

Has the Challenge of Designing for Space Exploration and Potential Habitation Beyond Planet Earth, Created the Need for a New Profession of ‘Space Architects’?

A DISSERTATION

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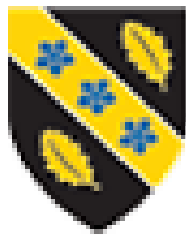
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Abstract

The adversities faced in a possible inhospitable Earth, have urged a new level of space exploration opening the doors to designers, to be the architects in the new worlds. This dissertation is an exploration into the prospects of 'Space architecture' becoming a recognized and mainstream profession, specifically answering the question 'Has the challenge of designing for space exploration and potential habitation beyond planet earth, created the need for a new profession of Space Architect?

The investigation outlines what constitutes protections in a profession and how this might apply to space architecture. Key physical and mental challenges are identified to show why it is necessary for designers, in the scope of space architecture, for solutions to be proposed in counteracting and overcoming these obstacles. The research of precedence and historical context is crucial in highlighting some of the previous space architectural resolution that have been proposed and whether or not this can form the basis for new designs.

In the efforts of gaining credible information, a series of six semi-structured interviews was conducted with practitioners who have gained experience in this field and individuals who are closely associated to the field of 'Space Architecture'.

Case studies have also been evaluated, digitally, forming conclusions based off successful precedent designs. These case studies have not been executed in their end environment but have been tested to the extreme in conditions on earth.

The result of my research and investigation have concluded in there are numerous physical, physiological and psychological challenges, all of which need to be accounted for in design 'Space Architecture'. It is currently, too early to form a regulatory body to manage this field beyond what exists today, however the exponential rise of interest in space exploration may deem it necessary and responsible to do so in the future.

1. Introduction

1.1 Context of Investigation

The design of structures to withstand the harsh and unliveable conditions in an extra-terrestrial environment are becoming ever more viable in the modern day. In the following chapters of this dissertation, I will be establishing how the unique challenges encountered in 'Space Architectural' design have paved the way for a new, protected discipline. I will address core aspects of specialist knowledge, invaluable skills, and knowledge that an architect might bring to the wider field along with supplementary information that an architect might need to consider when designing for extra-terrestrial habitats.

The level of technological advancement is unprecedented and exponentially rising giving route to wider possibilities in architecture and Structural design to the extent that structures can be built off-world. The need for this arises from unsustainable conditions on Earth, presenting the possibility towards an eventual inhospitable environment, that cannot support human race at the current rate of resource consumption at 173% (Cassella, 2021). This will not be in ten generations of human life or even five generations this could happen as early as 30 years, in the life of the current or next generation (Young and Mitchell, 2019) when conditions can no longer be ignored. Individuals within this field such as Elon Musk, understands that should the Earth environment become inhospitable there is a need to support life off-world (Weitering, 2020) where humankind can have a fresh start. This presents the demand for structures to permit long-term living for an extra-terrestrial environment and as such has drawn professionals and practitioners from a wide range of vocations. Since one of the fundamental members of building design teams on Earth includes Architects, off-world habitat designs have drawn the attention of Architects and Students of architecture, globally. A small following led to specialized architectural discipline under the scope of Architecture, a term originally classed as 'Aerospace Architecture' but has now been deemed 'Space Architecture' (Adams).

1.2 Discipline of Space Architecture

In the UK, the title of Architect is protected by law, confirmed by the 'Architects Act 1997' further requiring application to Architect's Registration Board (ARB) organization to use the title 'Architect'. It is illegal to use the title 'Architect' if an individual is not on this register. Other professions such as 'Naval Architect', 'Golf-Course Architect' and 'Landscape Architect' are permitted to use the title 'Architect' (ARB). In the U.K. Schools of architecture focus on historical, professional, business and detailed technical knowledge, running in parallel with studio design projects, addressing real-world applications to resolve key issues that are commonly encountered. All in future preparation for conducting business in a specialized field. The same can be assumed for different professions that use the title 'Architect'. Naval architecture, is the study, design and execution of maritime vessels, where the knowledge required in designing these vessels, involves a greater comprehension in engineering principles such as fluid mechanics, thermal dynamics, molecular analyses of materials, etc. The functional protection is also to ensure that 'Naval Architect' practitioners, who are supervised by the 'Royal Institute of Naval Architects' fully comprehend the consequences of decisions and actions they make. The institute also provides confidence of clients, who are informed that they are working with a qualified professional who has gone through years of extensive study to achieve that status.

In consideration of the above it could be argued that as the increased specialisation of 'Space architecture' becomes more mainstream it might be appropriate for 'Space Architect' to become a protected profession. It could also be argued that within this specialization, is a good understanding of physical, technical, and engineering principles, suitable for use in the standard environment and a much greater level of understanding of practical applications for extreme environments on earth. Extreme environments consist of intense and harsh conditions in an arctic or volcanic environment, previously deemed implausible to design for but could now be appropriate to off-world environments as well. Architects would need to consider varying gravitational field strengths, ecological stability, atmospheric pressures, etc. As space architecture becomes more mainstream, adjustments to syllabuses would be necessary, to the point that only specific institutions would be permitted to teach them, possibly requiring a protection within its own dedication. Protection which could ensure that any individual who pursues this course know what they are doing when it comes to 'Space

Architecture’, understanding the outcomes of any choices they make and providing accountability and full recognition of responsibilities. Architects assure a level of understanding in built environments assuming responsibility for immediate physical and mental health related to their design. Naval Architects similarly assure the appropriate comprehension in specialised engineering principles in marine vessel design for an individual’s safety and navigating waters in various and somewhat isolated conditions. It is the accountabilities, responsibilities, and the incorporations of such intense specializations in information that must be understood and maintained in a skilled environment, which warrants the protections of these professions.

1.3 Scope and Benefits of Investigation

The investigation will entail widespread search for published literature and relevant materials associated with space architecture, outlined in the second chapter. Chapter three will present primary research methods to be utilized, most likely in the format of targeted semi-structured interviews with specific individuals, to record, identify and analyse a key data set of information which draws out the most essential ideas. Chapter three will also highlight possible case studies and their design solutions to achieving a successful extra-terrestrial habitat.

In establishing the scope of challenges faced with designing space architecture, solutions can then be identified to resolve the challenges. Throughout the following dissertation an in-breadth search with pre-existing literature and first-hand interviews will be conducted to provide a more informed opinion and knowledgebase that lay the foundations of to the discussion section. With this information I can present findings as to the most feasible methods in tackling some of the challenges faced and readers of this dissertations will be informed of some key features to address in designing an extra-terrestrial habitat.

One benefit to this investigation is that certain sources that would not necessarily seem linked might have a connection drawn in the progression of the following dissertation such as the importance of greenery in affecting an individual’s mood and how this can aid in designing for

space architecture. These connections may display precedence for future investigators into the topic in assuring that a link has been explored and has further shown relation to one another.

1.4 Aims & Objectives

The aim of this dissertation is to investigate how the challenges in designing space architecture might serve route to becoming a distinct and protected profession.

The objectives of this project are:

1. To establish the origins of space architecture in the prospect of discovering precedent designs that can inform the future design of space architecture.
2. To study the discipline of space architecture in the modern day, and whether it serves a path to providing professional protections due to the highly specialized skill-set necessary in its design.
3. To identify some of the crucial physical and mental challenges in confronting the design, then leading way to solutions that endure these challenges, so habitants do not need to.

1.5 Limitations of Research

Due to the current COVID-19 pandemic, which has been present throughout the progression of this dissertation, the case study's selected, SAGA's Lunark Habitat and AI Spacefactory Mars Habitat could not be visited when plans were made to do so. To resolve this issue, observations were made from the literature base and the numerous images uploaded to analyse and evaluate the designs, presenting findings where possible.

1.6 Chapter Overview

Chapter 2 reviews existing literature related to the topic of space architecture including websites, journal articles, news articles and books. This may include psychological profiles, previously proposed designs, or history relevant to space architecture.

Chapter 3 presents the methodological structure I will be following to gain varying tiers of research including primary, secondary, and case studies. The chapter explains the route to which I will analyse and evaluate the research, drawing focal points to address, in the following results and discussion chapter.

Chapter 4 introduces my findings from the conducted interviews with individuals mentioned in my methodology section in the format of common themes and topics mentioned. This chapter will also draw small conclusions based on my literature search and interviews. It will be near impossible for the conclusions to be objective however they will be composed of well-informed opinions.

2. Literature Review

2.1 Introduction to Literature Review

The aim of this chapter is to establish a brief history of space architecture, ideas common to the space architectural community and recognized challenges faced with designing space architecture. The community includes organisations such as Spacearchitect.org, NASA (National Aeronautics & Space Administration), ESA (European Space Agency), UKSA (United Kingdom Space Agency), IAF (International Astronautical Federation) along with various Architectural firms. I will review current and historically published materials pertaining to the topic, to further clarify how to respond to these issues in order to achieve a more informed outlook, where problems are identified and solutions can then be proposed in the progression of this dissertation. It is noted for the purposes of this dissertation that the term 'Space Architecture' is also synonymously linked with terms such as 'Suborbital Architecture' (Alexander, 2012), 'Orbital Architecture' (Sherwood, 2002), 'Lunar Architecture' (Cohen, 2002), 'Martian Architecture' (Wapniak, Dudley-Flores, Gangale, 2007). Space architecture is also connected to the design of any habitats built to withstand extreme conditions (The Millenium Charter, 2002).

2.2 Historical/Context



Figure 1. Wernher von Braun Rotating space station concept (Braun, 1952)

The concept of space architecture has existed in Science-fiction based literature long before modern 21st century notions of commercial space travel, exploration, and extra-terrestrial habitation. It was perceived as early as the 'Copernican Revolution' (Kant, 1787) period where major astronomical breakthroughs were being made redefining the human understanding of space beyond planet earth. These were not widely accepted at first, however historical figures in vigorous study of the field will become noted, 'Galileo Galilei', 'Johannes Kepler' and 'Isaac Newton'. They all improved on the knowledge and works of 'De revolutionibus orbium coelestium' (Copernicus, 1543). As knowledge of astronomy advanced so too did space architectural concept which includes fictional works & detailed theoretical studies. The 'Copernican Revolution' preceded the beginning of an era considered the 'Age of Enlightenment', where the separation of church and state permitted development of greater intellectual advancements, thus the start of explorative Science-fictional genre novels emerged (Hatch, 2000). Carl Sagan and Isaac Asimov consider one of the earliest works in this genre to be *Somnium* (Kepler, 1634). It highlights ideas of travel to the moon, the expected conditions of the journey and descriptions of the environment, even detailing the possibility of indigenous inhabitation, community, and structures. 'Subvolva' is identified as the dark side of the moon where 'Privolva' is the side facing the Earth.

"the Subvolvan hemisphere compares favorably with our cantons, towns and gardens while the Privolvan resembles our fields, forests and deserts" (Translation by Falardeau, 1962)

As mentioned above this was only one of the first examples of 'fictional' work yet it was succeeded by numerous publications of written pieces that led to more detailed description of extra-terrestrial world's and related ambiance, conceiving of possibilities for mankind to inhabit structures in extreme or otherwise non-liveable environments. Fictional works explored ideas for space exploration in novels such as 'From Earth to the Moon' (Verne, 1865). The Smithsonian Institution Libraries in 'A Jules Verne Centennial' (Wolcott and Kalfatovic, 2005) compare the striking resemblance of events in the novel with recorded events of U.S's Apollo program concluding in landing the first humans on the Moon.

'Verne correctly identified the range of latitudes and time of year for a moon launch. (p. 66 Facing)' (Wolcott, 2005)

2.3 Fictional Transition to Theoretical Studies

2001: A Space Odyssey (Clarke, 1968), was a novel and film, both produced simultaneously, chronicling the travels of adventurers in extra-terrestrial environments. It had been recognized that depictions of various structures in Clarke's novel had taken inspiration from some of the first significant theoretical studies of space travel. Examples of these are: 'The Exploration of Cosmic Space by Means of Reaction Devices' (Tsiolkovsky, 1903) and Collier's Magazine article 'Crossing the Last Frontier' (Braun, 1952), which proposes a rotating space station. Tsiolkovsky also provides this solution for generating artificial gravity in weightless environment.

The development of advanced astronautics and rocketry has an intertwined history of being inspired by fictional works. Descriptions of space travel in aforementioned novels became more detailed as knowledge in the field of Astronomy continued to improve (Tseklevs, 2015). Earlier works such as 'Somnium' and 'From earth to the moon' incorporated the facts about space known at the time (Logsdon, 2021) compared to a later H.G. Wells' 'War of the Worlds' which had been inspired by numerous publications in the 1894 journal 'Nature' regarding Martian conditions during telescopic observations (Batchelor, 1985).

Tsiolkovsky's extensive studies introduced the idea of space exploration to the Soviet Union and the European Eastern Bloc, with his papers and defined equation the 'Tsiolkovsky Formula'. In the U.S researcher Richard Hutchings Goddard, encouraged by Wells' Novel (Lehman, 2020), started studying and producing a series of in-depth studies and publications related to Spaceflight shortly after Tsiolkovsky's papers were published. While his conclusions were not widely accepted, even mocked in American press (Lehman, 2020), Goddard's work informed the basis for German rocketry programs during WW2, Hermann Oberth and Wernher Von Braun further expanded this field with innovations in rocketry. After Wernher's integration into the U.S. space flight program through 'Operation Paperclip' his work became the foundation of the Apollo program leading to man's first steps on the Moon (Garza, 2019).

2.4 Analogs

Currently, active efforts are being made to explore the possibility of extended habitation on the lunar surface and Martian surface (Schlacht et al., 2016). Various organisations have utilised man's knowledge of living in the harshest environments on earth in order to inform a baseline of how this can be adapted and improved to live in the most extreme atmospheres for interplanetary habitation (Ahuja, 2020). These are what is known as 'Analogues'. They function as experimental forms, designed, via trial and error, to decide which is the most suitable structure for an extra-terrestrial habitat (Bannova, 2008). An exemplar of this is SAGA's 'Lunark' moon habitat which has been deployed in one of the most remote locations in northern Greenland, where temperatures can drop to -30°C, with the imposed loads of hurricane force winds. Two danish architects (Sebastian Aristotelis and Karl-Johan Sorenson) have designed an origami-style expanding, biomimicking, structure. They have cohabited in the adverse climate, assessing the strains on psychological wellness, actions under isolation and conflict resolution in a confined space for 2-3 months. The mental challenges will be established as a result of these expeditions to determine the feasibility of future missions working over longer periods of time (Angelopolou, 2020).

"If we as architects want to test the effect of architectural countermeasures in space we also need to simulate a realistic amount of stress on the participants." (Aristotelis, 2020)

Another example of these tests being conducted is the 'Flashline Mars Arctic Research Station' which functions as another baseline, but for possible habitats on Mars. Their mission criteria states

'To serve as a testbed for Human Mars exploration', 'To serve as a useful field research facility at a Mars Analogue site' & 'To generate public support for sending humans to Mars'. (Zubrin, 2017)

For the most part, the test site serves to condition and prepare astronauts for research expedition in a remote and unforgiving location. The 'Mars Society', headed by Dr. Robert

Zubrin, supervises this experiment, which spans over four projects including 'MDRS' in Utah, 'EuroMARS' & 'MARS-Oz'. The Arctic station is currently located on Devon Island, near Canada.

The primary aim of these test environments is to record, analyse and evaluate the best solution for establishing habitats on other planets, recognizing any physical or mental challenges that may be faced and providing the tools to overcome them (Schlact et al., 2016).

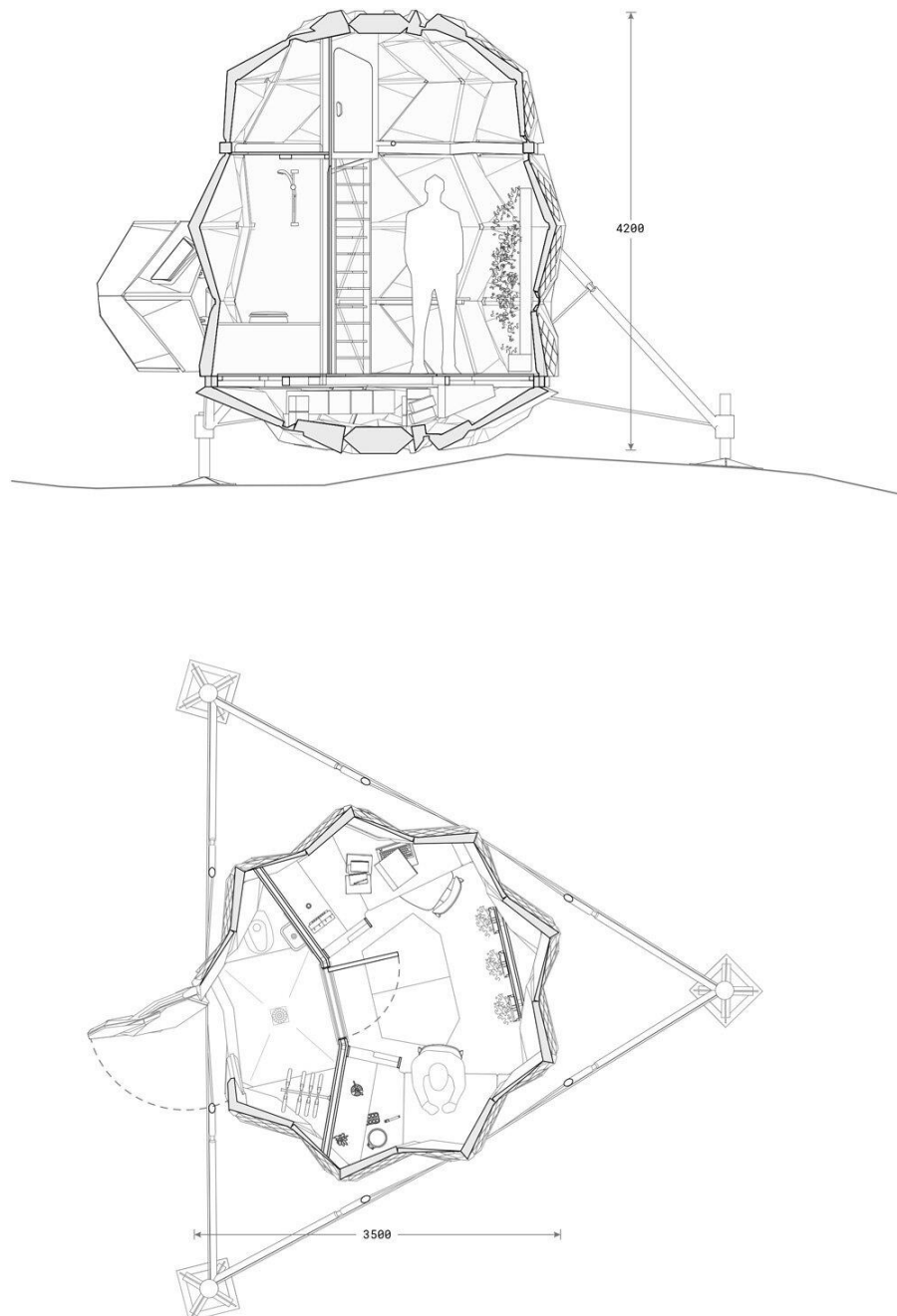


Figure 2. Plans & Elevation of Lunark Habitat (SAGA Space Architects, 2020)

2.5 Theoretical Transition to Practical Application

As the promotion of sophisticated rocketry programs became more prevalent, a consequence of the detailed theoretical studies being published, a period known as the 'Space Race' started to emerge with early signs of interest towards space exploration in Germany, approximately 1930's, with the development of sub-orbital missile designs (Neufeld, 1995), launched during the second world war era (Logsdon et al., 2021). The integration of German experts and scientists into NASA in 1945 (Brune, 2020) formed the foundations of the Apollo program, sending a series of satellites and rockets into space or orbit preceding the Apollo 11 moon landing. The Soviet Union also had a period of development and testing before acquiring sub-orbital missile capabilities, and sending satellites into space in 1957 (Yanes, 2015), finally succeeding in sending the first human, Yuri Gagarin, into space in a single orbit round the earth travelling in a 'Vostok 1' craft in 1961 (Hall, 2001). Gagarin had no control of the craft, sitting in a one-manned capsule with a small porthole window for external views. Shortly after some testing, NASA's Mercury program sent the next human into upper earth orbit in a differently shaped capsule and a slightly larger viewing feature, not quite a window (Logsdon et al., 1999).

