Space Architecture: an emerging discipline. Still at its infancy, much of its roles and definitions are matter of debate and discussions. Recently many international architecture workshops and symposia have put focus on the future development and goals for this upcoming genre. Through the process of many discussions it became clear that education would play a very significant role to the future of this discipline. Space Architecture would not be professionally recognized until it could relate back to the general architectural practice. It is necessary to consider how to deliver the related knowledge and understanding to the designers. Not only to the devoted ‘space architect’, but also to the general ‘architect who is just interested into space’.

This paper strives to give an overview of space architecture at its current state; a diagram to demonstrate some of the critical factors space architects have to consider when designing for space, followed by examples of the multi-disciplinary nature of space architecture, along with a map showing the reciprocal relationship between space architecture and other disciplines. A brief summary of previous generations of space design to explain where space architecture came from, and where it will be heading. This package of knowledge is aimed to deliver a better understanding to the general public and architecture profession on what space architecture is really about, and hope to clarify some misconceptions in return. Last but not least, this paper aims to put together a case study of space architecture – to demonstrate how the professional recognition of space architecture could benefit all the key players involved, and how various critical issues could limit space architecture, causing it to be regarded as merely white elephant for a very long time. The prospect of space architecture may rely on the general architectural education to recognize the significant added value space architecture has to offer.

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**Definition of Space Architecture:**

“Space Architecture is the theory and practice of designing and building inhabited environments in outer space.”

One of the defining roles of Space Architecture is its close collaboration with many disciplines. Therefore one could look at how Space Architecture relate to other disciplines in order to get a better understanding of its roles and criteria. A graphical representation showing the relationship between space architecture and other disciplines can be found in the following diagram 1.

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**Introduction:**

“Architecture” is a word infused with many meanings. It is not an easy task to derive a single, pristine definition for Space Architecture. During the World Space Congress at Houston in October 2002, a group of space professionals including scientists, engineers, architects, designers and many other experts and enthusiasts came together and discuss about the nature and prospect of space architecture. The workshop session was concluded by a set of fundamental principles and statements concerning about space architecture, agreed upon by the participants and was delivered as the end product of many discussions. This “Millennium Charter Manifesto of Space Architecture” is the first attempt to recognise space architecture as a discipline of its own, strive to define its relation to both architecture and space industry professional bodies. It also laid out the parameters and values that space architecture concerns and abided by. The full content of the manifesto can be found in the Appendix A.

This paper builds upon from the discussions and comments made from the previous workshops, it aims to contribute to the foundation of the syllabus for space architecture education; This includes the definition of Space Architecture, history of its development, its relationship with other disciplines and the many roles the discipline is responsible for. Beyond the syllabus, it is also important for architecture and space industry profession to appreciate the beneficial added values that come from the space architecture discipline. Space industry could gain the much needed creativity inputs and alternative rationale based on humanity instead of efficacy from space architecture. The architecture profession would benefit from the extensive multi-disciplinary nature of space architecture, as well as an unique opportunity to challenge existing preconceptions and means of practice. Space Architecture itself would need the support of both general architecture practice and space industry in order to conduct its education effectively. Their recognitions also help consolidating its identity as a respectful and valuable discipline.

**An overview of Space Architecture**

Today Space Architecture is a very specialized subject. Sometimes it is considered as part of the spacecraft systems, while at on the other hand it is being closely associated with Sci-Fi designs and technology forefront.

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Diagram 1: Relationship diagram between Space Architecture and other disciplines

**SPACE ARCHITECTURE**

- **Practice**
- **Education**
- **Theory**
- **Sci-Fi Architecture**

**ARCHITECTURE**

- Architectural education gains insights to other disciplines through space architecture

**BUSINESS & MANAGEMENT**

- Business & Management, Policy & Law are already well connected to space industry

**POLICY & LAW**

- **Engineering**
- **Education / Outreach**
- **Science**

**SPACE INDUSTRY**

- Space architecture provides realizable creativity to space industry

**ART**

- Sci-Fi architecture in art domain brings visions and dreams to space industry through space architecture
Space Architecture and terrestrial architecture
The relationship between Space Architecture and terrestrial architecture is quite similar to that between Newton’s classical physics and Einstein’s relativity physics. Newton’s laws of physics are true and correct but it is a law of localization and specialization. Therefore, it can only provide a good approximation under very limited and specific conditions. While Einstein’s law of relativity introduces a much more general, much broader view of physics, one that can be applied to anywhere in the habitable universe. It represents a more fundamental and more pristine form of understanding towards the physical universe.

