S.E.ARCH

SCIENCE FICTION AND
EXTRATERRESTRIAL ARCHITECTURE

S.E.ARCH
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A 120-point thesis submitted to the Victoria University of Wellington in partial fulfilment of the requirements for the degree of Master of Architecture (Professional)

Victoria University of Wellington
School of Architecture

2020

FOR GRANDAD

THE MOST DOWN-TO-EARTH MAN TO EVER HAVE
LOVED SCIENCE FICTION

"Provide ships or sails adapted to the heavenly breezes, and there will be some who will brave even that void."
— Johannes Kepler

ABSTRACT

Until this point in time, space architecture has relied heavily on engineering - resulting in little room for artistic practice. The resulting habitats are ill-equipped to sustain the quality of life required for long-term or interplanetary missions. However, rapid technological growth is beginning to enable the realisation of outer space for commercial enterprise, scientific gain, and personal exploration. Together, a budding space industry and the profession of space architecture are set to lead each other, hand-in-hand, into a new age of space exploration - and to destinations never before reached.

For almost as long as human culture has remembered we have been fascinated by the stars. A potent result of this fascination is science fiction and stories concerning space travel. A strong and tangible assemblage has formed between science fiction, social narrative, and outer space. Science fiction can make concepts of the future understandable. It can make communities focused on the future.

This thesis proposes that the discipline of architecture, with the help of popular science fiction, can re-imagine space architecture. It seeks to create empathy with the future inhabitants of outer space by envisaging the space industry of the future, and through the creation of a passenger ship it develops a hope for a future that unfolds differently to what we are planning for now.

This research seeks to investigate these connections in order to create safer and more fulfilling homes for spacefarers of the future. It does so by arguing against the typology we maintain. Through iterative designs which coincide with research on the use of science fiction and habitability in space, it concludes with a new ship typology.

ARCHITECTURE

SPACE - ~~TRAVEL~~ CERTAINLY WAS A COMPLICATED AFAIR - SO COMPLICATED THAT IT SOMETIMES DEPRESSD ME.

THEN I REMEMBERED THAT THESE MEN DIDN'T SEEM ANY CLEAVERER THAN I WAS: THEY WERE HIGHLY TRAINED, THAT WAS ALL.

ORIGINAL QUOTE FROM
'ISLANDS IN THE SKY' - ARTHUR C. CLARKE

FOREWORD

It's likely I created this thesis because I watched too much Star Trek during my university years.

But, this thesis is also a product of a belief that architecture (like many other disciplines) finds ways to bring opposites together to make sense of the world - whether those oppositions be the past and the future, people native to a place and those new to it, young kids and grandparents, lecturers and students, the Star Trekkers and the Star Wars-ers.

I've taken my chance to find where architecture meets outer space.

ACKNOWLEDGEMENTS

A galactic thank you to;

My supervisor, Guy, for your help, guidance, and constant reassurance that taking a giant leap is sometimes the best course of action.

To Mum and Dad, for getting me through thick and thin. I don't know where I would be without you two.

My sisters, another source of unending support and kindness.

To Shane, for knowing me better than I do myself.

For the friends in and out of school who; taught me tips and tricks, gave advice, and distracted when I needed it most.

And to myself.

I can't believe it's really done.

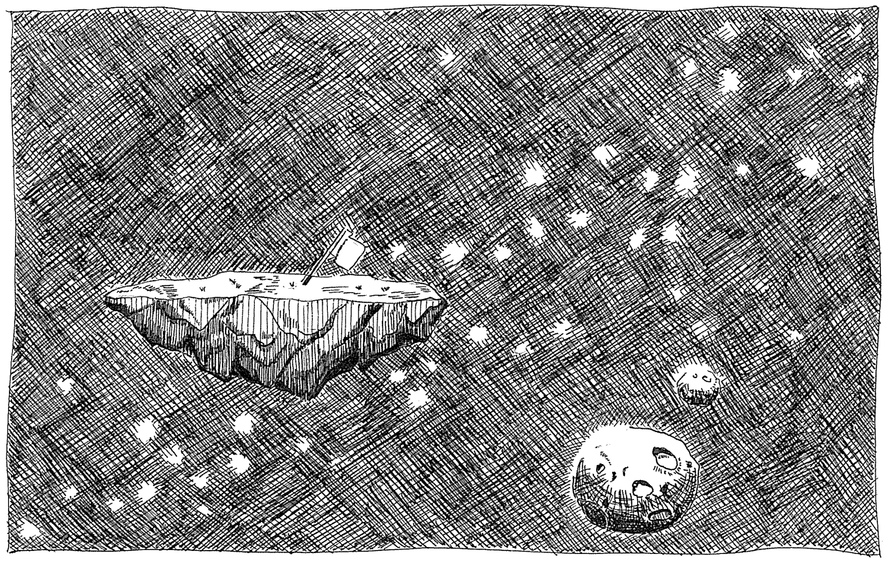


Figure.1 *Sketch experiments: Making our mark*

CHAPTER 1: **INTRODUCTION**

IMAGE REDACTED

Figure.2 *'Bootprint on the Lunar Surface' during Apollo 11 mission to the Moon (1969). From NASA. Apollo11 image gallery https://www.nasa.gov/apollo11-gallery*

Humans have always been Earth dwellers.

And for just over 50 years we have been Space dwellers.

The first person to inhabit space did so more than half a century ago. For 108 minutes – just enough time to circle the Earth once – cosmonaut Yuri Alekseyevich Gagarin was the sole occupant of outer space. In 1969, humanity took its first step onto the moon, onto a world that wasn't our own. After this feat, a series of successful and unsuccessful space stations paved the way to the International Space Station (ISS) which, for over 18 years, has maintained a constant human presence off-world.

Architects, artists, and entrepreneurs are seeing the world now like never before. Many have gone through their entire education while humans have lived in outer space. To some, outer space is a Plan B - a scientific treasure trove, the final frontier, or the solution to climate change.[1] To others, outer space is now an extension of human space. From geography to politics, architecture to gender studies, outer space contributes to the conversation.[2]

However, our time as space dwellers is limited. By 2030 the ISS will be vacated and carefully burned up in our atmosphere. NASA has recently announced Gateway, a new station orbiting the moon and a brand new venture for mankind. But this vessel will not be manned full-time, leaving both architecture and humankind with their feet and foundations firmly cemented to planet Earth.

1. Saletta and Orrman-Rossiter, "Can Space Mining Benefit All of Humanity?"; Sherwood, "Comparing Future Options for Human Space Flight"; Sherwood, "Decadal Opportunities for Space Architects."
2. Patrick, "Cosmopolitical Bodies: An Architecture of Space."

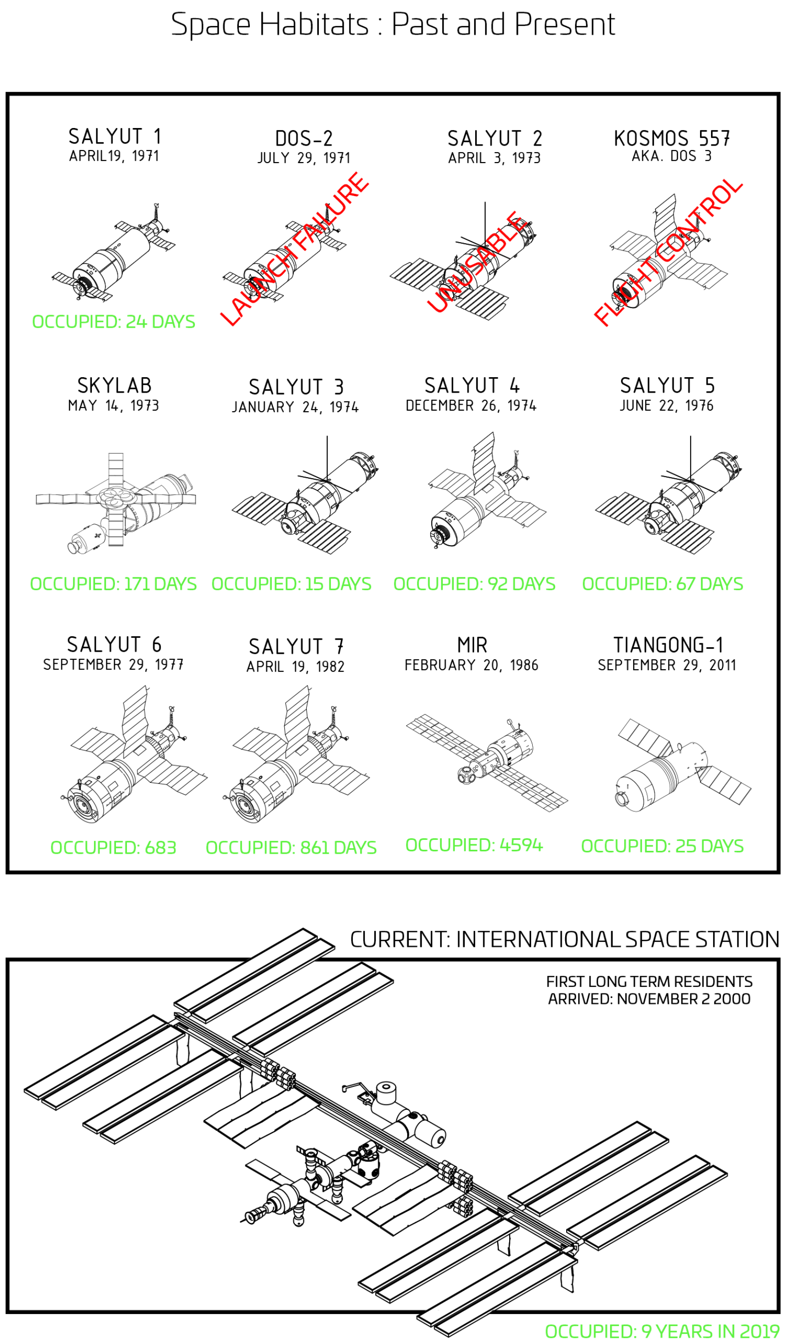


Figure.3 *Past and present space habitats*

"In general, if humankind is going to continue space exploration we have to stop treating space as a one-time lab experiment and start dealing with it as with any another habitation environment where living conditions differ from what humans are used to. Introduction to space architecture as a discipline and philosophy… may be an important step towards building such attitudes." – Bannova and Bell[3]

Generally, human habitats in outer space have not presented opportunities for safe long-term habitation.[4] Space architecture has thus far been "dominated by engineering and technology driven practices... [leaving] limited room for art and design". This is despite art, architecture, and creativity being beneficial for both the physical and mental health of astronauts.[5] The impacts of living in these environments include a range of physical and mental stresses including paranoia, increased radiation doses, social struggles, and loss of muscle and bone density.

Traditionally, space architecture typologies have been of modularity and functionality.[6] Adam and Jones speculate that, just as the ISS was based upon Skylab and the Salyut models, the modular archetype found in our current space station will affect how we design for years to come. Images of the Gateway project appear to corroborate this conclusion.

In 'Sources of Inspiration' Eckert and Stacey note that a profession's past works create a language for designers, influencing how they communicate and learn from each other.[7] If space architecture is still in its fledgling years where one structure can influence a lifetime's worth of habitats, it can only be concluded that it would be a good idea to develop new ways of working and designing – because we don't yet know what the effects of these first habitats further from Earth will have on our future.

3. "Space Architecture Education as a Part of Aerospace Engineering Curriculum."
4. Harrison, "Humanizing Outer Space: Architecture, Habitability, and Behavioral Health"; Suedfeld et al., "Psychosocial Aspects of Spaceflight and Aging."
5. Balint and Pangaro, "Design Space for Space Design: Dialogues through Boundary Objects at the Intersections of Art, Design, Science, and Engineering."
6. Adams and Jones, "Alpha: From the International Style to the International Space Station."
7. Eckert and Stacey, "Sources of Inspiration: A Language of Design."

PROPOSITION

This thesis argues that architecture should be made an integral part of the creation of space architecture - if only to visualise how we could design for a future of human space flight (HSF).

The proposition of this research is to explore the connections between architecture and science fiction to create a human-centered space habitat that cares for the physical, mental and social health of those aboard.

Ultimately, this thesis asks the question;
How could using science fiction help architecture to re-imagine and develop safer human habitats in outer space?

RESEARCH AIM

TO EXPLORE THE USE OF SCIENCE FICTION TO DESIGN AND DEVELOP

NEW AND SAFER ARCHITECTURE FOR INHABITANTS OF OUTER SPACE.

The principal objectives are;

- To explore the interactive relationship between science fiction, architectural design, and the future of HSF;
- To develop an environment that protects the inhabitants from most physical, social, and psychological harm.
- To establish strong connections to earth despite physical distance and to outer space despite lack of a 'physical' site;
- To develop a potential architecture typology for the future of the human spaceflight industry.

This is a piece of design-led research is undertaken in the knowledge that space architecture "in general", can be based on architectural processes.[8] It utilises design-led research to create an iterative process "that requires guiding choices towards a preferable outcome."[9] As noted in Peter Downton's *Design Research*, with this method "the outcome is expected to vary and not be able to be prescribed."[10]

Design was used to highlight and reflect upon both the successes and pitfalls of each research stage. Although the chapters are laid out to form a narrative, this process allowed for many stages to work largely in tandem.

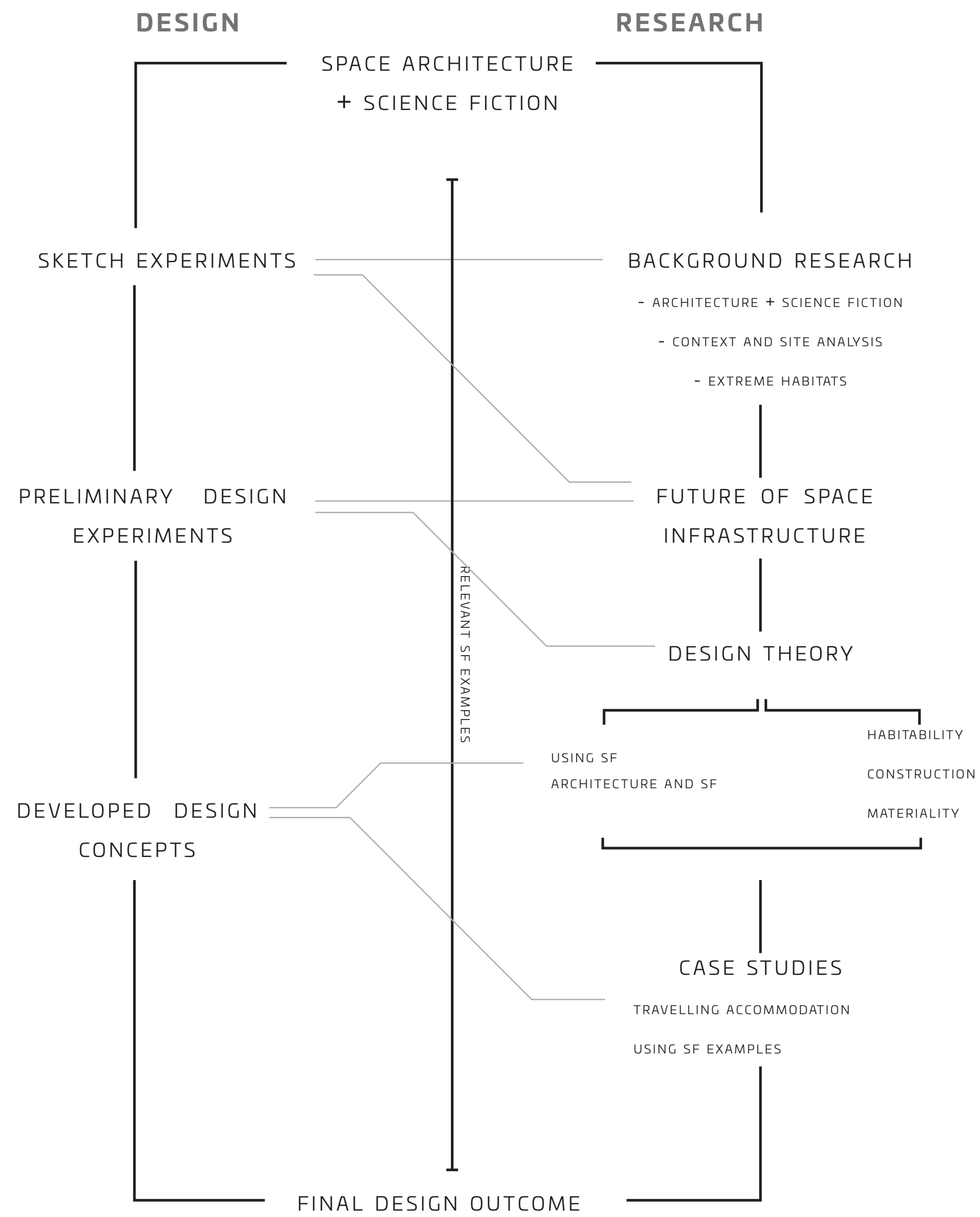
SCOPE OF DESIGN RESEARCH

The primary focus of the research was establishing the potential uses of science fiction (SF) as a design and research driver for long term transport vessels in outer space.

The research centres around visual and literary forms of SF that depict living in outer space. It is beyond the scope of the paper to create a comprehensive list of works to use as design material. Instead, it intends to open a conversation and put forward hypotheses for the connections between architecture, works of fiction, and the future of space exploration. To that end, while the thesis conforms to and considers the effects of physics and current and developing materials and construction techniques, it was not intended to conclude with an immediately actionable design.

8. Bannova and Bell, "Space Architecture Education as a Part of Aerospace Engineering Curriculum."
9. Balint and Pangaro, "Design Space for Space Design: Dialogues through Boundary Objects at the Intersections of Art, Design, Science, and Engineering."
10. *Design Research*, 12.

RESEARCH AND DESIGN METHODOLOGY



DOCUMENT STRUCTURE

Context Analysis
The context analysis encompasses both physical and cultural elements that affect the way that we design in outer space. It establishes the interaction between SF and the space industry as well as the potential future infrastructure of outer space in which the reserach operates.

Program Analysis
This chapter introduces the program choice for the ship in depth. It establishes the role of the ship within the guidelines for maintaining the physical and mental health of the crew and others aboard.

Theory Review
This review establishes a theoretical approach for applying the connections between architecture and SF. It investigates this relationship by looking at SF as both a social construct and as a design approach.

Project review
Architecture, space architecture, and SF examples are analysed for two reasons; to examine the conclusions drawn from the theory review and to find design solutions to unanswered questions raised in the program chapter.

Sketch Design
This design phase develops a set of design investigations using popular SF examples. These are used to explore the conclusions of the program, theory, and project reviews.

Design Development
The developed design phase critically reflects on the previous designs and forms a design conclusion.

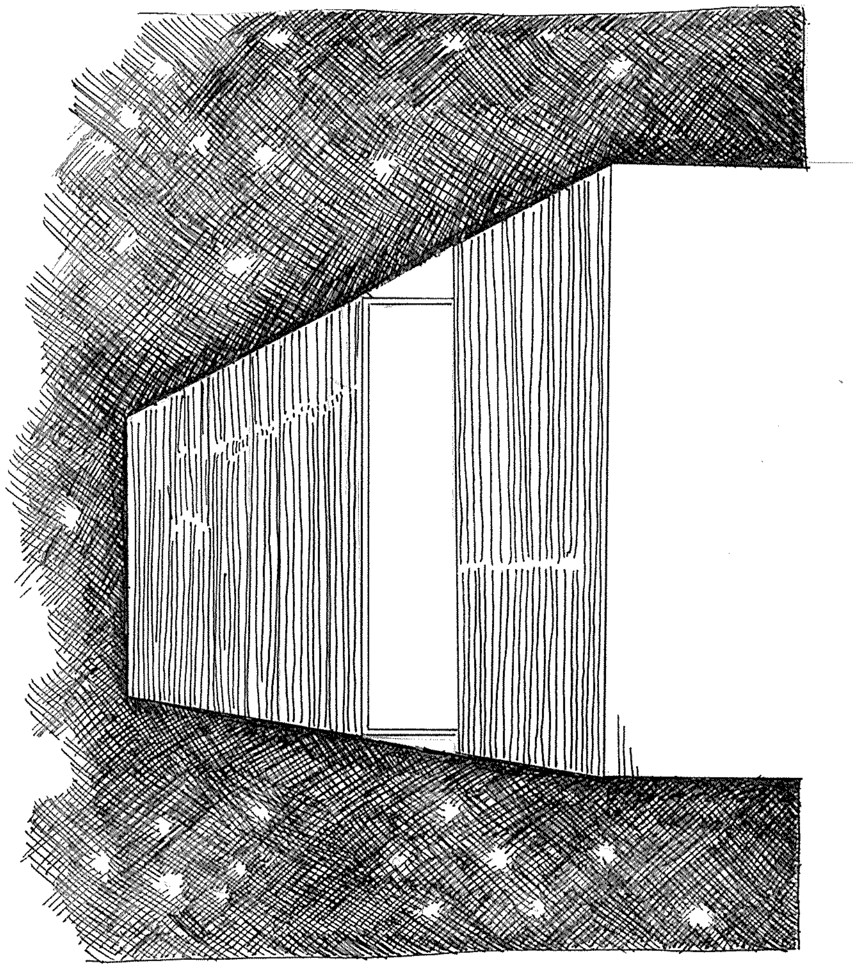


Figure.4 *Concept sketch - modern spaces in outer space*

CHAPTER 2: **CONTEXT REVIEW**

This architecture project is a space ship which moves between Earth and Mars. This journey is empty with the exception of a few scattered molecules. Without a homogeneous, man-made environment it is uninhabitable. As a result of the conditions, space habitats are classed as both Isolated and Confined Environments (ICEs) and Extreme and Unusual Environments (EUEs). Designing for outer space has often pushed the boundaries of what engineering can accomplish and how architecture can react.

This chapter's purpose is to define how the relationship between physical and social aspects of this uninhabitable site affect the research. It demonstrates how the extremes of the *physical* site establishes a greater need for developing a strong cultural connection.

The chapter begins with an explanation of the physical restraints of space architecture. It demonstrates how these effects stretch beyond the physical limitations to also play a role in how people envisage HSF and space exploration and how SF is understood as having an integral role in the creation of space architecture.

GETTING THERE IS THE HARD PART

Outer space is genrally considered to be just 100km away - not quite as far from central Wellington to Palmerston North. However, the rockets that take objects to space compete with Earth's gravity and the resistance of the atmosphere, severely limiting the weight and size of any objects launched.[1] During the Space Shuttle era, NASA estimated a cost of $450 million USD per mission to the ISS.[2] But living in space is far from the billionaire lifestyle.

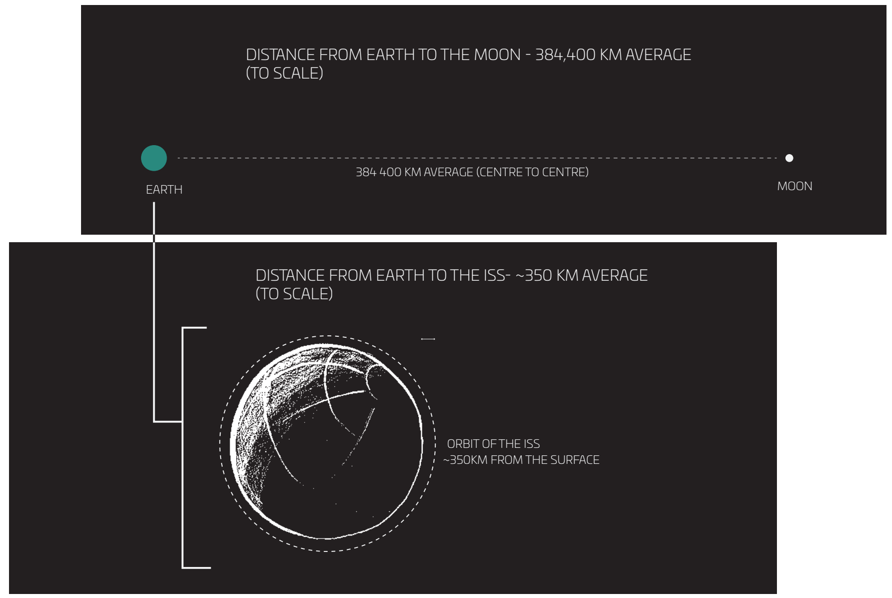


Figure.5 *The distance of the ISS to Earth, compared to the distance form Earth to the Moon*

1. Science Learning Hub, "Rocket Lab."
2. European Space Agency, "International Space Station: How Much Does It Cost?"

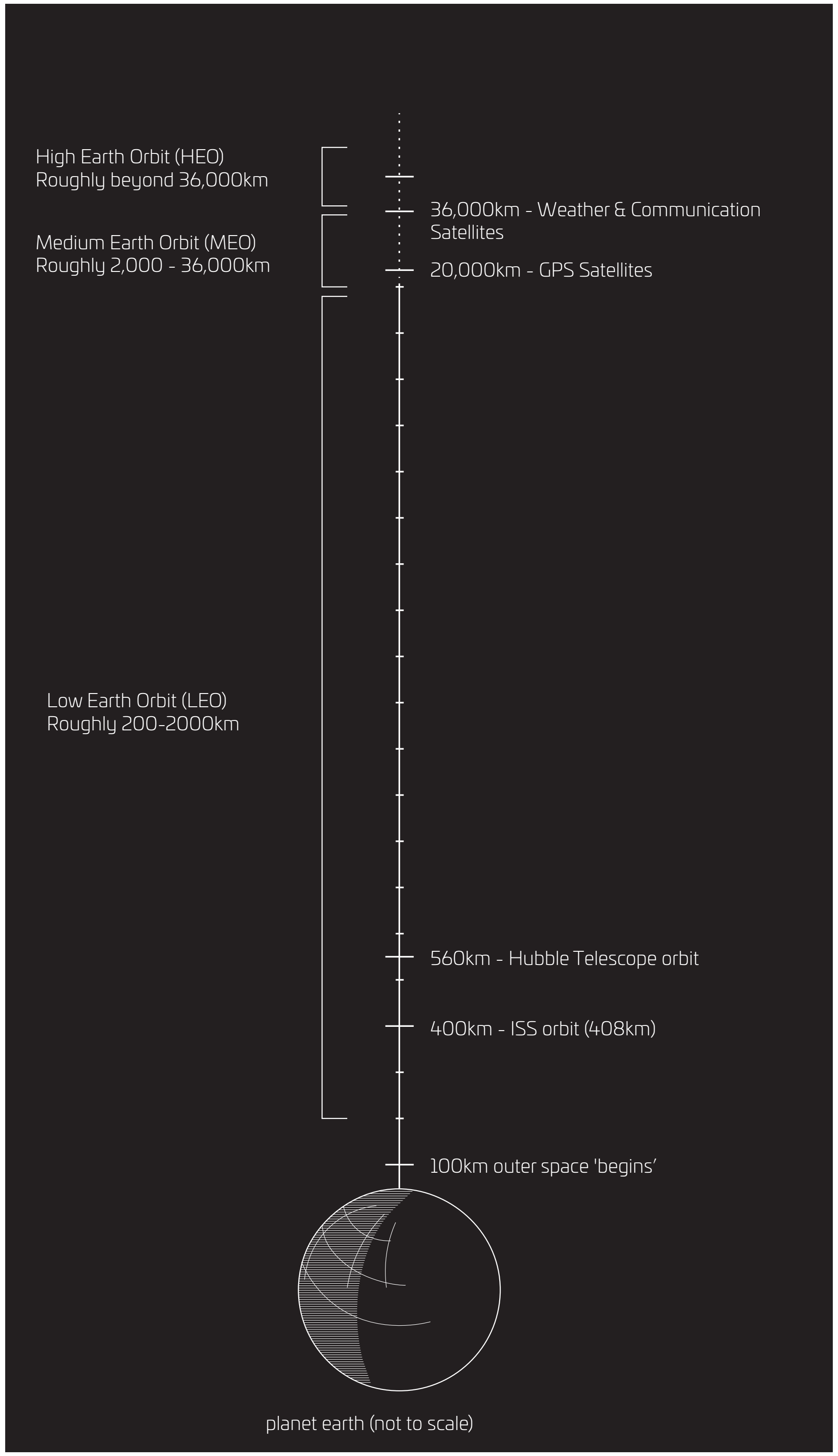


Figure.6 *Distance from Earth to commonly discussed destinations*

AND LIVING THERE ISN'T MUCH EASIER

Living in space means forgoing (generally) a normal day-night cycle, personal space, and fresh food. It also means manoeuvring without gravity. As a result of the living conditions astronauts frequently experience serious negative physical and psychological side effects including deteriorated eyesight, loss of muscle and bone density, social isolation, and a constant sense of danger.[3] Implosions and high radiation dosages are daily risks. Water and air must be continually and completely recycled. And, unless kept in control, germs could spread like wildfire. Additionally, and significantly, there are also no hot showers (or cold ones for that matter).

On the other side of the equation, there are several benefits to HSF. Often quoted (but most controversial) is the satiating human curiosity, and conquering the 'final frontier'.[4] Other benefits include signs of extra-terrestrial life, new homes in case of disaster, and the origin of the universe.[5] Many benefits directly assist life on Earth. Space mining could provide valuable materials and technologies developed for spaceflight can be integrated into everyday life. There are many benifits of space technology, from new materials and medicine, to the seemingly mundane such as the ability to package kimchi to be sold worldwide.[6]

On a personal level, those who have left Earth often report an increased sense of unity with mankind.[7] Peter Suedfeld has published a large amount of research on 'Salutogenesis' – the concept of "health-promoting, growth-enhancing effects of a challenging situation"[8] – in those who have lived in outer space.

3. Harrison, "Humanizing Outer Space: Architecture, Habitability, and Behavioral Health."
4. Launius, "Underlying Assumptions of Human Spaceflight in the United States."
5. Saletta and Orrman-Rossiter, "Can Space Mining Benifit All of Humanity?"; Crawford, "The Long-Term Scientific Benefits of a Space Economy"; Robinson and Costello, *International Space Station: Benefits for Humanity.*
6. Sang-Hun, "Kimchi Goes to Space, along with First Korean Astronaut."
7. Kanas, *Humans in Spac*e, 61–62; Ritsher, Ihle, and Kanas, "Positive Psychological Effects of Space Missions."
8. Kanas, 62.

IMAGE REDACTED

Figure.7 *NASA. 'Earth Rising over the Moon's Horizon' Apollo 11 mission 1969*

Suedfeld notes substantial and long lasting positive changes in astronauts, which (just as the bad) would likely compound over voyages of long duration.[9] A 2005 paper found the same results no matter how much time participants spend in space.[10] It is clear that living in outer space has profound positive and negative effects that can last a lifetime.

9. Suedfeld et al., "Personal Growth Following Long-Duration Spaceflight," 123; Suedfeld and Weiszbeck, "The Impact of Outer Space on Inner Space."
10. Ritsher, Ihle, and Kanas, "Positive Psychological Effects of Space Missions."

2.1. WHAT IS SPACE ARCHITECTURE?

The profession of space architecture is genrally concidered to have been 'incidentally' born with Skylab in 1973. Architect Maynard Dalton and Industrial Designer Raymond Lowy worked with NASA on their first space station, convincing them to include a window for the astronauts.[11] It could be argued that architectural principles were integrated on Russian space stations before - but seemingly not by an architect.

A 2002 symposium dubbed space architecture "the theory and practice of designing and building inhabited environments in outer space."[12] It is a "generalization of terrestrial architecture" that requires a redefining of how we relate to our planet and outer space. Wong argued in 2003 that "there is no other discipline would have a better capacity to solve these [issues] than architects would", with similar sentiments echoed in 'Space architecture education as a part of aerospace engineering curriculum'.[13] Looking forward, it appears as though space architecture is "on the brink of a new era"[14] with universities teaching space architecture, a space architecture symposium, and several journals dedicated to or featuring architecture in outer space.[15]

11. Wong, "Space Architecture - An Overview and Its Relationship with General Architecture Profession"; Howe and Sherwood, *Out of This World*.
12. Osburg, Adams, and Sherwood, "A Mission Statement for Space Architecture."
13. Wong, "Space Architecture - An Overview and Its Relationship with General Architecture Profession.", Bannova and Bell, "Space Architecture Education as a Part of Aerospace Engineering Curriculum"; Leach, "Terrestrial Space Architecture."
14. Sherwood, "Decadal Opportunities for Space Architects," 601.
15. Bannova and Bell

CURRENT DESIGN PRACTICES

Most contemporary papers discussing human-centered deisgn for space demonstrate a strong need for analogue models - "a fully integrated set of activities in support of, and/or simulating future exploration missions."[16] Through the utilization of physical and psychological parallels, psychologists, architects, and others with an interest in ICEs and EUEs can test and examine evidence without the show-stopping expense of actually getting into outer space.[17]

However, Suedfeld (from the studies on Salutogenesis) cautions that it is a 'highly questionable conclusion' that because a space is physically similar it will be useful as a research or design precedent. Even between bases in the Antarctic there are tremendous differences in conditions such as weather, stimuli, crew size, command structure, and even sunlight hours.

So, while the analogous habitats provide indispensable background research and affordable testing grounds, they are not a perfect solution to space design on their own. The unknowns of clientele, resources, and program of the future of space architecture make this especially true.

16. WIlliamson, Hipkin, and Berinstan "Exploration Architecture Validation Through Analog Missions."
17. Suedfeld et al., "Psychosocial Aspects of Spaceflight and Aging"; Suedfeld, "Antarctica and Space as Psychosocial Analogues."

NEW DEVELOPMENTS

In response to these difficulties, within the last couple of decades several research and design papers have emerged showcasing innovation in the way that designers design for outer space.

A paper co-authored by Irene Schacht featured a musical instrument (called 'cosmical seeds) that could be used in weightless environments, and which "may help to develop interest about space and science, and... to imagine a better future to live, play and work in space." They hint at the possibility of unforeseen results that come from space being so little explored, stating simply that because there is so little knowledge about artistic practice in space 'there were differences between assumption and results ... beyond our expectations'.[18]

18. Ono et al., "Innovative Musical Instruments Designed for Microgravity: Cosmical Seeds."

Cohen, Flynn and Matossian's Water Walls concept also recongises the disconnect between what habitats we design now, and the actual future of space travel. Their innovation allows a future where "design can happen differently."[19] This technology allows space architects to move beyond the paradigm of "designing" habitats and crew cabins by being forced to retrofit arbitrarily designed "primary structure" in the form of pressure vessels (e.g. propellant tanks, or ISS-type four-standoff modules scaled to fit the Shuttle cargo bay). Instead, Water Walls gives NASA and commercial space exploration companies alike the first opportunity to conceive, design, engineer, and build a truly integrated human spacecraft that considers supporting all the human requirements as a first priority instead of as an afterthought.

19. Cohen, Flynn, and Matossian, "Water Walls Architecture."

2.2. A HISTORY SPACE FLIGHT AND SCIENCE FICTION

SF has for a long time been the way that humans experience outer space - contributing "significantly to public perceptions of space travel,"[20] and even directly influencing the designs of NASA, as Penly explores in *NASA/Trek*.[21] As a forenote, this version of history is a particularly western view of SF and HSF.

So deeply intertwined, space architecture begins with the same roots as SF. Since 'ancient times' various cultures had myths and legends of outer space.[22] Yet, the first mention of space architecture as we might know it is considered to be Edward Hale's 1869 novel *Brick Moon* where a sphere made of brick was launched into outer space – with 37 workers accidentally aboard. After 2 years living on their own 3-acre planet they had made new lives and communicated with Earth via jumping up and down (in unison) in Morse code.[23]

In the latter half of the century Konstantin Tsiolkovsky, a soviet scientist, developed theories that made him a 'pioneer' of astronautics.[24] Tsiolkovsky himself was inspired often by Jules Verne (considered by many to be one of the first and best SF authors). He may have discredited Verne's methods of spaceflight, but he used that creativity to propose new methods. Tsiolkovsky is credited with developing some of the most important ideas in the field today including the metal spacecraft, aspects of solar power, and even artificial gravity.

20. Launius, "Underlying Assumptions of Human Spaceflight in the United States."
21. Penley, *NASA/TREK*.
22. Johnson, *Space Settlements: A Design Study;* Canavan and Link, "Introduction."
23. Hale, *The Brick Moon*.
24. Johnson, *Space Settlements: A Design Study*, 5.

And just as SF inspires technology, Tsiolkovsky inspired SF creators for years to come. Arthur C. Clarke is often credited with popularising a more 'hard' version of SF (those based on hard science). The novel and film '2001: A Space Odyssey' now has a cult following and depicts various forms of space architecture intended to be more 'true to life'. Today, SF ships have often been analysed as characters in their own rights - and not just those with AI.

SF stories often carry significant elements of heroism and exploration, just as stories of real-life space exploration does. These elements are quite clearly linked to the difficulty reaching and surviving in outer space.[25] As a result (and vice versa), they often carry significant themes of nationalism or anti-nationalistic sentiments depending on the writer and political climate.[26] To many, such as Philip Wylie, this ability to influence the public and human creation is one of the great powers and great dangers of SF.[27]

25. Launius, "Underlying Assumptions of Human Spaceflight in the United States."
26. Canavan and Link, "Introduction."
27. Seed, "Introduction," 2.

MOMENT OF NOTE
HUMAN SPACEFLIGHT
SF
HSF SPECULATIVE PROJECTS

1800s

1865 - JULES VERNE ***FROM THE EARTH TO THE MOON***

1869 BRICK MOON - EDWARD HALE
THE FIRST SF FEATURING A SPACE STATION

IMAGE REDACTED

Figure.8 *An artist's impression of Hale's Brick Moon*

1898 - H G WELLS *THE WAR OF THE WORLDS*

1900s

1901 - H G WELLS 'THE FIRST MEN IN THE MOON'

20s

1929 - BERNAL SPHERE

1929 - THE PROBLEM OF SPACE TRAVEL
HERMANN NOORDUNG (HERMAN POTOCNIK)

IMAGE REDACTED

Figure.9 *Two sections demonstrating artificial gravity in 'The Problem of Space Travel'*

30s

1930 - ASTOUNDING SCIENCE FICTION MAGAZINE

40s

1949 - CAPTAIN VIDEO AND HIS VIDEO RANGERS

50s

1950S - LANGLEY HEXAGON STATION

1952 - ARTHUR C CLARKE
ISLANDS IN THE SKY

1952 - WERNER VON BRAUN'S ROTATING STATION

IMAGE REDACTED

Figure.10 *Werner Von Braun's Rotating Space Station*

1950 - SPACE RACE BEGINS

1957 - FISRT LIVING PASSENGER, LAIKA THE DOG , LAUNCHED INTO SPACE

1957 - SPUTNIK 1 (FIRST ARTIFICIAL SATELLITE)

60s

1961 - FIRST MAN IN SPACE

1963 - FIRST WOMAN IN SPACE

APOLLO 11 - TO THE MOON

IMAGE REDACTED

Figure.11 *Apollo 11 Command Module*

1966 - LUNA 9 FIRST UNMANNED SOFT LANDING ON THE MOON

1965 - THUNDERBIRDS

1966 - STAR TREK: THE ORIGINAL SERIES

1969 - 2001: A SPACE ODYSSEY

MOMENT OF NOTE

HUMAN SPACEFLIGHT

SF

HSF SPECULATIVE PROJECTS

70s

1971 - SALYUT 1 (WORLD'S FIRST SPACE STATION)

1973 - SKYLAB (AMERICAS FIRST SPACE STATION)

IMAGE REDACTED

Figure.12 *Skylab*

1975 - STANFORD TORUS (NASA SPACE SETTLEMENTS)

1976 - O'NEILL CYLINDER

IMAGE REDACTED

Figure.13 *An artist's impression of an O'Neill Cylinder*

1977 - ORIGINAL STAR WARS FILM

1978 - ORIGINAL BATTLESTAR GALACTICA

1979 - ALIEN (FILM)

80s

CYBERPUNK GENRE BECOMES SOLIDIFIED IN POP CULTURE

1981 - FIRST SPACE SHUTTLE LAUNCH

IMAGE REDACTED

Figure.14 *Launch of the first successful Space Shuttle*

1966 - STAR TREK: THE NEXT GENERATION

90s

1990 - HUBBLE SPACE TELESCOPE LAUNCHED

1998 - ISS FIRST COMPONENT LAUNCHED

2000s

2000 - ISS READY FOR INHABITANTS

IMAGE REDACTED

Figure.15 *A young ISS - 3 modules old*

2014 - INTERSTELLAR (FILM)

2014 - ELYSIUM (FILM)

2016 -NEW ZEALAND SPACE AGENCY ESTABLISHED

2016 - AUCKLAND UNIVERSITY LAUNCHED 'AUCKLAND PROGRAM FOR SPACE SYSTEMS' (NON HSF)

FUTURE

2022 - LUNAR GATEWAY FIRST LAUNCH

IMAGE REDACTED

Figure.16 *An impression of Gateway and a Orion III shuttle*

2022 - SPACEX - FIRST CARGO MISSION TO MARS

2023 - SPACEX - STARSHIP FIRST PRIVATE PASSENGER TO THE MOON

2024 - BLUE ORIGIN - BLUE MOON

2.3. THE FUTURE OF SPACE INFRASTRUCTURE

'Space infrastructure' (an assemblage of various elements to do with space travel) is a viable, long term solution to decreasing cost and increasing accessibility to outer space. It is widely recognised as a necessity for a future where HSF is a regular activity. To some this looks like a lunar base and mining facilities and to others it is extensive space tourism and planetary colonies.[28]

Most agree that a resilient future of outer space is international.[29] The price of the endeavour requires multinational effort to lower costs. Currently the space industry consists primarily of individual space industries, the ISS, and a handful of commercial enterprises working with NASA to innovate and invigorate the industry. Yet, while space exploration is 'one of the best investments for the future of Mankind' the size and scale of it is 'not yet fully understood, by the public at large as well by the political circles, in terms of its implications and future prospects.'[30]

Brent Sherwood's 'Comparing Future Options for Human Space Flight' consolidates the main 'alternative value propositions' (options other than heroic exploration narratives) for a space industry.[31] Those options are 'Explore Mars', 'Accelerate Space Passenger Travel', 'Enable Space Solar Power For Earth', and 'Settle the Moon'. Surprisingly, he does not include asteroid mining, which is another strong contender.[32]

28.. Launius, "Space Stations for the United States: An Idea Whose Time Has Come—and Gone?"

29. Sherwood, "Decadal Opportunities for Space Architects."

30. Reibaldi and Grimard, "Non-Governmental Organizations Importance and Future Role in Space Exploration."

31. Sherwood, "Comparing Future Options for Human Space Flight," 347.

32. Crawford, "The Long-Term Scientific Benefits of a Space Economy."

The following is an excerpt from Sherwood's 'Decadal opportunities for space architects' which describes the likely shift of the industry;

> *'the space architecture 'frontier' can be mapped in time. Today the primary space architecture needs are immediately physical for small, professional crews. The 2020s sees this same set of challenges expand to passengers. Crew psychology does not evolve significantly because even multi-week trips into cis-lunar space are filled with task-directed activity. By the 2030s passenger psychology begins to shift away from sheer adventure and towards richer accommodation, crew psychology begins to reflect the reality of staff hired for partial-year tours of duty, and the number of simultaneous tourists introduces sociological considerations."*

An ideal and robust infrastructure in outer space will include elements of; mining and commercial enterprise, tourism, regular transport, space stations and hotels, and possibly the colonization of another planet. While the next decade will bring new innovation, it is at the point of passenger psychology that artistic practice will truly begin to flourish.

To got to this point necessities include; constructing in situ and with extra-terrestrial materials, a space tourism and science economy, and performing stable functions (including testing, docking, refuelling, and storage) in Earth's orbit or further afield.[33] Without this context, space architecture is unlikely to change significantly.

33. Naser, "Space-Native Construction Materials for Earth-Independent and Sustainable Infrastructure"; Sherwood, "Decadal Opportunities for Space Architects."

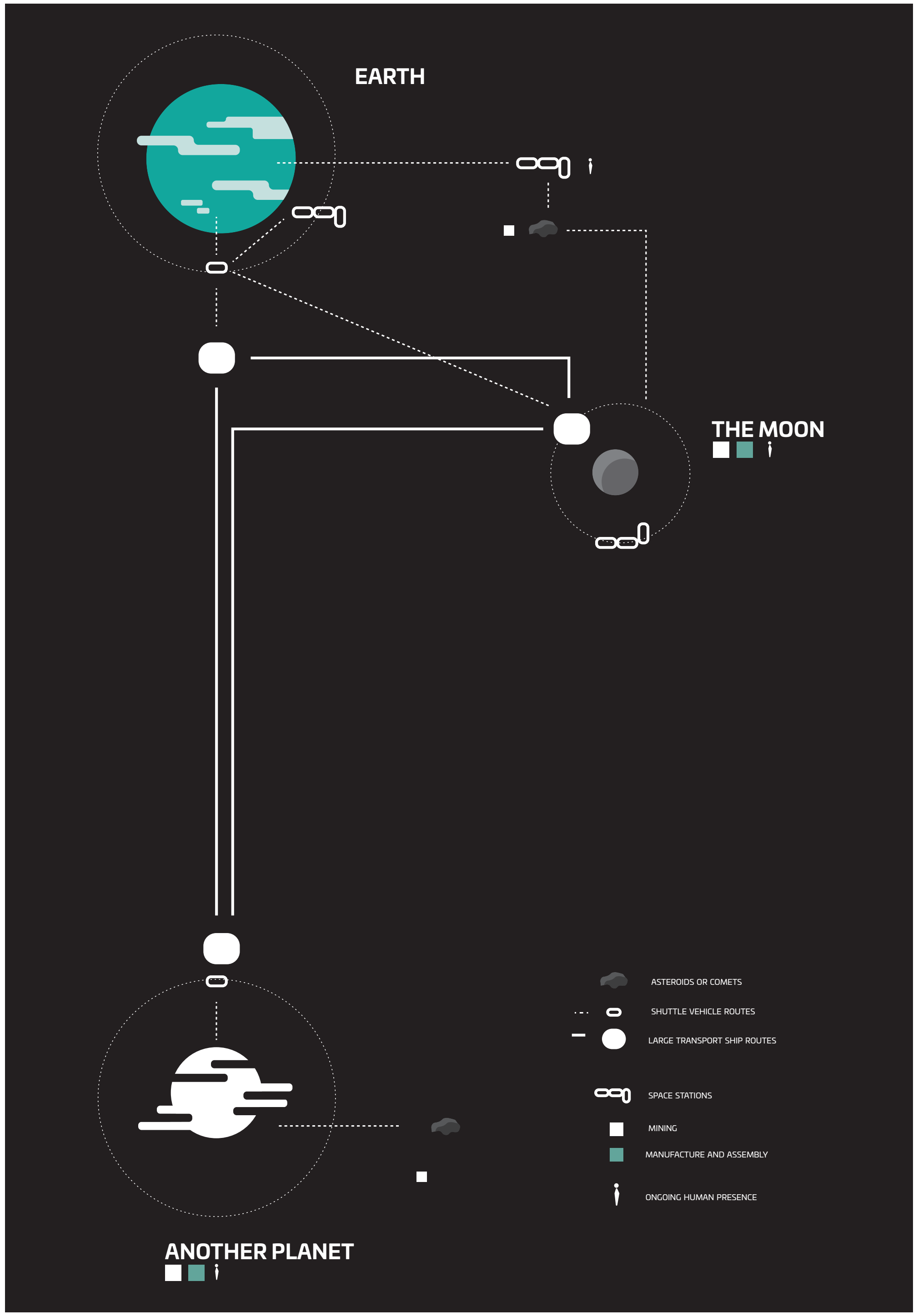


Figure.17 *Breakdown of a possible space infrastructure - including routes and likely activities*

CONCLUSIONS

The 'site' of outer space likely includes a complex assemblage of SF (collective imagination), a physical site, and a space infrastructure for which the outcome is still to be determined.

