SPECULATION ON ARCHITECTURE IN THE ABSENCE OF GRAVITY
Speculation on Architecture in the absence of Gravity.
How might architectural elements and design strategies function in outer space?

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Abstract

The evolution of architecture has been driven by a combination of elements such as style, context, materiality, aesthetic and technology. The development of materials and the technological advancements of the human race are conveyed through architecture; from the technical expertise of the ancient Egyptians in pyramid construction, to the engineering feats of the Eiffel Tower in Paris, to the physical realisation of Gehry’s Guggenheim through computer modelling. Architecture is a continuous evolution which revolves around the progression of the human race in all fields of life.

Space habitation presents the next step in this architectural evolution, in which Space tourism acts as the stepping stone for the transition of architectural design beyond Earth. Space design has been produced largely without architectural input. The aim of this project is to introduce an architectural sensibility, and to investigate the impact an absence of gravitational force has on architecture.

The research follows the transition of architectural design from an environment of gravity to one without, by reviewing both current literature and precedent case studies.
Acknowledgements

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Unitec Staff, your knowledge and inspiration have carried my pursuit in this field. Whilst I still consider myself a beginner in the scheme of things, I hope one day the architecture I create stands testament to your influence and teachings.

My Family, your support and love have made this all possible. Your pride and sacrifice is why I strive.

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Lan, your belief in me is what pushed me down this path. Your love and support have made this all possible.
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Nomenclature

space: as used in an architectural sense
Space: as used in an astronomical or cosmological sense; also referred to as ‘outer space’
Acronyms

AIAA: American Institute of Aeronautics and Astronautics
ATCS: Active Thermal Control System
CM: Command Module
CMG: Control Moment Gyroscope
CRF: Canister Rotation Facility
CSM: Command and Service Module
CSS: Commercial Space Station
EMU: Extravehicular Mobility Unit
IDSS: International Docking System Standard
ISS: International Space Station
LEO: Low Earth Orbit
LM: Lunar Module
NASA: National Aeronautics and Space Administration
SM: Service Module
TeSS: Temporary Sleeping Station
“The sense of gravity is the essence of all architectonic structures and great architecture makes us aware of gravity and Earth. Architecture strengthens the experience of the vertical dimension of the world. At the same time as making us aware of the depth of the Earth, it makes us dream of levitation and flight”

Juhani Pallasmaa
1.0 Introduction

1.1 Background

“The conquering of Space is a unique challenge that can help unify the world and encourage us to collaborate as a species. In the emerging global society, this collective project is essential not just as a symbol of human unity, but for future economic progress. After all, the story of the human race through the expansion into new territories and environments, and the eventual establishment of cities, is the essence of civilisation.”

The genesis of Space architecture begins with the involvement of “architect Maynard Dalton and industrial designer Raymond Loewy (who) designed the interior of NASA’s first Space station, Skylab.”

A lack of architectural input in Space habitation design has been found to impact negatively on the psychological well-being of astronauts. Engineers sought the expertise of architects to resolve issues of confinement, privacy and mental health. A report prepared for NASA – Ames Research Centre, discusses the importance of solitude, “the opportunity to withdraw from other people serves a number of important psychological and social functions, and is in the interests of safety, high performance, and high quality of human life.” Harrison suggests design strategies in the report to counter issues pertaining to undesirable visual, audible, physical and olfactory emission, and implies the necessity of architectural input for an empathetic design approach.

Orbital Technologies was founded to open outer space for private enterprise. The Russian company is “developing key systems, infrastructure, and technologies that are essential to rapidly accelerate the commercial Space industry and its applicability to the global marketplace.” Their success has heralded the creation of an orbital Space hotel, which will be ready for commercial use by the year 2016. This

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1 Dr Rachel Armstrong, guest editor, Space Architecture: Architectural Design (AD) Volume 70, Issue 2. (California, John Wiley & Sons, 2000), pg5.
2 A. Scott Howe and Brent Sherwood, editors, Out of this World: The New Field of Space Architecture. (Virginia, AIAA, 2009), pIX (Preface).
development plays a vital role in the evolution of architecture, a step in which a majority of today’s design strategies and architectural tectonics can be questioned. “Most architects work with models and blueprints, but how do you design a structure when terrestrial experience is no guide?” The project queries the role of gravity in relation to architectural design as a whole.

The first commercial flight occurred on January 1st, 1914. At the time, the 33.8 kilometre journey lasted 23 minutes although it was the cost of the ticket which holds the greatest significance in this particular instance. Today, the same journey can be completed by a motor vehicle in 27 minutes. A ticket to the first commercial flight was put up for auction in which the winning bidder paid $125US for the ticket (today’s equivalent of $2,900US). One way tickets on the commercial airline were then sold for $5US, today’s equivalent being $116US, an amount capable of flying you from Auckland to Christchurch via Air New Zealand (one way). The price of a ticket on Richard Branson’s tourism venture – Virgin Galactic costs $200,000US. With more than 500 tickets already sold the sub orbital flight experience is initially reserved for the wealthy. As the development of a programme of this nature occurs over time, the costs of such an experience will decrease while the experience of being in an environment of microgravity will only get better.

In October 2011, the exponential growth of the world population reached a staggering 7 billion, another contributing factor to the realisation of Space habitation, as the strain on Earth’s resources continues to increase. “As of Oct 31 (2011), according to the U.N Population Fund, there will be 7 billion people sharing Earth’s land and resources... According to demographers, the world’s population did not reach 1 billion until 1804, and it took 123 years to hit the 2 billion mark in 1927. Then the pace accelerated — 3 billion in 1959, 4 billion in 1974, 5 billion in 1987, 6 billion in 1998” Planet Earth continues to burden the influence of man – a growing population with an insatiable hunger for dwindling levels of finite resources. It is becoming clear that in future, mankind will have to make better use of “off-planet” resources.

1.2 Research Question

How might architectural elements and design strategies operate in the absence of gravity?

