively impacted the participants (Shepley et al. 2017). Furthermore, in substance abuse treatment facilities, environments that felt 'deinstitutionalized' or more homelike also positively impacted residents (Grosenick and Hatmaker 2000). Additionally, in healthcare settings, a well-organized environment with comfortable furniture, lots of daylight, and appropriate sounds positively impacted the health and wellbeing of those living there (Battisto and Wilhelm 2019).

Environmental features with the most significant impact included positive distractions, including views of nature, music, and art. Variety in the privacy of spaces made substantial differences in mood, ranging from public to individual bedrooms and semi-private spaces. However, the three attributes with the greatest satisfaction were

connections to nature, lighting, and noise levels (Battisto and Wilhelm 2019).

In ***Design for Happy***, Channon (2019) touches on aspects of what makes humans feel best in a space. This included high ceilings to give an increased sense of freedom, a celebrated and well-defined entrance as it is a reflection of ourselves, and a proportionally sized home, as too large or too small can have adverse effects on our psyche (Channon 2019).

For The Collective

Finally, there is design for connection - for the community. A sense of community has been shown to combat loneliness (Rokach 2018). Design for the community can reduce loneliness through programmatic ideas, layout, floorplans, and more.

A variety of programmatic elements in a space supports greater diversity and positive interactions across a community, which builds positive relationships (Battisto and Wilhelm 2019). This was discovered by studying two typologies. The first is a health campus that "promote[s] health through the design of neighborhoods and communities" (Battisto and Wilhelm 2019). The second typology is a wellness district intended to "promote health through the design of health care system facilities and campuses" (Battisto and Wilhelm 2019). By purposely designing for health, the spaces drew in people who were more interested in connecting to the community and engaging with others.

Furthermore, people need to have a proportional habitable volume,

meaning a space that feels appropriately sized for its purpose and the number of people using the space (Simon et al. 2011). If a space is too large, it comes across as intimidating and not great for connection, but too small can feel suffocating and too intimate. Harrison (2001) elaborates on the human element of spacefaring by including functional aesthetics as a necessary component as well. All of these components should be included in an open-plan environment, as open floor plans are better at promoting interpersonal connection (Harrison 2001).

Now with an understanding of design for an individual and collective, examination of previous space station design becomes important to see how these ideas are or are not implemented.

Why Not Study Space Stations?

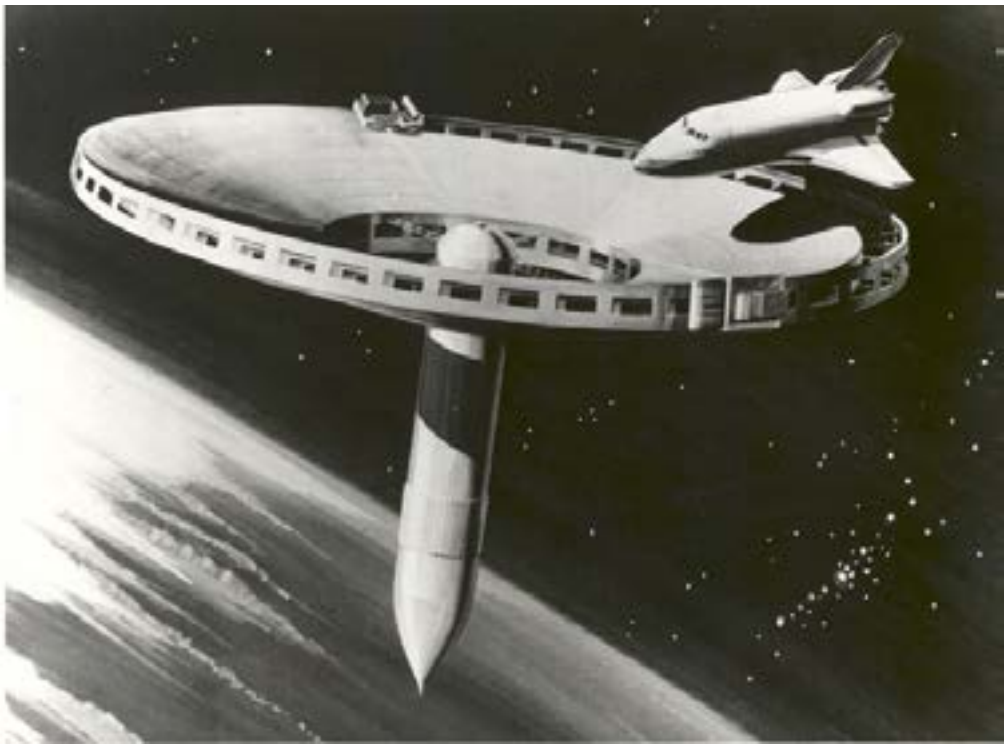


Figure 2. Spider Space Station Concept Drawing. (Image by NASA. 1977)

Previous space stations are an important step as their designs provide some insight into this limitation by demonstrating the nuances of space. Studying long-term habitation in space is a challenge in itself. Permanent residency is much different than a day or a week in outer space. Still, this type of long-term habitation has yet to occur - on average, astronauts only spend around six months on the ISS at a time (NASA 2011). This adds difficulty in finding a quantitative way to study long-term residence. However, we can begin to see problems or areas of concern within its design from short-term habitation. If it adversely affects people on a short stay in space, we can assume it will significantly affect people in long-term habitation.

The Space Race between the Soviet Union and the United States ended in 1969, when Neil Armstrong took man's first step on the moon. However, this was not the end of the push to explore and inhabit space as focus moved to the establishment of a permanent presence in space. In 1971, the Soviets launched the world's first space station Salyut 1 (Tillman 2012). In the following twelve years, they launched eight more. The Salyut 1 was a great stride forward in the space program. But it was tiny, and crews of three only stayed on it for as long as twenty-four days. It contained no showers or private areas as it was created primarily for function, making it difficult to study the role or physical space on behavior.

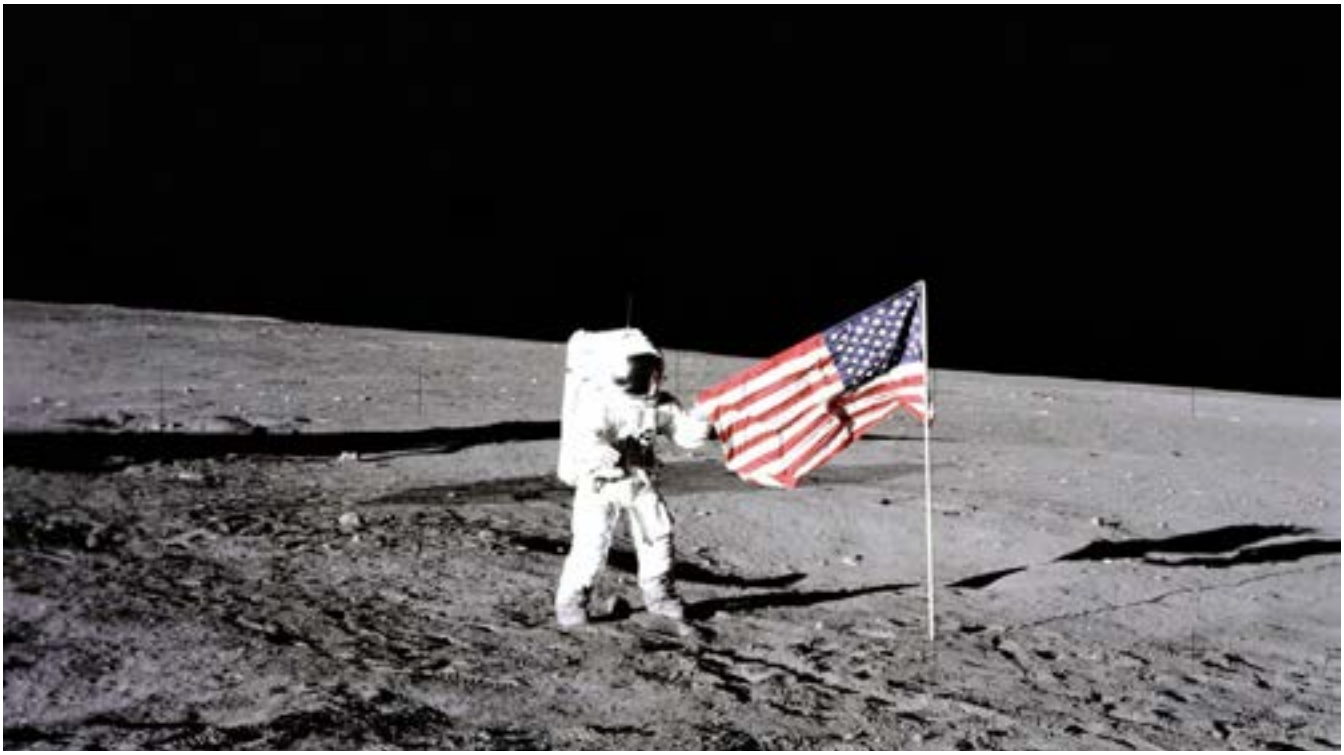


Figure 3. Apollo 12. (Photograph by NASA. 1969.)

Skylab

Shortly after Salyut, the US space program launched its station, Skylab, in 1973 (University of Oregon n.d.). Skylab was a larger, better-equipped station with four main components. Skylab consisted of the orbital workshop, the airlock module, the docking adapter, and the Apollo telescope mount.

The orbital workshop (OWS) was the primary living, working, and sleep compartment - the OWS even had a treadmill and kitchen. Although the entire workshop capsule was the interior of a tank intended to hold liquid nitrogen, the chamber below served as a trash storage bin with only an airlock in between the two (Kitmacher 2002).

The central part of Skylab was a converted portion of a Saturn Rocket, amassing seven meters in diameter, 39 meters in length,

totaling a habitable portion of about 480 cubic meters (Kitmacher 2002). Which is quite expansive at an equivalent of over 5,000 square feet.

Many astronauts from Skylab recommended having ample interior volume for acrobatics (Kitmacher 2002). Specifically, Ed Gibson, a designer and later astronaut on Skylab, wanted more open ample space to mitigate claustrophobia and have personal space, especially as they occasionally liked to play games, such as floating from one end of the spacecraft to the other without hitting anything He also recommended consistent verticals, meaning “up” is always the same direction for a continuous field of view, as the areas that did not have this became wasted space. The United States built the station for functionality and the absolute necessities without fully considering the needs of the mind. The station was built in modules- meaning independent subsections of a system or design that are grouped together to function as one and provide easier repair flexibility and replacement. It was so function-based that one astronaut remarked of Skylab, “locatability is so bad it almost looks like you had to go out of your way to design it that way…” (Kitmacher 2002).

