Metadesign of Spacevehicle-Building

AN APPLICATION OF GENERATIVE AND COLLABORATIVE STRATEGIES FOR THE DESIGN PROCESS' OPTIMISATION.

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Sapienza University of Rome Faculty of Civil and Industrial Engineering Department of Civil, Building and Environmental Engineering PhD programme in Architectural Engineering and Urban Planning Ciclo XXXV Nov. 2019 – Oct. 2022

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Per aspera ad astra

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I dedicated my enthusiasm, travelled three different continents and made personal sacrifices to carry out this work.

After the first year of professional work as assistant engineer, it occurred to me that what I was doing every day will be tedious for the 40-years-old me, a person who loves challenges and new stimuli. At the same time, I have always been a fan of Sci-Fi novels. In particular, I am deeply impressed by the idea of a Civilisation seeking a homeland among the Universe in Liu CiXin's *"The Three-Body Problem"*. Then I realised that I could contribute to the idea of extending human staying in Space from the Architecture and Building perspectives.

So I started my PhD at the Sapienza University of Rome in 2019, on the 50th anniversary of the Moon landing. That year is also known as the year when the COVID-19 pandemic started. Like many others, I suffered from the lockdown, and I worried about the bizarre situation we passed through. For this reason, I would like to thank those who gave me his/her support and stayed close to me, saving me from the awful loneliness.

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The scariest aspect for a researcher is that s/he will find less and less companionship, as s/he progresses in his/her investigation and exploring

fields that no one has ever explored. In this regard, I would like to thank everyone that has listened and helped me, when I was lost and desperate. You have contributed to make me stay with my original aspirations, keeping my pursuit, and working enthusiastically.

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I immensely desire that this work could contribute to the enterprise of human exploration in Space, and this amazing research-journey does not stop here.

College Station, TX (USA) Oct 22nd 2022 Zhelun Zhu, P.E., M. Eng.

Forewords

On 26th September 2022, the probe DART, launched on a SpaceX *Falcon 9* rocket out of Vandenberg Space Force Base in California, successfully impacted the asteroid Dimorphos, changing its trajectory. This mission is the first-ever Space mission to demonstrate asteroid deflection by kinetic impact and can be considered as the first human planetary defence operation. This mission has provided valuable experience in protecting us from an asteroid collision and has encouraged further investigation concerning Space exploration.

Since the dawn of Civilisation and from several places on Earth, human beings looked overhead and put their aspirations in the sky. No matter in Oriental or Occidental cultures, the Sky embodies hope, desire as well as a far frontier. In many mythologies, Sky symbolises heaven which is the place where divinities have lived and reaching there means the possibility of redemption for the common humans. For instance, in ancient Chinese mythology which is deeply influenced by Taoism, the *Jade Emperor* (simplified Chinese 玉皇大帝) – the God of all divinities and the ruler of the skies – had his abode in the *Celestial Palace* (simplified Chinese 天廷). Likewise in the other side on Earth, the ancient Greeks believed that *Zeus*, the king of the gods and heavens, lived on the top of *Mount Olympus*, far from mortals' communities.

The sky has also represented a source of Knowledge for our ancestors. Qu Yuan (simplified Chinese 屈原), an ancient Chinese poet and politician who lived during the Warring States period (475 BC – 403 BC), in his "*Tian Wen*" (simplified Chinese 天 问, which means literally "Questions to the Sky"), he made a series of questions concerning social-politic problems, natural phenomena and traditional believes, addressing them to the sky.

Eventually, the sky has also represented a frontier for scientific explorations. It started with many inventions related to bringing, even ideologically, humans to a higher position like kite, *Kongming* lanterns and fireworks. With the technology's development, scientists and inventors have worked on bringing humans physically into the Sky using balloons and airplanes. Through these tools, humans have gain new capabilities which s/he is not born with.

Figure 1. Similarities between the Eastern and Western traditional culture in heaven representation.



On the left: the Jade Emperor and his royal family, Unknown artist(s) (?). On the right: The Olympian Gods, Nicolas-André Monsiau (1754-1834).

The breakthrough happened on 12th April 1961, when the Spacecraft *Vostok 3KA-3* was launched from Baikonur Cosmodrome with aboard Yuri Gargarin. This is the first time that a man-made object has carried a human in terrestrial orbit, starting the Space era.

Under the particular cultural and political context of the Cold War, the Space became a stage where Nations display their technological and scientific achievements. In the decades of the second half of the 20th century are concentrated numerous Space missions, each time taking humans toward a new frontier and pushing the advancement of innovative technologies. In these contexts, humans succeeded in stepping on the Moon and built Space stations, allowing temporary staying in ETEs.