Inside Vostok 1

How the spacecraft that took the first man into space worked

Instruments

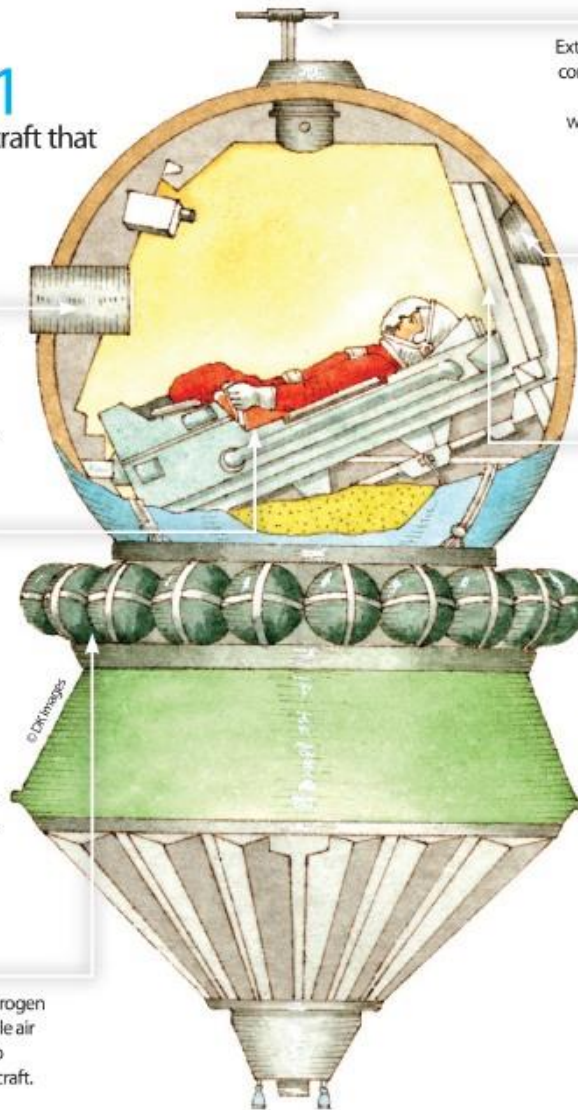
A variety of instruments allowed Vostok's pressure, temperature and position above Earth to be continuously monitored.

Out of control

Gagarin had no control over the spacecraft as scientists were unsure how humans would operate in weightlessness, although he did have an emergency override key.

Life support

Spherical oxygen and nitrogen tanks provided breathable air for Gagarin, in addition to propulsion for the spacecraft.



Antennas

External radio antennas provided continuous communication with ground control, transcripts of which show Gagarin repeatedly assure controllers he was fine.

Portholes

In addition to a visor to view the world, three portholes gave Gagarin a view of his surroundings.

Entry hatch

Upon re-entry, this hatch was blown off and Gagarin's ejector seat fired him to safety, landing by parachute.

Figure 3. Annotated Diagram of Vostok 1 Capsule carrying Yuri Gagarin (HOW IT WORKS TEAM, 2012)

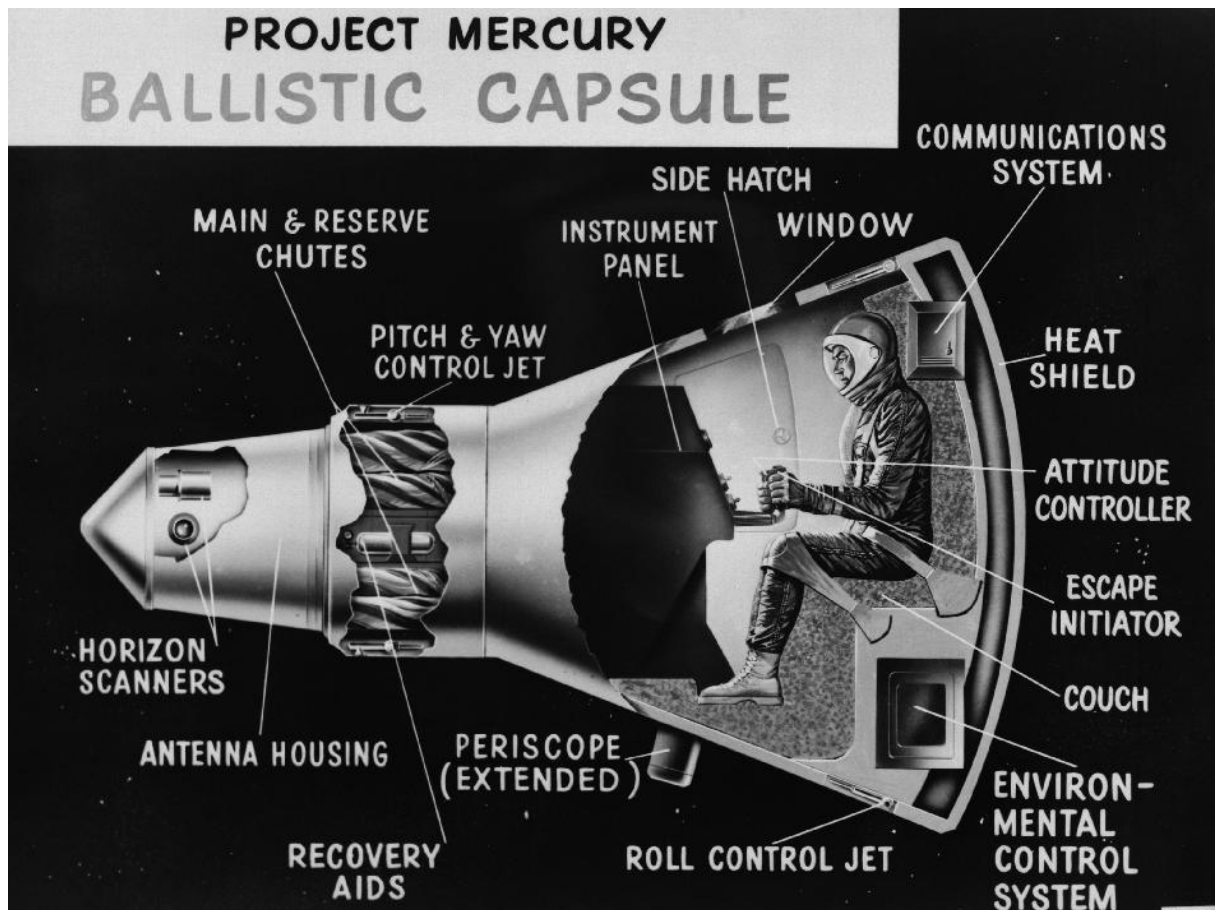


Figure 4. Mercury, MR-3, Freedom 7 Capsule carrying, Alan Shepard shown in cutaway drawing (NASA, 1960)

The organization SpaceArchitect.org is comprised of international space organisations and overseen by colleagues associated with Space Architecture Technical Committee (SATC) further managed by AIAA (American Institute of Aeronautics and Astronautics). Regarding, the United States space program, which was succeeded by the Skylab Program and Soviet Russia's space program which developed the Salyut Program, 'Spacearchitect.org' outlined in a 2014 document brief, that one of the first interventions of architects and designers in the industry was during the 'Space race' era (Spacearchitect.org, 2014). This period where the Soviet Union and United states had strived for extra-terrestrial dominance. Respectively Vladimir Chelomei, 'Chief Designer of Aviation Equipment' for the Soviet space program, had his design studio inducted into the design process of the Salyut 1 space station and NASA had brought in Raymond Loewy, responsible for the streamlining and industrial design movement (Anderson, 1979), who had introduced a window into the structure of Skylab space station for the purposes of providing terrestrial views.

2.6 Psychological Implications

Windows, though improved in recent years, still do not provide the same consistent level of structural integrity as a solid wall, so why would project managers from the respective space programs make these concessions? A paper entitled 'Windows to the world - Doors to Space - a reflection on the psychology and anthropology of space architecture' (Vogler, Jørgensen, 2004), expands upon the necessity for observational capabilities and portals. Vogler, an architect, and Jørgensen, a psychologist, explain the affect of confined habitation, (and cohabitation) on psychological and physiological health. The experience of the interior and exterior can have a deep effect on an individual's productivity in a social atmosphere. The extent to which an individual can attain stimuli is greatly reduced in a restricted area, where consistent thoughts of the emptiness and dangers of space is only separated by some inches of steel, nuts and bolts. Human beings are used to exercising their senses whenever possible, usually constantly. These assurances and assimilations in the wider context of an Earth's environment generate thoughts of comfort and security. Yet, when we consider the absence of an atmospheric shielding on a lunar surface, or the negligible oxygen content on mars, the thought of whether a six-month manned space flight to an uninhabited planet can be managed isn't the only question, it then also becomes how a human survives and copes in different planetary environments for an extended period of time. With the first manned missions to Mars and efforts to establish Lunar habitats likely to be attempted within a decade, it becomes vital to have the capacity for socially-productive behaviour. Coordination, communication, and ultimately common goal achievements are key for safe and reliable living within these habitats. described how the long-term habitation within any environment can have lasting effects on one's ability to socially interact, from the presence of windows and doors, generating feelings of control to the implementation of communal areas or interior colour of walls providing feelings of comfort. With the weight of these thoughts and pressures of tasks that must be completed bearing on the human mind, the intervention of designers becomes all the more necessary in the formation of space architecture, where the responsibility for emotional well-being, and the spatial experience that can influence one's actions, start to lie more with the designer than anything else.

2.7 Physical Challenges

As much as Architects must consider the interior and aesthetic effect on an individual's psyche, practitioners in Space Architecture will also have to address physical and payload challenges, applying basic engineering principles to deliver the required performance criteria. On earth, structural elements for buildings can be resolved by engineers. An architect should have some knowledge of engineering, but this isn't required in great detail, rather the acknowledgement of challenges can allow for a smoother transition to an engineer (Phillpott, 2021). Yet, when tackling design for orbital and interplanetary architecture, key physical laws will require more considerations, from changing atmospheric pressures to shielding cosmic rays in the absence and insufficiency of a protective planetary layer (Cogley, 2019).

2.7.1 Radiation Shielding

One of the primary challenges identified is radiation shielding. The cosmos radiates a number of harmful elements to human life, that can lead to health complications such as radiation sickness and cancer (Mars, 2017). This can be incurred from any rays on the electromagnetic spectrum if the intensity is high enough however the most harmful are shorter wavelength rays, X-rays, UV radiation, and gamma rays. This is because their small wavelengths allow them to pass easily through cells and ionize particles, essentially supercharging them. Cells then start multiplying at an unprecedented rate which has a high probability of causing mutated cells which further multiply and produce malignant masses (Papiewski, 2018). These higher wavelength rays are transmitted in high amounts from stars including our sun, however the Earth's atmosphere, ozone layer and magnetosphere provide a protective layer that dissipates and shield life on Earth from harmful amounts. Some still passes through the atmosphere such as UV radiation, which can be slightly more dangerous than usual in summer months when the Earth axis tilted more towards the sun, but this is usually easily shielded against. On other planetary prospects such as Mars and the Moon along with orbital architecture, the atmospheric shielding is either non-existent or near-negligible, therefore requires supplemental shielding for any habitats designed for these environments (Garner, 2017). One solution that has been identified is the sourcing of local materials and resources on the

planetary environments as it should already provide the necessary shielding, this could be either regolith or lava tubes (Cohen, 1996).

2.7.2 In-Situ Resource Utilization (ISRU)

Regolith is the loose dust and unconsolidated sediments that covers the surface of the Martian and Lunar environments in varying thicknesses and densities (Hsu, 2010), which has shown effective cosmic shielding through experimentation. One resolution proposed, is if water and ice deposits can be located and extracted from these environments, then by way of a chemical process, 'Additive Manufacturing' (AM) the two resources can create a permanent and structural material by which can be used to erect habitats. This is known as 'In-situ Resource Utilization' (ISRU) (Isachenkov; Chugunov; Akhatov; Shishkovsky, 2020). An alternative proposed by a Singapore University research suggests that 'Chitin', found in the exoskeleton of crickets, can also undergo a chemical process with regolith that results in a hardened material (Fernandez, 2020). Another solution is 'Regolith Additive Construction' (RAC) process, which utilizes a series of autonomous robots that excavate, extract and harden the Regolith to provide an effective structural material with good insulative properties, in the absence of water. The hardening process is done through use of 3D-printing and microwaves. The NASA '3D Printed Habitat Challenges' was set up for this specific purpose of finding the best combination of design and construction using the RAC process (Blahut, 2015). AI SpaceFactory, one of the finalists in the competition, designed an egg-shaped habitat, reasoning that this shape was one of the most efficient in minimizing material usage with an impressive compressive strength (Reilly, 2020)



Figure 5. 3D-Printed Mars Habitat from NASA Mars habitat competition (Plompmozes - AI SpaceFactory, 2020)

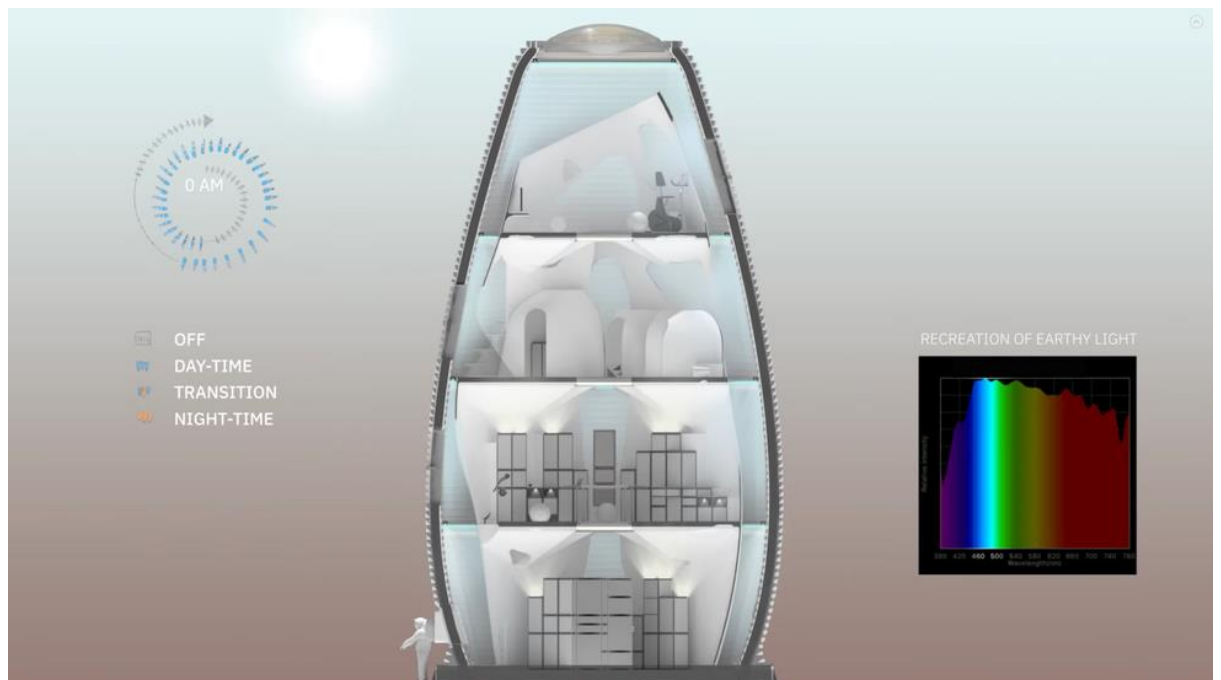


Figure 6. Section through 3D-Printed Mars Habitat (AI SpaceFactory, 2020)

2.7.3 Massing Challenges

The use of ISRU also solves another key physical challenge in constructing habitats on different planetary environments. When travelling to another celestial body, mass consideration is vital and crucial to the efficiency and success of a mission. It is highly inefficient to transport building materials in crafts designed for outer space where every drop of fuel is necessary, more mass requires more fuel to get off the ground and to land on the surface. Therefore, it becomes quite useful to either design an Integrated, Pre-fabricated Inflatable or ISRU structure (Cohen, 2002). An 'Integrated' structure is where the habitat is designed synonymously with the travel vehicle, as multi-functional, to be living quarters, workstation and a craft whether it's a landing module or ascent vehicle. A pre-fabricated habitat is also partially integrated with the modules but can potentially be expanded to provide a larger internal volume. An example of this is the ISS TransHab design, which is an Inflatable habitation module, proposed to also be adapted for a Martian environment (Kennedy, 2000)

2.7.4 Gravitational Obstacles

One essential factor that needs resolving is the differing gravitational field strengths in the non-earth environments. Consider the ISS, in an entirely weightless, microgravity environment which induces a free-fall like effect, this is a system where gravity is the predominant force acting upon system (Heppler, 2018). The vacuum of space maintains negligible air-resistance and as such the only force experienced on the ISS is microgravity from Earth's mass. The ISS is constantly under the pull of Earth's gravitational field strength at approximately 0.90g (May, 2017), however the velocity of its forward direction, parallel to the Earth's Surface, 200-250 miles above the surface generates enough momentum to keep it in orbit. Hence the ISS is in a constant state of free-fall and observers from within the system undergo a weightless effect. The objects inside the system (ISS) are experiencing the same forces as exerted on the system itself and therefore also encounter a weightless force, to consequently float around within the space. Operations cannot be done in the same way that they are on earth. Velcro strips line many interior surfaces to keep tools and instruments secure (Sample, 2011), workout equipment is accompanied by a series of harnesses and tethers (Jordan, 2018), which is a crucial countermeasure due to the immediate physiological effects faced, including bone

density reduction and muscle atrophy (McEvoy, 2019). A number of design considerations had to be prioritised when producing the ISS, four key elements in particular are focused on: modularity, maintainability, reconfigurability, and accessibility (Collins, 2018). Modularity was to improve the replaceability and expandability of interior components as well as the station entirely. In the initial construction, individual modules were sent up on a series of launches, modules which could dock with each other in space, this would be because it would be unrealistic to send it up fully prefabricated with regards to payload factors (Nixon; Stott, 2016). With more mass in this system, there is more for earth's gravitational field strength to act upon, therefore with every module added, calculations and adjustments to its orbital rotation were required. Another advantage to this modular state of design is that it allows for compartments to be sectioned off, in the event of accidental and unexpected decompression.