1.3 Aims/Objectives

The Aims and Objectives of this project are to test architectural design strategies in an environment of microgravity. The project attempts to design a safe, healthy and habitable environment in outer space, testing architectural tectonics and strategies, and their required adaptation and modification. A Space hotel, located at an orbital altitude from Earth's surface, provides a realistic goal given the recent developments of Orbital Technologies, with the potential that the elements derived from this thesis will aid in future design projects for architecture in outer space.
2.0 Project Outline

The project proposes the design of an Orbital Space Hotel in LEO. Guests will spend four to five comfortable days in this foreign environment. The project aims to provide an affordable facility, opening Space habitation to the world through a commercial venture. Comparatively smaller companies will be able to test their products in an environment once limited to Space, government and medicinal corporations. 3D printing and aeroponics have only been tested in microgravity due to interest from NASA, the ability to develop and test items without this pre-requisite entails greater variety and development programmes for microgravity technologies and systems. The hotel will act as an emergency evacuation point for the International Space Station.

The experience of life in microgravity, as well as the physical and visual experience of outer space will be the sole driver of the scheme, attracting Space enthusiasts, whose opportunity was once limited to dreams and their imagination. This form of adventure tourism will come at great financial expense, without the indulgent luxuries of fine dining and pampering that are generally associated with such price tags.

Travel duration from launch to the Space hotel is two days. Once arriving at the station, guests will experience habitation in microgravity. The design will be required to accommodate daily human activities pertaining to leisure, rest, work and hygiene.

The following spaces will be provided and will cater to the habitation requirements of guests for the duration of their stay:

- Entry/Lobby
- Lounge/Hall
- Dining/Kitchen
- Private Quarters
- Bathroom/Toilet
- Laboratory
- Electrolysis (Oxygen Production)
- Aeroponics (Food, Oxygen and Water Production)
- Gymnasium

Research will occur through the analysis of precedent case studies and relevant literature and articles, as well as video analysis of outer space experiences and website sources. Design will be explored through computer and physical modelling, as well as hand sketches.
2.1 Literature Survey

The Space race has enabled technological advancements, from the internet, telecommunication satellites and global positioning systems; it has also unveiled the potential for Space habitation. Elizabeth Song Lockard discusses the importance of an overall understanding of the fundamentals of architectural space. This understanding will ease the transition from design here on Earth, to design in outer space. The approach, in conjunction with the consideration of environmental and physical issues unique to microgravity, will mould Space architecture. Rather than simply adjusting or extending existing Earth paradigms, Lockard suggests entirely new paradigms must be developed, or perhaps old ones revisited.

Human activity in an environment of microgravity differs greatly from normal day to day life. Simple activities like eating and bathing become complicated and require alternative methods and spaces to accommodate these changes. A major issue Lockard covers is the absence of a true exterior realm; humans are no longer able to physically experience or inhabit 'the outdoors'. The absence of this transition indicates Space architecture will never be fully experienced as a habitat, but rather as a place of incarceration. In order to develop an empathetic connection to Space, it must be experienced directly. The loss of this interior/exterior transition indicates a psychological tension that must be countered through design. Lockard also pushes the importance of the aesthetic and how this particular element aids architectural design for the benefit of both psychological and physical well-being of the occupant in Space architecture.

Albert A. Harrison analyses privacy requirements for Space station occupants and suggests architectural techniques/strategies and other guidelines for helping inhabitants achieve desired levels of privacy. Given the confined nature of Space habitation, Harrison writes privacy helps people achieve greater focus and concentration, contributing to 'rest and recuperation'. This reduces stress and social tension, making it possible for members of small groups of people to interact with one another in a candid manner. The report covers location, visual, audible and olfactory privacy, and discusses general solutions and offers specific recommendations, to deal with issues that arise in such confined environments. Harrison’s strategies and suggestions will be utilised throughout the project.

Ted Krueger states extreme environments uncover hidden issues within common environments by reversing or eliminating constraints that then allow dormant variables to be manifested. On Earth

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heat rises, but in a microgravity environment heat does not disperse in the same manner. It forms a zone around the source and heat transfer must occur with fans to expel the heat from the origin. The elimination of gravity may highlight and reveal important strategies of architectural design that are underutilised or ignored.

Constance M. Adams writes of the terrible constraints which guide Space habitation design, which thus far have placed the responsibility on engineering and technologies of survival. On the early, a strong engineering influence has been required to resolve issues such as pressure-shell geometries, radiation shielding, power use and propulsion strategies, microgravity and its numerous effects on systemic functions, launch options and the forces involved. This illustrates the inability for the participation of the Architect during this process of technological development. The author highlights the predominance of engineering in Space facility design. Human survival is the obvious priority, now that these life sustaining systems have been developed, implemented and refined indicates the opportunity for the architect to make a contribution to this new way of life. The recognition of the human stresses imposed by long-duration habitation has created an opening for an empathetic role, somewhere between evaluation, systems integration and design, where the Architect can function and contribute to the overall efficiency and usability of the facility. Whether the project involve a Space station, a transportation vehicle for human Space travel, or prototypical habitats for lunar or Martian research, it is already clear that the early and continuous participation of the Architect is beneficial to the project’s development.14 The author’s stance indicates the architects’ ability of conscious and empathetic design, an approach which considers more than simply the bare essentials for survival, but the strategies and tactics for a better way of living.

Out of this World: The New Field of Space Architecture, by A Scott Howe and Brent Sherwood is a book dedicated to the transition from architect to Space architect, with a majority of the literature pertaining to design requirements in outer space. They compile the following list of environmental constraints:

- Orbit
- Microgravity
- Extreme Temperatures

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• Unfiltered Sunlight
• Tenuous Atmosphere
• Orbital Debris
• Variable Views

Essentially site conditions will be addressed through architectural design and materiality.