Space Architecture can be regarded as the generalization of terrestrial architecture. It does not limit itself to one set of prefixed rules. It challenges all preconceptions that we abide by for granted. It encourages us to extend our imagination and creativity, to “think out of the box”. Not to be restrained by gravity and earthly traditions, and forces us to question ourselves thoroughly on how extreme environment affects architecture and its users. What will architecture be like if there is no gravity or low gravity? How will an architect deal with a situation of Low Earth Orbit structure (e.g. International Space Station), where sun touches our Earth horizon every 45 minutes? And ultimately, can human live comfortably and safely in space? These are some serious architectural questions still waiting to be answered. And there is no other discipline would have a better capacity to solve these than architects would.

It is important to note that Space Architecture is not only applicable in space. As mentioned above, Space Architecture can be considered as the generalization of terrestrial architecture. Its theoretical and philosophical basis should remain true anywhere in the universe and certainly could apply back on Earth. Technologies and techniques learnt from space architecture could lead to a much more efficient and environmental friendly design on Earth. Major space agencies like ESA have already recognized this opportunity and have developed research programs focus on this topic.

Comparing to terrestrial architecture, Space Architecture deals with a much broader range of parameters and factors. While the comfort & survival zone similar to terrestrial architecture, space architecture need to face much more extreme degree of variant in terms of environment. This requires a whole new range of knowledge and understandings to be taken into account while designing for space. List below are some basic criteria that space architecture need to take into account. A sumerising diagram (Diagram 2) of major factors considered in space architecture design can be found on page 6.

Radiation
There are two types of radiation which should be given consideration: Ionising radiations like X-rays and Gamma rays, and exceptional high dose of electromagnetic radiation during Geomagnetic storms.

The first type usually originates from the cosmic background, or solar flares and coronal mass ejections from the Sun. It could constitute serious health risk to the crew in any space vehicles. The second type is originated from the Sun. Aurora Borealis which is sometimes visible on the sky of the Polar Regions on Earth is an indirect effect resulting from these solar wind-driven electrons bombardments to our Earth atmosphere. It poses serious threat to electronic circuits, potentially shut down or cause permanent damage to electronic equipments by electrostatic discharges, including critical components like solar panels and life support systems.

Radiation also causes significant impact on the space architecture itself too. Many materials could have their properties and structural behaviour changed by severe radiation. There are many scientific studies and research ongoing currently, focusing on this topic in order to gain a better understanding on the subject.

Thanks to our planet Earth’s atmosphere, the majority of the harmful radiation from outer space has been filtered out before they reached the ground. Therefore radiation rarely comes into design consideration for terrestrial architecture. However, even at the attitude of Low Earth Orbit (approx. 150-900km altitude), we no longer have the luxury of being protected by the atmosphere. Beyond that we could be outside the coverage of our Earth’s magnetosphere and become directly exposed to the solar wind and cosmic rays. Therefore all space architecture design must provide sufficient protection against the radiation.

Volumetric & Delivery Constraints
One of the major challenges of constructing orbital structure is that all construction materials must be delivered from Earth to the orbit in the first place. The mass, dimension and volume of orbital structure is strictly limited by the existing launch capability to the orbit. Furthermore, the design of the pressurised volume must conform the law of physics and aerodynamics. Otherwise the orbital structure would receive a major penalty on its structural efficacy.