Similar challenges are faced when designing for interplanetary habitats. The current prospects, the Moon and Mars, both have a fraction of the Earth's gravity on the surface, at about 0.167g & 0.38g, respectively. Due to the weaker gravitational field, the ability to hold as effective an atmosphere as Earth is reduced, meaning structures designed for these environments must be able to maintain an Earth magnitude pressure internally, causing a much greater tensile force on the enveloping structure from the internal to external pressures that are more inclined to escape and equalize with the surrounding environment (Sumini and Mueller, 2017). The compressive force under gravity that utilized materials will undergo will also be reduced, suggesting longer curing times of mortar or like-materials. Firmer foundations will be necessary to counteract the effects of imposed and live loads such as desert storms on mars, which may easily rip a structure out of the ground in the absence of sufficient downward gravitational force. Excavation will be challenged in these environments, where an external force exertion from humans on the surface will be more likely to push them away. The equilibrium of forces such as weight on ground and the opposing force of the ground on the person will become unbalanced. A strength gained on earth, will easily push an individual away from the object that is subject to the force in a lower 'g' environment (Hutson, 2019).

3. Methodology

3.1 Introduction to methodology

The following chapter will outline research methods undertaken to garner a more detailed insight and perspective into the topic regarding 'Space Architecture'. This will be done through a series of semi-structured interviews, to compile a qualitative data set, and pre-existing materials on related topics, forming the literature review, which highlights ideas already accepted or proposed. In this chapter I will explain why I have chosen these research methods along with the aims and objectives I intend to achieve.

3.2 Qualitative Approach

My primary research method is based on a qualitative framework of investigation in the efforts of seeking access to specialist knowledge. I have foregone a quantitative data study, which was initially suggested by supervisor, Paul Harries, in earlier preparations of this dissertation and study. A qualitative primary research data set, in the route of a small sample of targeted interviews based on semi-structured questionnaires, would afford me with a clear understanding of the issue involving space architecture. The targeted interviews would be distinctive and pivotal opinions from experienced practitioners. A general public survey or questionnaire on individuals who may or may not have knowledge in this subject area, would not provide specific focal points that I may draw conclusions from, in my own paper on the topic. Furthermore, there would be challenges in verifying reliability and credibility of the individual. Conflicting ideologies amongst individuals who have varying breadths of knowledge in the field may also produce a spectrum of responses that would yield unproductive results. Yet, a series of targeted interviews with specific practitioners who are associated with space architectural organizing bodies and experience in the field would generate more credible responses as they are 'Expert Opinions'. Another benefit to this route is that the questions given, can be more specific like "Does the specialization of skills and knowledge warrant protections in the field?" rather than being generically based like "How familiar are you with

the subject of Space Architecture?”, to allow a greater portion of people to answer the questions.

The qualitative approach was also used in targeting case studies. In the research prior to compiling the written elements of this dissertation, a basic internet search identified many proposals and designs for interplanetary habitats & orbital architecture, to review and analyse all these would have also proved unproductive as key considerations will only be replicated in a majority of these designs. Therefore, two exemplars were chosen as case studies to focus on highlighting the similarities and differences between them, identifying which traits work as advantages and which present as a hindrance. Due to the current Covid-19 situation and the further restriction imposed, these structures could not be reviewed in-person, therefore analyses of them must be done with digitally gathered data. As the digital review starts to fall in line with literature-review some traits and design implementations were discussed in Literature-review section, nevertheless any more analyses and conclusions that can be drawn from these case-studies will be put forward in this chapter with further discussions in the following chapter.

3.3 Secondary & Tertiary Research

The primary feature of my secondary research will predominantly be covered in the ‘Literature Review’ chapter, composed of technical papers, journals & articles. Secondary research is mainly a review of works for individuals who have experienced their respective data sets, first-hand and compiled their findings based on the data provided. The organization ‘Spacearchitect.org’ maintains a large database & archive of written materials regarding space architecture, especially some not freely available like ‘Out of This World: The New Field of Space Architecture’ (Sherwood and Howe, 2009) Therefore, I will access the publications from this online database to generate a more efficient research procedure as opposed to taking more time locating sources, which could vary in credibility and detail. As the subject of my study is relatively new & unfamiliar to most, the most prevalent published works will most likely be technical papers published by early members of SATC & Spacearchitect.org. Pre-existing written materials will also be analysed for common concept & themes that may inform more reliability to each source.

3.4 Case Studies

3.4.1 Case Study 1 - SAGA's Lunark Habitat

Lunark, was designed by firm SAGA with a primary focus of designing for and conducting tests in remote areas to record mental challenges experienced in isolated conditions. An expedition lasting two months was conducted in northern Greenland, by architects of the design Sebastian Aristotelis & Karl-Johan Sørensen where findings of mental & physical challenges was recorded. The design is Origami-inspired, unfolding structure, to take up minimal volume in delivery but can expand 560% post-delivery (SAGA, 2020). The internal volume is divided to accommodate sleeping quarters, vertical farm, living provisions & studying/working. Internal smart materials change colour to help maintain circadian rhythm and a weather simulator to maintain diurnal rhythm. A glued rubber skin, lined with carbon sheets and ArmaForm (Recycled Bottles) forms the resistive outer shell, strengthened by Aluminium framing, providing further internal insulation. Landing legs with steel cables tie the structure to the ground. A core intention of the design is to implement an "Algae Reactor" (Meisenzal, 2020) for, carbon scrubbing, nutrition, cosmic shielding due to being highly photosynthetic and resilient, making it suitable for the more stressful, extra-terrestrial environments.

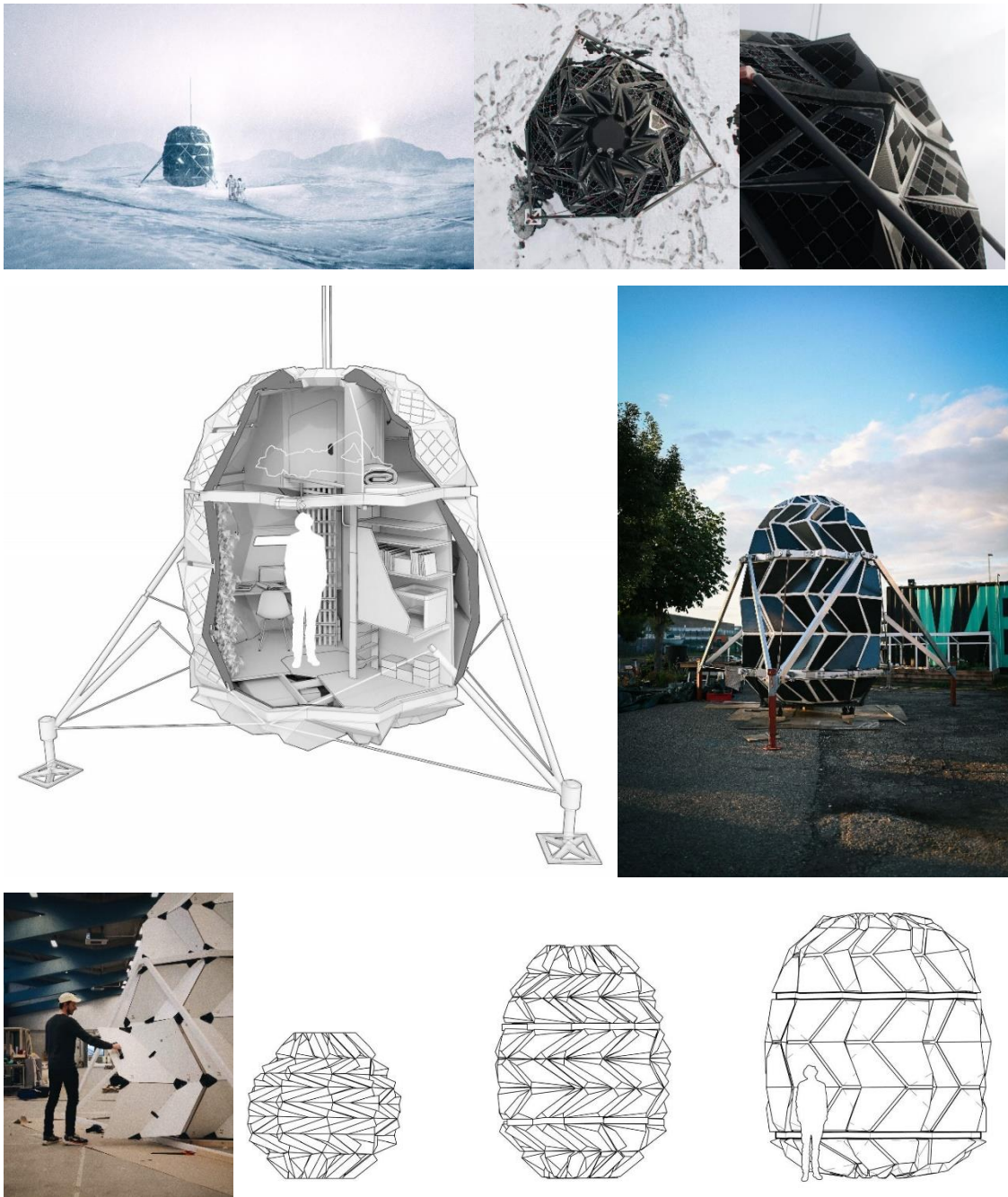


Figure 7. Collection of images associated with SAGA Space Architects, Lunark Habitat (SAGA, 2020)

3.4.2 Case Study 2 - AI Space Factory's Marsha (Mars Habitat)

The Marsha design was prepared by the team of AI Space Factory as a proposal in NASA's 3D printed Habitat Challenge, in which the design won 1st prize in the final stage of a series of competitions prepared by NASA. The aim of the competitions was to draw technological and innovative solutions for the implementation of possible extra-terrestrial habitats, due to the impracticality of sending construction materials and equipment to the moon. With collection of autonomous robots processing 3D-printable materials based on regolith deposits. The design featured a "light inner shell and a thick exterior" (Rose, 2019), with internal spaces split vertically and a main 'oculus' sky-lighting fixture to bring natural lighting all throughout the structure, all composing an "egg shape" (Reilly, 2020) structure. The processed material of regolith, Martian available basalt fibres & organic polylactic acid for binding, is proposed and tested to be stronger, biodegradable, recyclable and retains low embodied energy. The egg-shaped form was considered the most structurally efficient form whilst using minimal materials.

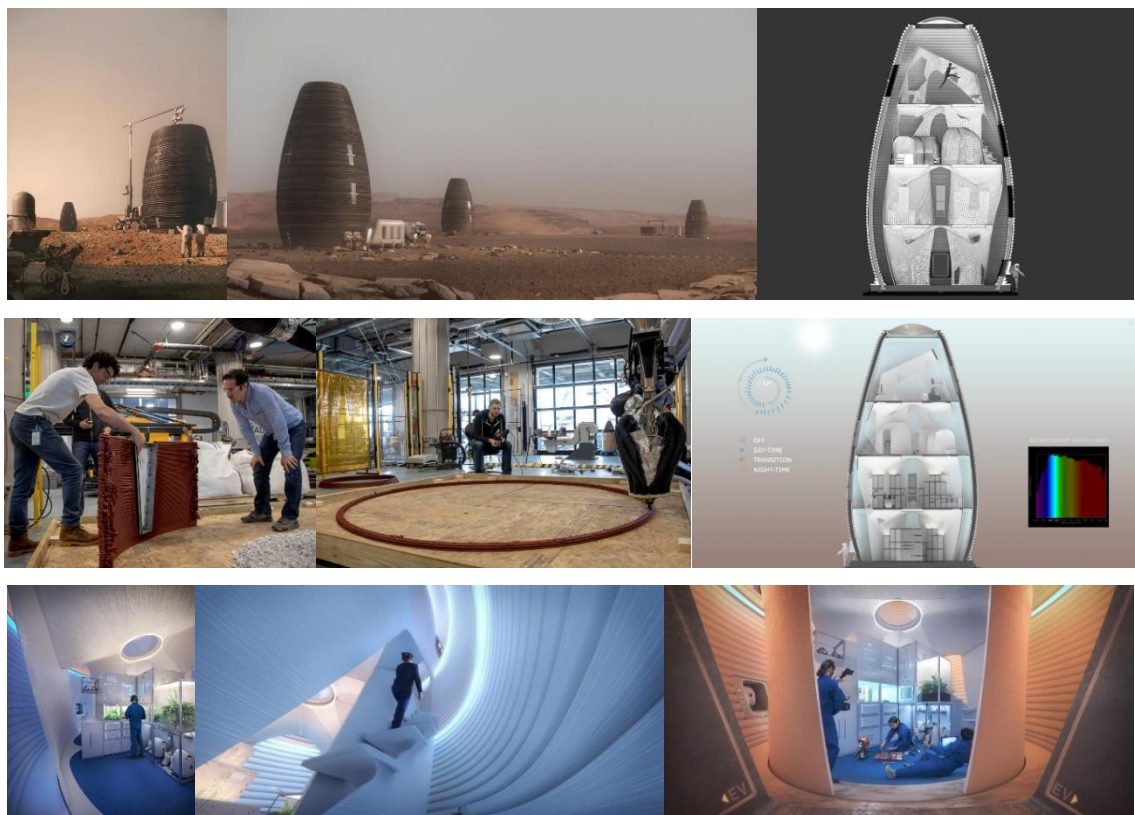




Figure 8. Collection of images associated with AI Space Factory Mars Habitat 'Marsha' (AI Space Factory, 2020)

3.5 Research Interviews

In order to identify key individuals who might possibly have extensive experience and knowledge in the field, a wide net was cast in an internet search which was simply 'Space Architecture', however I believe due to the variation of the mentioned terminology in the field of architecture, many unrelated sources appeared. Yet, fortunately with my previous research I had realised the space architectural field I was focusing on had encompassed sub-topics like 'Suborbital Architecture' (Alexander, 2012), 'Orbital Architecture' (Sherwood, 2002), 'Lunar Architecture' (Cohen, 2002), 'Martian Architecture' (Wapniak, Dudley-Flores, Gangale, 2007). Space architecture is also connected to the design of any habitats built to withstand extreme conditions (The Millenium Charter, 2002). Therefore, using 'Boolean Operators' my future searches could be refined to more specific content (Alexander, 2003). Using this method and particular terms I had uncovered an organization dedicated to the information, publication and

memberships of individuals, all related to 'Space Architecture' titled 'Spacearchitect.org'. From this organization, I was able to identify practitioners who had been associated with the built environment in extreme conditions.

There were quite a few members who were a part of the Space Architectural organization, therefore I analysed the data and profiles of each individual and placed the profiles into range of 'Who was most likely to respond' and 'Practitioners operating within the British framework'. Likelihood of response was assessed by practitioners who are U.K. based, where communicative effectiveness would be maximised and there would be no time differences causing a potential error in the schedule of meetings.

3.5.1 Hugh Broughton

The first I identified was Architect Hugh Broughton of the firm 'Hugh Broughton Architects'. Trained at the University of Edinburgh before setting up practice in 1995 (Tilley, 2018) and has worked closely with NASA on long-term isolation projects as well as designing habitats for the Lunar (Williams, 2020), Martian and Antarctic Earth, Environments (Carlson, 2020). Unfortunately, Hugh Broughton was unable to grant an interview, yet directed my details to an architect who has worked for his firm and after setting up his own practice has continued to work closely with Mr. Broughton on the developing space related projects.

3.5.2 Owen Hughes Pearce

Hugh Broughton had forwarded my details Owen Hughes Pearce, Architect and Director at PEARCE+ a collaborator and innovator in the architectural field, drawing specialists in various areas to produce revolutionary designs. Owen Pearce's professional history include studying Architecture at the University of Westminster & Oxford Brookes University alongside working for practices, JBD Architects and Hugh Broughton Architects as an Architectural Assistant before becoming RIBA (Royal Institute of British Architects) qualified and a practicing architect at the latter, leading to him setting up his own practice in 2018. Owen Pearce is an award-winning architect receiving several nominations and winning whilst still studying at Oxford

Brookes University to present. Owen further went on to teach at Oxford Brookes, specializing in the future of the built environment for the Human race (PEARCE+, 2018).

3.5.3 Marc Mitchell Cohen

The next individual, Marc M. Cohen is a California Licensed Architect, member of American Institute of Architects (AIA) along with the SATC. He has worked with NASA at Ames Research Center, Northrop Grumman and set up company Astrotecture who's prime directive is to be a leading provider in services related to Space Architecture. Marc Cohen's work has ranged from writing numerous published technical papers and patenting progressive designs that have been used in space station modules. Whilst working with NASA, he became a core member working on space station concepts and future designs comprising of projects and components connected to Interplanetary habitats, asteroid mining, and life support systems such as water walls (Wong, 2017). Marc Cohen has practiced in Space Architecture before the modern iteration of the highly skilled field became a defined discipline.

3.5.4 Mark Thomas Ditchfield

An interview was set up with aerospace engineering student, Mark Thomas Ditchfield, who is currently conducting a research project at Swansea University. The main objective of his research is to establish the feasibility of lunar mining and creating in-situ building materials, along with possible extraction methods especially with regards to the design of a parabolic mirror satellite. Through the course of his research Mark has been advised by practitioners in the aerospace industry, who have published technical papers themselves related to satellite operations and other aerospace components.

3.5.5 Patrick Harkness

I had also set up an interview with Patrick Harkness Ph.D., who has an engineering-based background, pioneering research in exploration technology, drilling techniques, solar sails &

more, studying at Queen's University of Belfast & Cranfield University. Patrick Harkness is currently a senior lecturer at the University of Glasgow.