New needs have emerged with the intensification of Space missions. After demonstrating the capability to keep humans alive in Space, the next goal of Space agencies across the world are working to provide permanent human staying in extraterrestrial conditions. As a matter of fact, prolonged time of Space missions is required to reach far destinations. For instance, a hypothetical mission to Mars could last for two years since it takes six months of Spaceflight to reach there. Astronauts must face up to many unusual conditions that can cause negative consequences on their health and wellness. Therefore, the crucial focus of the next generations of Space exploration is the human-related factors investigation to ensure a sustainable human presence in extraterrestrial environments (ETEs).

Space habitation plays a vital role in providing reliable protection from external hazards. Nevertheless, Space habitations, like Spaceships and Space stations, are still considered more likely to a workplaces and therefore, their priorities consist mostly of mere survival conditions as well as functional aspects.

In the perspective of ensuring a sustainable human presence in ETEs, new aims and requirements in terms of habitability in an altered context must be fulfilled. This represents a challenge for designers under several aspects, including unusual conditions (altered gravity, radiation exposure, extreme temperature), resource shortages (breathable air, drinking water, food supplies) as well as some potential life-threatening situations (impact from micro meteoroid and orbital debris, or MMOD, partial vacuum, and chemical corrosion). Furthermore, Space habitations are featured with very restricted internal rooms, with a few openings and represent as an isolated and closed environment (ICE). The combination of these characteristics causes negative impacts under psychological and emotional perspectives.

User experience's improvement can be achieved only by involving experts from different disciplines and considering this enterprise as a global common goal. To this regard, it can be affirmed that Space explorations affect the whole humanity and require interdisciplinary and international collaborations.

The present Doctorate Thesis aims to improve user experience to sustainably extend the human presence in Space and investigate this enterprise from Design perspectives. It embodies a design problem with high complexity due to unusual context, the myriad of objectives and the number of involved actors requiring a *holistic* approach. Therefore, adequate design strategies must be investigated to meet the mentioned needs and the possibilities of the ongoing 4th Industrial Revolution.

The crucial challenge consists in how to effectively collect human Knowledge from different disciplines to deal with the same enterprise. This is an instinctive skill in the past, for example during the Renaissance, when there were no clear distinctions between scientific domains. Artists and scientists were motivated to resolve problems, unconscious of the boundaries that have emerged with the development of Civilisation. In Modern Society, the separation between many disciplines has become sharper and increased in number. In many cases it even represents an obstacle, especially in front of complex problems.

The present Doctorate Thesis is circumscribed within a 3-year PhD programme at the Department of Civil, Environmental and Architectural Engineering of the Sapienza University of Rome. This research has been structured in:

Chapter 1 investigates the challenges in Space Architecture. Based on an extensive Literature Review, it has been analysed the Cultural, Social and Scientific background of the crewed Space explorations and in particular, the role of habitation in this enterprise.

Objectives of the present research are described in Chapter 2. It starts with the discussion of crewed Spacevehicle's needs in terms of sustainability principles and user experience. It has been observed that the sum of design challenges has led to the collapse of the traditional design approaches and therefore, it has been discussed characteristics of a Metadesign approach and explained why it is considered appropriate for the proposed design problem.

In Chapter 3 are defined methodologies that meet the needs of the present research's objectives. The theoretical aspects of Design as a creative process have been analysed and how digital tools can be implemented to enhance human design capabilities, both at the individual and collective levels.

The proposed methodologies have been empirically validated according to the objectives of the proposed design problem. Chapter 4 defines the generative process workflow, allowing a flexible and evolvable Design Process. On the other hand, in Chapter 5 it has been investigated the framework's collaborative aspects, enabling the participation of actors from different scientific domains and proposing a design-skill-free Design Process.

Chapter 6 describes the Overview Effect, an emotional climax that happened to several astronauts observing Earth from Space. This feeling can be experienced from a certain elevation, when our planet can be viewed in its entirety. It brings to the consciousness of Beauty, Connection with Nature and other people. Designers can experience a similar state of awe after dealing with a complex problem, bringing new expertise and enlarging the frontiers.

In conclusion, Chapter 7 summarises the achievements of the present Doctorate Thesis. Potentialities and possible applications of the proposed framework have been presented. In addition, there have been pointed out many open questions that require future investigations.

"[...] Space exploration is no longer science fictions, but is science and engineering fact. We have also learned that Space exploration is complex and very unforgiving of error. Designing Spacecraft and Space station and planetary habitats for humans requires knowledge spanning a range of disciplines: engineering, medical sciences, psychology, human factors, life support systems, radiation protection/space weather, and other extreme Space environments, at a minimum. These disciplines must result in an integrated human centered system, which should also be reliable, sage, and sustainable.

This is Space Architecture."

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Forewords for "Space Architecture Education for Engineers and Architects" (Sandra Häuplik-Meusburger & Bannova, 2016b)