Orbital Debris
Today, no less than 7000 objects with diameter bigger than 10cm are present in our Earth orbit, and millions smaller than that. Orbital debris ranges from old defunct satellites and rocket components to some tiny damage fragments or even fleck of paint. All these contribute to an estimation of over 2000 tonnes of space junk in space. On top of that there are many natural objects like meteoroids entering Earth’s atmosphere everyday. With an average relative velocity of approximately 10km per second, even a fleck of paint could cause serious impact damage. Space Architecture must provide adequate protection against such foreseeable impacts. Current measures include installing Kevler armor plating and providing high degree of contingency and flexibility in case of more serious incidents occurred.
Power
Solar energy has been and still is the dominant power source for almost all space missions to date. Solar energy becomes more reliable in outer space when weather conditions are no longer an issue. It produces continuous energy but subject to orbit day/night shifts, which generally handled by batteries. Similar to Earth, it also requires a relatively large surface area of solar panels in order to provide sufficient power to meet the energy demand of space structure.

Low level nuclear power was used on many solar system explorer probes. It produces constant power output for a very long time, requires minimal volume compared to solar power, and does not get affected by the degree of solar gain. However, sending a nuclear powered structure in space had always meant a bane to the general public. It is very difficult to justify its benefits against the public opinion on the possibilities of contamination if there was any accident during launch and its eventual decommissioning.

Heat exchange
Architecture on Earth often utilizes air convection and conduction to maintain the thermal equilibrium. In space, however, this is no longer possible. Since only vacuum existed outside of the hull of the space structure, there is no medium for heat conduction or convection. The only mean of dissipating heat is by radiation. With the external temperature varies more than 300 Celsius between day and night side of the orbit in a cycle of 90 minutes, the thermal layers of architecture in space must able to perform and sustain under such extreme and highly variable environment.

Microgravity
Human neutral posture is unique in a microgravity environment. As a consequence, for all human related interfaces must be redesigned specifically for microgravity usage. To give one example, there are no “chairs” we know of in microgravity environment. It is because the original function of a chair (supporting user’s center of gravity) becomes obsolete without the presence of gravity. Instead, various anchoring devices (handles, straps etc.) are needed to secure the users at any location, because “standing” is no longer a valid action in microgravity. Users travelling between spaces must move from one surface to another, using the anchoring elements or surface itself to control the direction of movement. This has direct impact of the circulation design of the space architecture.

The microgravity environment also leads to a very different perception to space. One obvious example is the lack of orientation. There is no ‘default’ definition of ceiling and floor in microgravity environment. The notion of ‘up’ and ‘down’ become inadequate to address the new possibilities of the ‘added dimension’.

The absence of a default ‘local vertical’ does not mean that it is no longer necessary. In fact astronauts feedback from the SkyLab Space Station back in the 70’s has highlighted the importance of a consistent orientation reference in the microgravity environment. Lack of orientation discipline in habitable spaces could cause confusion and hinder efficiency. It is important to design habitable spaces related not just to the new possibilities opened up by microgravity environment, but should also response to how human interact within the microgravity environment.

Space Architecture, Sci-Fi Architecture and Art
There is a common misunderstanding of the difference between Space Architecture and Sci-Fi Architecture. This misconception leads to many regarding Space Architecture as just the same as Sci-Fi Architecture. Due to this misconception, Space Architecture as a specialization has yet to gain proper respect or to be taken seriously by the mainstream architecture profession.

There is a fine line between Space and Sci-Fi Architecture. Space Architecture always has its primary concern on humanity. The focus is always on the need and desires of the user. Due to the expensive cost of launching materials to the orbit, space architect needs to have full awareness of the mass of their design, and able to justify their design vigorously to show that all design elements are value-adding to the project and are worthwhile to maintain. Against the general preconception, in a contemporary architecture world full of “visionary” and “virtual” designs, Space Architecture tends to be more realistic, more “down to Earth” than many terrestrial architectural projects in this aspect.

Sci-Fi Architecture on the other hand put emphasis on extraordinary visions. The design may not be realizable but it sets a clear direction and goal for technology development to head towards. Sci-Fi Architecture brings imaginations and humanistic passion to the engineering-dominant space profession. While today the two disciplines have very different ideals and follows very different protocols, Space Architecture could become the bridge between them. Space Architecture by definition operates in both realms of art and engineering, allowing dreams and visions transform into realizable creativity, integrate into the design of engineering process. It provides a way for the two disciplines to collaborate constructively and avoiding unnecessary misunderstanding.