3.5.6 David Wong

The fifth individual I identified that would be fundamentally beneficial to answer my questions about 'Space Architecture' was David Wong, a RIBA chartered architect, registered with the UK's ARB. Currently Director at Starlight Architecture Ltd., David Wong was chair at SATC, written pieces for published newsletters as well as publishing technical papers. He has also been member to various research programs on the relationship between space architecture & terrestrial architecture. David Wong has been in Space Studies Program at the 'International Space University', along with studying Architecture at the University of Bath & University of Westminster.

3.5.7 David Nixon

The final practitioner, David Nixon, is a British chartered architect and registered in California. Also working closely with NASA on space habitat modules, predominantly operating within the aerospace field. He has numerous published works including technical papers and books. David Nixon has studied Architecture at the Polytechnic of Central London and has gained a Ph.D. in Architecture from the University of Liverpool.

3.5.8 Ariel Ekblaw

As an alternative, attempts were made to contact Ariel Ekblaw who might bring recently graduated perspective into the field and is presently conducting research at MIT Space Exploration Initiative related to design regarding space future. She has recently attained a Ph.D. in 'Space Architecture' at the current date of this submission.

3.6 Structure of Interviews

A series of semi-structured interview questions was compiled for the interviewees. I decided on semi-structured format in order to encourage focused themes, topics or subjects to be set but wasn't restrictive, so a conversational flow could be maintained (SKILLSYOU NEED, 2011-2021). This would make the setting feel more like a natural experience for the interviewees, promoting an atmosphere of comfort, further garnering more and cohesive information. An issue had been encountered in terms of a time limit, since the interviewees were current practitioners, and their schedules would not allow for an extensive amount of time to be taken out. To resolve this, it was decided only five or six questions would be sufficient to maintain approximately 15 minutes of conversation. Though the questions had allowed 15 minutes as a baseline to record enough information, all interviewees had permitted more time to the extent of an hour for one.

3.7 Format of Interviews

All requests for interview were made by a tailored email and sent out simultaneously to the possible interviewees. Contact information for most of the individuals was obtained through the spacearchitect.org members page, which provided them with an associated user domain address. The email gave the option of setting up a video meeting call, via Microsoft Teams, to the interviewees at their preferential time and day, or typed reply at their earliest convenience. Through further correspondence, video meetings were set up with Owen Pearce, Marc Cohen, Mark Ditchfield & Patrick Harkness. Typed responses were received from David Wong & David Nixon. Throughout this process data protection and privacy was maintained, ensuring that permission was requested to record meeting and would only be used for personal research purposes. Confirmation was given and all recorded video interviews were saved to an online cloud platform, Microsoft Stream. Emails, Typed Responses and Transcripts can be found at the appendix of this dissertation.

4. Results & Discussion

Results of Methodology

4.1 Common themes & concepts in interviews

The interviews with various practitioners and researchers had highlighted some key considerations that should be met when designing for space architectural directive. It should be noted that, though these individuals have written papers, and some have followings of their own, ultimately the comments made are their own opinions. Some comments, however, had shown quite a bit of overlap on what should be a focal point and where priorities lie. The questions had directed the interviewees to attributes that I had already review in my previous literature search, these were, 'Origins of Space Architecture', 'Skills and Knowledge', 'Discipline of Space architecture', 'Possible syllabus adjustments', 'Habitat Physical & Mental Challenges'. Priorities, common themes & concepts of these interviews are outlined below.

4.1.1 Origins of Space Architecture

One interviewee had suggested that space architecture could not really be pinpointed as a concepted however in terms of fictional works, such as Clarke's '2001: A Space Odyssey' then thinking of this level has been present for centuries as my literature review had demonstrated (Harkness, 2021). In a practical sense then generally 1960/70's where space exploration had been a focus for national superpowers. This view was held by two other interviewees, emphasising anything encapsulating human and activity with safety could be called Space Architecture (Pearce and Wong, 2021). One interviewee had stated that it was 2002 (Nixon, 2021), which was the year in which the 'SATC' had been formed to manage architectural activity associated with space.

4.1.2 In-Situ Resource Utilization (ISRU)

All interviewees had promoted the concept of ISRU as method of saving on payload fuel, costs, and energy expenditure. Different methods of designing with this method was suggested, such as, using chemical hardeners produced naturally by humans, 3D-printing a regolith composite using harvested water deposits that is locally available or using partially integrated components with the landing vehicles. It was explained that this seems one of the most promising solutions for extended habitation on interplanetary conditions.

4.1.3 Physical challenges

In the acknowledgment of knowing there are numerous challenges that a designer may experience when design extra-terrestrial habitats, I suggested that the interviewees underline some of the key physical challenges that should be a priority to address. Of all the that was recommended in the list, many were repeated including, payload and mass challenges, consideration for atmospheric pressure differentials and how an internally maintained pressure would require the structure to withstand the inwards-outward forces, radiation shielding due to the insufficiency of a protective atmosphere and varying gravitational field strengths which will affects the way materials work along with affecting human movement, in turn feeding in to the anthropometrics used for design to create a more comfortable design.

4.1.4 Psychological Challenges

Once more, all interviewees recognized that these habitats accommodate human activity, and architects generally design with regards to this, considering mental wellness. The importance of this was stressed with extra-terrestrial habitats where inhabitants are conscious of the unliveable conditions externally, and therefore are more confined to the internal environment. The isolation was suggested to not just cause muscle degradation, but also a level of mental atrophy, so a considerate design should account for this with common & social areas where workout, communal dining, lighting provisions are made, compensating for the deficit that would otherwise be present on earth. A few of the interviewees proposed that comfort could

be maintained with weather simulators to keep circadian rhythm consistent, lighting was mentioned as crucial to generating a positive internal ambience even colour which could affects moods and productivity.

More aspects and considerations were outlined in the interviews, however the themes and concepts mentioned had the most overlap and were most emphasised in designing for a considerate extra-terrestrial habitat.

Discussion

4.2 Psychological Challenges

From the literature search and conducted interview it is clear that one of the core elements that needs to be considered when designing inhabited environments is the effect it has on an individual's mind. It is well documented in psychological profiles that living in extreme conditions for a period of time can impose different consequences on the mind, which can further manifest physically with psychosomatic symptoms, where one's thought can manifest physiological symptoms (Kansas, 2016). This is why it is vital for architects who design these long-term habitats to consider the true impacts of decisions made regarding anything from colours of walls to physically permanent forms. This remains true, and possibly even more essential for form designed under the space architectural banner. Consider that individuals living in these forms have a crucial need for protections from the external environment, which will be extreme and unliveable without shelter if not at all. The prospects of having these environments habitable will not be in the near future without specialised habitats. Elon Musk does propose a solution to terraform the Martian environment to make it more suitable for human habitability, however as of the moment it's not perceived as practical solution due to payload considerations, cost, containments, etc. (Childers, 2020), therefore the majority of time will be spent inside the sheltered form. This renders the need for consideration of the internal environment even more necessary. (Ahmadi, 2019) (Smylie, 2020)

4.2.1 Lighting Considerations

Consider the basics, natural or ambient light entering a space, studies (Harrison, 2009) have concluded that the level of presence of these factors, can either have detrimental effects on the human body or rejuvenating, regenerative influences further leading to a productive and positive outlook for the individual's day (Kansas and Manzey, 2008). This could be considered a primary necessity for inhabited structures. If you look historically, the earliest interventions of architects and designers in space related architecture was during the period known as the 'Space race' where the Soviet Union and United States of America were vying for the

recognition of being first to land on the moon. On the U.S's side, it was heavily argued by designers, that the cockpit of the craft needed a port hole window (Vogler and Jørgensen, 2004), to alleviate the stress and anxiety of being in an enclosed capsule being propelled to uninhabitable environment, protected only by some few inches of steel, nuts and bolts. Some reports highlight that this did indeed have a positive effect on the crew of the Saturn V for the Apollo 11 mission (Anderson, 1979)(Mohanty, Jørgensen and Nyström, 2006). As such, for the future of interplanetary space travel, it can be observed how the slightest intervention, such as the way light diffuses into a space or having windows and portholes to see as much nature as possible, can make a place more tolerable. (Harrison, 2009)

4.2.2 Greening Implementation

One other aspect that can prove beneficial to habitat's survivability is the presence of greenery. Any level of foliage shrubbery or plant-life produces encouraging effects on the human mind. A Lancet study conducted in England 2008 (Mitchell and Popham, 2008) along with a Manhattan study (Ellard, 2020), had proven that the presence of these factors in an individual living environment can actually have reduced health complications such as circulatory diseases. A series of studies by university professor, Dr. Roger Ulrich on the effects of a green presence on the physiological states of people were shown to be much more favourable in reducing symptoms such as stress, high blood pressure, muscle tension and inducing attributes such as increased skin conductance along with serotonin levels (Ulrich, 1984). It was proven in this study that post-surgery recovery patients at a medical facility with windows overlooking green areas had shorter recovery times compared with those who had a wall in place of a window. Associated studies had proven that even the visual of plant-life and greenery has positive impressions on an individual's physiological state. Inherently, it can be assumed when designing habitats for extreme conditions such is the prerogative with Space Architecture, that it will become responsible design to integrate and present these natural and organic factors in the execution of the structure to make the habitat more bearable.

4.2.3 Colour Theory

An architect could also consider the effects of colours within designed structures and how this impacts a person, through their mood, productivity, or routine (Mohanty, Jørgensen and Nyström, 2006). Swiss art theorist Johannes Itten developed the phenomenon of 'Colour theory' demonstrating the effects of colour on an individual's mood, emotion even physical health (BSBG Media Team, 2019). Exemplified by the proposition that a brighter and vibrant coloured ambient atmosphere promotes creativity and a motivational mood (TMD Studio LTD, 2017). Consider the oppositional colours on the wheel, Red and Blue. It was noted that the presence of blue ambiance generated a lower recorded heart-rate in a group of test subjects comparatively with Red which actually increased heart-rate (AL-Ayash, 2015). It is suggested that conscious symbolism is what informs these physiological emitters. Therefore, possibly, where the colour blue is linked to feature to do with water and the sky, conversely the colour red may imply thoughts of fire or danger as is commonly shown on many public indicators, informing feelings and emotions of warnings and cautions (Keskeys, 2020). However, it is also noted that varying hues and shades of the same colour can provide more positive effects on individuals. Such as a sunset red can promote emotions of glee, joy, and wonderment. These considerations will be vital in designing for interplanetary environments in order to further influence the mood of people already present in an anxious and unprecedented environment for the human race. (BSBG Media Team, 2019)

With all the considerations mentioned above, it is apparent that should a distinct space architectural profession be defined then, a core focus for the practitioner should be the psychological wellbeing of possible inhabitants. Interviews conducted along with literature review had presented a larger number of sub-considerations under the mental health factors, however I have presented and explained the most commonly repeated focal points that have been observed. This goes to suggesting that because features such as light, greenery and colour are mentioned most often, then this must mean these are a priority when designing for a humanely conscious design.

4.3 Physical Challenges

The core body of information I wanted to address when designing for space architecture, were the challenges imposed due to the extreme and harsh conditions that need to be accommodated for whether in space, on Mars or on the Moon. These challenges were split in two categories 'Psychological challenges' & 'Physical challenges'. As mentioned by one of the interviewees (Cohen, 2021) there are a great number of physical challenges when designing for extra-terrestrial habitats, however after reading research materials and conducting interviews, I highlighted a small selection of the most commonly repeated themes and phrases, outlined below.

4.3.1 Payload Considerations & Solutions

When designing launch vehicles for space explorations, the consideration for mass is a priority. More mass of the launch vehicle requires more energy to reach escape velocity, which is the point at which an object's velocity is enough to break free from a body of mass's gravitational pull (Canright, 2009). In this regard, it's apparent that any extra-terrestrial habitat implementation needs to have minimal effect on the launch vehicles loading or needs to be produced in-situ of the extra-terrestrial environment. One solution proposed (Cohen, 2002) suggests a 'Pre-Integrated' habitat, which can present a double functionality for a launch or landing vehicle, that already provides a life-support system, and the required living quarters. The pre-integrated habitat is the closest solution to the technology and resources available presently. Another solution (Cohen, 2002) states a 'Pre-Fabricated' could be possible which can generate a partially expandable habitat, which is deployed upon execution in the relevant environments. The prefabricated structure could be an inflatable environment, which adds only a small addition to the existing vehicles mass, whilst providing a relatively large volume for human movement. The final possibility was ISRU, a structure that utilizes locally available materials in the end environment to produce a solid building material. ISRU has negligible effects on launch vehicles payload, barring the equipment and machinery that will already be sent to process and manufacture the structure. One benefits of the ISRU method allows the potential for a larger inhabited volume, which can also be effected autonomously with a series of artificially intelligent (AI) robots, therefore allowing structures to be erected before a human

population arrives. ISRU generates the potential for a more expressive design, which has drawn more architectural practices to the field, allowing a level of creativity that would be less possible with pre-integrated or prefabricated structures. With AI Spacefactory's design, they have proven that an artificial material composite, using regolith, can provide a strength greater than concrete (Rose, 2019) which is necessary due to the outwards pressure on the volume, requiring airtightness. The process of ISRU is continuously being researched and developed to find the most effective method, however it seems from the research I have conducted in literature review and interviews with experienced practitioners, ISRU is the most promising solution at resolving ways to tackle the issues of habitat implementation.

4.3.2 Atmospheric Pressure

In the future prospects of space travel, the structures that are being designed for orbital, Lunar and Martian architecture all reside in environments that have an insufficient atmosphere if not negligible to sustain human life (Sumini and Mueller, 2017). Therefore, habitats that are designed for this environment have to be conscious to retain a suitable internal pressure that relates to air tightness. Where Earth-based structures are designed to protect inhabitants from external loadings, imposed on the structure, an extra-terrestrial structure needs to withstand the pressures that are maintained internally from escaping into a lower pressure environment. The magnitude of force from the internal enclosure, would require either a strong rigid material or a flexible and elastically capable material if the habitat is an inflatable structure. Maintaining a comfortable internal atmospheric pressure partly solves a psychological imperative as well as physiological imperative (Vogler and Jørgensen, 2004). Individuals living in an uncomfortable environment have been shown as having social tensions, depressive moods and becoming irritable, all of which can eventually affect productivity, where a high level of productivity will be necessary to complete the day-to-day tasks of living in the environment. This presents one aspect as to why it's crucial to maintain a pressurized volume. A method of resolving an accidental depressurization event is to design habitats in modular form (Sherwood, 2002). A modular state of design would allow for the developable structure that can be expanded easily when desired and with the implementation of a pressurized airlock, then parts of the modular complex can be closed off for partial salvation of the habitat in a depressurization event. A depressurization event can occur from meteoroid impacts, systems malfunction or material degradation, which is especially hard to predict due to the

unpredictability of extra-terrestrial environments. There is the possibility that a prefabricated design could be supplemented with ISRU where an inflatable habitat retains the pressurized environment needed, which can be tested whilst still on Earth, then supplemented with a regolith shielding that surrounds the soft membrane with a rigid material for structural integrity (COMPAC, 2020). An added benefit is the cosmic radiation shielding that regolith can provide, further described in the following section.

4.3.3 Radiation Shielding

As researched and identified from the literature review and interviews, one of the highest priorities to address for space architectural design is exposure to cosmic radiation. Without the denser atmospheric or ozone layer that exists on Earth protecting inhabitants from harmful radiation, measures need to be implemented in extra-terrestrial habitats in preparation for extended human living. The research and development into regolith structures has been increasing as it has been highlighted that locally available regolith on the Martian and Lunar surface has cosmic radiation shielding properties effective in maximizing reduction of harmful radiation transference (Isachenkov et al, 2020). With the possibility of using regolith, it can also alleviate the mass of payload delivery with any launch vehicles required in completing the mission, that results in human habitation. Regolith shielding generates a very viable prospect, however, should the development of research in the material uncover issues with its feasibility then an alternative method using water walls is also possible (Cohen, 2012). Through Marc Cohen's et al. study it has been identified that water also retains a radiation protective element, ideal due to the importance of water in many proposals for extended extra-terrestrial habitat. In the interview conducted with Mark Ditchfield, regarding the research project he is currently conducting, he outlines extracting water on the moon through ice deposits (Ditchfield, 2021). It was apparent that a sustainable water extraction method was key to survival in the future efforts of long-term occupation, where it becomes integral in life support systems with oxygen production and hydrogen fuel generation. Cohen further expands that if algae for oxygen production and organism research, fuel cell cooling methods, thermal control and CO₂ scrubbing is integrated into the habitat, then they will all become dependent on a sustainable water source emphasising a cohesive system of water circulation. In this state, a 'Water Walls Multi-Cell module' (Cohen, 2012) can easily be integrated into the system

encasing the extra-terrestrial habitat in an effective layer of radiation shielding providing an alternative or extra level protection as a failsafe.

5. Conclusion

This dissertation set out to investigate the question ‘Has the challenge of designing for space exploration and potential habitation beyond planet earth, created the need for a new profession of Space Architects?’ with aim of identifying these challenges that need to be considered. In analysis of the literature search, research interviews and case studies, I gained a clear understanding of the additional skills and knowledge-base necessary in designing for extreme and inhospitable environments. My conclusions are outlined below along with my answer to the question.

An architect inducted into the design process of space architecture, should retain a relatively extensive knowledge of orbital and planetary physics. This would not be taught as a standard in most schools of architecture currently, however the factors of loading, pressures, material properties and other variations for physical attributes in space and on other planets can present much higher, possibly fatal, consequences if not accommodated for. The solutions closest to modern day technology that is achievable is the concept of pre-integrated structure that fully integrate living environments with vehicles used to reach the environment, this is how the ISS was made possible, however, it is unsustainable in the long-term, which is shown where the longest single continuous spaceflight was 438 days by Russian cosmonaut Valery Polyakov (Wall, 2019). A designer for space architecture needs to consider the physiological and mental comfort of the inhabitant beyond the minimal life support to make habitation sustainable along with replenishable resources, allowing an extra-terrestrial habitat to operate independently from Earth-based interventions, such as regular delivery of supplies. The challenges and solutions mentioned above need prioritization for a feasible long-term mission and should an architect tackle these concerns, then a distinct pathway to accomplishing successful extra-terrestrial design presents itself.

5.1 Limitations of Research

An exhaustive and vast search within the scope of space architecture was made to achieve the aims and objectives of this dissertation. This uncovered numerous levels of physicals and

mental challenges which could have been mentioned but a higher quantity of the attributes mentioned would be at the cost of qualitative information. Qualitative information permitted more explanation on each sub-topic including the possible resolutions and implementations that could be made.