SF is part culture, part history. Acknowledging the past as a part of the context of outer space means acknowledging the narrative and wonder of SF. It also means understanding that images of the future play a leading role in our perception of what could be.

A form of infrastructure is necessary for space architecture to continue to progress and grow. Looking to the future also means creating architecture that acknowledges the shift in inhabitants from the professional and well trained to a much wider demographic.

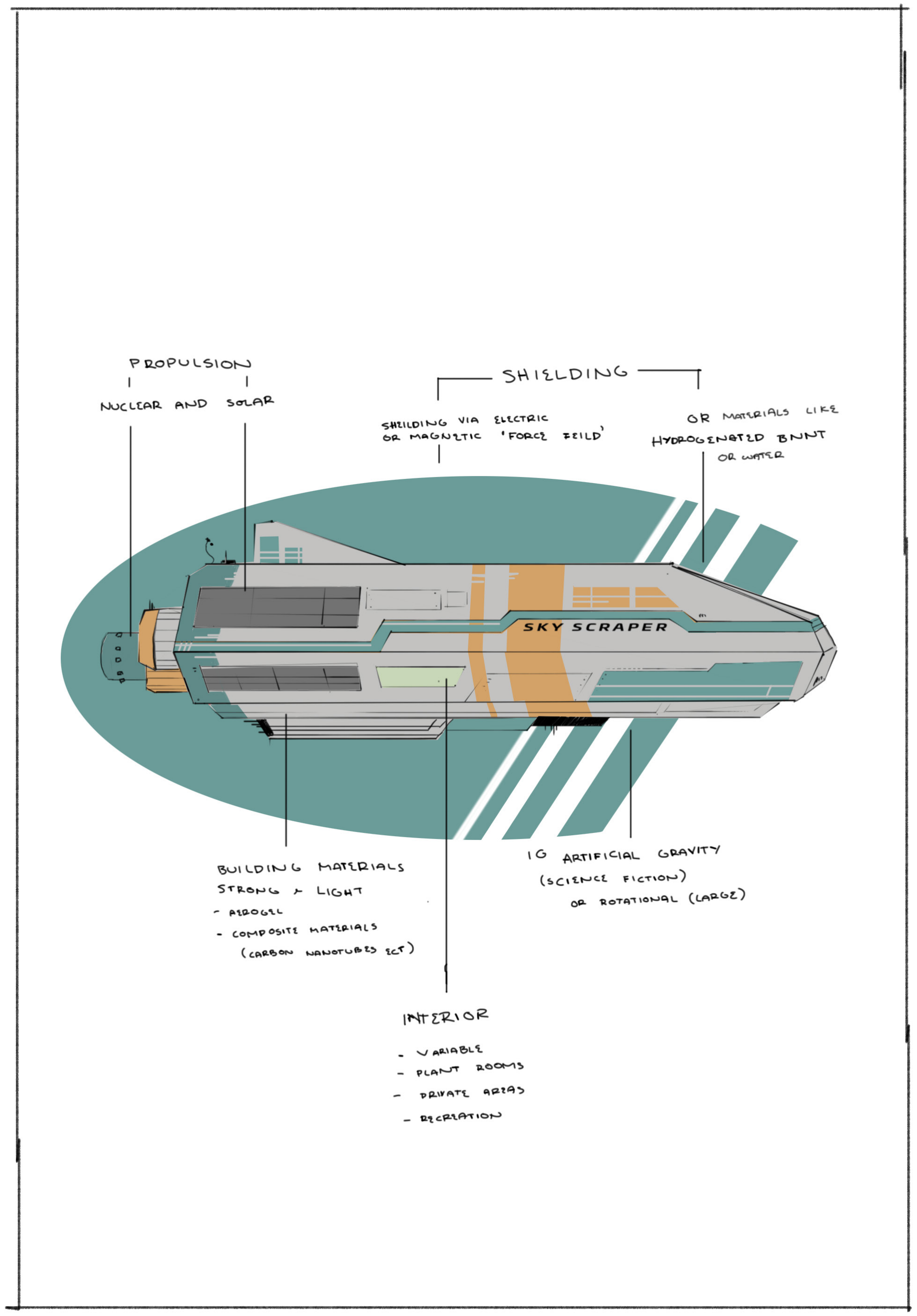


Figure.18 *Personal concept sketch - What does a 'perfect' star ship need?*

CHAPTER 3: **PROGRAM ANALYSIS**

This chapter aims to define a suitable program for the space vessel with emphasis on architectural requirements for maintaining the physical and mental health of those aboard. The program is a critical element of this research as it must respond to the possibility of future HSF and SF influences, while balancing practical requirements such as construction, safety, and feasibility.

The program developed by engaging an initial program (a scientific transport vessel to Mars) and re-working it while exploring key notes found in the context analysis and utilising key case studies. While only the final development of the program is discussed in depth here, the changes are visible in the design development stages.

The transport vessel between Earth and Mars was initially chosen because;

- the trip duration (up to 700 days) enabled a design that explores each of the habitability issues. As Denise Scott Brown commented on her book Learning From Las Vegas, as scientists use the most extreme examples to test, so too can that strategy work for architecture.[1]
- There are many popular SF transport vessels providing a large pool of precedents,
- A transport ship to Mars has been a possible goal from NASA, and therefore has research conducted to work from.

Throughtout this capter the final program utalised case studies to build on the initial idea. It increased in size and developed into a multi-stop vehicle with both professional crew and passengers. These changes are also reflected within the design chapters following.

1. "Lessons from Las Vegas."

PROGRAM DEVELOPMENT

SCIENTIFIC TRANSPORT VEHICLE

crew of 6
small gravity component
100m^2

↓

SCIENTIFIC AND COLONY TRANSPORT VEHICLE

crew of 6
passengers (up to 100)
245m^2

↓

MULTI-STOP TRANSPORT VEHICLE

crew of 35
passengers (up to 300)
primarily gravity components
520m^2

3.1. HABITABILITY REQUIREMENTS

"[Space stations] support human life under the most extreme and isolated conditions … a space habitat needs to be as much as possible a sustainable, closed-loop, and off-grid system with autonomy from Earth." Schlacht et al., Space Analogue Survey[2]

Extra-terrestrial habitats can vary from day-long transport vehicles, to a colony on another planetary body. Yet each shares extreme and isolated characteristics. As an indication of how inhabitants perceive the "quality of life" experienced, 'habitability' is one of the five factors that NASA has found to be a major contributor to crew safety and mission success - particularly those where mission control is deemphasised (such as those further away from Earth). A high level of habitability refers to a space that is the "optimal condition for life, while a low level of habitability only allows for survival."[3]

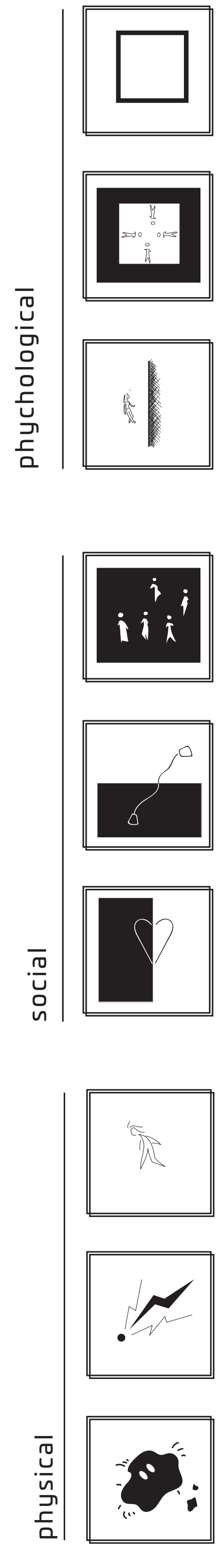
Factors that influence habitability requirements are;

- The number and nationalities of crew and passengers
- Distance to Earth and the ability to see Earth
- Personal cultures
- The length of time spent aboard

There are three major habitability topics – physical, social, and psychological – each of which contributes to the design and safety of a habitat.

2. Schlacht, "Space Analogue Survey."

3. Schlacht; Harrison, "Humanizing Outer Space: Architecture, Habitability, and Behavioral Health"; Sgobba and Schlacht, "Habitability and Habitat Design."



DULL, UNCHANGING ENVIRONMENTS

Variation is important in dull environments. People can feel lost or worse when their environment doesn't change through social interation, growth, or expansion.

CONFINED SPACES

There is no safe 'outside' in outer space. Even EVAs are perfomed within a space suit. Along with small spaces, this creates stress and unrest.

CONSTANT SENSE OF DANGER

Space is inhospitable. The dangers are often tangible, through sound, images, materials, and warning signs. This heightens the sense of danger at all times.

SMALL, ISOLATED GROUP

Social pressures are heightened in small groups, expe-cially those that are international.

MINIMAL AND DELAYED OUTSIDE CONTACT

Can cause social stress, as well as adding pressure to a crew that must maintain all aspects of the mission. There is also a lack of family, community, and culture.

TIES TO HOME AND CULTURE SEVERED

Ties to home feel severed, particulalry when there is a lack of;
Personal belongings,
Cultural/spiritual sapces,
A visual connection to Earth.

LOSS OF GRAVTIY

Gravity is important for physical health and longevity.
The effects of partial gravity are unknown.

RADIATION

Radiation is stronger in space and on Mars without the Earth's shielding. Long term exposure increaseds the risk of cancer exponentially.

HYGIENE

Zero and low gravity make keeping clean difficult, as well as often being a good environment for bugs to thrive in.

Figure.19 *Simple break-down of habitability issues in space habitats*

PHYSICAL

- **PERSONAL HYGIENE**

Hygiene upkeep becomes very different in space. Washing in space requires specialist soap, toothpaste, and limited water (which generally comes bagged)

- **GRAVITY**

Those who go without gravity for extended periods of time experience severe physiological deconditioning. The physical effects of micro or zero gravity (0G) on the human body include loss of muscle and bone density, depleted eyesight, disturbed and weakened cardiovascular rhythm and can even affect the cells.[4] We do not yet know what the effects of living in partial or low gravity are.

- **EXERCISE**

In 0G, regular resistance and cardio is necessary to maintain physical health. It is necessary to provide the space and equipment for this.

- **MEDICAL FACILITIES**

Medical facilities that are capable of surgical procedures and quarantine are necessary for vessels of long duration and large distance from Earth.

- **WASTE DISPOSAL**

The safe disposal of waste is important both on board and outside. In orbiting vessels jettisoned waste can be dangerous to other vehicles inhabiting or passing through orbit. Some germs and bugs can thrive in hermetic and zero gravity spaces.

- **RADIATION**

Without our planet's natural shielding radiation aboard a spacecraft can be considerably higher than on Earth and varies depending on location.

4. Clément, Bukley, and Paloski "Artificial gravity as a countermeasure for mitigating physiological deconditioning during long-duration space missions"; Norsk and Smith " Artificial Gravity Future Plans for ISS"

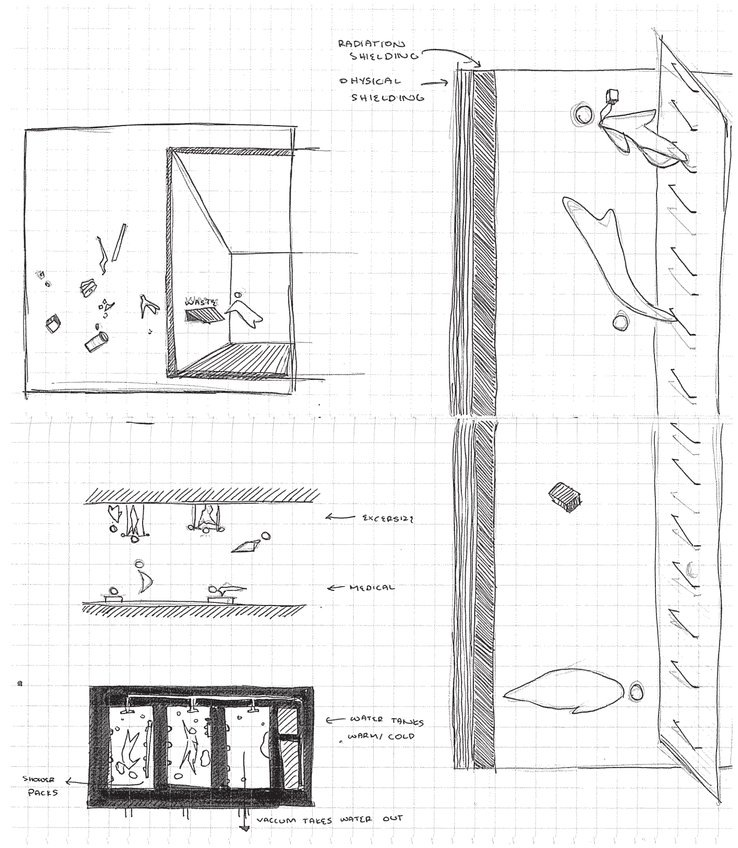


Figure.20 *Preliminary design exploration - exploring physical habitability*

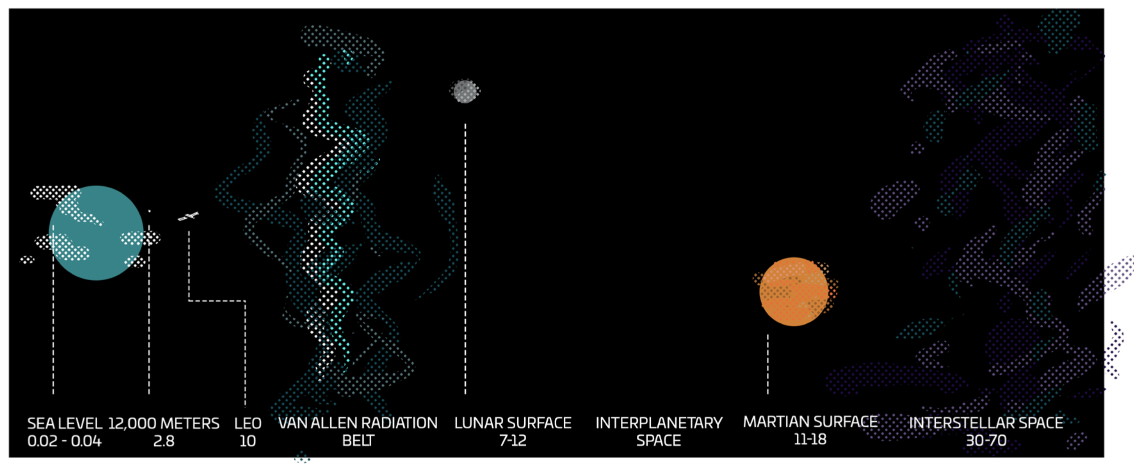


Figure.21 *Radiation levels found in outer space (in rems per year). Not to Scale. Diagram based on Eugene N Parker's ' Shielding Space Travelers'.*

PSYCHOLOGICAL

• RECREATION AND MONOTONY

Filling in leisure time with activity is important for mental wellbeing. Although contemporary missions are full of activity, monotony on long term missions has been classified "on par with technical challenges and biomedical issues such as radiation".[5]

• VARIETY AND CHANGE

Living within an isolated and sealed vessel for extended periods of time can cause a sense of confusion. Countermeasures to environmental monotony include including plants, animals, children, or a changing crew.[6] Design applications can include customisable and varied spaces and textures.

• CHOICE

Choices become limited when all of your supplies must be sent up from Earth, adding to the sense of captivity and monotony.

• LACK OF CIRCADIAN RHYTHM

Lack of regular circadian rhythm can decrease sleep and increase feelings of dissociation. Lighting can be a good solution, simulating an Earth-like rhythm and colour, while sleep training can also be useful.

• DISCONNECTION FROM EARTH, "EARTH-OUT-OF-VIEW PHENOMENON"

No human has been far enough from Earth to no longer be able to see it. However, the visual connection to Earth is singular most important aspect of having a positive emotional connection in outer space.[7] Art, plants, and features that mimic natural patterns also connect to Earth and provide calming properties.[8]

5. Peldszus et al., "The Perfect Boring Situation."
6. Peldszus et al.; Johnson, *Space Settlements: A Design Study.*
7. Ritsher, Ihle, and Kanas, "Positive Psychological Effects of Space Missions," 8.
8. Ono and Schlacht, "Space Art."

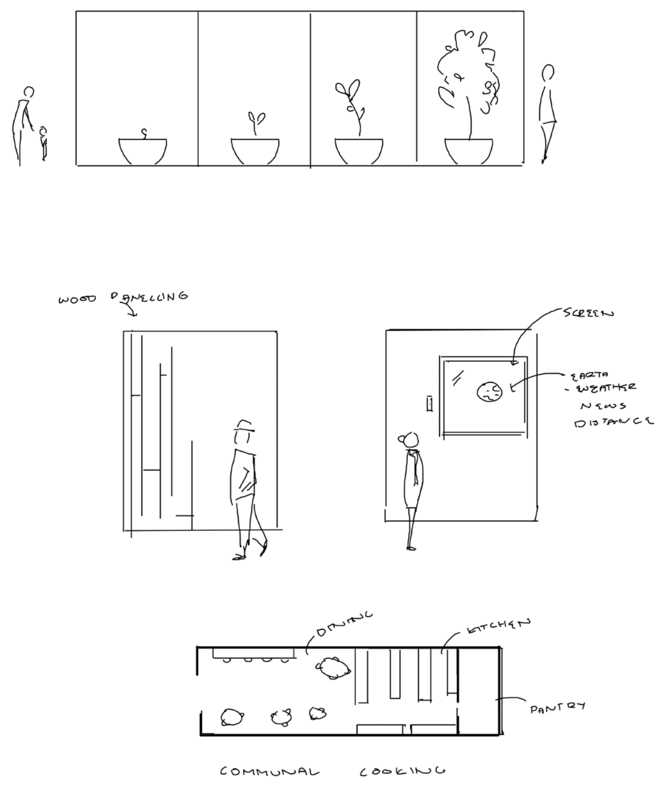


Figure.22 *Preliminary design exploration - remedying a loss of connection to earth*

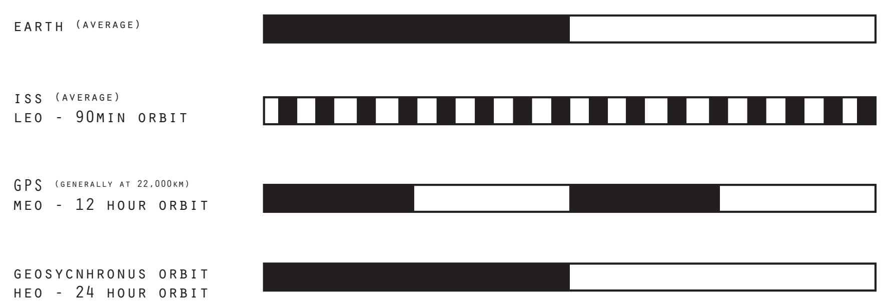


Figure.23 *Differing day/nigh cycles in different orbits*

SOCIAL

- **GROUP DIVERSITY**

While diversity can decrease monotony, extended and high pressure social situations can become stressful and strained particularly within international crews.

- **OUTSIDE COMMUNICATIONS**

Delays in communication affect the personal and professional lives of those aboard. Professionally, crews work better when given more autonomy, increasing creativity, efficiency and teamwork. However, adverse impacts occurred when unexpected delays in communication occur with Earth, as would be the case more often if sent further afield.

- **PRIVACY AND PERSONAL SPACE**

On longer journeys, the need for personal space increases.[9]

- **PLAY**

It is also anticipated that the need for recreation and play will increase significantly. Specifically designed architecture can assist with this.[10]

- **ORIENTATION**

Particularly in zero-gravity space, orientation can change between people, spaces and activities. This can cause confusion about the appropriate orientation when interacting with other people.

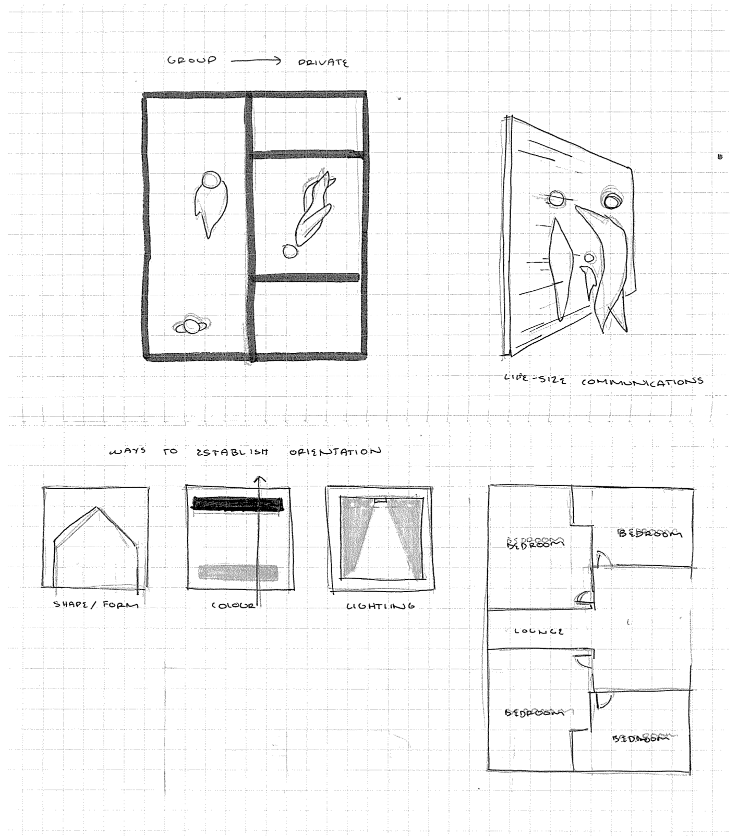


Figure.24 *Preliminary design exploration - exploring social habitability*

9. Sandal and Bye "Value diversity and crew relationships during a simulated space flight to Mars"

10. Liapi and Ackermann " Microgravity Playscapes"

3.2. GENERAL DESIGN CONSEQUENCES

"Early spacecraft had been designed to be operated and not lived in." Living and Working in Space: A History of Skylab [11]

According to Häuplik-Meusburger and Sgobba and Schlacht the key (general) design elements that create a level of habitability are;

- Usability;
- Liveability;
- And flexibility[12]

Simply stated, a space environment needs to be carefully designed with the crew's safety and happiness in mind. When they are not, the design of the space can work against the crew – even inadvertently.[13] Häuplik-Meusburger argues that "although the consideration of habitability and human factors has been integrated into the design process of human spacecraft, there is still a requirement for improving habitability.[14]

An infamous example is the pipe running along the window of the ISS, punctured as the astronauts used it as a handhold to look out. If the spacecraft was "designed from a more human-orientated view rather than a solely engineering one, the window would have been provided with means to hold on that was structurally suited for this function"[15]

11. Compton, *Living and Working in Space: A History of Skylab.*
12. Sgobba and Schlacht, "Habitability and Habitat Design"; Häuplik-Meusburger, *Architecture for Astronauts.*
13. Häuplik-Meusburger, *Architecture for Astronauts.*
14. Häuplik-Meusburger.
15. Häuplik-Meusburger.

"If something is going to stick out and make a nice handhold, it's going to be used for a handhold" (NASA [Bull.1], 1974 p.76).

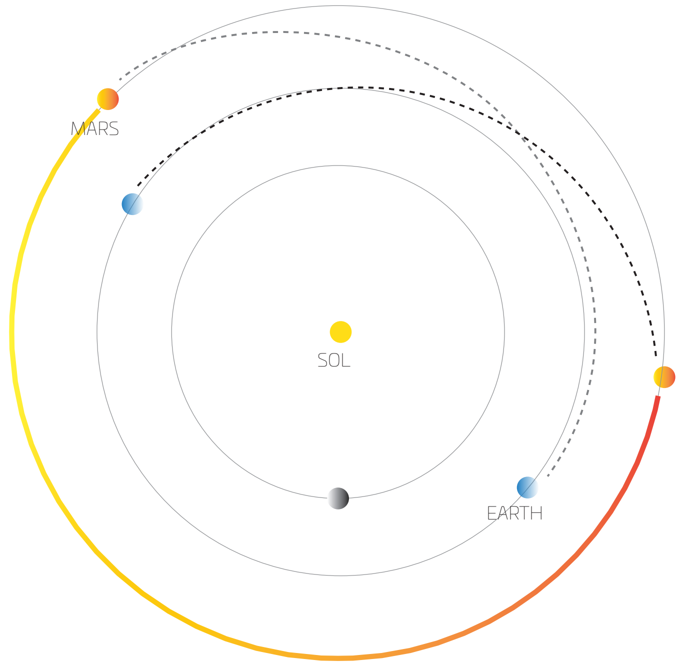
IMAGE REDACTED

Figure.25 *Illustrations made in Germany in 1925 showing journeys to the moon in the year 3000. The men pictures utilise special straps and the windowsill for gazing at the moon. - the floating chair presumably for emphasis of the zero gravity conditions, not a short-sighted idea of the designer.*

SCIENCE FICTION: LESSONS IN HABITABILITY

There are SF examples that demonstrate the dangers of low habitability. For example, certain episodes of *Star Trek: The Next Generation* (STNG). and *Voyager, (STV).* As an example, in the latter, when there isn't enough power for the food replicators the lack of choice has driven coffee-starved captains into dangerous nebulas while a lack of REM sleep drives the crew into madness, severely dangering the Enterprise D in STNG.

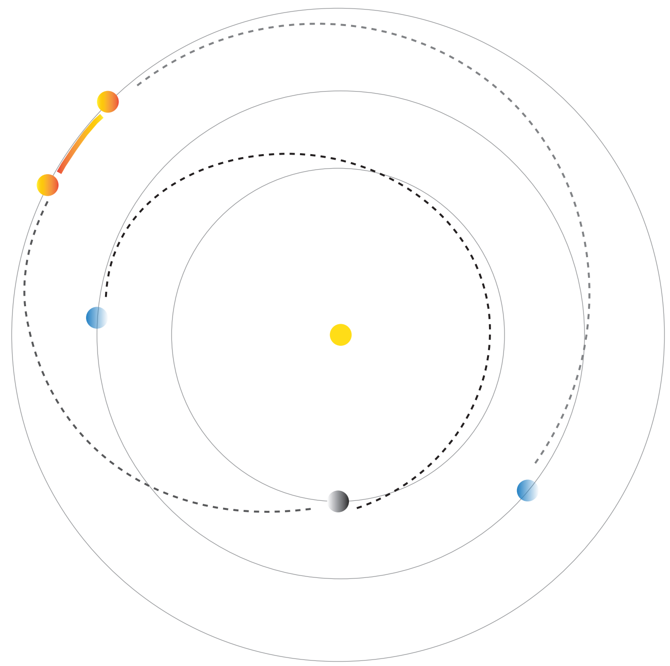
Figure.26 *(Following) Comparisons of typical long ans short stay mission architectures*



LONG-STAY MISSION

TO MARS: 210
STAY: 500
TO EARTH: 210

TOTAL TIME IN CRAFT: 520 DAYS



SHORT-STAY MISSION
WITH VENUS FLYBY

TO MARS: 217
STAY: 30
TO VENUS: 220
TO EARTH: 183

TOTAL TIME IN CRAFT: 620 DAYS

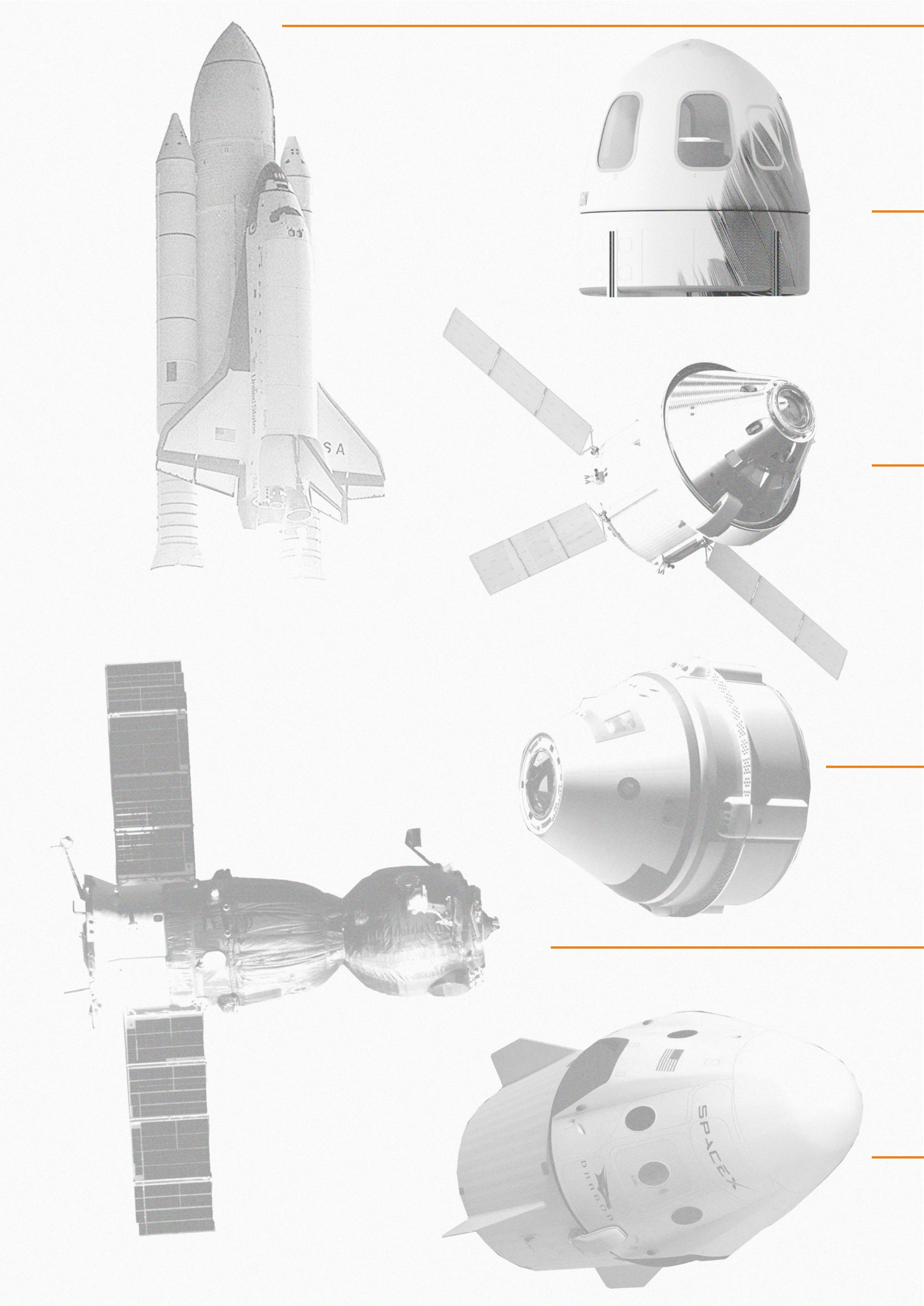


Figure.27 *An introduction to past, present and future space shuttles*

SPACE SHUTTLE | NO LONGER IN USE

CREW SIZE: MAX 8 HABITABLE VOLUME: 71.5M³
REUSABLE

BLUE ORIGIN'S NEW SHEPHERD CAPSULE | NOT YET IN USE (2020)

CREW SIZE: 6 HABITABLE VOLUME: 15M³
REUSABLE

NASA'S ORION CAPSULE | NOT YET IN USE

CREW SIZE: 6 HABITABLE VOLUME: 9M³
REUSABLE

BOEING'S STARLINER | NOT YET IN USE (2020)

CREW SIZE: 7 VOLUME: 11M³
REUSABLE

SOYUZ MS (CURRENT MODEL)

CREW SIZE: 3
HABITABLE VOLUME: 8.5M³ (4M³ IN DESCENT MODULE)
NOT REUSABLE

SPACEX'S CREW DRAGON | NOT YET IN USE (2020)

CREW SIZE: 7 PRESSURISED VOLUME: 9.3M³
REUSABLE

3.3.PROGRAM CASE STUDIES

An architecture that provides transport to Mars may not yet be a reality, but there are case studies that can inform the design. The following examples of extended stay transport were used as practical case studies of how people have historically approached designing for, and living in, transport vessels.

• THE TRANS-SIBERIAN EXPRESS TRAIN

The Trans-Siberian Express boasts one of the longest and most well-known train journeys in the world. The trip from Moscow to Vladivostok covers 9,258km and takes 7 days to traverse – even longer if you travel to Ukraine or detour through China.[16] The form of the train responds to different travel times and reasons for travel(from tourism to a commute) as well as responding to a past that imbues the trip with a sense of adventure.

While there are luxury trains, in general, those travelling on the Trans-Siberian go for the more traditional trains. Each of the carriages is equipped with toilets, staff bedrooms (who look after the guests, clean, and de-ice the trains), and constantly boiling water in a *samovar*. Although there are dining cars, guests generally bring their own dehydrated food, teabags, alcohol, and coffee, as well as sanitary items.

16. Lambert, "Everything You Need to Know about Booking a Trip on the Trans-Siberian Railway."

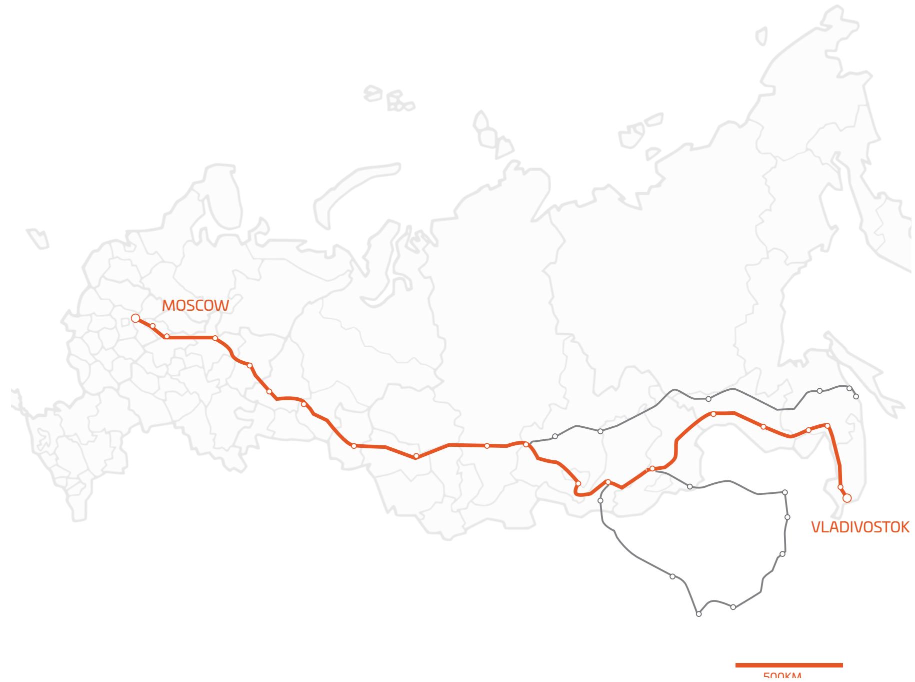
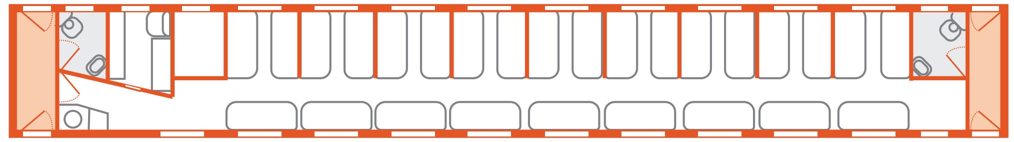


Figure.28 *The routes on the Trans-Siberian Express. The most popular is Moscow to Vladivostok, but there are also routes through China.*

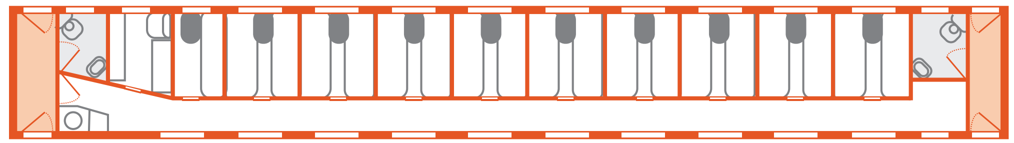
Each of the train car's classes have different cabin conditions (figure 30). The cheapest generally have upwards of 50 beds. Second class includes two bunk beds per cabin while first-class has single beds. Space is tight in all cabins, with about a metre for the walkways, and beds generally a metre and a half long.

Many use the train trips to engage with new people, opting for second class cabins where it's more peaceful, but you must still interact with strangers. Lower class cabins are generally occupied by locals and commuters. In second- and first-class cabins it is customary to use the bottom bunks as seats during the day.

LOWER CLASS | | 54 PASSENGER BEDS



MIDDLE CLASS | 36 PASSENGER BEDS



FIRST CLASS | 18 PASSENGER BEDS

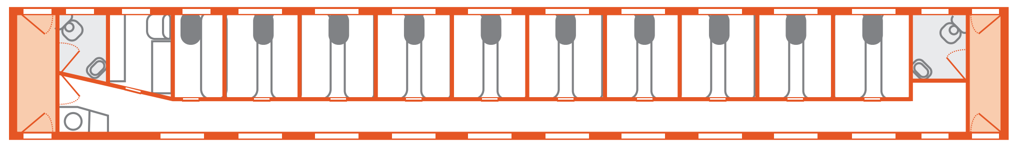


Figure.29 *Typical carriage layouts on a Trans Siberian Route. Space is crapmed and oftnen shared - all part of the experience to travelling.*

• NEW ZEALAND SETTLER SHIPS

Ships embarking from Europe to New Zealand in the 19th century took from 75 to 120 days to reach their destination, enduring the longest and harshest voyages. Some voyages saw passengers catching rats in order to survive.[17] It is noted that due to our current level of technology, like space travel, the length and harshness of this journey is now 'nearly impossible for us to conceive'.[18] The two journeys are similar in;

- Extreme social isolation
- The need for onboard staff and specialists
- A constant sense of danger
- A sense of community
- A strong sense of destination and adventure

The ships suffered from a strong class division exacerbated by the stark contrast in comfort levels and food. While the middle-class passengers often shared cabins, they could be quite busy. In a diary kept during his voyage Alfred Fell notes, "Our cabin passengers are fifteen in number… but all seem companionable, and express a willingness to do anything contributing to our mutual comfort." Lower-class passengers travelled in the steerage - a low-ceilinged space below the main deck - despite generally outnumbered the other passengers 10 to 1. Some ships were reported to have housed several people in cabins not much longer than the average person.

17. Wilson, "The Voyage Out - Journeys to New Zealand."
18. *The Immigrants*, 75.

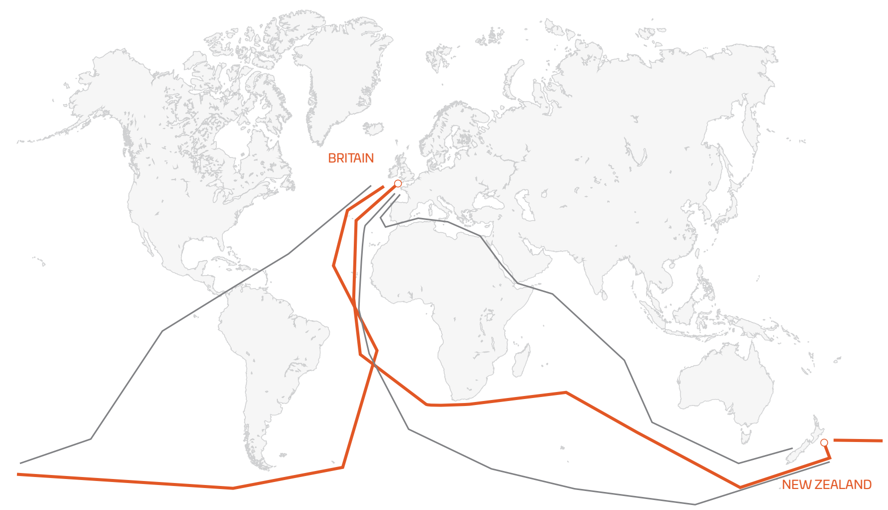


Figure.30 *This map consists of a number of routes from Britain and Europe to New Zealand - found in Alexander Turnbull Library,* Summer Ships, *and NZ history*

IMAGE REDACTED

IMAGE REDACTED

Figure.31 *(Above)*
Figure.32 *(Left)*
A comparison of deck and steerage accommodations on the Bolton and the John McVicar
(Alexander Turnbull Library)

Travellers on these ships shared the duties of looking after one another. While there was a supplied amount of food for each person (different for steerage than the higher-class passengers), other preferences such as nicer ingredients and soap and were required to be supplied. While there were regulations set by European and New Zealand governments, they were not always followed so far out at sea. Many captains were fined for putting the safety of the vessel at risk in order to shorten the long and tiresome journey, highlighting the risk of long-term voyages.

Group activities (other than keeping water out of the boat) largely consisted of church services and concerts above deck. Concerts generally brought the passengers together both as an audience as well as performers. Passengers ate in their own cabins (or in turns in steerage, as there wasn't enough space for the bunks and a table).

IMAGE REDACTED

Figure.33 *The Illustrated London News often used images to create images of the voyage and New Zealand that were in stark contrast to living conditions in London to inspire people to take the voyage. (Alexander Turnbull Library)*

IMAGE REDACTED

Figure.34 *An illustration from the Illustrated London News displaying the steerage spaces on the first immigrant ship to NZ - The Aurora. It illustrates the cramped conditions to a degree, but likely made the spaces far too large and the ceiling too tall. (Alexander Turnbull Library)*

• INTERNATIONAL SPACE STATION

The ISS is a microgravity laboratory manned full-time by a rotating international crew of six. It consists of a series of interconnected cylindrical, pressurised modules. There is plenty of research into the effectiveness of its spaces to benefit or harm its inhabitants. However, it also has no competitors with which to compare it to.

Those who stay on the ISS are vigorously trained, generally with a military or scientific background. Personal spaces intermingle with work spaces. In general, the station is acknowledged to be a visually busy space which can affect the psychological well-being of those on board.

The capability of growth and change was a fundamental objective when designing the ISS. The modularity of the space station (both the structure and the interior rack system) has allowed it to be very resilient, withstanding technological, logistical, finical, and political setbacks. Adam and Jones note that "by embracing a diligent modularity in the early 1980s, NASA initiated a design approach that has enabled replicability, flexibility and technological transparency." They predict that this sets a strong example for future space architectures, particularly those of a size that will require multiple launches.

Interestingly, the ISS's architecture was and still is heavily reliant on the restraints of Earth. Not only do the modules need to be of a size and weight that they can be launched, but the modules could not be any bigger than the roads they would need to be transported on would allow.[19]

19. Adams and Jones, "Alpha: From the International Style to the International Space Station," 74.

"The International Space Station we have today is in many ways the ultimate artefact – the embodiment, the fulfilment – of Modernist architecture." Adam and Jones, p73

IMAGE REDACTED

Figure.35 *The International Space Station photographed from the space shuttle Atlantis in 2011 (NASA)*

- **PROPULSION**

The station has its own propulsion on the Zvezda and Zarya modules. It uses these to, among other things, avoid potentially dangerous micro-meteorites. For periodic rebooting progress and resupply, unmanned vessels are often used.

- **MATERIALS**

The main materials are titanium, Kevlar, steel and aluminium. Whipple shielding is used as protection.

- **POSITIONING**

GPS systems are used to show the ISS where it is located at all times.

- **POWER GENERATION (EPS)**

The Electrical Power system is a set of solar power arrays, which also charge batteries for times when the ISS is in shadow.

- **CANADARM (MOBILE SERVICING SYSTEM)**

Robotic arm for assembly, docking, and maintenance.

- **LIFE SUPPORT SYSTEM**

The life support system is almost entirely a closed-loop system – recycling all of the air and water on board.

- **CUPOLA**

The cupola, berthed to the Earth side of the station, deserves a special mention as an important site for ship maintenance and crew leisure. Made up of 6 windows it is used to observe the station and control the robot arm. This small space (large enough to fit two crew members) is very popular for Earth gazing. The windows each have shutters on them to protect from collisions with micrometeorites.