Space Architecture and Space Industry
Space architecture uses a multidisciplinary approach to manage the complex nature of space projects. From the start of each project, success is derived from collaboration.

In space industry, space architects often take up the role as the integrator of design team. In a typical space project, the project team usually has more than a dozen experts from different fields of expertise, ranging from engineering to management, scientific to technical and political to legal. space architect is responsible to give a
A Brief History of Space Architecture

Space Architecture and Life Science
With more than four decades of human spaceflight experience, space agencies like NASA have established a very extensive knowledge base on life science data collected from previous missions.

The NASA-STD-3000 - Human - Systems Integration Standards is an online document providing quick reference and links to specific data related to human systems. It has specific chapters refer to architectural design - volumetric and orientation design in microgravity, accessibility, lighting, colour, materials, windows, sightlines, social design consideration and other psychological concerns. It also provides useful information on anthropometry and biomechanics – of how our body function and react on Earth and in space.

It is common knowledge to the architecture profession that, just by following the building regulations alone does not make good design. The same logic also applies to Space Architecture. Space architecture should provide interactions between the users and the environment, designing space in respond to the desire and well being of the users. The fundamental principle is the same as any architecture on Earth, only that the environment that needs to be dealt with is more extreme in variants and the desire of the users also change substantially due to the difference in environmental conditions.

Space Architecture and Space Business
It would be naïve to speak of how Space Architecture could be without backing the design up with a practical and factual business plan. It is important to understand what the client need and what they expect Space Architecture could deliver to them. In the past four decades space industry development was primarily about achieving political success and scientific breakthroughs. But this may change within the next couple of decades; The emerging space tourism industry, along with many market studies and analysis for the future of leisure space travel suggest that space architecture designed for leisure purpose will not remain as a fictional idea for long. In fact, some organisations like TATE in United Kingdom have already laid out solid plan on how to adapt itself to the foreseeable ‘space’ future. Space Architecture shall be aware of the new requirements and needs from the business, understanding the mechanics of this emerging market, and deliver the most effective spatial design. In essence, these considerations are nothing new compare to any hotel resorts design on Earth. And in both cases, commercial factors would be the primary criteria for the design consideration.

Space Architecture and Space Law
Legal issues in space is a developing field at the moment. Today there is no such thing as space property law or space architecture regulations that were recognized and ratified internationally. However there are international and regional space policies concerning intention and liability which must be complied by anyone or anything going up to orbit. Outer Space Treaty 1967 regards outer space as a res communis. “Outer space shall be free for exploration and use by all States” and “Prohibition of national appropriation by claims of sovereignty, by means of use or occupation, or by any other means”. Much like the case on Antarctica, architecture on South Pole region does not imply the ownership of the particular site. Space Architecture, be on orbit or on other planets, should not imply direct ownership of the specific site. Furthermore, the Treaty also limited the design of space architecture must be for ‘peaceful purpose’. And that architecture shall not bring irreversible impacts to the site.

Space Architecture and Management
Existing space law is a relic from the cold war era of last century. It was ultimately designed to avoid conflicts on Earth moving into space. However today these old codes are inadequate to cope with the rapid change of political and social agenda back on Earth. The lack of an international space construction codes also mean that construction quality and performance are subjected to various national standards. In case of international projects like International Space Station, any substantial design and modifications must go through all participating nation partners. Without any established space construction protocol it took nearly ten years to get the ISS design plan agreed on between all the members, and with the recent grounding of shuttle fleet due to the tragic failure of Space Shuttle Columbia, it would probably take many more years to fully complete the space station construction. It is therefore important for space architect to understand the political and legal significance, as well as the likely timescale of construction in outer space.