MIR

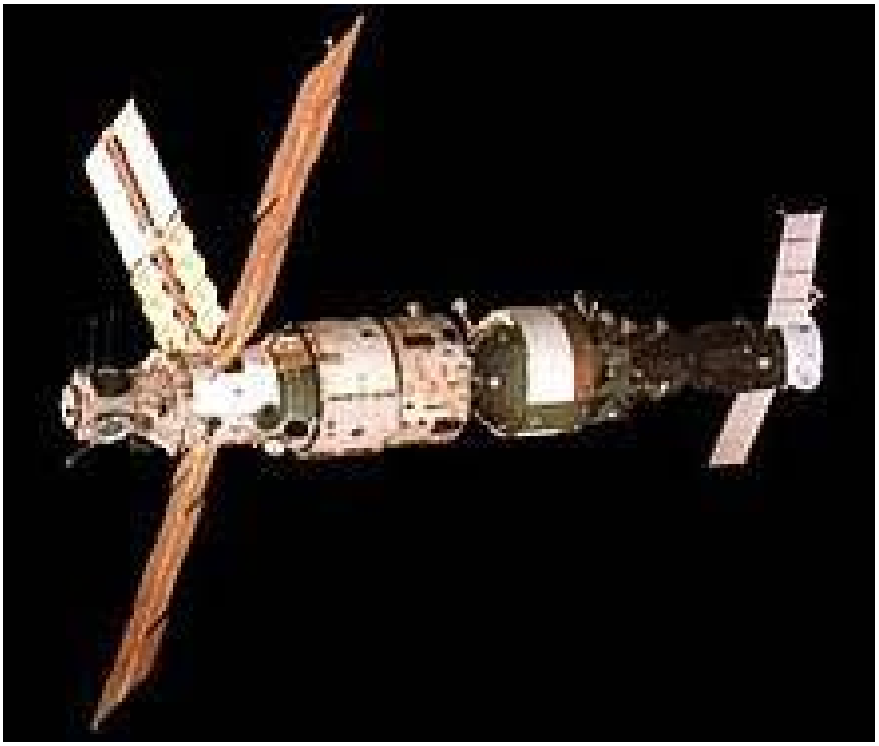


Figure 4. MIR Space Station. (Photograph by NASA. 1987)

The Soviet Union's Mir, meaning "peace" or "world," served as a transition from the previous Salyut and Skylab into a new, advanced generation of space stations (Long 2008). In 1986, the modular spacecraft was launched into low earth orbit and went on to stay in orbit for over three times its planned life, for a total of fifteen years (NASA n.d.a.).

Mir is a noteworthy station, although it has not been in use in over twenty years due to space station design and duration advancements. When in use Mir hosted many astronauts from around the world (NASA n.d.a.). The Soviet station was a precursor to the International Space Station that would be launched twelve years later.

Mir was made of its base block and in the following fifteen

years had six-module additions: the astrophysics module for research, an augmentation module for observation and biological research, a technological module, a power module used for NASA astronauts as a part of the co-operative program between the countries, a simplified module for docking, and the last module meaning “nature” was the Earth sensing module for understanding Earth’s environment (Hadfield 2021). Over time no stowage situation was ever decided, leaving floating bags of trash throughout as astronaut Mike Foale compared it to a fraternity house (NASA n.d.a.).

International Space Station & Modular Architecture

For the ISS, NASA spent over a decade understanding the station’s needs and landed on yet another modular concept because their teams believed it allowed a higher degree of success (Adams and Jones 2014). It was made up of four levels of modularity: the space station standard module, the rack system, the cargo transfer bag, and plug and play aspect. Modularity was preferred so maintenance could be more accessible and frequent replacement, not a hindrance (Adams and Jones 2014).

Summary Of Space Stations

From Salyut to the current International Space Station, the space stations were designed for replicability, flexibility, and technical needs. It resulted in floating trash and confused astronauts, showcasing many areas for improvement. While modularity is commonplace in space, it is not as prevalent in design on Earth. The opportunity exists to alter the function-based, modular approach to space station design by learning from design precedents on Earth.

When looking to research long-term habitation in space, one would naturally think of looking at space stations. While these do begin to reveal areas for improvement, they are not designed for long-term and permanent habitation. It’s the same way a hotel is designed differently than a home - they serve different purposes.

Figure 5. International Space Station. (Photograph by NASA. 2018)

Earth-Based

Earth- Based Analogue Simulations

In a similar vein, there are high caliber analog simulations here on Earth such as the Mars Society and the HI-SEAS that are great for understanding how humans behave in groups. Despite this, these analog simulations are not the best for understanding the influence of design, as the simulations were not created with the intention of examining the impact of design. Especially as some simulations are in quiet quarters that wouldn’t allow for design examination.

Earth- Based Precedents

When looking for precedents,there was criteria it needed to meet, a precedent needed to meet the majority of criteria that included: a select group of people who shared a common goal or mission, physical isolation, extreme environment, and long-term duration of habitation. Although when it comes to isolation, we can only experience this to a certain degree on Earth as these precedents are isolated from the rest of Earth, when Mars is isolated from the entire Earth. After searching for environments that shared these extreme facts, four areas of precedents were found:

-Antarctic research stations

-Deep-sea oil rigs

-Submarines

-Prisons

Earth-based precedents are a strong and logical choice as long-term habitation has a larger and varying set of needs in comparison to short-term stays, like on space stations. There are very few longer-term space missions and no permanent ones, we look for environments that share similar characteristics to space. This leads back to other extreme, isolated, and confined places of permanent living on our home planet. Earth-based precedents are the natural next step to studying space, as Vakoch (2011) said in his NASA-published research:

> "Illustrations of such environments are submarines, the Arctic and Antarctic research stations, undersea habitats, and high-altitude research stations. Once there was interest in how people might perform in tiny, crowded spacecraft, these studies of other extreme environments were looked at as analogs for spaceflight since all of the environments had salient social stressors in common"
>
> -(Vakoch 2011, page 105).

Vakoch also notes that extreme environments contribute to social stressors.

Antarctica is vital to understand the extreme environmental aspect of space as well as the isolation that comes along with it; more so, it has similar relationship and community issues. Deep-sea oil rigs also have the same relationship and community hurdles along with isolation and confinement. Submarines are extreme, isolated, and confined environments, with the same relationship and psychological aspects. Prisons were chosen to hone in on the architectural and behavioral connection to understand how design can form better relationships and create communities that are essential for a plausible second home on Mars.

Conclusion

Over time, great strides have been made in space station design, and we begin to understand the struggles of function-based spaces. In contrast to this, modular systems are still prevalent in space station design, which makes being in space a more challenging experience. Space also makes living in a small space with others even more complicated, leading to personal challenges for those who inhabited them. Under pressure and isolation, confinement in an extreme environment leads to mental health decline, which in turn harms life expectancy and quality of life (Novotney 2019). This demonstrates the importance of mental health in the mitigation of social conflicts. One way mental health can stay at the forefront of new missions is through design. Design impacts one's well being and, when wielded properly, can improve one's state of mind. A positive, healthy mental state is needed in extremely isolated environments like Mars. This need makes architecture and design essential for mission success. Space station design thus far has demonstrated a need for improvement. This is only furthered by outer space's psychological effects on humans. . This problem can be answered by design where we can see that intentional architecture has improved lives. Synthesizing information from across the above spheres of research was able to demonstrate the need for a framework for design in space.

As Vakoch said, ***“a watershed period has been reached in the history of spaceflight that requires a ‘paradigm shift’ in the way spacecraft are designed and people are selected and trained for spaceflight”(Vakoch 2011, page 103).*** This paradigm shift can be seen and made possible through design and architecture in order to bring space design into the future.

08

Grounded Theory

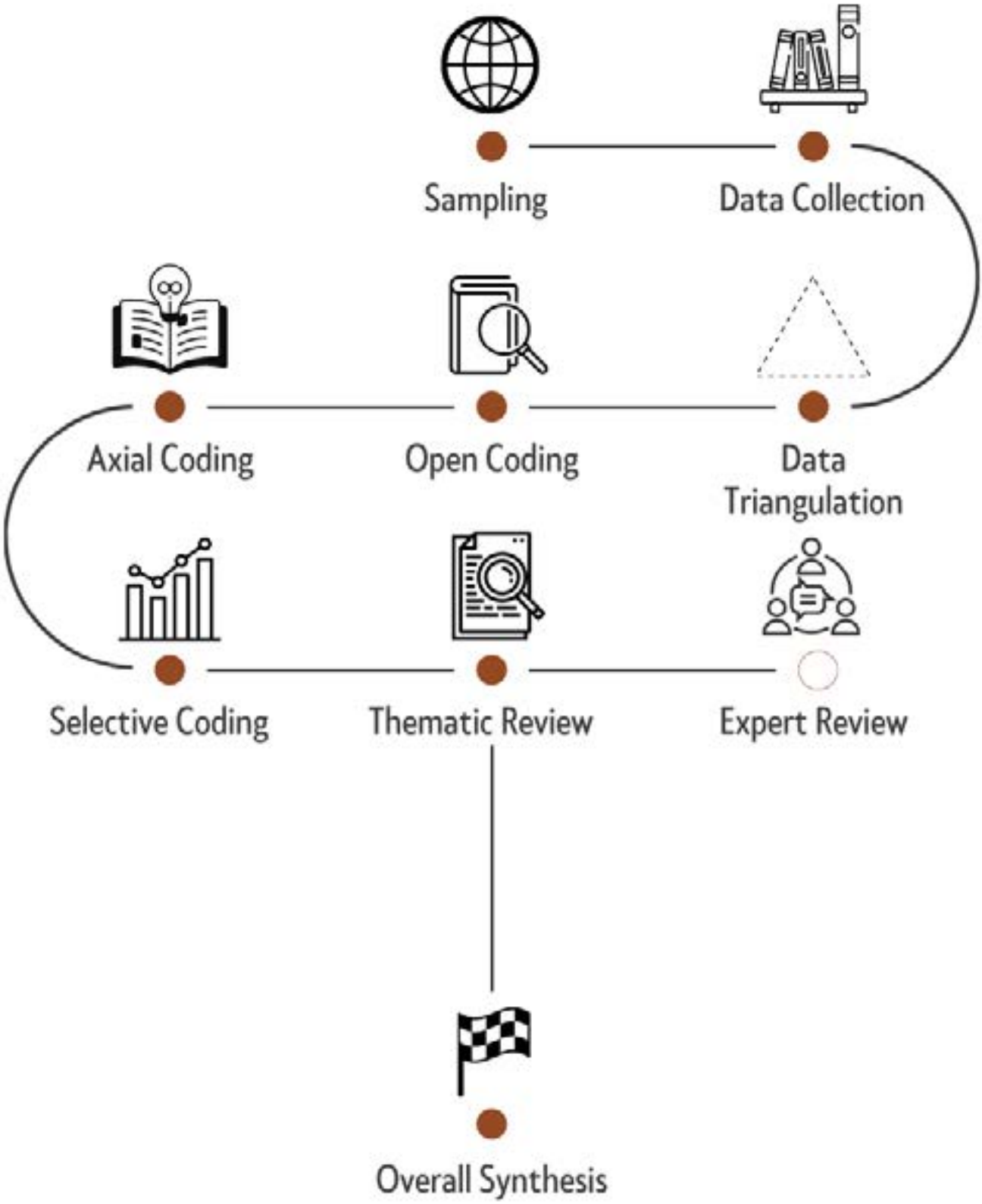


Figure 6. Method Graphic Utilizing Grounded Theory

Approach

To understand the impact of design on Mars, the research necessarily began on Earth. Earth-based precedents were used, as they serve as a preferable study due to the lack of long-term habitation in space. The longest single voyage for a NASA astronaut in space is 340 days (Garcia 2016), with the average stay at the International Space Station being approximately six months (NASA 2011). Furthermore, space stations have a significantly different length of habitation, setup, and community than a permanent settlement. And how one lives for six months versus how one would want to live for the rest of your life varies greatly. Determining Earth-based precedents that share similar conditions to a space settlement are more beneficial to this research.