In the current state of a global pandemic at the time of writing this paper, international travel bans were implemented and as such, plans to attend locations where the case study models were made, urged cancellation. Fortunately, this was supplemented as a digital case study where designers' statements for design choices along with personal observations made from uploaded images of the habitat proposal.

5.2 Recommendations for Future Research

The criteria for interviewee selections were predominantly set in the range of practitioners operating within a British Framework for time convenience, successful communication whilst still providing expert opinions. This had somewhat sectioned off more practitioners shown in the members directory of the 'Spacearchitect.org' website, therefore in the progression and development of researching space architecture in the future I recommend widening the search criteria to a global community of 'Space Architects' as this would provide various approaches to tackling space architectural design and inform more of an understanding as to whether or not a professional body to regulate the discipline is necessary.

5.3 Summary

From the research I have conducted in my literature review and interviews, it is clear that there are highly specialized fields that embody a precise and specific set of subject areas requiring extensive study and some years of training. Institutions and organizations generating protections of title and function are important in providing a sense of assurance, confidence and to hold accountability to the practitioners in their respective field. There are differences of opinion on whether a distinct route and a safeguard is necessary for 'Space architecture'. One of the interviewees suggests that space architecture is already an architectural specialization,

allowing for further study after the normal progression through an architectural course and the provision exists if individuals present interest in the field, but a separate institution would be unnecessary at the current state, where it is only a small percentage of the overall 'Architecture' discipline (Pearce, 2021). Another interviewee also highlighted that it was too early to determine the necessity for a separate body, regulating a small selection of space architects (Harkness, 2021), however as the discipline becomes more established, drawing in a larger number of individuals then it would be appropriate to have the relevant measures in place to ensure not just anyone can call themselves a 'Space Architect'.

Assessing all the information available to me, I conclude in my agreement with the interviewees. It is only very small number of practitioners who you might identify as 'Space Architects' that exist today, and these individuals still have somewhat of a regulatory and managing body that ensure for safe and suitable design. These bodies, such as the SATC, License designers inducted into a space program via organizations such as NASA & ESA, being educated and skilled in the extreme environment design. A professional Space Architectural regulatory body such as RIBA, ARB or AIA, setting out specific guidelines to practice space architecture to an acceptable level, would be premature. The demand has not reached this point. The interviewees proposed future conditions may require a regulatory association, in this I would agree. Interest in space exploration is exponentially rising, especially with calls for launching to mars, creating lunar bases and ventures from NASA, ESA, SpaceX (Bastani, 2019) who are invested in these voyages. This quickly-expanding field that used to be dominated in the field by engineers is now inducting various multidisciplinary individuals, including architects, psychologists and interior designers to compose a more holistic approach in extra-terrestrial climate design. An inevitable result attracting a large influx of designers interested in space architecture, as travel methods develop, encouraged by the challenge of designing for extreme conditions. It is at this point that well-defined and for-purpose professional body will not just be appropriate but inherently crucial to the field's progression.

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Appendix

Appendix A: Mark Thomas Ditchfield Interview Transcript

Host: Can I have your permission to record?

Mark: Yeah, Yeah.

Host: Okay, that's great. So, as a student at university Wales Trinity Saint David. I'm currently conducting dissertation on space architecture. Now, the main body of information that I want to address is some of the challenges that may be encountered when designing space architecture. There may not be enough information in the field of architecture and how to design for an extra-terrestrial environment or extreme environments which is why I believe that an aerospace engineer, might have one of the best perspectives on it, and as such, so Why don't you talk to us a little bit about the research that you're doing, and the experiment that you're currently conducting we're in the process of conducting.

Mark: So, my research at the moment is to do with satellites that will hopefully in the end be able to orbit the moon and reflecting light from the sun, towards the surface of the moon to melt the ice, that is beneath the surface of the moon, and then hopefully it can be extracted. And then we can utilize that water to turn into rocket fuel or air that future inhabitants of the moon could breathe and so that's in short, what my research is about really.

Host: That's a good start. So, in terms of extracting water from the moon, why is that a core part of what you're trying to research, as possible?

Mark: So, obviously, to pull this whole thing off, there is a big emphasis on in situ resources, because at the moment, transporting these resources to the lunar environment is incredibly expensive, so to transport water that is already available on the moon just seems like a bit of a waste of; the rocket fuel that would take to get there, the money that would have to be

important to build the rockets, when we can find sort of a way that we can easily extract this water in the environment and transforming it in the environment into a useable resource that could that could be very beneficial for future astronauts.

Host: So, can you talk to me a little bit about the process of what and how the water would if you were able to extract water from, beneath the lunar surface, and how that would help in producing some solid materials and rendering the need for taking materials to produce it lunar habitats unnecessary? because you talked about in situ resource utilization. So, how what happens in this process between the water? And from my research, the lunar regolith and how does that come together to create a solid material?

Mark: So, it's in the basis of it it's really not a complicated process. Obviously once, once the water is extracted, And then you have this resource that is like water that we know of, on earth, then you need to figure out if you want to use the oxygen in the water, or you want to use the hydrogen in the water, you got to figure out how to get them separated so that you can use them for whatever you may want to use them for So the plan is to use electrolysis to split the water just how it can be done on earth. The only problem is the equipment is expensive, you have to get the equipment there, and then some of the, the pieces of the equipment can be quite heavy. So that may be a challenge to be able to get out there. But that is the process, electrolysis, and then, once those resources are separated, there's a lot of research going into sort of how we can use regolith to mix it with sort of different types of bacteria and heating using microwaves. And through that process you can turn kind of a dusty, sandy, like material that is regolith into more solid building materials, and there's actually some studies that show that urea in astronauts, urine, can also be used to as a strengthener to gain more strength from these materials.

Host: I read some similar studies, they start to talk about how insect's eggs like cricket eggs, in the process of their growth they produce a chemical called Chitin, which can in turn, also harden materials they want to use that for you know the proposal Martian habitats. So, I think that's, a very understandable process, and if possible, yeah, that could definitely, reduce the cost of, transport, and, the material production, so that'd be pretty good okay. So, in terms of

what an architect brings compared to an engineer brings, and what kind of skills and knowledge, do you reckon, an architect could bring that an engineer might not be able to?

Mark: I do think that architecture in in the lunar environment or say, even the Martian environment there's going to have to be more bridges between architecture and engineering. And then, there may be now, on Earth, because obviously because of the very little resources that are available out there. Everything needs to be able to serve, the maximum you can get out of all the materials say on the moon. Everything needs to be fit for purpose, instead of designing for, like there's less focus on aesthetics, then we currently have, like maybe far in the future. Aesthetics will come into will come into this more but, definitely, definitely more focus on shielding them from the different environment that you're in there. Yeah, radiation is more of a problem. There is no atmosphere on the moon. So, all these particles. Just come straight down to the surface, whereas on earth obviously we are protected. The atmosphere from all these dangerous particles. So all this needs to be taken into account when designing a habitat, so they're safe for the astronauts to live in these really harsh environments, to be honest.

Host: Yeah. Okay, that makes sense because of course there are challenges, when designing with for an extra-terrestrial environment you got to think about the varying and gravitational field strengths for example, and the effect that has on the materials and like you said radiation shielding and all that stuff. So yeah, ok I see that so this this is something that architects would need to consider. Would you reckon the knowledge that architects have on structure, could be easily supplemented with a little bit of extra knowledge in the world of physics and engineering to create a more habitable extra-terrestrial environment?

Mark: I mean, there's going to have to be a lot of teams involved in this with Yeah, with knowledge from loads of different bases and to make sure that everything is covered. So, like temperature also like that vast differences in temperature, which is also going to present problems. the radiation problem that you mentioned. Different gravitational fields so although that's still experienced on the earth, and yeah, obviously that's still going to be taken into consideration, In these other environments as well.

Host: Okay, no that's good. So, take for example, space architecture, and the people who work under it sort of its typology as space architect. The term architect currently is protected under the laws of various countries like the ARB is a British register of architects, and by law to use that term, you have to have done the studies, done the work experience. And it's the same with organizations like in America as well. In regarding that, do you consider that a space architect should have his own recognized and protected title, the way that a doctor, a medical doctor has their function protected, or a chartered engineer, with the increased knowledge in engineering and physics that space architecture requires.

Mark: I mean, like I don't know that much about what needs to be known in the field of architecture. Maybe one day, potentially, it may be a protected title. Because from my opinion, from my viewpoint now, it does seem like the knowledge base will have to be definitely different. So maybe one day it will be a protected title.

Host: That leads perfectly on to my next question, which would be, let's take for example, an architect library, We have a lot of, emphasis on, design methods and construction ideas and detailed designs, the different materials we can use, all that stuff. So, in compared to an aerospace engineers library. What additions would be required in the syllabus of schools of architecture, that isn't currently present, what would you reckon it would need that doesn't currently have.

Mark: Well, for starters, the space environment, needs to be established thoroughly. So, structures can be designed to fit those specifications that is, that's one of the major differences So I think that would need to be established, Definitely. Then maybe some parts on sort of design, for the purpose. Initially, I'd say, and because I think a lot of a lot of the things that need to be designed for space, are literally just for the purpose of what tasks they perform or like what they protect from So I think those things would definitely need to be included. Yeah, a bridge the gap between architecture on this planet and architecture on another planet.

Host: So, would you reckon books with, formulas on, that allow you to calculate, different stuff because I mean we don't focus so much on Young's modulus, or so much on engineering principles, such as Kirchhoff's law and all that stuff, so that sort of level of material would be required on the same course that was, known as space architecture.

Mark: Yeah, potentially, but then then you're also getting into that the engineering side as well so definitely like force analysis of structure.

Host: Essentially that would allow a much smoother can make communication between an aerospace engineer and an architect, where the architect has a more slightly more advanced knowledge of engineering.

Mark: Yeah, yeah.

Host: Okay, that's good. So, when designing for space architecture. do not have to consider the effects on human psychology much more?

Mark: I think I think spending long in isolation, Like, for in in this lockdown for example. I think mental health. has been on the rise, like in the news, a lot of people struggling with mental health, but in the space environment, I think these conditions are going to be recreated like this. Initially, there's not going to be a lot of lot of, tasks that we take for granted today, if we may live on another planet, you can't step outside as easily.

Host: Yeah. So, you're isolated.

Mark: Yeah, very isolated. There's not going to be loads of people there. And obviously that's a part of human nature that we socialize with each other. I mean there's, there's been some great advances in video chat over the internet. So maybe that would be a part of future space travel but definitely what you said about architects is sort of including the aesthetics to try and

ease the stress on mental health is definitely going to be a major part of this to keep these inhabitants of the Mars The moon, it is going to be a big part of it because they're still people at the end of the day.

Host: I guess that's what they're kind of doing with these tests in Greenland, with the Lunark habitat design and flash line Mars Arctic Research Station, you know, scientists are essentially isolating themselves for an extended period of time, in the harshest conditions on Earth. So, to see if it's possible to prepare yourself in the conditions on where you practically will have no exposure to the external environment without this supplement of an EVA and some sort in a space suit. So, I mean, you know, I guess that does make of lot of sense. So just to end this off. What is the main thing that architecture, or space architecture should focus on? And, you know, on this going forward what is the forefront priority?

Mark: I would say, sort of, finding a design that uses and gets the most in space for as little materials from the earth as possible, as much in situ resources input into the design as possible, doesn't need loads of materials to be transported from Earth, as little cost as possible, is probably going to be a big benefit to it as well and also maybe the design of equipment to extract water maybe in this part of a space architects job. Because there's all these all this equipment that's going to be needed to be enclosed in potentially in this in a space habitat. So, I would say that's the biggest thing, like finding ways of incorporating as much in situ resources as possible and lessen the forces, needed to be transported from Earth. I think that's the biggest thing. I think that's the biggest thing to me.

Host: Yeah, no, that's good that's good no that makes a lot of sense. I mean, considering it's mainly just theory now we haven't built any definable human habitats on the moon or Mars, but I mean for us to know what the priority is, that is a big thing. Well thank you for taking time out of your day to, you know, respond to some of my questions, and I wish you the best of luck with your research project and, hopefully, you yield some pretty beneficial answers.

Mark: Best of luck with your project as well.

Host: Thank you very much. All right, you have a great day now.

Mark: Yeah, you too.

Host: Bye bye.

Mark: Bye.

Appendix B: Marc M. Cohen Interview Transcript

Host: Can I have your permission to record this interview?

Marc: Sure, go ahead

Host: Right, so in your opinion, when is it commonly thought that the emergence of space architecture was made known?

Marc: OK, so the first space architect in NASA was Maynard Dalton, and he was the editor of the Skylab experience bulletins, all of which we have, that are that were actually published, we have on the our bibliography website, on spacearchitect.org bibliography. Maynard worked on the Gemini. He was at Johnson Space Center. He worked on the Gemini Apollo, Skylab, the space Shuttle and space station programs, and he then retired at the end of 1985 but he's still alive, in his farm in Alabama, where he sells honey online anyway and he's 90 years old. So, anyway he was really the first architect in the US space circuit, there's a woman whose name escapes me at the moment, who did a lot of drawings and internal renderings for the Soviet space station program, the Salyut program and she was sort of a contemporary of Maynard in a sense that she started working in the 60s on what what was Salyut one and worked throughout the Soviet program into the Mir program in the 1980s. There's supposed to be a book coming out about her, I was interviewed by some author, two or three years ago, but I haven't seen the book anywhere so, 'cause I saw I saw some of her drawings, when I was working on space station in the early 1980s. Searched for some of her drawings for Mir, I saw before Mir was launched. I think her name was maybe Galina, but I don't recall I. So anyway, you know the question of when people actually began doing professional work and when it became started to become an academic discipline or are two different questions. Let me address the professional work, so I was the 2nd space Architect in NASA, by which I mean I have a professional degree in architecture like Maynard does but I'm also the first licensed space architect in NASA, i'm the first one to get a, you know, a, Government architect license from the California Architects board. Although at the time they called it the California Board of Architectural Examiners, but that's trivia. Anyway, so I I got my license in 1985, And, insofar as I know, the only other licensed architect who's worked as a space architect in NASA. Directly as a NASA civil servant is Kriss Kennedy that's spelled K-R-I-S-S Kennedy, and he retired just

recently from Johnson Space Center. Constance Adams worked as a contractor for Lockheed and then from for some other companies at Johnson Space Center. She was licensed also. So one of the one of the more spirited and recurring debates we've had is whether there should be any licensure requirements for, being a space architect. And from the pro-license side, People make the arguments which I used to do, I don't really care that much anymore, that, what a licensed architect does is it gives you a certification that you know how to protect the health and safety of the public, which is the fundamental basis of an architect or a civil engineers, structural engineers license. The people who don't have licenses, but maybe some of them have aerospace engineering degrees in a few cases argue that it's not relevant 'cause the space environment is so different than the terrestrial environment the hazards are so much greater that what you know about protecting health and safety, on earth. It's trivial by comparison. Then the up the Pro license people are saying yes, but unless you've been trained professionally to consider risk and liability, you just don't have that way of thinking, you don't have that mental discipline in your work, and so it goes back and forth and not so long ago, in our list survey, it's not really a listserv, anyway, I guess it is still sort of a listserv, some young guy brought up the question of or how are we going to? Make sure that people have the right credentials to be space architects. Now I did write an article of paper which I presented. I think it was in in 2002 at the World Space Congress, called occupational something for space architects and I went into all the issues from the point of view of the American Institute of Architects, and RIBA is pretty similar, in in their approach, not identical, but there's similarities that versus the NASA Civil Service system or the US government Civil Service System, which covers the working levels of NASA, and what the different professional criteria are. So, I go into a lot of detail about that and since then several of the space architects prepared an article which appears on the front page of the website (spacearchitect.org) called How to Become a Space Architect, which is OK except I have a kind of a different take on that a different approach, which is that I believe that if you're going to be an architecture and engineer, before you really commit your career to space architecture, aerospace that you should get a professional license? Whether it's, a civil engineers license or professional engineers license or an architect for two reasons. Number one is that employment in space architecture and aerospace is still very unstable. The big aerospace companies, the way they behave in the United States, especially is that when they get a big contract, they'll inhale, 10,000/15,000/20,000 people for that contract when the contract expires or when they're done with it, they lay all those people off, they expel them, and they are absolutely heartless and cynical about it. So everybody should have a way of making a living in their profession. If they're not working on their favorite thing, which is space architecture or whatever. Number 2

there is an important, training and discipline that comes with going through the licensing process that you learn going through the licensing process, about meeting, whatever it is, code and standard requirements, zoning requirements, life & safety code requirements, you come to understand what you need

to know and when and how you need to know it and none of that really exists in space architecture at this time. I mean there are, there are various kinds of codes and standards out there, but the requirements to conform to them or apply them, vary, wildly and and, there isn't a lot of consistency and you know we have seen. We have seen disasters occur in space with challenger lawsuit challenges. Loss of Columbia that is, the explosion and fire that killed 4 employees of. Whatever it is, Virgin Galactic Ground engine test firing and of course the loss of life of 1 pilot in a spaceship two or spaceship one, whatever it was, through a failure of a fairly basic human factors in our meta-ergonomic design. Yeah so, those protections, those precautions that, protect the health and safety of crews in space don't really exist yet on the same level. Eventually they probably will, and I published an article, at the IAC in 2019 about commercial spaceflight crew safety, and I've actually been working on a pretty major revision of that, 'cause I got a huge number of comments. I think I probably got more comments on that paper than, almost anything ever published, Lot of them from people in the FAA environment who were very critical of things that they thought I got wrong. And so, I'm incorporating those into something I'll hopefully publish the next asset in November this year,

Host: I mean, that's that's pretty good. You kind of answered my next question, which was, should space architect become a recognized profession and protected as a function as the title and the

use of the term architect is protected under the laws of various countries.

So I mean, the added body of knowledge you would need, you need enhanced engineering principles as opposed to regular terrestrial architecture and you would need a more understanding of atmospheric pressure differentials and you know, cosmic shielding. So I mean in your opinion, do you believe it should be a protected profession?

Marc: Eventually yes, but not now. Because, We don't have the foundation for it and we would never get agreement, among all the stakeholders, and I don't think it's important. Overall, for the profession, I think having a license is very important for individuals to have a secure, income and way to support themselves over you know overtime and whatever the economic and market conditions are 'cause even when you're in government and if you're in NASA and program start to go away. You end up getting put in a cubicle in a backroom and asked to do

**** for bureaucrats. So OK, so maybe now is not the time. It's not so widespread for the protection of a profession. If you know spot space architectures in its own right, I would say that there is a huge amount of work to be done in developing the methodology's and the principles and the process is for. Achieving good human factors and crew safety and I demonstrate it in two papers I published in 2010 pertaining to The Altair lunar Lander. When I was at Northrop Grumman, and, in that I cite examples of codes and standards provisions. That were in various NASA standards and in sort of Northrop Northrop Grumman Corporate. Specifications for Altair. And show how they might be applied to finding what was acceptable. Altair lunar Lander design in terms of in terms of the crew safety criteria, So, that's an example of the type of work that, we need to do a lot more in that direction.