A Brief History of Space Architecture
Space architecture is not a new concept. The first generation of serious studies appeared in the early twentieth century by pioneers like Konstantin Tsiolkovsky, Hermann Oberth, Robert Goddard and many others. Before that, many more ideas had been presented in science fiction literature. From the Herman Potocki's
APPENDIX C: MAJOR FACTORS CONSIDERED BY SPACE ARCHITECTURE DESIGN

Diagram 2: representation of major factors need to be considered for space architecture design

- Attitude Determination & Control
- Pressure & Atmosphere
- Launch Capability
- Orbital Debris
- Airlock & Other Related Hardwares
- Applied to both Earth & Space Architecture
- Management
- Legal & Politics
- Life Science
- Maintenance
- Thermal Control
- Acoustics
- Lighting Condition
- Structure
- Energy Consumption
- Mass
- Construction Methods
- Cost
- Multi-levels Contingency Against System Failures
- Life Support System
- Radiation Protection
- Communication with Ground Control

Applied to Space Architecture Only
‘Living Wheel’ design in 1928, to Wernher von Braun 1950s space station concept, up to Stanley Kubrick’s ‘Station V’ in the Sci-Fi classics movie ‘Space Odyssey 2001’, the idea of a spinning, wheel-shaped volume with artificial gravity was the most popular perception of how a space station was going to be built at the time. People were excited by the novel idea of living in space, and were optimistic about its technological development.

The situation became quite different in the post-Apollo era however. Soon after the Moon race came to an end, the space industry had adapted to a very different doctrine compared to the last decade. In the early 70s NASA had initiated the Skylab space station project. It was NASA’s first attempt to put long duration space station in orbit and its design was mainly derived from previous Apollo program hardware and technologies. Skylab was meant to be a logical next step to the space program. Although Soviet Union had already launched many smaller space stations into orbit before Skylab, their operational information were not as extensively published and well documented as Skylab missions did.

The main component of Skylab consisted of a converted third stage of a Saturn moon rocket. The workshop within was in ‘Bologna Slice’ layout: layers of floor stack over each other along the long axis of the rocket hull. It represents a totally different vision to the spinning wheel concepts, showing the ‘reality’ of space architecture was still far away from the visionary dream once hoped for.

Design was far from perfect on Skylab. Many things went wrong and many design philosophies were proved to be flawed or being negligent. But it gave many valuable lessons to the designers on how to achieve a better design in microgravity environment. Knowledge like the significance of the ‘local vertical’ - orientation references of up and down, circulation pattern, and many other first hand experience by the astronauts all got consolidated and became the critical foundation for the future space stations design.

From mid 70s to early 80s, NASA focused its resource on the development of space shuttle, while Soviet Union carried on the Salyut and later Mir space station development. The SpaceLab module operated in Shuttle cargo bay was the first to adopt modular rack interior system that provides excellent flexibility and man machine interface. The improved version was later adopted as the ISS interior space configuration system.

The first component of Russia’s Mir space station was launched in 1986. Its fifteen years orbital operation set many human spaceflight records and produced many valuable life science data for future manned space program. Its spatial configuration is based on a central core (Mir module) acting as a central hub, connecting other program specific modules. The adaptable feature of the design enables modification to be made to accommodate US shuttle docking with relative ease – something that would be unthinkable back in the 80s.

The realization of International Space Station is a marvellous engineering achievement and only becomes possible by working in cooperation between 16 nations worldwide. Not only does it represent the forefront of our technological development, it also demonstrates the ability of human as a species able to become united and achieve common goals. The design of International Space Station is a consolidation of all the lessons learned from previous generations of space station. The spatial design of ISS is very efficient and versatile. Also taken into account of human physiological and psychological factors, the new space station provides more generous and comfortable space compare to the crew quarters on board of Mir or Skylab.

‘TransHab’ was a research program focus on the technology development for inflatable habitation module. It was proposed as the alternative ISS habitation module as well as for Mars mission. The program successfully demonstrates the feasibility of the inflating shell and other related technologies that open up new opportunities of space architecture.

In the foreseeable future, Space Architecture is no longer limited to governmental scientific based projects. At the beginning of this century we have witnessed the dawn of the new space industry: space tourism. Many market analysis have concluded that there is a huge potential market available on orbital leisure space travel14. When this market become mature, more leisure orientated space architecture would be required as part of the infrastructure to serve this industry.

Critical Issues to Space Architecture

The development of space architecture had been on a difficult path. There are a few challenging issues which are still holding back the discipline. Below is a summary of some of these major impediments.