Criteria for Earth-based precedents included:

1. A select group of people with a similar goal or mission
2. Physical isolation from the outside world, although on Earth it’s isolation from others, whereas in space it’s isolation from Earth in general)
3. The setting needs to be extreme to parallel Mars.
4. And finally, there needs to be a long duration of habitation at said Earth-based precedents.

Based on the Earth-based precedents that meet the above criteria, the methodology for this study consists of qualitative descriptive data. The data was collected from a gathering of sources from multiple research bodies to improve validity and gain a comprehensive

understanding of selected precedents. Research began with the question of how design impacts these Earth-based precedents, specifically how design affects those who live at the chosen precedents. From there, qualitative data was collected, as it best described how people felt living at these precedents. From secondary sources, descriptive data was collected to understand the cause-and-effect relationship between design and psychology, using triangulation of sources to increase data accuracy.

Data Collection

In order to gain insight into the cause-and-effect relationship between design and psychology, qualitative secondary sources were selected, which included records, observations, and diaries. The data was selected if it had the following attributes:

1. relevant to one of the selected precedents,
2. built on Earth,
3. articulate about design,
4. the intentions of the design,
5. housed a group of people,
6. has been built, and
7. had data to prove its validity.

As well as it had to be dealing with psycho-social information, and not exclusively about technical aspects like water, air, and more. When looking for viable precedents, the main considerations followed

the conditions that could be expected in space habitation: a select group of people with a shared goal or mission, physical isolation from others, located in extreme environments, and long-term habitation. Additionally, the source needed to contain more than three keywords from the bank below.

Space	Emotion	Extreme Environment	Built Environment
Design	Community	Relationships	Social Connection
Isolation	Confinement	Mental Health	Oil Rigs
Submarine	Wellbeing	Psychological	Antarctic Research Stations
Prison	Mars Mission		

Figure 7. Word Bank

Analysis & Matrix

Qualitative research analysis was done through the inductive approach of Grounded Theory. Grounded Theory is a systematic method of analyzing qualitative data, typically regarding social phenomena, resulting in categories and concepts for understanding a subject or developing theories (Lingard, Albert, and Levinson 2008). This method enables a researcher to systematically analyze studies by theme in an inductive manner that consistently compares data for similarities and differences to achieve a higher level of understanding (Urquhart 2012).

Open Coding

Utilizing the Grounded Theory to analyze the data begins with the process of ‘open coding’. Open coding is the process where collected data is read and combed through for small bits of data. Then these small pieces of information are broken down and added into a matrix, per each source and precedent. Importantly, this data then undergoes what is referred to as coding where the information is distilled into descriptive labels that describe the bits of information (Uri 2015).

Axial Coding

The next step is axial coding where, through analysis and comparison, patterns are recognized from the small chunks of data found in open coding. By using inductive and deductive reasoning, relationships between the patterns identified in open coding are made explicit through connections and relationships. During the axial coding process, patterns were identified as solutions when they improved daily life. In contrast, during analysis and comparison of the open coding data and labels, where design attributes were adversely affecting residents, they were marked as opportunities for improvement. For each precedent, the areas of strengths and opportunities as well as design considerations were compiled. Furthermore the data from open coding was filtered down to only bits of data that involved the built environment or interacted with it.

Selective Coding

Finally, through selective coding, patterns of design attributes emerged to create categories and overarching themes of importance. These themes created the overarching categories for design considerations. Through this process three main categories emerged as the overarching and encompassing connections between all the data: architectural spatial, experiential, and social.

Source	Issue/ Topic	Solution V. Opportunity	Which Precedent	Type	Description
Redesigning Prison: The Architecture and Ethics of Rehabilitation (Karthaus et al. 2019)	The Panopticon Style- continual surveillance results in fear based behavior	Opportunity	Prison	Architectural Spacial	
Redesigning Prison: The Architecture and Ethics of Rehabilitation (Karthaus et al. 2019)	"Learning Works a '21st Century Prison' model"	Solution	Prison	Architectural Spacial	"The Learning Prisons Report which suggested key principles for reform 'seeing prisons as a core public service that... begins to reimagine how prison's role as educator could be placed centre stage to issues of public safety'"
The 21st Century Prison (Cottam, 2009)	19th century Fordist prison	Opportunity	Prison	Experiencial	
The 21st Century Prison (Cottam, 2009)	programmatically based in central education goal	Solution	Prison	Social	

Table 1. Sample Of Findings

(To view full matrix, refer to Appendix A)

09

Results & Analysis

In order to gain a better understanding of the value of each precedent and how it contributes to space design each is reviewed below. Each precedent reviews its connection to space design. Followed by the results from the Grounded Theory analysis per precedent. In order to give a comprehensive understanding of what each precedent contributed to space design and the considerations it created.

Prisons: Results & Analysis

Figure 8. Prison Interior. (Photograph by Emiliano Bar. 2019)

Prisons meet the selection criteria as a precedent in this study due to:

1. A select group of people with a similar mission or goal.
2. Group relationships & individual relationships under tension.
3. Isolation from the outside world and other people.

Furthermore, prisons demonstrate how the design of the built environment impacts human behavior. Findings from “Redesigning Prison: The Architecture and Ethics of Rehabilitation” demonstrate this phenomenon. It includes layouts with a constant field of vision, in the traditional Panopticon (circular) style, which can increase consistency in behavior (Karthaus, Block, and Hu 2019). This improvement is due to the Panopticon style being centered around one guard who is able to watch all prisoners, but the prisoners cannot tell if they are being watched. This uncertainty forces prisoners to act as if they were being watched at all times, resulting in better behavior. However, this design also results in most prisoners recounting a feeling of fear, which is not good for one’s mental health (Karthaus, Block, and Hu 2019).

Formerly, the architecture of prisons spoke to power, while the re-invented prison is oriented towards rehabilitation which inverts the logic of the Panopticon style (Karthaus, Block, and Hu 2019).

This inversion of the panopticon style is clear in the “21st Century Prison” which continues these ideas with the creation of a new building program for prisons, orienting the prisons toward learning and making education the programmatic center. In order to make these programmatic and spatial changes, Cottam (2002) found that behavior improvement required users to have strong relationships with other members of the group. Additionally, one way to maintain order was the use of symmetry inside cells, as well as a sense of control through

the use of sliding doors which also focuses on internal regulation of behavior. In the floor plan, the organizational hierarchy of the lowest floor as the most public and the upper as the most private helped centralize the ideas of education through having learning spaces on the first floor (Cottam 2002).

“Prison As Home” broke down more of the aesthetic connection between behavior and design. Fear was the most common emotional state described in interviews, so finding trust is a central theme in the prison environment to contrast the high-security environment. Fear was noted as a spatial issue with the layout of the prison. In aesthetics, views of nature repeatedly caused improvements as well as noise control affecting feelings, routine, and time making the largest impacts (Galford 2021).

“Ravenhall Correctional Centre” reviewed the internal organization of spaces within a prison facility. This research was done in Australia to increase prisoners’ outcomes through master planning and design. Levels of privacy in master planning were a central idea in order to give inmates a sense of control over their environment. Changing the overall style from a classic concrete and metal bar style to cottages and lodges was a large shift in typical prison design. A variety of housing types was proven valuable for inmates. To eliminate feelings of fear, security measures were discreet. Visible security, instead of making inmates feel safer, created feelings of fear and being watched, which was not beneficial for individual or group temperament.

Aesthetically, nature views were made central in the master planning by creating landscaped recreational courtyard views that could be seen from all lodgings (Grant 2020).

"Improving Mental Health in Prisons Through Biophilic Design" debated how nature affects inmates. What is the change in stress, fear, and joy when there is an increase in nature? How does this nature shift alter mental health? The author includes how nature should be applied in prisons for improvement (Söderlund and Newman 2017).

Oil Rigs: Results & Analysis

Figure 9. Ship Heading Out To Oil RIg. (Photograph by Emmaus Studio. 2020)

Deep-sea oil rigs are a desirable area of study due to the isolation the workers face when on duty. Furthermore, oil rigs, especially in the deep sea, are high-risk environments that can be quite dangerous. Due to the isolation, extreme conditions, and select group of people with a common goal, it serves as a plausible precedent for understanding considerations for space colony design.

"In A Day on An Oil Rig" is an author's account of the routine and life on a deep-sea oil rig. A main problem for the sailors, that is an opportunity for improvement is how the days are different from one another, as someone is working 24/7 on the rig. In order to accommodate this lifestyle, the rigs have 24/7 amenities and food. An example of an amenity onboard is a recreational room and gym. The gym even has a workout specialist on board, as these amenities have become the focal point for how workers spend their time, when not working. These amenities give structure and purpose that the employees enjoy and appreciate ("A Day on an Oil Rig: Exercise Physiologist's Life Offshore" 2013).

"Offshore Rig Island Living" describes a different rig living situation. Those on board lack socialization areas, and this is impactful too. Employees note the difficulty of time on the rig with nothing else to do and how this affects them (O'Rourke 2012). "Life On An Oil Rig" brings up similar issues, noting the need for amenities and socialization on the rig. In order to combat the harsh toll the job takes, they provide amenities such as cinema halls, gyms,

and indoor sports. They also have time on and off the rig in two-week increments in order to let workers have time with their families and relieve stress. Choices made on the rig revolve around socialization and the need to relieve stress as they even have bunk beds on board for comradery (Mehnazd 2021).

Antarctic Research Stations: Results & Analysis

Figure 10. Antarctica. (Photograph by Henrique Setim. 2018)

Antarctica parallels Mars, as it feels as if you're in another world. The barren desert, chilling temperatures, arduous travel times, and physical isolation from the rest of the world create an

extreme environment. Isolation both socially and geographically shares similarities to Mars that make it ideal for understanding life on the red planet. Along with the extremes of Antarctica's environment that only further lends itself as a precedent to Mars design.