- **THERMAL CONTROL**

The ISS utilises both active (ATCS) and passive systems (PTCS) in its thermal control system (TCS). The ATCS is a set of closed loop systems that use either air or water to cool. It also pumps heat around to be dispelled via radiators. It is generally only used when the PTCS - insulation, surface coating, heaters and heat pipes - fail.

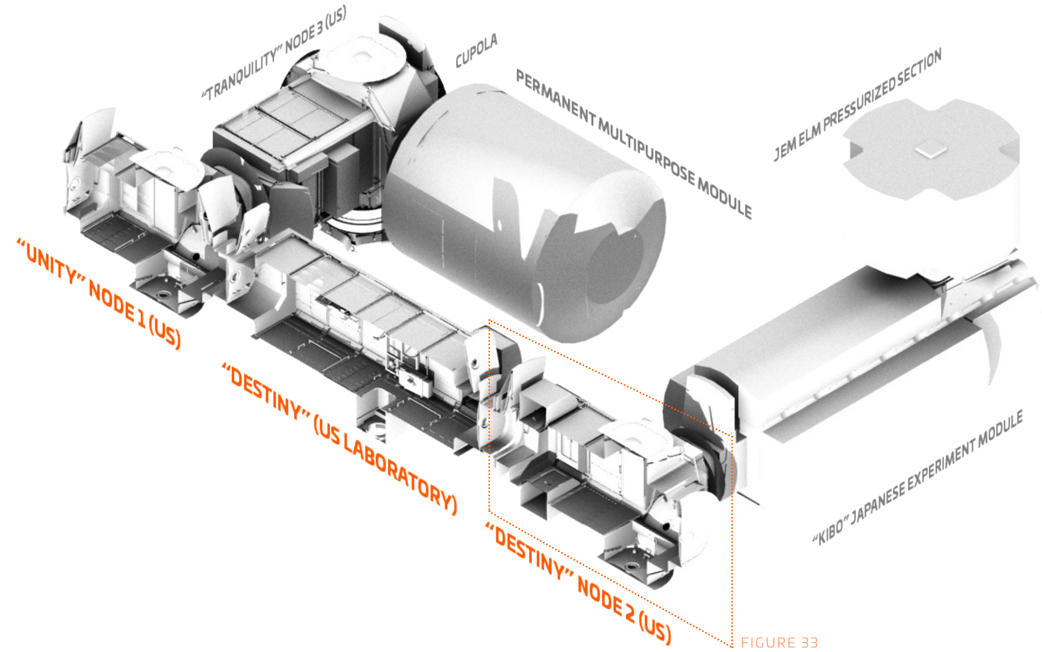


Figure.36 *A section through a portion of the ISS showcasing the position of Node 2. It is worth noting that with the Canadarm, these modules may not stay where they are currently docked. Base 3D model base courtesy of NASA.*

- PERSONAL ROOMS

The crew have their own 'sleep compartments' which also act as a personal office. These spaces are very small, less than a meter and a half wide "sort of like a little phone booth".[20] Astronauts strap themselves into sleeping bags in order to stay put as they sleep. They also include computers and personal effects that make it 'sort of like home'.

- BATHROOMS

The ISS contains multiple bathrooms, but it appears that just one is generally used. The toilets include specialised equipment to make the process easier and tidier. Water for cleaning and showering is kept in small squeezable packets.

- DISPOSAL

Much of the waste on the ISS that cannot be recycled is stored on a visiting shuttle to be returned to Earth or burned up in the atmosphere.

- EMERGENCY EVACUATION

A shuttle is kept berthed to the ISS, and it can take as little as a day to get another one up there should the crew require evacuation.

- PLANTS

Initially, greenhouses were used to test the ability for plants to be grown for food and for ventilation. However, it was found that greenhouses were also very popular, and astronauts often have their own personal versions. The technology used to grow plants in space is continually evolving.

- GRAVITY

As the station is in constant free-fall around Earth there is no tangible gravity force felt. This affects both the useable space and crew interpersonal interactions.

- PHYSICAL HEALTH

There is a range of equipment on board to monitor and assist with physical health. Exercise machines are used to maintain muscle and bone mass. Several different sets of equipment are also used to assess radiation effects, brain activity, and perception.

20. *Station Tour.*

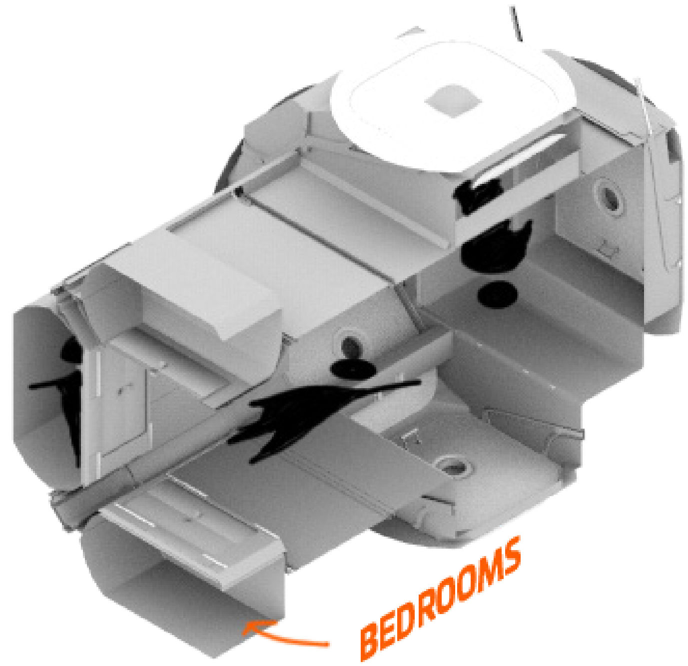


Figure.37 *A close up section of Node 2 showcasing the 'phone booth' like bedrooms. Base 3D model courtesy of NASA.*

With the cost of space infrastructure being so high, a transport vessel to Mars could house several programs in its lifetime in order to be feasible. Such a ship would take advantage of the burgeoning tourism and space mining industries by being a multiple-stop transport vessel, designed to take passengers to and from places of leisure and work. Not only does this provide stimulation for the crew, but also multiple places for refuelling, restocking, and greater stretches of time where abort manoeuvres are possible. The ship could often reach the moon and various asteroid mining settlements, and even occasionally Venus. This program relies heavily on the presumption of a bustling and varied space economy. However, it allows for a variety of design solutions to problems that are uncommon to our space habitats today. As a transport ship it would not land on any of these destinations but rather stay in orbit to receive and drop off users via shuttlecraft, as the ISS does today.

The final program, without the need for design, inherently establishes the ship in a future of HSF and decreases monotony through variation. This allowed the extremes of habitability requirements to be tested, enabling innovative design to be a large part of the solution. However, it still allows exploration in the design phase to introduce and test the interaction of architecture and SF.

While the program has largely been chosen to enable the research to investigate the future of HSF through the lens of SF, which often investigates the future, it is limited by the lack of real-life examples from which to analyse.

MOVING INTO THE DESIGN PHASE

- Work and private spaces should be adequately differentiated through program and design
- Architecture, not just engineering, should aim to make spaces feel safer.
- Supply at least one area that has gravity, preferably 1G.
- Variation in the environment should be provided, through design or other introduced factors such as plants.
- Emotional sustenance and a connection to Earth must be cultivated in order to replace the absence of a visual link to the planet.

PROJECTED PROGRAM REQUIREMENTS

TIME

UP TO 2 YEARS, ROUND

STAFF

10 GENERAL
CLEANING, SECURITY, CATERING, ADMIN ECT

15 SPECIALISTS
ENGINEERS, SCIENTISTS, MEDICAL

BEDS

25 LONG-TERM	100 SHORT TERM	100 MID-TERM / CLASS

INTERNAL PROGRAMS

SPORTS/GYM	GREENHOUSES	LABORATORIES AND OFFICES
MEDICAL	LOUNGES	DOCKING BAY
COMMUNITY SPACES	STORAGE	ADMINISTRATION
PROPULSTION / ENGINEERING	KITCHEN	CONFERENCE AND MEETING

28 ESCAPE VESSELS (8 PEOPLE EACH)

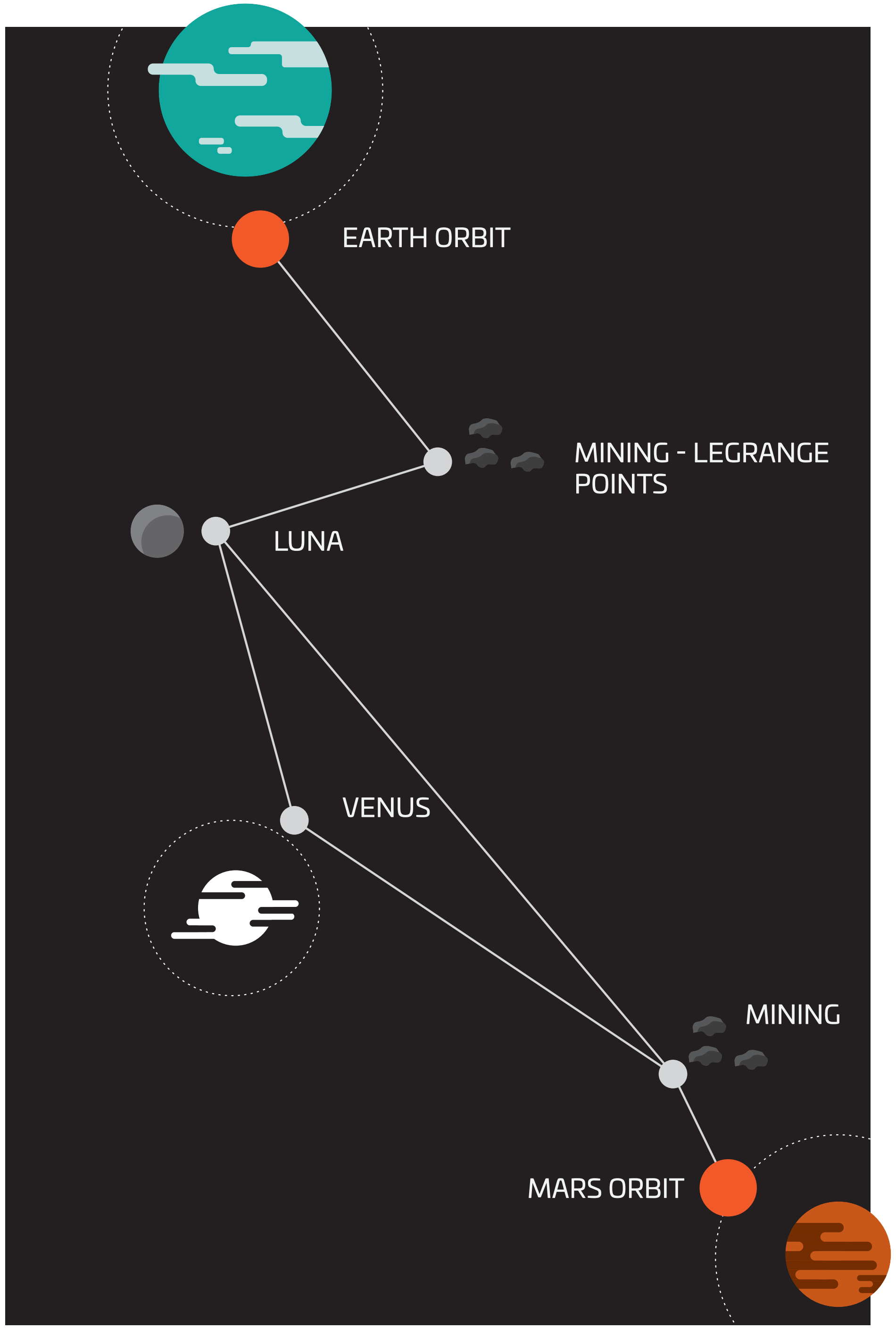


Figure.38 *The main stops on the Earth-toMars Transport. Destinations may change depending on the position of planetary bodies. Please check before booking a ticket on the Earth to Mars transport.*

S.E.ARCH VESSELS TIMETABLE | 2030 - 2032

THIS PAMPHLET IS A GUIDE ONLY. CALL US OR YOUR SPACETRAVEL AGENCY TODAY FOR INFORMATION ON TRAVEL AND CARGO AVAILABILITY.

MAJOR AND MINOR STOPS	SCHEDULE 1 DEPARTS 2030	SCHEDULE 2 DEPARTS 2030	SCHEDULE 1 DEPARTS 2031	SCHEDULE 1 DEPARTS 2031
EARTH NASA SHIPYARDS	FEBRUARY 2	MARCH 1	MARCH 20	MARCH 30
L5 ORBITAL HOTEL 0G HOSPITAL	FEBRUARY 5	MARCH 5	MARCH 25	APRIL 3
LUNA MOON MINING SCIENTIFIC BASE	FEBRUARY 8	MARCH 6	MARCH 27	APRIL 5
VENUS KEPLER SCIENTIFIC BASE	JUNE 31	-	AUGUST 2	AUJGUST 6
MARS SHUM MINING OPERATIONS (ARR. - DEPT.)	MARCH 4 2031 - APRIL 4	SEPTEMBER 18 - OCTOBER 23	DECEMBER 10 - JANUARY 2032	DECEMBER 30
VENUS KEPLER SCIENTIFIC BASE	-	FEBRUARY 20	MARCH 3	
LUNA MOON MINING SCIENTIFIC BASE	OCTOBER 25	MAY 17	JUNE 30	
L5 ORBITAL HOTEL 0G HOSPITAL	OCTOBER 28	MAY 16	JULY 1	
EARTH NASA SHIPYARDS	DECEMBER 1	MAY 22	JULY 8	

DATES INDICATIVE ONLY, DEPENDING ON SPACE WEATHER AND SOLAR ACTIVITY.

Figure.39 *A theoretical sample timetable for a Earth-Mars multi-stop transport. The information for this theoretical timetable based on NASA's* Human Exploration of Mars Design Reference Architecture 5.0, *with a fraction of SF imagination.*

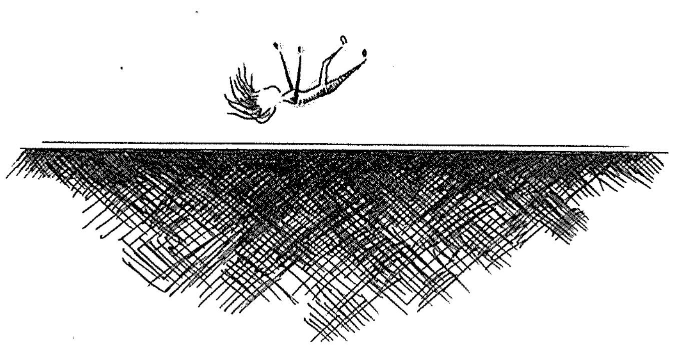


Figure.40 *Personal concept sketch - Feeling vulnerable in a tin can*

CHAPTER 4: **THEORY REVIEW**

"Design-oriented research is an act of collective imagining—a way in which we work together to bring about a future that lies slightly out of our grasp."
Dourish and Bell[1]

This review addresses the ability for SF to assist in the creation of space architecture. It determines how SF can manifest itself in the creation of architecture and more suitable space environments.

Section one evaluates the opportunities, and dangers of using SF as a design medium.

Section two establishes SF and stories as tools of creating place, while section three investigates how to analyse physical attributes of SF spaces and apply them to architecture.

1. Dourish and Bell, "'Resistance Is Futile': Reading Science Fiction alongside Ubiquitous Computing."

ON SCIENCE FICTION

"We do not know what science fiction is, but we recognize it when we see it."
Mark C. Glassy The Biology of Science Fiction Cinema

'Science fiction' can encompass a number of genres, settings, and media.[2] It is beyond the scope of this research to define SF, so it borrows from other architectural theorists. Fortin and Clear say simply that SF has the characteristics of newness, or novum first discussed by Darko Suvin.[3] Novum allows for an exploration between the known world, and the unknown possibilities, or 'speculations about the future.'[4] Because of the use of the unknown, there is a negotiation that occurs between the creator of SF and the audience, each being asked to understand the genre calls for an adjustment in how they understand and interpret each-other.[5]

2. Shippey, "Hard Reading"; Bould et al., "Introduction."
3. Fortin; Clear, "Architecture."
4. Hewitt and Graham, "Vertical Cities," 925; Suvin, "On the Poetics of the Science Fiction Genre."
5. Shippey; Canavan and Link, "Introduction."; Fortin, *Architecture and Science-Fiction Film*.

4.1. SECTION ONE: ARCHITECTURE AND THE FUTURE

"No discipline has been propelled forward more by the promise of the onward march of progress than architecture. Since the early 20th century, architects and designers have been smitten by the novel and the new."[6]

SF inherently works within a space of the unknown. As a discipline merging the two dichotomies of art and engineering, architecture only occasionally occupies the same space. This section identifies how SF and speculation may manifest within the discipline of architecture.

Reyner Banham was an open enthusiast of the use of SF as a tool for architects. His writing (published in the mid 20th century) had "an emphasis on the lasting impact of technology on the imagination of architects and designers."[7] To Banham, SF could create images that 'shaped attitudes.'[8] Fortin notes that the two disciplines have often found common ground in the and the celebration of new technologies.[9]

Around this time emerged Archigram. The Guardian once stated, "Archigram's fascination with the technology of the moment… is obvious. They loved the capsules and spacesuits that went with the Apollo moonshots, and wanted to transfer them to Earth-bound buildings."[10] But more than an interest in the (then) current technology, their work centred on how architecture and society would respond to it. They utilised fictional images of architecture to frighten, inspire, and educate - forgoing the restraints of physical architecture in order to better reflect on the possibilities of the future.

6. This comment, made by Helen Castle in Architectural Design's 2009 issue 'Architectures of the Near Future', questions if an architect's fascination with the future implies more about the future or a need to be "constantly exceeding" what we have now.

7. Aynsley and Atkinson, The Banham Lectures: *Designing the Future*.

8. Bamham, *Theory and Design in the First Machine Age*; Whitley, "Banham and 'Otherness': Reyner Banham (1922-1988) and His Quest for an Architecture."

9. Fortin, *Architecture and Science-Fiction Film*; Marriage, "Darth Vader and the Death Star."

10. Moore, "The World According to Archigram."

However, the terms 'SF' and 'utopia' are often married, creating "unrealistic" expectations of what the world could be.[11] Venturi, Scott Brown and Izenour's text *Learning From Las Vegas* is a prominent criticism of designing architecture for a world which does not yet exist. The text does not specifically address SF but an architects' main concern, they argued, should be "with what is," not what 'ought to be.' In contrast to the Modernist movement and groups like Archigram, they emphasise that a "more promising" goal for an architect is to produce meaning from what is familiar rather than an "architect's utopia".[12]

Cohen and Häuplik-Meusburger's more recent paper 'What Do We Give Up and Leave Behind?' also rejects utopian depictions of space travel. It instead utilises classical artwork to illustrate what is often forgotten – what astronauts will need to give up. Images clearly serve as an important tool to inspire and teach. However, it is also clear that some elements of SF - utopia, in particular – although effective, should be treated mindfully.

IMAGE REDACTED

Figure.41 *Archigram's 'insect like' Walking City 1964. Herron Archive*

11. Todoran, "Addendum to the Arcadian Myth: Science Fiction and Contemporary Utopian Discourse in Architecture."

12. Venturi, Scott Brown, and Izenour, *Learning from Las Vegas.*

Criticisms such as those in *Learning From Las Vegas* can easily be aimed at groups like Archigram. Their images stood out (and still do). Their "ideas were depicted as frivolous and indulgent and the fact that their plans went unbuilt were signs of delinquent cop-outs instead of conceptual trailblazing."[13] However, like images of the moon landing, their evocative presentation style and surprisingly accurate premonitions continue to inspire more than half a decade later.

Nic Clear echoes such sentiments as found in *Learning from Las Vegas*, suggesting that the believability of architectural design set in a better future is lessened by proving "incapable of suggesting what the future may hold."[14] However, he still turns to SF as an "often more believable" solution. He clearly sees a divide between the two disciplines – perhaps seeing SF as rooted firmly in the future, and architecture belonging in the here and now. However, Thomson in *Visionary Architecture* disagrees, believing architecture to exist at the corners between imagination and reality, one profession and another, stating, "human imagination contributes materially to the construct or image of reality that we hold in our minds, and hence that it is no longer possible to draw a clear distinction between imagination and reality."[15]

13. Anderson, "Archigram's Radical Architectural Legacy."
14. Clear, "Introduction: A Near Future," 6.
15. Thomsen *Visionary Architecture* 7.

4.2. SECTION TWO: SCIENCE FICTION AND THE CREATION OF PLACE

As human connection has been a central habitability concern, this section investigates theories relating to SF's ability to forge connections to tangible and intangible aspects of a site. SF has strong ties to poetics, narrative, and design fiction - characteristics also found in urban and architectural theories. In fact, the relationship between the three is "complex, but fully visible, reciprocal, and longstanding."[16]

In SF texts, a city is often used to emphasise "future urbanisation"[17] through the scale, density and forms of buildings, and "a certain control [of humanity] over nature."[18] The spaceship is similarly experienced though a manmade interface, the density of population and the tug between nature and technology. A ship or station could even even theoretically reach the size of a city. In fact, although earth-bound, Archigram's fictional cities often "suggested a nomadic way of life."[19]

16. Hewitt and Graham, "Vertical Cities," 934.
17. Bukatman, *Terminal Identity : The Virtual Subject in Postmodern Science Fiction*.
18. Lehan, The City in Literature : *An Intellectual and Cultural History*, 13.
19. Gili, "The Plug-In City."

In *The Practice of Everyday Life*, Michael de Certeau argues that the interaction between stories and histories connect people to a place, and 'makes [that place] concrete and inhabitable.'[20] That is to say that stories we tell by moving in a city and interacting with it "carry out a labor that constantly transforms places into spaces."[21] And to many, this connection is not one-sided, but reciprocal.[22] Throughout time, the city and SF have affected one another in such a way that the city 'has [now] become inseparable from our personal and national destiny.'[23]

Natalie Collie believes that this relationship will be a more powerful tool in building people's personal interest in future community planning than traditional maps or images. She also suggests that "narrative can be a powerful means of making highly abstract, difficult, idealistic, terrifying or difficult ideas and situations possible to imagine and be meaningful."[24] Three of those topics which are particularly relevant to a space habitat are;

- The alienation produced in subjects in and by built environments;
- The relationship between built environments and nature, and;
- Relations between space and time.

Again, Archigram's various cities can be called on as examples. Although they were strictly Earthbound, their use of their illustrations as a narrative device to depict difficult and far-off concepts was the most effective element of many of their projects.[25] Their images connected their audience with a site that hadn't yet even come to be.

20. Collie, "Cities of the Imagination," 424; de Certeau, *The Practice of Everyday Life*.
21. de Certeau, *The Practice of Everyday Life*, 118.
22. Kneale and Kitchin, *Lost in Space : Geographies of Science Fiction*; Hewitt and Graham, "Vertical Cities," 926.
23. Lehan, *The City in Literature : An Intellectual and Cultural History*, 3, 5.
24. Collie, "Cities of the Imagination," 426.
25. Cook et al., *Archigram*.

In outer space, the site is made more complex by being so bare and unfamiliar. Balint and Pangaro establish that art and design can also play significant roles in connecting people to their own world-views and each other.[26] By creating 'circular conversations with our environment' they believe that objects can positively support those in outer space connect to themselves and to others. 'Boundary objects' have the ability to communicate through form to a range of otherwise socially disconnected people – and create effective exchanges of information and experiences across cultures and disciplines, people who would otherwise have different 'languages' to each other.

Outer space may generally be inhospitable, has been made familiar to us by SF and narrative throughout time. Narrative and form is a tool that can connect people to places they've been as well as those they have not. It can inspire people to be engaged with the future as well as educate. And additionally, narrative and form can be used to connect groups or individuals who would otherwise struggle to communicate or form a community, strengthening a vessels inherent habitability.

26. Balint and Pangaro, "Design Space for Space Design: Dialogues through Boundary Objects at the Intersections of Art, Design, Science, and Engineering."

4.3. SECTION THREE: CHARACTERISTICS OF SCIENCE FICTION

This section develops a theoretical proposition for using SF imagery as a design tool. In this case, that means how architecture can use selected images to create spaces that have a higher chance of connecting inhabitants to the social and physical site of outer space, thus improving the living conditions.

Vivian Sobchak suggests that the "representational freedom" of a SF film city "literally 'real-ises' the imaginary."[27] It can convince people of a whole new world. In 'Space, Architecture, and SF', Salih Ceylan uses this opportunity by showing stills from movies to understand architecture's role in HSF. Contemporary SF films, he argues, can illustrate different profession's design approaches to a wide audience.[28]

Ceylan assumes that the popularity of the films implies their usefulness as examples. Caplescu, on the other hand, analyses what it is about each film's materiality that connects people to narrative. The following conclusions relate specifically to elements of the future, humanity, and the unknown which were uncovered as important to the research;

27. Sobchack, "Cities on the Edge of Time," 78.
28. Ceylan, "Space, Architecture, and Science Fiction."

- Utopian spaces make use of lighter materials like glass, and lighter colours. An abundance of vegetation and soft curves soften spaces. Dystopian futures use heavier materials and closed in spaces, with smaller windows and little or dead vegetation.
- Familiarity with the types of spaces benefits both utopian and dystopian narratives. In the former, it compliments humanities' previous developments, but in the later it creates an unnerving sense of familiarity.
- Futuristic representations from before the 1990s generally vary from those seen afterwards. The shift is from a 'black box' machine-asthetic environment, to a 'white cube' environment which is generally glossy and clean. This should be kept in mind when analysing spaces from older SF, which are still large parts of popular culture.
- A mix of styles is a technique that creates a believable and rich environment. People respond to forms that are familiar, but not an over-abundance of the same design language.

Caplescu mentions a few cities in space (in *Elysium* and *Interstellar*) but pays little attention to the difference in setting and how that affects the overall form it will need to take, such as the ring structure.

IMAGE REDACTED

Figure.42 *The Kunsthaus Graz (2003) designed by Colin Fournier with Archigram's Peter Cook (creator of The Plug-In City) invokes science fiction - simply through the use of irregualr architectural forms and materials.*

'Astrofuturism' is a term used by De Witt Douglas Kilgore to describe a speculative 'tradition' of merging SF with popular science. It rose to prominence with sources such as 2001: a Space Odyssey (and many other novels of Arthur C Clarkes, such as *Islands in the Sky*) which attempted to depicted life in outer space in a frank manner.[29]. Generally, he claims this was done in order to educate and convince audiences of the value of HSF. In an argument reminiscent of Banham's, Kilgore states;

> *"**How humanity advances into the space frontier is at least as, if not more, important than the whys and the wherefores**… Through accurate presentation of the science and technology of space travel, astrofutuists claim realism for their space future speculations. Thus, it is not surprising to find the authoritative rhetoric of "how to" popular science validating the speculations of the scientific romancer. Indeed, given the context of a society in which technoscience competes with religion to be the dominant explainer of the unknown, science fiction relies on popular science to make the space future convincing as a social, political, and cultural project."*[30]

Kilgore's Astrofuturism is, though, deeply entrenched in utopian narrative. It displays the importance of an "elsewhere and else*when*" steeped in a "sense of wonder". Kilgore postulates that in order to make future HSF palatable and understandable, it needs to maintain the sense of wonder and utopianism that Venturi, Scott Brown and Izenhour warn so strongly against. That is not to mention that varying levels of 'science' in SF can be confusing and misleading.[31] However, at the core of Astrofuturism is a desire to educate, rather than ignore the present world of design.

29. Kilgore, *Astrofuturism*.
30. Kilgore.
31. Barnett et al., "The Impact of Science Fiction Film on Student Understanding of Science."

CONCLUSIONS

Ultimately, SF is a powerful tool to assist developing human-centric space architectures. The reciprocal relationship between architecture and narrative creates a loop that sustains human connection and could assist to foster safer architectural spaces. While the program analysis located the passenger as a passive observer, passenger, and tender of a ship, this review has also located them as an active participant in the recalling and creation of space culture.

Also noted was that utopian values are strong in SF, but can cause wariness when used to force an unreasonable future upon the present. However, theories such as astrofuturism work to restrain otherwise outlandish conceptualisations of the future with fact. These images can be used to educate and inspire design and innovation.

IMAGE REDACTED

Figure.43 *A 1969 Artificial Gravity Space Station concept from NASA. It demonstrates astrofuturist principles - a collision of science fiction and science fact.*

A Typical Rocket

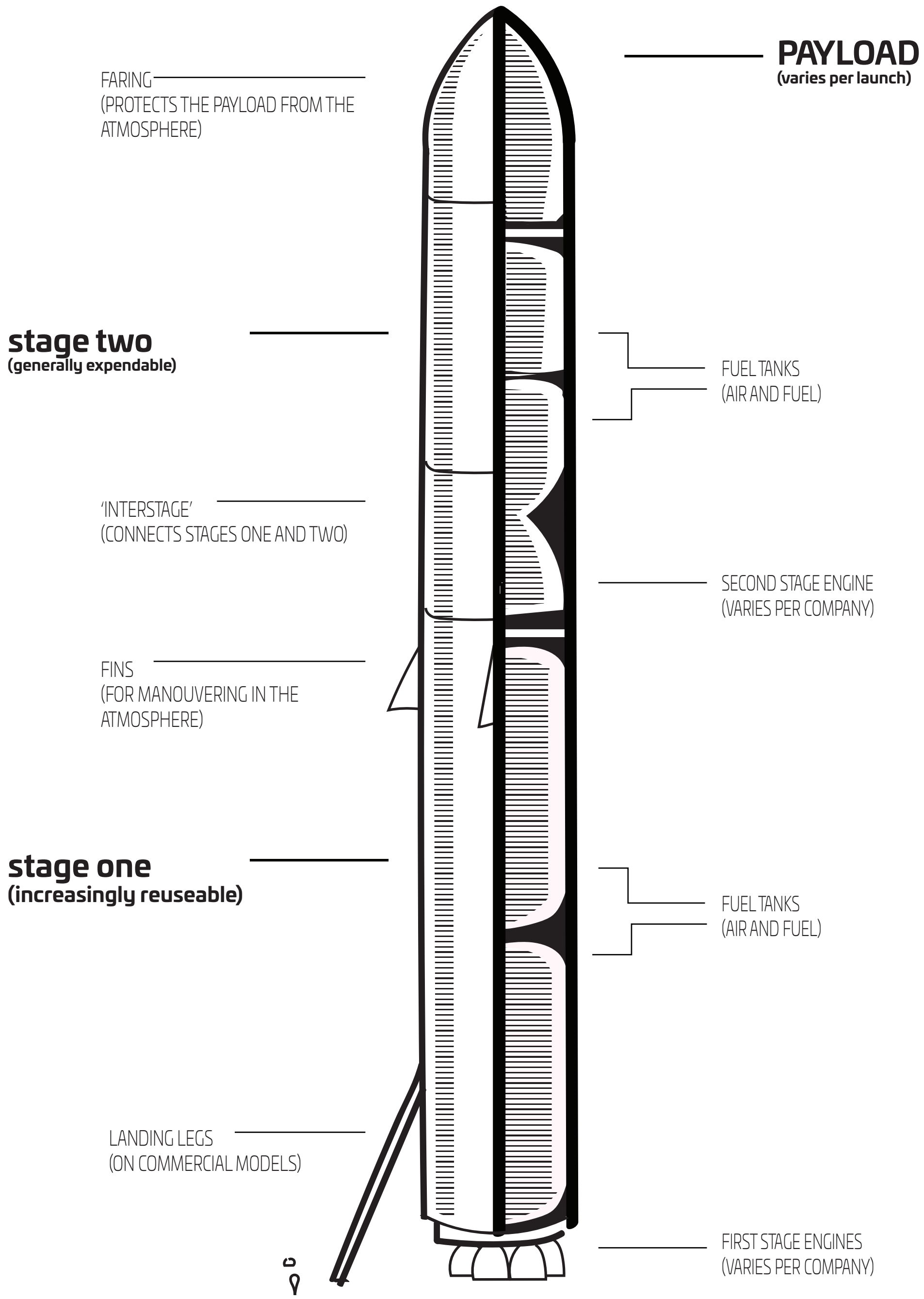
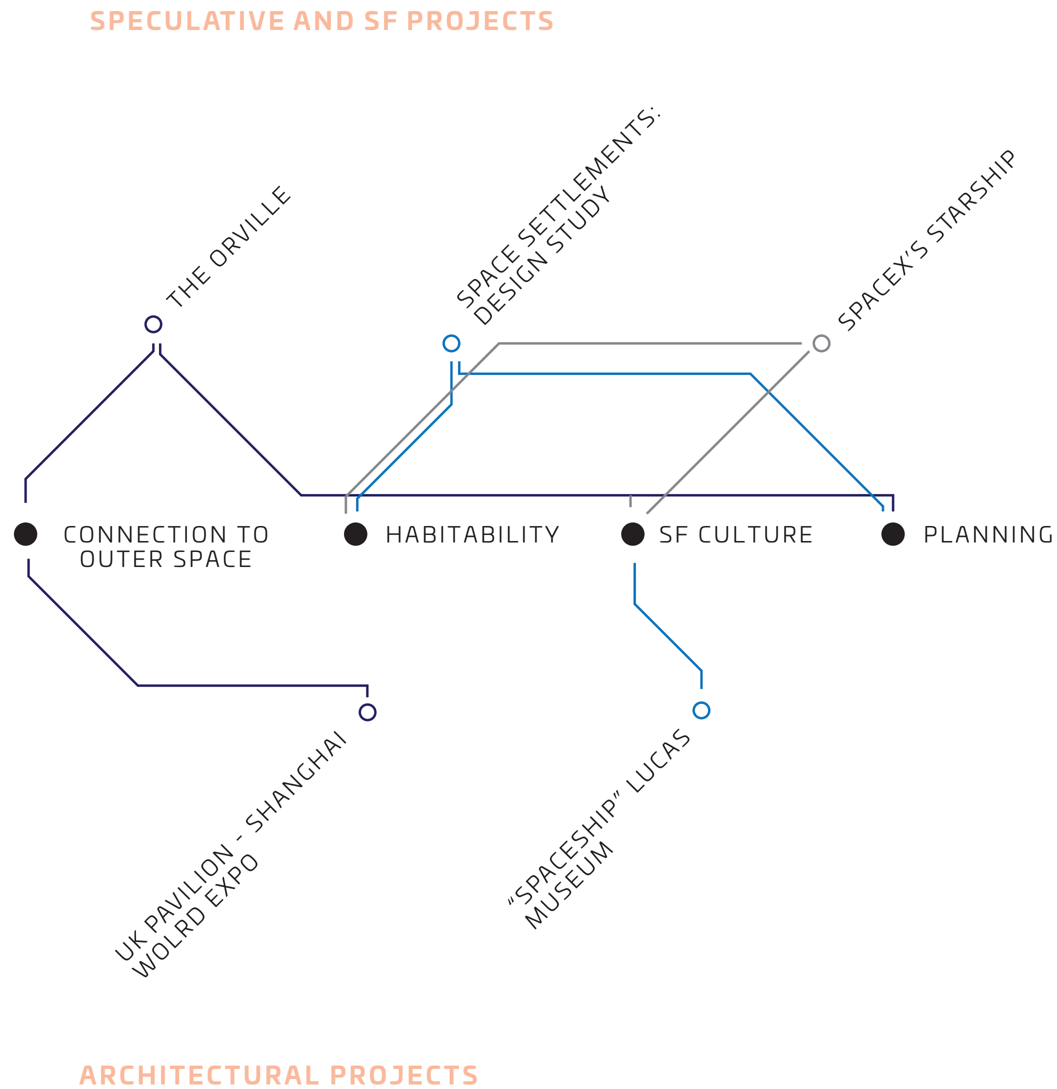


Figure.44 *Testing of different ascetics though diagrams - The design of a typical contemporary rocket*

CHAPTER 5: **PROJECT REVIEW**

A series of HSF and SF projects were analysed to establish design approaches for the preliminary design stage. The projects were chosen to understand how design can assist aspects found in the program and literature reviews:

- Utilising SF motifs and narrative to communicate,
- Utilising form to connect the inhabitants to outer space and other human communities,
- Programming and planning for wellbeing.



5.1. THE ORVILLE

TV PROGRAM | PREMIERED 2017 | CREATOR SETH MCFARLANE

The Orville is a contemporary representation of SF culture - containing several visual and written allusions to Star Trek and similarly popular SF universes. As such it is also able to provide an example of familiar planning for a space vessel as well as SF design. Compared to the theme of dystopia, the Orville was created to be "aspirational and optimistic."[1] Likewise, the ship embodies many 'utopian' characteristics.

The USS Orville is a 25th century mid-size exploratory vessel with a mostly humanoid crew. It contains sweeping white, blue and silver spaces and modern touch screen controls. The exterior of the ship, which is equally as sleek, can be taken into planetary atmospheres and quantum space. The blue light emitted is a reminder of the fictional fuel that allows faster-than-light travel for the ship.[2]

Windows serve to connect the occupants and the viewer to outer space through the ship. A skylight on the apex of the ship and a curved view-screen (where the bridge is located) are included to fully immerse the occupants - and viewers - in outer space.[3]

Similarly to the Enterprise and Voyager Class ships of Star Trek, while the bridges are the view screens are not often used as windows, but as screens able to give extensive 360° and magnified views with the help of communications systems. The ships are celebrations of technology as much as they are of outer space.

1. *The Orville Panel At Comic-Con 2017.*
2. Bond, *The World of The Orville.*
3. Grobar, "How 'The Orville's Production Designer Created The Two-Story Spaceship For 'Aspirational' Series."

COMPARISON OF SF MOTIFS

SHIP EXTERIOR

IMAGE REDACTED

Figure.45 The Orville: *The Orville* 'Command Performance'

IMAGE REDACTED

Figure.46 USS Voyager: *Star Trek Voyager* E1 'Eminations'

SHIP INTERIOR

IMAGE REDACTED

Figure.47 The Orville's Briefing room: *The Orville* 'Identiy pt.2'

IMAGE REDACTED

Figure.48 Observation Lounge: *Star Trek, TNG* S4 'Family'

EVIL TECHNOLOGY

IMAGE REDACTED

Figure.49 Kaylon Ship: *The Orville* S2'Identiy pt.1'

IMAGE REDACTED

Figure.50 HAL 9000: *2001: A Space Odyssey*

ENEMY SHIP

IMAGE REDACTED

Figure.51 Krill Ship: *The Orville*, S1 'Old Wounds'

IMAGE REDACTED

Figure.52 Romulan Ship: *Star Trek, TNG*

"I do everything [at The Orville] through illustration—you have to, for the future. It doesn't exist. You have to draw it, and that's the way we've worked together for a long time,"[4]
Stephen Lineweaver, Production Designer

DESIGN OPPORTUNITIES

- The familiarity of the forms and the narrative of the show allows an instant connection with the SF genre.
- Form and colour is utilised to establish the way that the ship travels.
- The ship uses established building hierarchy – ie bridge and senior officers at the top, engineering below - to familiarise the viewers.
- Touch screens reduce visual and physical clutter.
- Personal space is abundant.
- Communal mess hall provides community space and a flexible space for a range of activities in a small vessel.

CAUTIONS

- Little attention paid to privacy through windows - a necessity if space is to become busier.
- Spaces are repetitive - which likely creates unity through the fleet - which may be confusing to those unfamiliar or untrained with a vessel.
- Personal space appears to be minimally customisable.

4. Grobar

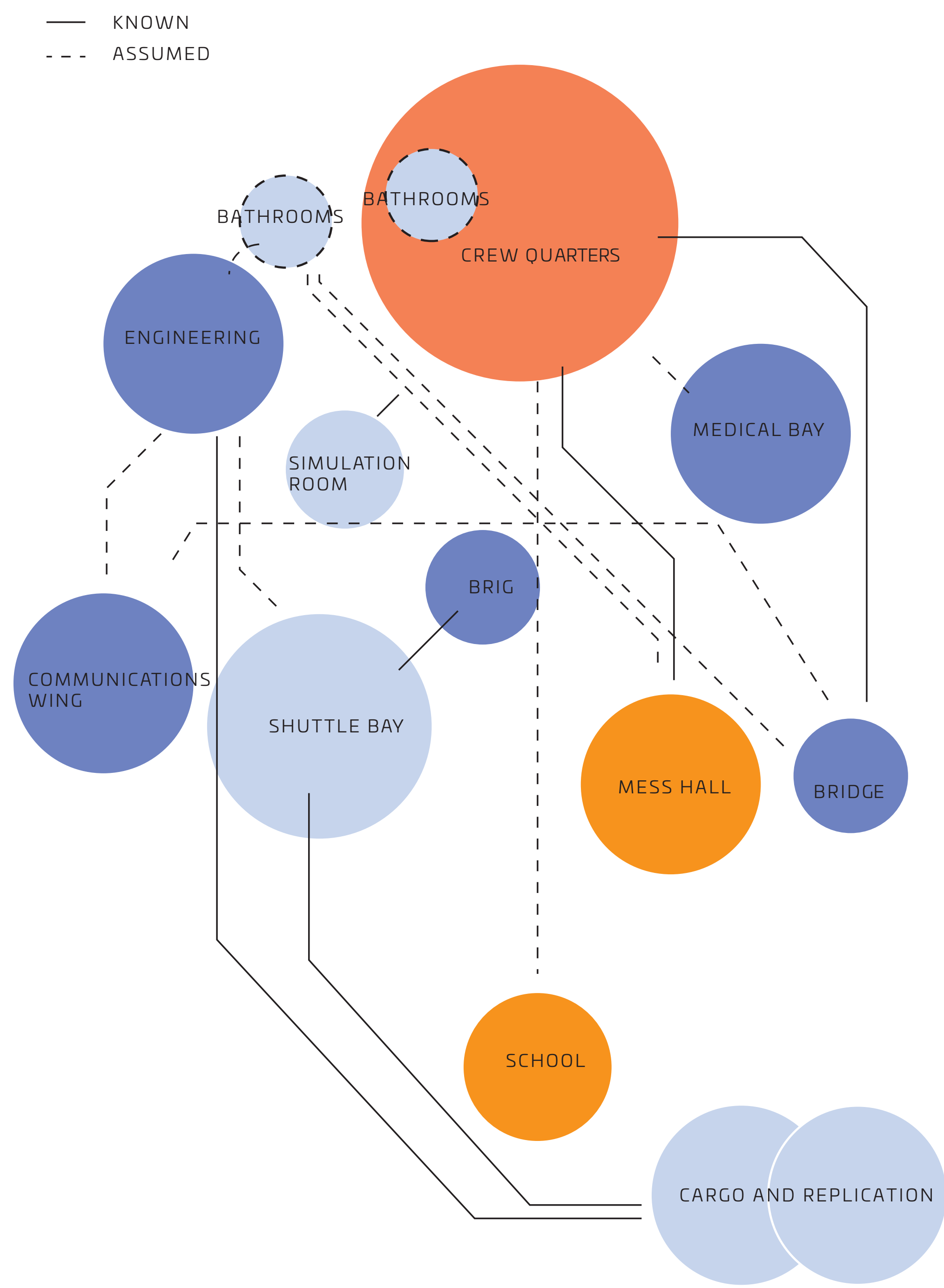


Figure.53 *A program analysis and connection diagram of the Orville*

5.2. SPACE SETTLEMENTS: A DESIGN STUDY

This 1975 report was a conjoint project from Ames Research centre and Stanford University. The program's aim was to "construct a convincing picture of how people might permanently sustain life in space on a large scale" while being technologically sound.[5] It provides insight on the programming and planning for a large space habitat as well as integrating habitability solutions into the design process.

The station's typology is now commonly known as a Stanford Torus. The 'wheel' was 895m in radius, and spun at 1RPM to simulate 1G. It could have housed 10,000 people. As the station was located at Lagrange point 5 - keeping it at a fixed location from the Earth and the Moon - the majority of the materials were anticipated to come from the moon. Natural sunlight is produced by a large mirror at 45 degrees to the axis of rotation. The concept considered the necessity for self-sustainability as well as the ability to produce trade. It contains sections for agriculture (including fishing, crops, and animals), housing, and community facilities such as parks.

The study does not explicitly draw from SF, but it is developed in a strongly narrative and sense of novum as well as echoing the popular 'new frontier' narrative of the era. It also utilised creating writing as a narrative tool.

IMAGE REDACTED

Figure.54 *The colony at Lagrange Point Five - from Space Settlements p8*

5. Johnson, *Space Settlements: A Design Study*, 4, 51.

The study implies that Earth-like elements such as the scale of the settlement, familiar layouts, sunshine, and housing would connect people to humanity as well as materials which could not be made in outer space. There are very few physical elements designed to link the inhabitants of the architecture to its site. Rather, it is implied that the sense of being in outer space would be made explicit through the "egalitarian" and hard-working frontier culture on the station.

OPPORTUNITIES FOR DESIGN

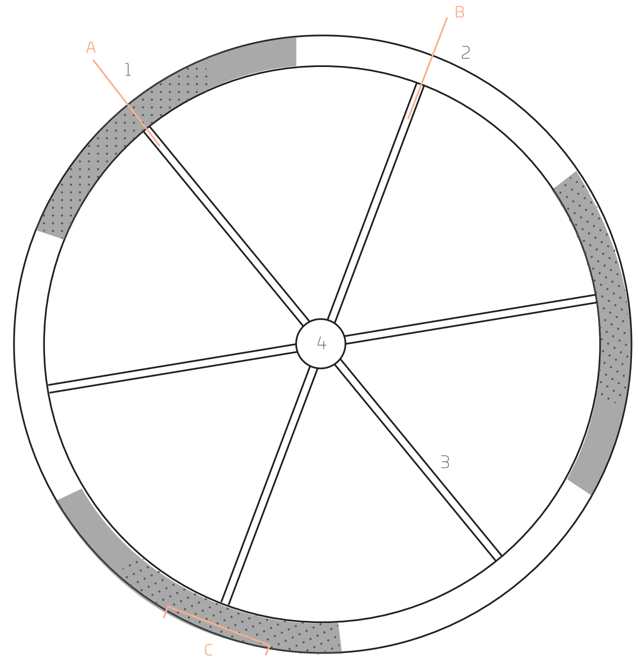
- Connection to Earth is made through familiar scale, housing arrangements, and even class distinction.
- The agricultural layout may be a reminder that the wheel is in space, as it is unlike anything seen on Earth.
- The form of the torus is utilised to create a sense of spaciousness through terraced housing above and keeping processing and storage below the 'ground'.
- The radius is large enough that negative effects from the rotation is minimised.
- Agricultural programs are separated by housing areas, allowing for smaller communities to form within the larger one.
- Mechanical functions such as elevators are a part of the landscape.