The following list of 'human activities'\textsuperscript{15} compiled by Sandra Häuplik-Meusburger, take place in all habitable Space satellites and transportation elements.

• Sleep
• Hygiene
• Food
• Work
• Leisure

These essentially programmatic requirements will be reconfigured for their new context in Space. Häuplik-Meusburger suggests the best strategies in catering to these requirements.

\textsuperscript{15} Sandra Häuplik-Meusburger, Architecture for Astronauts: An Activity-based Approach (Germany: Springer Wien, 2011) pg4-10.
2.2 Precedent Survey

Precedent analysis pertains to Space vehicles and satellites in which human habitation has occurred. Precedents will give insight into what is required for functionality, whether this contribution is technical, structural or architectural, they will give the design proposal a sense of realism and accuracy. All precedents were, or are currently operational, except for the Commercial Space Station, which has been incorporated into this analysis as it is a proposed representation of what this thesis is attempting to design.

2.2.1 Apollo Spacecraft

The Apollo programme (1963 – 1972), was created to land humans on the Moon and return them safely back to Earth. The spacecraft’s were designed for human transportation as well as habitation. The Apollo system contained two main architectural elements, the Command and Service Module, and the Lunar Module. The CSM accommodates three astronauts, transporting them to the lunar orbit and back to Earth. The CSM consists of two compartments, the Command Module and the Service Module. The CM provided the crew living space and was equipped with operational equipment for the spacecraft. The SM accommodated the main propulsion systems and consumables. The LM accommodates two astronauts, transporting them from the lunar orbit to the lunar surface, providing occupants with a habitable volume of 6.6 m³. Apollo missions were extremely work orientated, with schedules indicating activities other than work being minimal or non-existent. The CSM and LM had no spatial separation of functions, with all human activities taking place in the single volume. The need to segregate function through architectural means will be utilised for this project.

2.2.2 Salyut Space Station

The Salyut programme (1970 – 1991) produced the world’s first Space station, reaching Earth orbit in 1971. The Soviet Union’s venture continuing the Space race; the US had already landed man on the moon. Konstantin E. Tsiolkovsky, a pioneer in rocket and Space research stated the importance such a programme held, in which the Space station would act as the stepping stone for human habitation throughout the universe.\(^{18}\) The Salyut programme produced a total of seven Space stations, each successor refined architecturally, as well as the consideration and incorporation of cosmonaut ideas and suggestions to design. The programme utilised strategies of colour co-ordination, and later on Velcro carpeting in order to imply an orientation.\(^{19}\) These strategies and the introduction of sealable compartments, shower devices, refrigeration elements for food storage and the installation of windows indicate a development of Space architecture that goes beyond solely sustaining human life. The lengthening of Space station occupation led to the development of systems capable of supporting human life comfortably throughout these extended durations.


\(^{19}\) Häuplik-Meusburger, Architecture for Astronauts, pg44-51.
2.2.3 Skylab Space Station

The Skylab is America’s first experimental Space station, with the programme objectives of proving humans could live and work in Space, and the expansion of solar astronomy knowledge beyond Earth based observations. Launched into orbit on May 14th, 1973, and was occupied until February 8th, 1974. The empty spacecraft returned to Earth on July 11th, 1979 via a controlled crashed landing. The attempts of self-sufficiency, independent from frequent re-supply led to the development of life support systems that form the basis of today’s ISS systems. The contributions to interior design by Raymond Loewy are praised by NASA’s deputy administrator Dr. George Mueller. In a letter Mueller writes, “I do not believe, that it would have been possible for the Skylab crews to have lived in relative comfort, excellent spirits, and outstanding efficiency had it not been for your creative design, based on a deep understanding of human needs, of the interior environment of Skylab and the human engineering of the equipment and furnishings which the astronauts used.”20 The utilisation of the vertical implied a greater sense of spatial separation through the idea of levels, with hand rails, handholds, straps and foot restraints aiding the transition from room to room.

2.2.4 Space Shuttle

The Space shuttle has been used as a platform to build the ISS, as well as transport people, equipment and supplies to the station. This system will be utilised by the project to convey a realistic approach to building construction. Shuttle flights generally last seven to ten days, and can be extended to approximately 17 days. The crew can consist of up to of seven astronauts. The middeck of the Space shuttle is the living area, where crew members sleep, eat and conduct hygiene activities.

2.2.5 Mir Space Station

Considered by some as the first international space station, the program evaluated different docking techniques and resupply methods, leading to international collaboration on Mir, and eventually the ISS. Frank L. Culbertson Jr., Director of the Shuttle-Mir program refers to the original use of the word 'mir', meaning the notion of a village; where the local people live closer together to better share the limited resources.21 Launched in 1986, the Shuttle-Mir program began in 1994. Based on the collaboration with international partners, the program reduced the risks in developing and assembling a Space station. Mir is distinguishable from its predecessors through its modular concept. The ‘Core module’ of Mir contained two docking and four berthing points. For the duration of Mir’s orbital lifetime, Russia implemented expansion plans by attaching additional modules to the abundant docking ports. The need for expansion acknowledged that the lack of habitable volume can lead to negative physical and psychological effects.22

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2.2.6 *International Space Station (ISS)*

“The International Space Station is an orbiting laboratory and construction site that synthesizes the scientific expertise of 16 nations to maintain a permanent human outpost in space.”

It acts as a “microgravity research complex for biological, materials, fluid physics and other science experiments and technology demonstrations.”

The construction of the Zarya Module began in December 1994 at KhSC (Khrunichev State Research and Production Space Center). Reaching completion in 1998, the first of the ISS Modules was launched on November 20th, 1998. Whilst the station's primary purpose is that of a scientific research laboratory, it must also accommodate tenants which occupy the satellite for long periods of time. Continuous human occupation has occurred since November 2nd 2000, giving the ISS the record for “longest duration continuously manned outpost in spacelflight history.”