Recreation has been documented as vital for Antarctic living (Hamilton 2013). For every crew member, there are approximately 100 square feet of recreation space for a total of 5,100 square feet total (Hamilton 2013). Large windows and apertures were specified as important for the crew thus giving views of the environment and lighting. The color palette was closely examined and selected by a consultant and invigorating and calming colors were intentionally placed in programmatic spaces. The color and lighting continued to be valuable by using alarm clocks that simulate daylight to combat the daylighting or lack thereof in Antarctica (Hamilton 2013).

'A History of McMurdo Station Through Its Architecture' hones in on programmatic elements that improve life on the station, through single rooms, recreational areas, attention to personal privacy, and the creation of the environment. Programmatically they decided to place everything in one building as it improved the inhabitant's life by increasing efficiency. Furthermore, reducing noise and relocating machinery was found to create a better space. Covered passageways were used to improve routine. They also emphasized windows in the space to give views of light and the environment (Davis 2017).

Additional research articles including “From The Midnight Sun To The Longest Night: Sleep in Antarctica” (Pattyn et al. 2018) and “The Human Element in Space: Lessons from Antarctica” (Palinkas 1988), emphasized light and the creation of microcultures.

Submarines: Results & Analysis

Figure 11. Submarine Resurfacing. (Photograph by Ан Нет. 2020)

Submarines are precedents usable for space due to the physical and social isolation as well as consisting of a selected group of people with a common goal. Furthermore, the lack of sunlight underwater is similar to the changes in weather on Mars where there can be prolonged periods of time without sunlight. And when they’re underwater they also lose reception and contact with the outside world similar to

the prolonged contact between Mars and Earth. Upon reviewing interviews from submarines, areas of opportunity were identified. Mainly the hot racks and personal space, or lack thereof, were the main issue for crew members as the beds felt ‘like MRI machines’ (Sciutto 2016).

In summary, the Earth-based precedents provide a foundation from which key elements for space-based design could be organized into considerations. The following table summarizes ten of these considerations based on the individual precedents. As illustrated, large light apertures and multi-purpose rooms are the most common considerations. However, each of the considerations is included as it was given importance in one or more precedents. These considerations are further put in context in the following Discussion section.

Topic / Issue	Prisons	Oil Rigs	Antarctic Research Stations	Submarines
Large Light Apertures	☑	☑	☑	☑
Noise Control	☑	☐	☑	☑
Color Selection Based On Room Function	☑	☐	☑	☐
Rooms in Variation of Public To Private	☑	☐	☑	☐
Clear Wayfinding	☑	☐	☑	☐
Layout Based on Common Circulation	☑	☐	☑	☐
Multiple Smaller Communities Instead of One Large Community	☑	☐	☐	☐
Multi Purpose Rooms	☑	☑	☑	☐
Concentrate communal facilities together minimize distance between here and and houses sleeping / personal space	☑	☐	☐	☐
Symmetry For Visual Control and Calm	☑	☐	☑	☐

Table 2. Summary of Findings Table By Precedent.

(To view full matrix, refer to Appendix C)

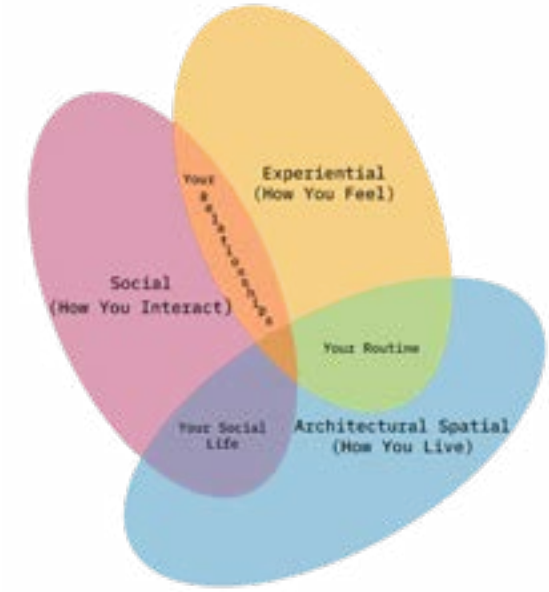
10

Discussion

Throughout the analysis and findings, three major categories emerged that explained the findings from the literature and precedent analysis: architectural spatial, experimental, and social. There are also categories of safety and interior design that were found through grounded theory to help describe design considerations. These categories are used to describe considerations that came from the precedent review using Grounded Theory.

Figure 12 illustrates the three main categories that resulted from the use of Grounded Theory and how they interact with each other. The categories in their most simple form revolve around, how you live, how you feel and how you interact. Considerations from each precedent are shown as dots or letters (the letter corresponds to the precedent) in the image and is located based on what category the consideration comes from.

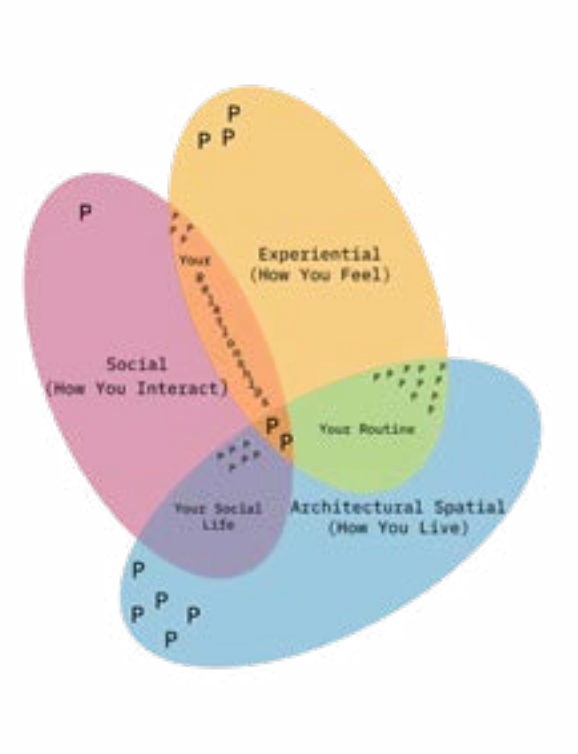
Overall Data Points



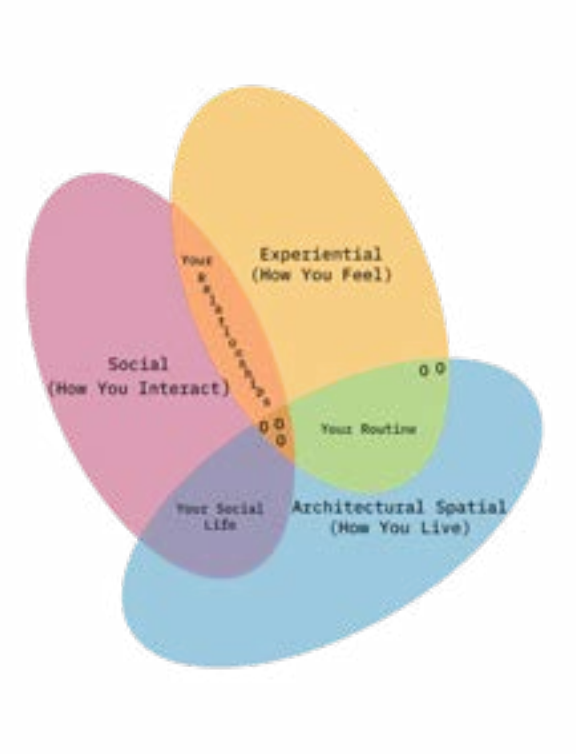
Overall Venn Diagram Showing Relationships

All Data Points Arranged In Respective Category

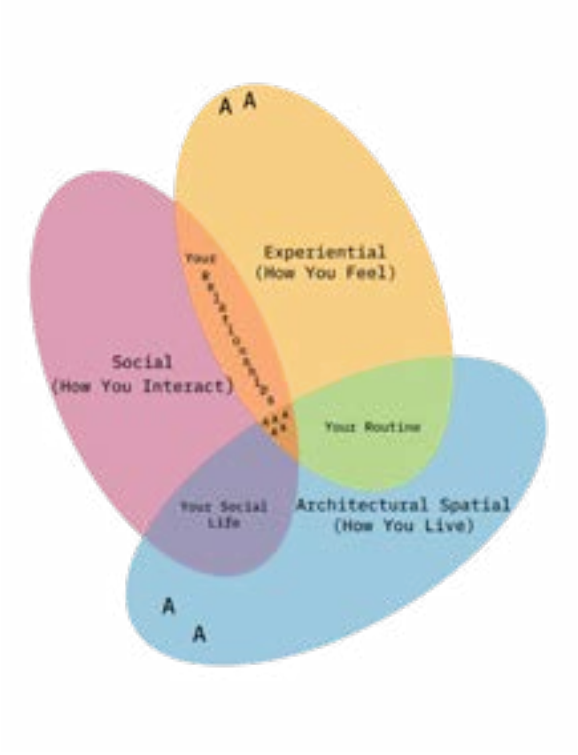
Points By Precedent



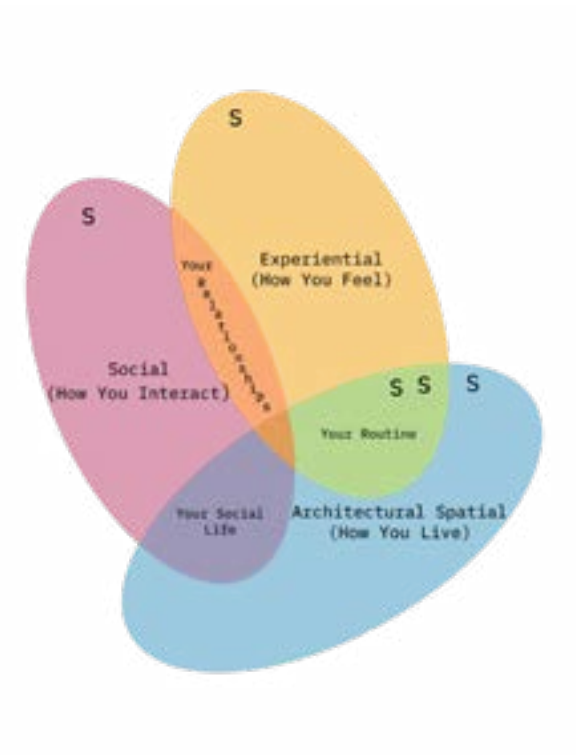
Prison Data Points



Oil Rig Data Points



Antarctic Research Stations Data Points



Submarine Data Points

Figure 12. Venn Diagrams Of Data Points Distribution By Precedent & Category.

*** Each dot represents an individual finding**

By Category

Architectural Spatial

The Architectural spatial category includes programmatic elements such as social rooms, layout organization for wayfinding, spatial arrangements of rooms, and overall building.

Experiential

The experiential category encapsulates how the space makes you feel, or alters how you feel. Common examples include biophilia, light apertures, colors, finishes, and the atmosphere.