CAUTIONS

- Modular housing develops little veriety.
- Physically, there is very little attachment to outer space as a setting.

IMAGE REDACTED

Figure.55 *'View of Housing' from* Space Settlements *p84*



1 agricultural zones
2 housing and living zones
3 'spokes' containing elevators
4 docking hub

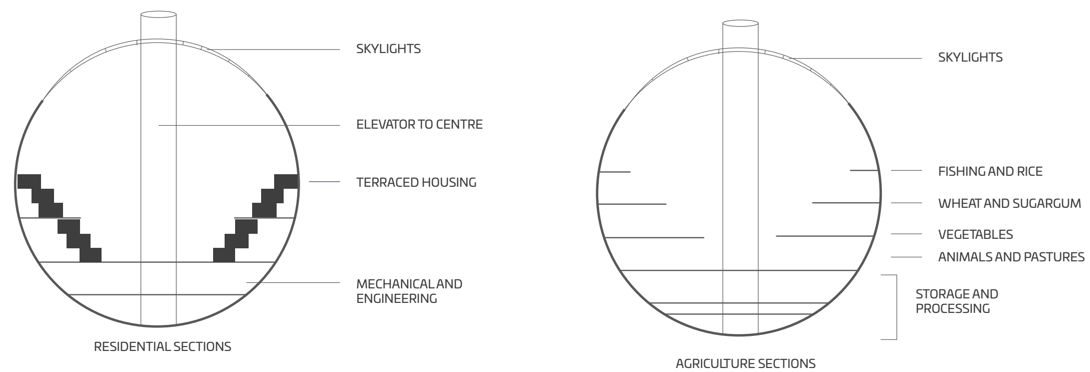


Figure.56 *Sections of the residential (section B) and agricultural spaces (section A)*

5.3. SPACEX'S STARSHIP (2020 ONWARDS)

The Starship is designed by SpaceX, a commercial space flight company specialising in reusable rockets and spacecraft. Starship is intended to work in conjunction with other SpaceX infrastructure to enable super-fast travel around Earth as well as journeys through space.[6] It is projected to initially be used for sub-orbital space flight in 2020. The starship system provides an opportunity to examine what an emerging space infrastructure could look like. At this stage, very little is known about the habitable interior configuration of the Starship.

IMAGE REDACTED

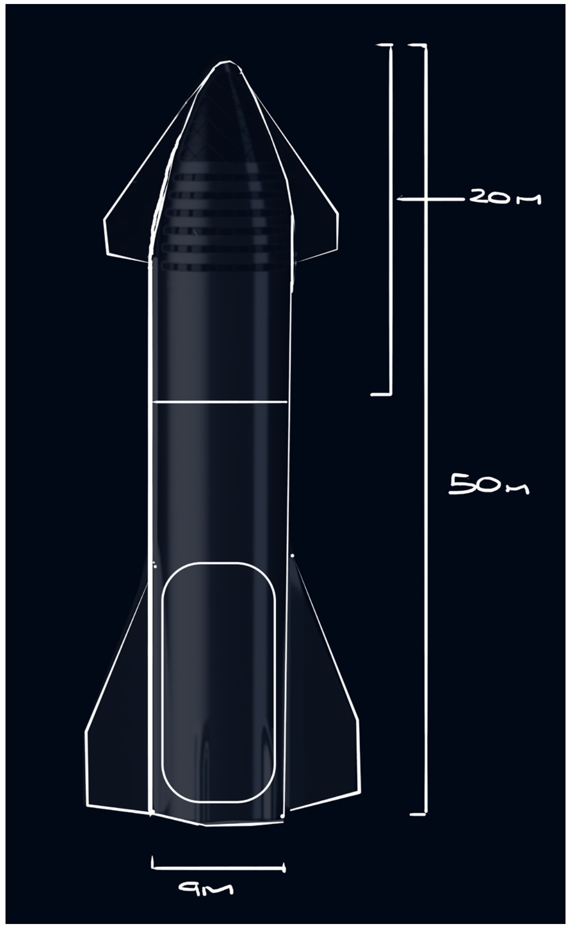


Figure.57 *SpaceX's Starship - 'Starship Update' YouTube September 28 2019*

6. SpaceX, *Starship Update.*

Elon Musk, the founder, CEO, and chief engineer of SpaceX, believes that one of the most "critical" paths for humankind is creating "the fastest path to a self-sustaining city on Mars". He intends for the Starship to encourage technological advancement and affordable space travel.

By utilising the Super Heavy Rocket to deliver fuel separately, the Starship can refuel in outer space. Not only does this allow for the most propellant in the tank to reach further destinations, but the design can optimised for HSF rather than launch capability. Unfortunately, this is not yet apparent in the design.

The Starship has around 1000m^3 of pressurised volume, leaving 10m^3 each if occupied by 100 people. It appears to have many windows along its length with one expansive window at the front of the ship. However, otherwise, there is little to imply that the design has been considered at a human scale. Visually, the ship and its promotional material draw heavily from SF sources. They accentuate the journey out of the atmosphere and beyond.

MATERIALS AND PROPULSION

As its intention is to be used as transport vessel, the materials used on the Starship are important precedents. It is the only known vehicle designed to withstand the same environmental issues as the proposed program. As of late 2019, the Starship contains:

- Length 50m (approx. 20m occupiable), 9m diameter
- Propellant of mainly oxygen
- Manoeuvrable fins to assist with the controlled fall in atmospheres.*
- Separate engines for vacuum and in the atmosphere (up to 37 engines on the Super Heavy)
- A heatsheild of ceramic tiles and stainless steel ("very light but crack resistant")*
- 301 stainless steel which is light, doesn't get brittle in cold, and stronger in hot conditions.
- That is to say that it works better in Space than it does on Earth. It is also much cheaper than carbon fibre, Musk noting that steel is about 2% of the cost. 301 steel is also easily modifiable - ideal if it is to be deconstructued and used on the Moon or Mars surface.

*The SEARCH vehicle is not intended to enter the atmosphere, however these materials may be helpful as it will be subjected to extreme heat and solar conditions.

5.4. "SPACESHIP" LUCAS MUSEUM OF NARRATIVE ART

MA YANSONG OF MAD ARCHITECTS | 27000M2 | LOS ANGELES

The Lucas Museum, founded by George Lucas (the creator of Star Wars) will house "a collection that tells stories from many places and times". Its aim is to tell a story "in every kind of medium".[7] The collection is also intended to connect people to each other, creating a a 'social bridge' between generations and cultures. The architecture itself is utilised as a piece of living narrative art.

The ground floor and the roof of the building are public spaces, designed for exercise and relaxation – further engaging interactions between users. Additionally it contains a restaurant, cafe, classrooms, and a research library. By creating spaces for a multitude of people to meet, the building is actively creating new narratives each day.

The building presents as a spaceship just landing. The architecture aims to impress, with sweeping curves in all directions. It is an embodiment of the future. The building "couldn't have been built even 15 years ago. It is absolutely of its moment and looking forward to the future."[8] The building is intended to make visitors feel as though they have stepped into another world.[9]

Although not yet built, the Lucas Museum provides an example of how narrative can be actively created by architecture through form - just as it is in de Certeau and Collie's urban landscapes. Not only does the museum create interaction between generations, but one stranger to another, the viewers and makers of stories.[10] The museum actively acknowledges "that all visual art forms can make a meaningful connection with viewers" - including architecture.

7. "The Lucas Museum of Narrative Art."
8. "What Is a 'Narrative Art Museum'?"
9. Nast, "George Lucas Finally Breaks Ground on the Lucas Museum of Narrative Art."
10. "The Lucas Museum of Narrative Art."

"Narrative is one of the oldest and most important impulses in art. It is also the most popular form of art. Tracing the arc of narrative art reveals how culture is created, reinforced, and then compelled to evolve" George Lucas - Lucas Museum website

IMAGE REDACTED

Figure.58 *Exterior view of the museum and site* - MAD Architects

IMAGE REDACTED

Figure.59 *View of the lobby of the Lucas museum* -MAD Architects

5.5. UK PAVILION FOR SHANGHAI WORLD EXPO 2010

HEATHERWICK STUDIO | 'SEED CATHEDRAL' | SHANGHAI

The UK Pavillion, also known as the 'Seed Cathedral', actively contrasts the interior from the exterior world while utilising material and construction to bring the two together again.[11] The cathedral was made of 60,000 fibre optic rods, each 7.5 meters long with one or more seeds embedded at the end. The main pavilion connected to a circulation zone with installations. Below that was commercial and event spaces.

The pavilion simultaneously creates a sheltered space while acknowledging its surroundings. The interior of the pavilion was dim, yet the fibres change light levels with the passing of the day and the clouds overhead, allowing the exterior to be experienced as 'fluctuating luminosity' on the interior. Meanwhile, front he exterior the rods could be seen to move with the wind. It is vital that the SEARCH vehicle utilise its form to make the occupants feel safe as well as connected to the site of outer space.

11. Jordana, "UK Pavilion for Shanghai World Expo 2010 / Heatherwick Studio."

IMAGE REDACTED

Figure.60 *The exterior of the pavilion - the fibres wave in the wind*

IMAGE REDACTED

Figure.61 *The interior is lit by light from outside as well as bulbs in the frame*

SHIPS AS DESIGN PRECEDENTS

Using similar technique as Capescu in "Architecture in science fiction Movies" a group of ten popular SF ships and space stations were investigated. The examples were gathered by searching the top page of results for 'memorable' and 'best science fiction space ships' separately, noting those that occurred the most often. The criteria chosen provided an intentionally wide band of ships without dictating what the criteria for a good ship should be. The intention was to gather forms that most often arose in SF culture.

A further set of criteria established which ships are most useful as precedents for this particular research. The precedents deemed inappropriate for practical purposes are still provided as an overview of SF aesthetic for the design stages. By then further categorising the ships by criteria below, conclusions could be drawn.

The further criteria were;

- Designed to accommodate primarily humans (note: human, not humanoid)
- At least 6 occupants (6 being the largest crew size for a NASA Mars mission architecture.)
- Designed for travel further than earth orbit and be occupied for more than a month.

Initial design conclusions drawn from this activity were;

- There is a relatively good mix of modern utopian and steampunk imagery and design. (Steampunk being a 'skin' generally based on older SF or in defiance of the 'truism in speculative fiction that you get one impossible thing for free'.[1])
- Yet none are necessarily dystopian in nature.
- Only one of the 10 most represented ships utilised correct gravity, or tried to represent the means for creating artificial gravity. That ship (Discovery 1) only portrayed correct gravity in one interior space.
- Half of the ships were military vessels. Whether this is a result of military vessels being popular or simply because of popular SF narratives is undetermined.
- The majority of disqualified ships (those that would have made it into the top 10) were single or double person fighters.

These conclusions present some immediate design considerations.

- Popular designs generally developed forms that looked aerodynamic, despite a few not being shown to enter a planet's atmosphere (for example the Star Destroyer and Discovery One. The Enterprise has been shown to be able to enter atmospheres if needed).
- A realistic simulation of gravity has very little to do with popularity - and may even decrease it's chances by appearing less aerodynamic.
- Yet, circular and spherical forms were popular in long-term ships - but didn't tend to denote known forms of artificial gravity.
- Traditional rocket imagery is surprisingly not utilised in the SF examples.

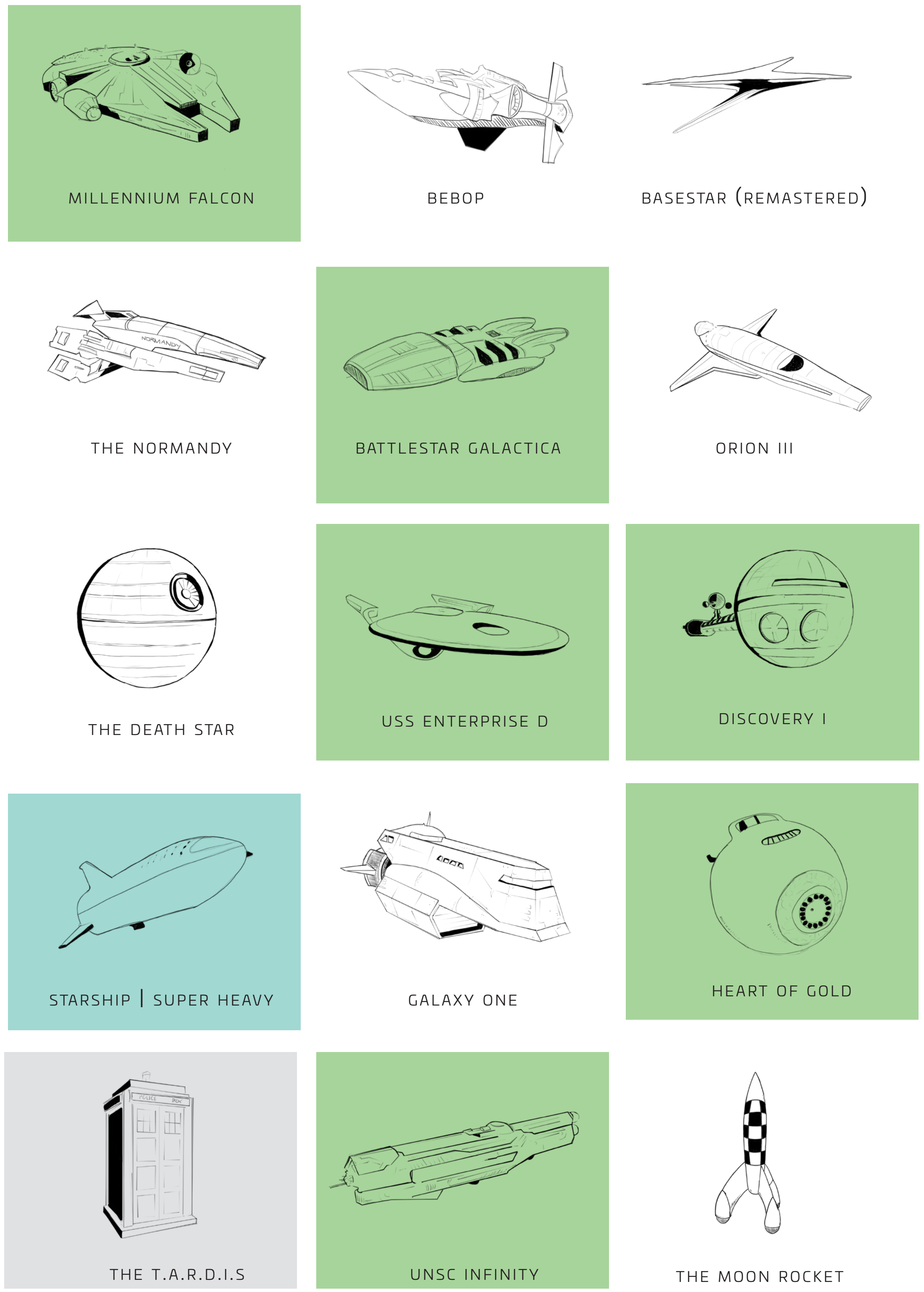
Figure.62 *(Following page) A collection of popular science fiction ships to be used as design precedents. Sorted in to categories relating to their popularity and functions as precedents.*

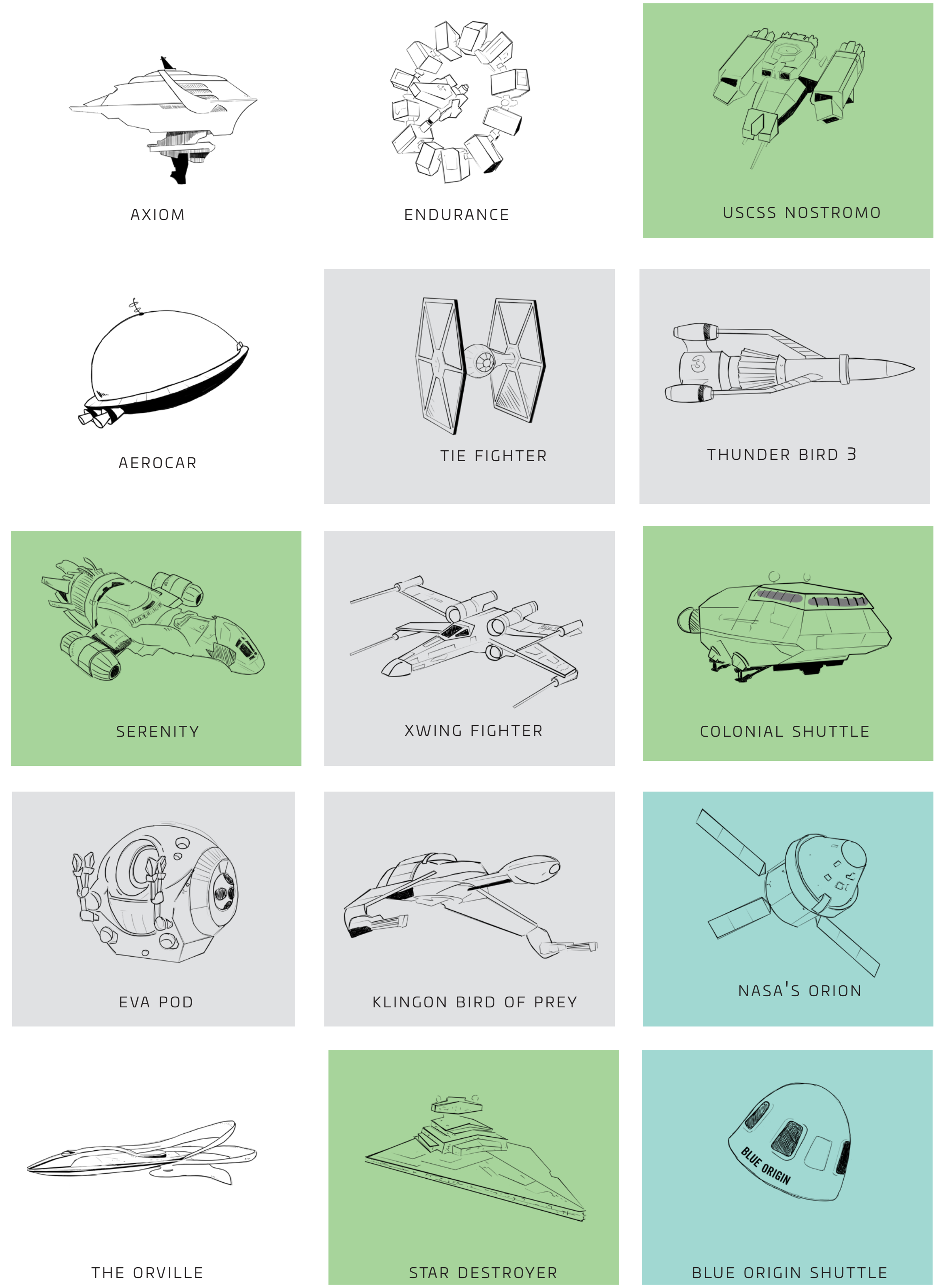
1. Lake, " Exploring the world of steampunk"

10 MOST POPULAR

(POPULAR) DISQUALIFIED
CONDITIONS: TOO SMALL, ALIEN VESSEL, OR NOT INTERGALACTIC

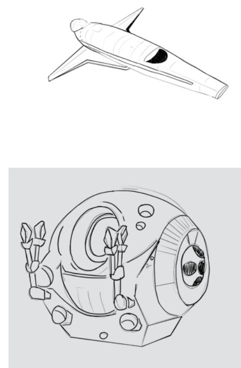
REAL-LIFE PROJECTS



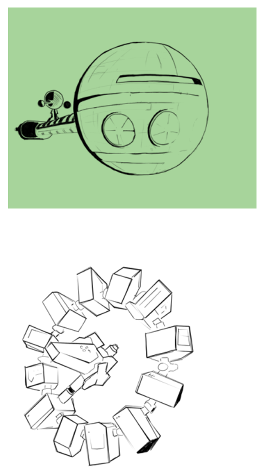


See page 119 for references

NO GRAVITY



INDUCED GRAVITY



'SF GRAVITY'

IE. NOT SCIENTIFICALLY EXPLAINABLE - YET

Figure.63 *SF architectures - Gravity status*

INTENDED TO ENTER AND EXIT THE ATMOSPHERE

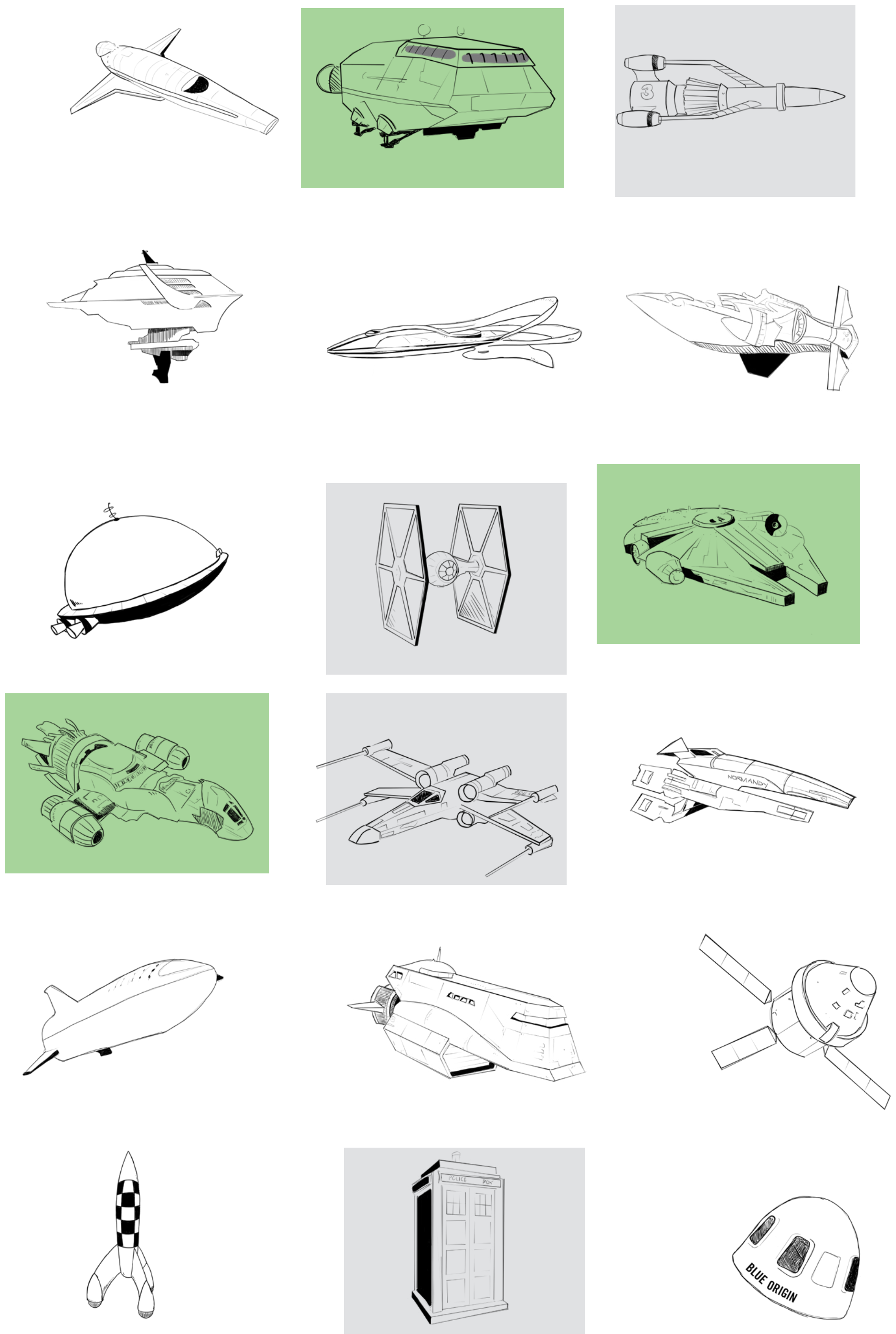
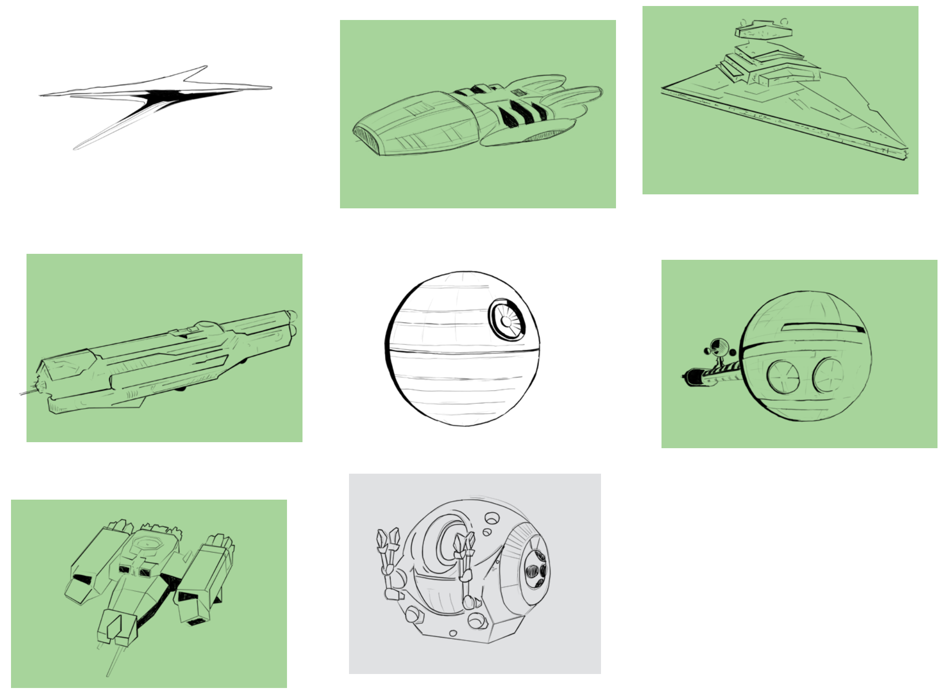
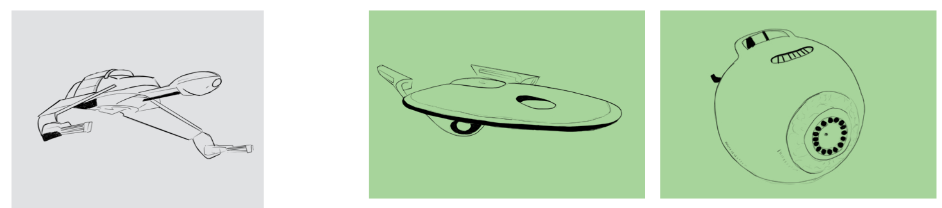


Figure.64 *SF architectures - function vs. aesthetics*

SPACE ONLY



SPACE – USUALLY



HYBRID

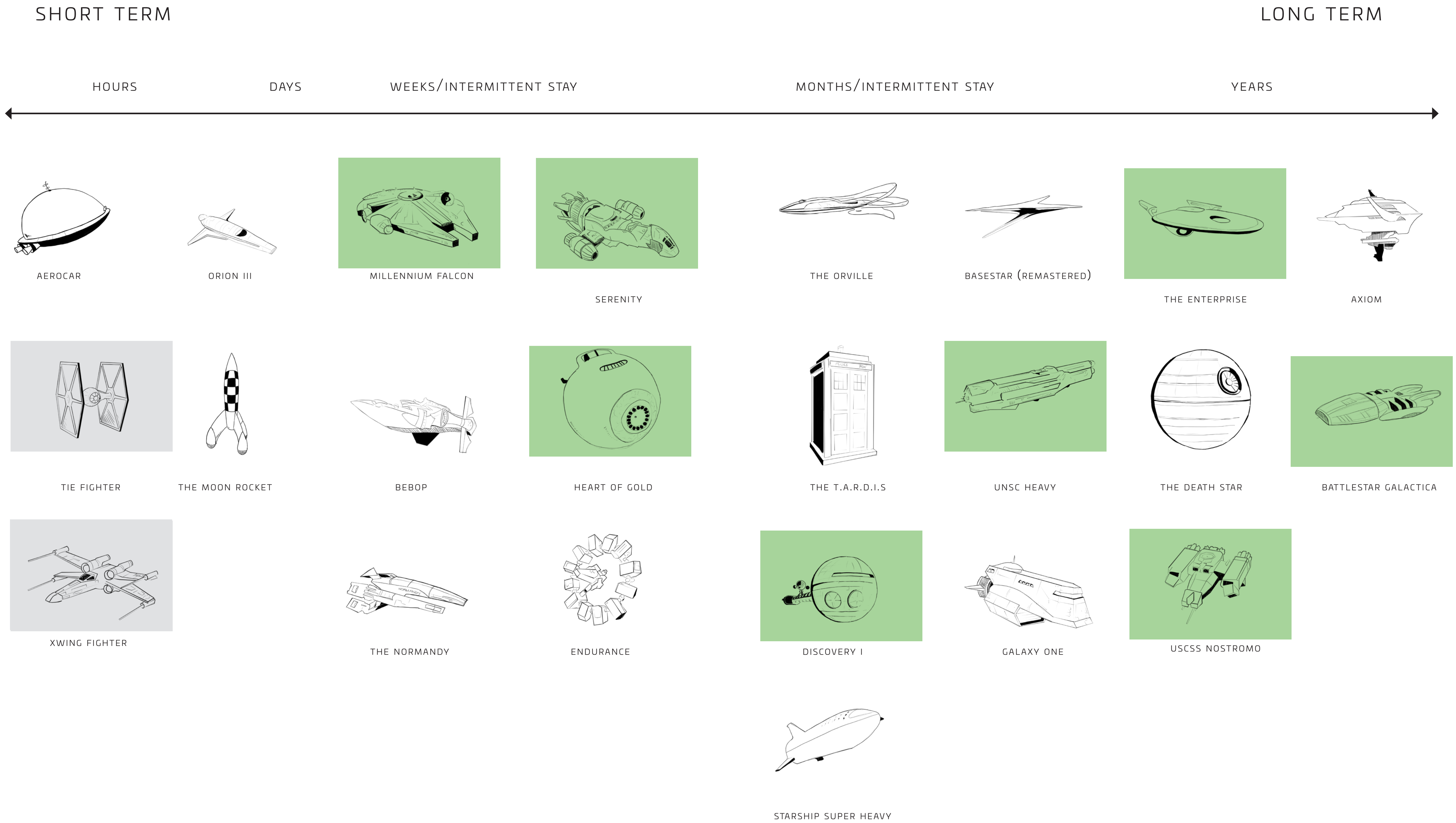
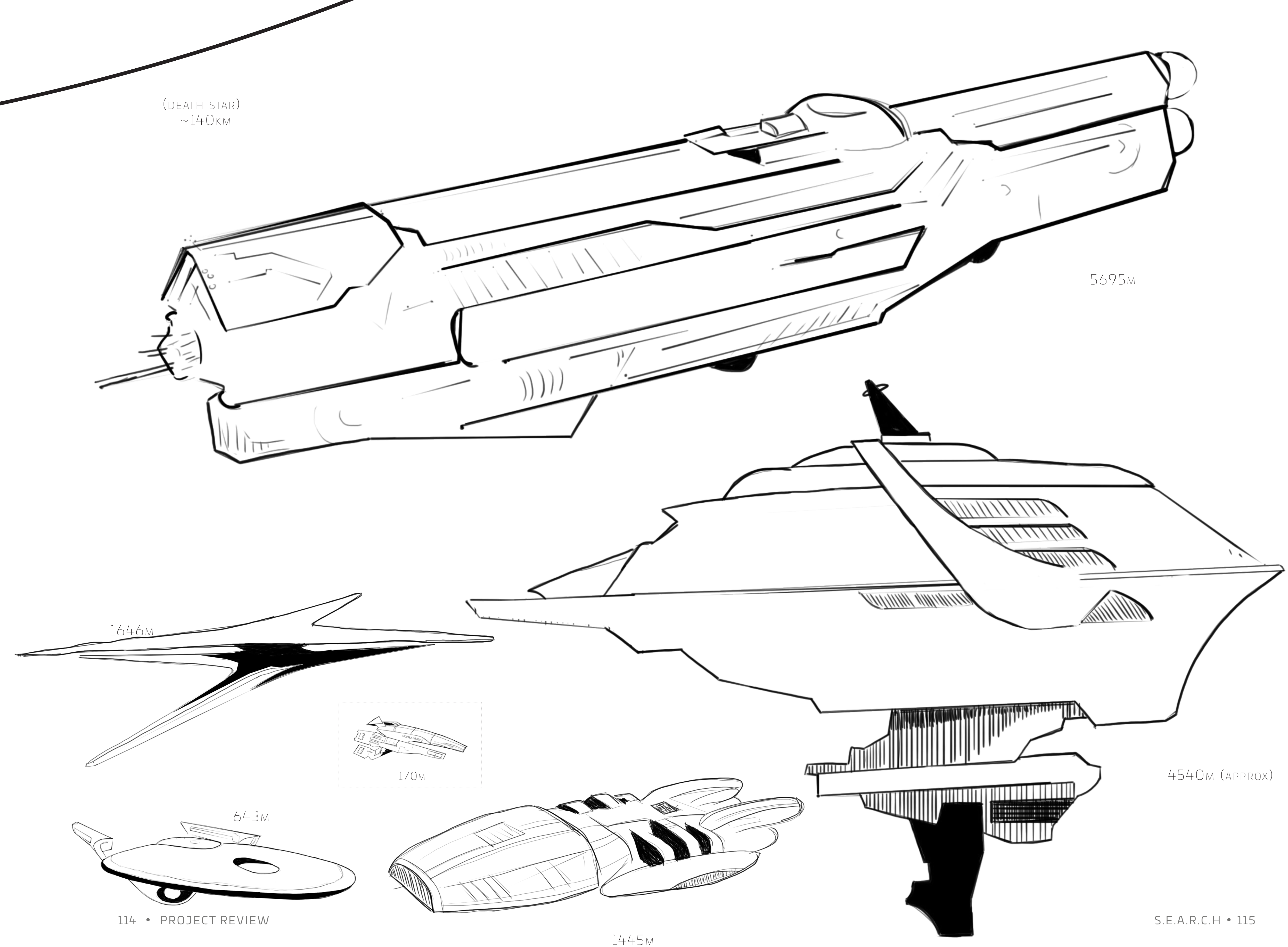
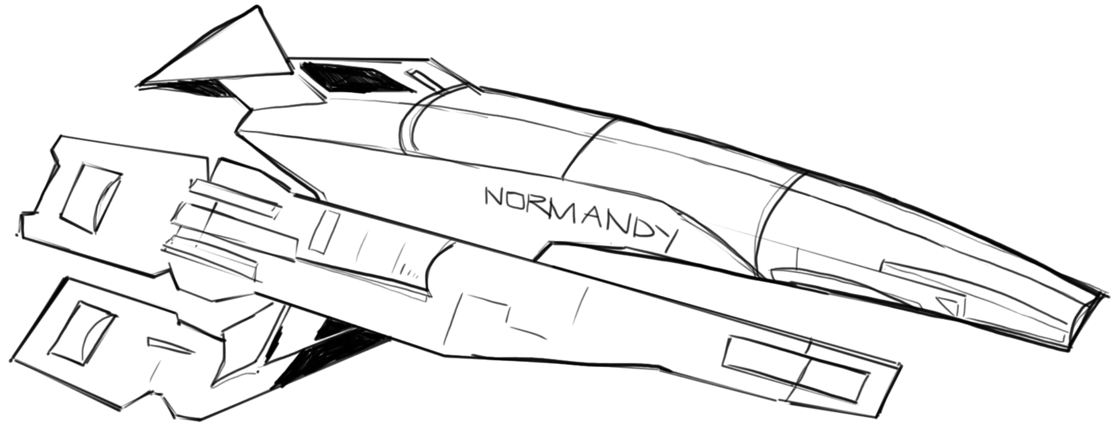


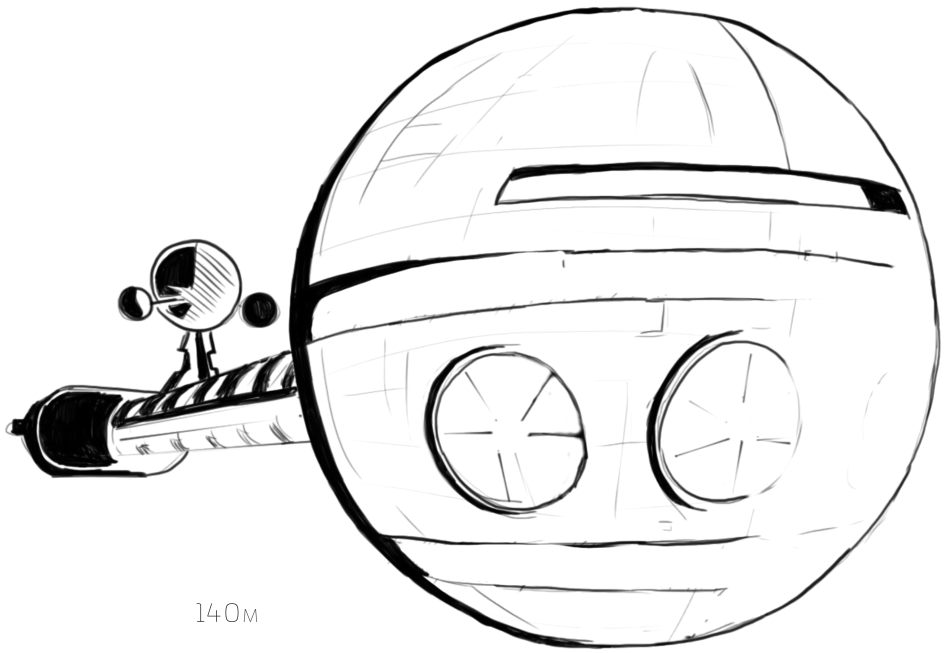
Figure.66 *(following pages) A size comparison chart for the SF ships*

Figure.65 *SF architectures - form and functionality as a long term vessel*

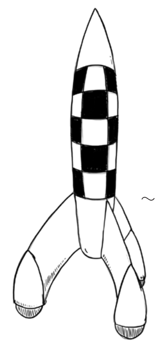

(DEATH STAR)
~140KM
5695M
1646M
170M
643M
1445M
4540M (APPROX)



170m

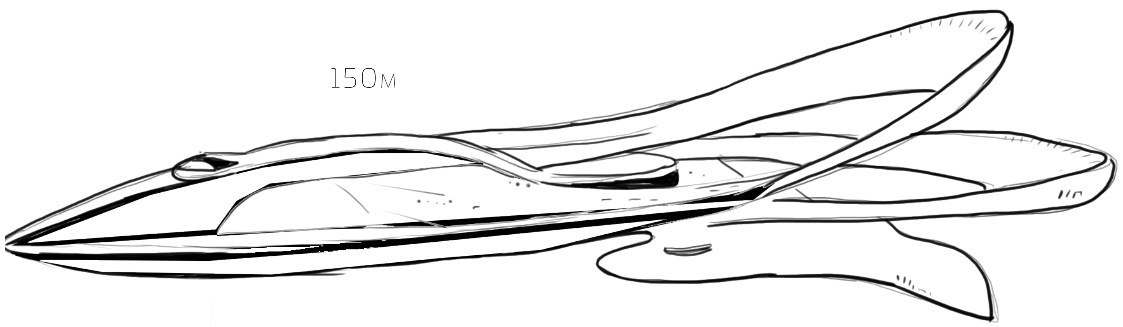


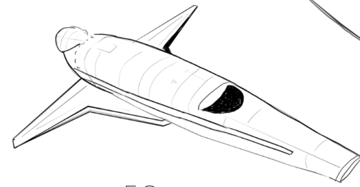
140m



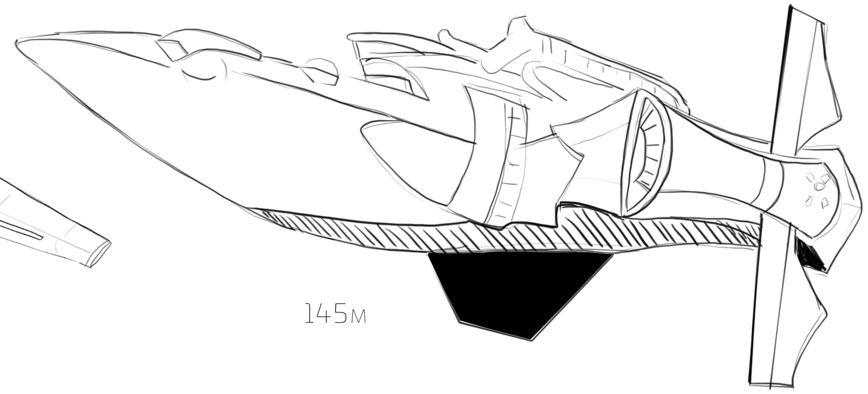
~50m

150m

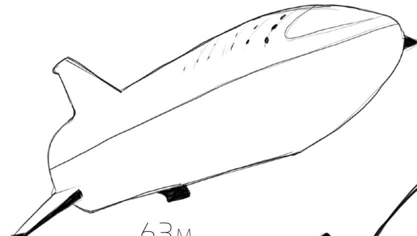




~50m



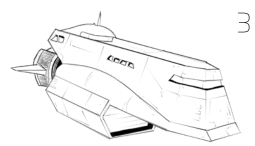
145m



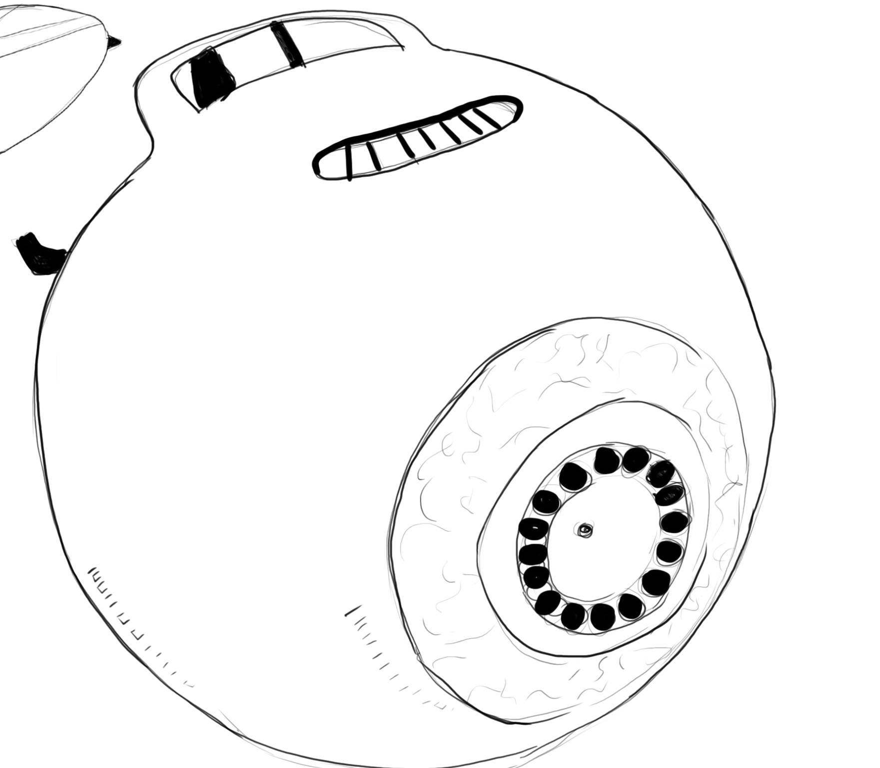
63m

2m (exterior)

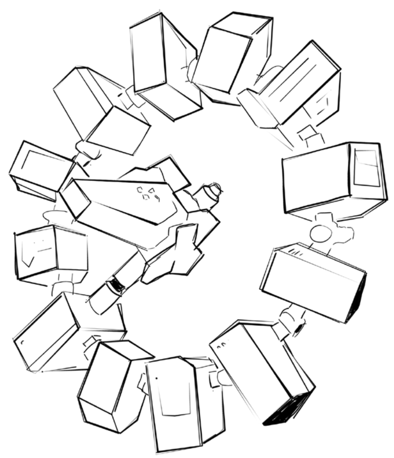
3m



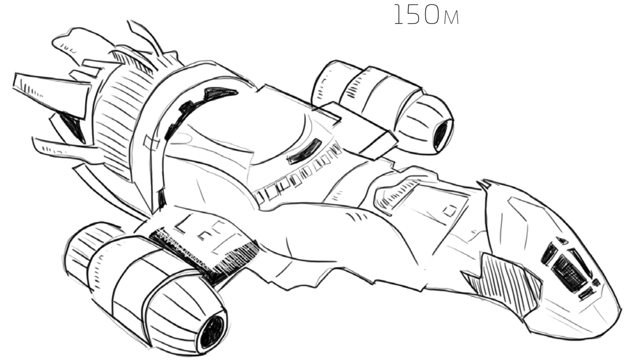
~30m



150m



65m



82m

NARRATIVE, SCIENCE FICTION, AND ARCHITECTURE

Each of these projects find commonality as expressions of the future or creator of narrative. They each display a celebration of technology the goes hand-in-hand with their speculations of the future. Many use visually poetic and utopian forms as tools of persuasion for a future of HSF, just as steampunk and astrofuturism use a sense of reality as a tool.

Surprisingly, even in the SF examples, connections between space architecture and outer space are kept strictly visual. There is little physical connection between inhabitants and outer space. Instead, a passive connection is created through extensive use of windows. Each completed space vessel also takes care to separate work and personal life.

As the only existing example of space architecture in the review, the Starship paid little attention to habitability, instead focusing on what can be accomplished in terms of safety and buildability. However, it makes far more use of the understanding of how the space industry will affect and be affected by the architecture that is built.