Host: OK, you know that's that's pretty good. That answers the question perfectly. So on to the next question. What kind of skills and knowledge can an architect specifically bring that an engineer might not be able to do?

Marc: Oh boy, this is a huge discussion. You could write 10 dissertations on this question alone. OK, first you gotta understand that until, The early 19th century there was not, any significant division between, architecture and engineering, perhaps starting around the last quarter of the 18th century, with the development of cast iron structures, like the Colesdale bridge in Britain, there started to be a a distinction between architects and engineers and that gradually grew until, let me think, in the 1840s, the expansion or elevation of the French Ecole Polytechnique in Paris under J&P Durant kind of completed the schism, where you know it was kind of like the architecture of the Catholics and the engineers were the Protestants or something like that or the Shia and the Sunni's, you know it was like that kind of a split. If you follow me, so

Host: Yeah, that makes sense

Marc: You know, where I mean it's more than just, like a throwaway line. It's like the engineers were like the Protestants, who believe that that Salvation is by faith alone in engineers believe that, excellences by calculation by math alone. You see, you see what I mean.

Host: Yeah, yeah, so I mean, that's kind of the response I've gotten from other people, the fact that engineers have a sort of breakdown approach, they carefully and, you know, calculate all

the specific components, whereas architects consider holistic approach. Now the whole thing comes together.

Marc: Well, well, right. Yeah, I mean there is that distinction, but let me let me see if I can frame this in my own mind before I try to say it. It's also very important for architects to be able to comprehend all that engineers do, and Be able to speak their language and argue with them in their own terms. And unfortunately, most architects have no interest in that. I'm not going to comment on aptitude, or ability, but you know, I my training in architecture school I kind of came out of an old, very old school curriculum at Princeton where we had to learn structural engineering. We had to be able to, design and size, a steel frame building and concrete building, and you know specify how to do that and I know I have designed foundations and in concrete and structures in wood and everything. Without covering my *** with an engineer stamp, you know, but by the late 80s. It was common for clients that complain that architecture firms weren't doing the engineering themselves, that they had to pay, you know, for all these additional engineering consultants in every trade, in every discipline, in the United States. Whereas, you know, I even sized air conditioning units and all kinds of other stuff because that was the training, but there's been further, you know, further schism. it looks like a continuing fragmentation, of discipline into more and more specialization. And what that means is not only in the professions, but in academia, there's more and more stovepipes, everything, it's separated into more and more smaller, narrower smoke stovepipes all the time. You run into that a lot in big aerospace projects, you may have, a dozen or 16 or 18 different engineering specials with they called specialty engineering including the major groups, and people don't talk to each other it's almost, Saina Kwannon of aerospace project that the biggest problem you have in developing and running the project is getting. All the different engineering groups to talk to each other and exchange information.

Host: So that communication and collaboration kind of breaks down where they saw all settle into their cliques, and they don't seem to have a smoother handoff, you know from design to, you know, structural engineers to electrical engineers, and so being able to speak that language, you as an architect.

Marc: Yeah, but that's another thing I'll come to, but I'll tell you about experience I had when I was on Northrop at Northrop Grumman. So the first big thing I worked on was the phase two proposal for the Orion, which at that time was called the crew exploration vehicle and So, I

worked on a number of parts of the project. There was a spacecraft architecture, spacecraft design and architecture group, and I also worked on the, What was it called? The operations and logistics Appendix team. Anyway, in the Spacecraft Design Group, it was being led by this very bright young guy who was like an excellent engineer but in their Section on architecture and human factors that had only one item listed for specification or just that the seats folded up out of the way that was the only thing. And I wrote about a 15-page narrative for description of all the different human factors in ergonomics and operational issues on the interior cabin and it was like these guys had never realized that all these things affect and relate to how people would function inside the spacecraft. You know, I mean, they didn't even have anything about controls and displays, which is, you know, basic cockpit aircraft, cockpit, human factors. They didn't even have that which had really surprised me, 'cause you know, 'cause that's been, you know, so well established, you know. Really the first real research on cockpit, Human factors, controls, and displays were accomplished before the Second World War, in the first aircraft. Where, any of any of that analysis was applied was possibly the DC3 or what is it the C47 Dakota? I could be wrong about that, but I would say the earliest aircraft of which I'm aware that that was a contribution to the design was that aircraft and then later for the fighter aircraft and bombers. There was a lot more research 'cause that plane started flying in the late 1930s? So anyway, that was one of the second examples, was when I was in the appendix operations team where we were writing the kind of the backup documentation for the front part of the proposal. I wrote a chapter that was called something like.

Alt of CEV in the constellation system of systems, and this had to do with, you know, all the different types of operations that took place. Between subsystems among the subsystems, 'cause 'cause the way all the different pieces, that is to say the ISS, the Altair wasn't called the Altair then, yet or just the lunar Lander, and that the CEV, Orion and any other spacecraft in the system the way that they, in how the shuttle is still flying then that was that was 2006. The decision to stop the shuttle flying had not really come to the front of, you know, I mean the shuttle flew for another five years. So anyway what Connected them with you was the subsystems you know from one space from the communications, rendezvous and docking, plume impingement from thrusters, if there was a power connection, a data connection between spacecraft when they docked, and so on, refueling. Which would have to happen through, you know, some kind of piping. OK, so anyway, So what happened was so, I wrote this like 25 page chapter and the chair and his vice chair who was from Boeing, told me I was full of ****. I didn't understand anything. Because none of that had to do with operations and the deputy or the vice chair said

operations only happen when you're burning propellant, and I, you know, I answered well what's the name of this project? The crew exploration vehicle? I say that operations happen whenever the crew is doing is awake and doing anything. So we had a major disagreement about that and they threw out my 25 page chapter and the vice chair drew a few single line drawings that did I mean single line diagrams to try to explain operations.

Host: OK,

Marc: And the punchline is that. Lockheed won the orion contract and we lost for very good reason.

Host: No. Well, I mean I guess I kind of agree with you there. I would say that operations is probably active anytime the crew is awake and doing their tasks, not just during propellant burn. Yeah, I agree with you completely. So I mean, not that that's brilliant. So I mean, I guess this kind of leads onto my next question.

Marc: I Haven't given you the second half of this answer.

Host: Go ahead, go ahead,

Marc: which is that, I'm kind of an outlier. I'm very much an outlier among people who do this, not just because of the background I have in my education. But because, my greatest talent, my superpower is to be a B minus student, which is, you know it when you're grading, the grading rubric is typically that a B minus is like 80. Get about 80% the answers right. So, my superpower is that I can read up in almost any discipline and get it 80% right the first time, and that's not enough to be an excellent professional, but it is enough to **** people off and make them feel. Make them worried and feel threatened when I'm talking to engineers, and so, I don't know why that is but I spent an awful lot of time reading technical nonfiction so I can at least spout the jargon in most cases. And, The other thing which goes goes to whether architects are really holistic and this is another set of 10 dissertations for somebody but, you know the way art history is taught, art is very problematic, I mean, art history provides kind of the big background for a lot of architects, you know the history of architecture is taught as art history and the way that's usually taught, at least the classes that I've had, is that you know so and so did X and he influenced somebody else, and they did Y, and then they influence somebody else. And so on and so forth and it's

like all these sort of little, incremental chunks that occur in the past and they're finished, they stop, but I read Vitruvius, Alberti Palladio, Serlio, Walter Gropius other you know, Ruskin. Viollet-le-duc and others, and I feel like you're speaking to me right now. They're speaking to me across the centuries across the millennia to me right now and nothing in architecture is ever obsolete. Nothing is ever expired and all of that feeds into feeds into to the way I think about things. I mean, the first person to write about privacy was Vitruvius when he says that the private rooms are the ones into which you need an invitation to enter and you know, I could go out, rattle on and on about this for a long time, It's one of my pet peeves, but I have actually, applied some of these things like Palladio offers these three methods of calculating the proper height for a ceiling in a room, and I actually applied that when I designed the space station proximity Operations simulator mock up to determine how high to make the silhouette really meant how high we would make the floor since we were doing it in a cylinder and we had to build a floor in there and so I applied one of his methods and they do work nicely. You know, even though it was a different configuration, it was a different you know century it was, you know, like 4 centuries later or whatever and you know the fundamentals, had this similarity of connection, and so it's valuable to try all these different methods. I only wish that I have I had learned more about methods, of design in other cultures, you know whether it be this person or this Islamic world or India or Japan or China, because there are fascinating methods. One of the one of the things that that has always struck me very powerfully is the Japanese principle, you must always include a certain number of flaws in a building, you should not try to make it perfect because 'cause then you're insulting the gods or something like that, but I mean, the, you know, the sort of the cultural background to the reason it is not so important, it's the idea that you've got, to allow for anomalies. You know the anomalies are not only OK, they're good in certain respects. It's not just a sort of a spiritual cultural thing, it's, at least the way I interpret it, I probably take it further than its origin, but that's an important thing to accommodate.

Host: So it's like you don't realize with these ages old principles you don't realize like certain things that as you described, anomalies don't realize their usefulness until we actually act on it. You know you've used these principles and you know, like what you were saying about privacy quarters as probably one of the main considerations goes into mental, you know wellbeing and health.

You know, in terms of being on the ISS, you know not having privacy is kind of detrimental to their productivity well.

Marc: Yeah, private privacy is a very complex discussion over the fact that that the amount of privacy we can provide in very small like, you know, telephone booth size cabins, is not really that useful because it's it's too small an environment for the crew to want to spend much time in there. I mean, yes, they could sleep in there to get away from the noise and the lights, but, one of the most interesting little studies that we did was we had a law student working with us in the space Human Factors Office back in 83 or 84. Sharon Matsumura, who, we ask her to research, what would be a living environment, so small, that it would constitute cruel and unusual punishment. So, she did this research. It's a three-page memorandum. It's on our website, but it's superb because she found that under the laws of all the states, that address cruel and unusual punishment from small jail cells or small prison cells, they were all much larger than we could ever accomplish in a space station private cabin. So what is the difference? The difference is that prisoners are not there voluntarily. Right, whereas astronauts are sort of the ultimate volunteers, you know there are people who will **** up anything, for the, you know, or go through, almost any hardship for the for the privilege of flying in space.

Host: So in that in that regard, do you consider that it becomes all the more necessary for the architects approach to it. 'cause I mean in in a sense, I mean, those really small cabins purely functional now they allow a person to sleep at all, people to recuperate but then the architect has to have it's sort of intervention in terms of, OK, so now that we've got this purely functional space, how do we make it so, it's liveable, you know, as in some, not just, you know, survivable, but you know, cope can be coped with. Is that one of the responsibilities an architect might have?

Marc: Yes, yes, I agree with that.

Host: OK, that's brilliant. So I mean that is in terms of the sort of the effects on human psychology. So I mean, I know there's probably numerous physical challenges out there, and I read one of your papers on in the Journal of Aerospace regarding cosmic shielding and using Martian regolith as a source of cosmic shielding for habitats in sort of vernacular space architecture.

Marc: So, only one paper?

Host: I've actually read quite a few I've read it and it's quite good, I mean, you alone have about 80 sources of space architecture, which I think is more than anyone and any of the other people on there. So that's one of the key physical challenges what other I mean. I'm sure there's like I said, there's numerous, what key physical challenges would architects and designers have to overcome in order to design effective extra-terrestrial habitats?

Marc: Huey OK, look at look at my 2015 paper called first Mars Habitat Architecture. OK, I go through a lot of it there,

Host: Let's say three key principles that are like the first primary considerations.

Marc: Well. So. OK. Number one and I'm actually trying to complete a first draft manuscript on this for this summer's ICES, is ECLIS first habitat that you should start from the design of the environmental control and life support system to support the crew and then develop the entire habitat around that. You should not start with a predetermined shape, predetermined racks, predetermined everything, you have to force the packaging of the ECLIS system into it and limit you know, Ration or limit the amount of area and volume provided for the ECLIS system because that badly compromises the ECLIS system functionality and performance And that's what's keeping your crew alive more than anything else far more than regolith shielding, You know. Number 2 I would say if you're talking planetary surface, understand the site. You need to have a really good site study, from the point you know from an architect's POV. As if you were, you know, I don't know if you've ever surveyed a site,

Host: Yeah, I've done it a few times

Marc: So, you understand how much you discover when you do that, how important that is and how important and I'm including with that, I would say you need an analysis, you know of the soils. In the soil mechanics, not regolith. This soil regolith is not soil, because this is one of the most common errors everybody makes, Regolith is not soil because soil implies a biological process of decomposition. Regolith is different. And, third principle I would say I would just say that the health and safety of the crew is the, highest priority, requirements or generator requirements.

Host: OK, so in terms of, you know for them at again like how they survive then how they live their their time, their experience of being there.

Marc: Yeah, right. I would say the fourth thing. I'm just getting warmed up here. The fourth thing is. Oh yes, that when one speaks of habitability there's a tendency to think that only the so-called habitability module or living environment needs to be available, but the working environment must be equally habitable. You know, there are a lot of things that distinguish the so-called living environment from the working environment, but the working, is really part of the living environment, it must also be habitable but because there are often additional hazards in the working environment you need to apply extra, scrutiny and precautions to the working environment that you don't necessarily need to do with the, you know, the dining area or whatever.

Host: So, hence this whole idea that you know the consideration is the architect again needs to affect a more holistic approach, not just as you say, the habitable environment but the working environment like the, you know, they're not going to spend 24 hours a day and just sleeping cabins or their living quarters, or, you know, as such they will be working, they'll be doing tasks. So, an architect to be able to design for all of those, whether their responsibilities come in to design effectively for all of those things, that's all necessary?

Marc: Yes, yes it is.

Host: OK, no, that's that's brilliant. Thank you. I mean those were all the questions I had and this is certainly been very helpful, Incredibly helpful.

Marc: But there's one thing I answer I didn't complete within your first question. I said there were two parts, 2 architectures or profession, first, there's the working professional, but then the academic I never got to the academic part.

Host: Please do OK

Marc: So as far as the academic profession goes, I would say that I was the founder of trying to or the instigator of trying to develop architecture as an active space architecture as an academic discipline, I was the one who started writing papers about. I mean, Maynard Dalton, wrote and edited all those Skylab experience bulletins, but he was really, his audience was really just Johnson Space

Center, you know and actually, you know what I recommend to everybody who says they want to be a space architect.

I say read all the Skylab experience bulletins although one of the things I've learned, it's more of a problem for engineers and architects, is that they're not really that good at reading the reading comprehension isn't always there, you know. In fact one time I said to a young Aerospace and mechanical engineer. Just because you went to MIT, it doesn't mean you know how to read. When he objected to, he was an intern or whatever, new employee and I put a stack of reports on his desk, and he complained. I said just 'cause you went to MIT, it doesn't mean you know how to read. So anyway, the other person, I think, who was most instrumental in helping develop, the other two people, I think are most instrumental in helping develop space architecture as an academic discipline are Constance Adams, who sadly passed away a couple of years ago and Ted Hall who was the manager of our bibliography, and Scott Howe has also been a major contributor I would say the four of us have been the most responsible for advancing space architecture as an academic discipline in terms of writing all these technical papers. One of the things that that is a challenge for a lot of people is. Writing in a way that's accessible 'cause in many disciplines, both scientific and engineering disciplines you see this, people write in extremely complicated language that is impenetrable, to you know, people who aren't totally immersed in it, and they do that deliberately, I've had several arguments with scientists and engineers who writes stuff that's just almost incomprehensible, even to me and I had an argument, big argument, with Walter Schimmerling, who was running the NASA radiation program, radiation research program for couple decades and he would publish these papers were for his citations his reference citations then in his reference list, It would be something like, see which literally say RR. 32: 234 and I took this to our life science reference librarians at Ames Research, NASA Ames Research Center and it said you, can you tell me what this means, and they couldn't. So, I called Schimmerling and I asked them, you know, I said, I'm reading, I'm reading this article from this Journal or in your paper or article, it was from somewhere, I said I wanna follow up on some of the references, but I can't decipher them. Hey could you could tell me what you know what this means and he said "if you were a real radiation scientist, you wouldn't have to ask if you were a real radiation scientist. You would have that Journal of radiation research on your shelf and you would just reach for it, you just reach for volume 32 and turn to page 234" and as I said, but what kind of what kind of bibliographical citation does not give the name of the author or the title of the article? And he said, "haha see, you're not a real radiation scientist." I mean, I've personally I mean, I've met a few. Yeah, so let me just finish this.

So the argument went on for a while and I said, but aren't you trying to communicate what you do your research? To the, you know, to the space community. And, he said "I'm only interested if it can be communicating it to the half dozen people in the world who would understand it." And I've had similar arguments with engineers who wrote incomprehensible articles. So, make your comment or question.

Host: No, I mean, I completely agree with you. I mean, I've met personally I've met quite a few professional architects, especially who have used unnecessarily complicated language and vocabulary that in a sense, it could get almost gets to a point where it doesn't make sense anymore, you know, in the whole point, as an architect, you know you're a consultant for a client, you're supposed to be able to pass back and forth, you're supposed to bridge the communication gap and so, now, I mean, I completely agree with you. Sometimes, in certain you know professions, certain individuals will use unnecessarily complicated languages, so that's that's brilliant.

Marc: I mean so, let me explain something. Actually, other (professions) in the United States, there's really a huge amount of variation among the states in terms of, local culture and levels of education and emphasis on Achieving and excelling in education and so on so Constance Adams and I grew up in Connecticut and Southern Connecticut, Long Island, she was in New Haven, I was in Fairfield and actually Brett Sherwood went to Yale, Also like Constance did and, so, we and others in Connecticut and Massachusetts to share a tremendous emphasis on excellence in education that doesn't really exist in the same way throughout most of the rest of the United States. I mean, there are locales in other states where you find you find you know, areas of excellence but, anyway, this was something where in like in my 12th grade classes, those last year of high school in the USA had to write an 8 paragraph essay every week, and you know, and they really, they really beat the **** out of us. In fact, you know I had an eighth-grade teacher who made us write a paragraph every week, and she gave detentions for grammatical and spelling errors and you know you go to detention and she beat on you too, you know to write correctly, and so you know I I went through this, you know this sort of. I don't know what you describe it this gauntlet of a fire or whatever, is hazing, this major hazing and so you know, I learned to write clearly and directly and it's a constant problem reviewing papers. In fact, I've largely given up reviewing anybody's papers 'cause it's just become so painful to me that people write in passive language they write with passive verbs, there's no subject.