The ISS is the culmination of almost 50 years Space habitation experience, and will serve as the key project precedent.

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Orbital Technologies is attempting to have a Commercial Space Station in operation as early as the year 2016. The construction and transportation methods utilised by this venture will be important for this thesis. Whilst a lot of this information is still confidential, the renders and images that have been released to the media indicate a strong relationship between the ISS, with a similar modular set up. The company intends to utilise Russian rockets Soyuz and Progress for transportation and servicing, and will consider other “commercially available vehicles.”

The simplicity in relation to design indicates a strong engineering influence, only the bare essentials are provided for the inhabitants.

3.0 Develop Project: Design/Research

3.1 Site Analysis

3.1.1 Context
The project will be designed for the stratosphere of Low Earth Orbit. NASA defines this stratosphere as platforms that orbit between 80 km and 2000 km from Earth’s surface. Capderou discusses the importance of satellite placement and positioning, “no matter how advanced it may be; will never yield the results required of it unless it is placed on an appropriate orbit and with suitable orientation, so that it can deliver the predefined spatial and temporal resolutions.” Such control and precision would ease the incorporation of additional programme elements such as an evacuation point for the ISS; it would also diffuse the strain on tracking systems and simplify connection processes for docking ships. The site is an orbital path located 400 km from Earth’s surface. The Space hotel will be required to complete a 360 degree rotation (in relation to orbital path) every Earth orbit in order to sustain an attitude relationship to Earth, and counter orbital decay which is estimated at a rate of 2 km per month.

Ömer Akin speaks of the importance of context, how design is generally tailored specifically to a site to incorporate views, existing elements such as neighbouring buildings and vegetation, and how an architectural proposal must abide by building regulations and codes. Design output is also influenced by budget, client requirements, and in some cases seasonal climate/environmental conditions. How does one design in the absence of built environment, where vegetation and neighbouring infrastructure are absent? In a context that is constantly changing by a mobile architecture? The absence of a consistent physical context unveils the potential for the production of any architectural form, and in relation to architectural design: no constraint is the worst constraint. Context (nature, neighbouring buildings, climate conditions etc.) provides the architect visual clues and guidelines for design; Jackie Craven believes Frank Lloyd

Wright's writings on organic architecture pertain to the idea that buildings should grow naturally from its context.\(^{32}\) The Space hotel is constantly moving; meaning anything in its vicinity is only there temporarily, contextual surroundings are in a scale that is ridiculously macro. “Given that architecture is defined as architecture because it is within a context, design becomes integral with the context. Therefore building design which is not within any context is not architecture.”\(^{33}\) Frank John Snelling’s comment immediately evokes the idea that this particular project is not architecture, although the comment only applies to a built environment. Culture, climate, psychological and environmental conditions also contribute to the idea of context, the proposal utilises these elements as well as architectural ideas and strategies to provide an architectural response to an engineering driven product.

The inability to visit a building site can be a great disadvantage in relation to architecture. The physical and visual experience of outer space alone is one that photos and personal accounts of others who have been to Space, cannot compensate for. This factor is evident by the attempts of engineers and designers working on vehicles and satellites for use in outer space. Constant recommendations and requests by astronauts and cosmonauts have referred to design flaws and elements that were unsuccessful, such as the lack of privacy and separation elements. These strategies and systems can only be queried in the environment they are designed for. This approach indicates the difficulties of hypothetical design. The development and evolution of Space architecture must derive from the personal experiences of a microgravity environment. Hypothetical design for human occupation of outer space “cannot be accommodated on giant platforms, but at first must be hosted in small, feasible, and realistic modules based on already tested systems.”\(^{34}\)


\(^{34}\) A. Scott Howe and Brent Sherwood, editors, Out of this World: The New Field of Space Architecture. (Virginia, AIAA, 2009), p105.
3.1.2 Site Conditions

Site conditions include absence of terrain, weather conditions and seasonal variations, as well as:

- Orbit: A major issue in relation to this transition, in LEO location is forever changing. On Earth, a site can be accessed with an address, giving an individual a means in which to locate it. In LEO, revolving satellites are never in a single location and travel at speeds of 7 km per second.
- Microgravity: Elements found in LEO are subject to the sensation of microgravity because they are in constant free fall in an elliptical path around the earth. This sensation implies the absence of ground, in which orientation can occur at any angle, in any plane. This single aspect will query the notion of floor, wall and ceiling, in which each surface is capable of being considered one and all.
- Extreme Temperatures: Temperature variations in LEO can vary from -157° to 121° degrees depending on whether “they face the sun, the Earth, each other, or deep Space.” Therefore thermal comfort within any orbital Space habitation is crucial in regard to human safety. The variations of temperature create a dependence on artificial systems that must function constantly.
- Unfiltered Sunlight: Direct exposure to the sun’s rays (an absence of atmosphere) means all exposed elements that bear this strain require ultra violet (UV) tolerant materials. Damage inflicted from the “unfiltered solar spectrum, including UV wavelengths that can embrittle or degrade materials, blind sensors including retinas, burn tissues and cells, and induce thymine-dimer DNA damage.”
- Tenuous Atmosphere: Reactive monoatomic oxygen is rich in the lower region of LEO; protective coatings are required to counter its erosive effects. Howe also writes how electrical contactors, when exposed to the conductive plasma, can control the charge potential of space craft or use the geomagnetic field for propulsive benefit. This strategy is utilised to counter orbital decay, which can be as much as “2 km per month.” Atmospheric drag influences altitude which must be corrected from time to time.
- Orbital Debris: The hotel will occupy the field with an array of articles including dust, shrapnel, rock and

dead space craft, all which possess a hazardous presence. This is a contributing factor to material selection
in the ISS design, which utilises Kevlar, the material used in bullet proof vests. Kevlar will be used for the
exterior shell of this proposal.