Social

The social category encompasses interaction focusing on how members of a group interact and form relationships. More specifically, how can the building design improve this, such as an increase in the number of multi-purpose rooms, locations of rooms and those adjacent, size, style, mixed sleeping arrangements, or others.

By Precedent

Prisons

Out of the analysis of prisons, a common theme that emerged was spatial attributes, such as location and layout. Aesthetic considerations began to contribute to the style and feel. Organizational design considerations showed through in master planning.

“Redesigning Prison” had great overarching concepts and gave an explanation review of common prison types, but lacked specificity in how they were to achieve their rehabilitation goals. It spoke to overarching prison styles and why each was beneficial or not and how concepts from these themes could be extracted. For example, when people believe they are watched they will act more controlled, but this does not increase their quality of life. This means the inversion of the Panopticon style would be more beneficial for a permanent settlement in order to find a balance of private and public, prospect and refuge (Karthaus, Block, and Hu 2019).

“The 21st Century Prison” worked to move from antiquated ideas such as the Fordist prison, where prisons were seen as temporary confinement, and from the 19th-century views of severe punishment. Instead looking to create a space for trust to grow and in turn make positive relationships form, as relationships were a key to making the education-centered design successful. A large variety of spaces were included throughout and the creation of smaller sections within the prison was vital for community creation (Cottam 2002). Efficiency was

also considered when creating smaller sections in order to improve the day-to-day routine of inmates. Creating multiple smaller communities instead of attempting to make one large community proved to be more beneficial. Using routine and efficiency to indicate in the planning of the prison the spaces needed and their use. This was done, but putting communal spaces at the bottom of smaller communities, and on the third floor having private spaces for sleep which included sliding doors in order to give inmates a feeling of trust and control to decide if they wanted their room shared with a roommate or individual (Cottam 2002).

“Prison As Home” was strong in aesthetic concepts for improvement. Using trust was central to minimizing fear, which was a common emotion for those interviewed. It lacked how it would create trust exactly through design, but gave good overall concepts to consider when designing. For example, sound and noise control was found to make individuals feel routine and structured, with loud noise being connected to fear. With routine being a connector between sound and time, it demonstrated the impact sound has on one’s daily life, along with the importance of nature and how it increased health in participants (Galford 2021).

“Ravenhall Correctional Center” was strong in its ideas for master planning and organizational design of prisons. This resulted in an internal organization and space configuration that enabled a better routine and encouraging connection. Changes in the living environment ended up helping the community as it gave even smaller groups of people

an opportunity to form tight bonds, but also privacy where needed, giving a form of independence to the inmates, as the power of control is known to help people feel better in an environment. They followed therapeutic architecture ideas to result in minimizing environmental stressors through design. They instead had intentional color choices, nature views, a variety of spaces, and maximization of natural light to create better prisons, which can all be implemented in space (Grant 2020).

"Improving Mental Health in Prisons Through Biophilic Design" explored the relationship between greenery, biophilia, and mental health. In order to see improvements, they found that greenery improved life overall but mainly in a reduction in stress when inmates could see it (Söderlund and Newman 2017).

In summary, lessons from prison design can contribute to space design as the research demonstrates that the experiential, social, and Architectural spatial attributes of prisons directly impact prisoners' lives.

Main Prison Takeaways

-Layout of Programmatic Elements

-Symmetry

-Multiple Smaller Communities Instead of One Large

-Additional Private Spaces

Oil Rigs

On oil rigs, there was an extensive emphasis on social aspects of the design, as the planning and layout of social aspects made a large difference in the lives of the workers. This was seen through amenities open 24/7 to give workers something else to do and lessened stress. As many noted this was the only time to relieve stress and do something other than the intense work of being on an offshore oil rig.

Main Oil RigTakeaways

-Necessity of Social Rooms

-De-Stress Through Activities

-Variation of Public and Private

Antarctic Research Stations

Antarctica has design attributes that embody experiential, Architectural spatial, and social categories. Due to the isolation and extreme environment, it is useful for examining space habitation. The social setting mirrors what would be anticipated in a permanent settlement from the small groups in close proximity all specialized in different fields of necessary science.

In Architectural and spatial areas the design attributes of many Antarctic stations serve as inspiration. Wayfinding in McMurdo Station was noted as very needed since many employees found it needed in the stations. With this, the circulation route was also emphasized in the buildings' layout to have an intuitive flow to the wayfinding within McMurdo station.

Socially, relief and improvement were found in social areas aboard the station, as relief from isolation. However, the attention to personal privacy was also a much-needed element of life on the station such as in the need for single rooms. In order to maintain this balance, designers found that keeping the balance between the public and private was done by keeping all of the programs within the building, leading to the creation of a community within the station. Part of this community was done through the creation of microcultures within the station, which were done through personal touches throughout the area, as well as groups forming between commonalities to create family and friends within the station.

Experientially, how the members feel aboard the station was emphasized. Part of how those felt within the station was due to intentional color selection and pallets that either were chosen to be invigorating or calming. Additionally, the elimination of visual clutter through storage solutions was a key design element. Elimination of noise from heavy machinery was also important as it distracts and makes users uncomfortable in the main spaces. For comfort, covered passageways were immensely helpful, as one member said "[i]n cold weather there are psychological advantages in being able to get away from living and working areas by walking in the covered passageways' ' (Davis 2017). Along with this, the building's envelope was essential. One main envelope change that increased the overall environment of the station was an increase in window apertures to increase daylight.

Main Antarctic Research Station Takeaways

- Wayfinding
- Personal Touches and Decor
- Large Light Apertures

Submarines

In the category of architectural spatial, submarines were filled with areas of opportunity, or places to improve. This is through the lack of balance between social and private spaces. Sailors only have on average fifteen square feet of semi-private space (Bender 2016). Fifteen square feet is enough space to fit a full-size bed, but not your entire private existence on board. Furthermore, that little space is not just yours, but due to the limited amount of space, it is shared through a process called “hot racks” where sailors share beds when one works, another sleeps.

Socially, the implications of such little space, in such a cramped and isolated environment, create problems. Sailors remarked on unspoken rules to keep the peace and live in such close quarters. The design of the beds and interiors were noted as something that one sailor even remarked felt like MRI machines, noting how the interior details cause distaste and uncomfortable feelings for the sailor (Sciutto 2016). The environment also impacts the sailors’ experience as the darkness of the ocean impacts circadian rhythms, mental health, and emotions. This lack of light was seen as a primary area of improvement for space design in similar environments.

Main Submarine Takeaways

- Lighting
- Personal Space
- Storage For Necessities

Topic / Issue	Architectural Spatial	Experiential	Social
Layout of Programmatic Elements	☑	☐	☑
Symmetry	☑	☐	☐
Rooms in variation of private to public space	☑	☐	☑
Clear wayfinding	☑	☑	☐
Program requirements	☑	☑	☑
Large light apertures	☑	☑	☐
Elimination of extra sound	☑	☑	☐
Color selection for room function	☐	☑	☐
Discreet Security	☐	☑	☐
Sensory Rooms	☑	☑	☐
Quite Rooms	☑	☑	☐
Programattic Grouping	☑	☑	☑
Multi purpose rooms	☑	☐	☑
Private Spaces	☑	☐	☑

Table 3. Summary of Considerations by Category

(To view full matrix, refer to Appendix B)

Summary Of Main Design Considerations

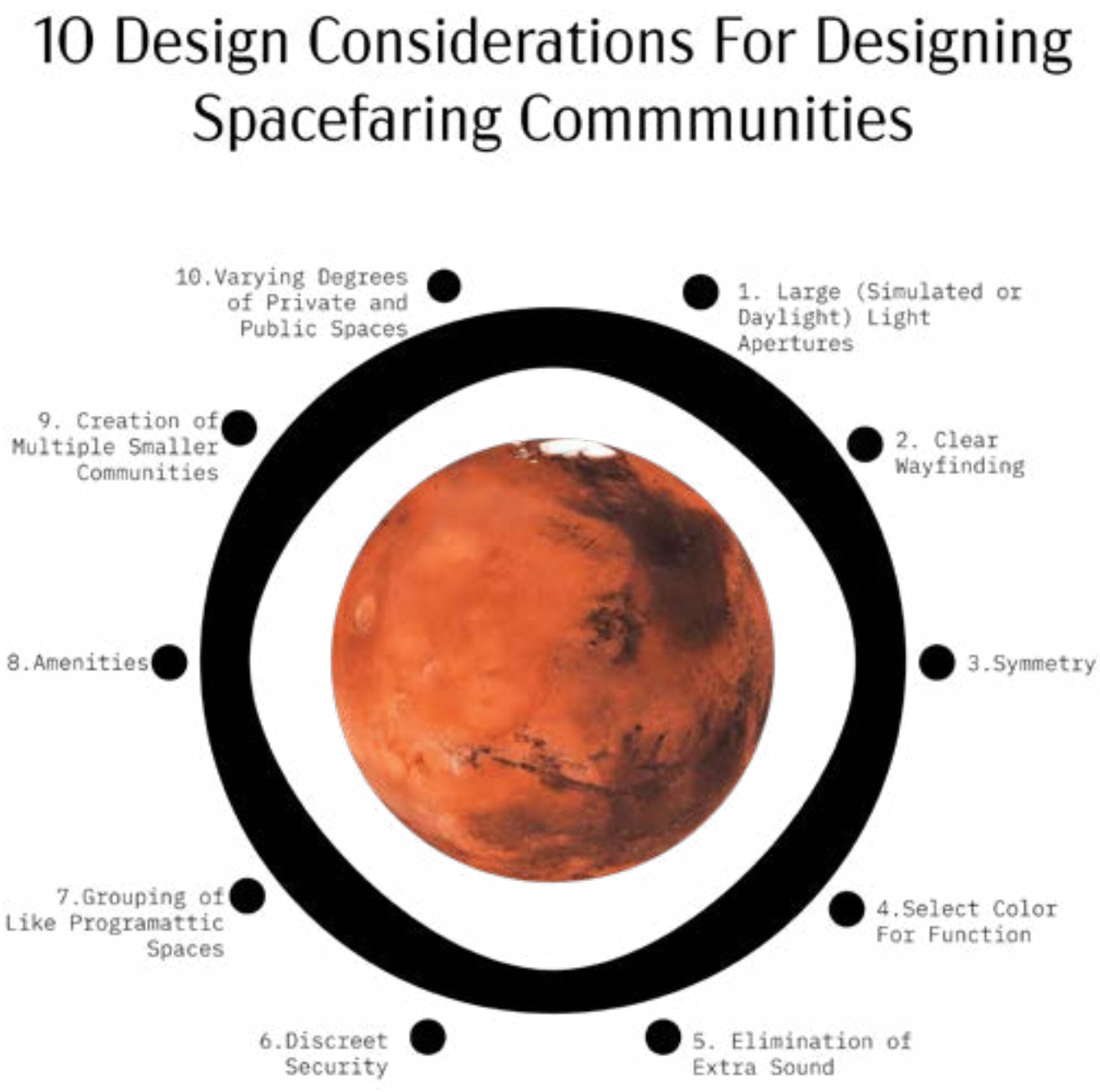


Figure 13. Main Design Considerations For Spacefaring Communities

After analysis through Grounded Theory, some of the main and most recurring considerations were identified. These considerations can be seen in figure 13, in no particular order.