Safe and affordable propulsion system to LEO
With current propulsion technologies and existing system capability, the soaring cost for orbital access is still prohibitive for majority of general public. According to a space tourism study done by CNES, the ticket price for an orbital tour would remain between 3-10 Million USD for the next 20 years, assuming that there were no significant transportation technologies breakthroughs.15 The transportation cost constitutes to a critical portion of any space projects, and is the dominant economic factor which has prevented commercial ‘space-liners’ enterprise from realization.

For any substantial orbital construction project like a space hotel, orbital access cost for heavy lift operation must be low enough for multiple trips of material transportation during construction. Furthermore, architecture in Space would need to be serviced and maintained frequently, for which inexpensive and regular ferrying of staff and supplies between Earth and orbit is necessary. Unfortunately these two criteria have not yet been met today, and will remain so until the related
technology advances have taken place. Safety is another challenge waiting to be resolved. Space travel is a risky business. Even with the robust disposable system like Soyuz spacecrafts, its track record is still far from meeting the commercial airliner’s 99.99% reliability standard. The next generation orbital transportation must therefore satisfy this requirement in order to initiate a space-ferrying business.

Effective countermeasures against adverse effects to human in microgravity environment.
In a microgravity environment, there are two major physical threats to human bodies: Lost of bones and muscles, and high doses of radiation. The lack of gravity means we longer need strong leg muscles and bones to stay upright. As a result of our bodies’ natural regulating system, which reduce any unused components of our bodies very efficiently, would weaken our bones and muscles (including the heart muscle) significantly over time. This could cause serious problems when a passenger returning back to 1G environment after a long duration orbital trip. Current counter measures compensate the degrading effect by exercising vigorously everyday. While this is adequate for shorter period of orbital stay, more researches are still in progress concerning its efficiency for long duration stay. (eg. trip to Mars).

Without the shielding protection offered by Earth’s atmosphere, architecture in Space needs to provide all necessary radiation protection by itself. However even much efforts have been put into tackle the issue, astronauts, especially those who need to carry out EVA, could receive a significantly higher radiation dose, comparable to those who work in nuclear power facilities for a long period. More researches would be needed to find better means of radiation protection, with possibly new materials and technologies, in order to create a safer and more protective environment before commercial orbital passenger service could be feasible.

Legislation and law in space
As mentioned in previous section, existing space law is a relic of cold war era and is no longer adequate. Existing codes like Outer Space Treaty and many related resolutions belong to the category of international law. This means that while these codes have binding authority to any signed and ratified countries or states, the law does not apply to individuals or corporations venturing into space. At present, international space laws state that the launching state is responsible for any subjects it sends up in orbit and liable for any damage the subjects may cause. Individual responsibility and liability is only defined by national space policy of the individual state. Very often the domestic laws remained vague and ambiguous on issues like property ownership, definition of personal liability and the legal uses of orbital infrastructure.

Emerging space industries like space tourism depend on clear and well-established legislations to formulate their business plan and to evaluate the risk they are undertaking. Until the legislations are in place, a detailed and reliable business plan could not be formed and space tourism would continue to be unrealisable. The development of orbital leisure facilities would remain impractical and tentative assumptions as the direct consequence.

Identity of the discipline
Compare to other specializations within the architecture profession, space architecture has yet to acquire a clear and distinctive identity for itself. The discipline is still at its infancy. Its definition and its roles are still a matter of discussion and debate. Its ambiguous definition has led to many different interpretations of what space architecture supposed to offer. Different disciplines tend to have a very different expectation from Space Architecture to what an architect would have thought of.

From the perspective of space industry, Space Architecture is often considered as one of the ‘hardware’ systems, just like the other investments of scientific apparatus. It is considered as a system designed to sustain quality performance of the boarding crew. From the perspective of architects, Space Architecture should be about how to establish and manipulate spatial design, and how to deliver the experience to the user within. From the commercial sectors and in part the general public, they expect Space Architecture to bring them visions - Realizable dreams in form of creative design that could one day bring space closer to their life.