• Variable Views: “Sun, earth, dark sky, astronomical objects, nearby hardware, clean vacuum, beamed-
power sources, oxygen ram flux, debris flux maxima – are generally incompatible and change with time.”38
Astronauts never bore of the view of our planet, like waves, despite a sense of constancy, Earths views are
forever changing due to rotation and weather.

“Biomimicry (from bios, meaning life, and mimesis, meaning to imitate) is a discipline that studies
nature’s best ideas and then imitates these designs and processes to solve human problems. Studying a leaf
to invent a better solar cell is an example. I think of it as ‘innovation inspired by nature.”39In this instance, the
concept of Biomimicry is utilised to justify the implication of a horizon, a sense of orientation. Scyphozoa,
a classification in which more than two-hundred different species of jellyfish belong, contribute to this
argument, they “lack basic sensory organs and a brain”40, yet orientate themselves in relation to light which
their nervous systems are able to recognise, thus implying a sense of ‘up’.41 The similarity of an environment
of low gravity implies the ability to manoeuvre in any position and direction but Scyphozoa always adopt a
constant orientation towards the light. Here on Earth, navigation is derived from the points of a compass:
north, east, south and west. In plan, these elements are all that is required for mapping purposes, although
the incorporation of ‘skyward’ and ‘Earth core’ compass points, as well as the inability to differentiate
between these navigational determinants, create confusion and disorientation. This factor is eased by a
simple, single level structure (in relation to an Earth bound orientation) allowing inhabitants to quickly
map out the proposal mentally for easy navigation through the building.

3.1.3 Construction Logistics

Constraint assists in shaping architecture. Surrounding buildings, vegetation, culture and climate help mould a design so that the building operates in sync with its surroundings. A constraint for this project came in the form of the Canister Rotation Facility (CRF)\(^{42}\), which assists in the construction and logistics of elements intended for outer space. Modelled dimensionally identical to the Space shuttle payload bay: the maximum module envelope diameter while vibrating during a shuttle launch is 180 inches (4.572 m) and 19 m long. Engineers and scientists construct ISS modules and elements for Space inside the CRF, meaning “canisters periodically must be rotated to vertical or horizontal, depending on payload processing requirements”\(^{43}\), this factor is also used during construction and development, manipulating the horizontal plane allows workers to experience the interior spaces as the astronauts do. Whilst the CRF eases the multi directional nature of design for microgravity, it highlights the dimensional and weight constraint of transporting elements constructed on Earth for use in outer space.

Kennedy discusses an alternative method of module construction, where CRF dimensions are applied to building element sizes (dimension and weight) which can be transported into Space. Once there they can be constructed into larger assemblies.\(^{44}\) Whilst such an approach allows a greater potential for size, it has only been tested on elements in outer space that are not inhabited, predominantly truss structures which support the solar panels of the ISS.

The International Docking System Standard (IDSS) is the connection between modules. This universal standard allows integration of Space modules and systems, regardless of which country they were constructed in and transported from. The system will be utilised to make all but one connection through the orbital Space hotel modules, although this system will be manipulated and altered to create the final outstanding link, completing the proposal.

The project acknowledges the impossibility of testing in-situ construction techniques.

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\(^{44}\) A. Scott Howe and Brent Sherwood, editors, Out of this World: The New Field of Space Architecture. (Virginia, AIAA, 2009), pg8.
3.2 Programme

Requirements for the hotel fall under two different categories, habitation and services, both these elements intertwine for successful design. Habitation includes bedrooms, bathrooms, living and dining spaces whereas services include thermal comfort systems, gyroscope orientation controls, aeroponic areas and electrolysis systems. These elements serve a necessity in relation to the functionality of the project, working together to provide an environment suitable for human occupation.

3.2.1 Spatial Planning

Sleep is the natural cyclical state characterized by a reduced or absent consciousness and the transition into this state of mind would generally be considered the simplest of tasks. Here on Earth, lying parallel to the floor on a comfortable surface usually allows an individual to sleep. In outer space this task is slightly more difficult. Architecturally, such a space is the bedroom; thermal comfort, security, privacy and acoustic buffering elements, along with blinds/curtains and bedding assist sleep. Initial sleeping quarters in Space lacked darkness and quiet. The ninety minute earth orbit would create disruptive light patterns for astronauts, the sensation of sunrise through openings every 45 minutes, and sound emission from operating equipment would disrupt rest. The design of a ‘bedroom’ in an environment of microgravity will need to go beyond the incorporation of furniture and fittings. The ISS utilises the TeSS45, a small volume measuring roughly 1200 mm wide by 1200 mm deep and 2200 mm high. The TeSS houses a sleeping bag, which is attached to a wall so the occupant does not float around freely during sleep, as well as a laptop and monitor for communication and entertainment purposes.

The category of hygiene pertains to three main elements: personal hygiene, toilet and general housekeeping. In a microgravity environment water floats freely in every direction making actions like bathing and brushing your teeth slightly more complicated. Design in this instance will cater to alternative methods of cleanliness, but will be required to provide the same outcome and certain attributes of its earth counterpart, the bathroom.

In earth orbit, one does not sit at the dining table in order to consume a meal; crockery and cutlery do not stay in place on the table, meaning neither does the meal one is attempting to consume. If the fittings and furniture help define the function of our architectural spaces, how can architecture

alone represent them in this absence? The adaptation of activity requires the adaptation of architecture to facilitate this transition in a more effective manner. Currently on the ISS, one simply consumes liquid drinks from a straw attached to a sealed bag, and solid foods are selected over liquid meals (soup/curry) to reduce cleaning requirements.

Leisure space is often represented by large, open, outdoor areas. In Space most leisure must take place within a fully enclosed volume. This enclosed volume must be large enough to cater to a range of Space activity, as well as fit within the constraints of construction, transportation and structural capacities set by the dimensions of the Space shuttle cargo bay. In leisure time, astronauts and scientists are generally left alone to do as they please, and a lot of their activity utilises technologies and items used on Earth. Laptops, mp3 players, books etc. fill in the period set aside in the schedule for ‘personal/private’ time. Duration of stay is no longer than five days, although there will be a need to provide activities to occupy and challenge visitors mentally and physically. Whilst there is opportunity to provide areas for activity on a hypothetical assumption, the validity and plausibility of such things would compromise the legitimacy of findings.