1. Beginning with large light apertures, which were noted as beneficial in prisons, Antarctic research stations, and submarines. This can be through simulated or natural light, as on the Halley VI, alarm clocks using simulated daylight were used to combat the long periods of dark and despite being simulated light had the same effect as traditional daylight on members of the station (Hamilton 2013).
2. Clear wayfinding was an important consideration in the category of architectural spatial as when properly marked it eliminated confusion and increased efficiency for users (Grant 2020).
3. Symmetry in the built environment is noted as having a calming impact and invoking a feeling of order within viewers (Cottam 2009).
4. Using wall color to imply and amplify the purpose of a room was used in the Halley VI research station as well, where a palette of intentionally selected colors by a professional psychologist were used to either create calming or invigorating spaces throughout the station. This worked by for example painting work space using the invigorating palette and private spaces using the calming palette (Hamilton 2013).
5. Elimination of extra sound is noted as improving the morale of McMurdo station, as they moved all machinery and extra noise to another non central location (Davis 2017).
6. Discreet security measures are beneficial, in contrast to apparent

security as fear and control were felt by users when they could see the security and as a result felt as if they were always being watched (Grant 2020).

7. Grouping of like programmatic elements was valuable as it gave each area of the facility a common goal or purpose (Galford 2021).

8. Amenities and inclusion of multi purpose rooms are vital to giving people something to do other than work, as well as it gives valuable opportunities for social interaction which is needed (Hamilton 2013).

9. Creating multiple smaller communities (around 30-40 people) instead of having one large group is shown to improve socialization and community connection, which can be architecturally achieved by designing for multiple communities instead of one large community (Cottam 2009).10)

10. And finally having variation in public and private spaces was seen across multiple precedents as being impactful in order to combat isolation (Davis 2017.)

Implications

The implications on the field of environmental design from this research are demonstrating how deeply intertwined design is within everyday life. For some, this connection may be subconscious, but it is inevitably there. Not only do we affect our built environment, but it also affects us. This shows the importance of design and the need to be intentional in what we as designers make because it changes others' mental well-being and lives. Furthermore, this research can also be directly applied to the same Earth-based precedents examined in the methodology. As these precedents have similarities to space making them a great indicator for space habitation, the knowledge gained can now also be applied back to these extreme, isolated environments.

Interpretations

After examining the Earth-based precedents it was interesting to see that prisons yielded the most results, which can be seen in Figure 12, as well as there has been an abundance of research on the topic of behavior and correctional facilities. While it may seem like prisons and space are a far stretch there are similarities between them that can make practical applications in space. Oil rigs were harder to find research on their design but they had a lot of first-person accounts that made it easier to understand a feel for life on the rigs. Antarctica is nearly a whole different world but the designs within

are very beneficial to space. There are clearer connections between Antarctica and space and it is an area where we have an intentional design for mitigation of issues, which is rarely seen in many other places. Antarctica has enough information to have a whole research paper on its own, in contrast with the submarines as they were vague on design and intention which I am under the impression that part of the veil could be for military reasons.

Limitations

When conducting this research, the main element missing in the above Earth-based precedents is weightlessness; as there is no way to truly simulate this on Earth. Weightlessness is vital due to how it affects one's body, for example, zero-gravity alters spatial orientation, head-eye, hand-eye coordination, balance, and locomotion (Abadie et al. 2021). Furthermore, if given ample resources, the next step would be to use high-quality simulations to test how different design considerations found alter how people feel and interact with one another, along with direct accounts from astronauts and cosmonauts. Furthermore, when evaluating these Earth-based precedents it's important to note that they are isolated either from the physical world or socially from others, but in space, a permanent settlement would be isolated from Earth in general. Interviews with other architects & designers of some of the specific projects and precedents above would be valuable to better evaluate the design features that impacted the user.

Futures

Recommendations for future research include ancient vernacular architecture. Vernacular architecture is a local or regional construction method where traditional materials from the area are used. Vernacular architecture is beneficial as it too had limited resources, time, and technical ability to create their worlds, similar to the challenges of building in space. This means the development of their built environment shows what is essential for a decent quality of life. There were no resources or time to spare, so what was made in vernacular architecture was intentional and served a purpose. What these ancient civilizations made was very intentional, due to limited resources and construction knowledge, therefore what they did build was intentional and necessary.

Science fiction also serves as an interesting point of research. When these worlds were made, did they have sound reasoning to them? Was it a plausible built environment, and if so, how? Science fiction can reveal other needs and ideas not traditionally thought of but also necessary.

11

Conclusion

This research has examined the intersection of design, psychology, and space to gain design contributions for living on another terrestrial body. Through an understanding of space psychology, design for wellbeing, and a review of space station design, we have seen the need for improvement of space design. This research has combined the above fields to fill a gap in knowledge for necessary design considerations in order to thrive on Mars.

Research has been done on isolated environments and harsh conditions, including how they affect humans, but the consideration of architecture has not become prevalent and widely considered in this process. This research fills a gap, as it includes Architectural elements & programs on how isolated and extreme environments impact people. This paper began with a question of how our built environment affects us, and if it could help us improve for the better, resulting in the main categories of Architectural spatial, experiential, and social design considerations.

The final contribution of this paper was consideration for how to design for a high quality of life on Mars by mitigating some of the negative factors that can cause adverse effects on one's life. It is with increasing certainty that humans will become an interplanetary species so we must prioritize increasing our understanding of what is necessary for this life to be successful. This research fills a gap in that interplanetary knowledge base. As well as the consideration of Architectural attributes when examining isolated and extreme

environments has not been prominently covered.

The goal of design to mitigate the negative effects of isolation is threefold: increase communication and interaction between spacefarers, create a positive environment community and atmosphere within the settlement, and finally use the built environment to enable better adaptation to the extremes of the setting.

12

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Appendices

Appendix A- Initial Matrix

Source	Issue/ Topic	Solution V. Opportunity	Which Precedent	Description	Type
Redesigning Prison: The Architecture and Ethics of Rehabilitation (Karthaus et al. 2019)	The Panoptic on Style+ continual surveillence results in fear based behavior	Opportunity	Prison		Architectural Spacial
Redesigning Prison: The Architecture and Ethics of Rehabilitation (Karthaus et al. 2019)	"Learning Works a "21st Century Prison' model"	Solution	Prison	"The Learning Prisons Report which suggested key principles for reform 'seeing prisons as a core public service that ... begins to re imagine how prison's role as educator could be placed centre stage to issues of public safety"	Architectural Spacial
The 21st Century Prison (Cottam, 2009)	19th century Fordist prison	Opportunity	Prison		Experiential
The 21st Century Prison (Cottam, 2009)	programmatically based in central education goal	Solution	Prison		Social
The 21st Century Prison (Cottam, 2009)	concentrate communal facilities together minimize distance between here and and houses sleeping / personal space	Solution	Prisons		Architectural Spacial
The 21st Century Prison (Cottam, 2009)	wing for smaller groups to minimize riots	Solution	Prison	Residential care is about (10-40) which strikes individual and community with economic benefit, results in personal accountability	Architectural Spacial
The 21st Century Prison (Cottam, 2009)	Symmetry in cells to assert order	Solution	Prison		Architectural Spacial
The 21st Century Prison (Cottam, 2009)	vary spaces that can be made individual or group	Solution	Prison		Architectural Spacial
Prison as Home (Gafford 2021)	Trust is key theme to environment instead of high security	Solution	Prison		Experiential
Prison as Home (Gafford 2021)	Visual control	Solution	Prison	Many have fear of the not being seen by an officer when in need because of the raised surveillance view not workin	Architectural Spacial
Prison as Home (Gafford 2021)	Views to Nature	Solution	Prison	Improved mental state of prisoners	Experiential
Prison as Home (Gafford 2021)	Sound	Opportunity	Prison	Control noise was connected to routine But otherwise loud noise was connected to fear Sounds connect to the temperament of the environment	Experiential
Prison as Home (Gafford 2021)	Routine	Solution	Prison		Experiential
Prison as Home (Gafford 2021)	Time	Solution	Prison		Experiential
Ravenhall Correctional Centre (Crane 2020)	"hard architecture"	Opportunity	Prison	bars on windows, concrete walls, hard-surface floors, drab colours, indestructible and uncomfortable furniture]	Architectural spatial
Ravenhall Correctional Centre (Crane 2020)	Organization of small groups	Solution	Prison		Architectural Spacial
Ravenhall Correctional Centre (Crane 2020)	Security not externally displayed	Solution	Prison	Didnt have fear based control	Architectural Spacial
Ravenhall Correctional Centre (Crane 2020)	Variation in housing types	Solution	Prison		Architectural Spacial
Ravenhall Correctional Centre (Crane 2020)	Therapeutic architecture	Solution	Prison	design focuses on maximising natural light, eliminating environmental stressors (e.g. noise), safety, security, observation, avoiding of visual disturbances, color, group interaction and access to nature and external environments.	Experiential