Each of the perspectives hold some truth about what Space Architecture is about, yet none of them is more appropriate than the others. However, when it was realized that Space Architecture does not exactly match each sector’s own expectation, disappointment and in some cases disapproval arise. General architectural profession found it difficult to apply contemporary architectural experiences to existing or developing space architecture design, which is still predominately based on Cartesian system rationale. As direct consequence Space Architecture was often considered as out of the professional context. The subject is often regarded as ‘outcast’ inside the architecture profession and treated with dubious mind-set.

Added value of Space Architecture
The education of Space Architecture is more than compiling a comprehensive syllabus for those who choose the discipline as their career. It is as important to demonstrate the added value of the discipline to other related professions as to establish the discipline’s own agenda. The prospect of Space Architecture relies on close collaboration with other professions. Therefore the education of Space Architecture should aim to inform other professions of why Space Architecture is important to them, and to explain briefly and precisely what benefits does Space Architecture offer. Listed below are some reasons and rationales for general architecture profession, space industries and space business of why collaboration is beneficial to each respective sector:
To the architectural profession, Space Architecture distinguishes itself by its strong emphasis on the importance of effective and practical design. The harsh environment in space forces space architects to seriously consider the realistic constraints of the design. Some conventional parameters became more extreme, while new parameters such as radiation and day/night cycles issues are unique to different cases of Space Architecture. This provides a very unique demonstration of the essence of architecture: to deliver a safe, efficient and comfortable haven to the users - A wake up call to contemporary architecture education that often left its students lost behind the haze of seductive images and sophisticate philosophies. Space Architecture encourages purge of mindset - it offers a unique and valuable opportunity to demonstrate the high diversity of alternative ways to approach architectural design, beyond the current trend of styles and techniques. Last but not least, the multi-disciplinary nature of Space Architecture would give architecture students a better preparation to appreciate and to deal with the complexity of real construction projects in architecture practise.

To the space industry, Space Architecture provides a unique perspective that is based on humanity values. So often space architect would come up with ‘outside the box’ solution and creativity to different challenges. Given its understanding of other professions, space architect could also taken up the role of mediator, becoming the communication bridge between different disciplines within the design team, deliver the ideal organisation strategy to the team and as a result increasing the effectiveness of the team dynamics and reducing time and money loses.

To emerging businesses like space tourism, Space Architecture would be a crucial part of the business investment. It represents new possibilities and new opportunities – space tourism will open up a new space travelling market that is not orientated towards governments or multinational corporations, but to the general public – to bring the dream of space into their life for real, and for a profit. Space Architecture in this context could becoming the new pioneering business front of the new Space Age: to break away from existing mission-orientated mindsets and engineering-dominated spatial layout, and to deliver a new space architectural design rationale that is based on commercial interests.

Conclusion

"... the ideal architect should be a man of letters, a skillful draughtsman, a mathematician, familiar with scientific inquiries, a diligent student of philosophy, acquainted with music; not ignorant of medicine, learned in the responses of jurisconsults, familiar with astronomy and astronomical calculations." \(^{16}\)

Vitruvius, 25 B.C. “De Architectura”, Book 1, Introduction \(^{16}\)

The definition of space architect, in its bare essence, is simply a reiteration of what Vitruvius has described in his “Ten Book of Architecture” two millenniums ago. And this is not at all by coincidence; Architecture, be it in Space or not, shall be defined by its multi-disciplinary nature. Space Architecture today offers the general architecture profession a unique opportunity to re-adapt some traditional principles and values of architecture as described in the previous paragraphs.

The prospect of Space Architecture may ultimately rely on the general architectural education to recognise the added value space architecture has to offer. Compared to other space disciplines, the general architecture profession appears to be the most reluctant to embrace the alternative values and approaches offered by Space Architecture. Therefore it is necessary to introduce Space Architecture into the education of the general architectural profession, explaining its principles and delivering a better understanding of the Space discipline, replacing the existing dubious attitude with a more positive and constructive one. Certainly there will remain many challenges besides the need to change mindsets as mentioned in earlier sections in the paper. However most of the other issues were either of technological or political basis, and I believe it’s only a matter of time and will to overcome those issues.

In the long term, the recognition of Space Architecture could benefit both the general architecture profession as well as the space industry, reinforcing the value Architecture as a whole has to offer to the human society.