Work does not require a desk and chair. One is carrying out experiments in relation to the environment of microgravity. Design will resolve the absence of furniture by treating the space defining elements as entities capable of providing both.

The absence of the constraint of gravity allows a multitude of architectural outcomes. Construction is capable of occurring in any direction (horizontal/vertical), without area loss to vertical circulation. Stairways and elevators are not required in the design. Additional elements may be added to provide increased privacy or separation throughout the scheme, e.g. transitional volumes.

The field of Anthropometrics provides the dimensions of doorways, stairs, shelves, fixtures, railings, work surfaces and seating. The elements are given a universal dimensionality which accommodates the average human body. Dictated by reach, stride, and other ranges of motion, movement through an environment of microgravity does not occur on two feet. Different floor levels can be reached without the aid of staircases and elevators and doorways are no longer required to accommodate one’s height. The Metric Handbook indicates human movement and motion and provides a range of measurements for crawling, kneeling and bending: positions that will apply in a microgravity environment.46

A gymnasium has been incorporated into the scheme for leisure purposes. The duration of stay in

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the hotel is insufficient for the development of muscle deterioration and bone atrophy. Resistance training will provide hotel guests with the only implication of gravity.

Composition of spaces for the building was based purely in regard to room layout and transition from public to private without the assistance or influence of orientation and context (views). Generally, issues like security and orientation in relation to the building site would impact on planning and layout, pedestrian and vehicle access also making a contribution. The proposal has a single point of entry/exit. The difficulty and control of accessibility implies that building layout might not be required to have some kind of conscious arrangement. The transition from public to private realms assists in the arrangement, implying a sense of control and consideration in relation to planning.

A spatial experience in LEO occurs, where one is confined to the hotel interior, and yet sails through a vast, endless space. Whether occupants will suffer from claustrophobia or agoraphobia differs in each case. The implication of an indoor/outdoor transition is introduced to reduce the psychological tensions of the hotel guests.

3.2.2 Services

Outer space is a radiation dominated environment. The absence of air indicates an absence of conduction or convection, illustrating the difficulties of utilising sustainable strategies for thermal comfort. The project, like the ISS, is dependent on electrical services. The absence of atmosphere allows the suns full potential as a source of energy on which all operational systems are dependant.

The ISS is thermally insulated to such an extent that cooling is the only requirement in relation to thermal comfort. “Energy from the solar arrays flows into the ISS to run avionics, electronics ... all of the Station's many systems. They all produce heat, and something has to be done to get rid of the excess.”

Air is a poor conductor of heat, evident in the utilisation of insulation elements which trap the air in wall cavities. The project will utilise Multi Layer Insulation (MLI) which is made of Mylar and Dacron. The Mylar is aluminized meaning solar thermal radiation cannot penetrate it, while the layers of Dacron fabric separate the Mylar sheets, preventing heat from being conducted between layers. MLI also consists of layers of Kapton, which protect the fragile sheets of Mylar, which are generally 0.3 mm thick.

In relation to cooling, the ISS utilises heat exchangers and cold plates, both of which are cooled by a circulating water loop, which sends the energy to exterior radiators rejecting the heat into Space. Given the

large temperature fluctuations experienced by the ISS, water circulated through the pipes would quickly freeze, meaning waste heat is exchanged a second time through an ammonia loop which has a freezing temperature of -77° C. The lowest temperature of Space is -157° C, the circulating ammonia does not lose heat fast enough to reach freezing point, and circulates back into the ISS before this can occur.49

Aeroponics is the process of growing plants in an air or mist environment without the use of soil. Aeroponic systems can reduce water usage by 98 percent, fertiliser usage by 60 percent, as well as eliminating the need for pesticides.50 The system alone is insufficient in providing oxygen, water and food for the hotel occupants, and will be used in conjunction with other systems.50

Electrolysis is the process of passing an electrical current through an ionic substance, resulting in chemical reactions at the electrodes and separation of materials. When applied to water, the molecules which are made up of two hydrogen atoms and one oxygen atom (H₂O), separate and recombine to produce hydrogen gas (H₂), and oxygen (O₂). This method provides the ISS its main source of oxygen, and will also be utilised for this particular scheme.

Water supply in the Space hotel will occur in the absence of plumbing, with all water, both for consumption and hygiene coming from pre-packaged containers which will be transported to the hotel along with the passengers. Reserves and back-up supplies will ensure this essential product is always present on board.

The horizon has been introduced on the ISS for attitude purposes, easing the process of docking when shuttles are delivering supplies and guests, as well as stability for scientific analysis of exterior views, whether these are directed at Earth or into deep Space. The ISS utilises a Control Moment Gyroscope system in order to create a horizontal plane parallel to Earth's surface, creating a balance between elements like torque, movement, orbit and momentum. The CMG system has been adopted into the project to provide a controlled attitude, implying a consistent horizon throughout the scheme as a whole.

When astronauts are needed to complete activities on the exterior of ships and satellites in outer space, they are required to wear an Extravehicular Mobility Unit. The EMU protects the occupant by providing oxygen, a pressurized atmosphere, thermal control and a protective shield against the harsh elements of outer space.51 EMU’s will be provided in the Space hotel solely for maintenance purposes on the hotel exterior.

The incorporation of these elements to design ensure the safety and comfort of all hotel guests.

3.3 Design Strategies/Process

3.3.1 Construction Limitations
The image on the right is an exploration of form using CRF dimensional constraints, by manipulating the surfaces of cylinders.