Ravenhall Correctional Centre (Grant 2020)	Wayfinding	Solution	Prison	as legible environments reduce stress and increase health outcomes for people living with mental health conditions and psychosocial and/or cognitive disabilities.	Architectural Spatial
Ravenhall Correctional Centre (Grant 2020)	Listening room	Solution	Prison	room with opaque glass to allow others to observe helps diffuse situations	Architectural Spatial
Ravenhall Correctional Centre (Grant 2020)	sensory room	Solution	Prison	assist in the management and treatment of people with sensory disorders (see Martin 1996).	Architectural Spatial
Improving Mental Health in Prisons Through Biophilic Design (Söderlund and Newman 2017)	increasing nature decreases stress and improves mental health	Solution	Prison		experiential
A Day on An Oil Rig	obscure transportation method	Opportunity	Oil Rig	have to use helicopter to get to oil rig	Architectural Spatial
A Day on An Oil Rig	24/7 amenities	Solution	Oil Rig	for use based on weird schedules	Social
Offshore Rig Island Living (ORourke)	few things to do other than work	Solution	Oil Rig	need other things to do work	Social
Offshore Rig Island Living (ORourke)	no programmatic things to do	Opportunity	Oil Rig		Social
Life on an oil rig (Mohnazd 2021)	scheduled time off for regular increments	Solution		gave down time from high pressure job	Social
Hamilton, William. 2013. "Come in From the Cold: Hugh Broughton's Antarctic Research Station." Interior Design. June 26, 2013.	recreation area	Solution	Antarctica	relief from isolatioin	Social
Hamilton, William. 2013. "Come in From the Cold: Hugh Broughton's Antarctic Research Station." Interior Design. June 26, 2013.	palette of calming or invigorating colors by consultant	Solution	Antarctica		experiential
Hamilton, William. 2013. "Come in From the Cold: Hugh Broughton's Antarctic Research Station." Interior Design. June 26, 2013.	alarm clocks that simiate daylight	Solution	Antarctica		experiential
Hamilton, William. 2013. "Come in From the Cold: Hugh Broughton's Antarctic Research Station." Interior Design. June 26, 2013.	hydraulic ski legs for movement	Solution	Antarctica		Social
A history of McMurdo Station through its architecture, Davis	attention to personal privacy	Solution	Antarctica		Social
A history of McMurdo Station through its architecture, Davis	layout due to circulation route	Solution	Antarctica		Architectural Spatial
A history of McMurdo Station through its architecture, Davis	wayfinding	Solution	Antarctica		Architectural Spatial
A history of McMurdo Station through its architecture, Davis	single rooms	Solution	Antarctica	40% increase in single-occupancy rooms, highlighting the importance of privacy for everyone working at the station	Social
A history of McMurdo Station through its architecture, Davis	building envelope - windows	Solution	Antarctica		experiential
A history of McMurdo Station through its architecture, Davis	daylight	Solution	Antarctica		experiential
A history of McMurdo Station through its architecture, Davis	covered passageways	Solution	Antarctica	'[]n cold weather there are psychological advantages in being able to get away from living and working areas by walking in the covered passageways' (DOD 2004:1-1).	experiential

A history of McMurdo Station through its architecture, Davis	moving loud utilitizes from main areas for noise issues increasing morale	Solution	Antarctica		Social
A history of McMurdo Station through its a	visual clutter	Solution	Antarctica		experiential
A history of McMurdo Station through its architecture, Davis	pedestrian safety	Solution	Antarctica		Architectural Spatial
A history of McMurdo Station through its architecture, Davis	use of multipurpose rooms	Solution	Antarctica		Social
A history of McMurdo Station through its architecture, Davis	all in one building	Solution	Antarctica		Social
From the midnight sun to the longest night: Sleep in Antarctica	daylight	Solution	Antarctica		experiential
The Human Element in Space : Lessons From Antarctica	creation of micro cultures	Solution	Antarctica		Social
Life Aboard A U.S Submarine	Hot racks	Opportunity	Submarine	sharing of beds	Architectural Spatial
Life Aboard A U.S Submarine	Beds felt like in a MRI machine	Opportunity	Submarine		experiential
Life Aboard A U.S Submarine	unspoken rules	Solution	Submarine		Social
Life Aboard A U.S Submarine	lack of natural light	Opportunity	Submarine		experiential
CRAMPED, ISOLATED, AND HEAVILY-ARMED: What Life Is Like on a Navy Submarine.	lack of natural light	Opportunity	Submarine		experiential
CRAMPED, ISOLATED, AND HEAVILY-ARMED: What Life Is Like on a Navy Submarine	average of 15 sqft of room for themselves and all their items	Opportunity	Submarine		Architectural Spatial

Appendix B- By Type Matrix

ARCHITECTUAL Spatial [how you live]					
Source	Issue/ Topic	Solution V. Opportunity	Which Precedent	Type	Description
Redesigning Prison: The Architecture and Ethics of Rehabilitation (Karthaus et al. 2018)	The Panopticon Style- continual surveillence results in fear based behavior	Opportunity	Prison	Architectural Spatial	
Redesigning Prison: The Architecture and Ethics of Rehabilitation (Karthaus et al. 2018)	"Learning Works a '21st Century Prison' model"	Solution	Prison	Architectural Spatial	"The Learning Prisons Report which suggested key principles for reform 'seeing prisons as a core public service that... begins to reimagine how prison's role as educator could be placed centre stage to issues of public safety"
The 21st Century Prison (Cottam, 2009)	concentrate communal facilities together minimize distance between here and and houses sleeping / personal space	Solution	Prison	Architectural Spatial	
The 21st Century Prison (Cottam, 2009)	wing for smaller groups to minimize riots	Solution	Prison	Architectural Spatial	Residential care is about (30-40) which strikes individual and community with economic benefit, results in personal accountability
The 21st Century Prison (Cottam, 2009)	Symmetry in cells to assert order	Solution	Prison	Architectural Spatial	
The 21st Century Prison (Cottam, 2009)	vary spaces that can be made individual or group	Solution	Prison	Architectural Spatial	

Prison as Home (Calfoos 2021)	Visual control	Solution	Prison	Architectural Spatial	Many have fear of the not being seen by an officer when in need because of the raised surveillance view not workin
Ravenhall Correctional Centre (Grant 2020)	'hard architecture'	Opportunity	Prison	Architectural Spatial	bars on windows, concrete walls, hard-surface floors, drab colours, indestructible and uncomfortable furniture)
Ravenhall Correctional Centre (Grant 2020)	Organization of small groups	Solution	Prison	Architectural Spatial	
Ravenhall Correctional Centre (Grant 2020)	Security not externally displayed	Solution	Prison	Architectural Spatial	Didnt have fear based control
Ravenhall Correctional Centre (Grant 2020)	Variation in housing types	Solution	Prison	Architectural Spatial	
Ravenhall Correctional Centre (Grant 2020)	Wayfinding	Solution	Prison	Architectural Spatial	as legible environments reduce stress and increase health outcomes for people living with mental health conditions and psychosocial and/or cognitive disabilities
Ravenhall Correctional Centre (Grant 2020)	Listening room	Solution	Prison	Architectural Spatial	room with opaque glass to allow others to observe helps diffuse situations

Ravenhal Correctional Centre (Grant 2020)	sensory room	Solution	Prison	Architectural Spatial	assist in the management and treatment of people with sensory disorders (see Martin 1998).
A history of McMurdo Station through its architecture, Davis	layout due to circulation route	Solution	Antarctica	Architectural Spatial	
A history of McMurdo Station through its architecture, Davis	wayfinding	Solution	Antarctica	Architectural Spatial	
A history of McMurdo Station through its architecture, Davis	pedestrian safety	Solution	Antarctica	Architectural Spatial	
Life Aboard A U.S. Submarine	Hot racks	Opportunity	Submarine	Architectural Spatial	sharing of beds
CRAMPED, ISOLATED, AND HEAVILY-ARMED: What Life Is like on a Navy Submarine.	average of 15 sqft of room for themselves and all their items	Opportunity	Submarine	Architectural Spatial	

EXPERIENTIAL [how you feel]					
Source	Issue/ Topic	Solution V. Opportunity	Which Precedent	Type	Description
The 21st Century Prison [Coltarn, 2009]	19th century Fordist prison	Opportunity	Prison	experiential	
Prison as Home [Galford 2021]	Trust is key theme to environment instead of high security	Solution	Prison	experiential	
Prison as Home [Galford 2021]	Views to Nature	Solution	Prison	experiential	Improved mental state of prisoners
Prison as Home [Galford 2021]	Sound	Opportunity	Prison	experiential	Control noise was connected to routine But otherwise loud noise was connected to fear Sounds connect to the temperament of the environment
Prison as Home [Galford 2021]	Routine	Solution	Prison	experiential	
Prison as Home [Galford 2021]	Time	Solution	Prison	experiential	
Ravenhall Correc	Theriputic architecture	Solution	Prison	experiential	design focuses on maximising natural light, eliminating environmental stressors (e.g. noise), safety, security, observation, avoiding of visual disturbances, color, group interaction and access to nature and external environments.

Improving Mental Health in Prisons Through Biophilic Design (Soderlund and Newman 2017)	Increasing nature decreases stress and improves mental health	Solution	Prison	experiential	
Hamilton, William. 2013. "Come in From the Cold: Hugh Broughton's Antarctic Research Station." Interior Design. June 26, 2013.	palette of calming or invigoratinng colors by consultant	Solution	Antarctica	experiential	
Hamilton, William. 2013. "Come in From the Cold: Hugh Broughton's Antarctic Research Station." Interior Design. June 26, 2013.	alarm clocks that simiate daylight	Solution	Antarctica	experiential	
A history of McMurdo Station through its architecture, Davis	building envelope > windows	Solution	Antarctica	experiential	
A history of McMurdo Station through its architecture, Davis	daylight	Solution	Antarctica	experiential	

A history of McMurdo Station through its architecture, Davis	covered passageways	Solution	Antarctica	experiential	'[i]n cold weather there are psychological advantages in being able to get away from living and working areas by walking in the covered passageways' (DOD 2004: 1-1).
A history of Mc	visual clutter	Solution	Antarctica	experiential	
From the midnight sun to the longest night: Sleep in Antarctica	daylight	Solution	Antarctica	experiential	
Life Aboard A U.S. Submarine	Beds felt like in a MRI machine	Opportunity	Submarine	experiential	
Life Aboard A U.S. Submarine	lack of natural light	Opportunity	Submarine	experiential	
CRAMPED, ISOLATED, AND HEAVILY-ARMED: What Life Is like on a Navy Submarine.	lack of natural light	Opportunity	Submarine	experiential	
A history of McMurdo Station through its architecture, Davis	moving loud utilitizes frpm main areas for noise issues increasing morale	Solution	Antarctica	Experiential	

SOCIAL [how you behave]					
Source	Issue/ Topic	Solution V. Opportunity	Which Precedent	Type	Description
The 21st Century Prison (Cottam, 2009)	programmatically based in central education goal	Solution	Prison	Social	
A Day on An Oil Rig	24/7 amenities	Solution	Oil Rig	Social	for use based on weird schedules
Offshore Rig Island Living (O'Rourke)	few things to do other than work	Solution	Oil Rig	Social	need other things to do work
Offshore Rig Island Living (O'Rourke)	no programmattic things to do	Opportunity	Oil Rig	Social	
Life on an oil rig (Mehnazd, 2021)	scheduled time off for regular increments	Solution		Social	gave down time from high pressure job
Hamilton, William. 2013. "Come in From the Cold: Hugh Broughton's Antarctic Research Station." Interior Design. June 26, 2013.	recreation area	Solution	Antarctica	Social	relief from isolatioin
Hamilton, William. 2013. "Come in From the Cold: Hugh Broughton's Antarctic Research Station." Interior Design. June 26, 2013.	hydraulic ski legs for movement	Solution	Antarctica	Social	
A history of McMurdo Station through its architecture, Davis	attention to personal privacy	Solution	Antarctica	Social	

A history of McMurdo Station through its architecture, Davis	single rooms	Solution	Antarctica	Social	40% increase in single-occupancy rooms, highlighting the importance of privacy for everyone working at the station
A history of McMurdo Station through its architecture, Davis	use of multipurpose rooms	Solution	Antarctica	Social	
A history of McMurdo Station through its architecture, Davis	all in one building	Solution	Antarctica	Social	
The Human Element in Space: Lessons From Antarctica	creation of micro cultures	Solution	Antarctica	Social	
Life Aboard A U.S Submarine	unspoken rules	Solution	Submarine	Social	