Like you know, NASA's favourite phrase mistakes were made, but of course nobody made them 'cause

there's no subject to the sentence and anyway, that's a really big challenge for a lot of people. They just really never learned to write well.

Host: Yeah, I mean personally I've looked over, I mean like I said, I've looked over some of your papers, I think I've looked over one of Constance Adam papers and I'm about a couple of chapters into Brent,

Sherwood and Scott. Howe's Out of this world the new field space architecture and I mean from everything I've read I mean, it's just It's all explained, explained concisely without any unnecessary use of, you know, passive verbs and adjectives. It's all just direct to the point.

Marc: Yeah, Brett was really the one who did the back end editing Scott did the initial kind of inviting papers and kind of getting people to focus on the important topics, but Brent was the one who went through all the papers and really, forced people to write clearly and you know, did some editing and changing a lot of a lot of direct editing himself.

Host: OK, that's brilliant. I mean, I'll hopefully I'll continue to read more of your papers and some of the work that you've done. And yeah, I mean, though, my research. I've found pretty much 4 maybe 5-6 people who've really become the definition of space architects and Luckily I get to have an interview with one of them today, which is, yeah

Marc: Yeah, ok, Well, I'm glad I'm glad to be of assistance. I'd love to see a copy of your dissertation when it's finished, and certainly will certainly want to put it on our website and if you have any further questions, please feel free to ask.

Host: Yeah, I I certainly will do. Thank you so much for taking time out of your I'm sure your busy schedule. And yeah, this will help me massively. And, If it's OK, when when the dissertation

gets written up and out of the way, I'd love to send it to you too, to get your thoughts on it that would be brilliant. So I guess I'll I'll bid you farewell and have a great rest of the day.

Marc: Sure you too.

Host: Thank you very much. Cheers, bye.

Appendix C: Owen Hughes Pearce Interview Transcript

Host: Do you mind if I record this meeting

Owen: Are you going to be uploading it anywhere?

Host: No, it's just for me.

Owen: That's fine then, Yeah

Host: That's perfect, so let's just get these up.

Owen: Do you wanna give me a brief overview of what it is you're looking at again.

Host: Yep, so I'm researching the topic of space architecture and in general it's more about I'm focusing on three principles. It's physical and mental challenges, it's origins and, whether it becomes an area that served by a professional body, or, um, you know serves as a protection of function, as like a medical doctor is. So those are my main areas of focus currently. So, In that sense, let's just start it off.

So, what are some of the space based projects that you've worked on so far in you know throughout your history of working with Hugh broughton and in your own practice as well.

Owen: Do you want to talk about Antarctic bases?

Host: Yeah, sure.

Owen: Thing is, like space, because you know there's outside the Earth's atmosphere type projects or I mean, often the Antarctic work is considered as like a precedent for space. So, um, as you said, I was at Hugh Broughton Architects for quite some time, about seven years and HBA they are, well, you know, probably the world experts in Antarctic research stations and some other architectural offices have now designed Antarctic bases, but I think Hugh's, you know, they've designed five or six now, which is definitely the biggest proportion of Antarctic bases being designed by architects and that ranges from Halley Six, which yes, kind of probably the most, sort of spaceship like, aesthetically and in terms of its design, it can be

relocated, its modular and it was built in one of the most sort of extreme environments on an ice shelf. So, it was all prefabricated and various components and delivered and then Hugh has gone on from that to be working on lots of other bases. So Rothera is being built for the British at the moment, Scott Base, New Zealanders, and he's also working for the Australian Antarctic Division. So, Hugh was approached, and, while I was still there, is approached by NASA to work on long duration Mars missions. So, we were looking at what the required volume was. So, in space, sort of zero gravity sort of design, it's no longer about floor area, it's about volume. Yeah, it's around everywhere you want to go, so it's like how much volume would be required for six astronauts to travel to Mars for two years? Without going completely crazy, so we were doing a few sort of studies for NASA. You know, looking at how you might layout that spaceship, to sort of maintain well being.

for their astronauts, the smallest, how compact can you make everyone be? Yeah, you know 'cause that's a lot cheaper.

Host: I mean, I've seen some of the analogs. They had the flash line Mars, Arctic research station. And then there's the SAGA Architects who were doing Lunark Habitat, so I've seen some of the analogs and how they have to try and set a precedent like see the commonality's and how you combat the challenges. So no, that's good. So, I guess I'll go start in terms of origin. So, most of these questions might be in the form of your own opinion, but that's the valuable part of it. So when is it commonly thought the emergence of space architecture was made known?

Owen: Have you have you read this book?

Host: I literally just downloaded that book. Yeah, I haven't read it yet though.

Owen: I think you will find a lot of your answers. You know in there and there's a whole chapter on kind of space vernacular and when it was kind of considered, you know, an actual sort of branch of architecture for me. I think, you know 50s and 60s as soon as you're launching people into atmosphere, even if it's a capsule. So people might say it's a spaceship. I feel that that's if it's encompassing people. then it's a kind of form of architecture so, you know, as soon as people were taking off in rockets. I think, you know, that a rocket is a piece of architecture, but the same time I have been looking more sort of earth based. Sort of isolated architectures and so from the sort of Antarctic or even like early naval ships where it's like or submarines. All those kind of things I think of is

kind of precursors to space architecture, you know, if you're isolated, cut off, self sufficient. There's another book you might like, called the architecture of Closed Worlds, and that is just it lists the history of people trying to do self contained, I don't know like circular waste systems. That's kind of great, but I think really for me it's like the 50s and 60s. You know, it's the first.

Host: I mean, that's that's kind of what my research has concluded, so far, you know, with the Skylab station, Raymond Loewy's induction into the design process, and then as well as the Salyut one program, which inducted Vladimir Chelomey into their, you know, their design process. I think it was just a small intervention, like a window, but I mean I think you would agree just even the intervention of a window can be considered architecture. You know, 'cause you know brings in light for numerous mental Wellness effects as well. So yeah, OK, That kind of leads me into my next question, what kind of what kind of skills and knowledge could an architect bring that engineer might not be able to?

Owen: Urm. So, I'd say the engineers are brilliant at doing calculations and solving the problem put in front of them. But maybe Architects, need to have their, training allows for a sort of you to think of the whole the whole picture, it helps. The architects training might help to ask what the right problem is that needs solving, in an engineering way and also probably just you know more consideration for the occupants and the people. You know, just making sure that someone is fighting the astronaut or inhabitants' corner and that's something that's come up in Antarctica, so up until really recently, Antarctic bases were always designed by engineers but living there was kind of it was really tough for those inhabitants. You know, it wasn't laid out to ensure things like, people didn't become isolated. So I mean that in terms of Halley five or early Halley research stations, it was designed and it looked a bit like portacabins. It was designed by a series of rooms. There was like, OK there's a bar room, there's a gym, there's the reading room and there was a door in every single one. What that meant was that you ended up with kind of cliques, so you'd get the bar group, the people who love the bar, people who went to the gym and you find that people, residents, who would arrive at the door. You hear people having a good time inside, and their self confidence or whatever would mean that they wouldn't want to go and join. So, you ended up with people, It's sort of fragmented, the inhabitants and their cut off for nine months of the year. So in Halley 6, which is the Hugh Broughton Architects one, the bar, the restaurant, where you eat, all those things, it's all open plan, It's all open so it broke down barriers. Yeah, of course the Halley five works it does give you a bar and it does give you, you know, but what's the next thing to that improves it? And

that's the architectural kind of approaches, how might we sort of, you know, tweak this and get it to work for everyone.

Host: Yeah, it's like that holistic approach to designing things, not just the core elements, but how it all comes together and interconnects. Yeah, that's perfect.

Owen: Also. I mean architects and engineers, you know the aesthetics of space travel at the moment is very much functional, but that's fine for 100 days in space or a year in space, but if you're planning to live there long term. That might become a little bit grating, and yeah, probably space to be in the aesthetics, you know and architects probably get a bad Rep just like only caring about the aesthetics.

Host: Yeah, but that's not entirely true though.

Owen: I think that will become quite important. I mean Space X at the moment or even Philippe Starcke has just been, I mean, he's, I don't think he's an architect, he might be qualified, but, you know, the aesthetics of space more and more important and I think that will come back into it, of course, you know, the mental Wellness, it does, you know it is affected from things like light entry into space to the colours on the walls, To, you know, the amount of space that you have, the way they're arranged. So no, I mean, that's that's pretty considerable, so on the on the Martian house, so it's a project I've been working on. We've built the Mars Martian house in the prototype is going up in Bristol, one of the things we're trying to do is integrate the hydroponic system, producing greenery, within the inhabitants spaces so they can actually use it. It's like a hydroponic living room, is what we're calling it. It's not the most efficient thing to do in terms of engineering but it's not just the hydroponics aren't there to, well, they produce some food, but it's not the main reason there is, about the well being.

Host: Yeah no, of course. So, in terms of these considerations that an architect will have to design for, space architecture or just architecture in extreme environments, they're gonna need to solve and a slightly more advanced level of, you know, understanding of physical principles and knowledge. So in that sense, You know, and the kind of knowledge that they would have to retain, would you consider that space architect that that term 'space architect' should be like a recognized profession as the title architect is protected under the laws of various countries or a medical doctor is protected as a function in most countries, you know, do you reckon the term space architect? Should it become more mainstream.

Owen: I'd say I'd say no because architect is already used, on a huge map like software architect, electrical architect, naval architect, yeah, it's already thrown around everywhere but the term architect protected under the ARB or RIBA know it's its' own thing and already within the profession you have, you know people who specialized in, you know designing airports or designing Antarctic bases, or you know these different things, and I think that within the profession you can specialize without having to have an official title or term or name for it. I mean, you found and you got in contact through the space architects.org, you know, I think it's enough to have, you know organisations talking about this and yes, rather than having to, you know, have a new governing body that makes sure that you are a space, an official space architect and you have the right space architect knowledge and I think getting architects involved the design in space, is you're trying to bring some aspects of health and safety wellbeing, sustainability from Earth, which to space you know otherwise just be, you know, rewrite, you'd have to rewrite all the rules and I think a lot of it is actually there is crossover there, so I mean you don't need a special term for it.

Host: Yeah no, I think a lot of, some of, the other designers and engineers I've interviewed don't quite see as we've gotten to that yet where we need that protection. It's not, so it's more of a specialization within a protected title field. So, I mean that's, yeah, kind of gone with the common consensus, so onto my next question, what additions would be required in the syllabus of schools architecture that isn't currently present? and could such a body of knowledge be supplemented with in the current syllabus of Schools of architecture, especially within the British framework of Schools of Architecture?

Owen: I think there's lessons to be learned. If you're designing for space that could influence, you know, the current syllabus in terms of reduction in material to do with designing for lightness. So in space lightness is really important, by how much you're putting into orbit that could have big effects for your design on Earth, I mean I teach Oxford Brookes and what you find is, there's always a proportion of people who love space architecture and they wanted to space projects, but it's usually quite a small proportion. You know, maybe it's 5 or 10%, so I think if you had whole modules entirely focused on space architecture at the moment and what's required like the physics, the radiating principles, etc., you find that a small proportion find it really useful currently, but a lot of people wouldn't, so I don't know if I would suggest it yet. As the whole syllabus changes

as in terms of the criteria for Part 2 or part one? I'm not sure if the RIBA or ARB would be adding in, because space architecture, you know, core module, but I would say there is definitely a place now. There's enough students that are interested in this kind of field to have studios or Masters or modules set up specifically for dealing with or talking about either space architecture in its own right or space architecture principles, but what that requires is it's, you know on Earth we have a mechanical electrical engineer, we have a structural engineer, those are the kind of things you need to have and the advice you get as a student, if we wanted to really tackle space architecture, you need aerospace engineers coming in. We'd need you know, sort of, material scientists. We need all the things that we aren't there yet, which is kind of, you know, quite tricky for a University. Externally to that, there are sort of networks being formed between academics and professionals. One is called SONNET, which is the 'Sustainable Offworld Research network' I'm part of that and I don't know if you've seen that I've heard about it.

Host: It's been circling around my research somewhere, but I haven't delved into it quite in much detail.

Owen: Yeah, So What that is? It's a group of academics, and I mean you could join if you wanted to, or at least apply academics and professionals where we're discussing the ideas of space architecture, and it gives you that knowledge and expertise that you can pick up on and a lot of us have students. That we can then introduce to the wider team to, pull knowledge and get extra information. So that's where I see, it's how it works quite well. I mean, it be lovely to introduce some of these sort of principles into the curriculum, but I think that's probably not going to happen for some time.

Host: Yeah, of course, I mean the University of Houston, you probably know the SICA, they have their space architecture, you know, course over there and the Vienna Institute. So I mean, it's in certain places and if someone's very, you know, like focused on going for that distinct pathway, they can do better in terms of the wider range. I understand what you're saying, it doesn't really need a mass implementation into schools of architecture as a whole. I just wanted to mention we're slightly overtime but do you still have more time to answer a couple more questions?

Owen: Yeah, keep keep going. I'll try and keep it quick.

Host: OK perfect. So on to my next question, what are the key physical challenges that architects and designers will have to overcome in order to design effective extra-terrestrial habitats and habitats for extreme environments

Owen: Dealing with radiation, Galactic solar radiation is a tricky one and also to do with air pressure, negative pressures and controlling them in terms of if you make your building too big then you need the structure to get bigger and it's all gets quite complicated. But then the terms of radiation, it's a tricky balance between unless a new material gets invented, a real way to deal with the radiation is to put mass between the people, the residents, and you know the solar or Galaxy, which means no light. It's that balance of reducing radiation but creating a habitat, that's kind of nice to be in. They're kind of,

Host: They've kind of addressed that in the in the mars habitat competition that invited so many like teams, AI space factory, they designed something that could be 3D printed out regolith so you wouldn't have to transport the materials up there, You have the materials there, he's needs, the means of designing that.

Owen: Maybe there is there is, I mean, regolith or using lava tubes, or you see you see a lot of that, but it still is a tricky thing to design around, how that works in terms of, considering it compared to Earth, yeah, just to get your head round that, is kind of tricky. I would say that's probably the biggest difference is that you need to. You need to consider.

Host: Yeah no, of course. So, my last question to you is when, and you kind of answered this already, but when designing for space architecture, how much more do you have to consider the effects on human psychology? In terms of mental Wellness, and, you know, how they can cope with in the fact that there's almost the near-death environment outside and there's only a thin wall separating the two.

Owen: Yeah, I think. It's a, huge consideration that probably we're not quite well not fully understanding yet, because no one's been put in that situation. The closest, as I said, the closest we come to is in Antarctica for nine months and you're cut off, or, you know, on a

submarine kind of space and yeah, it does affect people in a in a huge way, and, um it's only, I mean, it's becoming more and more prevalent in day-to-day architecture as well. How do you facilitate community in a housing development? You know those kind of things. And there's certain aspects, another one is, in the Martian house project, where with the M&E systems the life support systems are choosing to reuse them from a rocket rather than manufacturing or building something in-situ and the reason for that is that well, if you imagine you've just landed somewhere and you're being asked to manipulate and build the thing, that will keep you alive I'm sure, they'd rather the experts in Houston or whoever, actually assembled that for you. It's influenced which elements we plan to have flown from Earth and which elements we want to utilize, you know, the sort of the dumb elements, as it were, the regular reusing as much as possible, but for the things that might keep you alive and that's to do with psychology, because astronauts have been shown not to enjoy mucking around with their life support systems. So, it plays a part in all elements, like the layout of it, to try and encourage community without sort of getting people isolated, the environmental conditions of lighting, how much air you need to supply on Mars you end up with it. It's a very sort of dull red sort of tingy light that makes people sleep. So in the Mars design we mimic, you know Circadian rhythm sort of lighting systems to make people feel a bit better. So it's everywhere every from the very bottom, like the little start to the end you have to consider the psychology of your residents.

Host: Of course, you know I doubt anyone could survive in like a closed pod for a, you know, for upwards of two years. So, it becomes when designing Martian and lunar habitats for extended periods. This is quite crucial to that, just not just their survivability, but to their, you know, their whole productivity. You know productivity is influenced by your mental state. You know your rhythm

Your routine is also you know, influenced by your mental state. So yeah, no, I guess that's true.

Owen: Another feature we thought of integrating into the Mars house was if you look at most space. What in ISS or somewhere, they spend 2 hours a day on a treadmill running away trying not to reduce the you know muscle mass. So, we're thinking about how to introduce exercise into the routine so the design of the base actually uses multiple levels where people have to go up and down staircases in their day to try. Yeah, exercise built, built in. I would say that's to do with this psychology. It depends who's being sent, you know. And when you're talking about, if these are, you know, highly trained, selected crews. The first people landing on Mars. Probably have gone through, it'll be tough for them, but they are selected for their mental strength to

deal with living in a little enclosed capsule for large periods of time. If we have about 50/60 years time. And it's maybe you arriving that will like be a very different thing. We probably less likely to, you know, cope with their condition. So I think it depends when you're considering it, of when that will start to you know, know become a really important factor in this.

Host: Well, I mean you answered pretty much all of my questions, so that's that's perfect. I mean, I've gotten quite a lot of detail from this, and it's been massively helpful. I'm really interested in your projects like this specifically as well in terms of I've seen something referring to infrared architecture, which I found to be quite interesting, like what's that, architecture without borders, essentially.

Owen: Exactly, yeah, yeah,

Host: I found that to be amazing, so I mean, I'll I might, yeah, if you're OK with that, I might cite some of the research that you've done and you know, get some sort of conclusions from that. But yeah, thank you for taking time out of what is your busy schedule to answer my questions. And yeah, that's brilliant. I hope you have a great rest of the day. And yeah best of luck with your projects

Owen: Good luck writing this up. I'd love to read what you end up with what you end up writing when you're at the end. Please feel free to Send it over. I'd like to see what you been up to. And infrared architecture, I mean, I'd love to do some more of that would be good fun. Yeah, it's quite interesting. It was a good thought experiment and it was great to actually test it out physically. It's one of those ones that I think I'd quite like to have another go at.

Host: Definitely it might be something, It might be the topic of my next essay, who knows? That's perfect, so thank you so much, and once again thank you for taking time out of your day it's been very insightful,

Owen: No problem. Let me know if you got any other questions.

Host: I will do. I will do.

Owen: Alright

Host: Have a good one,

Owen: Bye.