Fig 3.10: Form exploration using CRF constraint.
This exploration was produced through a construction process that occurs in Space. Dimensional constraints are applied to prefabricated elements to be constructed in Low Earth Orbit.
3.3.2 Horizon Concept

Utilising the ideas in which architecture must grow naturally from its environment, building form was inspired by the 'horizon'. Given this particular environment is pure space with no immediate context, the idea of horizon was utilised in the sense of a land mass viewed from across a body of water, in which the land seems to taper out from the water and slowly rise creating a landscape, before disappearing again into where it once came. This concept was adopted early in the design phase and has remained a constant throughout the project as a whole. An organic form would convey this idea greater than a faceted approach, and would also make a greater structural contribution to the building.

Video analysis of a tour of the ISS illustrated the difficulties of multiple orientations. The complications of mentally mapping your surroundings with an inconsistent orientation meant such a process would take several days as opposed to several minutes. The installation of fittings in the ISS would imply the orientation of a volume, hence in one room you could be in a single orientation, and in the next upside down in relation to the previous room. Thus the implication of horizon and orientation are for the beneficial requirements of the psychological wellbeing of occupants. The ability to navigate easily within the hotel is desirable.
3.3.3 Formal Consideration

The ‘corner’ is an interior element generally occupied by furniture or at which a doorway is located. The junction represents the union of two perpendicular walls and the floor plate. The generally structural detail is inadequate in outer space, the orthogonal geometries exposed to a different force.

With an idea of form, initial planning exploration utilised volume (m³) as opposed to area (m²) to represent the different spaces within the hotel. Given the nature of organic form and the ability to occupy all volume, working in plan was redundant. The intended volumes do not have parallel walls meaning they could not be represented by area, only by volume. In outer space you are not limited to ‘floor’. The planning exercise unveiled the need for a central public space, capable of accommodating all occupants with enough room to manoeuvre with a lack of obstruction, to truly feel the sensation of microgravity in outer space. The organic volumes took into consideration accommodating the human body. Fusing the faceted volume planning and organic building form would create the desired building. Although in this stage of production existed the fear of conveying a lack of architectural control through organic form.

Fig 3.13: Volume planning.
With an idea of spatial planning, an exterior form was produced through computer modelling.
3.3.4 Faceted Exploration

The faceted exploration provided a greater sense of control over composition in relation to organic exploration. The central element pictured (blue lines) represents the large open area in which occupants can experience the environment with little obstruction (10m diameter). Leading into the space was a claustrophobic experience in which one travelled through a series of narrow passages (tunnel like, floating on belly, not walking on feet), before arriving into this large, open and free volume. Utilising the construction process of the ISS Cupola as a guide, the central space caters to views looking toward Earth or into deep Space, a sensation in which the inhabitant could experience deep space without the requirement of an Extravehicular Mobility Unit Space suit (EMU). Each segment of the core comfortably fits into the CRF constraint. The grey components represent the building’s main supply of energy, the solar panel. The solar panels were shaped and positioned to further contribute to this idea of horizon, helping the overall form taper out into Space.

Whilst the exploration was successful in relation to planning and aesthetic, it felt alien to the environment of LEO.
3.3.5 Organic Exploration

The attempt to transition the faceted exploration into organic form was a difficult task when the volumes had been set in a linear nature to begin with. Multiple attempts resulted in a failed form and aesthetic.
Fig 3.21: Fusion perspective.
3.3.6 Material and Structure Considerations

3D Printing, the ability to print tools for construction, or replacement parts on site\(^{52}\), could potentially result in elements unrestricted by Space shuttle cargo load dimensions.

Discussions in relation to materiality are usually synonymous with structural and aesthetic concerns, although they are capable of having a psychological influence on the inhabitant. Pallasmaa writes, “Natural materials – stone, brick and wood – allow our vision to penetrate their surfaces and enable us to become convinced of the veracity of matter. Natural materials express their age and history, as well as the story of their origins and their history of human use… But the machine-made materials of today – scaleless sheets of glass, enamelled metals and synthetic plastics – tend to present their unyielding surfaces to the eye without conveying their material essence or age.”\(^{53}\) Whether an individual would want aging characteristics in a material which his/her life is dependent on is questionable, and while these ‘unyielding’ materials will be used on the exterior cladding and structural elements of the building, there is an opportunity to explore interior spaces with natural materials.

Timber, brick and stone, the three main natural materials of the architectural palette evoke different psychological responses from building inhabitants. Brick and stone represent durability, mass, a solidity that can be oppressive or authoritative, whereas timber evokes a warmth, lightness and a natural sensation that is both safe and yet limited in the sense that it does not imply a permanence. Thus, timber elements will be incorporated into the building design to evoke a sense of nature and imply a comfort of home, inhabitants may be able to connect with the temporary nature of timber in a consoling manner. “Spatial perception, spatial reasoning, spatial orientation behaviour or experience; architectural psychology is a field where findings reveal how we can design buildings better for occupants”\(^{54}\), this mentality will help shape and refine the proposal, such consideration paramount to the buildings success in regard to habitation.


Biomimicry is also utilised in a structural manner. Neri Oxman, founder of ‘Materialecology’ uses materiality to determine form; instead of manipulating a material into the desired form, the material is utilised in its natural state. Analysing the composition of an egg shell membrane through a microscope, Oxman mimicked the composition to create a structural element with an aesthetic as well as rigidity. The discontinuous nature of this composition also allows the opportunity for physical and visual openings into other spaces and exterior views. ‘Nature’s engineer’ creates a composition that evenly distributes the structural load throughout the eggshell membrane.

The building façade utilises this opportunity of Biomimicry, contributing to the hotel's overall structural capacity. Elements intended for outer space are required to withstand the force of launch (3G: three times normal gravity).\(^55\) Once in outer space items are under a constant tension, being pulled on from every direction, as though the forces acting on elements want it to explode from the inside out. Engineers utilise a cylindrical form for this matter, the perfect geometry to counter such a force. Applying a similar structural makeup to that of an eggshell membrane, the organic forms shall be able to distribute the load almost evenly throughout each portion of the proposal as well as contribute a compression element to the building skin.