BIBLIOGRAPHY OF SPACE SHIPS

2001: A Space Odyssey. Directed by Stanley Kubrick. United States: Stanley Kubrick Productions, 1968.
Discovery I | Orion III | EVA Pod

Alien. Directed by Ridley Scott. United Kingdom: 20th Century Fox and Brandywine Productions, 1979.
USCSS Nostromo

Battlestar Galactica [2004 Remake]. Originally created by Glen A. Larson, Developed by Ronald D. Moore. United States: First produced by David Eick Productions, 2004.
Basestar (Remastered) | Battlestar Galactica | Colonial Shuttle

Cowboy Bebop. Directed by Shinchiro Wantanabe. Written by Keiko Nobumoto. Tokyo: TV Tokyo, 1998.
Bebop

Doctor Who. Created by Sydney Newman, C. E. Webber, and Donald Wilson. United Kingdom: BBC Studios, 1963.
The TARDIS

Final Space. Created by Olan Rogers. United States: Warner Bros. Television Distribution, 2018.
Galaxy One

Firefly. Created by Joss Whedon. United States: Mutant Enemy Productions and 20th Century Fox Television, 2002.
Serenity

Halo 4 {video game]. Written by Christopher Schlerf. United States: Microsoft Studios, 2012.
USNC Infinity (first appearence)

Hergé."Destination Moon" *Tintin.* Created by Hergé. Belgium: Casterman, 1953.
The Moon Rocket

Interstellar. Directed by Christopher Nolan. United States: Legendary Pictures Syncopy and Lynda Obst Productions, 2014.
Endurance

Mass Effect. Developed by BioWare. Canada: Microsoft Game Studios, 2007.
The Normandy

Star Trek, The Next Generation. Created by Gene Roddenberry. United States: Paramount Domestic Television, 1987.
USS Enterprise D | Klingon Bird of Prey

Star Wars: Episode IV - A New Hope. Directed by George Lucas. United States: Lucasfilm Ltd, 1977.
Millennium Falcon | The Death Star | Xwing Fighter | Tie Fighter | Star Destroyer

The Hitchhiker's Guide to the Galaxy. Directed by Garth Jennings. United Kingdom: Touchstone Pictures, 2005.
Heart of Gold

The Jetsons. Originally Directed by William Hanna and Joseph Barbera. United States: Hanna-Barbera Productions, 1962.
Aerocar

The Orville. Created by Seth MacFarlane. United States: Fuzzy Door Productions, 20th Century Fox, 2017.
The Orville

Thunderbirds. Created by Gerry Anderson and Sylvia Anderson. United Kingdon: AP Films, 1964.
Thunderbird 3

WALL-E. Directed by Andrew Stanton. United States: Walt Disney Studios Motion Pictures, 2008.
Axiom

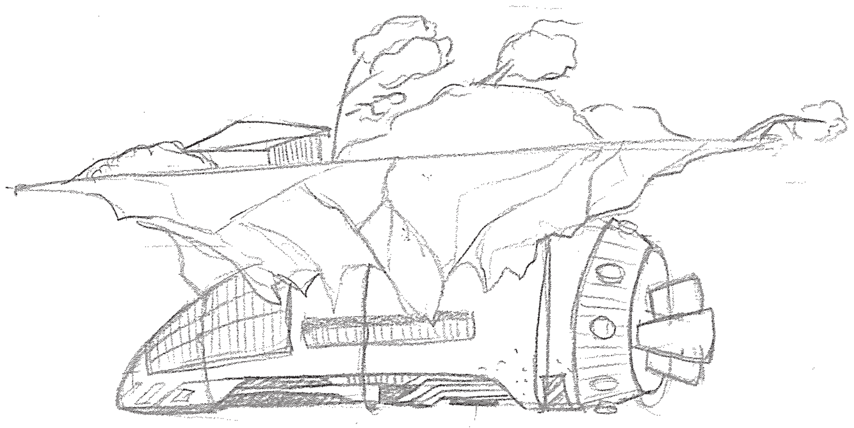


Figure.67 *Sketch experimentation - Exploring taking Earth with us on intergalactic travels.*

CHAPTER 6: **SKETCH DESIGN**

This and the following chapter represent the testing and generation of architectural design solutions. Several opportunities were identified in the program, context, and project reviews that are accumulatively applied to the design. Despite being located later in the document, these design stages largely occurred alongside the research phases. The program development in particular is visible across the design stages.

This phase is represented in a line of design and research series. Beginning with form generating exercises (including the creation of artificial gravity and testing SF typologies) it then progresses into more specific design challenges. Two design iterations, each with critical summaries, are used as a reflection points for further design/research studies.

RESEARCH AND DESIGN STUDY ONE

ARTIFICIAL GRAVITY

"Engineering rotating structures is far less complex than engineering humans to thrive indefinitely in weightlessness."[1]

A major objective of the research was to create physically safer spaces. For a long-term mission, a lack of gravity is the most prominent affector of physical health. NASA believes that more than a dozen major risks of extended space flight would be mitigated by its inclusion - including hygiene, fitness, and the effectiveness of medication.[2] Rather than targeting individual symptoms of weightlessness, the creation of gravity addresses the cause down to an atomic level.[3] However, due to being technologically difficult, only one test has been undertaken in outer space, on the Gemini XI mission, with little success.[4]

Most SF spaceships feature a form of artificial gravity, very few of which are physically possible (dubbed 'SF gravity'). As an accurate representation of scientific ideas has been revealed as likely to allow the design to be more convincing as an architectural ideal, this series investigates theoretically possible solutions – gravity through rotational or linear acceleration. Frames from SF ships were collaged to visualise what each of these conditions would feel to occupy (figures 76-80).

This preliminary series consisted of sketch explorations. Consisting of little planning, the forms generated expressed the exterior aesthetics that may accompany the generation of artificial gravity. In general, those exhibiting the strongest expression of form were those developed through rotational gravity. Linear gravity on the other hand created forms which could have been dictated by SF gravity instead. While this may be could have been beneficial to explore the mysticism that accompanies SF ships, it was decided that those utilising artificial gravity developed a closer connection to recognisable space architecture speculation.

1. Hall, "Artificial Gravity in Theory and Practice"
2. Norsk and Smith. "Artificial Gravity Future Plans for ISS."; Zipay " Near-Term Artificial Gravity Concepts for Deep Space Missions"
3. Hall.
4. Darling, *The Complete Book of Spaceflight*

ROTATIONAL GRAVITY

As early as the 1920s Hermann Oberth and Herman Potočnik were proposing vehicles with artificial gravity through the rotation. By spinning a vessel, a centrifugal and gravity-like force can be felt. As there is no friction cause by air, very little energy would be needed to maintain the spin of the vehicle. Rather, the materials of the ship require technological improvement to withstand the force.

Rotational gravity's success relies on the vehicle's radius and the rate of spin. Both have important design and habitability considerations. Clement, Buckly and Polosky succinctly state, "The radius of the structure will have a direct impact on the cost and complexity of the space vehicle, whereas the rotation rate will mostly influence physiological and psychological responses of the crew on board."[5]

Difficulties that arise with a short radius include the Coriolis Effect and a differential in gravity felt between a person's feet and their head (as they would be at different radii from each other). It is theorised that in order to mitigate these issues, a radius of 55m or above would be ideal, with a maximum of 4 RPM (rotations per minute).[6] However, astronauts could likely withstand less ideal options.

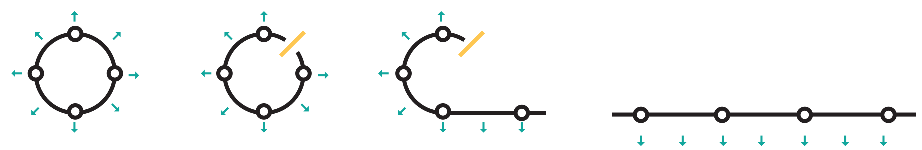


Figure.68 *Diagram illustrating the direction of forces created via rotational gravity. The forces push objects outwards, making the outside edges of the circle feel like the floor or 'down', forming what would feel like a long, upcurning, building with the two ends making a loop.*

5. Clément, Bukley, and Paloski, "Artificial Gravity as a Countermeasure for Mitigating Physiological Deconditioning during Long-Duration Space Missions."
6. Zipay. "Near-Term Artificial Gravity Concepts for Deep Space Missions."

SPACE STATION ARCHITYPES

WITH ROTATIONAL GRAVITY

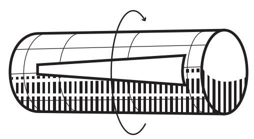
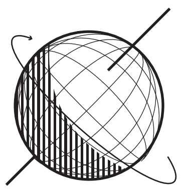
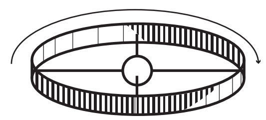
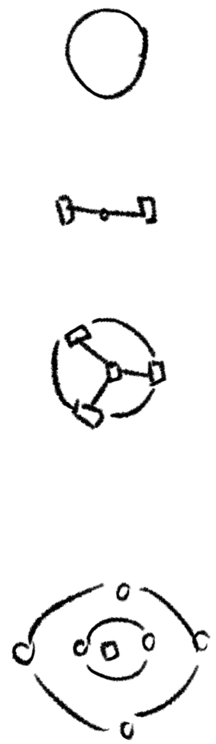
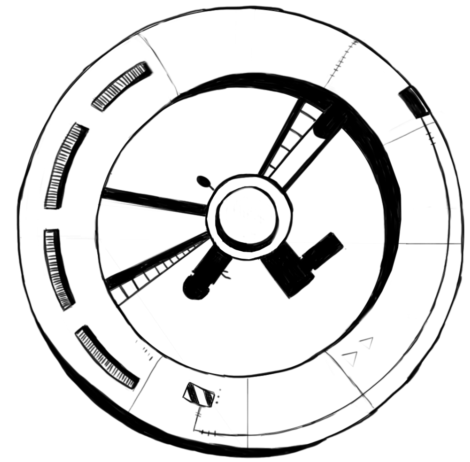
CYLINDER	SPHERE	ROTATING WHEEL
		
OTHER FORMS AND NAMES	OTHER FORMS AND NAMES	OTHER FORMS AND NAMES
O'NEILL CYLINDER	DYSON SPHERE (MEGA SCALE)	STANFORD TORUS
LIMITATIONS	LIMITATIONS	LIMITATIONS
ONLY WORKS IN LARGE SIZES	ONLY WORKS IN LARGE SIZES	SCALES FROM MEDIUM TO COLONY SIZED HABITATS
AS SEEN IN:	AS SEEN IN:	AS SEEN IN:
ENDER'S GAME BABYLON 5	STAR WARS STAR TREK (TNG)	ELYSIUM 2001: A SPACE ODYSSEY RINGWORLD ISLANDS IN THE SKY

Figure.69 *A demonstration of typical pseudo-gravity based space station archetypes and SF works that utilise them.*





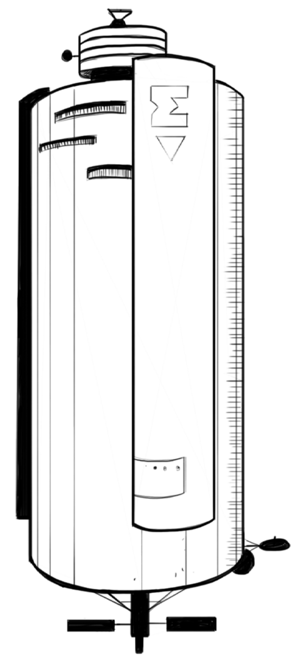


Figure.70 *A few possible configurations of rotating modules;*
- Wheel
- Counterweighted modules
- Connected modules
- Connected modules with different radii

Figure.71 *Design exploration: The Wheel*

Figure.72 *Design exploration: The Cylinder*

LINEAR ACCELERATION

It would also be possible to simulate gravity through linear acceleration. The rate of acceleration would need to be carefully controlled. If a vehicle is to stop, there would be no gravity. Likewise, if it accelerated too fast the gravity would be too strong. From a design perspective, the interior of the ship would need to function in both 1G and 0G situations, as well as partial gravity situations - and even in extremely high gravity situations.

The only technology that may be able to provide this acceleration would be future solar sails. However, this option would mean that getting to and from Mars and other extra-terrestrial destinations would take a fraction of the time it does now, and the principles of this thesis would be made redundant. This technology would work best on unmanned satellites, cargo ships, and possibly emergency vehicles.

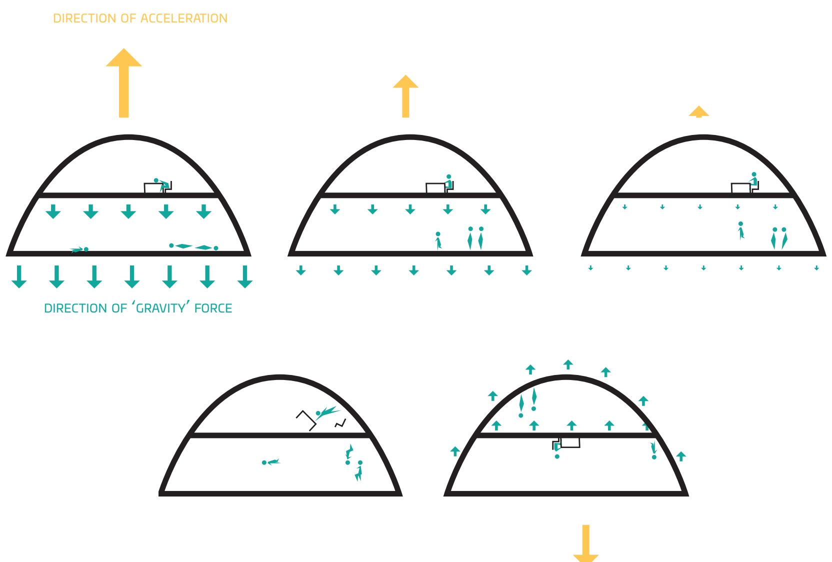


Figure.73 *Diagram illustrating the direction of forces created via linear acceleration. The level of 'gravity' (green arrows) changes with the rate of acceleration (yellow arrows). That 'gravity' force is opposite the direction of travel.*

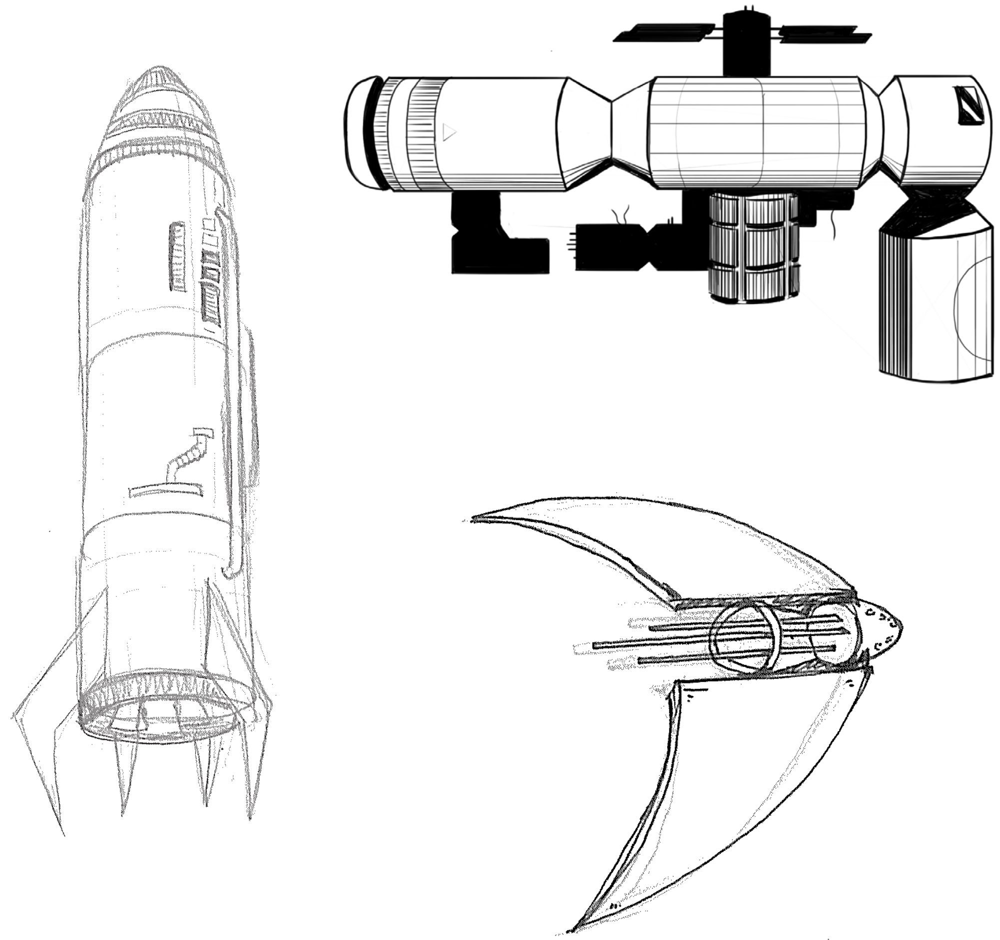


Figure.74 +
Figure.75 *Sketch experiments utilising linear acceleration.*

COLLAGES: DIFFERENT GRAVITY SPACES

Figure.76 ***Microgravity***
2001: A Space Oddyssey (Orion III) + Star Wars (Cloud City)

Figure.77 ***Rotational Gravity***
Star Trek TNG (Enterprise D hallway + arboretum)

EXPERIMENTING WITH SCIENCE FICTION IMAGES

Figure.78 ***Rotational Gravity + Coriollis Effect***
Star Wars (Star Destroyer)

Figure.79 Rotational Gravity
2001: A Space Oddyssey (Discovery I) + Star Wars (Cloud City)

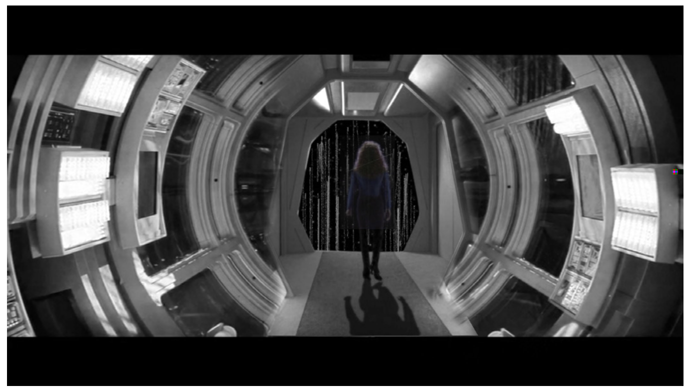


Figure.80 ***Liniar Acceleration***
Star Trek TNG (Enterprise D) + Star Trek, 2009 (The Jellyfish Ship)

DESIGN STUDY TWO

TYPOLOGY EXPERIMENTATION

As Balint and Pangaro noted, familiarity with SF forms could assist with establishing community. Additionally, when applied with aspects of Astrofuturism, they can educate and create a sense of reality rather than fiction.

Design study two was an initial form-finding exercise to determine a general design direction. By grouping the familiar ship designs from the ships previously gathered, it attempts to decipher how these typologies interact with habitability principles, architectural planning, and construction techniques. The following are a selection of these experiments. The forms that prevailed were those that took the accentuation of rotational gravity for their similarity to an urban landscape as it has been identified as having a strong connection to narrative and SF.

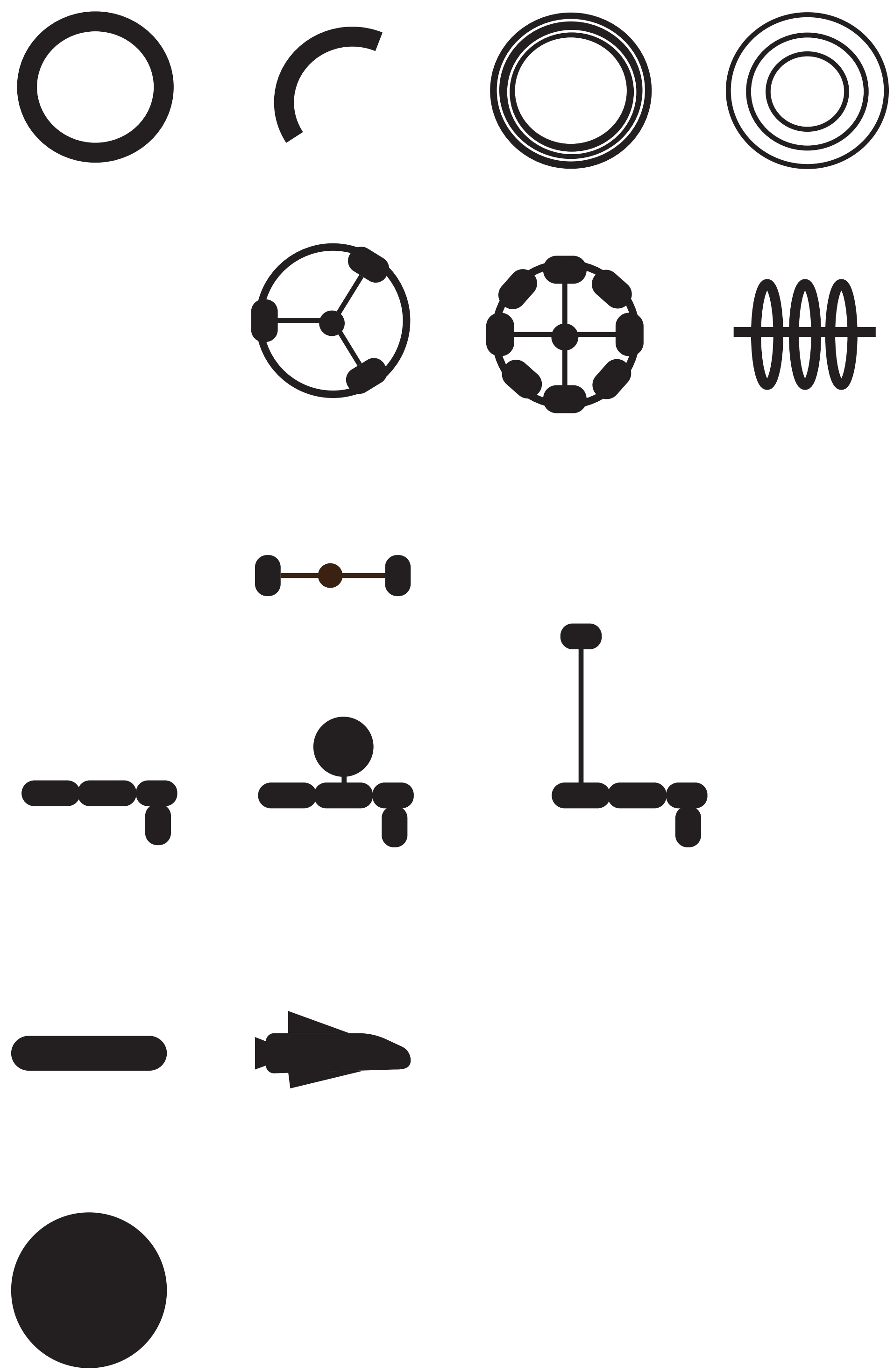
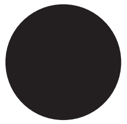


Figure.81 *A range of architype and familiar science fiction space ships and stations, with variations.*

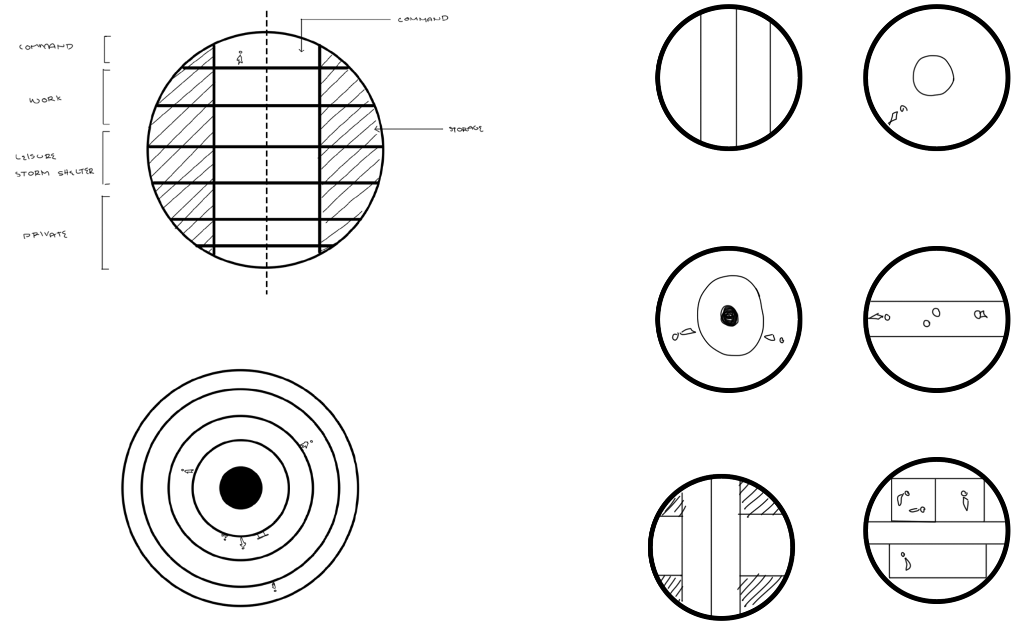
1. THE SPHERE



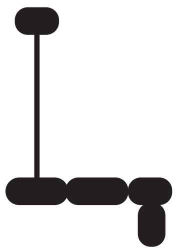
AS SEEN IN:
Star Wars

POSITIVES
- if large, it could house a number of differently shaped spaces
- strongly reminiscent of SF

NEGATIVES
- OG unless utilising SF gravity



2. MODULAR - PARTIAL GRAVITY



POSITIVES
- most easily constructed with current technology
- established research exists on living in a 0G space

NEGATIVES
- transitions between gravity levels may be difficult and disorientating
- may not be a viable solution for long term health
- may be off putting for tourists

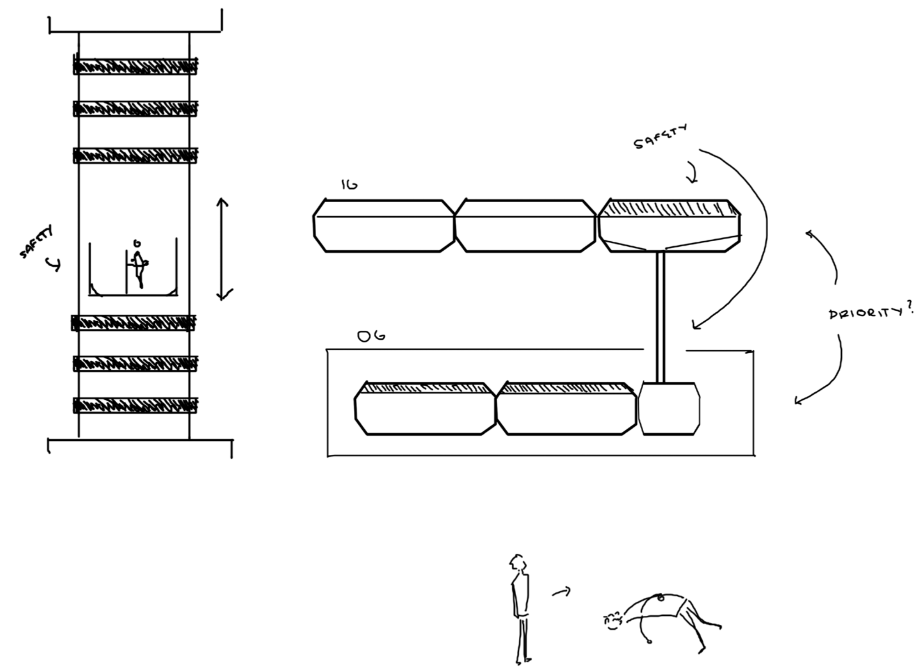
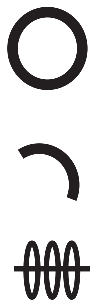


Figure.82 *Sketch experiments utalising the sphere and modular forms*

2. STANFORD TORUS

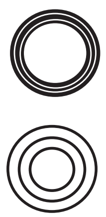


AS SEEN IN:
Ringworld (ringworld) - Niven
Islands in the Sky (Mars transport)- Clarke
Stanford Torus (settlement) (1971)

POSITIVES
Large - can provide gravity without significant drawbacks
Could house a large population to decrease monotony
Possibilities for agriculture

NEGATIVES
Not likely to be for smaller missions
Extremely expensive to build
A small population would be sparce

2.5. MODIFIED / SPLIT LEVEL TORUS



AS SEEN IN:
Islands in the Sky (space hotel) - Clarke

POSITIVES
Could create different gravity without separate energy generators. This could save time on Mars ground missions and extend sample lifespan.
Large amount of floor space for planting, recreation, and private space
One ring could provide radiation shielding for the other.

NEGATIVES
Force of acceleration either does not match both Earth and Mars gravity with a safe RPM, or significant space must be made between each ring.

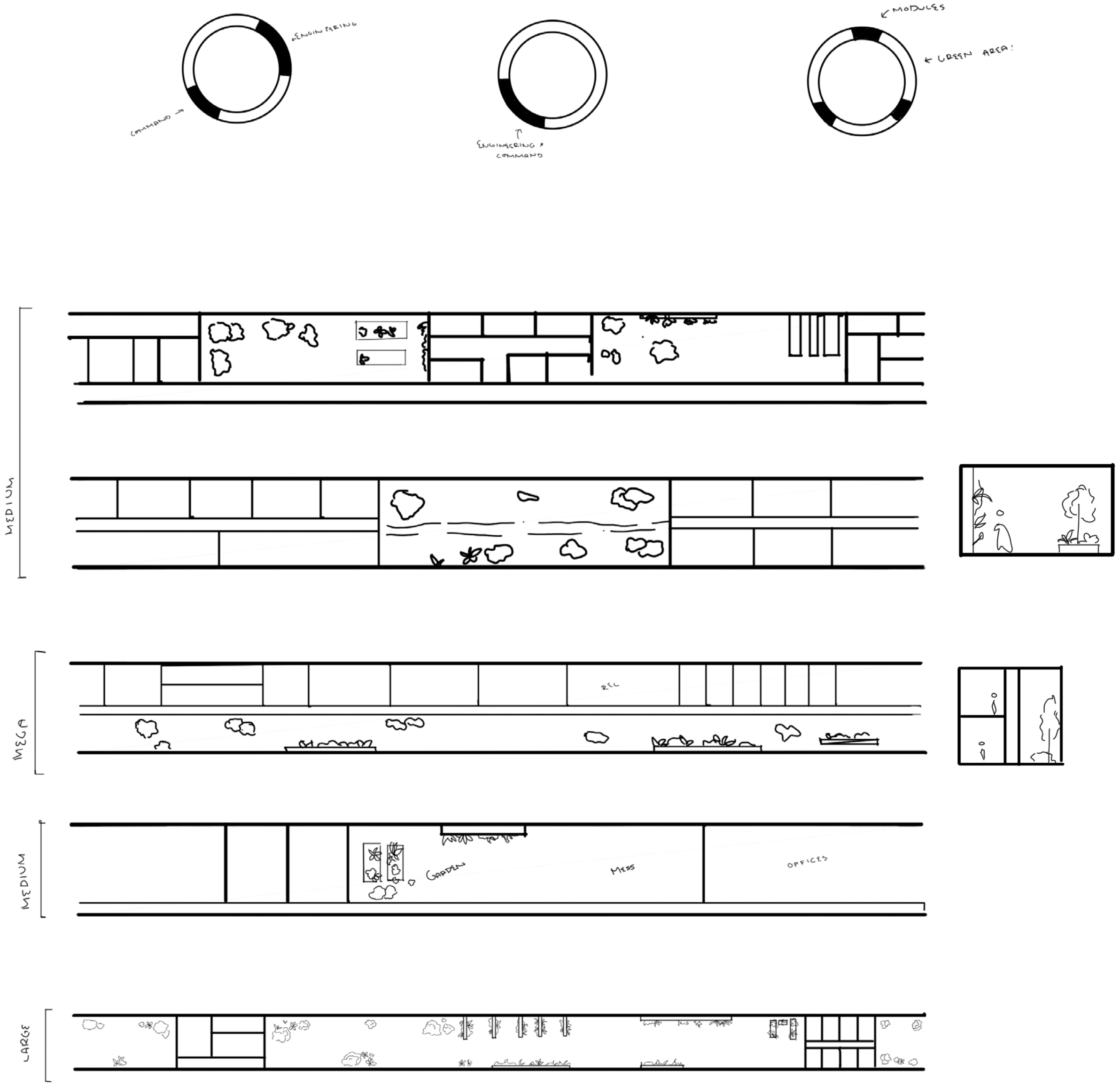
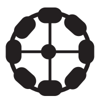


Figure.83 *Sketch experiments utilising the torus form, similar to that of the Stanford Torus precedent. This shape lends itself to large and monumental forms as evident in the garden-like spaces and trees.*

2.5. MODULAR TORUS

AS SEEN IN:
Interstellar



POSITIVES
Easily constructable with current methods
Easily modifiable and expendable

NEGATIVES
Possibly repetitive spaces
The creation of gravity requires a large radius.
Potentially uses far more material than other options

REFLECTION

Many of these forms could allow for prioritising wither gravity or zero gravity spaces as the principle living area. Those that prioritised gravity left the 0G spaces to be playful areas, whereas gravity generally delegates a space to work.

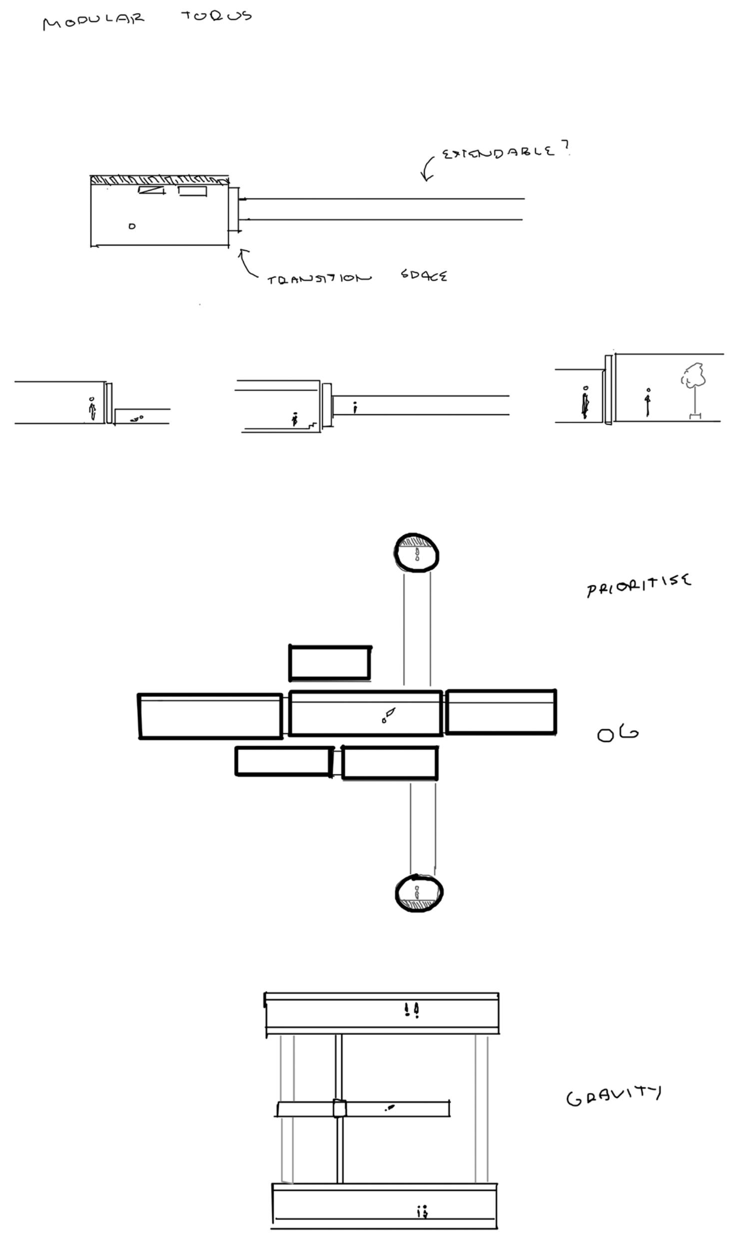


Figure.84 *Sketch experiments utilising the modular torus system.*

6.1. DESIGN ITERATION ONE

Derived from precedents, the form finding DS 2, and the first program iteration, RAPIDS was the first design iteration milestone. RAPIDS is a small, compact, crew vessel to Mars. The crew size is of six, the higher end of crew members found in academic and NASA mission architectures of the past few decades.

RADIUS: 50000 MM
LENGTH: 61000 MM
FLOOR AREA: 812M²
PROGRAM: SCIENTIFIC TRANSPORT VEHICLE
OCCUPANTS: 6

RAPIDS : Reliable And Practical Interplanetary Delivery System

The RAPID Mars scientific exploration vehicle and personnel carrier is your one-stop shop for a compact personnel and laboratory transport. Our innovative design is equipped with 0.95G and 0.4G rings for maximum crew comfort and efficient acclimatisation to the Martian atmosphere. Each gravity level accommodates specially designed laboratories for en-route work and sample handling, ensuring a maximum cost to scientific gain ratio.*

This transport is constructed from prefabricated modules designed to fit a Falcon Heavy rocket, ensuring a an affordable construction method with tried and true results.

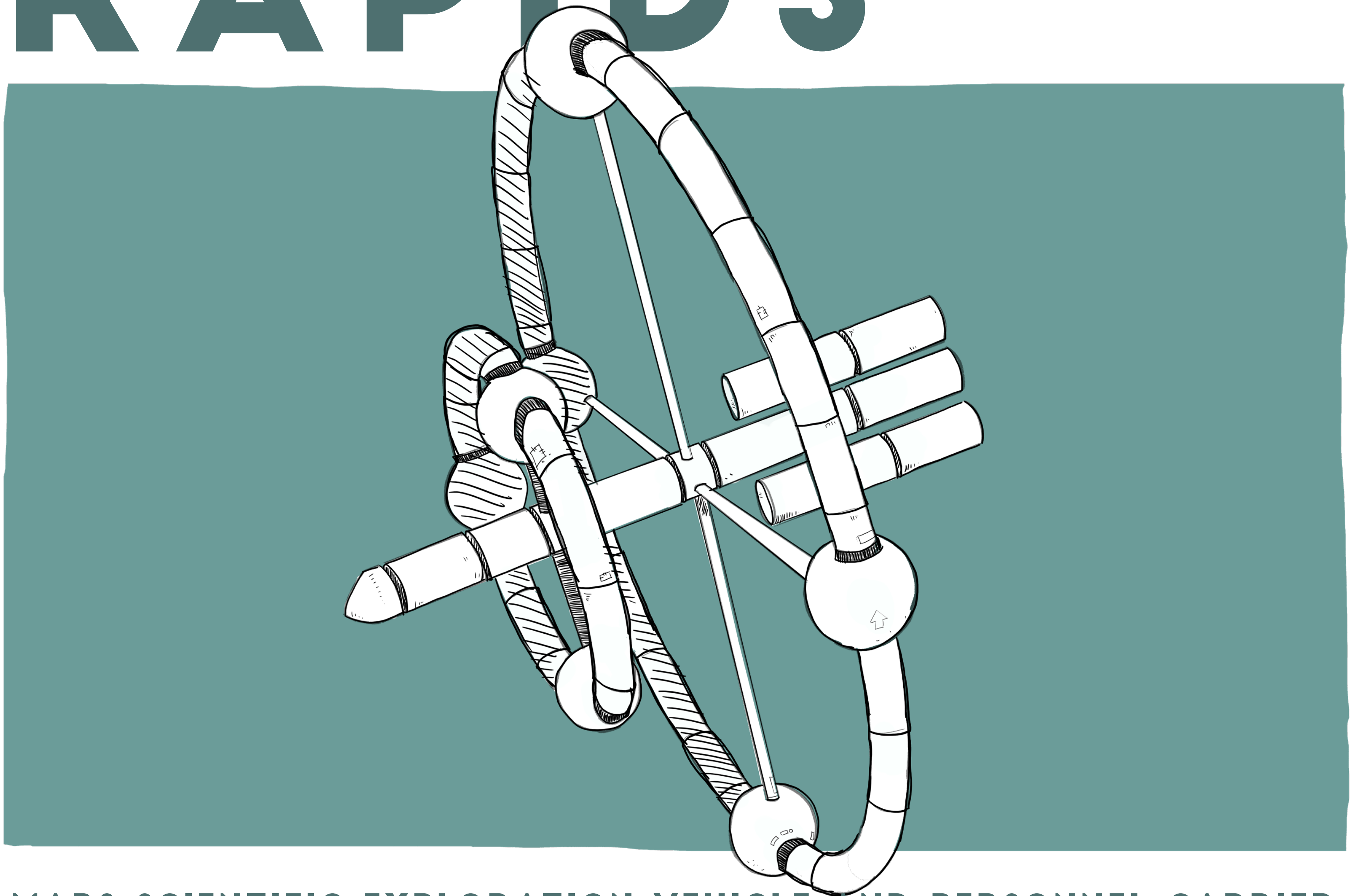
Innovative inflatable walkway components (utilising NASA-grade materials found on the ISS hotel) equipped with planting spaces and separate atmosphere controls help to enable a healthy work-life balance for your team of up to six crew members. Cosy individual rooms ensure the crew have their own space on the lengthy trip.

Rotational gravity training is supplied preflight to equip your crew with the knowledge to adjust to negative side effects of a short-radius spin as well as general tools to work within a rotational habitat.

For a well constructed, tried and true, no-frills alternative to personnel transport, choose RAPIDS.

*S.E.ARCH does not retain any liability for illness associated with artificial gravity on its ships. Please consult your space physician before entering an artificial gravity vehicle.

RAPIDS



MARS SCIENTIFIC EXPLORATION VEHICLE AND PERSONNEL CARRIER

Figure.85 *A sketch of the external form of the RAPIDS vehicle.*

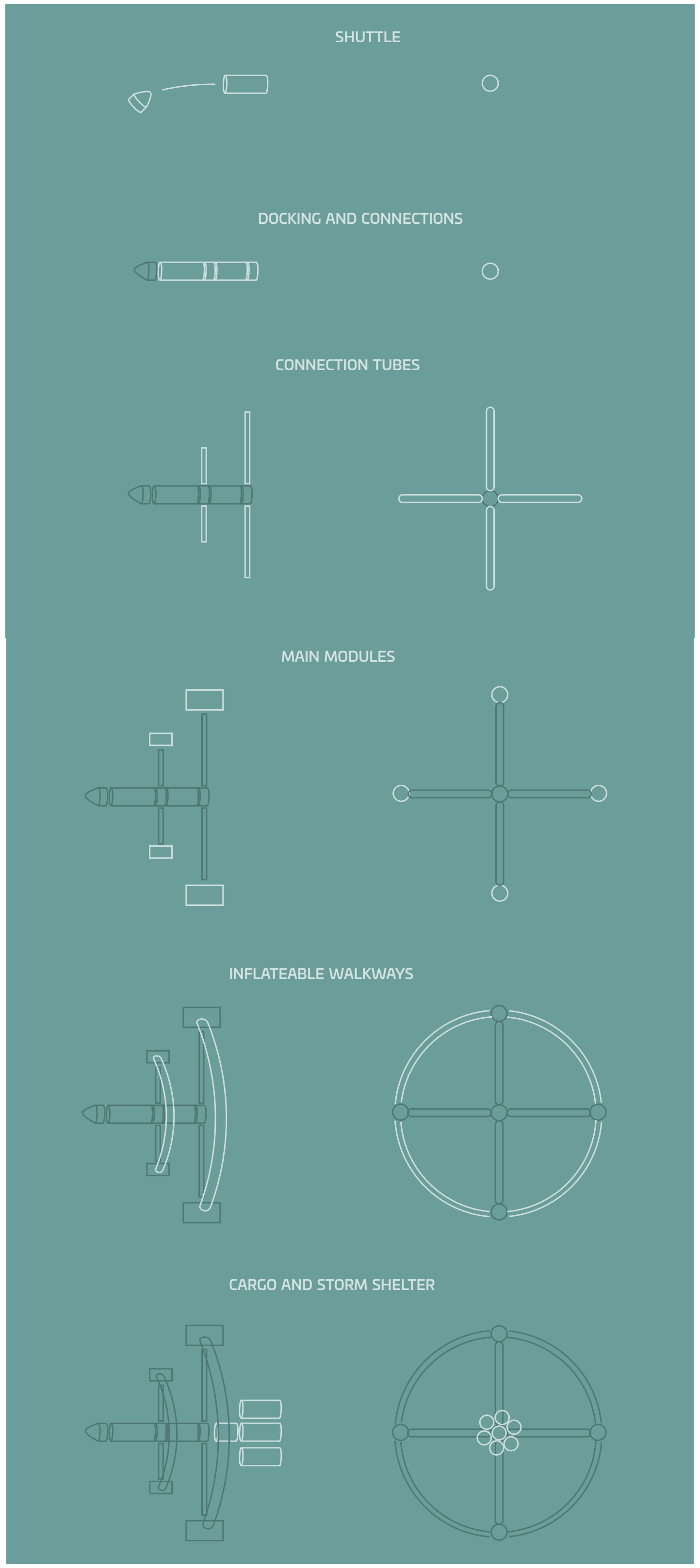


Figure.86 *Breakdown of the components and construction order of RAPIDS.*

DESIGN PROCESS

The design was based upon the three most influential architectural principles identified previously; the separation of personal and work spaces, the creation of gravity, and modularity.

In hindsight, RAPIDS was a very stripped down version of what space architecture could be - with the minimum radius for comfort, personal space, and a module size based on the technology available to us in the next half a decade.