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11. “Tate in Space’ is a space art program by Tate organisations, UK. It focuses on how to cooperate art into outer space environment. Recently ‘Tate Sat” was launched as the first step of the program. Further details could be found at http://www.tate.org.uk/space
THE MILLENNIUM CHARTER
Fundamental Principles of Space Architecture
October 12, 2002 Houston, Texas, USA

SPACE ARCHITECTURE MISSION STATEMENT

Space Architecture is the theory and practice of designing and building inhabited environments in outer space.

Motivation
We are responding to the deep human drive to explore and inhabit new places.

Contributions of Architecture
Architecture organizes and interprets the creation and enrichment of built environments.

Knowledge
Designing for space requires specialized knowledge of orbital mechanics, propulsion, weightlessness, hard vacuum, psychology of the hermetic environments, and other topics.

Other Fields
Space Architecture has complimentary relationships with diverse fields such as aerospace engineering, terrestrial architecture, transportation design, medicine, Human Factors, space science, law and art.

TYPOLOGY

- Architecture is defined by “firmness, commodity and delight” (Vitruvius).
- Architecture is conceived within an ambient environment that has multiple variable and pre-existent states.
- The multiple variables occur on spectra or ranges (such as temperature, chemistry, atmospheric pressure, humidity, gravity, light, colour, sound, air movement, etc), combinations of which define the current state of the ambient environment.
- Architecture subsystems are designed to compensate for conditions in the ambient environment that would otherwise compromise the “firmness, commodity or delight”.
- “Firmness, commodity or delight” may be conditional upon survival ranges (minimum and maximum values within which the conditions of “firmness, commodity or delight” remain valid) within the environmental spectra.
- Optimal operational ranges or “comfort zones” may be a subset of the survival range.

- Human-occupied structures are a subset of architecture.
- Typology of architecture is multi-dimensional and is not hierarchical. Each type within its space is defined by the range of environmental conditions it intended to address. Terrestrial architecture is a small sub-array defined by the ambient environmental conditions on Earth.
- Extreme environments also fall within the multi-dimensional array, and include environments that require extraordinary artificial compensation to maintain “firmness, commodity or delight”. These include desert, polar, underwater, subterranean, high altitude, earth orbital, Moon, Mars, interplanetary transit, etc.

CATEGORIES for Action: Team 11 Principles

1. Sustainability
As in earth architecture sustainability is multidimensional and encompasses the following areas:
- Ecology
- Technology
- Economics
- Social
But in the context of space architecture it requires greater flexibility to adjust to unknown situations.

2. Human Interaction
Space Architecture is influenced by the interaction between
- Human - Human
- Human - Machine (product)
- Human - Universe

3. The User
Because user needs and well being are critical components of mission and vehicle design, user contributions are indispensable in the practice of space architecture.

4. Human Factors
Human requirements for inhabited space systems are fundamentally similar to our requirements for daily life on earth.

5. Human Condition
Space architecture is concerned with the continuum and the future of the human condition.

6. Social Aspects
Community life, communication and interaction among space voyagers are important considerations for space architecture.

7. Environmental Conditions
Space architecture must respond to a wide range of different environmental boundary conditions (orbital, interplanetary, surface).

8. Education
Space Architecture uses a multi-disciplinary approach to manage the complex nature of space projects. From the start of each project, success is derived from collaboration.

9. Life Cycle
The Life Cycle of architectural elements is an essential aspect of mission planning and design.

10. Humility
Architecture involves forging harmony around the human system, balancing culture, biology, planetary knowledge and technology in counterpoint to the unknowable.

11. Benefits
The involvement of space architecture from project onset provides great benefit to space development and exploration: measurable savings in cost, time, maintenance and extended usability. Knowledge and Technics derived from the practice of space architecture can improve the sustained quality of life on our human mothership, the Earth.
PHILOSOPHICAL GUIDELINES

- We seek to improve the human life experience by providing environments conducive to intellectual, spiritual and social enhancement.

- Our work is to be accomplished in an environment of cooperation... in which no single idea or concept is considered greater than the whole, and the focus is always on the needs and desires of the user.

- We seek to understand the implications of our presence in a space and what kind of footprint we want to leave.

List of attendees / signatories:

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