Transparent elements of the hotel will be made of fused silica and borosilicate glass panes,\(^56\) which are identical to the material used by the ISS cupola. The windows will be shuttered when not in use in order to protect them from micrometeoroids and the harsh environment of outer space.

The exterior shell of the hotel will be made of Kevlar. The synthetic fibre is used in bullet proof vests, and is also used on the ISS to counter dust and small debris collisions that occur at 27,000 km per hour.


3.3.7 Physical Modelling

Physical model experimentation tried to mould several linear elements into a single, organic, continuous form. Physical modelling was initially avoided for the sake of control and accuracy, although resolved the issue of trying to design a flowing organic form. The physical models created were more informative than the computer’s ‘Perspective’ view.
3.3.8 Form Exploration

A successful form was achieved by reducing the elements that required moulding together. The required spaces are represented in volumes that still fall within the Canister Rotation Facility constraint of dimension. The reduction of elements (by producing several together) allowed an easier transition between modules. This breakthrough in development allows the pursuit of interior development, an issue that up until now has been restricted by exterior form. This also allows the development of structure, and the consideration of connection between modules. Given the walls mould and protrude to provide fixed furniture like elements, the volumes within are subject to each other and the exterior form. With the success of exterior form, interior development can now begin.

Fig 3.27: Organic elevation.

Fig 3.28: Organic plan.

(right) Fig 3.29: Organic perspective.
CRF dimensional constraint.

Space Hotel volume requirements.

Volume arrangement with connection considerations.
Initial moulding process.

Solar panels and truss incorporation.

Fig 3.30: Final composition.
Window placement is done strategically to further contribute to the realisation of location. Interior form exploration revealed the need to truly differentiate between implied planes so the elements of wall, floor and ceiling are not easily confused.
4.0 Conclusion

There is a strong ISS influence throughout the entire scheme. The modular construction approach and the adoption of a majority of ISS services create a sense of realism. This project could be realised using today’s technologies such as the CRF and ATCS.

The absence of a built and topographical context hindered initial form exploration. The inability to exploit visual clues and suggestions imply pure architectural form. Wall, floor, and ceiling, share roles in the environment of Space. Technicalities that represent different planes on Earth, fuse in outer space to define the parameters of habitation. The organic approach was utilised so these three different elements were not as easily confused in relation to their orthogonal counterparts. The negative effects of confinement have led to an implied interior/exterior transition. The strategic placement of interior and exterior windows, visually suggest this experience is attainable physically.

Design for microgravity unveiled the inability to work in plan, design consideration primarily volumetric, with the continued strategy of public to private transition. Despite the ability to map spatial arrangement in two-dimension, consideration of planning occurred in the third. The utilisation of organic form is also a contributing factor, a plan drawing misleading in representing the organic spaces. A plan drawing implies the extrusion of lines toward the viewer represent volumes and suggest the building’s shape, in relation to organic form, this does not occur.

Currently, solar energy is the sole energy provider for the hotel. The absence of atmosphere and weather variation, indicate a dependence on this constant and continuous power source. The further development of other sustainable strategies will reduce the structural components and volume requirements of this system.

Whilst the hotel is a single storey complex, the reduction of vertical circulation space is an obvious factor in relation to Space architecture. The ability to float or glide from one level to another mitigates the argument of whether one should use the stairs or the elevator. Vertical corridors occupy less space than their gravity equivalents.

It is evident that the field of engineering will continue to be important in the design and construction of elements for outer space. If Space habitation is to excel, an architectural presence is vital to contribute to human wellbeing. The ability to create environments that evoke emotional responses and visual delights are the psychological and physical benefits of architectural design.
The modular nature of the design allows for expansion by incorporating additional modules. Future expansion could introduce the requirement of a centrifugal force or artificial gravity, which detracts from the nature of this project. At the hotel’s current scale, the implications of an artificial gravity are unrequired. Whilst such a force would ease the activities of bathing and dining, at this stage of development hold a futuristic mantle in the overall scheme of things.

The computer programme Rhinoceros 4.0 has allowed an exploration of organic form through modelling. “Digital techniques and tools significantly broaden the areas of architectural thinking and acting. They influence analysis, concepts, simulation and production and thus the prospects of architecture itself. Interdependencies between analogue and digital processes lead to new conceptual and substantial solutions, the gap between thinkable and buildable ideas disappears, different spaces can be experienced.” What is interesting is how architecture contributes to the definition of space without the aid of fittings or furniture. Is the bedroom a bedroom if it does not house a bed? Is it a kitchen if it does not have an oven, sink, or bench? What actually defines the spaces within architecture? Is it the furniture? Is it the activities that occur inside each individual space? As architects, do we merely define space? And are we capable of making a contribution that goes beyond that definition? The space is defined by its user. Whilst design can pertain and accommodate to a specific usage, the volume is subject to the occupants want or need.

The concept of gravity is merely implied in the virtual world. Regardless of what is being constructed within modelling software, gravity is a construct to assist in the design game despite its non-existence in a digital world. Whilst gravity is an automatic construct of the user, the models prepared in Rhino 4.0 for the environment of outer space also convey this idea of gravity. Interior walls and elements are fixed to the structure, nothing is left to float freely within the designed volumes, despite the ability to model them in this manner, they have been automatically attached, as though gravity itself, despite not existing in this virtual world, demands presence regardless. Digital software allows free floating structures and elements that cannot be fully exploited. The demands of design insist on a ‘groundedness’ or at least connection.

The most interesting element making the transition into microgravity design is the horizon concept. Conveyed through form as well as interior layout, its importance goes beyond the merely navigational. The psychological and physical importance of the notion for orientation remains in Space, as it does on

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Earth.
Bibliography


structure/elements/fgb.html