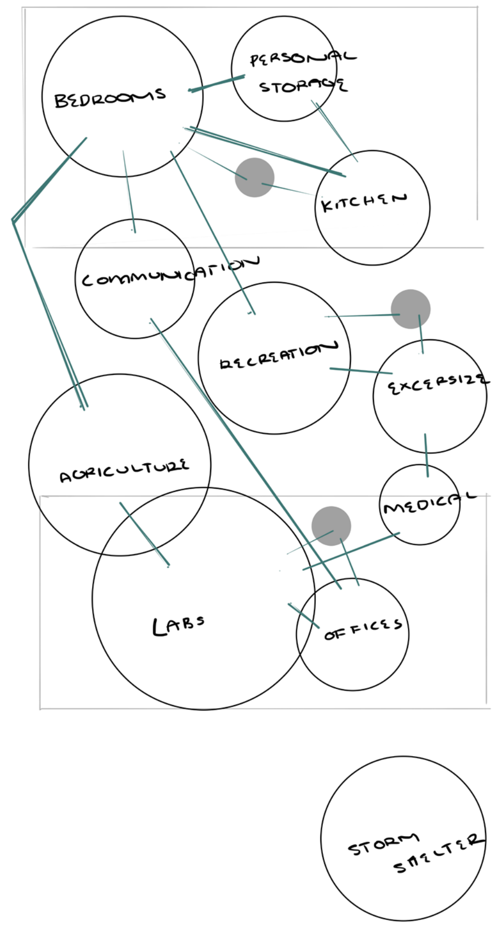
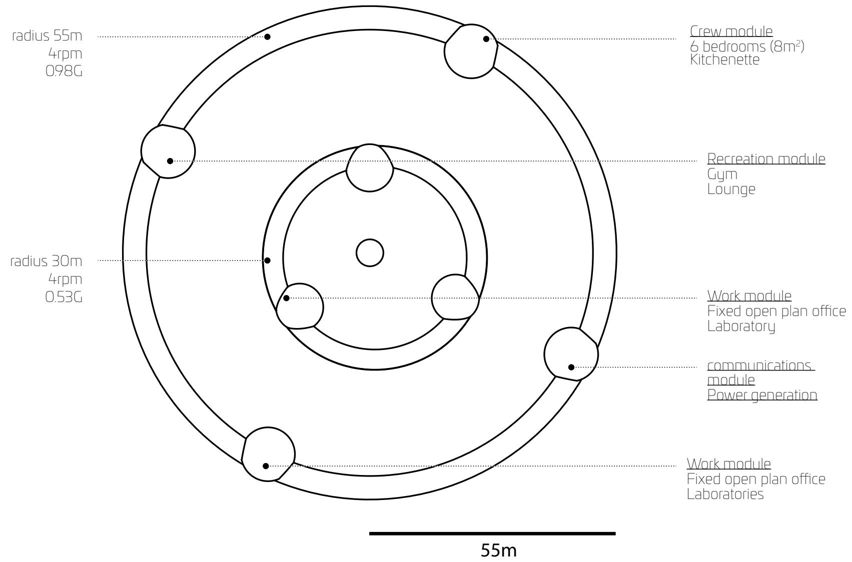


Figure.87 *Program diagram detailing the separation of the personal spaces from the work spaces. Recreation and communication spaces are used as a buffer.*



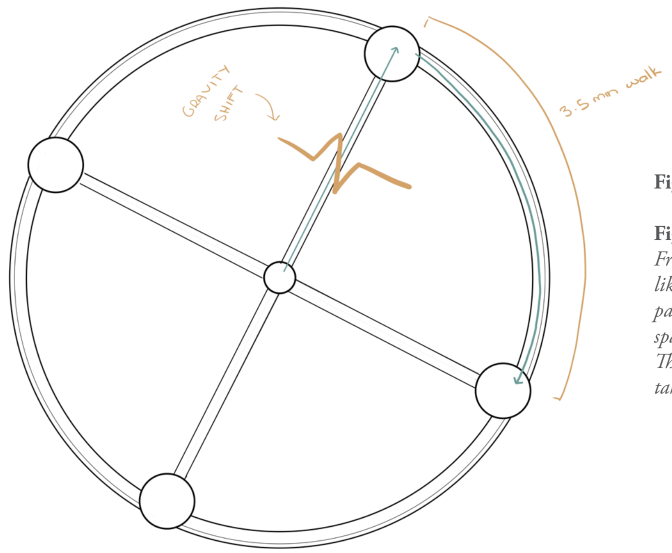


Figure.88 *(above) Overview section of RAPID*

Figure.89 *Demonstrating the circulation of the ship. From the connection node there is a shift from 0 to 1G likely to disorientate and be difficult to manoeuvre - particularly from those who have wakened bodies from space travel.*
The distance from one module to the next is 85m and takes about 3 and a half minutes to walk.

What it adapted from the SF portion of the research was the sense of novum. A ship where all of the spaces which are intended to be lived in are also designed as gravity spaces is an image currently only seen in SF. The walkways are a space where 'greenhouses' are used as a multi-functional space.

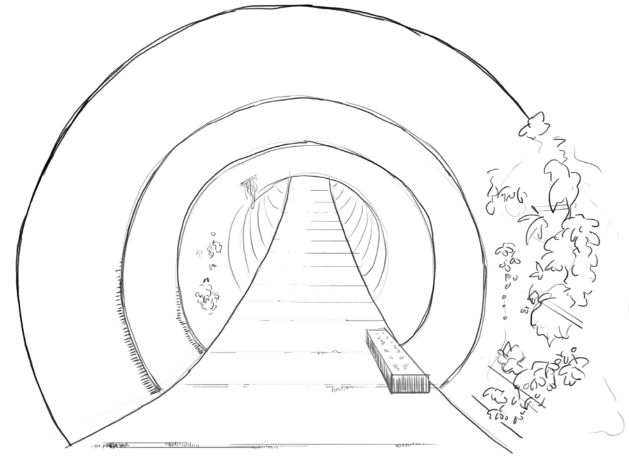


Figure.90 *View through a curved walkway. Although it appears curved, the force of the artificial gravity is always perpendicular to the edge of the curve making it feel as though the ground is flat.*
The inflatable walkways were initially used to save space on the rocket launches.
Their use was expanded to including the greenhouse spaces thus providing the inhabitants with variation, food, and a resemblance of outdoor spaces.
The plants closest to the kitchenette would be herbs, those furthest away decorative plants and starchy vegetables.

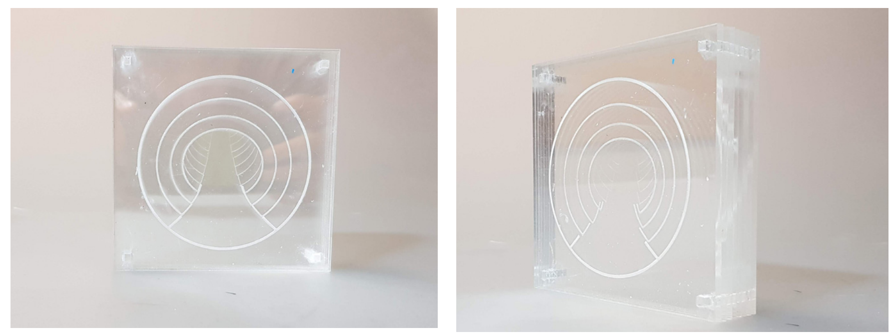


Figure.91 *Physical models - exemplifying the confusing perspective of being in a rotational gravity space.*

The two separate rings was extrapolated from Arthur C. Clarke's *Islands In the Sky.*[1] In this novel, Clarke has two different architectures that utilise multiple gravity spaces; the ship to Mars which increases and decreases its rate of spin as it travels to acclimatise its passengers, and the hotel orbiting Earth which has three separate levels therefore changing the radius (and force) as one moves between the floors. Both are designed to aclimatise the occupants before arrival.

1. Clarke, *Islands in the Sky*

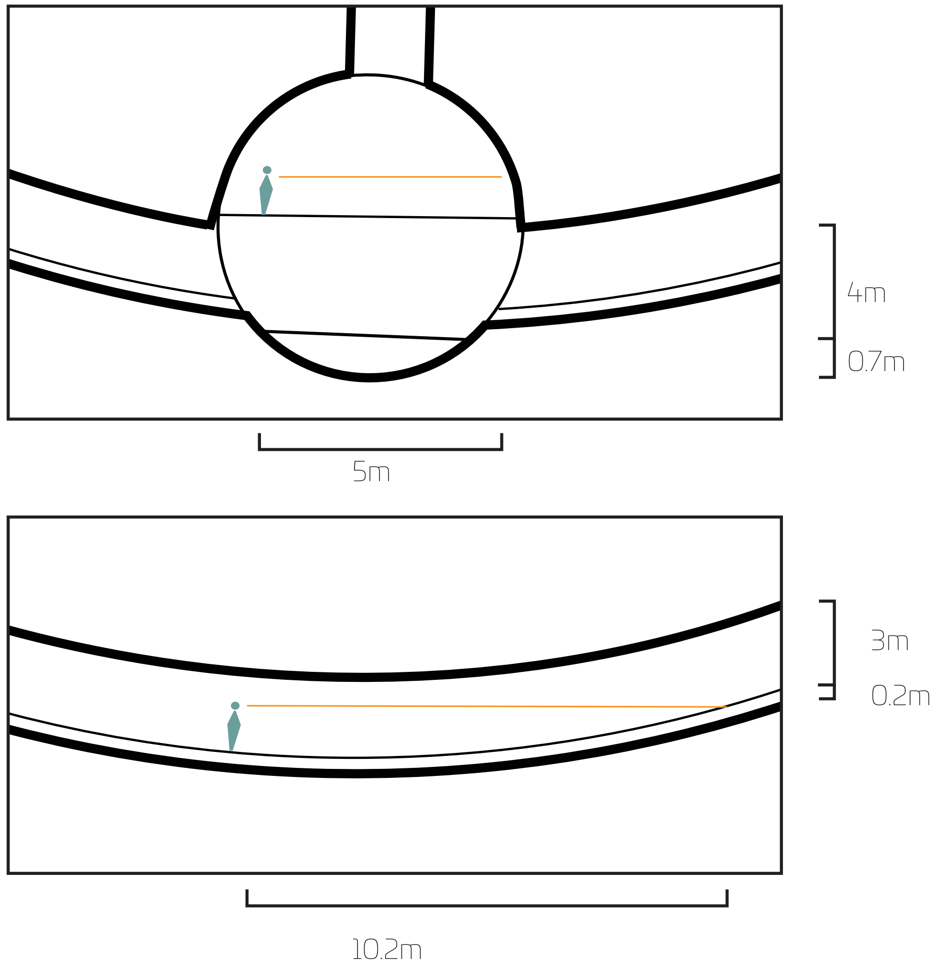


Figure.92 *RAPIDS has very short view lines, the maximum in the general living spaces being just over 10m, but the effects are likely hampered by the curve in the floor visually enclosing the space.*

CRITICAL SUMMARY

RAPIDS was a useful exercise to utilise design as a tool for understanding how previously separate pieces of research interacted with each other. It was also useful to highlight shortcomings of a primarily gravity orientated design and revealing the stressors such a space would create on the inhabitants.

The pros and cons below reflect the main feedback from personal reflection and a design presentation;

PROS:

- The ship immediately presents through its form two of the design drivers - modularity and the gravity intended to protect from one type of harm suffered in space.
- The use of the walkways as greenhouse and exercise spaces is novel, and effective.
- The program is effective at establishing a basic work-life balance.

CONS:

- The design was far too bland, and it doesn't expand on the SF aspects of the research. It lacks adventure.
- The overall form was considered, but not much architectural design iwasdemonstrated on a human scale.
- The form directly relates to the program and the creation of artificial gravity, but does not begin to respond.
- An extended program would be beneficial for creating a unique architectural environment.

DESIGN STUDY THREE
EXTENDING VIEWS

A critical concern of the first iteration is that the craft exacerbates a sense of monotony and enclosure. Two main strategies were developed to mitigate these while maintaining the typology; enlarging the radius, and extending the modules.

Of the two, extending the modules provides the simplest answer. This solution is easy to construct and modifiable over time. It embodies the modular system of current space architecture. Extending the radius, on the other hand, provides a more suitable environment for creating gravity without negative side effects discouraging passengers. However, the added length is mitigated somewhat by the enclosed feeling of the ever-sloping floor.

Overall, the modular solution is better suited to missions with smaller crews and has applications that would suit a part-torus or modular form. The larger radius provides opportunities that are in line with a more varied space industry, including a more utopian and polished exterior representation and extra space to expand the activities of the ship.

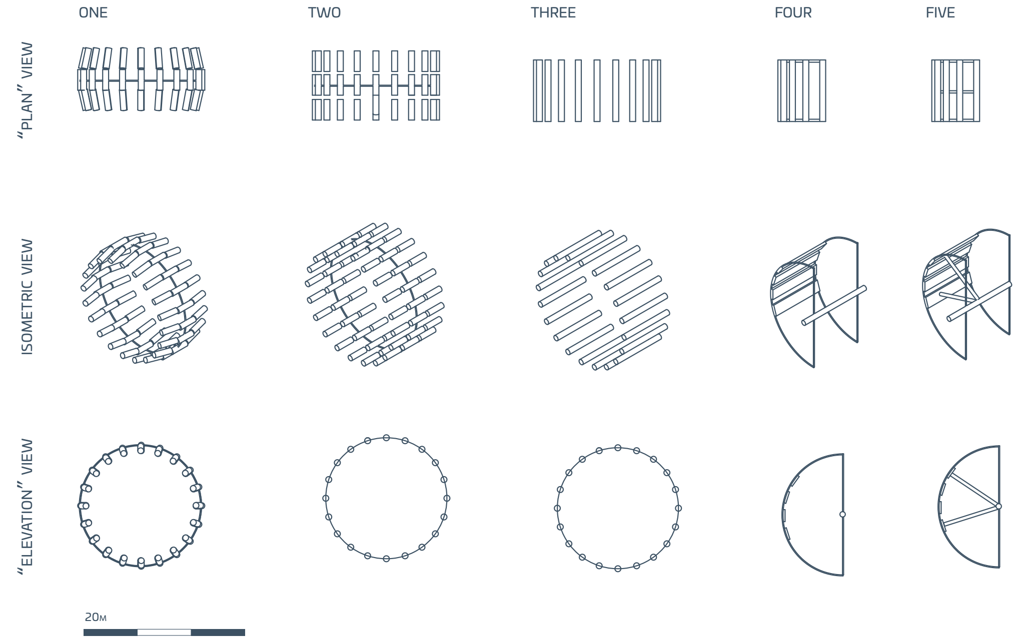


Figure.93 *extending view lines through the use of lengthy modules - similar in typology to that found on the ISS*

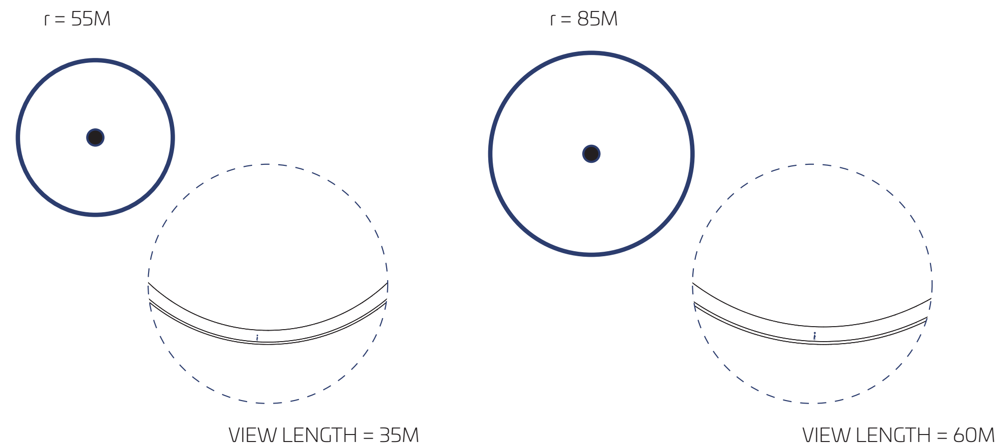


Figure.94 *Testing the length of view lines by increasing the radius of a vehicle*

DESIGN STUDY FOUR: CREATING MOTION

This series investigates strategies present the ship as 'aerodynamic' or exemplifying movement. This vessel has two distinct motions; forward to show it's journey, and rotational which signifies it as a human habitat. While innitially the foward motion was shown to be the significant, this excersize revealed that the expression of habitation created through the rotational motion may be a valuable symbol when developing a sense of community in space.

As the ship is essentially one whole made of many fairly uniform parts, many techniques utilised a gradient in the thickness or staggering of forms, mimicking ships such as The Orville, USCSS Nostromo, and the Millennium Falcon.

Figure.95 *'Take her out for a spin'*
This model explored exaggerating the sense of movement by having the modules expand the faster they spin, and contract as they slow down - mimicking the Conservation of Angular Momentum in reverse.

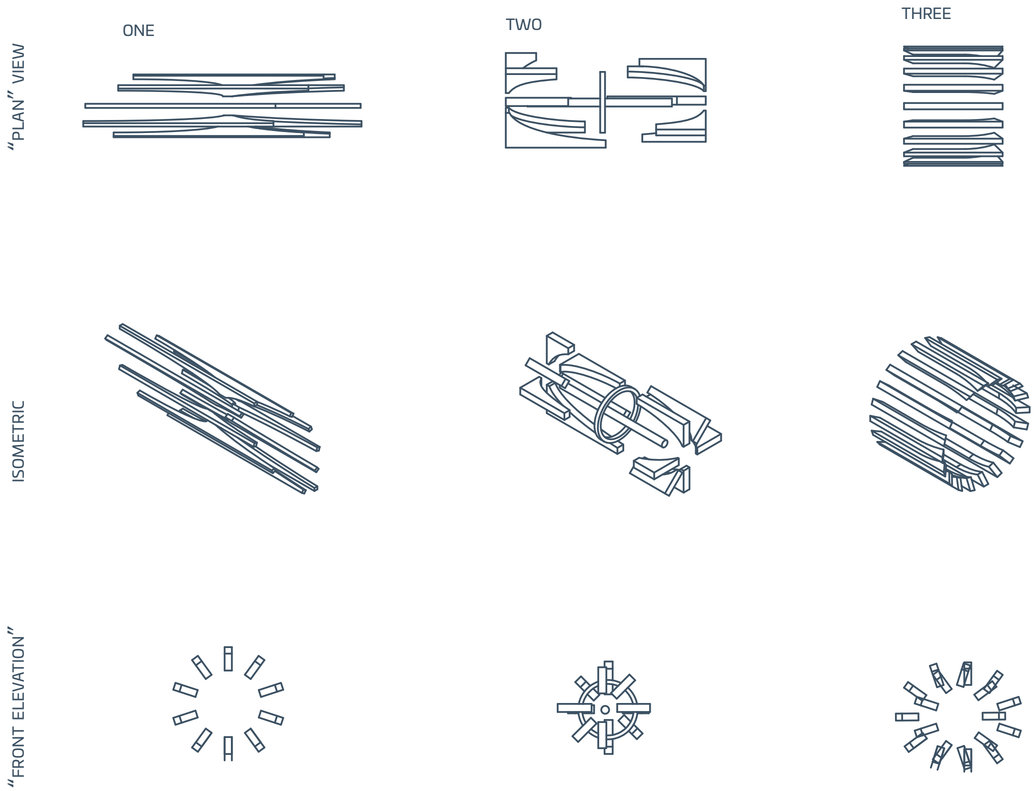


Figure.96 *Exploration emphasising the linear velocity of a space architecture in motion*

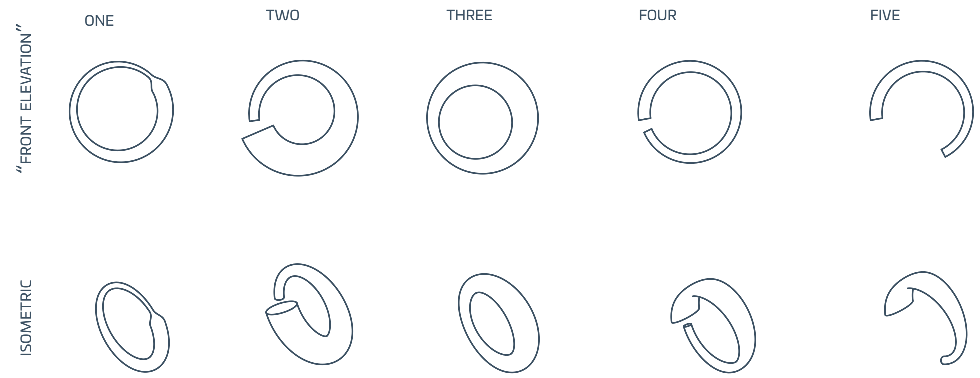


Figure.97 *Emphasising the angular velocity of a rotational gravity vessel*

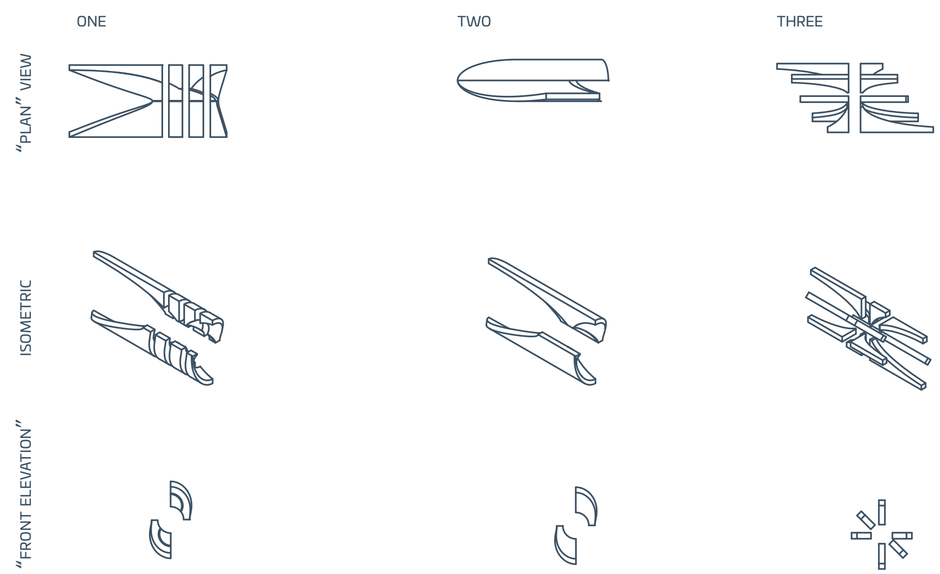


Figure.98 *Explorations combining angular and linear approaches*

6.2. DESIGN ITERATION TWO

Iteration two of the SEARCH vehicle is the Dual-ringed Artificial Gravity Flyer (AKA the DRAGonFly). This scheme prioritised the mitigation of the main drawbacks of RAPIDS, namely; the lack of anchoring features, developing a sense of movement, reducing monotony, and rebalancing size with program developments.

RADIUS: 60000 MM

LENGTH: 92000 MM

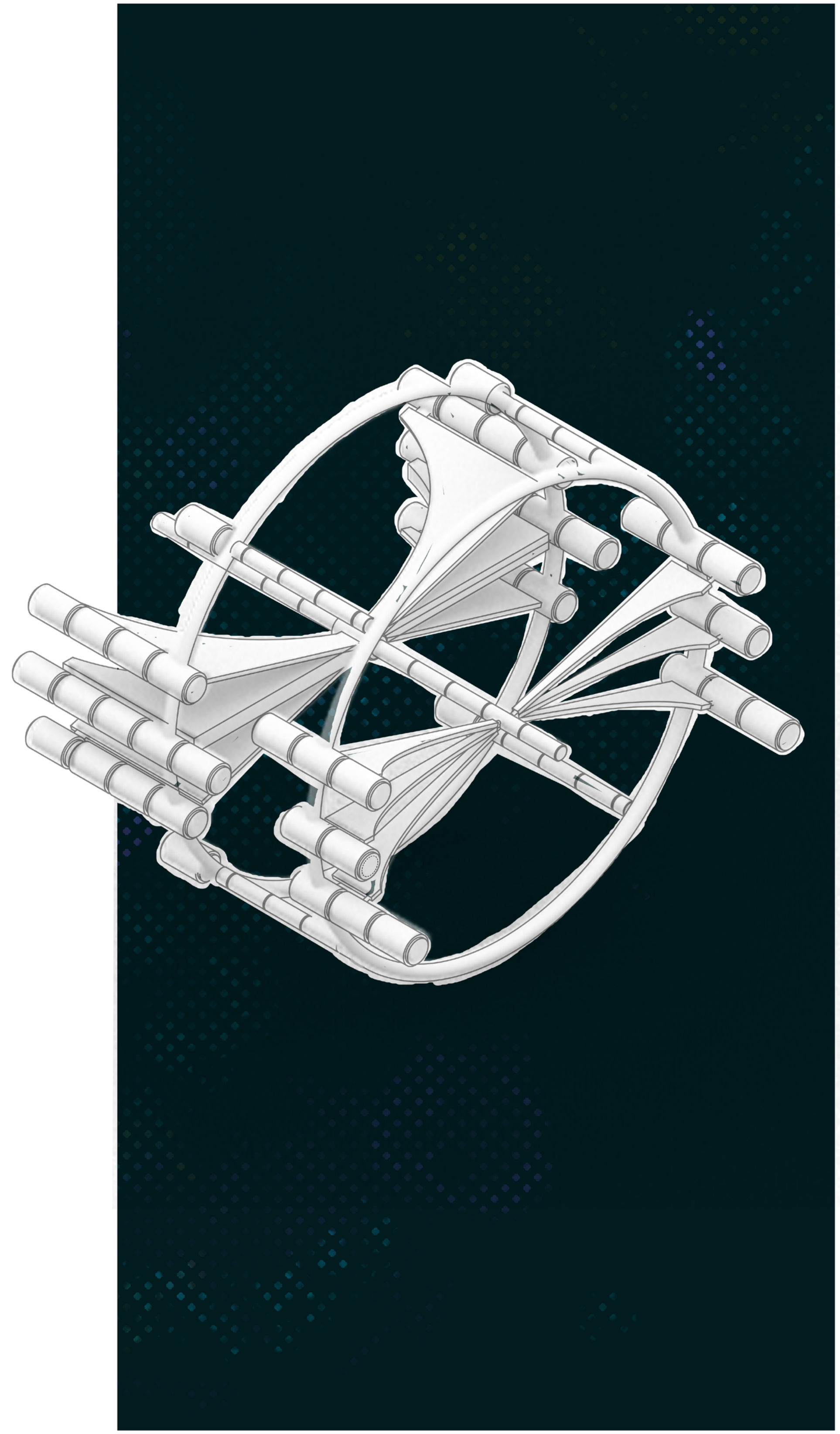
FLOOR AREA: 835M^2

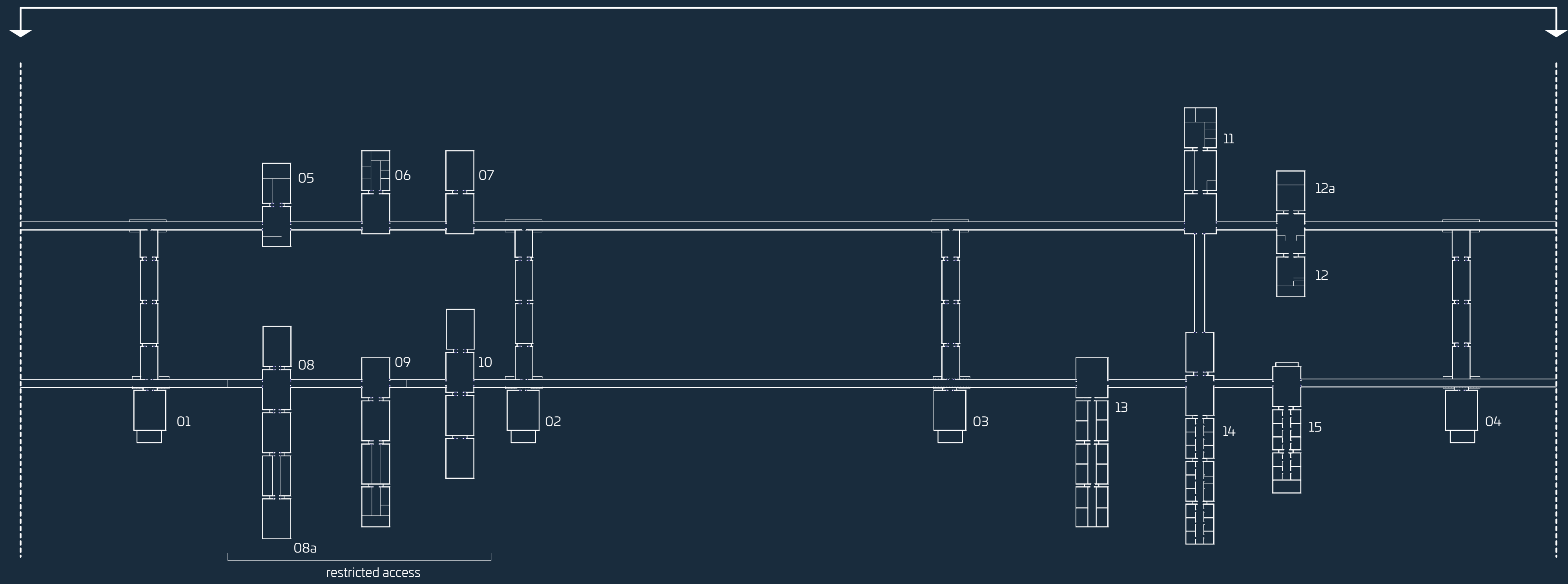
PROGRAM: CIVILIAN AND SCIENCE TRANSPORT VEHICLE

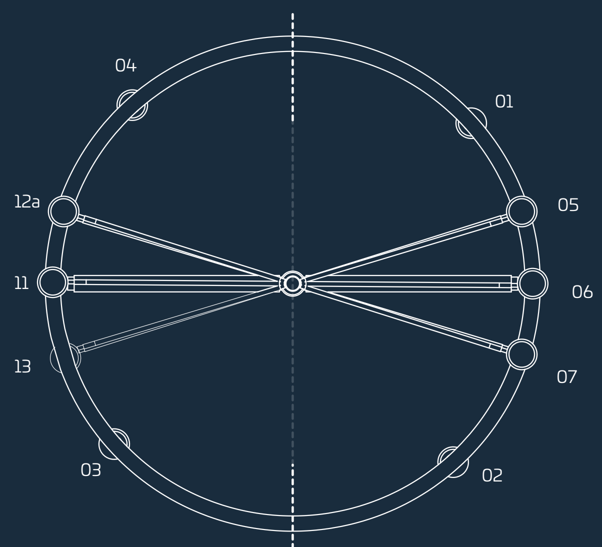
OCCUPANTS: MAX 40

Figure.99 *The Dragonfly's exterior*

Figure.100 *(Following) Plans*







01 - 04	propulsion nodes
05	eduction spaces
06	communications
07	lounge
08	laboratories
08a	laboratory docking
09	storage
10	engineering and storage
11	reception and admin
12	lounge and resturant
12a	bar
13	long term accommodation
14	mid term accommodation
15	short term accomodation

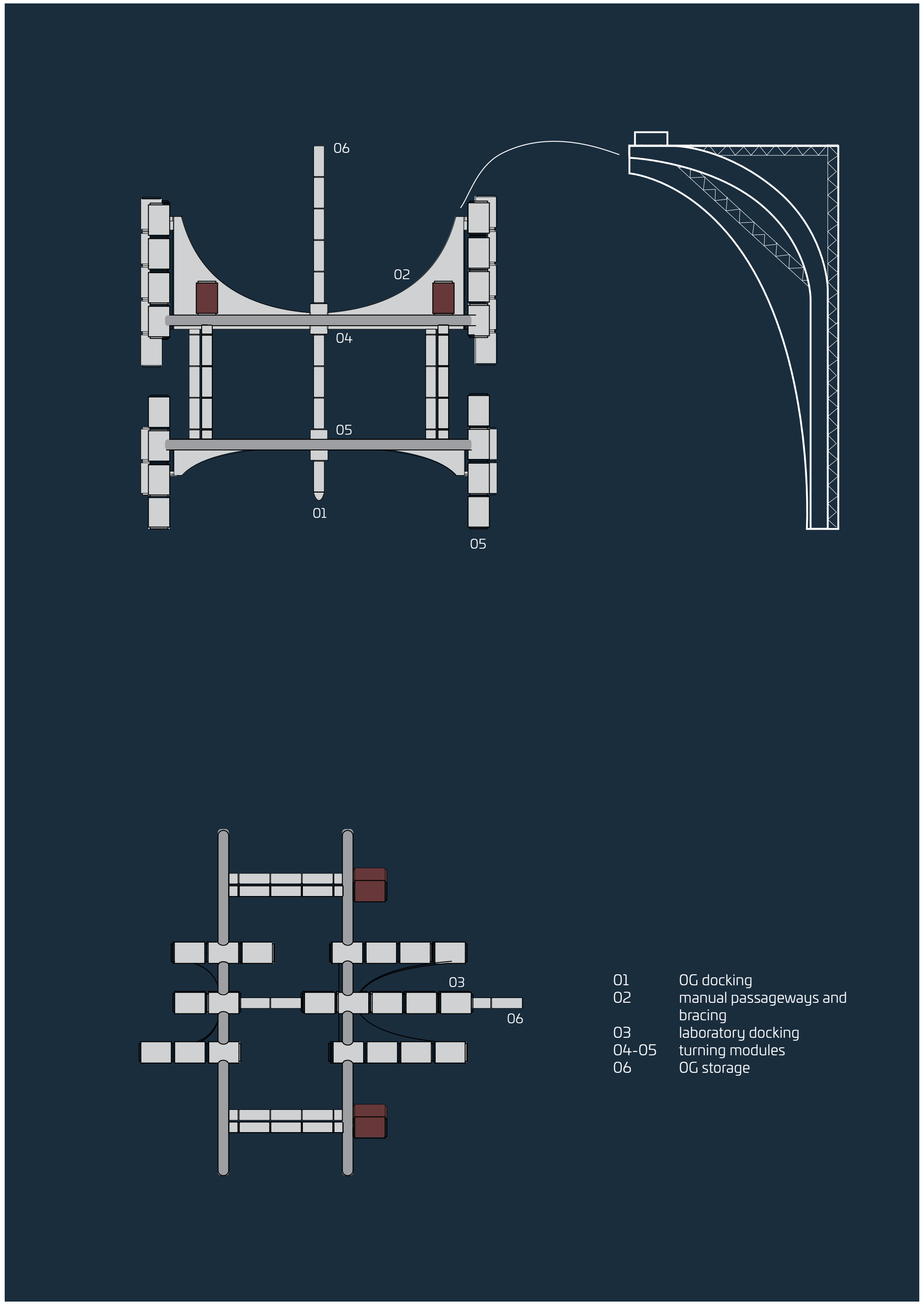


Figure.101 *'top' and 'side' elevations*

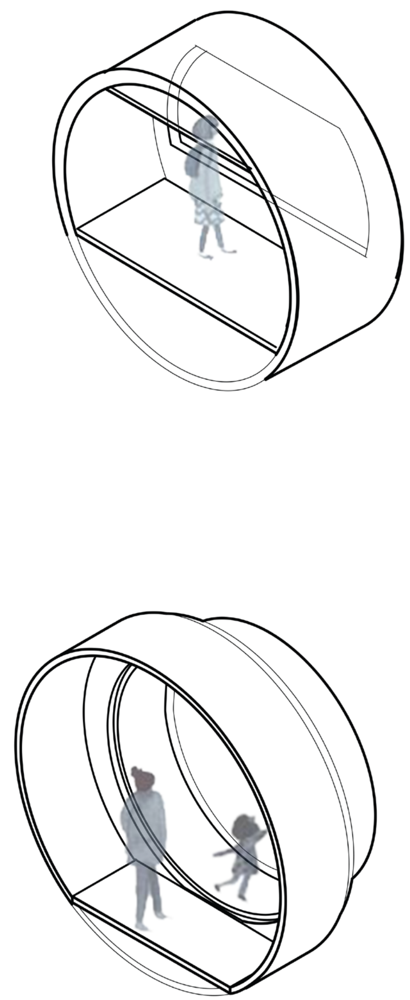


Figure.102 *Interaction with the windows is encouraged via playful and solitary spaces.*

ITERATION TWO SUMMARY

The scale of the ship increased, in an effort to integrate predictions of the future of the space industry as well as harmonising the view line length and overall form. As the program and construction restraints on iteration one serve to stagnate the design, it has adapted to integrate programs which allow for and require freedom of architectural form (as predicted by Sherwood).

Longer modules combinations stretch away from the bow to indicate a sense of movement. The modules are staggered along the walkway to decrease monotony and improve navigation through variety. Meanwhile, the two rings spin at the same rate to create a sense of stability. Onlookers from one ring can look in to the adjacent module - providing and anchor point in an otherwise empty site. The 'wings' provide stability to the modules as well as solidity to the otherwise visually flimsy form. In addition, two on each half house gravity walkways reminiscent of Noordung's ship for everyday and emergency use.

Propulsion and engineering nodes are located at four equal points for stability. Cross-ship walkways are located at each of the nodes to ensure quick access to from either ring. A separate docking module is provided for the laboratories. Community spaces are provided in the form of a lounge and eating spaces to improve passive and active interaction opportunities. Single and group communications rooms assist with maintaining bonds to Earth.

The division of the two halves of the ship effectively conveys the duality of it functions. They also provide an ability to create restricted areas with minimal disruption for civilian travellers. The staggering of the walkway connecting modules is a simple to construct method of decreasing monotony and confusion while navigating the ship.

While The DRAGonFly begun to resemble a ship of the future, it is hardly utopian in nature. There is little consideration of the interior of the ship or architectural elements at this stage. Although the exterior form is vital as it is more strongly influenced by the program and construction than terrestrial architecture, the nature of the ship means it will be experienced primarily from the interior.

Particularly as a critical objective of the ship is the social and psychological wellbeing of those aboard, careful consideration of the interaction between the interior architecture and the occupants is vital. The interior should take precedent over the exterior form rather than vice versa. Notably, little change has been made to the garden aspect of the walkways despite being identified as one of the most effective and multifunctional elements of the past iteration.

DESIGN STUDY FIVE: PROPULSION AND POWER GENERATION

Another strong and memorable influencer of form for the SF ships was their methods of power and propulsion, which often went hand in hand with the aerodynamic nature of their silhouettes.

Indicators of what methods of power generation used often included a mixture of light, colour, and form. Torus rings, (for example in the movie Contact and the TV show The Orville) can imply wormholes or subspace travel. The colour blue often implies futuristic energy-sources.

Warp drive, hyperspace, cold matter, antimatter… These are all familiar terms in SF, but are not possible in real life. In practical terms, the means of propulsion and power generation used in manned vessels need to be light, compact (or readily available), and safe.

Possible means of propulsion include;

- CHEMICAL / SOLID

Our current means of propulsion. Much of our space travel at the moment is spent launching from the earth where chemical propulsion is very effective…
This has given the world images of flaming rockets, noses pointed toward the sky.

- ELECTRIC AND SOLAR ELECTRIC

While huge amounts of thrust are needed to launch spacecraft and land them safely again, comparatively little is needed to actually cruise in outer space. Along with nuclear, forms of electric propulsion are often deemed much more sustainable than using traditional chemical methods of propulsion. It would likely be used in conjunction with chemical options.

- NUCLEAR

Fission reactions could be used to harshly decrease the amount of time spent on space travel. Resources can easily be found and mined in outer space.

• PHOTON PROPULSION / SOLAR SAILS (PROPULSION ONLY)

In 1608, in a letter to Galileo, Johannes Kepler stated that if we had ships to sail the heavenly breezes, we could surf the stars. Arthur C Clarke's novel The Sunjammer utilised a solar sail on the same principles.[1]

While heavenly breezes cannot be utilised in exactly this manner, solar sails use sunlight (photons) to push a spacecraft. Photons create a small amount of force when they connect with an object. While undetectable on Earth, in space this force has the potential to send spacecraft incredible distances incredibly fast with minimal fuel. The sails are incredibly lightweight and can be unfurled after launch. Current versions of solar sails such as Lightsails are "4.5 microns (1/5000th of an inch) thick" but are by necessity extremely large, and need a radiator to dispose of excess heat.[2]

Not only do the solar sails convey a sense of journey and exploration so important to the idea of SF, but they are likely to be a common technology in the future. Currently, they cannot carry humans and all of the necessities required to keep them alive - but that technology is certainly being developed.[3]

1. NASA, "A Brief History of Solar Sails"; The Planetary Society "What is Solar Sailing?"
2. Johnson, Young, Montgomery and Alhorn " Status of Solar Sail Technology within NASA"
3. The Planetary Society

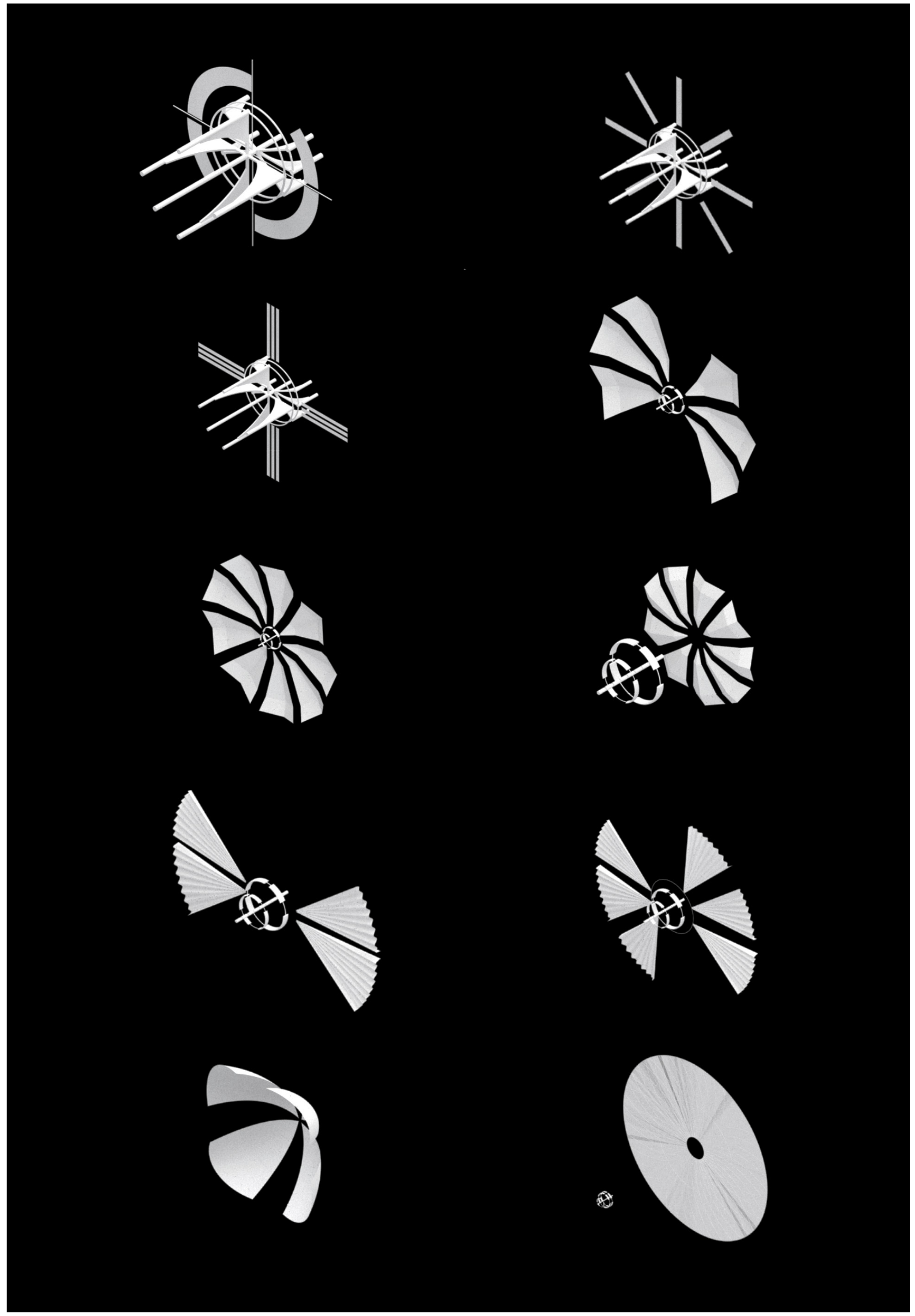


Figure.103 *Solar sail design iterations*

PRELIMINARY DESIGN REFLECTION

This stage was critical in establishing how the size and form of the structure may interact with the daily goings on of an interplanetary crew.

Measures to develop an environment that was protective of the crew were systematically tested and revised in each design, particularly in the creation of variation and the use of unique spaces due to the creation of gravity. Connections to outer space has been found to rely heavily on the use of windows, so measures were taken to ensure they both grounded the vehicle and developed a relationship between the inhabitants and site. Science fiction examples have been used throughout as a basis for establishing an exterior form.

Going forward, objectives that had not been adequately addressed was the integration and use of science fiction on a human scale for every day interaction and further establish connections to Earth and community. Critically, the design had also responded very little to the aspect of the future of the spaceflight industry.

While the first iterations were futuristic in their idealisation of a different space industry, they relied heavily on constraints found on Earth today. The ambition of the research to investigate the future possibilities between architecture and SF had been obscured somewhat by a drive to create an architectural solution which had in my mind become synonymous with a soon-to-be possible solution. It leaned much further from the arguments of Banham or Archigram despite the literature review establishing that fanciful creations are vital in science fiction imagination which in turn can affect the population and future designs.[1] The process of designing had been so cautious that they denied one of the key points of the research - to go where no one had gone before.[2]

1. Whitley, "Banham and 'Otherness': Reyner Banham (1922-1988) and His Quest for an Architecture."; Anderson, "Archigram's Radical Architectural Legacy."
2. Star Trek

What had been forgotten was that none of the SF examples relied on current technology. In fact, all of them defied what a space ship that humanity can currently create looks like. Astrofuturism and steampunk are tools that can then be utilised to establish a sense of reality on top of that.