Appendix D: Patrick Harkness Interview Transcript

Host: Can I have your permission to record

Patrick: Yeah, sure

Host: Thank you, so that's now recording

Patrick: Yeah, so space odyssey, and all this kind of what i mean like this is where you see these ideas of like spending space stations with artificial gravity. So I guess that is some form of space architecture in as much as the form is following the requirement to have artificial gravity and all this kind of stuff, but I don't think those things in that movie which would have been what 1970 something like. I don't think they would be new or startling concepts. Even the enemy like I think this would have been like that. To top of science fiction for a long time before hand, you know, yeah. I think when when these examples may be. I guess you let me think. What else can you say. Where does your idea of space architecture end and things that are more related to astronautical hygiene begin? So, I'm thinking in terms of. Things like Skylab, where they were trying to provide a large amount of space for astronauts to use. It's Astronautical hygiene in the sense that you're trying to provide them with a space in which you can move around or trying to apply changes to the form in such a way that people don't get ill, and this is all about like using the right colours from trying to create cues, what is up and down and this kind of stuff and those are hygiene matters, but it also kind of blends into architecture as well. I'm now thinking of sort of like early space flights, you know, like sort of in the capsules where there's really just room for like one or two people. I don't know if you could really call that architecture. I mean like It's all entirely functional. And yeah, yeah it comes down your definition of architecture. When is architecture in terms of like the psychological impact it has on people, when does that merge into their requirement just to keep them alive, you know? And when do these two things start to be start being seen as distinct and I guess it comes whenever you start to see, people in space for an extended period of time who aren't necessarily professionals doing a job of trying to stay alive while they do something else. You know? Yeah, yeah. In that sense i mean like you probably are into like first mentions in your

early 20th century, scientific literature, Science fiction literature is probably where it starts, I guess.

Host: That's actually kind of goes along with the research that I've conducted so far. I mean, there's a sort of intertwined history of how fiction science fiction works gets more detailed with new astronomical breakthroughs. I mean, from what I learned, it started with the Copernican Revolution way back when Johan Kepler was, as his was making his breakthroughs and then he came out with a novel called *Somnium*. Which he himself didn't publish, but I believe his children did. Where he starts detailing things like extra-terrestrial habitats and things like that. So, I think yeah, no, of course fiction and nonfiction works. There definitely plays a part in it and you know, I think it was, Goddard himself who said he was inspired by HG Wells's novel *War of the Worlds*, so that's perfect. In terms of the organizers spacearchitect.org they detailed in their document that they One of the first recorded instances of a designer was Raymond Loewy, who brought a some sort of viewing tool into the Skylab orbital Observatory. So I would agree with you that, like that's probably when the 1st integration of designers and architects maybe and introduced?

Patrick: Yeah, it's round about the time skylab that you start, I mean, I'm not sure if it was Skylab or one of the other missions where the astronauts had what they called the rebellion where they just said that they're going to take a day off. Are you aware of that? I guess that's the kind of point where people are not on duty 100% of the time. And that's where, maybe that maybe that's where you draw your line between hygiene and architecture. You know somewhere. I think they punished these guys. I Don't think any of them ever flew again, but they just had enough, you know, and I think the lessons were learned from that that you can't just put people in a box that is barely big enough to fit them in and expect him to stay on duty 100% of the time forever. You know, and I think that might've been a bit of something that you could call a turning point when people realize that actually even people working in space, you need to have some sort of time off duty. And that's whenever? Yeah, that's maybe the requirement of architectural rather than hygienic. Maybe you know.

Host: Yeah, that's perfect, that kind of goes into my next question. What kind of skills and knowledge could an architect bring that an engineer might not be able to. So I mean, in terms of that, do you reckon an architect also plays a sort of a psychological role in terms? Yeah, like the Wellness is the, I think Marc Cohen he wrote a paper saying it was, the being there versus

the getting there. Like getting there is one thing, but being in you know in the capsule or a hub that you know where you're an enclosed space and then outside you know it's just almost certain death. Trick someones mind so yeah. Yeah, no, that's perfect.

Patrick: So I wonder, I wonder if you, I wonder if there's any historical precedent there, I wonder? Is it worth looking up for past examples of people who would have been trapped in a small environment and it was death outside. I'm thinking particularly often. Are you aware of the voyage of the Endurance and Captain Ernest Shackleton? And all of this

Host: I've heard of Ernest Shackleton, yeah,

Patrick: He was a polar is a polar Explorer who did this and he was in one of these sailing ships. They went to the South Pole 1912/14 somewhere about that, and one way or another his entire crew had to spend the entire year trapped inside their ship, which was probably pretty small because it was like dark and death outside, you know. I just wonder if there's any thought would enter the design of those kind of ships, those ships which would of been designed for that kind of exploration. I wonder if it was a lot of thought went into it, to be honest, it was probably pretty functional, but maybe in terms of the importance that they might have attached to group events like maybe they all sat down for dinner together and you need to have an architectural spaces big enough, for them all to sit down together. Yeah, so maybe there's something like that are worth looking at precedence and you know, once you get the whole team to sit down together at, that's gonna be a forum to, you know diffuse any difficulties that are brewing or I mean like a lot of this has to do with like leadership. You need a forum to do your leadership and then you know if there's a mutiny developing. You know this needs to be addressed and you can't do that if you can't bring the whole team together. And this is, you know, like the psychological like working so architecture as well.

Host: Yeah, no, of course. I'll definitely check that up. See if some relation between enclosed spaces and actual implementations. So for my next question, the title of architect is protected under the laws of various countries, You've got the ARB and the RIBA regulate the use of architect in Britain and then in America you have, their Institute of Architects, but all across

the world, especially in Europe, that you know, we have this sort of legalization of the term and the title architect in the same way that being a medical doctor, the function is protected. So you have to go on undergo all these years of study and research in order to practice openly practice. It essentially holds accountability, and it holds you responsible for the work that you do, so to make sure the work is more effective. So in terms of that, do you consider the term space architect, If it becomes a recognized profession, should it be a legally protected title or should it just be a specialization?

Patrick: Oh, oh, K. I myself, I'm an engineer, which is not a protected title, but I'm also a chartered engineer, which is a protected title. Do I consider myself to be a space architect? I would never represent myself as an architect because one of the ethical requirements of being a chartered engineer is that you don't present yourself as having expertise which you don't have and So I myself would not, call myself Space Architect in capital letters and try to present myself as this is what my job title was. Is it necessary to have a separate institution that is taking money to maintain a list of people who call themselves space architects? I just don't think we're there yet. You know, I just don't think there's really enough people who are working space architects making money in this enterprise for really requiring a degree of regulation. You know? I mean, I think if the term architect is a protected terms, that you know that everyone is calling themselves an architect is actually at charter or whatever it is. That provides some degree of protection, perhaps perhaps your question is better directed towards should words like engineer be protected? Because I believe that the term engineer is strongly protected in Germany, for example, whereas it's just a general term here and in the depths of the I-MAKE website they argue all night long about whether or not this should be the case, you know? So that's yeah, that's that's a live debate, You know? But at least I debate the affect on people in here and now. I just don't think that there's going to be a case of somebody fraudulently practicing this space architect anytime soon. You know? Yeah, I suspect it's just not needed yet,

Host: But as it becomes more mainstream then possibly.

Patrick: Yeah, I would. Yeah, go for some answer like that.

Host: Yeah, yeah. It's perfect, that leads onto my next question. So, space architecture is taught in. I believe the University of Houston and Vienna and Institute of Technology and as a separate course. So in terms of schools, schools of architecture specifically because in space architecture you require a sort of enhanced level and understanding of engineering because you need to understand the, you know the pressures of outside environment. You know the this sort of shielding, cosmic shielding and all of that.

Patrick: Also weird little things that you wouldn't even think of. I mean, it's things like in reduced gravity, that height of the risers on steps, biomechanically, are different ventilation. You're sitting in a room with radiators in it, but as you know I'm sure that they're not actually radiators. They're actually convectors, and they're moving the heat around. Ultimately because of gravity because the hot air is lighter. If there is no apparent gravity then your heating system doesn't work. If people when you go to sleep at night, the fact that you breathe out warm air makes it float away from your face. If you're in space and you go to sleep, the warm air doesn't rise, so all the carbon dioxide build-up around your head and chokes you. There are any number of these an issues that arises that aren't usually things that you think of

Host: So should space architecture be taught in more schools, do you believe that adjustments to the syllabus the current, syllabus needs is required? You know you might need books, on, you know psychological Wellness and the physiological effects on a human being, just being in that environment, you know with the CO2 buildup or, the shielding from cosmic Rays. So do you believe the syllabus would have to be amended? compared to architecture, just as standalone.

Patrick: It's obviously going to have to be expanded to cover the specialism, but as I said back to the previous discussion about does the term need protection, and the answer is, I feel not yet, 'cause I think there's not really feel fraudulently practicing a space architects in exactly the same way A University should not turn out graduates equipped with skills that they cannot use. This doesn't make sense, you know, so there is not a huge market demand for space architects, then every University in the country should not be turning out, 30 space architects every year because this is just going through everyone's time, you know, so long as there is a route to gain the specialist information that is commensurate with the demand for those skills.

I think that's all you need, and again it comes back to, how the human exploration of space expands and how many people are needed with these skills, and making sure that the skills pathway is in place, 10-15 years in advance of the curve, 'cause that's what you need, 'cause if you want people to join the industry at the age of 25, you need to inspire them 20 years before or whenever it is.

Host: Yeah, so all professions need to look at what the demand for their new entrance will be 20 years in future and try to estimate, is there going to be a demand for hundreds of space architects 20 years in the future? Probably not. I mean like look at me maybe like some some, but who knows, you know, and these are. These are decisions that have to be taken and I can't just say to you, 20 years from now we're going to need 30 space architect per year in the UK 'cause I just don't know and that you know that means it needs to be bottomed out I guess, but I just don't think we're yeah, whenever that critical status point in the game yet or we need to look into this, you know?

Patrick: Yeah, no, that's perfect. We are running a little bit overtime. Have you still got a couple of minutes? OK, so my last question to you is from you are from an engineering background, so you could provide more insight as to the physical challenges in terms of lunar habitats or Martian habitats in when they are implemented in the future. What challenges, physical challenges do we have to address when designing for these habitats? I mean, you can give a few points as many as you want, really, but. Just a few key points would be appreciated you know if you have any idea what they might be.

Patrick: It's materials, in such in-situ resource utilization and can you make concrete side out of lunar dust? These these kinds of questions, and whenever you imagine the cost of the monetary cost and energetic costs and everything else and bringing materials like cement from the Earth to a new environment at the limiting factor, is how much you can use the environment, the materials that are already there. So that is, that's all about making concrete out of lunar dust that is about finding ice, finding water, and any of these. Any of these kind of things, It's all about in-situ resource utilization. A great expert in space concrete is a friend of mine called Sung Yu Lim, Have you heard of him?

Host: I haven't no.

Patrick: Look up open Univerity Sung Wu, Yeah, look up Sung Wu Open University space architecture, words like that. You'll find him and the guy knows a lot about space concrete, so he might be worth and get in touch with.

Host: OK, so definitely I will, I'll give that a shot. Hopefully they can get back to me so that that is perfect. That's pretty much answered. All the questions I had for you and thanks for taking time out of your day, yeah. Thank you and have a great day now

Patrick: You too, take care bye bye.

Appendix E: David Wong Typed Response via email

David Wong <davidwong@spacearchitect.org>

Sat 3/6/2021 5:11 PM

To:

- Saihaan Islam-hmed (1707809)

Cc:

- education@spacearchitect.org

Hi Mikael, please find my comment below. Please note that these are my personal opinion, and not representing the opinion of SpaceArchitect.org as a whole:

1. When is it commonly thought the emergence of space architecture was made known?

The active participation of architects and industrial designers in the aerospace industry began in the 1960s. In the USSR, the studio of Vladimir Chelomei designed the Salyut 1 space station, which launched in 1971. In the USA in 1968, industrial designer Raymond Loewy persuaded NASA to include a window in the Skylab space station so that astronauts could see out and observe the Earth; Skylab launched in 1973.

The beginning of human space flight was dominated by engineers proving out the necessary transportation and life support systems, but it did not take long for architects to envision their role in designing space stations and planetary bases. NASA relied on their crew systems division for capsule design and in the early 1970s, a few architecture students expanded the scope defending graduate theses on space station concepts. Toward the end of the decade, NASA's interest in building a space station exposed the need for architectural-level thinking. This cracked the door for aerospace support contractors to consider hiring an architect. Later, the Space Station Freedom program further

opened the door including architects within NASA, the broader contractor community, and academia working together in the emerging field called Space Architecture.

Q2. What kind of skills and knowledge could an architect bring that an engineer might not be able to?

It is not specific skill sets or knowledge, but rather the difference in ways of thinking that separate the respective disciplines. Generally, engineering professions are trained to be analytical and decompositional - or in layman terms, to start by breaking things down into small elements, learn about each of them and then put them back together with a better understanding of how it could then be modified to suit the requirement. Whereas design professions are trained to be holistic, synthetic and creative minded - in other words, to start with a big idea and then figure out how to make it work. These are two completely different – but complementary – ways of thinking. I believe it is this different mindset and approach that would be of great value.

Q3. Should Space Architect become a recognized profession and protected title as the use of the term 'Architect' is protected now under laws of various countries?

This has been a subject of ongoing debate within the Space Architecture community for decades, and there is still no clear consensus. While many believe that licensure of some sort would happen at some point in the future, there is disagreement on whether it is worthwhile for the space architecture community to pursue after it proactively. Many would argue that there are other more immediate and effective means our community could do to promote our discipline and to get closer towards the ultimate goal of making human spaceflight more accessible to more people.

Q4. What additions would be required in the syllabus of schools of architecture, that is not currently present? Could such a body of knowledge be

supplemented within the current syllabus of schools of architecture. Or would it require a distinct pathway to a new profession?

Space architecture beyond Earth differs from terrestrial architecture by extreme environmental conditions: high radiation, low (or no) atmospheric pressure, low (or no) apparent gravity, and large temperature variations, to name just a few. Nevertheless, the goal is still the same: to provide a shelter that protects and supports good quality of life for the inhabitants. With the attitude of an architect, the task is to learn everything you can about the environment you're designing for – whether on or off the Earth – and learn the techniques for dealing with the extremes.

Q5. What are the key physical challenges that Architects & Designers will have to overcome in order to design effective extra-terrestrial habitat?

I would refer you to read up on the "The Millennium Charter" - a space architecture manifesto that strives to spell out the many aspects and challenges related to the discipline.

Q6. When designing for space architecture do you now have to consider the effects on human psychology much more?

A space architect would consider all aspects of design as much as its terrestrial counterpart. However, there are many environmental conditions (e.g., gravity, access to life supporting infrastructure, etc.) that are mostly constant on Earth but become varied and vastly different in extra-terrestrial conditions. A space architect would therefore need to have a good understanding of their implications to the design.

Good luck to your dissertation and all the best!

David Wong
SpaceArchitect.org

Appendix F: David Nixon Typed Response via email

On 3 Mar 2021, at 17:46, Saihaan Islam-hmed (1707809)

<1707809@student.uwtsd.ac.uk> wrote:

Dear David,

Thanks for getting back to me and I have checked out Spacearchitect.org, and all the resources, provided, they were incredibly helpful, including the bibliography for which some of the papers and journals published, presented some fairly interesting thoughts, which I may use as references in my dissertation.

I have done some research on the Space Architectural Technical Committee although when I saw they were managed by the AIAA, I assumed their focuses lied within the American framework, however now knowing the SATC is an international body, I'll do some more research into them.

Thank you for taking the time to answer any questions you can, I will attach them via word document and have also copied them in below. Whenever you can get back to me would be greatly appreciated.

Q1. When is it commonly thought the emergence of space architecture was made known?

It was in 2002. See this file:

Q2. What kind of skills and knowledge could an architect bring that an engineer might not be able to?

All the skills and knowledge an architect accumulates on Earth at architecture school and then in practice.

Q3. Should Space Architect become a recognized profession and protected title as the use of the term 'Architect' is protected now under laws of various countries?

Not yet. Sometime in the next thirty years maybe.

Q4. What additions would be required in the syllabus of schools of architecture, that is not currently present?

Examples of typical additional subjects would be:

Anthropometrics and Ergonomics

Space Environments (deep space, lunar, planetary)

Environmental Control and Life Support (i.e. habitat atmosphere)

Structures and Mechanisms (inc. pressurized structures)

Orbital Mechanics (basic)

Thermal and Electrical Systems (basic)

Health and Safety (inc. medical)

Launch Vehicles

Geology (Moon/Mars)

Human Behaviour and Psychology

- Could such a body of knowledge be supplemented within the current syllabus of schools of architecture. Or would it require a distinct pathway to a new profession?

Some schools of architecture run design studios on space topics, usually with outside expert support from engineers or architects working in the field. The main need would be at least

one professor or instructor with an adequate level of knowledge to run a studio.

Beyond that, it could be developed as, say, a one-year postgraduate Masters that a student pursues after completing a normal five-year architecture degree.

See this file:

Q5. What are the key physical challenges that Architects & Designers will have to overcome in order to design effective extra-terrestrial habitats?

Go to the bibliography at [www.space architect.org](http://www.spacearchitect.org) and type in various keywords dealing with Lunar and Mars Bases and you'll

get a stack of papers of papers you can go through for this.

For starters, have a look at:

[https://www.nasa.gov/centers/hq/library/find/bibliographies/Long-Term Challenges to Human Space Exploration](https://www.nasa.gov/centers/hq/library/find/bibliographies/Long-Term_Challenges_to_Human_Space_Exploration)

Q6. When designing for space architecture do you now have to consider the effects on human psychology much more?

Yes, see list above.

Regards,

Mikael

Hope this helps. DN.

Appendix G: Email Request for Interview



Saihaan Islam-hmed (1707809)



Wed 3/3/2021 12:38 PM

To: mc@spacearchitect.org

Hello,

Dear Mr. Cohen

My name is Mikael (Saihaan) Islam-Ahmed and I am a final year student on the Architecture BSc course at the University of Wales Trinity Saint David, in the Swansea School of Architecture.

For my final year dissertation, I am researching the topic of 'Space Architecture' and whether this is an area which could, eventually, become an area served by a recognized profession. As part of this research I am interviewing a small selection of architects, designers and engineers who have an interest in the idea of Space Architecture

As you have experience in this (or a related) field I wonder if you could spare some time to answer a few short questions about the topic? This could be in the form of a 15-minute interview on team or, if you prefer, I could send a text version of the questionnaire, where you could reply via email at your convenience.

I look forward to hearing from you

Regards,
Mikael

Abbreviations

- AIA – American Institute of Architects
- AIAA – American Institute of Aeronautics & Astronautics
- ARB – Architect’s Registration Board
- ESA – European Space Agency-
- IAF – International Astronautical Federation
- ISRU – In-Situ Resource Utilization
- NASA – National Aeronautics & Space Administration
- RIBA – Royal Institute of British Architects
- SATC – Space Architecture Technical Committee
- USKA – United Kingdom Space Agency