Appendix C- Results Matrix

#	Source	Issue/ Sight	Precedent Source	Keywords	ARCHITECTURE Spatial (Nodes, Edges, Configurations)	INTERIOR DESIGN (Materials, Furniture, Configurations)	SOCIAL (Interpersonal)	EXPERIENCE (Sensory)	SAFETY (personal and others)	Quotes/Ideas
1	Redesigning Prisons: The Architecture and Ethics of Rehabilitation (Smith et al. 2019)	The Panopticon Sight: an Great surveillance, habitat or fear based behavior	Prison	Surveillance, privacy, Psychology		Placement of Surveillance equipment and level of surveillance		monitored and monitoring or freedom	Surveillance, freedom	
2		"Learning Works a 21st Century Indoor model"	Prison	Relaxation, Checkerboard pattern, maximize social interaction	Checkerboard pattern - program organization		Increase social interaction		Probable/increased lines of sight	"The Learning Works report which suggested key principles for reform, seeing prisons as a task public service that...begins to reimagine how prisons can be educator could be placed centre stage to issues of public safety"
3			Prison	Enhance natural daylight, ventilation, views for prisoners	Apertures for Views and Ventilation			natural daylight and views to outside		
4	The 21st Century Prison System, 2019	Anti-corrupt architecture	Prison							
5		Prisons' typology	Prison	Like, work, learn center same space or group	program organization		Increased interaction as multiple programs in same space	increases local through options and decision making for herself		
6			programmatically based on center education goal	Layout/Plan	program organization/ center building goal central in layout					
7		centralized cinema rail facilities together minimize distance between here and prisoners sleeping / personal space	Prison	Layout, Organization of spaces, adjacencies, program	program organization/accessibility/ circulation		Increased social interaction due to centralized communal spaces			
8		Correctional circulation as one between Prisoner and correctional	Prison	Program, adjacencies, circulation	Circulation/program encounter				permeability and mobility of spatial organization	
9		wing for smaller groups to optimize data	Prison	30 adjacent cinema groups, program walls, clusters, views	program organization		varying scales provide for varying degrees of interaction		people can be accountable for each other	residential care is about (1) (2) which strikes individual and community with economic benefit results in personal accountability
10		Symmetry in cells to assert order	Prison	Interior Design						
11		vary spaces that can be enact individual or group	Prison	Controlled Privacy, option for interaction		controlled privacy closer to	choice of level of social interaction, accessibility			
12	Prison as Home (Forland 2007)	Trust is key theme to reverse recent trend of high security	Prison	Surveillance, Privacy		Placement of Surveillance equipment and level of surveillance		restricted and monitored or freedom, increases trust	Surveillance, freedom	
13		Visual contact	Prison	Safety, Lines of Sight	increase lines of sight between programs	ensure lines of sight within programs			views lines of sight	Many families of the not being seen by an officer which is need because of the usual surveillance was not within
14		Views to Nature	environment		Apertures for external views			natural daylight and views to outside		improved mental state of prisoners
15		Sound	environment		Adjust programs to manage sound levels - zones for different levels of environment		Indicate motion	sounds have varying interpretations		Control noise was connected to calms. Talk other noise but noise was connected to fear. Sounds connect to the human aspect of the environment
16		Routine	Prison	Stability				predictability and stability		
17		Time	Prison	Redistribution, Centralization (individual level)						
18	Marshall Correctional Centre (Clark 2020)	"Food architecture"	Prison	Definition of thresholds and borders, materials, symbols		materiality and form imply meaning		materiality and form imply meaning - aim the comfort		Carpet windows, concrete walls, hard surface floors, drab colours, indestructible and uncomfortable furniture
19		Facing inward to Courtyard	Prison	Focal Point, Orientation, spatial organization, safety	program organization			predictability and orientation lead to stability	views lines of sight	
20		The entry points to each immensely similar program, interior and multiple/pod rooms	Prison	Orientation, stability, programmatic organization	program encounter			predictability and orientation lead to stability		
21		Organization of small groups	Prison	Layout/Plan						
22		Security not externally displayed	Prison	Trust, visibility		Placement of Surveillance equipment and level of surveillance		restricted and monitored or freedom, increases trust	Surveillance, freedom	Doll House Bard Lockd
23		Variation in housing types	Prison	small groups 4-6, interpersonal assignment, trust	program organization		Interpersonal development and trust		trust and accountability	
24		Triangular architecture	Prison	maximize light, minimize noise, deterrents, adjacencies	apertures for light, geometry with triangle, accessible from cells			natural daylight and views to outside, predictability of noise levels		Triangle focuses on maximizing natural light, eliminating environmental diseases (e.g. mold), safety security, observation, avoiding of dead corners/nooks
25		Common Spaces lead to common courtyards	Prison	Orientation, environment (light), adjacencies	program encounter			light predictability and orientation lead to stability	views lines of sight	
26		Wayfinding	Prison	Predictability, programmatic encounting	program encounter			light predictability and orientation lead to stability		as legible environments reduce stress and increase health outcomes for people living with mental health
27		Listening room	Prison	Programmatic events with distinct unique environments		interior design - unique spatial environments for safety		ability to isolate into unique environments		rooms with unique place location allows to observe noise without anyone
28		Anxiety room	Prison	programmatically organized as us		interior design - unique spatial environments for safety		ability to isolate into unique environments		space in the management environment of people with anxiety (Ann Dale Martin 1998)
29	Improving Mental Health in Prisons Through Essential Design (Gallery and Newman 2017)	Increasing nature decreases stress and improves mental health	Prison	environment (close to nature, sounds), increasing nature	apertures for light	Increased ability to have plants indoors		natural daylight and connection to nature		
30	A Day in An Oil Rig (Worksite Fitness, 2012)	Natural transportation method	Oil Rig	transportation						Have to use helicopter to get to oil rig
31		24/7 services	Oil Rig	access to essentials, living staples	program services			sense of security that staples are always available		Focuses based on natural consumables

#	Source	Issues/ Topic	Environment Source	Keywords	ARCHITECTURAL Spatial (Spaces, Volumes, Configurations)	INTERIOR DESIGN (Materials, Finishes, Configurations)	SOCIAL (Interpersonal behavior)	OPERATIONAL (Behavior-level)	SAFETY (yourself and others)	Description
32		Play, work, and game	Oil Rig	non-essential programs	program-services2		non-essential related programs provide alternate modes of interacting	ability to disengage, take a break, socialize		
33		workout specialist on board	Oil Rig	specialized non-essential staff						
34	Offshore Rig (Island Living (2 Rounds)	few things to do other than work	Oil Rig	need for recreational programs	program-services2		non-essential related programs provide alternate modes of	ability to disengage, take a break, socialize		need other things to do well
35		no programmatic things to do	Oil Rig							
36	Life on an oil rig (Mainwood 2007)	scheduled time off for regular movements	Oil Rig	spatial operating terms				scheduled down time - spatial previous stability		gave down time from high pressure job
37		bunkbeds for comfortably	Oil Rig	pain, directions, layer of safety, connection		interior design2	bed wear-correction		extra layer of safety and accountability	
38		cinema halls, gyms, indoor sports	Oil Rig	non-essential programming	program-services		non-essential related programs provide alternate modes of interacting	ability to disengage, take a break, socialize		
39	Hamilton, William. 2013. "Come in from the Cold: Hugh Broughton's Antarctic Research Station." Interior Design. June 25, 2013. http://interiordesign	recreation area, 1,300 sq ft for a crew of 52, approx 100 sq ft of recreation space/member	Antarctica	commercial programs grouped together (dining/cooking entertainment), programmatic configuration	program-services3		non-essential related programs provide alternate modes of interacting	ability to disengage, take a break, socialize		relief from isolation
40		large apertures		environment (views)	large apertures for views and light			natural daylight and views to outside		
41		palette of calming or invigorating colors by consultant	Antarctica	environment, color effect on activity		interior design - color palette related to activity		color has an effect of activity		
42		alarm clocks that simulate daylight	Antarctica	predictability, safety, environment		interior design - daylight simulation		predictability	sense of security	
43		hydraulic sleeping movement	Antarctica							
44	A history of Mawson Station Through its architecture, David	attention to personal privacy	Antarctica	privacy	program-organization7					
45		sensitive to insulation issue	Antarctica							
46		wayfinding	Antarctica	predictability, safety, orientation	program-organization			clear wayfinding is predictable and provides stability	clear wayfinding is safer and avoids confusion especially in an emergency situation	
47		single rooms	Antarctica	single and double occupancy, choice and variety, privacy	program-organization8 - varying degrees of occupancy		choice of privacy and interaction	ability to choose isolation		with increase in single occupancy rooms, highlighting the importance of privacy for everyone working at the station
48		building envelope - windows	Antarctica	environment (daylight)	apertures for light			natural daylight and views to outside		
49		daylight	Antarctica		apertures for light			natural daylight and views to outside		
50		covered passageways	Antarctica	transition space between living and working areas, horizontally different, threshold, circulation, permeable, sequence	program-organization			predictability and stability		"In cold weather there are psychological advantages in being able to get away from living and working entirely, walking on the covered passageways" (200 200-11)
51		moving loud utilities from main areas for noise issues increasing example	Antarctica	environment (building noise)	program-organization - noise zones			predictable sound levels		
52		visual clutter	Antarctica							
53		pedestrian safety	Antarctica							
54		use of multipurpose rooms	Antarctica	non-essential programs	program-services5		non-essential related programs provide alternate modes of interacting	ability to disengage, take a break, socialize		
55		all in one building	Antarctica	perhaps efficient but challenging so to lack of variety	program-organization11					
56	From the midnight sun to the longest night: Sleep in Antarctica	daylight	Antarctica		apertures for light			natural daylight and views to outside		
57	The Human Element in Space: Lessons From Antarctica	creation of micro cultures	Antarctica	social and leisure activities contribute to anxiety-reducing functions, psychology, non-essential programs, group activities	program-services6		non-essential related programs provide alternate modes of interacting	ability to disengage, take a break, socialize		
58	Life Aboard a U.S. Submarine	hot-racks	Submarine							sharing of beds
59		Birds fall like in a Hill machine	Submarine	comfort, form, symbols, materials		interior design - materiality and form		materials and forms should communicate comfort		
60		unspoken rules	Submarine							
61		lack of natural light	Submarine	environment (light)	apertures for light			natural daylight and views to outside?		
62	CRAMPED, ISOLATED, AND HEAVILY ARMED: What Life is Like on a Navy Submarine	lack of natural light	Submarine	environment (light)	apertures for light			natural daylight and views to outside?		
63		average of 8 sq ft of room for themselves and all their items	Submarine	non living requirements	program-organization10					