As a result, before the process of creating the final design it was decided that it should focus on developing a design that balances a yet-to-be-seen form in HSF as we know it. It instead utilises a form more poetic and SF-orientated form which was established earlier in the preliminary design as an effective between of SF and architecture - the Torus. The final design stage integrates the reflections and discoveries of the previous designs with this new emphasis on the narrative of the novum through architecture.

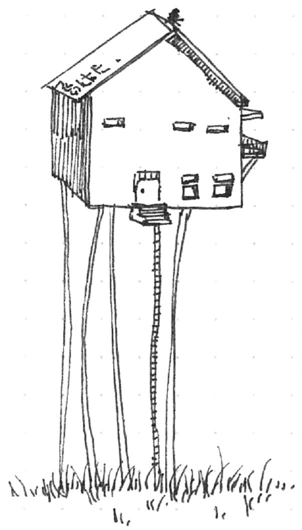


Figure.104 *Sketch experimentation - 'A house on the move'*

CHAPTER 7: **DESIGN OUTCOME**

Presented in this chapter is the final iteration of the SEARCH vehicle. The SuN DRAGon (Solar Navigator and Dual-Ringed Artificial Gravity ship) is described along with sets of research which guided the realisation of the design. This iteration coincides with the final program development.

DESIGN CATALYST

The Sun Dragon is an ambitious attempt to apply the principles learnt in the past iterations to a non-modular arrangement. A prominent research objective was to establish a new typology for human spaceflight vehicle. This new arrangement is an acknowledgement that the past forms, while providing valuable architectural insight, could be pushed further to imagine how space architecture could evolve if it were less inhibited by current space architecture construction methods. It is also an acknowledgement that the form created through rotational gravity is a strong symbol of human habitation and an outer space community.

The form of the ship is thus poetic and driven by narrative. In the absence of an aerodynamic form, the solar panels, solar sails, and radiators surrounding the ship are modelled on the sails of a terrestrial ship. Their inclusion exemplifies the journey of the vehicle which would have otherwise been lost.

Rather than utilising the sails as simply a form of propulsion, navigational fins are included. The journey requires a length of time travelling which allows small changes in direction to make a large difference. Other 'sails' include radiators for the dispersion of heat and solar panels (figures 108 and 109).

RADIUS: 85000 MM
LENGTH: 146000MM
FLOOR AREA: 9720M^2
PROGRAM: CIVILIAN AND SCIENCE MULTI-STOP TRANSPORT VEHICLE
OCCUPANTS: MAX 400
AREA PER PERSON: 32M^2

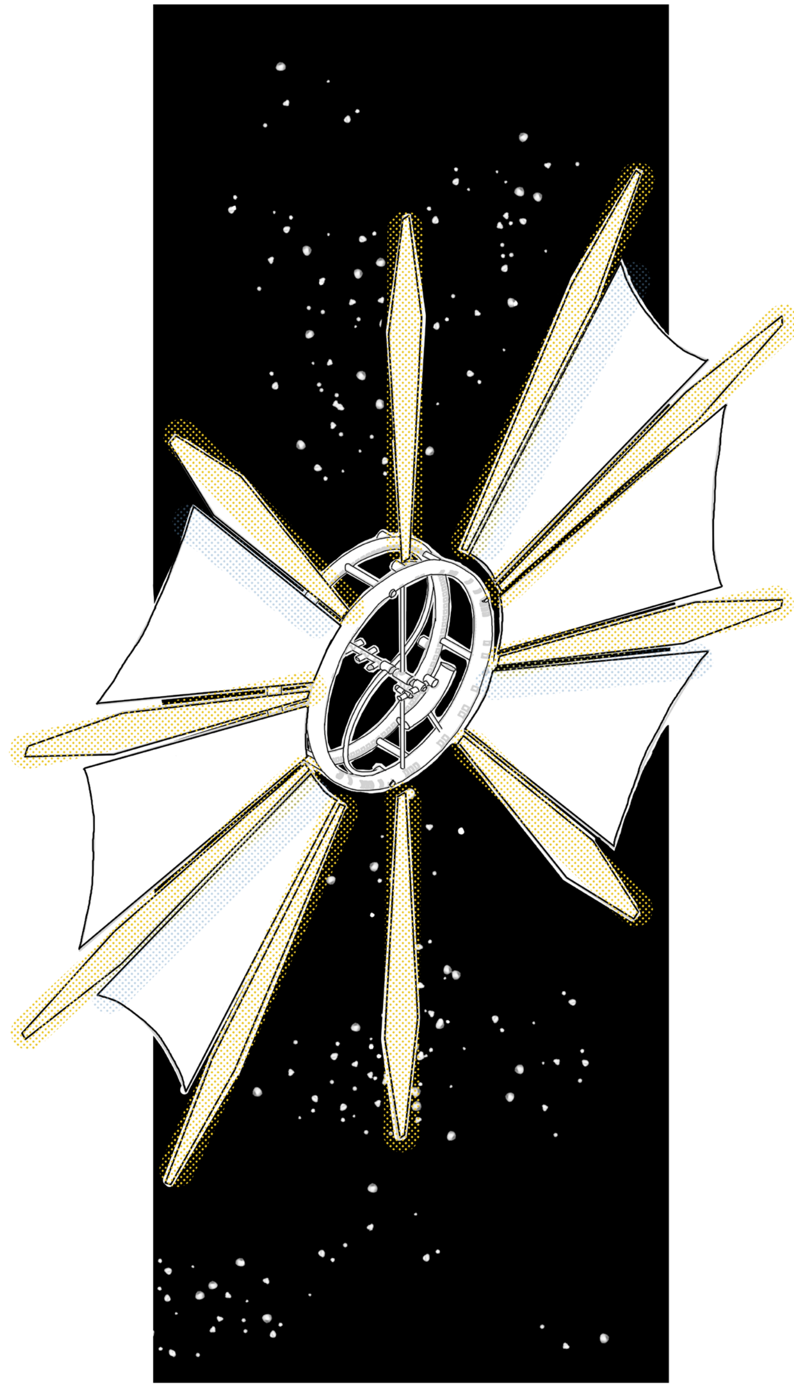
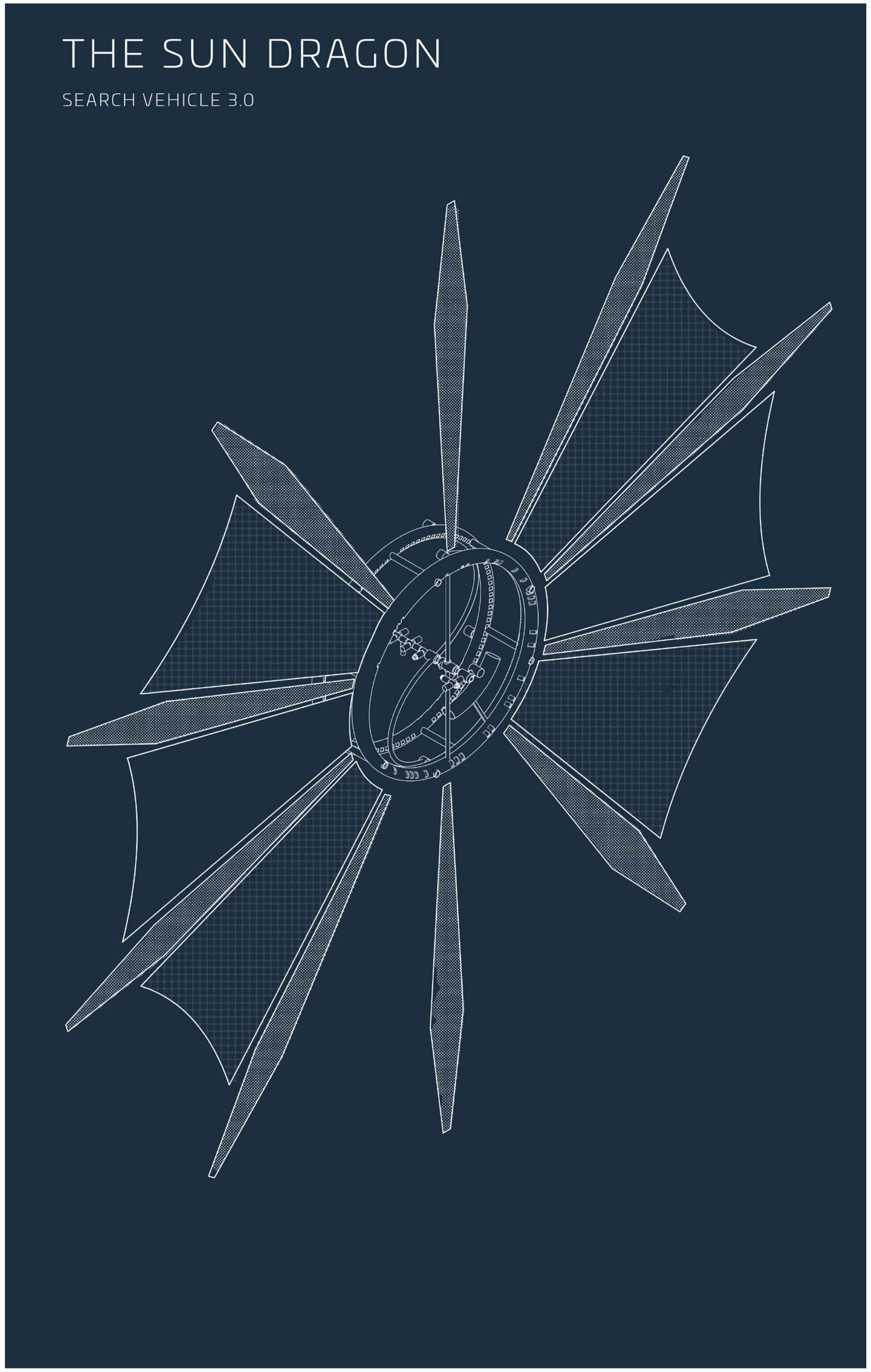


Figure.105 *The Sun Dragon's exterior - with the navigation fins out.*



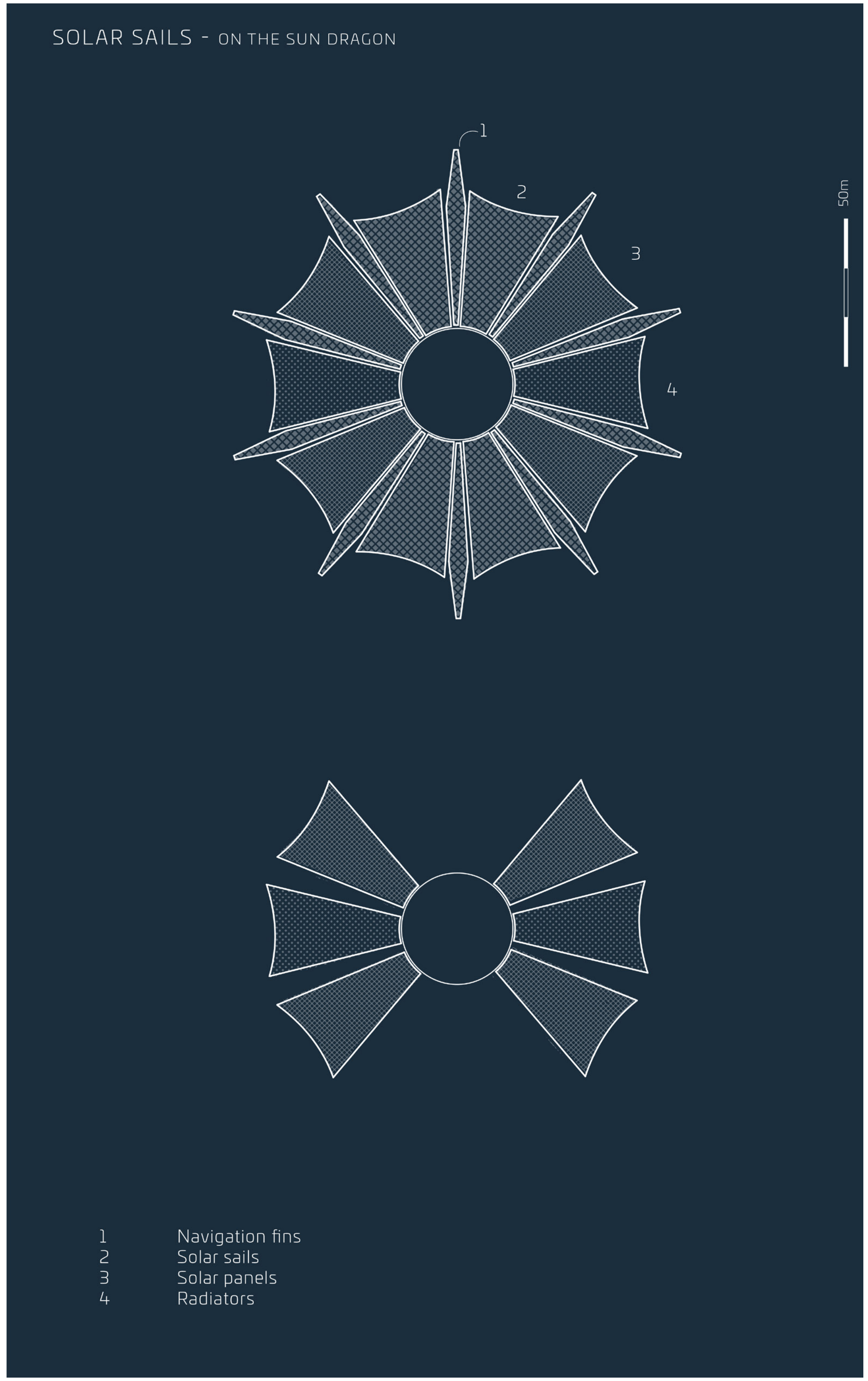


Figure.106 *and*
Figure.107 *Each of the 'sails' of the Sun Dragon actually has a distinct use*

OVERALL FORM

The SUN DRAGON consists of two rings. The main ring holds the living, working, and community areas while the secondary ring (the 'green belt') is dedicated to greenhouse and propulsion. This layout maximises leisure space and perceived environmental variety. Both rings rotate at the same rate and has corresponding windows, passively creating a sense of community and stability in outer space. The distance between the rings enables a sense of depth to the vehicle while avoiding the use of too many heavy materials.

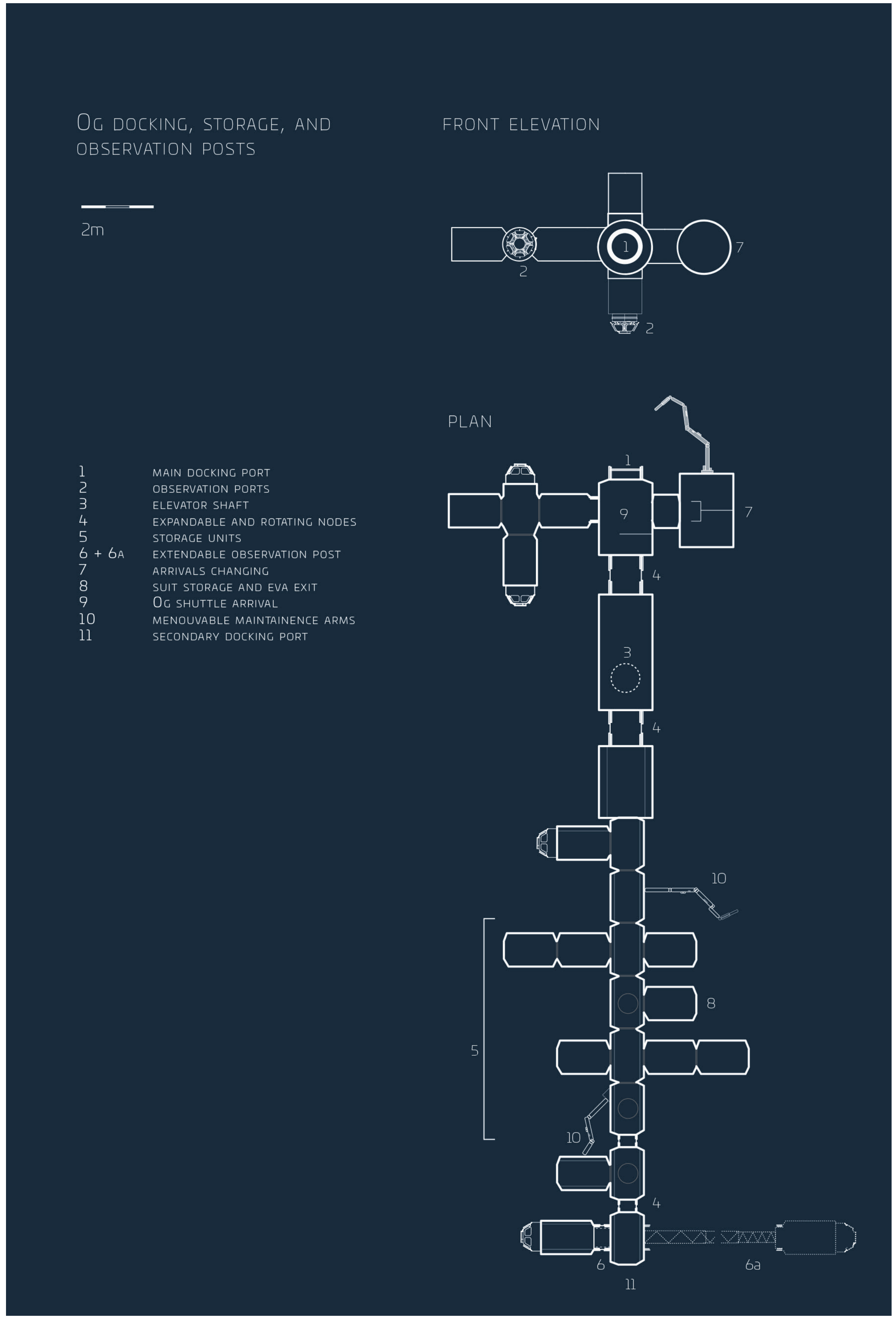
The 0G spaces (figure 108) function as an arrival zone, storage, and observation areas. The elevator node constantly rotates with the outer rings. The main docking port is intended for use when the craft is already spinning, while the secondary is for crew and cargo use. Four observation nodes are located along the length to allow for observation and maintenance of the rings. Being able to rotate allows them to, if needed, maintain a rate of rotation consistent with the outer rings. The ability to extend these to a longer radius avoids unnecessary gravity adjustment phases and allows closer observation. Mechanical arms provide maintenance, assist with docking, and move modules when necessary. Further shuttle bays are located along the main ring of the ship for loading large items unsuitable for 0G movement, passengers, and restricted access such as at the laboratory (figure 109).

In addition, 0G spaces house workstations for debris monitoring equipment. Additional nodes berthed adjacent to the main shuttle bay allow for 0G recreation away from the storage and monitoring equipment. It is anticipated that these will be active personal and group spaces.[1]

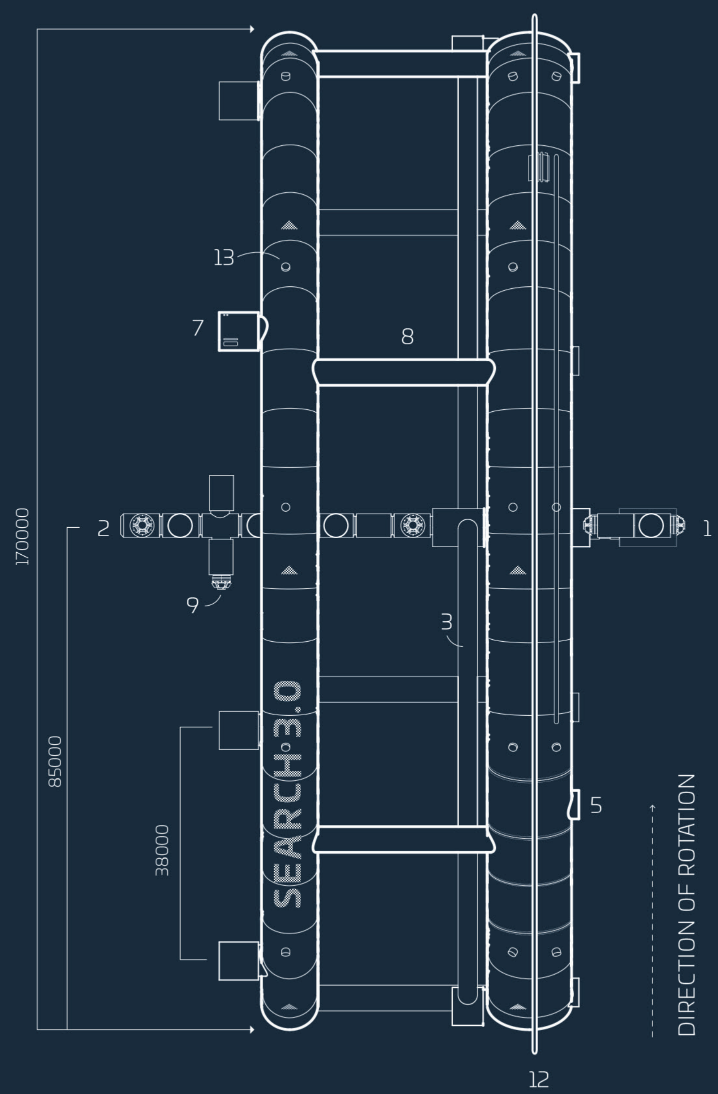
Figure.108 *The 0G areas serve mainly as practical areas - but with plenty of space to play around.*

Figure.109 *(Following) The Sun Dragon looks far more practical close up than the poetic image from afar.*

1. Liapi, " Microgravity Playscapes"

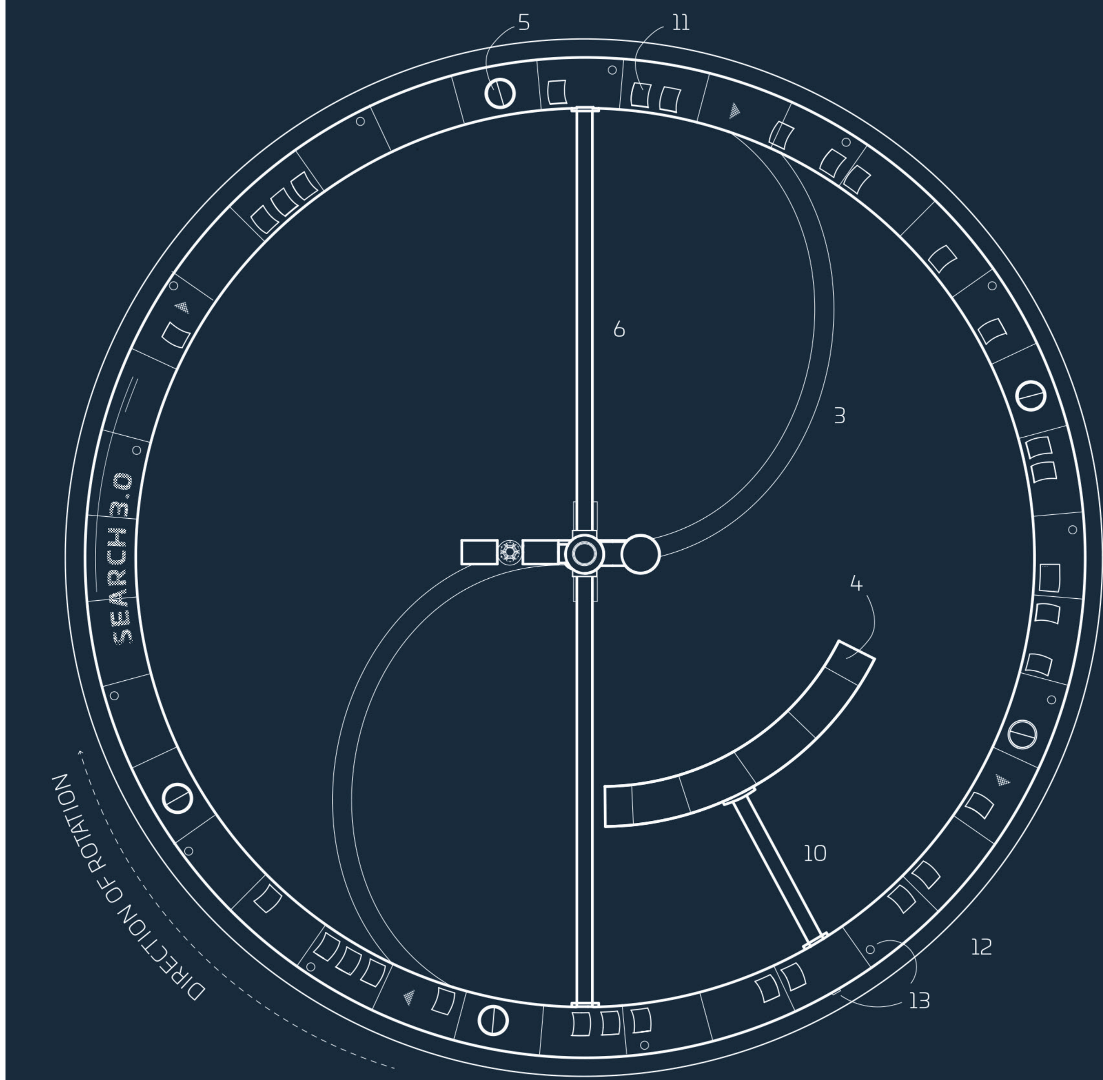


SIDE ELEVATION



1 Og shuttle bay
2 Restricted shuttle bay
3 Manual walkways
4 Mars gravity module
5 Emergency and barding shuttle bay
6 Elevator
7 Propulstion nodes
8 Ringways (cross-ring walkways)

FRONT ELEVATION



9 Maintainence cupolas
10 Laboratory - Mars node elevator
11 Exterior widows
12 Solar sail supports
13 Power and data graplling points for robotic arms

10M

CONSTRUCTION

Similar to the construction of a building, the SEARCH vehicle's main rings are divided into a 9m grid - providing and underlying order for both planning and construction. The radius of the vehicle is such that the curve is minimised, allowing it to fit in to a large rocket if necessary - such as the Falcon Heavy or it's future iterations. This division allows the ship to be more easily manufactured on Earth or in microgravity as well as efficiently and easily put together in situ.[2] The ship is to be constructed mainly of space-native or moon-manufactured materials, including 301 (or it's future equivalent) steel and carbon nanotubes[3] and launched from the moon to mitigate costly menouvers form Earth.

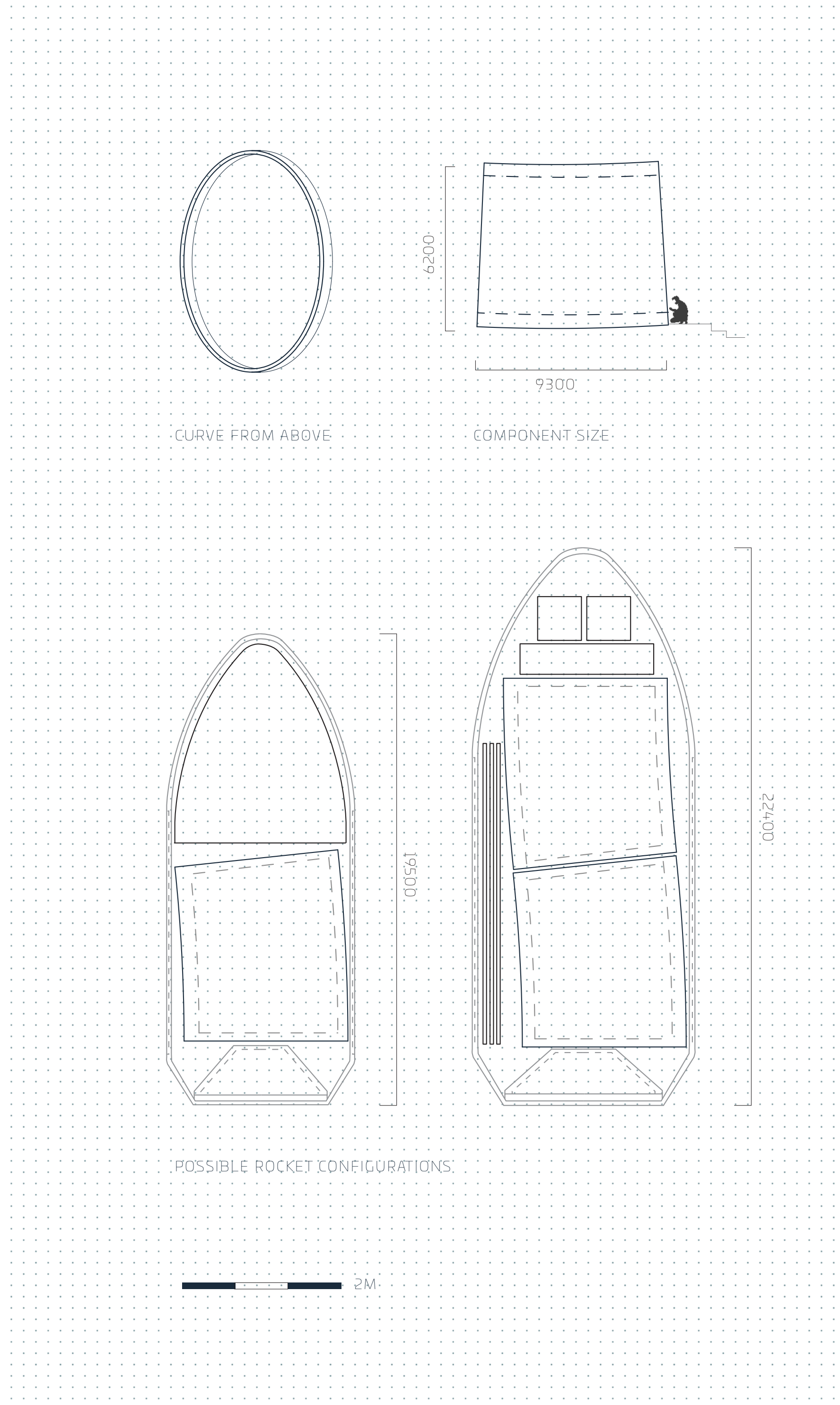


Figure.110 *The construction and delivery methods of a module.*

2. Sherwood, "Comparing Future Options"; Naser, "Space Native Construction Materials";
3. Musk, "Starship Update", Zipay "Near-Term Artificial Gravity Concepts"

INTERIOR ORGANISATION

At 85m, the radius is significantly larger than previous iteration. It provides view lines of up to 48m and significantly decreases the rate of rotation required as well as the slope over the length of a human body (for comfort while lying down). Long and mid-term accommodations are located near each other and far from the work spaces and laboratories, offering as much distance between professional and private spaces as possible. Communal recreation, administration, lounges and gymnasiums are located between to encourage passive community interaction between each of the short, mid, and long-term occupants

Along the interior edges of the rings sits the central circulation (figures 111 and 113). The corridors are lined with matching windows to maximise the sense of stability created by the dual rings. Once again, manual walking tubes (similar to on Hermann Noordung's vessel)[4] are provided as an alternative to an elevator for going between the 0G and 1G zones. As well as providing veriety, they allow access during maintenance and emergencies.

As seen in figure 109, an additional module with access from the laboratories (at a radius of 40m) allows for Mars-like gravity. This space can be used for acclimatisation by particularly gravity-sensitive passengers as well as a laboratory and storage space for Mars samples.

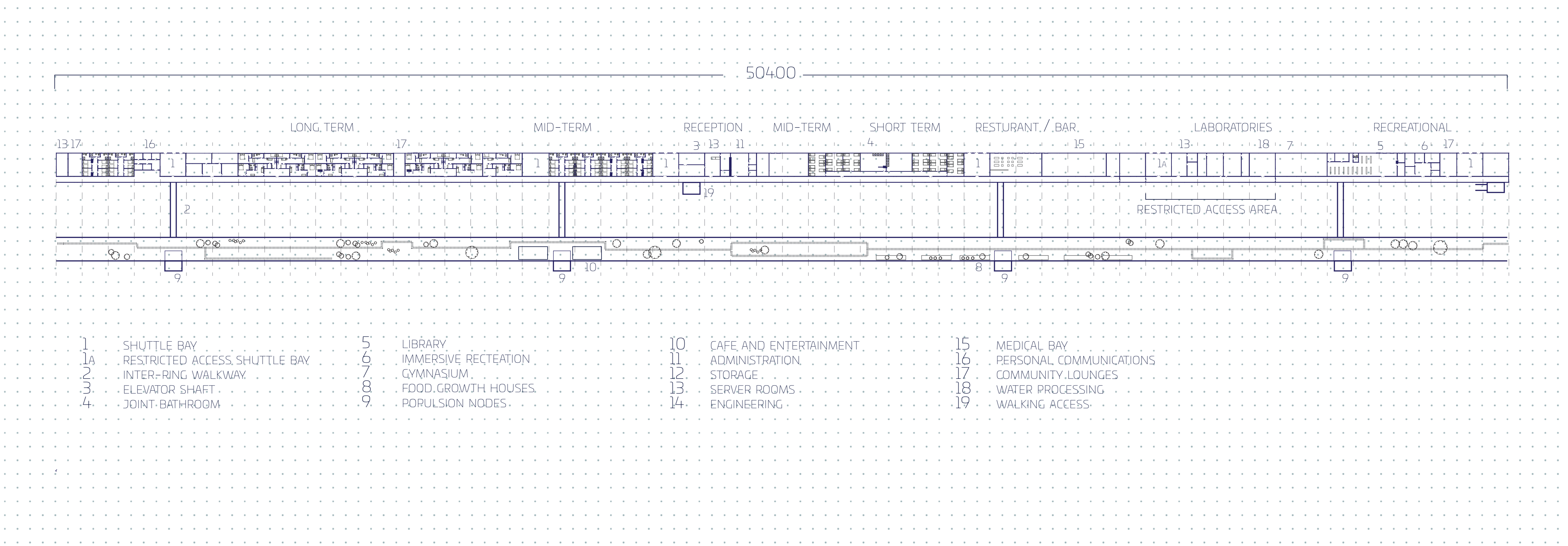


Figure.111 *The plan for the Sun Dragon - although each end touches to form a loop.*

4. Noordung, *The Problem of Space Travel*

The inclusion of the green belt allows space for food production, exercise, and additional personal space. Additionally, it provides spaces for smaller educational areas and cafés to instil a sense of variety for those living aboard. Being separate from the main ring, atmospheric controls can be individually tuned improving the best environment possible for both the plants and the people. Its inclusion provides another safeguard for adequate environmental variation, human-system interaction, and nutrition.[5] The propulsion modules are kept away from high population areas – allowing for easier access in an emergency as well as minimising risk to human life. External lighting ensures each ring is visible from the other.

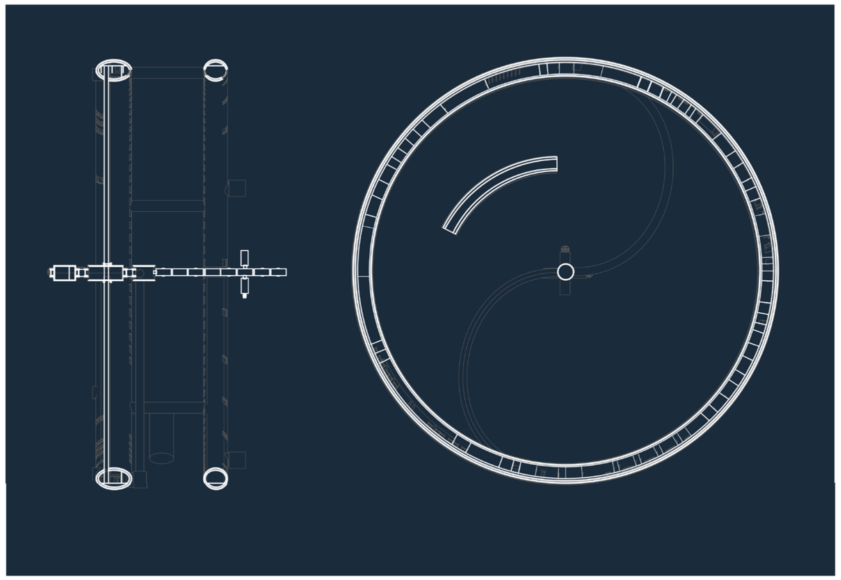


Figure.112 *Sections*

5. Norsk and Smith, " Artificial Gravity Future Plans for ISS", Haeuplik-Meusburger, Paterson, Schubert, and Zabel " Greenhouses and their humanizing synergies"

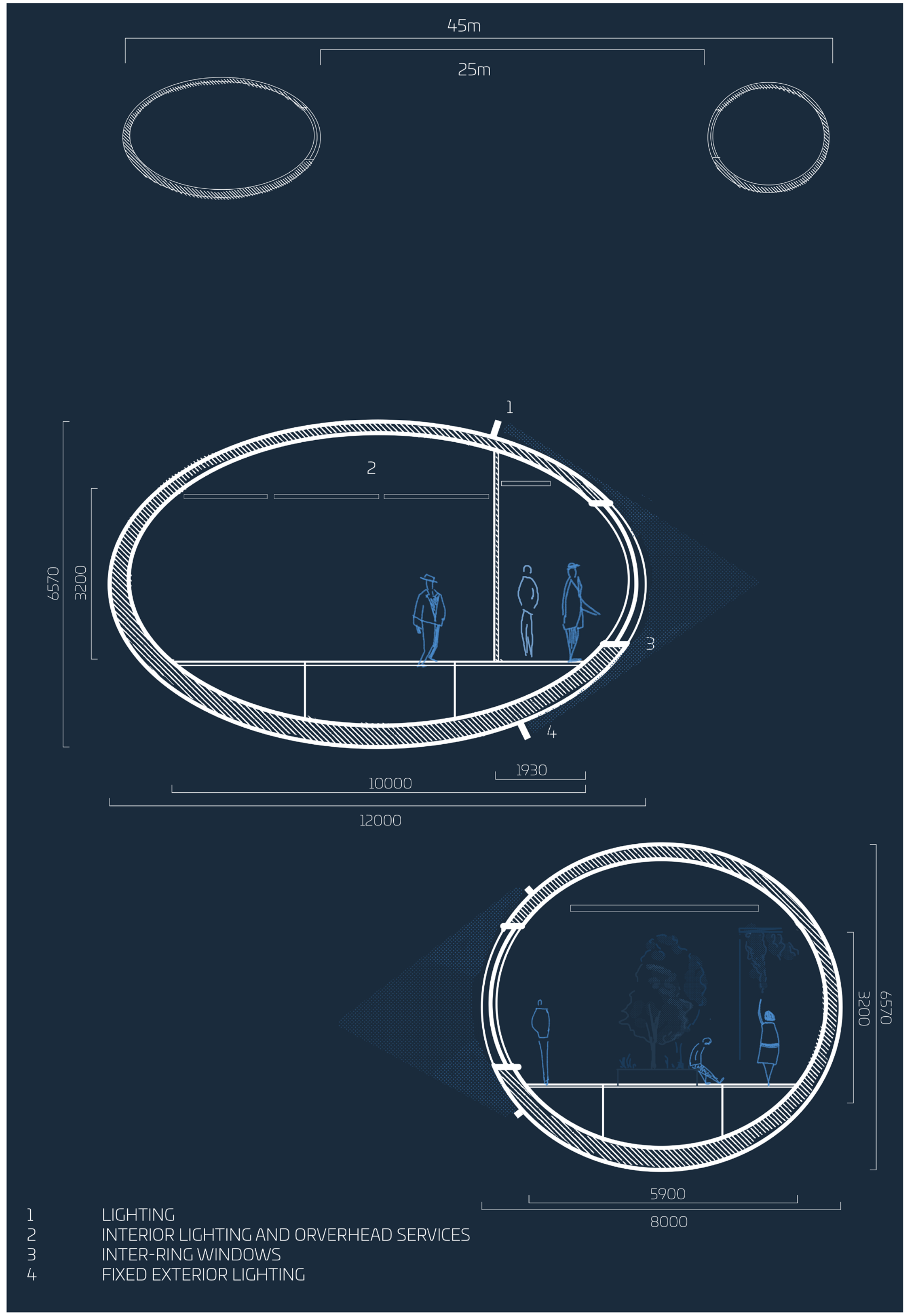


Figure.113 *The division of spaces in each ring*

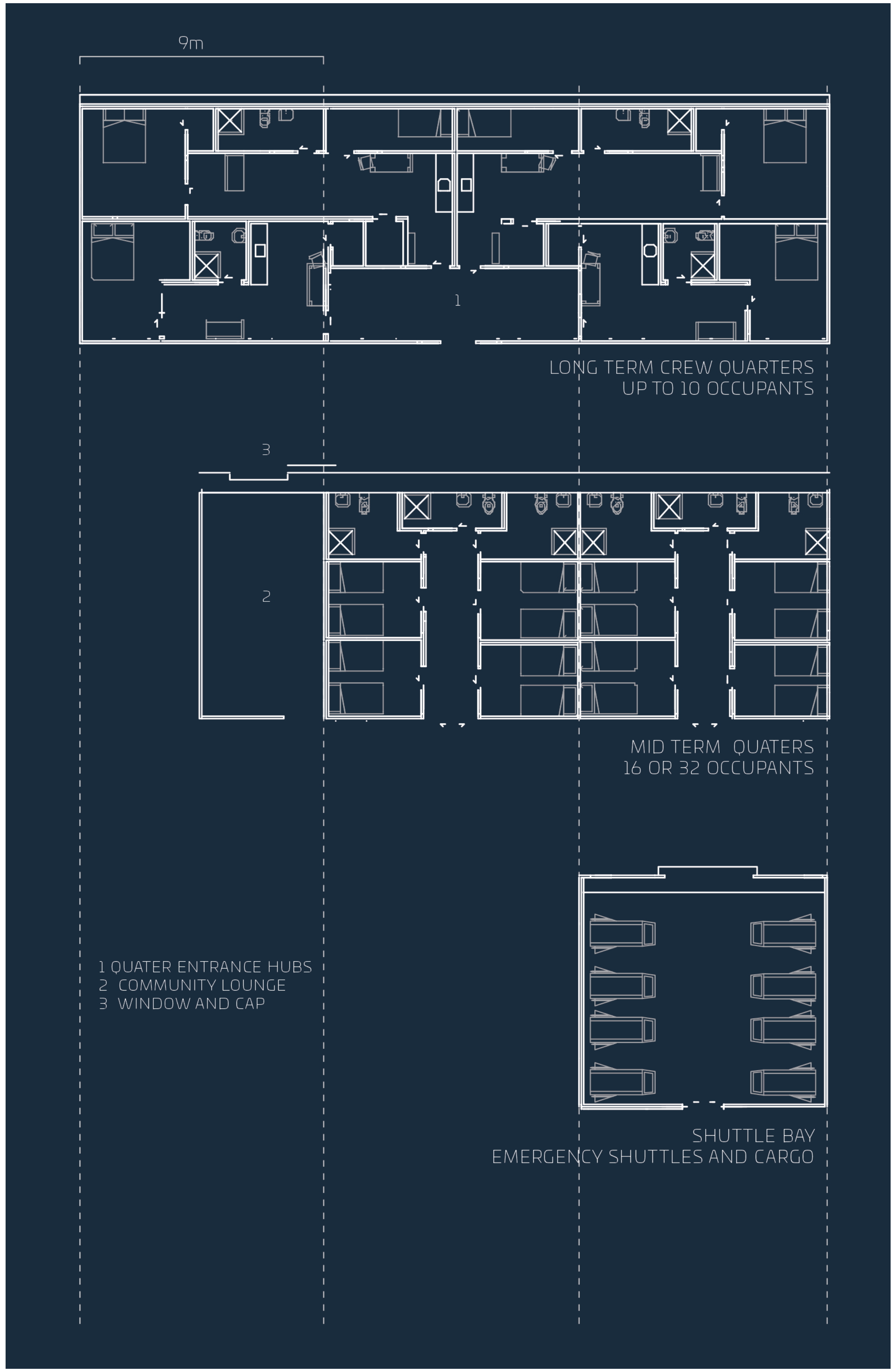
CREATING COMMUNITY

Several planning techniques are utilised to engage smaller and wider community within the ship.

Throughout the ship some spaces are developed to bring together the entire community, such as the restaurant, library, and recreation and sports centres. The loop formed by the ship means that the main circulation spaces (the strip on the main ring, and the green belt) also provides plenty of passive community engagement.

Each of the accommodation modules contains smaller community spaces to foster familiarity (figures 116 and 117). The long term quarters share an entrance space with their neighbours, providing privacy as well as the opportunity for micocomunities. Mid-term and short-term accommodations are provided with lounges along the ship.

Figure.114 *Each area is designed to conform to the size of the module area, allowing for easy construction in situ.*
In events of extreme material movement (ie in high temperature zones), each module could contain an expanding connection although this will effect the consistency of the artificial gravity.



Accommodation and bathrooms are shared in the mid- and short-term areas. Similar to the Trans-Siberian express trains, short-term accommodations utilise the bunk-beds to foster smaller communities and a sense of safety in an otherwise very exposed setting (figure 115).[6] The beds are divided into units of four with a shared table. Each bed has its own locker in lieu of other secure personal space. The forms of the beds and separators are intended to utilise utopian curved forms as earlier anticipated as important.

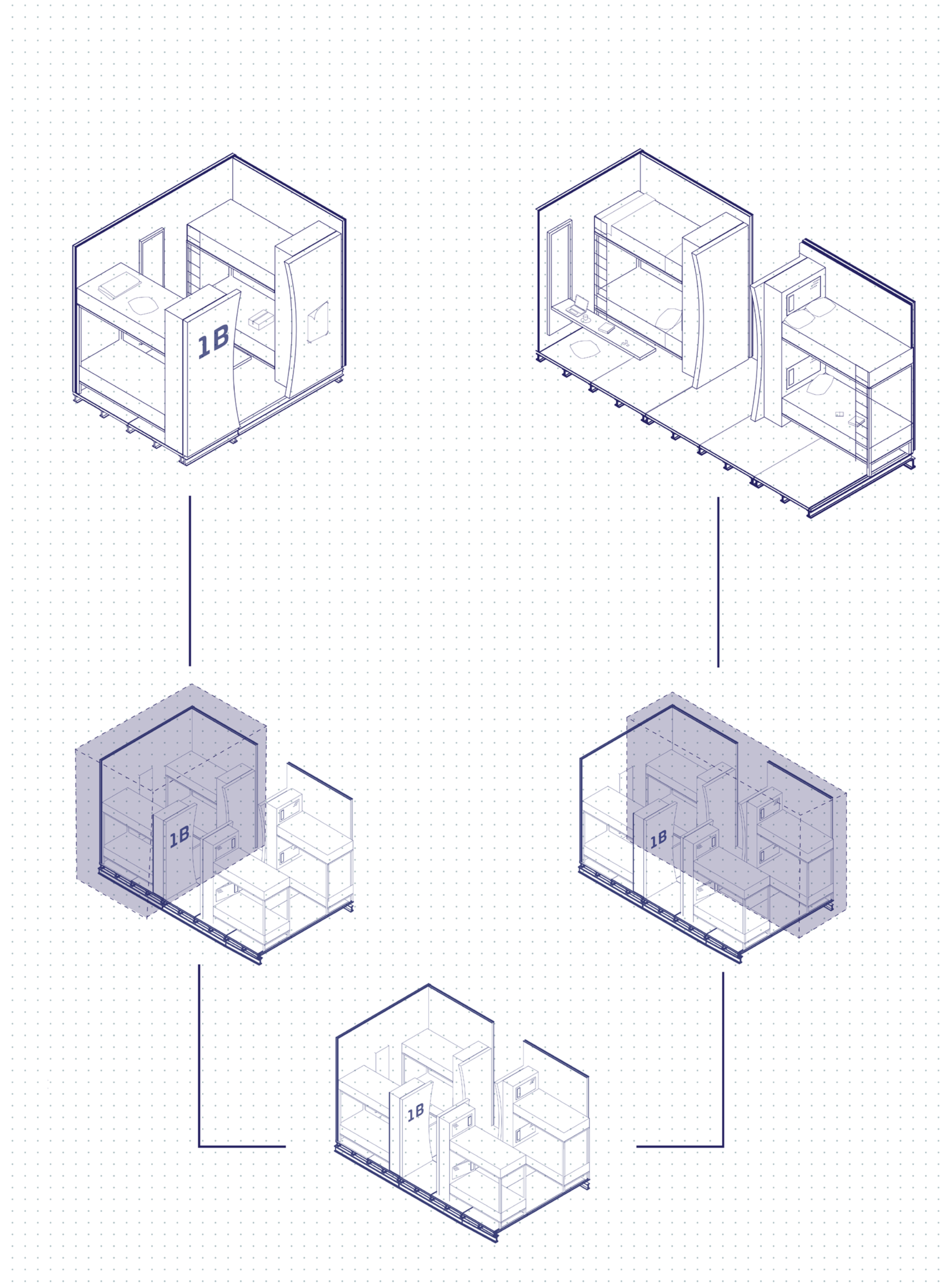


Figure.115 *The short-term accommodation is divided into several smaller units to foster a sense of safety.*

6. Lambert " Everything you need to know about booking a trip on the Trans-Siberian railway"

RESEARCH SERIES: SHIELDING

RADIATION SHIELDING

"In science fiction, the worst threats to space travellers are large ones: careening asteroids, ravenous creatures, imperial battle cruiser. Though, the scariest menaces for humans in space are the tiniest: fast-moving elementary particles known as cosmic rays." [7]

- ELECTROMAGNETIC

A 'forcefield', similar to the Earth's natural protection, can theoretically be man-made. It has not been tested and the effects on humans is unknown.

- MATERIALS

Materials can be used to 'block' radiation particles. However, most materials are either too heavy to feasibly transport. If the materials do not block the right amount of radiation they can do more damage than minimal shielding.[8] Popular options include lunar or asteroid rock, heavy metals, or Aero-gel.

- WATER

Water could be an invaluable method of radiation shielding. Not only is it one of the most efficient weight to shielding ratio (if being launched), but it can also be constantly reused and replaced. The shortfall with this option is the requirement to source it (either from Earth or other bodies such as asteroids) and transport it to where it is needed.

7. Parker, " Shielding Space Travelers"
8. Parker

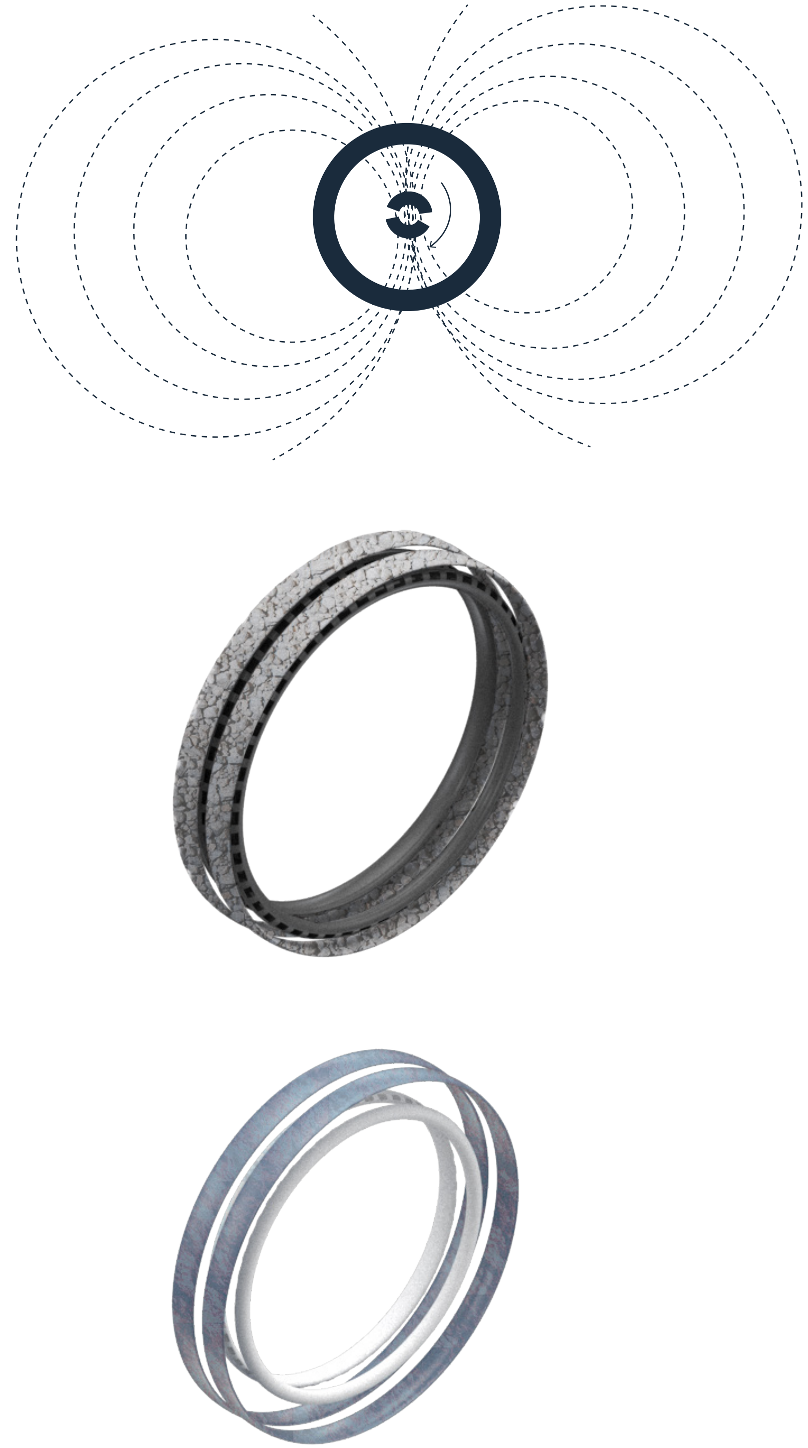


Figure.116 *Basic radiation shielding exploration - a test of materiality in space.*

PHYSICAL SHIELDING

In space, particularly when moving at incredible speeds (as the ISS does and transport ships are likely to do), the most danger comes from micrometeorites. Objects as small as paint chips can breach a spacecraft and are, in fact, the most dangerous. While there are measures in place to track larger objects (around 10cm), anything smaller cannot be tracked by our instruments. Most methods of physical shielding are far too heavy to be feasibly taken into space, and generally not strong enough.

- WHIPPLE SHIELDS

AKA 'hypervelocity impact shields'. These were the first spacecraft shields ever implemented and are still used today. Rather than withstanding impacts, Whipple shields work by using multiple layers. The outer layers (generally aluminium) break up and disperse objects before they come into contact with the rest of the ship. Newer iterations (called stuffed Whipple shields) include layers such as Kevlar to further dissipate the strength of the projectile.

While Whipple shields are highly effective, they add bulk and require replacing. Ships further into space will likely run in to less objects than found in orbit around Earth, but may be unable to track them as thoroughly without GPS.

- MULTI-SHOCK AND DOUBLE MESH BUMPER SHIELDS

These work in similar ways to Whipple Shields, but the layers and materials may differ.

- HONEYCOMB AND FOAM PANELS

Aluminium honeycomb panels are used in many spacecraft. Metallic foam panels are similar, but with better shielding capabilities.

- TRANSHAB

Transhab is "a prototype shield developed for a future manned mission to Mars." It is a compressible shield - smaller for launch and it expands in situ. It is made out of layers of Mylar, Nextel, Kevlar, and foam.

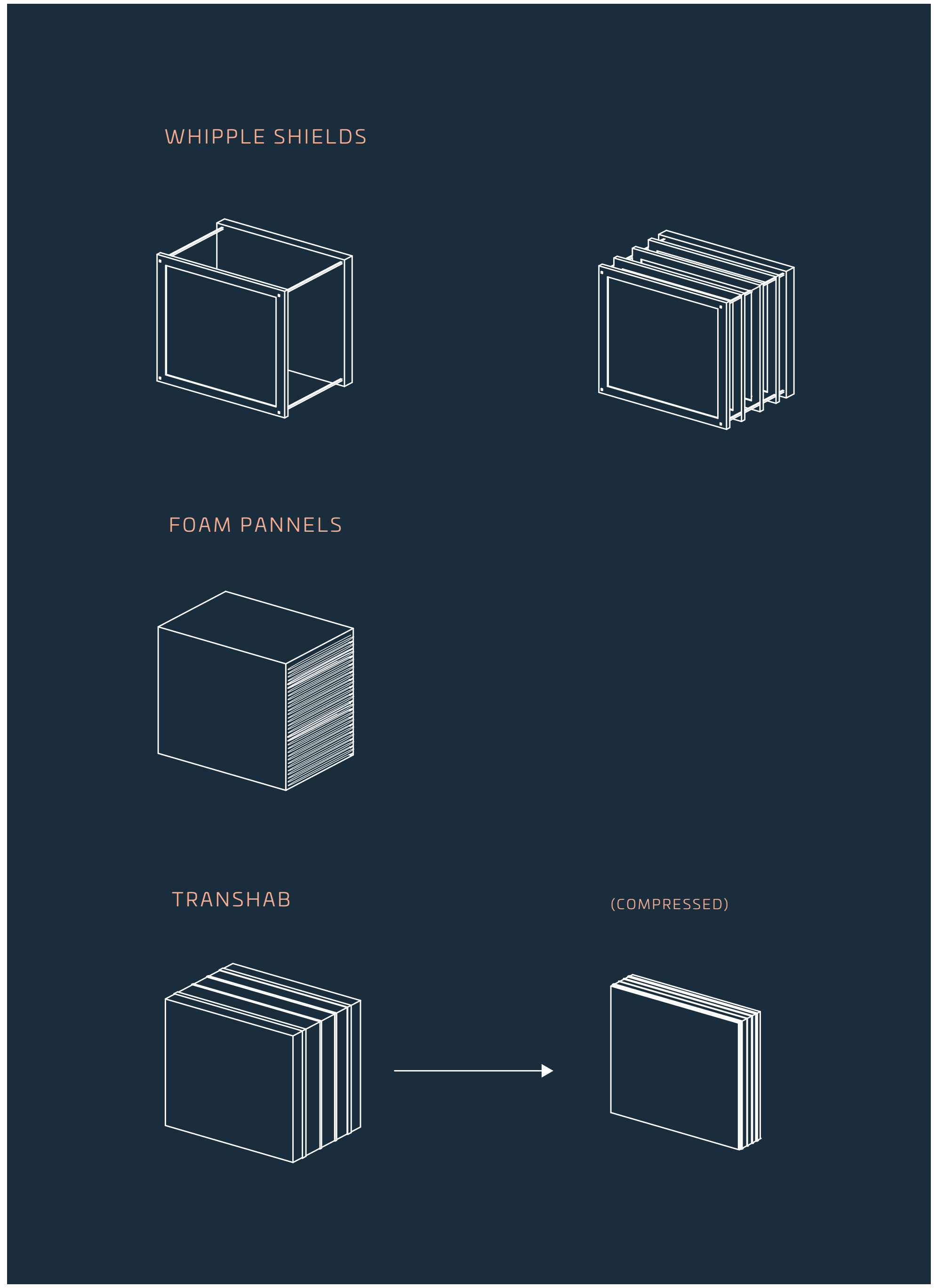
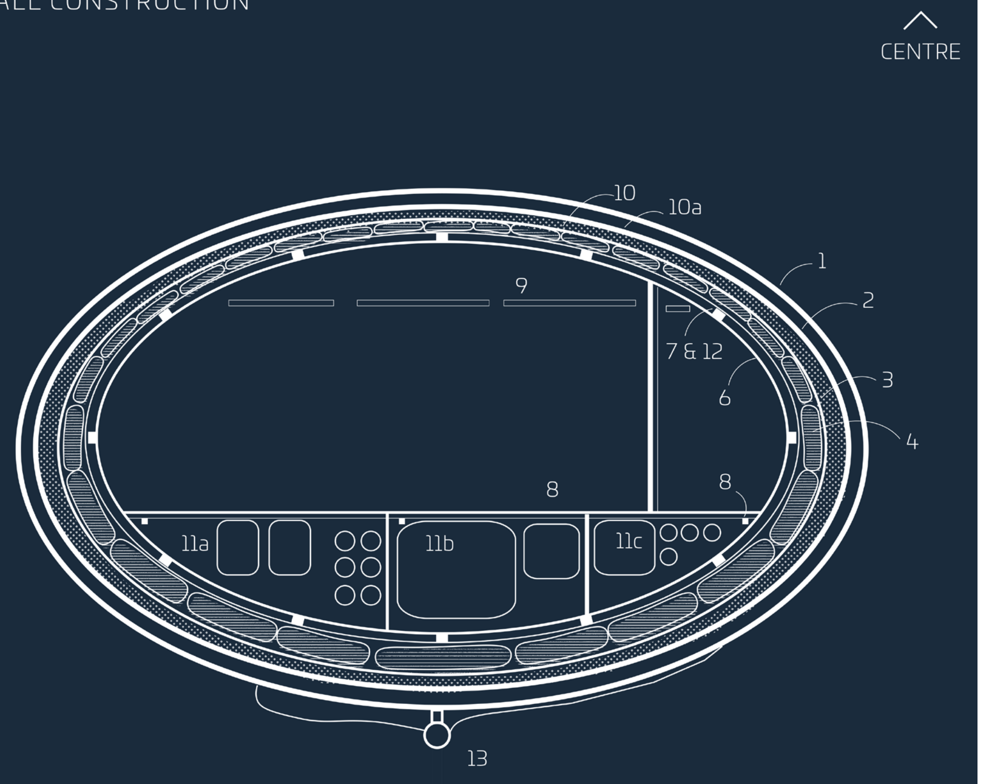


Figure.117 *Basic physical shielding strategies*

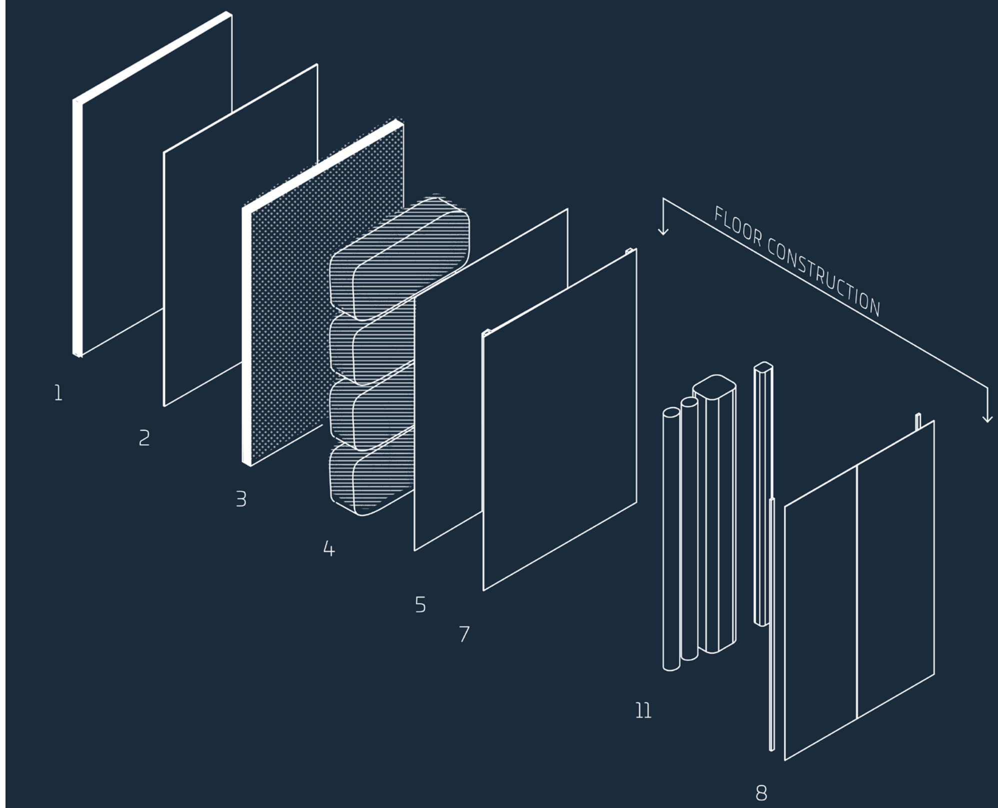
Figure.118 *(Following) The SEARCH vessel wall construction and shielding strategy utilises water packs and Whipple shield-like structure.*

WALL CONSTRUCTION



1 PRIMARY MICORMETEORIOD AND DERBRIS PROTECTION
2 SECONDARY MICORMETEORIOD AND DERBRIS PROTECTION
3 THERMAL INSULATION BLANKET
4 WATER PACKETS - RADIATION SHIELDING
5 SERVICES CAVITY
6 INTERNAL CLADDING
7 PRIMARY STRUCTURE
8 FLOOR PLATES
9 CEILING CAVITY AND LIGHTS

The SEARCH vehicle's radiation shielding, inspired by Water Walls study and the Bio-neural Gel packs of Star Trek, is intended to be fully maintainable from the inside of the ship. As a part of the ship's assemblage, the water can be processed and recycled. The 'floor' of the ship contains more shielding due to its heightened exposure to radiation and micrometeorites. In the event of a high radiation event, the floor could be packed with further water rations.



10 THERMAL INSULATION
10A RADIATOR AND HEAT DISTRIBUTION PIPES
11A AIR SERVICES
11B WATER SERVICES
11C ELECTICAL SERVICES
12 CAVITY FOR PASSIVE THERMAL REGULATION STRATERGIES
13 SOLAR SAIL SUPPORTS AND SYSTEMS CAVITY

Similar to under-floor services in a building, the SEARCH vehicle floor contains the services for easy maintenance, working hand in hand with creating a large floor surface (as in the Stanford Torus). Overhead services are limited to fire suppression. Wall cavities allow for services to be run between the two. The physical shielding will need to be maintained through EVAs.

DESIGNING FOR ROTATIONAL GRAVITY

The production of artificial gravity is invaluable for those living on a starship. The effects of rotational gravity are mitigated on the SEARCH ship through careful use of form and detailing. As turning and changing direction can be disorientating, visual cues are provided in the assumption that they will allow inhabitants to subconsciously pick up on the direction and force of rotation.[9] The inter-ring windows which accompany the main circulation camber away from the direction of rotation, as do a series of non-structural column-like details on the opposite wall which house lighting. The lighting provides slightly different colours to the same effect - more yellow (a longer wavelength) as you follow the follow the rotation, and bluer as you walk in the opposite direction (a shorter wavelength).[10]

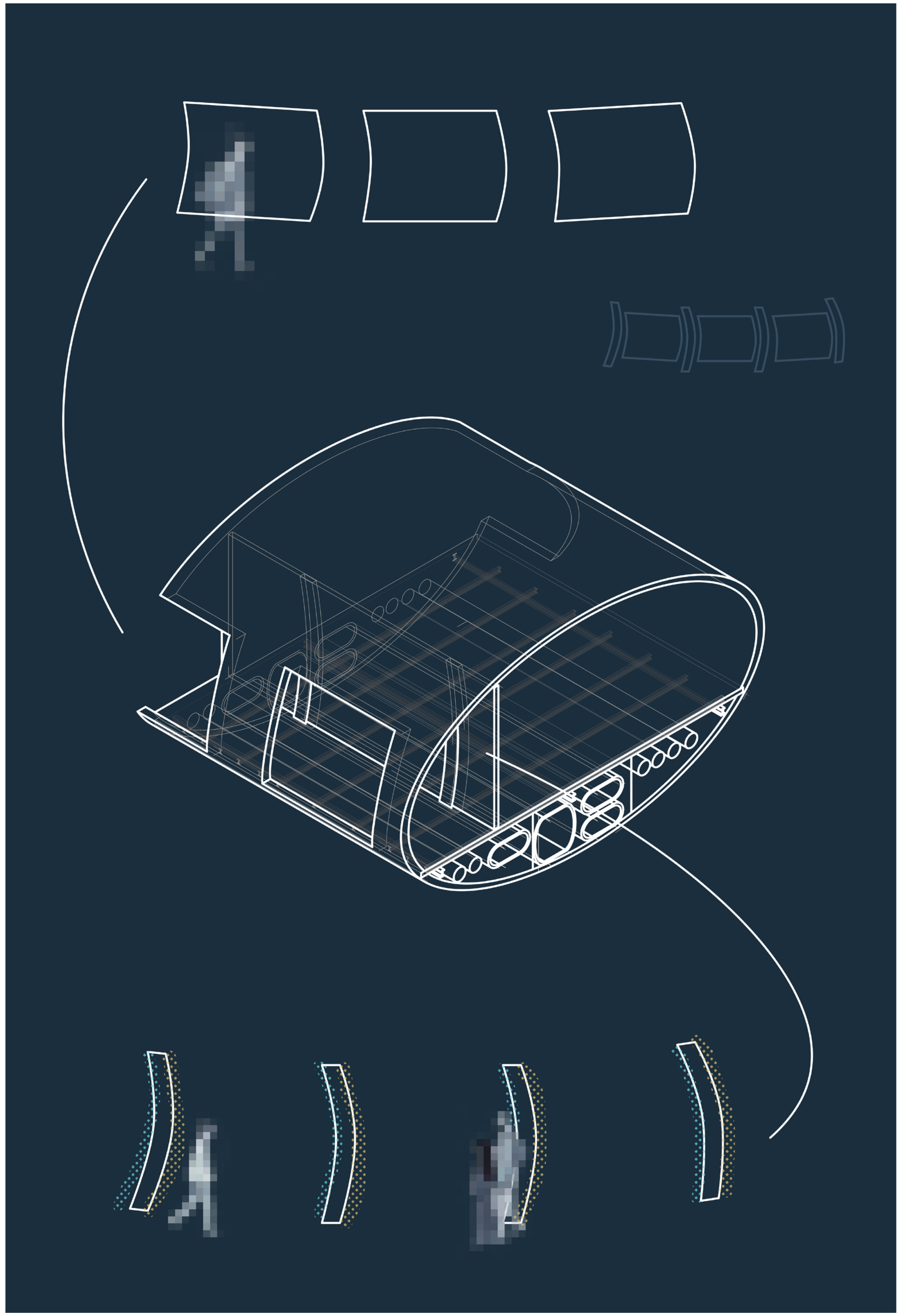


Figure.119 *Thumbnails of key areas in the ship.*

9. Hall, "Artificial Gravity Visualisation, Empathy, and Design"
10. Hall; Sgobba and Schlact

DESIGN SERIES: DETAILING

The detailing philosophy within the ship was an important architectural consideration. Aside from being visual cues to define community areas from high security ones, detailing has been established to reinforce boundary objects which assist with creating communities through SF.[11]

The following set of door explorations provided a study into what detailing philosophies were the most effective in different settings. Explorations began by testing the effect manifesting 'white-box' utopian and steampunk values had on spaces. Both familiar terrestrial and space architecture (for instance, the airlock) thresholds were tested alongside SF versions. The iterations focused on several aspects that had been identified as critical to the study - primarily those of utopian spaces, safety, and a decrease in monotony. Sliding doors, as well as being a space-saving strategy, were chosen as they are highly recognisable as an element in many SF vessels studied.

Through the creation and grouping of these studies, several conclusions were drawn:

- Doors which included smaller frames and visual permability indicated a sense of community and public space. In contrast, thicker doors and steampunk elements help to establish a sense of safety or areas off-limits to the public.
- Tactile elements such as handles, keypads, and touch screens provide an opportunity to encourage the interaction between people and the boundary objects around them. They engage the occupants rather than alienate them from their surroundings.

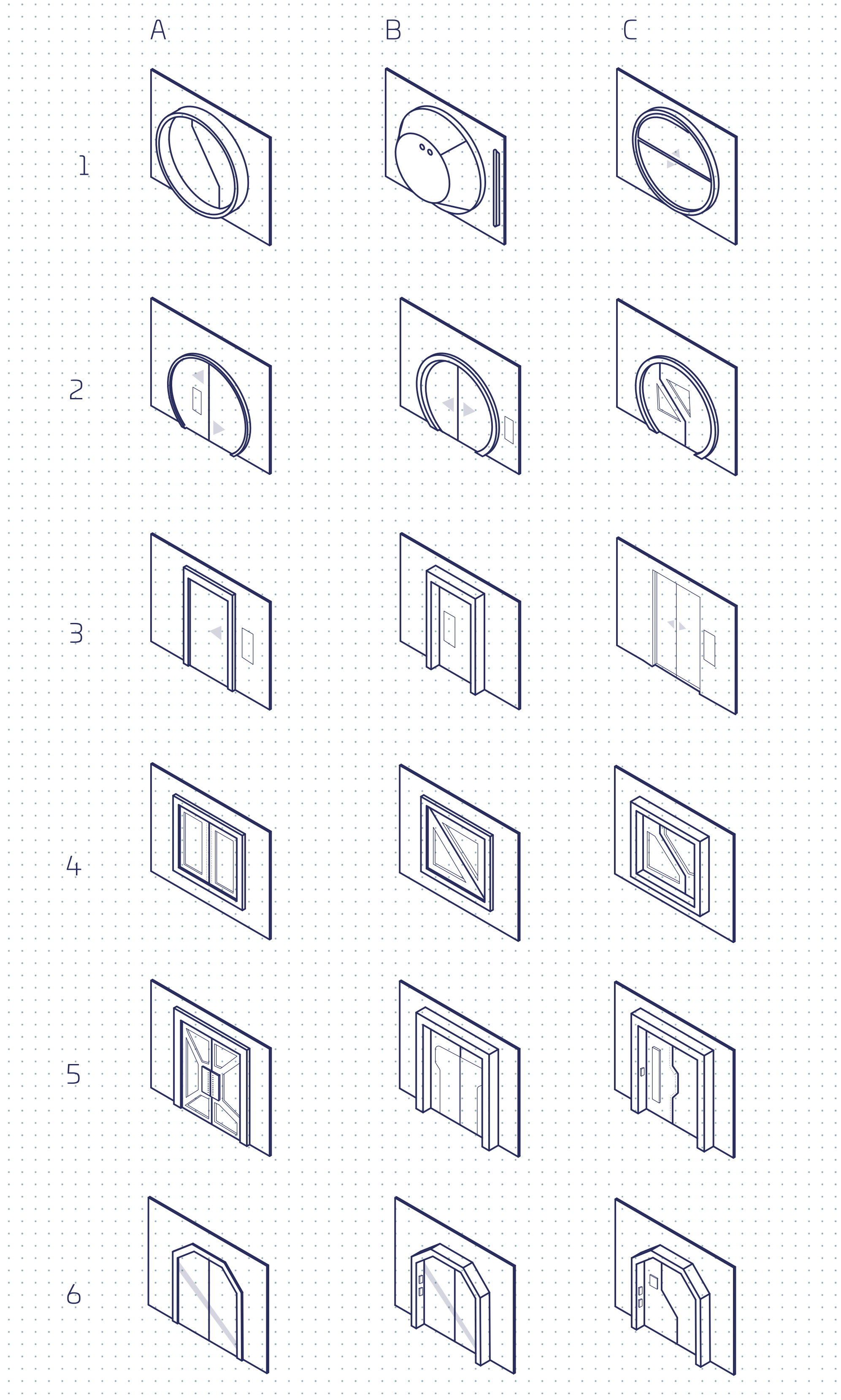
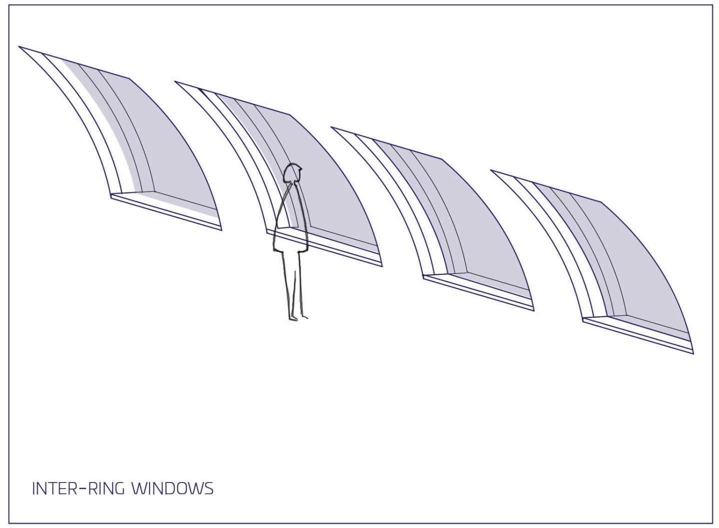


Figure.120 *Door exploration for detailing philosophy.*

11. Baling and Pangaro, "Design Space for Space Designs"; Eckert and Stacey, "Sources of Inspiration"

The results of the door detailing study likewise establishes a detailing strategy for the rest of the ship. Elements such as the windows which encourage the safe interaction between people and outer space are provided with extra depth to enable a sense of safety (figure 121). By prioritising horizontality as well as verticality the windows prioritise the rest of the vehicle on par with outer space. Large windowsills invite interaction through tactility while symbolising the structure of the ship in an area that could otherwise feel like a very vulnerable area. For the same reason the windows actively display the 'doubled' structure of the wall. The columns, too, express a notion of safety through added thickness despite being non-structural.

Doors such as 3C and 2C which encourage tactility are used throughout the ship. Their design not only encourages interaction with the ship but provide visual depth to what otherwise would be a disorientating space due to the curve. Community spaces are denoted by the curved doors while rectangular ones symbolise personal rooms.



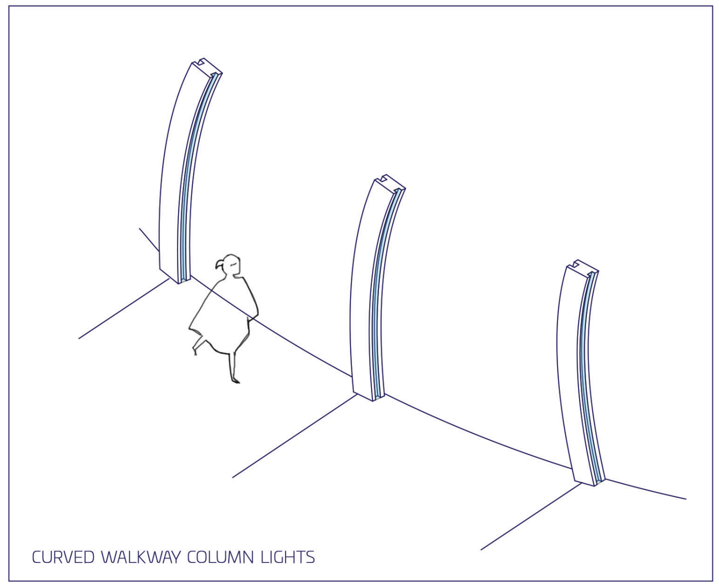


Figure.121 *Further detailing decisions.*

OTHER SPACES

Spaces that provide a sense of community through technology, such as the elevator and communications rooms (figure 124) exhibit utopian materials and forms. This is to evoke a celebration of technological advancement that goes hand in hand with an extraterrestrial community. Communication pods are provided as walk-in interactive spaces to provide a human-scale connection to communities and families on Earth or elsewhere in the solar system.

In contrast, spaces that develop a ship-wide community utilise steampunk and Earth materials. Steampunk elements that have previously assisted with creating a sense of mechanical safety and connection to the ship through tactility, while natural materials connect people to Earth.

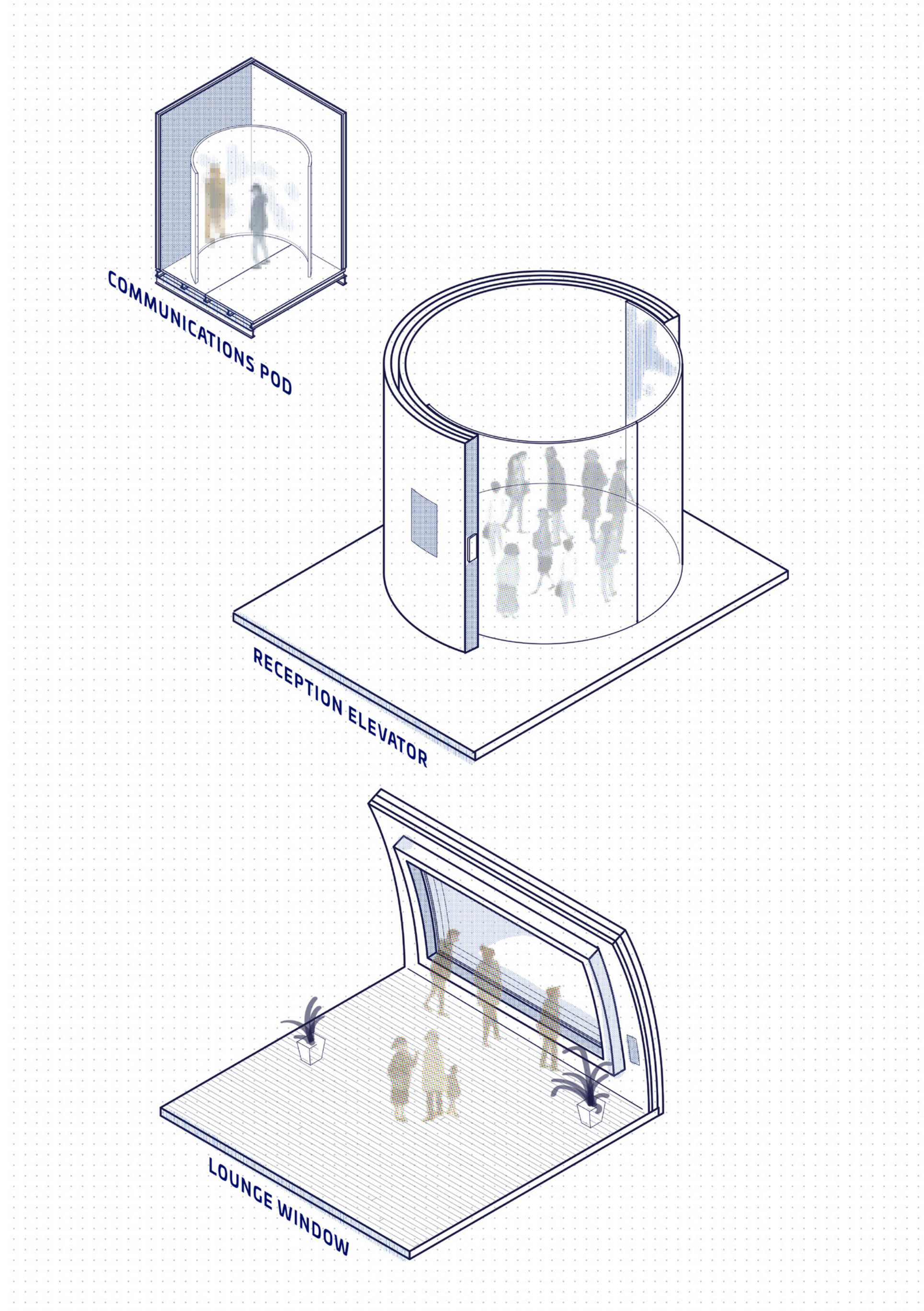


Figure.122 *Thumbnails of key areas in the ship displaying a variety of detailing philosophies.*

The only way to discover the limits of the possible is to go beyond them into the impossible.

- Arthur C. Clarke's second law in "Hazards of Prophecy: The failure of Imagination"

In Profiles of the Future: An Inquiry Into the Limits of the Possible

CHAPTER 8: **CONCLUSIONS**

This final chapter reflects on the research as a whole. It summarises each stage where the design and research aspects influenced each other. The results of the research are compared against the aims, objectives, and research question. Finally, it acknowledges the limitations on the research and what avenues could be taken to further explore this topic in the future.

Space architecture resembles an outdated typology from the twentieth century – one that is woefully ill equipped to manage human wellbeing for long-term and passenger-focused missions. Through necessity, it prioritises functionality and survival over human-centred and wellbeing design. This design-led research utilised SF as a catalyst for addressing this problem. By attempting to justify (the often dichotomous) habitability issues with SF forms it reconsiders how space architecture can develop typologies for humankind's future.

The success of space architecture, the same as its terrestrial counterpart, hinges on the combination of both artistic practice and engineering. A major contributor to quality of life in space is the ability for inhabitants to express themselves artistically as well as see it in the surroundings. Throughout the first stages of this research it became clear that SF (which allows empathy with those living in outer space and assists those who otherwise have communication barriers to establish relationships) has an interactive and mutually affective relationship with the space industry and spatial planning. This opens the industry to utilise this connection to develop socially and psychologically sustainable habitats as well as postulate on the future of space habitat technology.

Alongside the research stages, initial sketch experiments were developed to understand where personal expression meets the narrative of outer space. Their inclusion uncovered the need for analogue models to provide tangible case studies for architectural organisation and design. These models could be explicitly for outer space as well as those unrelated on the surface. The research itself also called for a measurable sense of safety and plausibility, which was done through the consideration of both terrestrial and speculative case and program studies.

A constant challenge present through the research was harmonising poetic form and construction constraints. Rather than finding a solution at a single stage, the design often and visibly struggles with this - despite an understanding that the research would likely not culminate in an immediately actionable design. There is a strong pull from the architecture as well as space architecture profession to use design to solve current issues rather than speculate on what could be fanciful interpretations of the future. *Learning from Las Vegas* and 'What do we give up and leave behind?' are prominant representations of this mindset. While this is a logical approach, when it was employed (in iteration one), it stagnated the design to the point where it failed to illicit the poetic response previously predicted would be essential for architectural imagination to thrive in outer space. A shift in design thinking was needed, and was aided by such theories as Astrofuturism – where a balance of fiction and reality are developed in order to inspire and educate – and emerging technologies such as Water Walls.

As a result of this understanding, the final outcome focuses far more on the typology of and moments within the architecture rather than the technicalities of creating such a space. It utilised predictions of space infrastructure to reinvigorate the design process. The architecture becomes an expression of a whole assemblage rather than developing a definitive expression of the next generation of space ships. The expression of the final design's drawings exemplify its position in the future of humankind, rather than a current possibility.

It was discovered that richer accommodation designs are likely to develop at a point where HSF is cheap enough to accommodate passengers who are not simply looking for adventure, and "reflect the reality of staff hired for partial-year tours of duty."[1] As a result, the ship became larger, with more emphasis on expressing the difference between private and community spaces. Additionally, the use of creating micro communities within housing hubs and a collection of lounge rooms was established.

The exploration of different typologies – rather than honing just one – meant that simple adjustments such as those expressed in iteration two to reduce monotony, are rejected in place of a more poetic and familiar form in the last design phase, possibly at detriment to the success of the scheme. It is only through the course of being able to test a physical design or the creation of new analogue models will this truly be known.

Through developments of objects relating to safety, the SEARCH vessel became an expression of the forces within it. From the rings to the transitional walkways it impresses upon the viewer the inner workings of the ship. This form inadvertently and organically becomes a display of Astrofuturism and human occupation. Just as the ISS's form exhibits the limitations forces upon the form by the earth, the SEARCH vessel exemplifies requirements set upon ourselves for a fulfilling space industry.

A possible shortcoming of the design is its reliance on recognisable SF motifs to connect the inhabitants to a planet they can no longer see. While it is established that these boundary objects provide a social anchor, it is likely that these will change in the time it takes us to become a comfortably space-faring species. To mitigate this one solution, small aspects such as natural materials from Earth and immersive communications spaces are included. But overall, it is hoped that the research provides a catalyst point for the inclusion of whatever forms arise in popular culture between now and a time it is ready to be employed on a real Mars space ship.

1. Sherwood

The design that concludes this research provides an architectural proposition to reconcile the future of our space industry with the sense of exploration so vibrant in its past and seen in SF.

The proposition itself is responsive to the future of a possible industry where space architecture is a part of everyday life. It is a general design scheme which distils a large number of general design solutions into one vessel. It is fitting for this context but provides a number of avenues for further research into how space architecture and its inhabitants may respond to each-other and the context of space exploration. The potential for further research into this condition is vast, and would provide much-needed broadening to the research.

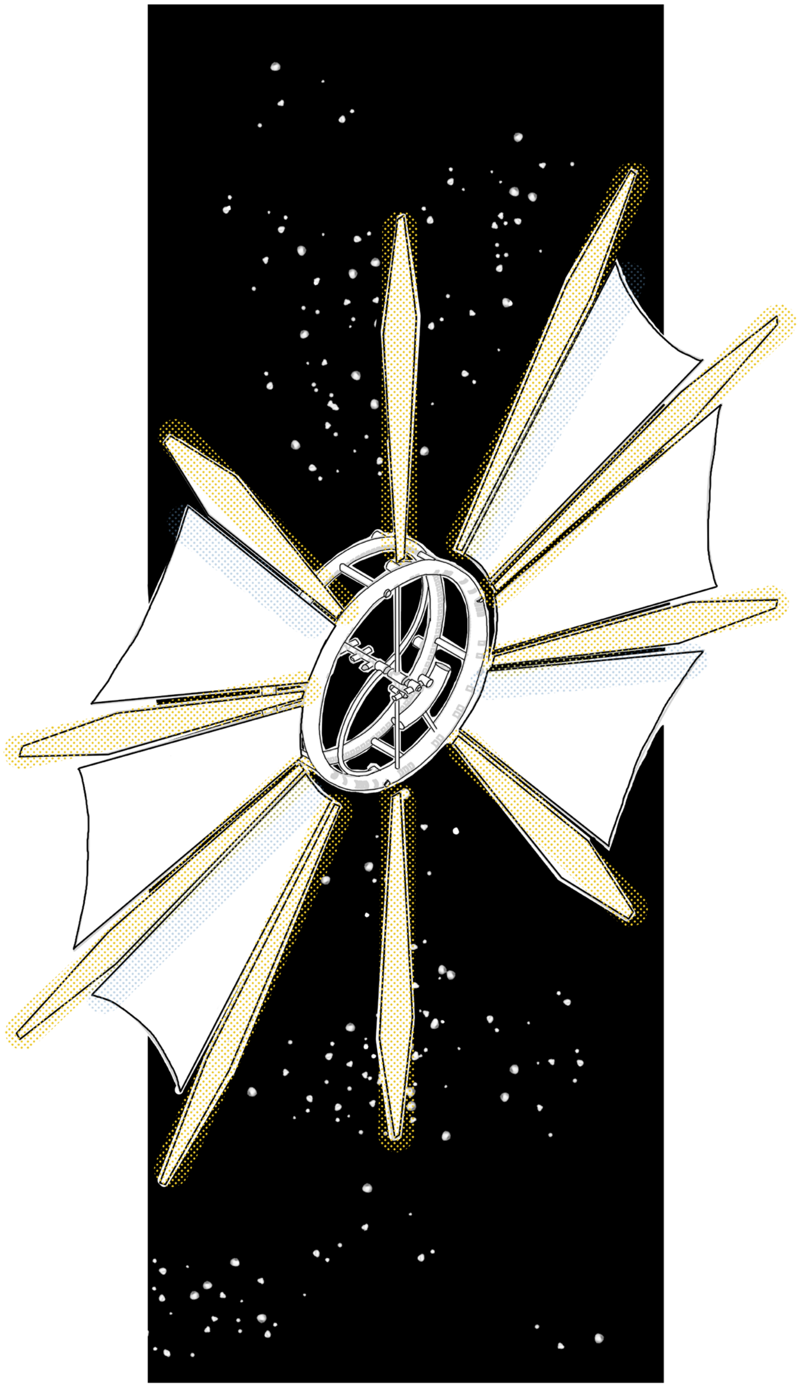
Some possibilities to expand the scope of this research uncovered in the design stages include;

- How might SF or architecture assist with the creation of certain spaces (particularly those of the private and communal spaces) within a vessel?
- How might they be applied to a shorter-term vessel?
- Given the condition of a one-way trip, how might architecture provide stability for those who will never return home?
- How could more habitable space architecture be developed that is equally resilient as the ISS?
- How can recreational and private space be better differentiated an encourage passive engagement with the architecture?
- How might space architecture assist with the acclimatisation to artificial gravity?

It is likely (and I personally hope) that new technology and innovative sources of fictional inspiration will drastically change the course of space architecture as we know it. This research serves as an argument for integrating what often appears to be a dichotomous relationship between the imagination and reality,

engineering and art,

Earth and Outer Space.



CHAPTER 9: **END MATTERS**

9.1. FIGURES

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